DRAFT

Omnibus Essential Fish Habitat Amendment 2
Volume 5: Appendices

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Amendment 14 to the Atlantic Sea Scallop FMP
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Including a

Draft Environmental Impact Statement

Prepared by the
New England Fishery Management Council
In cooperation with the
National Marine Fisheries Service

Updated November 25, 2013

Appendices

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OMNIBUS ESSENTIAL FISH HABITAT AMENDMENT 2
DRAFT ENVIRONMENTAL IMPACT STATEMENT

Appendix A: EFH designation methodologies

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1.0 Introduction

Note: The methods described in this appendix were used to develop the EFH text descriptions and maps for the 2007 draft of the environmental impact statement. Subsequent modifications in methodology that were used to develop the proposed EFH descriptions and maps are described in the body of the DEIS.

The New England and Mid-Atlantic Fishery Management Councils are responsible for managing the fishery resources within federal waters of the Northeast region (Maine to North Carolina). Currently, the New England Fishery Management Council manages fisheries which target 28 species that are managed under seven different fishery management plans (FMPs) (Table 1):

Table 1 – List of species under management by the New England Fishery Management Council

FMP	***Species – Scientific Name***	***Common Names***
Multispecies	*Anarhichas lupus*	Atlantic wolffish Wolf eel
Multispecies	*Gadus morhua*	Atlantic cod (official) rock cod
Multispecies	*Glyptocephalus cynoglossus*	witch flounder (official) gray sole Craig fluke pole flounder
Multispecies	*Hippoglossus hippoglossus*	Atlantic halibut (official)
Multispecies	*Hippoglossoides platessoides*	American plaice (official) American dab Canadian plaice long rough dab
Multispecies	*Pleuronectes ferruginea*	yellowtail flounder (official) rusty flounder
Multispecies	*Macrozoarces americanus*	ocean pout (official) eelpout Congo eel muttonfish
Multispecies	*Melanogrammus aeglefinus*	haddock (official)
Multispecies	*Merluccius bilinearis*	whiting silver hake (official) New England hake
Multispecies	*Pollachius virens*	pollock (official) Boston bluefish coalfish green cod
Multispecies	*Pseudopleuronectes americanus*	winter flounder (official) blackback Georges Bank flounder lemon sole sole

FMP	Species – Scientific Name	Common Names
		flatfish rough flounder mud dab black flounder
Multispecies	*Scophthalmus aquosus*	windowpane flounder (official) sand flounder spotted flounder New York plaice sand dab spotted turbot
Multispecies	*Sebastes fasciatus.*	Acadian redfish (official) redfish ocean perch Labrador redfish beaked redfish
Multispecies	*Urophycis chuss*	red hake (official) squirrel hake ling blue hake
Multispecies	*Urophycis tenuis*	white hake (official) Boston hake black hake mud hake
Multispecies	*Merluccius albidus*	Offshore hake (official) Blackeye whiting
Monkfish	*Lophius americanus*	monkfish (official) American goosefish angler allmouth molligut fishing frog
Sea Scallop	*Placopecten magellanicus*	Atlantic sea scallop (official) giant scallop smooth scallop deep sea scallop Digby scallop Ocean scallop
Skates	*Amblyraja radiata*	Thorny skate (official) Mud skate Starry skate Spanish skate
Skates	*Dipturus laevis*	Barndoor skate (official)
Skates	*Leucoraja erinacea*	Little skate (official) Common skate Summer skate Hedgehog skate Tobacco Box skate

FMP	***Species – Scientific Name***	***Common Names***
Skates	*Leucoraja garmani*	Rosette skate (official) Leopard skate
Skates	*Malacoraja senta*	Smooth skate (official) Smooth-tailed skate Prickly skate
Skates	*Leucoraja ocellata*	Winter skate (official) Big skate Spotted skate Eyed skate
Skates	*Raja eglanteria*	Clearnose skate (official) Brier skate
Deep-Sea Red Crab	*Chaceon quinquedens*	Deep-Sea red crab (official)
Atlantic Herring	*Clupea harengus*	Atlantic sea herring (official) Labrador herring sardine sperling brit
Atlantic Salmon	*Salmo salar*	Atlantic salmon (official) sea salmon silver salmon black salmon

The EFH Final Rule (50 CFR Part 600.815(a)(1)(i))) states that "FMPs must describe and identify EFH in text that clearly states the habitats or habitat types determined to be EFH for each life stage of the managed species. FMPs should explain the physical, biological, and chemical characteristics of EFH and, if known, how these characteristics influence the use of EFH by the species/life stage. FMPs must identify the specific geographic location or extent of habitats described as EFH. FMPs must include maps of the geographic locations of EFH or the geographic boundaries within which EFH for each species and life stage is found."

Life stages are unique developmental periods and for the purposes of this action are defined as follows:

1. Egg stage – The life history stage of an animal that occurs after reproduction and refers to the developing embryo, its food store, and sometimes jelly or albumen, all surrounded by an outer shell or membrane. Occurs before the *larval* or *juvenile stage*.
2. Larval stage – The first stage of development after hatching from the *egg* for many fishes and invertebrates. This life stage looks fundamentally different than the *juvenile* and *adult stages*, and is incapable of reproduction; it must undergo metamorphosis into the juvenile or adult shape or form.
3. Juvenile stage – The life history stage of an animal that comes between the *egg* or *larval stage* and the *adult stage*; juveniles are considered immature in the sense that they are not yet capable of reproducing, yet they differ from the larval stage

because they look like smaller versions of the adults. Young-of-the-year juveniles are juveniles less than one year old.
4. Adult stage – In vertebrates, the life history stage where the animal is capable of reproducing. Spawning adults are adults that are currently producing eggs.

This appendix describes the methods and data used to develop each major EFH designation alternative for all 28 species managed by the NEFMC. Because different methods were used to develop EFH designation alternatives for deep-sea red crab and Atlantic salmon, the methods for these species are described separately.

2.0 Development of the No Action designations

The 1998 Omnibus EFH Amendment 1 (NEFMC 1998) established EFH designations for 18 species managed by the New England Fishery Management Council. Designations for offshore hake, deep sea red crab, seven species of skate, and Atlantic wolffish were completed in subsequent management plans (NEFMC 1999; NEFMC 2002; NEFMC 2003, NEFMC 2009).

The original EFH text descriptions were based on information contained in a series of NOAA Technical Memoranda (also known as the EFH Source Documents) that included information on the geographic distribution and habitat requirements for each managed species. These descriptions included the geographic area covered in the EFH maps, the type of habitat (pelagic or benthic), and general information regarding substrates and ranges of depth, temperature, and salinity where EFH for each life stage of each species was defined. In addition to eggs, larvae, juveniles, and adults, the original EFH text descriptions included spawning adults as a fifth separate life stage.

The map designations of essential fish habitat identify the geographic extent of area within which certain types of habitat (as defined in the corresponding text description) are considered EFH. Several sources of distribution and abundance data were used to develop the original EFH maps.[1] Then as now, the NEFSC bottom trawl survey (1963 - 1997) and the NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) ichthyoplankton survey (1977 - 1987) provided the best available information on the distribution and relative abundance of Council-managed species in offshore waters. The bottom trawl survey was used for juveniles and adults, and the MARMAP survey was used for eggs and larvae.

The Council used other sources of information to map EFH in inshore areas, including the Massachusetts inshore trawl survey (1978 - 1997), the Connecticut Long Island Sound trawl survey (1990 - 1996), and information collected for a number of coastal bays and estuaries by NOAA's Estuarine Living Marine Resources (ELMR) program. Data on the distribution and relative abundance of fish in other inshore areas were not available in a timely enough manner to be used. The Council also considered information provided by the fishing industry, as well as several sources of historical information. Information on the distribution and abundance of sea scallops was obtained primarily from the NEFSC sea scallop survey (1982 - 1997) and from representatives of the scallop fishing industry. Information on the range and distribution of Atlantic salmon was obtained primarily from the available literature.

Detailed descriptions of the surveys and databases used by the Council to make the original EFH designations, including the sampling protocols and methods, are provided in Appendix C of the 1998 EFH Omnibus Amendment. A detailed discussion of the

[1] The designation methodology used originally to define the extent of EFH was the same for most of the species managed by the NEFMC. The exceptions were Atlantic salmon and deep sea red crab. Atlantic salmon EFH was defined to include the watersheds of rivers and estuaries currently or historically accessible to salmon for spawning and rearing. EFH for red crabs was based on their presence in different depth ranges on the continental slope.

limitations associated with using these data and information sources as the basis for designating EFH is provided in Appendix D of the 1998 EFH Omnibus Amendment.

Four categories or levels of information needed to describe and identify EFH were defined in the Interim Final Rule.[2] They were:

- Level 1: Presence / absence data are available for portions of the range of the species. At this level, only presence / absence data are available to describe the distribution of a species (or life history stage) in relation to potential habitats. In the event that distribution data are available for only portions of the geographic area occupied by a particular life history stage of a species, EFH can be inferred on the basis of distributions among habitats where the species has been found and on information about its habitat requirements and behavior.
- Level 2: Habitat-related densities are available. At this level, quantitative data (i.e., density or relative abundance) are available for the habitats occupied by a species of life history stage. Density data should reflect habitat utilization, and the degree that a habitat is utilized is assumed to be indicative of habitat value. When assessing habitat value on the basis of fish densities in this manner, temporal changes in habitat availability and utilization should be considered.
- Level 3: Growth, reproduction, and survival rates within habitats are available. At this level, data are available on habitat-related growth, reproduction, and/or survival by life history stage. The habitats contributing the most to productivity should be those that support the highest growth, reproduction, and survival of the species (or life history stage).
- Level 4: Production rates by habitat are available. At this level, data are available that directly relate the production rates of a species of life history stage to habitat type, quantity, and location. Essential habitats are those necessary to maintain fish production consistent with a sustainable fishery and the managed species' contribution to a healthy ecosystem.

Table 2 displays the levels of information that were used to develop the No Action alternatives. For most species, the best information consisted of relative abundance and distribution data (Level 2) and presence / absence data (Level 1). In a few cases, some Level 3 information was available, but there was then (and is now) a lack of detailed and scientific information relating fish productivity to habitat type, quantity, quality and location. Guidance provided in the Interim Final Rule suggested that when working only with Level 1 and Level 2 data, "the degree that a habitat is utilized is assumed to be indicative of habitat value." In other words, if all that is known is where the fish tend to be in relatively high concentrations, these areas are assumed to be the essential fish habitat. This is the approach the Council adopted in 1998 to define the spatial extent of EFH.

[2] The four levels of information are described a little differently in the Final EFH Rule, which went into effect in January 2002, but the distinctions are essentially the same as they were in the Interim Final Rule, which was in effect when the original EFH designations were developed.

Table 2 – Levels of information used for No Action (No Action) EFH designations. Numbers represent the highest available level of information available for each life history stage. Level "0" indicates that there was very little information available for this life history stage. "N/A" indicates that this does not exist as a distinct life history stage for this species.

Species	*eggs*	*larvae*	*juveniles*	*adults*	*spawners*
American plaice	2	2	2	2	1
Atlantic cod	2	2	3	2	1
Atlantic halibut	0	0	1	1	1
Atlantic herring	1	2	2	2	1
Atlantic salmon	1	1	1	1	1
Atlantic sea scallop	0	0	0	2	1
Barndoor skate	0	N/A	2	2	0
Clearnose skate	0	N/A	2	2	0
Deep-sea red crab	1	1	1	1	1
Haddock	2	2	2	2	1
Little skate	0	N/A	2	2	0
Monkfish	0	1	2	2	1
Ocean pout	0	0	2	2	1
Offshore hake	2	2	2	2	1
Pollock	2	2	2	2	1
Red hake	2	2	2	2	1
Redfish	N/A	2	2	2	1
Rosette skate	0	N/A	2	2	0
Silver hake	2	2	2	2	1
Smooth skate	0	N/A	2	2	0
Thorny skate	0	N/A	2	2	0
White hake	0	0	2	2	1
Windowpane flounder	2	2	2	2	1
Winter flounder	1	2	2	2	1
Witch flounder	2	2	2	2	1
Winter skate	0	N/A	2	2	0
Yellowtail flounder	2	2	2	2	1

2.1 ELMR data

Used by the Council in 1998 as the primary source of information on species distribution and abundance in the bays and estuaries of New England and the Mid-Atlantic, NOAA's Estuarine Living Marine Resources (ELMR) program was conducted jointly by the Strategic Environmental Assessments (SEA) Division of NOAA's Office of Ocean Resources Conservation and Assessment (ORCA), NEFSC, and other agencies and institutions. The goal of this program was to develop a comprehensive information base on the life history, relative abundance and distribution of fishes and invertebrates in estuaries throughout the nation. The nationwide ELMR database was completed in 1994, and includes information for 135 species found in 122 estuaries and coastal embayments. The Jury et al. (1994) report summarizes information on the distribution and abundance of 58 fish and invertebrate species in 17 North Atlantic estuaries. The Stone et al. (1994) report summarizes information on the distribution and abundance of 61 fish and invertebrate species in 14 Mid-Atlantic estuaries.

The ELMR program was developed to integrate fragments of information on many species into a useful, comprehensive and consistent format. The framework employed for the ELMR program enabled a consistent compilation and organization of all available data on the distribution and abundance of fishes and invertebrates in the principal estuaries and embayments in the Northeast region. Thirty-one bays and estuaries (see are included in the Jury et al. (1994) and Stone et al. (1994) reports:

Passamaquoddy Bay
Englishman/Machias Bays
Narraguagus Bay
Blue Hill Bay
Penobscot Bay
Muscongus Bay
Damariscotta River
Sheepscot River
Kennebec/Androscoggin Rivers
Casco Bay
Saco River
Wells Harbor
Great Bay
Merrimack River
Massachusetts Bay
Boston Harbor
Cape Cod Bay
Waquoit Bay
Buzzards Bay
Narragansett Bay
Connecticut River
Gardiners Bay
Long Island Sound
Great South Bay
Hudson River/Raritan Bay
Barnegat Bay
New Jersey Inland Bays
Delaware Bay
Delaware Inland Bays
Chincoteague Bay
Chesapeake Bay

Species distribution and abundance information was compiled for egg, larval, juvenile, adult, and spawning adult life stages by month and salinity zone for these locations by conducting literature searches and examining published and unpublished data sets. Salinity zones were defined as tidal fresh (0-0.5 ppt), mixing (0.5-25 ppt), and seawater (>25 ppt) and maps showing the spatial extent of each zone in each location were produced (see NOAA 1985). To complement the information from these quantitative studies, regional, state, and local biologists were interviewed for their knowledge of estuary/species-specific spatial and temporal distribution patterns and relative abundance levels based upon their species expertise and research experience. More than 72 scientists and managers at 33 institutions were consulted (the ELMR reports list the individuals and their affiliations). The final level of relative abundance assigned to a particular species was determined from the available data and expert review. To rank relative abundance, ELMR staff used the following categories:

- *Not present* -- species or life history stage not found, questionable data as to identification of species, and/or recent loss of habitat or environmental degradation suggests absence.

- *No information available* -- no existing data available, and after expert review it was determined that not even an educated guess would be appropriate. This category was also used if the limited data available were extremely conflicting and/or contradictory; in these cases, *no information available* actually describes a situation where the available information was indecipherable.
- *Rare* -- species is definitely present but not frequently encountered.
- *Common* -- species is frequently encountered but not in large numbers; does not imply a uniform distribution over a specific salinity zone.
- *Abundant* -- species is often encountered in substantial numbers relative to other species with similar life modes.
- *Highly abundant* -- species is numerically dominant relative to other species with similar life modes.

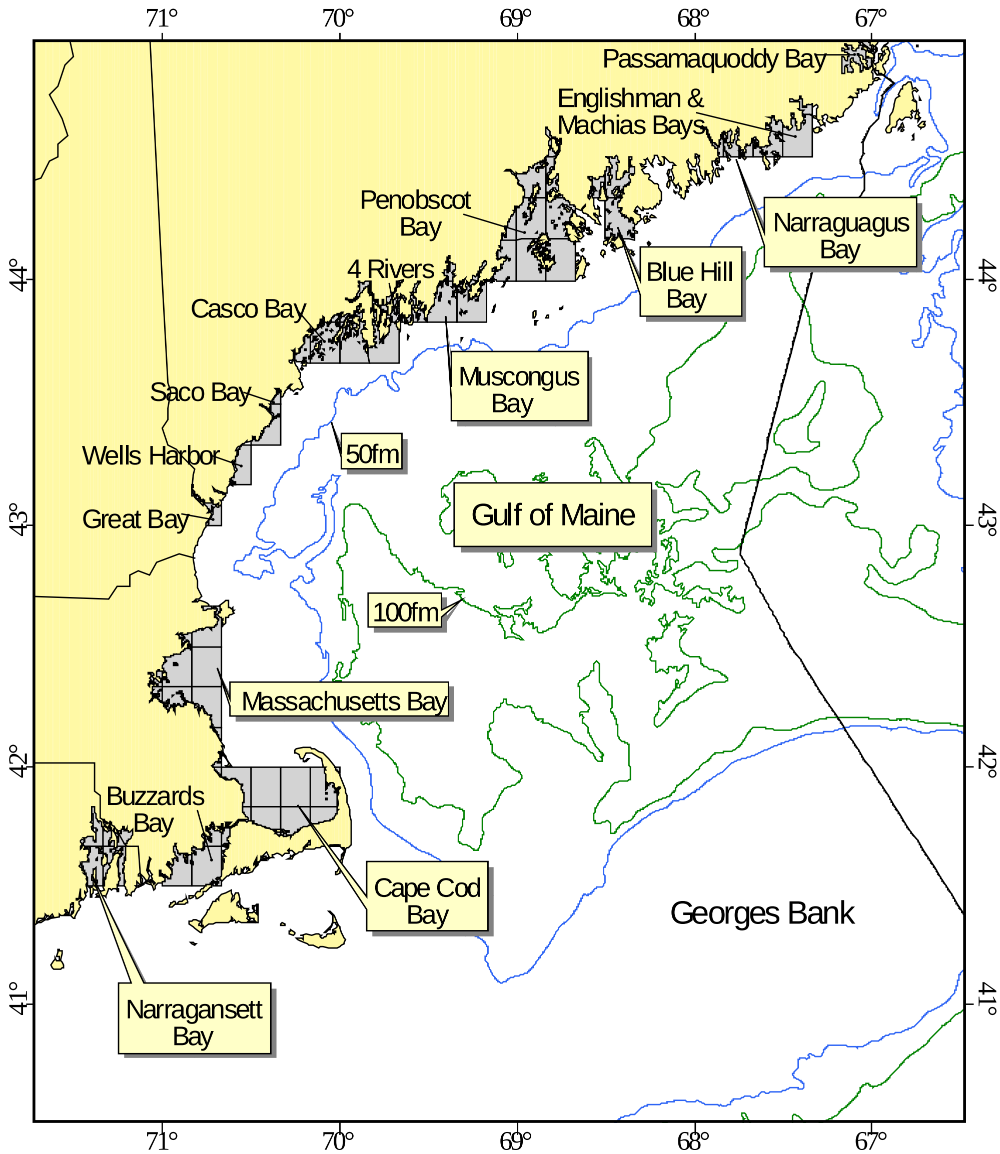
An important aspect of the ELMR program, because it was based primarily on literature and consultations, was to determine the reliability of the available information. The reliability of available information varied between species, life stage, and estuary, due to differences in gear selectivity, difficulty in identifying larvae, difficulty in sampling various habitats, and the extent of sampling and analysis in particular studies. Data reliability was classified using the following categories:

- *Highly certain* -- considerable sampling data available. Distribution, behavior, and preferred habitats well documented within the estuary.
- *Moderately certain* -- some sampling data available for the estuary. Distribution, preferred habitat, and behavior well documented in similar estuaries.
- *Reasonable inference* -- little or no sampling data available. Information on distributions, ecology, and preferred habitats documented in similar estuaries.

The seaward boundaries of each estuary or embayment were originally defined as straight lines from headland to headland or passing through islands, but these boundaries were modified in the No Action EFH designations to conform to ten minute squares of latitude and longitude that most closely represented the original boundary lines (Map 1 and Map 2).

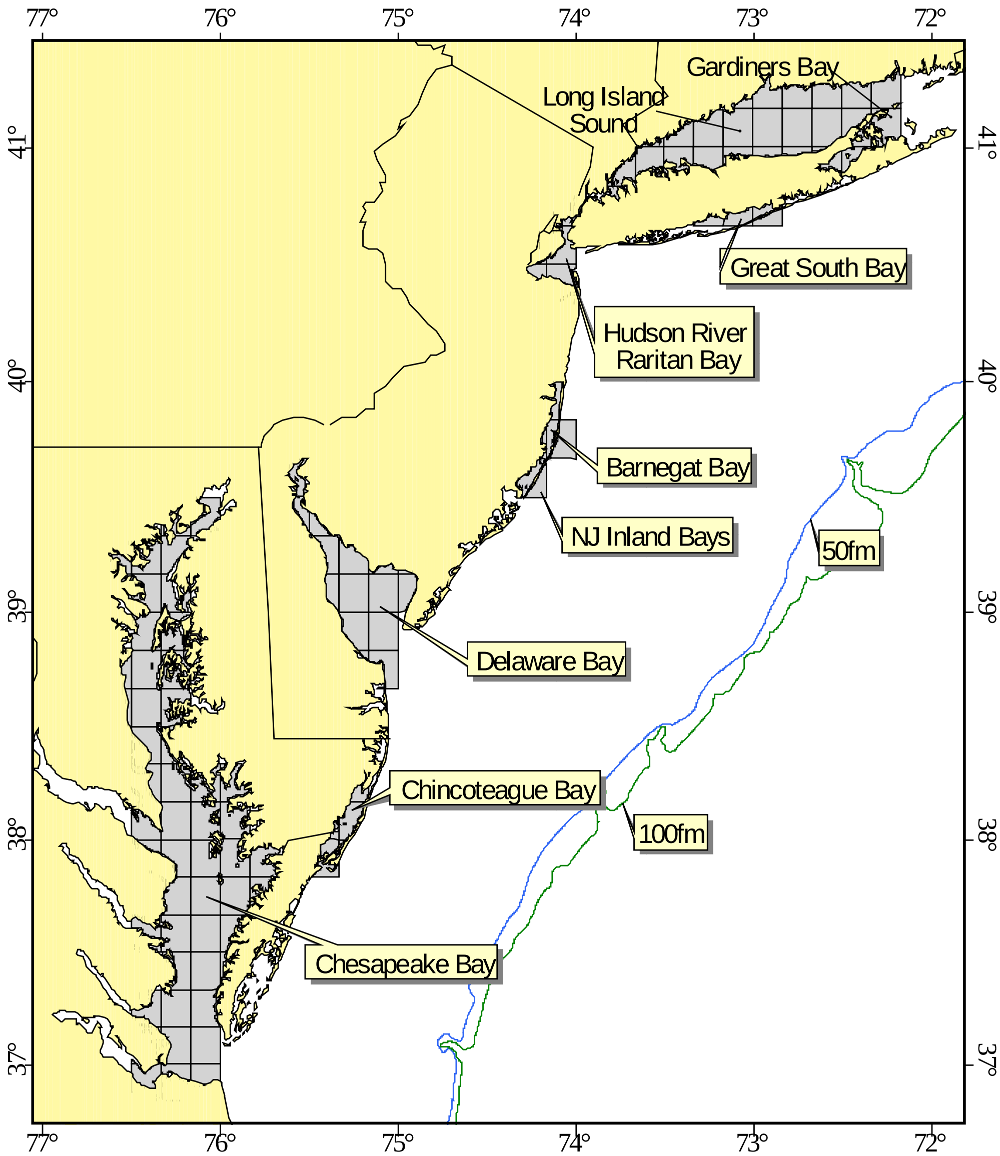
For those species' life history stages for which the Council designated EFH based on the 100% alternative (i.e., EFH is designated as 100% of the range observed for the species' life history stage in the NMFS trawl survey), all bays and estuaries in which the species' life history stage was categorized as *rare*, *common*, *abundant*, or *highly abundant* were included in the EFH designation. For those species' life history stages for which the Council designated EFH based on the 90% alternative (see next section for an explanation of the percentile rankings used in the alternatives), all bays and estuaries in which the species' life history stage was categorized as *common*, *abundant*, or *highly abundant* were included in the EFH designation. For species for which the 50% or 75% alternative was used, all estuaries in which the species' life history stage was categorized as *abundant* or *highly abundant* were included in the EFH designation. The EFH maps included the salinity zone(s) for each bay or estuary where a given life stage and species met the defined abundance criteria.[3]

Map 1 – North Atlantic ELMR areas used in No Action EFH designations



[3] The No Action EFH maps were based on ten minute squares of latitude and longitude that overlapped the ELMR salinity zone maps and therefore include more coastal area than is included in the ELMR designated areas.

Map 2 – Mid-Atlantic ELMR areas used in No Action EFH designations



2.2 NMFS trawl survey, MARMAP, and scallop survey data

The alternatives considered by the Council in 1998 were based on the relative densities of fish (numbers per tow) observed in the fall and spring NEFSC bottom trawl and summer scallop dredge surveys and on the relative densities of pelagic eggs and larvae in the NEFSC ichthyoplankton (MARMAP) surveys on the continental shelf. The time periods used were 1963-1997 for the bottom trawl surveys, 1982-1997 for the scallop survey, and 1977-1987 for the MARMAP surveys. In addition, some information from the Massachusetts inshore trawl survey (1978-1997) and the Connecticut Long Island Sound trawl survey (1990-1996) were also used. For all species, a set of alternatives was developed for each of the major life history stages, with the exception of sea scallops, Atlantic salmon, and Atlantic halibut. Those stages include eggs, larvae, juveniles, and adults. The maps presenting the alternatives displayed the distribution and abundance data by ten minute squares of latitude and longitude.[4]

Juveniles and adults were distinguished based on lengths-at-maturity for each species, which was defined according to the length at which 50% of the fish in a population mature sexually. For most species, these sizes vary by sex and stock units. They also vary over time, according to changes in growth rate, sometimes considerably. Lengths used to distinguish juveniles and adults for most species were based on data reported by O'Brien et al. (1993). Lengths at maturity for the skate species were based on information included in EFH source documents. These lengths are listed in Table 3. In most cases, O'Brien et al. based 50% lengths at maturity on females; if there was more than one size available because of analyses that were performed at different time periods or for different stocks, they were averaged.

Table 3 – Lengths-at-maturity used to distinguish juveniles and adults in EFH designations. Juveniles are less than the specified length; adults are equal to or larger. Source: O'Brien et al. (1993) and EFH Source Documents for skates.

Species	*Length at Maturity (cm)*
American Plaice	27
Atlantic Cod	35
Atlantic Herring	25
Barndoor Skate	102
Clearnose Skate	61
Deep-sea Red Crab	8
Goosefish	43
Haddock	32
Little Skate	50
Ocean Pout	29
Offshore Hake	30

[4] Although their size varies according to latitude, each ten minute square includes about 75 square nautical miles.

Species	*Length at Maturity (cm)*
Pollock	39
Red Hake	26
Redfish	22
Rosette Skate	46
Sea Scallop	10
Silver Hake	23
Smooth Skate	56
Thorny Skate	84
White Hake	35
Windowpane	22
Winter Flounder	27
Winter Skate	85
Witch Flounder	30
Wolffish	47*
Yellowtail Flounder	27

* Not used in EFH designations – from Templeman 1986

The Council used two methods for developing the EFH designation maps: one based on average catch rates per ten minute square (TMS), and the other based on percentages of observed range. The catch rate method was used for all demersal life history stages (juveniles and adults of all species with the exception of Atlantic herring and Atlantic salmon). The percentage of observed range method was used for all planktonic life history stages (eggs and larvae of most species) and the juvenile and adult stages of the pelagic schooling Atlantic herring. The "observed range" for each species includes all TMS where the species was observed during either the NEFSC bottom trawl or MARMAP surveys.

Selection factors were applied to the NEFSC bottom-trawl and ichthyoplankton survey databases to construct the data sets for the Council alternatives and EFH designation maps. The selection factors were recommended by NEFSC Northeast Fisheries Science Center (NEFSC) scientists who collected and work with the data. Correction factors were used to standardize the bottom-trawl catch of various species due to variation in the size and type of trawl doors and nets, and/or the performance characteristics of vessels used in the surveys over time. Specific correction factors were applied to individual species (see NEFMC 1998, Appendix C, Table A-4). After the bottom-trawl and ichthyoplankton data were selected, the summarization process was the same. Data were assigned to a TMS based on the location of the starting point of the bottom-trawl or ichthyoplankton sample tow. Only those squares that had greater than three samples and one positive catch were selected. In order to minimize the effects of occasional large catches on the averages, catch data were transformed by taking the natural logarithm of the catch [ln(catch + 1)] and the mean of the transformed data was calculated for each ten minute square. The resulting values (indices) could be compared on a relative scale, but could not be expressed in units of numbers of fish per tow.

In analyzing the data for each species' life stage using the catch rate method, each TMS throughout the survey area and included in the analysis was ranked from highest to lowest according to an index of the mean catch per tow (i.e., the number of fish caught in each tow of the survey trawl). The second step was to calculate the cumulative percentage that each TMS made up of the total of the average catch rates for all TMS. For each life history stage, the alternatives considered included: (1) the area corresponding to the TMS that account for the top 50% of the cumulative abundance index, (2) the top 75% of the cumulative abundance index, (3) the top 90% of cumulative abundance index, and (4) 100% of the observed range of the species, i.e., the area covered by all TMS where at least one fish was caught in at least three tows.

In analyzing the data using the area percentage method, each TMS throughout the survey area included in the analysis was also ranked from highest to lowest according to its catch rate index. In this case, however, the alternatives represent the percentage of the total area covered by all the squares (the observed range) rather than a percentage of the total catch rate indices. For each life history stage, the alternatives considered included: (1) the area made up by the TMS that account for the top 50% of the observed range, (2) the area corresponding to the top 75% of the observed range, (3) the top 90% of the observed range, and (4) 100% of the observed range of the species. The percent catch rate method was used because it accurately reflected that, for most benthic life history stages, the population is more concentrated in portions of its range where habitat conditions such as prey resources and substrate are most favorable, and less concentrated in other portions of its range where habitat conditions are not as favorable. Clearly, EFH should be designated where environmental conditions, especially habitat, are most favorable, thus the highest percentages of the catch rate index were a suitable proxy for identifying these areas.

In the case of the planktonic life history stages and the pelagic species (Atlantic herring), the catch rate method was not used to define areas most favorable to the species. Planktonic eggs tend to be concentrated immediately after a spawning event, and then are dispersed over a much larger area by the prevailing currents. Thus, chance plays a large role in the eggs and larvae ending up in areas where environmental conditions are most favorable. Other factors related to the sampling methods for these life stages also affected the decision to use the percent range method for the planktonic life stages and pelagic species (see 1998 Omnibus Amendment Appendices C and D).

For each life history stage of each species, the Council considered the remaining alternatives, selecting the EFH designation for each individually. The Council employed the most consistent approach possible, given the variety of species and unique characteristics of many of the life history stages and the limitations of the available data and information considered. <u>The Council's approach was focused on designating the smallest area possible that accounted for the majority of the observed catch, taking into account the habitat requirements of the species and any areas known to be important for sustaining the fishery.</u> The Council considered the status of the resource, and was more conservative with those species considered at the time to be overfished. The Council also considered the historic range of the species, including areas of historic importance, where appropriate. In some cases, the Council used a proxy to determine the most appropriate EFH designation for certain life history stages. This was done by applying the range of one life history stage as the EFH designation for another stage. The Council most often used a proxy designation when information was not available for a particular life history stage, but also used a proxy on occasion when the observed range of a particular life history stage did not accurately represent the true range.

The habitat description and identification for a managed species was based on the biological requirements and the distribution of the species. For all species, this included a combination of state, federal, and international waters. According to the regulations, EFH can only be designated within U.S. federal or state waters. Although there may be areas outside of U.S. waters which are very important to Council-managed species, EFH can not be designated in Canadian waters or on the high seas. In cases where the range of a species extended into waters managed by the Mid-Atlantic Fishery Management Council (MAFMC), the NEFMC designated EFH for species that are managed under a New England Fishery Management Council FMP. Accordingly, the maps representing the Council's original EFH designations were based on survey data that included tows made in Canadian waters, but the EFH maps stop at the U.S - Canada boundary. The Council recognized that, in many cases, habitat areas located in Canadian waters may be just as important, if not more important, than habitat areas located in U.S. waters, even though areas with high catch rates in Canadian waters were not identified as EFH.[5]

2.3 Limitations of the No Action EFH designations

Quite often, the original EFH designations had quite patchy spatial distributions. While this is normal in natural systems, to some extent this patchy distribution was based not on the natural distribution of the species, but on the limitations of the sampling methods. Once the proposed EFH maps were completed, including whatever additional information was available (ELMR, inshore surveys, fishing industry, landings, historical, etc.), the Council chose to also include any empty TMS surrounded by either seven or eight "filled in" TMS. This approach "smoothed" the designations, and, thereby reduced to some degree the patchy nature of the EFH designations.

Certain geographic regions were not represented in the data originally considered by the Council, such as Nantucket Sound and near shore waters of Maine, New Hampshire, Rhode Island, and eastern Long Island – where either no survey had been conducted, or where the data were not available – and smaller bays and estuaries not included in the ELMR database. These areas, therefore, were not considered in the EFH designation process. This does not mean that they are not potentially important, only that they represent data and information gaps. Similarly, the original EFH designations (text and

[5] During the development of these original designations, all survey tows, even those in Canadian waters, were used to calculate relative abundance percentiles. This method was changed during development of Omnibus Amendment 2.

maps) did not extend beyond the edge of the continental shelf (approximately 500 meters), which is the deepest extent of the NEFSC trawl survey.[6]

[6] The exception is deep sea red crab, which was designated to a depth of 1800 meters on the continental slope, based on limited red crab survey data.

3.0 Development of updated designations

3.1 Abundance only method (Alternative 2 in 2007 DEIS)

3.1.1 Data sources

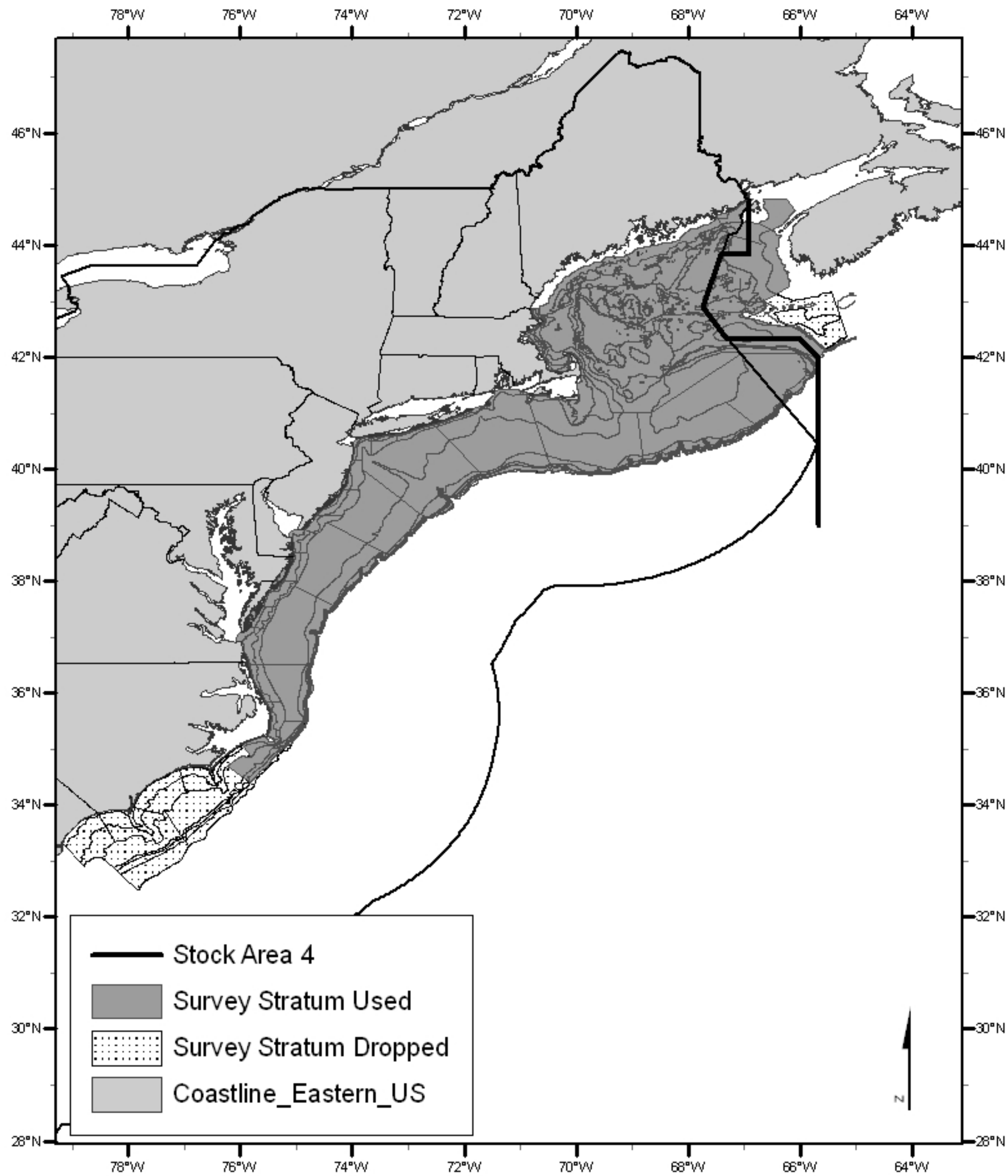
3.1.1.1 NMFS trawl survey data

The Alternative 2 EFH maps were developed using a similar method as described above under Alternative 1 (No Action) except that the time series of NEFSC spring and fall bottom trawl survey data for the continental shelf was updated to include data from 1968 to 2005. Data collected during 1963-1967 fall surveys were eliminated from the analysis in order to create a more uniform time series that equally represents the two times of year. (No data were collected in the spring in those years). In addition, with regards to many of the demersal species that are sampled in the NEFSC bottom trawl survey, ten minute squares (TMS) which were located entirely within poorly sampled survey strata were not included in the calculations nor were they mapped.[7] Strata that were excluded from the analysis are located south of Cape Hatteras and in Canadian waters on the southern and eastern Scotian Shelf (Map 3.)

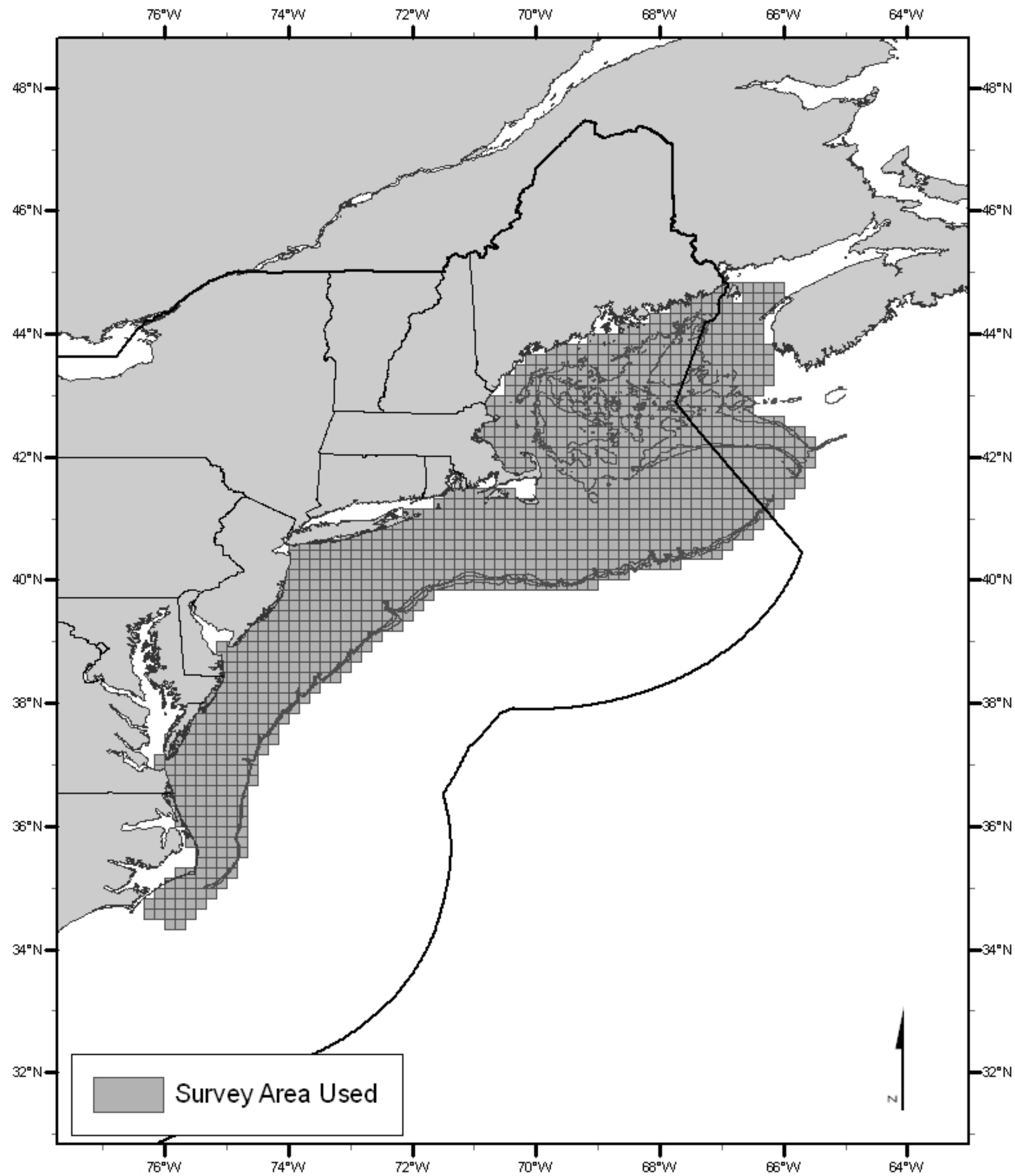
TMS on the shelf that were included in the analysis for most species are shown in Map 4. For the five species with stocks in the Gulf of Maine and/or on Georges Bank that are distinct from Canadian stocks on the Scotian Shelf (Atlantic cod, haddock, Atlantic herring, winter flounder, and yellowtail flounder), all TMS entirely within management area 4 (Map 5) were removed from the analysis, but TMS in Canadian waters on the Northeast Peak of Georges Bank were left in the analysis (but not mapped). With the exception of a few TMS in the entrance to the Bay of Fundy, all of management area 4 is in Canadian waters.

[7] Tows made in ten minute squares that overlap the U.S.-Canada border were included in the analysis.

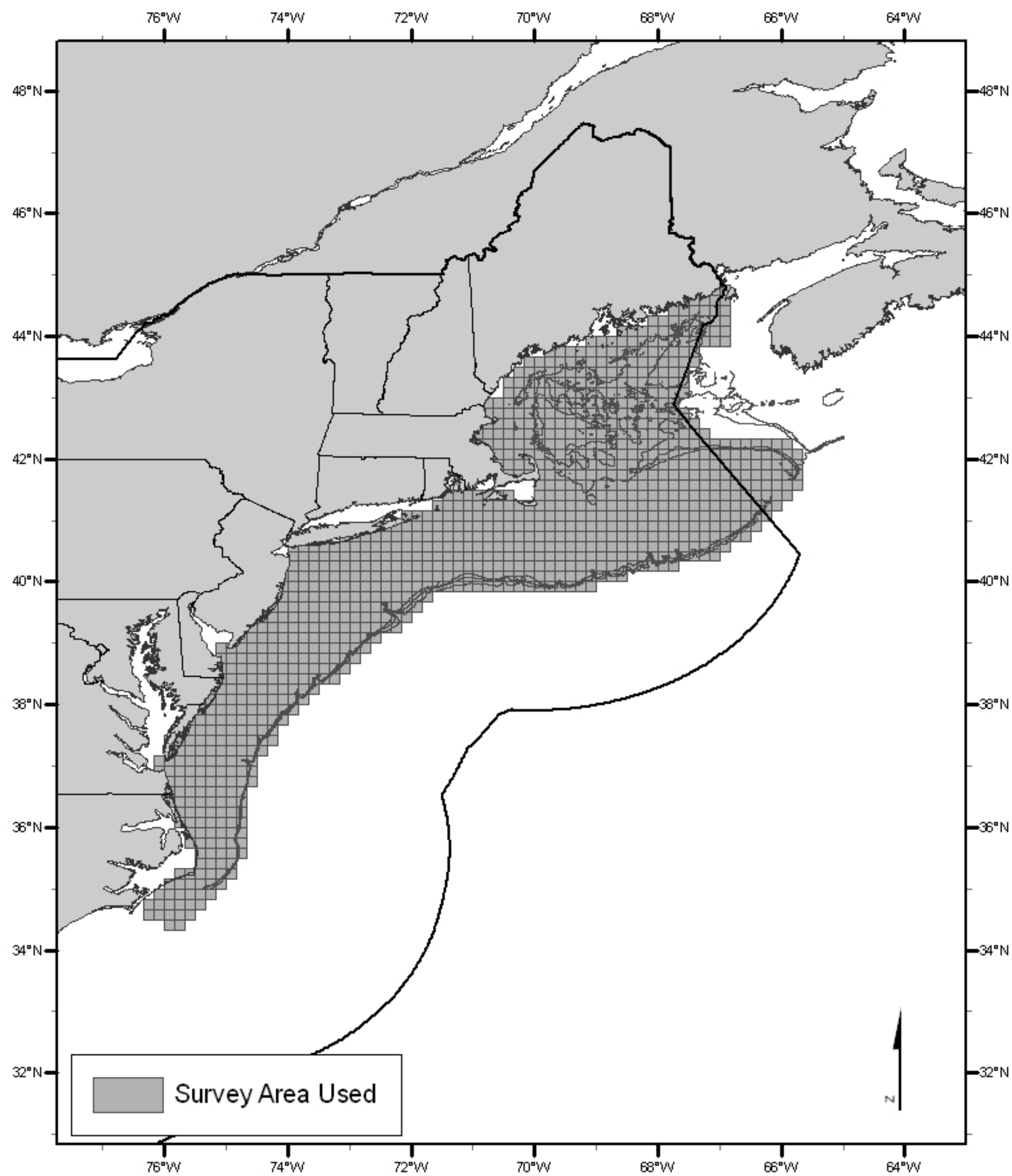
Map 3 – NEFSC bottom trawl survey strata for Northeast U.S. that were included in and excluded from the EFH analysis. Additional strata on the Scotian shelf that were surveyed in the early years of the time series were also excluded from the analysis and are not shown on this map. The heavy dark line is the western boundary of management area 4.



Map 4 – Ten minute squares used for most species in analysis of NEFSC trawl survey data



Map 5 – Ten minute squares used for species with distinct stock areas in U.S. and Canada (Atlantic cod, haddock, Atlantic herring, winter flounder, and yellowtail flounder).



The cumulative percent catch rates in this alternative changed from 50%, 75%, 90% and 100% as considered in the No Action alternative to 25%, 50%, 75% and 90% to reflect a wider range of survey-defined species habitats. As in the No Action alternative, EFH maps for benthic life stages were based on cumulative percentages of the average catch rates in each TMS. No Alternative 2 designations were developed for the eggs and larvae of species that are based solely on 1977-1987 MARMAP survey data.[8] However, alternative 2 egg and larval designations were developed for those species which were originally based on distributions of juveniles or adults as "proxies" because there was new bottom trawl survey information for juveniles and adults (see above). Unlike the No Action alternative, no TMS were added to the EFH maps in this alternative to "fill in" gaps or areas of historical importance that might be under-represented in the trawl survey data.

NEFSC survey catch data for the continental shelf were processed slightly differently in order to further reduce the impact of high abundance tows on average catch rates for each ten minute square (see details in Alternative 3).

The spatial extent of EFH in Alternative 2 does not extend beyond the edge of the continental shelf (depth of approximately 500 meters).

3.1.1.2 **State survey and ELMR data**

Additionally, state survey data were included, along with ELMR data, in the GIS analysis used to create the inshore portions of the EFH maps. A ten minute square (TMS) was considered EFH if more than 10 percent of the tows in the ten minute square were positive for the species and lifestage. This approach combined survey data from all states. A positive tow was defined as any tow catching at least one fish). Inshore TMS were identified as EFH in Alternative 3 using the same method. (For a complete listing of state surveys used, see the Alternative 3 methods section).

3.1.2 **Text descriptions**

Text descriptions for this alternative differ from the descriptions in the No Action alternative because they were based on an explicit analysis of up-dated NEFSC trawl survey data, analysis of inshore survey data, analysis of a greatly expanded USGS marine substrate database that became available in 2005, and new evaluations of habitat-related information in updated versions of the EFH Source Documents. They also do not include any descriptions for a separate spawning adult life stage. Methods used to define habitat characteristics in the text descriptions (depth, temperature, and salinity ranges, and substrate types) of EFH were the same for this alternative and for alternative 3, except that the Alternative 2 maps and text descriptions do not include Level 1 information from the continental slope (see methods for Alternative 3 for more details). Alternative 2 EFH

[8] An intensive series of ichthyoplankton surveys were conducted for several species on Georges Bank as part of the international Global Ocean Ecosystem Dynamics (GLOBEC) program during 1995-1999, but this information was not included in the text descriptions or maps for this alternative because it was more limited in geographic scope than the MARMAP surveys and did not include the months August-December. The results of the GLOBEC surveys are summarized in recent up-dates and revisions to the EFH Source Documents (NOAA Tech Memo series).

designations (maps and text) were based, in most cases, on level 2 information (see Table 4). Proxies were used for ten species. Substrate types and depth, temperature, and salinity ranges used in the text descriptions where individual life stages and species were "common" are summarized in the supplementary species tables in Appendix B.

Table 4 – Levels of information and life stage "proxies" used for Alternative 2 EFH designations

Species	***Eggs***	***Larvae***	***Juveniles***	***Adults***
American plaice	NAD	NAD	2	2
Atlantic cod	2[a]	2[a]	2	2
Atlantic halibut	NAD	NAD	2[b]	2[b]
Atlantic herring	1	2	2	2
Atlantic sea scallop	NAD	NAD	2[b]	2[b]
Barndoor skate	NAD	N/A	2	2[c]
Clearnose skate	NAD	N/A	2	2
Haddock	NAD	NAD	2	2
Little skate	NAD	N/A	2	2
Monkfish	0[d]	1[d]	2	2
Ocean pout	0[b]	N/A	2	2
Offshore hake	NAD	NAD	2	2
Pollock	2[e]	2[e]	2	2
Red hake	NAD	NAD	2	2
Redfish	N/A	NAD	2	2
Rosette skate	NAD	N/A	2	0[b]
Silver hake	2[c]	2[c]	2	2
Smooth skate	NAD	N/A	2	2
Thorny skate	NAD	N/A	2	2
White hake	0[c]	0[c]	2	2
Windowpane flounder	NAD	NAD	2	2
Winter flounder	NAD	NAD	2	2
Witch flounder	NAD	NAD	2	2
Winter skate	NAD	N/A	2	2
Yellowtail flounder	NAD	NAD	2	2

[a]: juveniles were used as a proxy in combination with egg and/or larval survey data.
[b]:a combination of juveniles and adults was used as a proxy
[c]: juveniles were used as a proxy
[d]: adults were used as a proxy in combination with egg and/or larval survey data
[e]: adults were used as a proxy
Level "**0**" indicates that there is very little information available for this life history stage.
N/A: indicates that this does not exist as a distinct life history stage for this species.

NAD: indicates No Alternative Designation due to lack of new information

3.2 Habitat Features plus abundance method (Alternative 3 in 2007 DEIS)

In order to develop a new approach for designating EFH that was based on peer-reviewed methodolgies, a Peer Review Committee of three independent experts was convened in June 2005 to recommend a course of action for the New England and Mid-Atlantic Fishery Management Councils, the NEFSC Northeast Regional Office, and the NEFSC Northeast Fisheries Science Center to follow in implementing new EFH designations for the Northeast region. The purpose of the peer review exercise was to evaluate available EFH designation methodologies and to identify an approach that could be applied for identifying essential habitats and their characteristics for federally-managed species in the region. Preliminary work was performed by a Habitat Evaluation Working Group made up of academic and government agency fishery scientists who held a series of meetings during the fall of 2004 and spring of 2005 and prepared a report which evaluated the potential applicability of six different methods. Candidate methodologies that were selected by the working group and evaluated by the panel of experts were: 1) the No Action method (see Alternative 1); 2) regression models, especially General Additive Models (GAM); 3) Habitat Suitability Index (HSI) models; 3) use of Geographic Information Systems (GIS); 4) an integrated approach used on the west coast; and 6) an optimization approach using a model called MARXAN.[9]

The peer review panel reached the following conclusions:

General Recommendations

- Until a thorough cross-calibration exercise is completed with the candidate EFH methods, the panel recommends the application of a method(s) that requires the minimum assumptions for any species or life-stage in order to stay as close to the available data as possible and provide the least ambiguous interpretation.
- The framework for development and use of EFH methods must be consistent across temporal and spatial scales for comparative analyses, visualization and interpretation of processes.
- The focus on methodological development should move from EFH Levels 1 and 2 data to EFH Levels 3 and 4 data as fast as possible to be consistent with the ecosystem-based management mandate.
- Habitat variables could be enriched by expanded exploratory data analyses to include other abiotic (circulation, salinity, rugosity, turbidity, patchiness, etc.) and biotic (primary productivity, prey availability, predation, etc.) covariates.
- Prioritization of methodologies will be based on the number of assumptions (i.e. simple to complex) required to implement them. For example, No Action, to HSI, to GAM, to West Coast, etc. Further, the HSI as a concept is appropriate, but not as analytically powerful as other candidate methods. Therefore the panel recommends that methodologies that are quantitatively robust such as the GAMs should replace the HSI approach as soon as reasonable. However, the panel

[9] More information regarding the peer review process, including the names of the three reviewers and the members of the working group, and a copy of the working group report, can be found on the NOAA Northeast Regional Office web site.

recognized there are sufficient analytical restrictions on the use of GAM models that some cases might require supplementation by an HSI type approach. In the short term, the West Coast model and bioenergetics methods will be difficult to implement given the apparent lack of available data and analytical requirements. The West Coast method may have greater utility in the longer-term, but the method and results need to be compared and rectified relative to other competing approaches using data of comparable time and space scales. The panel also felt the spatial optimization methods (e.g. MARXAN) would likely be the downstream recipient of the outputs (e.g. spatial maps of presence-absence, density, and preference) from the comparative analyses and would likely be most useful in the delineation of EFH designations in single or multiple species contexts. The panel did not think GIS should be considered as a stand-alone analytical tool for EFH designation; however, GIS will be a fundamental component of EFH model development, implementation, and visualization.

- To satisfy simultaneous objectives of stock assessment and EFH designation by the fishery-independent survey mechanisms, it would be prudent to develop minimum mapping units for specific habitat types that could also be used as the basis for stratifying the sampling domain in resources surveys conducted by NEFSC and others.
- For each of the short, intermediate, and long-term recommendations, immediate and serious consideration must be given as soon as possible to fiscal and personnel requirements to accomplish these goals.
- The HEWG should continue to provide stewardship role to the iterative process of EFH evaluation and designation in the short and long-term. In the process the stewardship function provided by the HEWG will facilitate development of ecosystem-based methods. This approach would provide an integrated framework that would ultimately lead to ecosystem-based management.

Short-Term Recommendations

- Improve the text descriptions in the No Action EFH methodology source documents to be more comprehensive of the habitats that the species utilize.
- The panel believes the utility of evaluating EFH designation for eggs and larval life-stages is questionable at this time and efforts should be focused on EFH designation for juveniles and adults.
- Develop a comprehensive sensitivity analysis strategy to compare the candidate EFH methods that involves the following:
    - Data: An identification of those species that are sufficiently data rich such that all methods or models could be compared simultaneously in an objective manner (i.e. in space for selected areas, e.g. Eastern Georges Bank, Great Sound Channel, or New York Bight Apex; or in time for selected species, e.g. cod, Atlantic herring, summer flounder, redfish).
    - Time and space scales: Give high priority to defining the appropriate minimum mapping unit (e.g. at present analyses use 10-minute squares).
    - Species and life-stages: Develop the appropriate life history and population-dynamic contrasts for method comparisons (e.g., pelagic vs.

demersal, fast-growing vs. slow growing, high mortality vs. low mortality).

- Improve the quality of the base maps ("habitat" layers) on which the methods analyses are predicated.
- Develop selection criteria for objectively assessing method performance. This will require a clearer articulation of management needs.
- For the EFH Omnibus Amendment 2, the No Action method should be pursued, with possible inclusion of Habitat Suitability Index- type information, until inter-calibration of models is completed.

Intermediate & Long Term Recommendations

- Attention should be paid to temporal and spatial dynamics of fish distributions and "habitats." For example, recast the data analyses to focus time on intervals (e.g. decades) in response to trends in climate, fishing impacts, shifting habitat, etc.
- Build a relational database that links data from fisheries, fishery-independent resource surveys conducted by various agencies, and biophysical "habitat" information (e.g. remote sensing, physical oceanography, etc.) across institutions, municipalities, states, and federal jurisdictions.
- Serious attention should be paid to revision of sampling designs based on the concept of EFH maps which provide clear covariates for survey stratification. Develop a strong focus on improving base maps and layers at both local and regional levels.
- Use operations research methods to assist in identifying criteria with which EFH is defined, but also to establish thresholds for management actions. Clarification of these definitions would allow greater flexibility in modeling EFH and management decision-making.
- Develop a strategy for improving methods in order to move from descriptive, statistical-based (collected data) presentations to mechanistic, model-based (parameter estimates) forecasts that support ecosystem-based management.

3.2.1 **Data Sources**

Based on the general advice provided in the general and short-term recommendations by the Peer Review Committee, the NEFMC Habitat Plan Development Team (PDT) developed a GIS-based EFH designation methodology that combines the primary elements of Alternative 2 (up-dated survey catch rate data for the continental shelf and ELMR and state survey information for inshore areas) with habitat features that are associated with high catch rates of benthic juveniles and adult life stages. To this end, the spatial extent of EFH was divided into four general geographic realms (inshore, continental shelf, continental slope and seamounts), largely because of the different data sets and levels of information that were available within each area. Below is a general description of the methods used to create options under Alternative 3.

As noted in section 1.0, EFH designations include a text description and a map for each life stage of each managed species. The maps depict the geographic extent of the areas within which the text descriptions must apply in order for a particular location to be designated as EFH. In this alternative, the EFH text descriptions and maps are "linked" more explicitly than in the other designation alternatives. Depth and temperature ranges, and in some cases substrate types, that are included in the text descriptions were also used to create the EFH maps for benthic life stages in this alternative. Bottom temperature and substrate type aspects of EFH were displayed on a ten-minute-square basis, whereas depth was indicated at a much higher spatial resolution (see Section 3.2.3.2). Lengths at maturity used to distinguish juveniles from adults were the same as those used in the original EFH designations (see Table 3). Pertinent information on young-of-the-year juveniles and spawning adults was included in the juvenile and adult life stage text descriptions.

These are the data sources the PDT utilized in developing the Alternative 3 EFH designations:

Inshore (ELMR and states) data sources

- ME Beam Trawl Survey
- ME/NH Inshore Trawl Survey
- NH Estuarine Seine Survey
- MA Inshore Trawl Survey
- RI Narragansett Bay Trawl Survey
- RI Coastal Trawl Survey
- RI Coastal Ponds Seine Survey
- RI Narragansett Bay Seine Survey
- CT Long Island Sound Trawl Survey
- CT Long Island Sound Small Mesh Trawl Survey
- NY Raritan Bay Trawl Survey
- NJ Trawl Survey
- NJ Delaware Bay Trawl Survey
- DE Delaware Bay 16ft Trawl Survey
- DE Delaware Bay 30ft Trawl Survey
- MD Coastal Bays Seine Survey
- MD Coastal Bays Trawl Survey
- MD Chesapeake Bay Seine Survey
- VA Chesapeake Bay Trawl Survey
- VA Coastal Bays Seine Surveys
- NC Trawl Surveys
- NOAA Estuarine Living Marine Resource information

Continental shelf data sources

- NEFSC Bottom Trawl Survey
- NEFSC Scallop Dredge Survey
- NEFSC MARMAP Ichthyoplankton Survey

Continental slope and seamount data sources

- Deep Sea Experimental Fishery project reports

- Smithsonian Institution collection data
- Research cruise reports
- Literature

Habitat data sources

- NDGC Coastal Relief Model 3 arc-second and USGS 15 arc-second raster bathymetry
- USGS usSEABED substrate database
- Bottom temperature derived from NEFSC, MARMAP, bottom trawl, and hydrographic survey data.

Table 5 shows the levels of information that were utilized in developing each species' EFH designation and identifies instances in which other life stages were used as proxies. For most species, the information used to develop the alternative 3 designations consisted of relative abundance and distribution data (Level 2). In a few cases, some Level 3 information was also available, but there was no level 4 information relating fish productivity to habitat type, quantity, quality and location.

Table 5 – Levels of information and life stage "proxies" used for Alternative 3 EFH designations

Species	*Eggs*	*Larvae*	*Juveniles*	*Adults*
American plaice	NAD	NAD	2	2
Atlantic cod	NAD	NAD	2	2
Atlantic halibut	0[b]	0[b]	2[a,b]	2[a,b]
Atlantic herring	1	NAD	NAD	NAD
Atlantic sea scallops	0[b]	2+3[b]	1,2,3	2
Barndoor skate	NAD	N/A	2[a,c]	2[a,c]
Clearnose skate	NAD	N/A	2	2
Haddock	NAD	NAD	2	2
Little skate	NAD	N/A	2	2
Monkfish	NAD	NAD	2[a]	2[a]
Ocean pout	0[d]	N/A	2	2
Offshore hake	NAD	NAD	2[a]	2[a]
Pollock	NAD	NAD	2	2
Red hake	0[c]	2[c]	2	2[a]
Redfish	N/A	2[a,c]	2[a]	2[a]
Rosette skate	NAD	N/A	2	0[c]
Silver hake	NAD	NAD	2	2[a]
Smooth skate	NAD	N/A	2[a]	2[a]
Thorny skate	NAD	N/A	2[a]	2[a]
White hake	NAD	NAD	2	2[a]

Species	*Eggs*	*Larvae*	*Juveniles*	*Adults*
Windowpane flounder	NAD	NAD	2	2
Winter flounder	1[e]	1+2[e]	2	2
Winter skate	NAD	N/A	2	2
Witch flounder	NAD	NAD	2[a]	2[a]
Yellowtail flounder	NAD	NAD	2	2

[a]:a Level 1 continental slope designation is included in this alternative
[b] juveniles and adults were used as a proxy.
[c]juveniles were used as a proxy
[d]designation based on source document information on the depth range and fall bottom temperature for spawning adults
[e]designation based on the depth ranges of eggs in inshore waters and on Georges Bank
Level "**0**" indicates that there is very little information available for this life history stage.
N/A: indicates that this does not exist as a distinct life history stage for this species.
NAD: indicates No Alternative Designation due to lack of new information.

3.2.2 Text descriptions

The following methods were used to determine substrate types, ranges of depth, temperature, and salinity, and primary prey types associated with all four life stages of each managed species in the inshore, continental shelf, continental slope, and seamount spatial realms. For each species, all relevant supplementary information was summarized in a table (See Appendix B) and EFH text descriptions were written based on a synthesis of this information. For most of the benthic life stages, the same information that was used in the text descriptions was also used to map EFH habitat features.

For most species, no alternative text descriptions (or maps) were developed for pelagic life stages in this alternative because there was no new egg and larval survey data. For a few species (red hake and redfish) for which juvenile distributions were used as a proxy in the map representations of EFH for eggs and/or larvae (see Table 5), new Alternative 3 text descriptions were developed. As was the case for the benthic life stages, depth and temperature ranges cited in the text descriptions were based on level 2 information for the inshore and continental shelf spatial realms and level 1 information for the continental slope. For level 2, the minimum and maximum values defined where eggs or larvae were "common" and for level 1, where they were "present" (see Appendix B).

3.2.2.1 Inshore

Minimum and maximum values of depth, bottom temperature, and salinity were determined from analysis of data collected during all inshore (state) bottom trawl and seine survey tows (or seine hauls) in ten minute squares (TMS) where at least 10% of the tows (or hauls) caught at least one of the target species and life stages. (For an explanation of why this approach was taken and how EFH in inshore survey areas was mapped, see Section 3.2.3.1). Depth, temperature, and salinity ranges were defined to include data from all tows in these TMS and, on a more limited basis, as minimum and maximum values where a given species and life stage was "common". The latter criteria were used in the text descriptions whenever possible. Other information relating to inshore habitat features (e.g., depth and substrate) available in EFH source documents or other published sources was also incorporated into the text descriptions. A more detailed description of survey designs, times of year, locations, gear types, net and mesh sizes, and tow speeds and duration is given in Table 6. The last column in this table indicates which years were used in the analysis.[10]

Depth, bottom temperature, and salinity were determined from bottom trawl survey data histograms (see example in Figure 1) showing the frequency distributions of tows, positive tows (i.e., tows which caught at least one of the target species and life stages), and total catch for the target species and life stage at each interval of depth, temperature, or salinity. Inshore survey data were available in this form from trawl surveys in Massachusetts (1978-2005), Maine/New Hampshire (2000-2005), Raritan Bay (1992-1997), Delaware Bay (State of Delaware, 1966-1997 or 1999), and the lower Chesapeake Bay (1988-2005).[11] Data from other surveys were either not available in this form or were insufficient to support a reliable analysis. In most cases, minimum and maximum values were based on the intervals where percent catch exceeded percent number of tows. In the example shown in Figure 1, the depth range is 41-85 meters and the temperature range is 4.5-10.5ºC.[12] In cases of low sample size and/or "noisy" data, percent occurrence (positive tows) was used instead of percent catch (minimum depth of 31-35 m in Figure 1 instead of 41-45 m). If a species' life stage was known to utilize intertidal habitats, the minimum depth of EFH was defined as 0 meters relative to the mean high water (MHW) datum and an explicit reference to the intertidal zone was made in the description. For surveys conducted at more than one time of year, the lowest minimum and highest maximum values were selected to represent an annual range. [13]

Substrate types identified in the EFH text descriptions were based on a GIS "overlap" analysis of a U.S. Geological Survey substrate database (usSEABED) and NEFSC trawl survey data for the continental shelf (see Section 3.2.3.2 for details). Substrate information was supplemented using additional information from the EFH source documents or update memos, or from other sources. In some cases, these sources were also used to provide information regarding depth, temperature, and salinity. When available, specific information related to the habitat characteristics of young-of-the-year juveniles and spawning adults was included in the appropriate text description. All the data used in the Alternative 3 text descriptions are summarized in the individual species

[10] In many cases surveys have been conducted for a longer time period.

[11] Updated Massachusetts survey data (through 2005) were compiled in 2nd edition EFH source documents and update memos for individual species, Maine/NH data were provided by the Maine Department of Marine Resources, Raritan Bay data were in the original EFH source documents, Delaware Bay data were either in Morse (2000) or in 2nd edition EFH source documents and update memos, and Chesapeake Bay data in Geer (2002).

[12] Depths were "rounded off" in the text descriptions and for the maps (e.g., 41 to 40 meters).

[13] Most species' distributions extend from inshore waters to deeper water on the continental shelf, thus the minimum depth was often derived from state trawl survey data and the maximum depth from NEFSC trawl survey data, or in some cases, from level 1 continental slope information. For species with distributions that include shallow, inshore waters, temperature and salinity ranges were closely related to annual variations that are more extreme than the more modulated conditions in deeper water on the shelf, e.g., low bottom temperatures in the spring and high bottom temperatures in the fall.

tables in Appendix B. Footnotes to these tables identify information sources that were used for each life stage in the inshore and continental shelf and slope spatial realms.

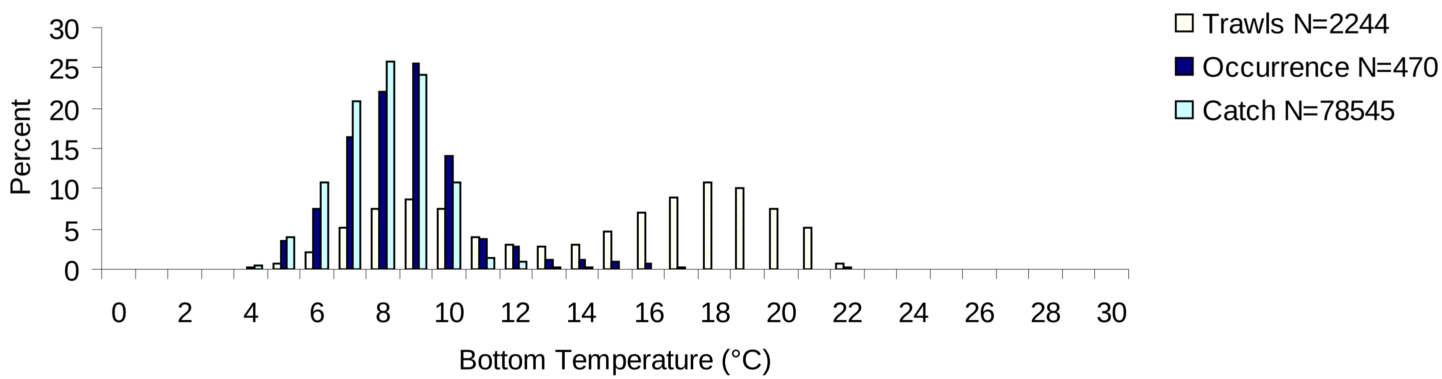
Table 6 – Details regarding state surveys used to determine extent of EFH for species managed by NEFMC in inshore waters

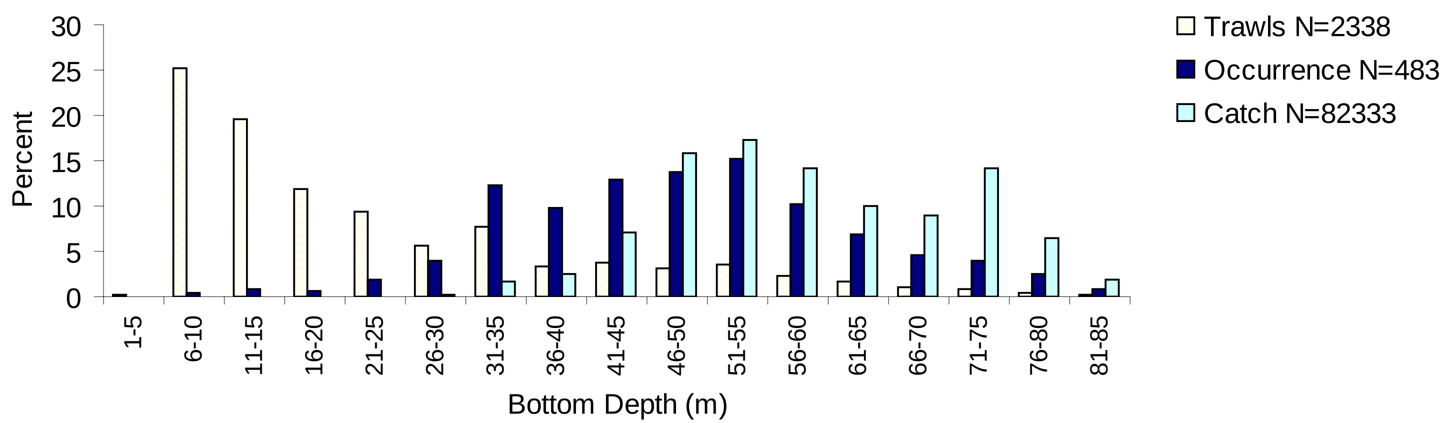
State	*Survey Location*	*Gear Type*	*Mesh Size*	*Survey Design*	*Headrope (ft)*	*Footrope (ft)*	*Tow Duration/Speed*	*Time of Year*	*Years Analyzed*
Connecticut	Long Island Sound	Bottom Trawl	4 inch with 2 inch cod end, no liner	Stratified random	30	46	30 min@ 3.5 kts	Spring (April–June), Summer (July–August), Fall (Sept–Oct), and November	1984–2004
Connecticut	Long Island Sound	Bottom Trawl	2 inch with 0.25 inch cod end liner	Stratified random	30	46	30 min@ 3.5 kts	?	1991-93, 1996
Delaware (16ft Trawl)	Delaware Bay and Delaware River	Bottom Trawl	1.5 inch, 0.5 inch liner	Fixed	16	21	10 min @ minimum hp	April - October (monthly)	1980–2004
Delaware (30ft Trawl)	Delaware Bay	Bottom Trawl	2 inch	Fixed	30	40	20-30 min @ minimum hp	March - December (monthly)	1966-2004
Maine	ME/NH Inshore Waters	Beam Trawl	0.125 inch	Random stations in fixed areas	6	N/A	5 min	Bi-Monthly April-Nov	2000-2004
Maine	ME/NH Coastal Waters	Bottom Trawl	2 inch with 1 inch cod end liner	Stratified random plus fixed stations	60	70	20 min @ 2.2-2.3kts	Spring & Fall	Fall 2000-Spring 2005
Maryland	Coastal Bay	Beach Seine	0.25 inch mesh	Fixed	100	N/A	N/A	June & Sept	1989-2005
Maryland	Upper Bay	Seine (striped bass)	0.25 inch bar mesh	Fixed	100	N/A	N/A	July, Aug & Sept	1954-2005
Maryland	Coastal Bay	Bottom Trawl	0.25 inch	Fixed	?	16	6 min @ 3.0 kts	Monthly, April-Oct	1989-2005
Massachusetts	Coastal	Bottom Trawl	1.25 inch mesh, 0.25 inch liner	Stratified random	39	51	20 min @2.5kn	Spring & Fall	1978-2005
Massachusetts	Coastal	Seine	0.25 mesh	Fixed	20	N/A	N/A	June	1975-2005
New Hampshire	Great Bay Estuary, Little Harbor, Upper Piscataqua	Seine	0.25 inch	Fixed	100	N/A	N/A	Monthly, June-Nov	1997-2004

State	Survey Location	Gear Type	Mesh Size	Survey Design	Headrope (ft)	Footrope (ft)	Tow Duration/Speed	Time of Year	Years Analyzed
	River								
New Jersey	Delaware Bay	Bottom Trawl	1.5 inch with 0.5 inch liner	Fixed	16	N/A	20 min @ 2.1kts	April 2004-October 2004	1991-2005
New Jersey	Coastal Waters	Bottom Trawl	4.7/3 inches, 0.25 inch bar mesh cod end liner	Stratified random	82	100	20 min	5 times a year	1988-2004
New York	Hudson-Raritan Bay	Bottom Trawl	1.75 inch cod end, 1.375 Liner	Stratified random	28	34	10 min @ 2kts	Monthly (except May, Sept)	Jan 92-June 97
North Carolina	Pamlico Sound	Bottom Trawl (2)	0.9 inch bar mesh, 0.75 in cod end	Stratified random	30	?	20 min @ 2.5 kts	June and Sept (also March and Dec prior to 1991)	???
North Carolina	Pamlico Sound (Juvenile Survey)	Bottom Trawl	0.25 inch bar mesh, 0.125 in cod end	Fixed	7.5	?	1 min	May and June (Feb-Nov prior to 1990)	???
Rhode Island	Narragansett Bay	Bottom Trawl	1 inch cod end, 0.25 inch liner	Fixed	39	54	20 min @2.5kn	Monthly	1990-2005
Rhode Island	Coastal	Bottom Trawl	1 inch cod end, 0.25 inch liner	Fixed and stratified random	39	54	20 min @2.5kn	Spring and Fall	1983-2005
Rhode Island	Narragansett Bay	Seine	0.25 inch with 0.1875 inch in bunt	Fixed	200	N/A	N/A	Monthly, June-Nov	1988-2005
Rhode Island	Coastal Ponds	Seine	0.25 inch	Fixed	130	N/A	N/A	Monthly, May-Nov	1992-2004
Virgina	Lower Chesapeake Bay and major tributaries	Bottom Trawl	1.5-inch, 0.25 inch liner in cod end	Fixed and stratified random	30	?	5 min @ 2.5kts	Monthly	1988-2005
Virgina	Coastal Bays (striped bass)	Seine	0.25 in bar mesh	Fixed	100	N/A	N/A	Bi-weekly, April-Oct	1967-2005

State	***Survey Location***	***Gear Type***	***Mesh Size***	***Survey Design***	***Headrope (ft)***	***Footrope (ft)***	***Tow Duration/Speed***	***Time of Year***	***Years Analyzed***
Virgina	Coastal Bays (bluefish)	Seine	0.25 in bar mesh	Fixed	100	N/A	N/A	Bi-weekly, July-Sept	1993-2005

Figure 1 – Distribution of fall juvenile American plaice catches and sampling effort in Massachusetts coastal waters by bottom temperature and depth, 1978-2003. Light bars show the percent distribution of all trawl tows, dark bars show the percent distribution of all tows in which juvenile American plaice occurred and medium bars show, within each interval, the percentage of the total number of juvenile American plaice caught. (Temperature values on the X-axis are interval mid-points, e.g., "10°C" represents the interval 9.5-10.5°C).





3.2.2.2 **Continental shelf**

Frequency distributions of the complete set (in the selected U.S. and Canadian survey strata, see Map 4 and Map 5) of fall and spring NEFSC trawl survey catch rate data were analyzed to determine minimum and maximum depth and bottom temperature values for benthic juveniles and adults during 1963-2003 using the method described below.[14] Tow by tow salinity data were not analyzed; instead, salinity ranges used in the text descriptions were based on the less restrictive percent catch exceeds percent tows method that was used in the inshore area (see Figure 1). The minimum and maximum values for the fall and spring were combined to create a single annual range. Substrate types in some cases were identified using a GIS overlap analysis which is also described below. Additional information for the shelf was obtained from the EFH source documents, or other sources (see individual species tables in Appendix B). Note that not all criteria were used in the text descriptions and maps for all species/lifestages.

Temperature and Depth

Minimum and maximum depths and bottom temperatures that were associated with the highest catch rates (number of juvenile and adult fish caught per tow) during the 1963-2003 NEFSC fall and spring trawl surveys were estimated from survey data. An example frequency distribution curve is shown in Figure 2 and the number of fish that were available for analysis is shown in Table 7. Minimum and maximum values for most life stages and species were determined for the fall and spring (separately) by selecting intervals that each represented approximately 50% or more of the modal value. Using 50% of the modal value captured the core of the distribution without overly restricting the habitat analysis. An analysis was also done for all species using values that represented 33% of the modal value. The results were either indistinguishable from the 50% ranges, or overly restrictive. Thus, in the example shown in the figure, the temperature range is 2.5 to 5.5°C (lower limit of interval with midpoint of 3°C and upper limit of interval with midpoint of 5°C), since the catch rates for each of the temperature classes in that range equal at least 50% (2.75 fish per tow) of the maximum catch rate (5.5 fish per tow).[15] These depth and temperature ranges were considered along with minimum values derived from state survey data (see Section 3.2.2.1 for details) and supplementary information from the EFH source documents and update memos to determine annual ranges for the entire continental shelf used in the EFH descriptions (see supplementary tables in Appendix B). Corresponding maps for the continental shelf were produced using a GIS analysis of the same spring and fall depth and temperature ranges and, in some cases, substrate types (see section 3.2.3.2).[16]

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[14] Note that this time period differs slightly from the time period used to calculate average catch rates by TMS for the EFH maps in Alternatives 2, 3, and 4.

[15] Some judgment had to be used in the case of frequency distributions that were not uni-modal, or where the data were "noisy" without any clear maxima. In these cases, the 50% criterion had to be somewhat relaxed and the ranges were broader.

[16] For the purpose of developing EFH text descriptions and maps, the "offshore" continental shelf spatial realm was differentiated from the "inshore" spatial realm, even though the inshore area included coastal continental shelf habitats. Depth ranges referred to in the text descriptions incorporated level one inshore data and level two offshore data. Thus, EFH for a species and life stage that met the 10% frequency of

Figure 2 – Frequency distribution of average catch rates by one degree Centigrade intervals of bottom temperature for adult American plaice during 1968-2003 spring NEFSC trawl surveys.

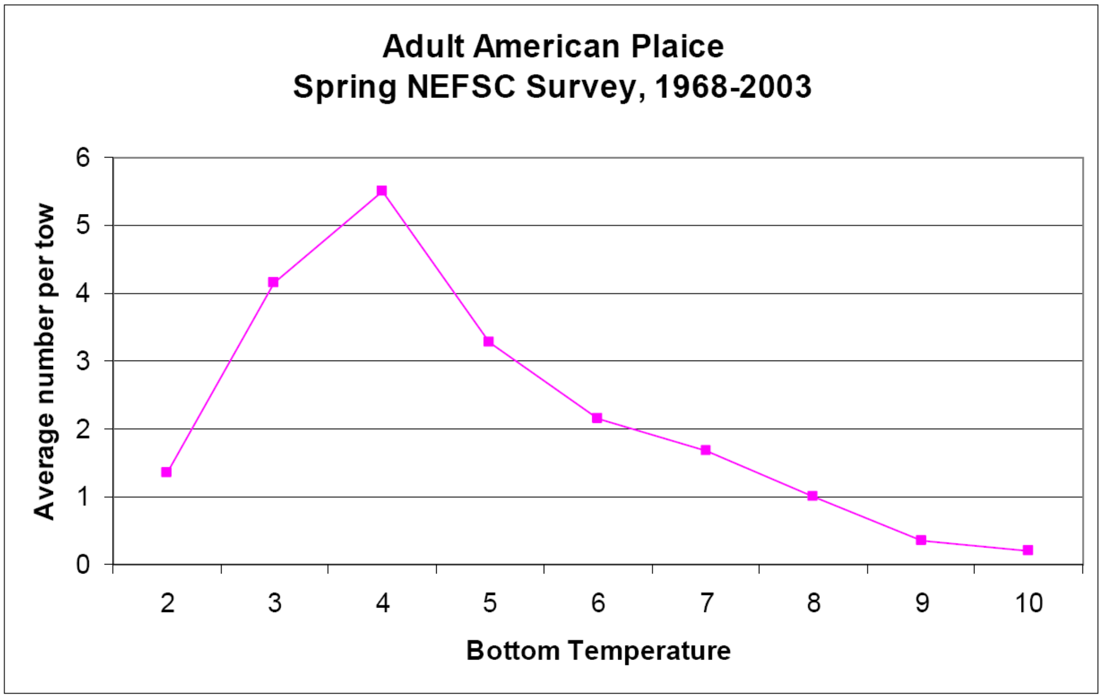


Table 7 – Numbers of NEFMC-managed species caught and numbers caught per tow (CPUE) in 1963-2003 spring and fall NEFSC bottom trawl surveys in the Northeast region and included in the analysis.

		Spring		*Fall*		*Both*	
Species	***Lifestage***	***Number caught***	***CPUE***	***Number caught***	***CPUE***	***Number caught***	***CPUE***
American plaice	Juvs	27838	2.22	37217	2.62	65055	2.44
	Adults	27176	2.17	35655	2.51	62831	2.35
Atlantic cod	Juvs	6978	0.56	7661	0.54	14639	0.55
	Adults	26689	2.13	22413	1.58	49102	1.84
Atlantic halibut	Juvs/Adults	413	0.03	415	0.03	828	0.03
Atlantic herring	Juvs	184284	14.73	78453	5.53	262737	9.84
	Adults	84332	6.74	74283	5.24	158615	5.94
Barndoor skate	Juvs	252	0.02	629	0.04	881	0.03
	Adults	65	0.01	98	0.01	163	0.01
Clearnose skate	Juvs	1942	0.16	2072	0.15	4014	0.15
	Adults	1107	0.09	954	0.07	2061	0.08
Haddock	Juvs	30910	2.47	73837	5.20	104747	3.92
	Adults	49704	3.97	89807	6.33	139511	5.23
Little skate	Juvs	232621	18.59	72414	5.10	305035	11.42

occurrence criterion in the inshore area in depths of 10-50 meters and was common offshore in 30-200 meters was described as occurring in 10-200 meters on the continental shelf.

Species	Lifestage	Spring Number caught	Spring CPUE	Fall Number caught	Fall CPUE	Both Number caught	Both CPUE
	Adults	5062	0.40	4939	0.35	10001	0.37
Monkfish	Juvs	3062	0.24	3923	0.28	6985	0.26
	Adults	3859	0.31	3305	0.23	7164	0.27
Ocean pout	Juvs	3615	0.29	1299	0.09	4914	0.18
	Adults	34935	2.79	5698	0.40	40633	1.52
Offshore hake	Juvs	2065	0.17	1003	0.07	3068	0.11
	Adults	2394	0.19	1330	0.09	3724	0.14
Pollock	Juvs	7222	0.58	3683	0.26	10905	0.41
	Adults	9193	0.73	7957	0.56	17150	0.64
Red hake	Juvs	31561	2.52	53107	3.74	84668	3.17
	Adults	66425	5.31	84046	5.92	150471	5.64
Redfish	Juvs	34433	2.75	57823	4.08	92256	3.46
	Adults	109959	8.79	140037	9.87	249996	9.36
Rosette skate	Juvs	566	0.05	468	0.03	1034	0.04
	Adults	2	0.00	0	0.00	2	0.00
Silver hake	Juvs	243107	19.43	385702	27.19	628809	23.55
	Adults	183013	14.62	210635	14.85	393648	14.74
Smooth skate	Juvs	2045	0.16	1924	0.14	3969	0.15
	Adults	353	0.03	407	0.03	760	0.03
Thorny skate	Juvs	7061	0.56	9356	0.66	16417	0.61
	Adults	695	0.06	1230	0.09	1925	0.07
White hake	Juvs	5862	0.47	13593	0.96	19455	0.73
	Adults	14178	1.13	23707	1.67	37885	1.42
Windowpane	Juvs	8633	0.69	20481	1.44	29114	1.09
	Adults	43919	3.51	38124	2.69	82043	3.07
Winter flounder	Juvs	20579	1.64	13639	0.96	34218	1.28
	Adults	30839	2.46	31422	2.22	62261	2.33
Winter skate	Juvs	47363	3.78	26676	1.88	74039	2.77
	Adults	3583	0.29	4839	0.34	8422	0.32
Witch flounder	Juvs	4240	0.34	4152	0.29	8392	0.31
	Adults	10076	0.81	9859	0.69	19935	0.75
Yellowtail	Juvs	13008	1.04	21251	1.50	34259	1.28
	Adults	48010	3.84	48341	3.41	96351	3.61

Salinity:

Salinity ranges were determined from frequency histograms of NEFSC fall and spring survey data in updated EFH source documents using the same method described above for inshore depth and temperature ranges and illustrated in Figure 1.

Substrate:

Substrate types that characterized EFH were identified using a GIS-based analysis which evaluated the degree to which substrate types overlapped spatially with the relative abundance of target species and life stages as represented in the NEFSC trawl survey database, or which were clearly identified in the EFH source documents and in other sources such as Collette and Klein-MacPhee (2002).

To perform the analysis, a surficial sediment habitat layer was created using the U.S. Geological Survey's USSeabed database, utilizing sample data that were based on grain size analysis and data that were derived from verbal descriptions. Only samples collected in the upper 10 cm of the bottom were analyzed. The sixteen Folk sediment classes (Table 8) were reclassified into six classes (plus rocky/hard bottom) in order to simplify the analysis (Table 9).[17] Once reclassified, the substrate data were analyzed by ten minute square. In each ten minute square, the percentage of all samples classified in each of the seven substrate classes was calculated.

Table 8 – Folk Sediment Classification Scheme

Folk Code	*Description*	*Grain size composition*
G	Gravel	≥ 80% gravel
M	Mud	≥ 90% mud, no gravel
S	Sand	≥ 90% sand, no gravel
(g)M	Slightly gravelly mud	> trace to 5% gravel, >9:1 mud
(g)S	Slightly gravelly sand	> trace to 5% gravel, >9:1 sand
(g)sM	Slightly gravelly sandy mud	> trace to 5% gravel, >1:1 mud
(g)mS	Slightly gravelly muddy sand	> trace to 5% gravel, >1:1 sand
sM	Sandy mud	10-50% sand, 50-90% mud, no gravel
mS	Muddy sand	10-50% mud, 50-90% sand, no gravel
gS	Gravelly sand	5-30% gravel, >9:1 sand
gM	Gravelly mud	5-30% gravel, >1:1 mud
gmS	Gravelly muddy sand	5-30% gravel, >1:1 but <9:1 sand
mG	Muddy gravel	30-80% gravel, >1:1 mud
sG	Sandy gravel	30-80% gravel, >9:1 sand
msG	Muddy sandy gravel	30-80% gravel, >1:1 but <9:1 mud

Table 9 – Substrate Reclassification

New Substrate Class	*Folk Codes*

[17] Two sediment classification schemes were included in the usSEABED database, one developed by Folk (1954; 1974) and another by Shepard (1954). The Folk codes were used because more samples were classified using them. The usSEABED database can be accessed at http://walrus.wr.usgs.gov/usseabed.

New Substrate Class	***Folk Codes***
Mud	M, (g)M
Sand/Mud	sM, (g)sM, mS, (g)mS
Sand	S, (g)S
Gravelly Sand and/or Mud	gM, gS, gmS
Sandy and/or Muddy Gravel	msG, sG, mG
Gravel*	G
Rocky/Hard Bottom**	H

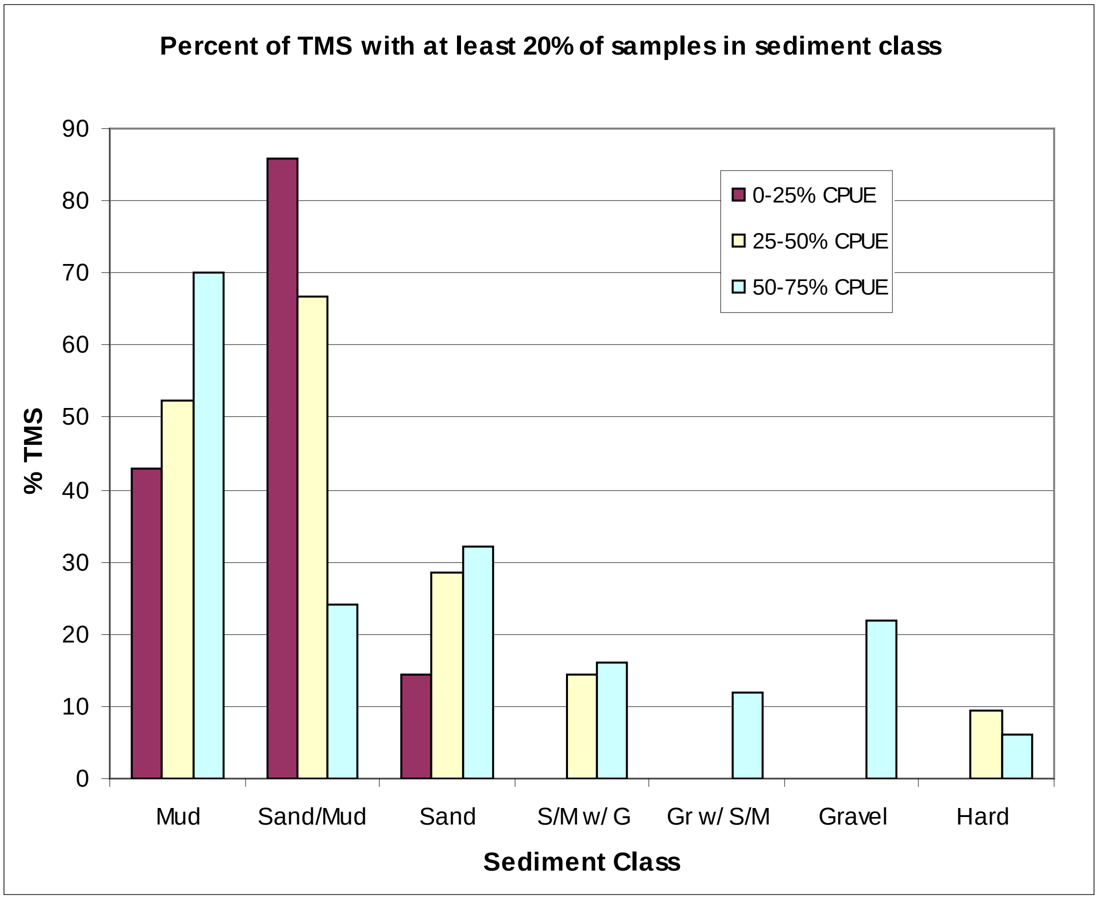
* For this analysis, the term "gravel" refers to all grain sizes above a diameter of 2 mm, i.e., any substrate coarser than sand. "Gravel" therefore includes pebbles, cobbles, and even boulders.
** "Rocky bottom" refers to visual identification of bedrock on the seafloor, or to attempts to collect a sediment sample that failed because the bottom was so hard that no sample could be collected. Due to sampling limitations, gravel and rocky substrates are under represented in the substrate database.

A ten minute square (approximately 75 nmi^2) was considered to include any given substrate type if that substrate type accounted for 20% or more of the total number of samples in that ten minute square. Thus, a ten minute square with 100 substrate samples, 25 of which are classified as sand, 22 as mud, and 20 as gravel, was considered to "contain" all three of those substrate types. The 20% threshold was chosen because it provided a balance between several factors. The percentage of samples of a substrate type in a ten minute square and the area covered by that substrate type within the ten minute square are not necessarily related. For example, in many cases one section of a ten minute square is heavily sampled, while others are not. Additionally, the purpose of the habitat analysis is not only to identify ten minute squares that in their entirety contain essential habitat, but also those that contain sections of essential habitat. Thus, a threshold of 20% balances the need to select ten minute squares with a reasonable amount of certain substrates with the uncertainties of the data.

The substrate type or types associated with the benthic life stages of each species was determined by analyzing which substrate types were correlated with different levels of abundance from the spring and fall NMFS trawl surveys, and by examining the information in the EFH source documents. A positive correlation was indicated when the degree of spatial overlap between a substrate type and ten minute squares that accounted for the 25th, 50th, and 75th percentiles of the survey catch rates for the target life stage and species averaged approximately 25%, as seen in Figure 3.[18] This value was chosen as the threshold because analysis of the data showed that for many species a 25% overlap corresponded with a natural break in the distribution and for key species it correctly identified their known substrate affinities. The results of the substrate analysis for each benthic life stage and species are shown in Table 12. For many species, the analysis was not specific enough to identify preferred substrate types. Also, gravel and rocky substrates are under-represented in this analysis because the sampling devices used do sample hard bottom substrates well, or at all.

[18] In this example, the overlap averaged 25% or higher for mud, sand/mud, and sand.

Figure 3 – Juvenile American Plaice Substrate Analysis



3.2.2.3 **Continental slope and seamounts**

Text descriptions were based on level 1 (presence only) information. For species and life stages that extend beyond the edge of the continental shelf, the text descriptions identify a maximum depth that was determined by consulting relevant deep-sea experimental fishing project reports, the EFH source documents, and other publications (see Table 10).

Table 10 – Depth ranges and maximum depths for NEFMC-managed species that occur on the continental slope. The right hand column indicates maximum depths used in text descriptions of all EFH designation alternatives that include the continental slope and seamounts. Abbreviations: GB – Georges Bank, GOM – Gulf of Maine, MAB – Mid-Atlantic Bight, NEFSC – Northeast Fisheries Science Center, SNE – Southern New England.

Species	*Depth (meters)*	*Location*	*References*	*Maximum Depth Determined by PDT*
Atlantic Halibut (Hippoglossus hippoglossus) juveniles/adults	37-550	Virginia to Greenland	Moore et al., 2003	700 (juvs/adults)
	200-750	Iceland Slope	Haedrich and Merrett, 1998	
	typically 100-700, max 720-900	Virginia to Labrador	Cargnelli et al., 1999	
Barndoor Skate (Dipturus laevis) juveniles/adults	0-750	Cape Hatteras to Grand Banks	Moore et al., 2003	750 (juvs/adults)
Monkfish/Goosefish (Lophius americanus) juveniles/adults	0-948	Florida to Gulf of St. Lawrence	Moore et al., 2003	1000 (juvs/adults)
	max 744-839	SNE Slope	Kvilhaug & Smolowitz 1996	
	very few >823	GB/SNE Slope	Balcom 1997	
Offshore Hake (Merluccius albidus) juveniles/adults	80-1170 (mostly 160-640)	Northern Brazil to Le Have Bank	Moore et al., 2003	750 (juvs/adults)
	200-750	SNE Slope	Haedrich and Merrett, 1988	
Red Crab (Chaceon or Geryon quinquedens) juveniles/adults	200-599	Continental Slope MAB thru GOM	Wahle, 2005	1300 on slope (juvs) 900 on slope (adults)
	360-540	Continental Slope-Sable Island to Corsair Canyon	Stone and Bailey, 1980	2000 on seamounts (juvs/adults)
	max 915-932	SNE Slope	Kvilhaug & Smolowitz 1996	
	274-1463 (juvs mostly 503-1280, adults mostly 320-914)	Continental Slope (between 38° and 41°30 min N)	Wigley et al., 1975	
Redfish (Sebastes sp.) juveniles/adults	200-592	Virginia to Labrador/Greenland Slope	Moore et al., 2003	600 (juvs/adults)
	200-750	Newfoundland; Iceland Slope	Haedrich and Merrett, 1988	

Species	***Depth (meters)***	***Location***	***References***	***Maximum Depth Determined by PDT***
	max 768-786 (mostly 490-616)	GB/SNE Slope	Balcom 1997	
Red Hake (Urophycis chuss) juveniles/adults	37-792	North Carolina to Southern Newfoundland	Moore et al., 2003	750 (adults)
	200-750	SNE Slope	Haedrich and Merrett,1988	
Smooth Skate (Malacoraja senta) juveniles/adults	46-956	North Carolina to southern Grand Banks	Moore et al., 2003	900 (juvs/adults)
Thorny Skate (Amblyraja radiata) juveniles/adults	18-996	South Carolina to Greenland	Moore et al., 2003	900 (juvs/adults)
White Hake (Urophycis tenuis) juveniles/adults	0-1000	North Carolina to Labrador	Moore et al., 2003	900 (adults)
Witch Flounder (Glyptocephalus cynoglossus) juveniles/adults	18-1570 (mostly 45-366)	North Carolina to Greenland	Moore et al., 2003	1500 (juvs/adults)
	max 635	GB/SNE Slope	Balcom 1997	

3.2.3 **Map Representations**

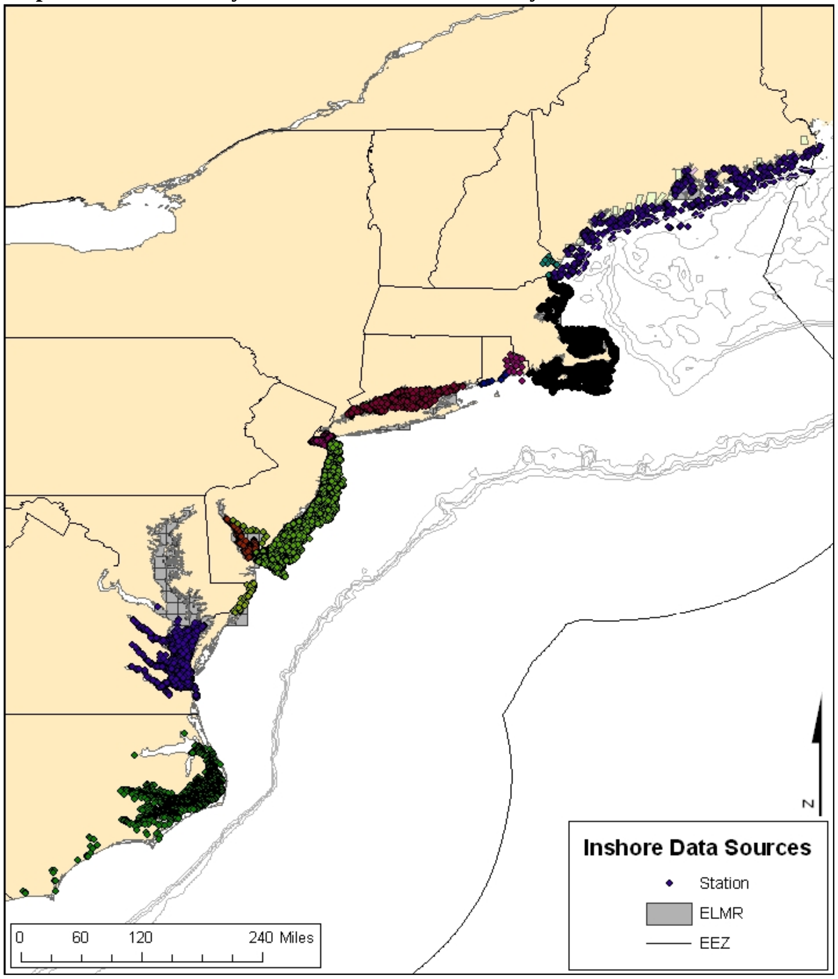
3.2.3.1 **Inshore**

For inshore and estuarine areas, the maps show the spatial extent EFH for each target species and life stage as ten minute squares where at least 10% of the state survey tows (or hauls) caught at least one fish as well as entire ELMR bays and estuaries in the mixed or full salinity zones where the target species and life stage was “common,” “abundant,” or “very abundant.” Although habitat characteristics (depth, temperature, salinity, and substrate types) were included in the text descriptions as described above, they were not used in the development of the inshore portions of the Alternative 3 maps.[19] Because the inshore TMS were not “clipped” by depth, the maps include inshore areas that do not satisfy the defining characteristics of EFH, and are therefore not EFH.[20] The spatial extent of the state survey data that were used to map EFH in inshore waters is shown in Map 6.

The 10% frequency of occurrence is an arbitrary threshold value that was applied by the PDT in order to identify inshore areas where any target species and life stage was relatively common. A conservative threshold value was selected (10% instead of, say, 20%) that could be applied across all surveys with the least risk of biasing the results in favor of sampling gear or survey practices that might be more efficient at catching particular species or sizes of fish. A list of state survey data that were utilized in the analysis is given in Section 3.2.1. A more detailed description of survey designs, times of year, locations, and time periods (years), gear types, net and mesh sizes, and tow speeds and duration is given in Table 6.

[19] “Inshore” in most cases refers to state waters – within three miles from shore – since this is the outer limit for most of the state surveys and the ELMR areas. However, some state surveys (e.g., the NH/ME trawl survey) extend into federal waters and some of the NEFSC trawl survey tows are made in state waters, so there is some overlap between the inshore and continental shelf spatial realms and the methods that were used to map EFH in them.
[20] The EFH maps for the continental shelf spatial realm were clipped by depth (see Section 4.5.2.1).

Map 6 – Inshore survey areas included in EFH analysis for alternatives 2, 3, and 4



3.2.3.2 **Continental shelf**

EFH distribution maps were developed for benthic life stages on the continental shelf by generating GIS habitat layers that were based on the spatial distribution of spring and fall depth and bottom temperature (and, for some species and life stages, substrate types) that were derived from the analysis used to generate information for the text descriptions (see Section 3.2.2.2).[21] The final Alternative 3 maps combined habitat features with relative abundance data (catch rates) from the NEFSC trawl surveys. The survey data were compiled by ten minute squares using the same methods used in Alternative 2: in fact, the same data were used in both alternatives. However, survey TMS in the Alternative 3 maps were "clipped" so that they only included the portion of each square that corresponded with the annual depth range that was associated with high catch rates for each target life stage and species. Like the survey data, the habitat layers covered successively larger areas of the shelf at higher cumulative percentile designation options. More detailed explanations of these methods are provided below.

[21] For most species, benthic life stages were limited to juveniles and adults, but for Atlantic herring, ocean pout, and winter flounder EFH maps were also produced for benthic eggs.

The standard 3A-3D maps were generated using a combination of survey catch data processed at the 25th, 50th, 75th, and 90th percentiles – as was done for alternative 2 – in combination with habitat layers of increasing size (see table below). In some cases, an additional 3E map was produced that included small areas that were added because they were inadequately surveyed or because members of the Council's Habitat Committee believed they were, in fact, essential habitat areas that were not identified by the methodology used to create the map. Also, in some cases a different life stage was used as a proxy for a poorly-represented life stage.

Option	Catch rate percentile	Habitat layer bounded by
A	25	50% catch TMS
B	50	75% catch TMS
C	75	90% catch TMS
D	90	100% catch TMS

Depth and Temperature

Depth and bottom temperature ranges (Table 11) were derived from the NEFSC fall and spring survey catch rate distributions, as described in Section 3.2.2.2. The annual depth ranges were used to "clip" the survey TMS for the 25, 50, 75, and 90% designation options (steps 3-6 in map construction, see Section 3.2.3.4). The NDGC Coastal Relief Model 3 arc-second raster bathymetry was used to create the depth habitat layer. On the southern portion of Georges Bank nearest the outer boundary of the EEZ which is not covered by the Coastal Relief Model, the USGS 15 arc-second Gulf of Maine raster bathymetry was used instead.

Preferred bottom temperature ranges for each species and life stage were mapped throughout the region using spring and fall averages of bottom temperature by ten minute square derived from the 1977-1987 NEFSC MARMAP surveys. A variation layer was then made using additional temperature data collected during a broader time series of hydrographic and bottom trawl surveys. The procedure also accounted for temporal variations in sampling intensity. Fall and spring maps of average bottom temperature are shown in Map 7 and Map 8. Fall and spring habitat layers were generated from the intersection of depth and bottom temperature layers for each time of year (steps 11-12 in Section 3.2.3.4). These were then overlaid to create annual depth-temperature GIS coverages (step 13) for each life stage and species.

Methods used to estimate average bottom water temperatures

The seasonal temperature distributions were based on NEFSC databases. Bottom temperatures were extracted on 10/21/05 from the bottom trawl survey data base for each station having a bottom temperature value[22]. Bottom temperature and salinity values

[22] The trawl survey data appeared to have two surveys with incorrect temperatures – 197508 and 197708. Upon review there appeared to be a format problem that such that a value of 2.4 probably was supposed to

were extracted from the hydrographic database on 09/14/05. There is redundancy in the two data bases, which is accounted for in the procedures described below.

To make seasonal average distributions of bottom temperature and salinity representing the time period of the trawl survey (i.e., 1963 to the present), the interannual variability in observations scattered over space and time had to be addressed in a rigorous manner. To do this a 'reference ocean' derived from the NEFSC MARMAP data was used. The MARMAP program occupied a set of over 150 standard stations (i.e., stations at set locations) over an eleven year period (1977-1987) and made about 50 observations of temperature and salinity at each location over that period. Characteristic annual cycles of bottom temperature were calculated from these data for each standard station location. By interpolating between the standard station locations, a method was developed to estimate the expected bottom temperature at any location on the shelf on any calendar day (see Mountain and Holzwarth, 1989 and Mountain et al., 2004 for explanation). Using this method, the difference between an observed value and the expected value (i.e., an anomaly) could be determined for every observation in the trawl survey and hydro databases.

The EFH temperature distributions were determined on a 10 minute square basis. The EFH value for each 10 minute square was determined by adding a mean value derived from the MARMAP annual curves and an average anomaly derived from all of the observations in the data bases. This was done separately for four seasons, defined as spring (March-May), summer (June-August), fall (September-November) and winter (December-February). These seasons were based on the NEFSC spring trawl survey generally beginning in March, the fall survey generally beginning in September or later and the winter survey being in February.

For each season the mean MARMAP value at the center of each 10 minute square was derived by averaging the values estimated by the MARMAP annual cycles for each day of the 3 month season. This was done for bottom temperature for each season and for each 10 minute square which contained at least one observation in the trawl survey data base.

The bottom temperature anomaly was calculated for each observation in the hydrographic data base. For a temperature observation to be considered a bottom value, it had to be taken within 10 meters of the observed bottom depth. Similarly bottom temperature anomalies were calculated for all observations in the trawl survey data base through the end of 1991. Beginning in 1992 the survey observations were made by CTD instruments and are in the hydrographic data base.

The bottom temperature anomalies in each 10 minute square and within each season were then averaged for 3 time blocks (1963-1976, 1977-1991, and 1992-2005). For each square that had an anomaly value in each time block, the three average anomaly values were themselves averaged to get the average anomaly over the whole time period. This

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be 24, with the tenths digit uncertain. These two surveys were therefore omitted from the analysis. Given the very large number of observations available, this loss was not significant.

procedure was done 1) to insure that the whole time period was represented and 2) because the recent decade had many more observations than the earlier decades which could bias a straight average of all anomalies toward recent environmental conditions. For the 10 minute squares in which an average anomaly was not able to be calculated (i.e., which did not have a value in each of the three time blocks), a value was determined by averaging the anomalies of the neighboring squares that did have anomaly values. For each 10 minute square and for each season, the anomaly was added to the MARMAP seasonal average value.

It is useful to recognize that the characteristic interannual variability in temperature is approximately +/- 1°C. Given the seasonal mean distributions, this magnitude of year-to-year change would correspond to spatial changes of many 10's of kilometers, suggesting that the meaningful spatial scale for these parameters is fairly coarse.

Table 11 – Ranges of depth (meters) and bottom temperature (°C) associated with high catch rates of individual species caught in NEFSC spring and fall bottom trawl surveys in the northwest Atlantic during 1963-2003.

American plaice						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	51-180	81-160	51-180	2.5-5.5	3.5-6.5	2.5-6.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	71-200	101-200	71-200	2.5-5.5	3.5-7.5	2.5-7.5
Atlantic cod						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	31-90	31-120	31-120	2.5-5.5	3.5-11.5	2.5-11.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	31-100	51-140	31-140	2.5-6.5	2.5-9.5	2.5-9.5
Used MA data for juvenile temperature range in fall – not enough NEFSC data						
Atlantic halibut						
Juveniles/Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
Catch>Tows	81-140	61-140	61-140	2.5-7.5	4.5-12.5	2.5-12.5
Atlantic sea scallop						
Juveniles/Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	41-120	n/a	n/a	5.5-10.5	n/a	n/a
Barndoor skate						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	71-100	51-160	51-160	2.5-13.5	5.5.11.5	2.5-13.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both

50%	Low N	Low N		Low N	Low N	
No information in source doc, so used fall temperature data for spring and juvenile depth and temperature data for adults						
Clearnose skate						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	1-30	1-20	1-30	14.5-16.5	18.5 -21.5	14.5-21.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	1-20	1-30	1-30	14-15	18.5-21.5	13.5-21.5
Haddock						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	71-120	41-100	41-120	4.5-8.5	4.5-12.5	4.5-12.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	61-120	71-140	61-140	3.5-7.5	4.5-8.5	3.5-8.5
Little skate						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	11-50	31-70	11-70	1.5-5.5	13.5-15.5	1.5-15.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	31-100	31-100	31-100	1.5-6.5	10.5.-15.5	1.5-15.5
Monkfish						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	51-200	51-180	51-400	4.5-12.5	6.5-13.5	4.5-13.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	61-200	51-200	51-400	6.5-15.5	4.5-12.5	4.5-15.5
Relatively high catch rates between 200 and 400 m in spring and fall and a few catches >500 m						
Ocean pout						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	41-70	51-70	41-70	2.5-4.5	8.5-11.5	2.5-11.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	41-60	41-100	41-100	1.5-4.5	5.5-11.5	1.5-11.5
Offshore hake						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	201-400	301-400	201-400	9.5-12.5	8.5-12.5	8.5-12.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both

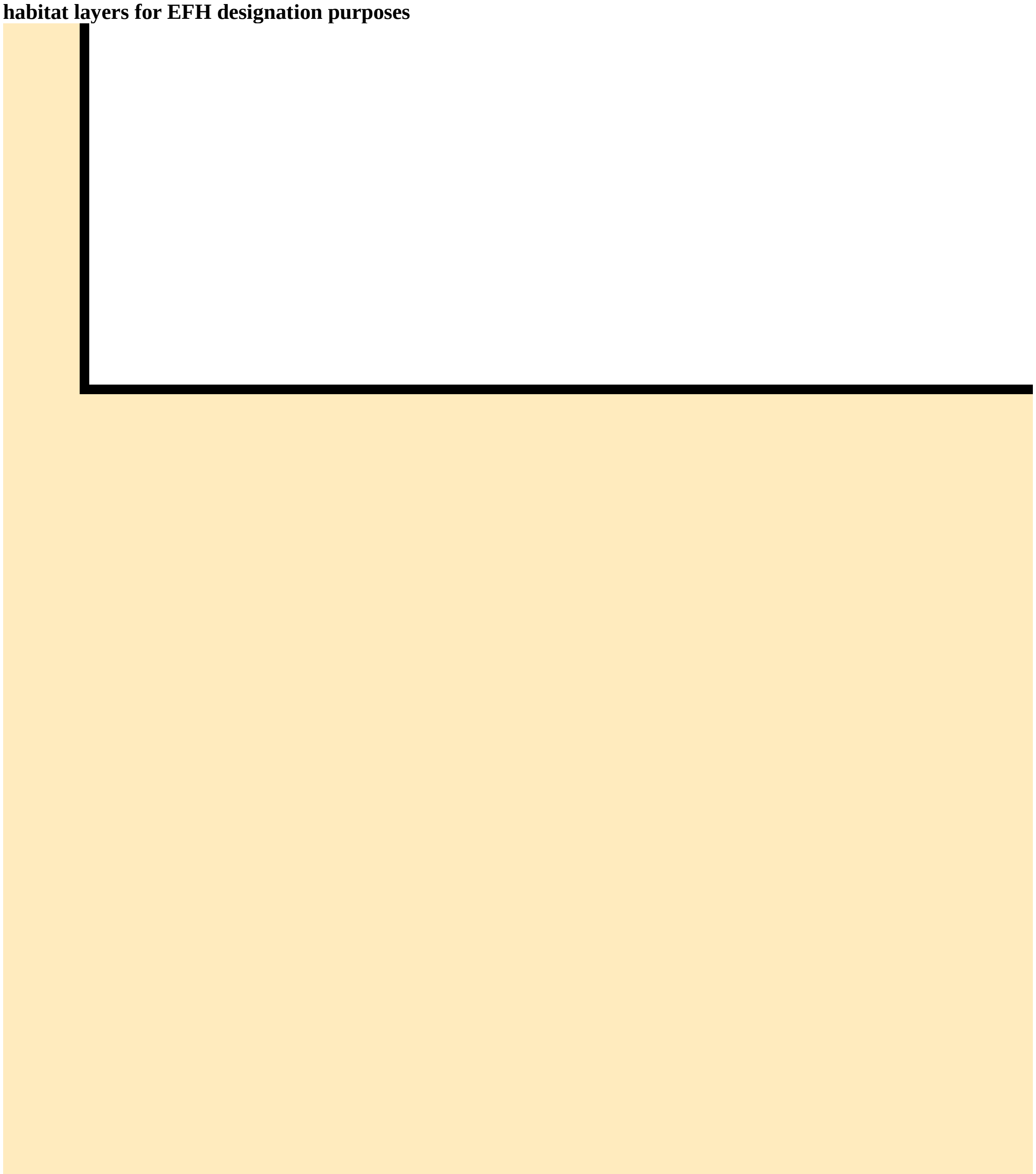
50%	201-400	301-400	201-400	11.5-12.5	6.5-11.5	6.5-12.5
Pollock						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	41-160	41-180	41-180	2.5-5.5	7.5-9.5	2.5-9.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	161-180	81-180	81-180	5.5-9.5	5.5-9.5	5.5-9.5
Redfish						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	121-200	101-200	101-200	5.5-9.5	2.5-7.5	2.5-9.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	161-200	141-200	141-200	5.5-9.5	3.5-7.5	3.5-9.5
Red hake						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	1-30	41-80	1-80	3.5-15.5	9.5-17.5	3.5-17.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	61-300	61-160	61-300	7.5-10.5	5.5-12.5	5.5-12.5
Rosette skate						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	71-300	81-140	71-300	9.5-17.5	11.5-14.5	9.5-17.5
No data for adults						
Silver hake						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	141-400	41-100	41-400	5.5-8.5	4.5-10.5	4.5-10.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	121-500	141-300	121-400	7.5-13.5	5.5-10.5	5.5-13.5
Smooth skate						
Juveniles(Low Catch)						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	121-400	141-400	121-400	5.5-9.5	3.5-7.5	3.5-9.5
Adults (Low Catch)						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	121-300	121-300	121-300	5.5-8.5	3.5-7.5	3.5-8.5
Thorny skate						
Juveniles						

Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	71-400	71-400	71-400	0.5-8.5	3.5-6.5	0.5-8.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	141-300	121-200	121-300	2.5-7.5	3.5-6.5	2.5-7.5
White hake						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	141-300	61-120	61-300	3.5-9.5	8.5-15.5	3.5-15.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	161-400	101-300	101-400	6.5-9.5	4.5-10.5	4.5-10.5
Windowpane						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	1-20	1-60	1-60	2.5-6.5	13.5-18.5	2.5-18.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	1-20	1-70	1-70	2.5-12.5	12.5-18.5	2.5-18.5
Winter flounder						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	11-50	31-50	11-50	1.5-5.5	9.5-16.5	1.5-16.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	11-60	31-60	11-60	1.5-6.5	9.5-12.5	1.5-12.5
Winter skate						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	11-70	21-80	11-80	1.5-5.5	13.5-17.5	1.5-17.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	31-60	31-50	31-60	1.5-6.5	13.5-16.5	1.5-16.5
Witch flounder						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	81-400	81-400	81-400	3.5-13.5	3.5-8.5	3.5-13.5
Adults						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	121-400	121-200	121-400	2.5-8.5	2.5-6.5	2.5-8.5
Yellowtail flounder						
Juveniles						
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	31-70	41-60	31-70	2.5-4.5	8.5-12.5	2.5-12.5
Adults						

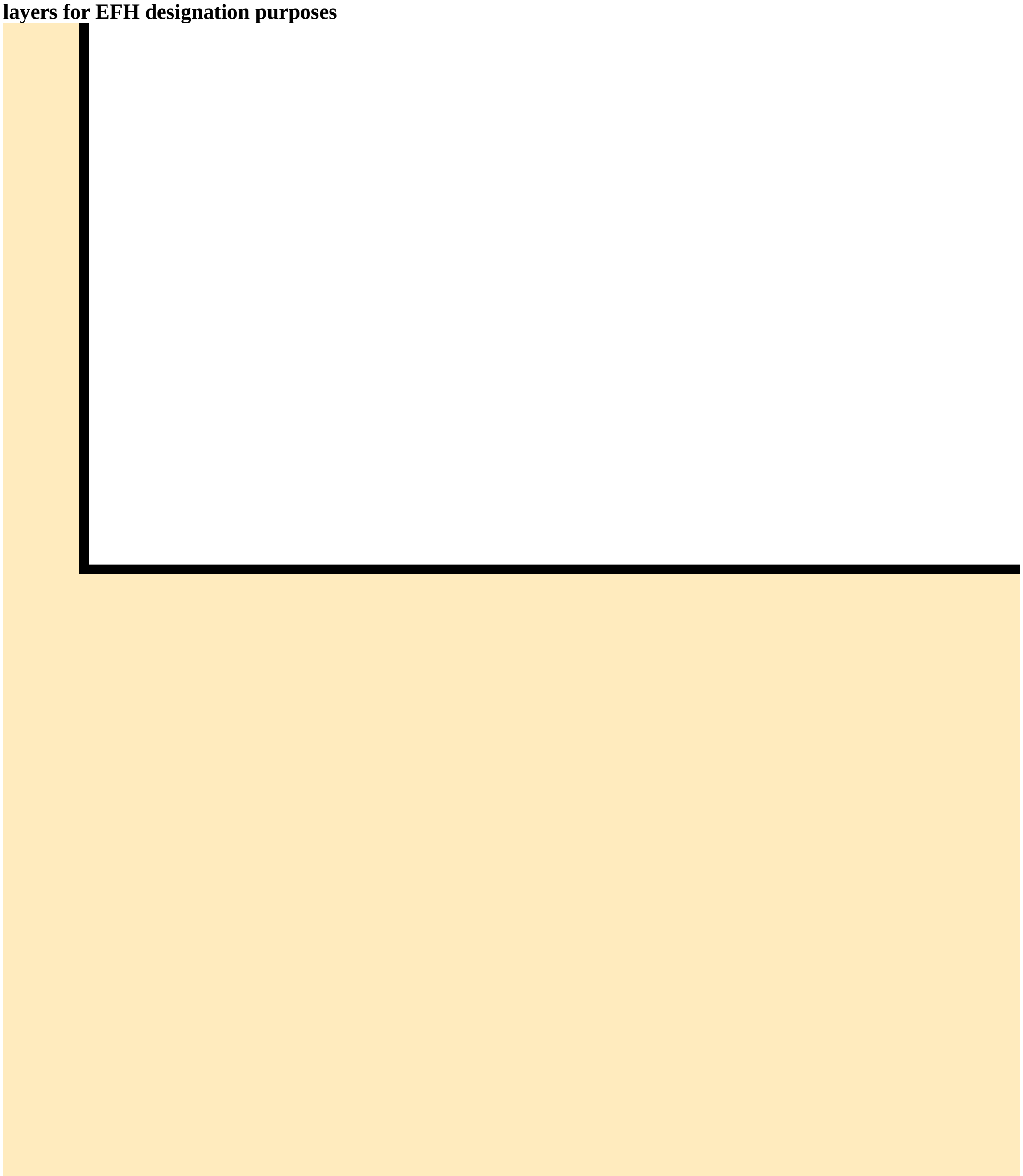
Pct	Depth-Spr	Depth-Fall	Depth-Both	BT-Spr	BT-Fall	BT-Both
50%	31-80	41-80	31-80	2.5-6.5	8.5-12.5	2.5-12.5

Note: Deep-sea red crab and Atlantic salmon were not included in this analysis because trawl survey data were not available for them. Data were available for Atlantic herring, but since it is a pelagic species, the data were not considered to be representative of its primary habitat.

Map 7 – Distribution of average fall (September-November) bottom water temperatures (°C) used to create habitat layers for EFH designation purposes



Map 8 – Distribution of average spring (March-May) bottom water temperatures (°C) used to create habitat layers for EFH designation purposes



Substrate

Preferred substrate types used for habitat mapping were derived from the overlap analysis of NEFSC fall and spring survey catch rate distributions and usSEABED substrate data that is described in Section 3.2.2.2, as supplemented by additional information from other sources – primarily the EFH source documents.[23] The results of this analysis are given in

[23] In some cases (e.g., see juvenile haddock in Table A-11) additional substrate types that failed to meet the 25% overlap criterion were added if there were strong indications in the literature that they were important habitat components.

Table 12. Note that in many cases the results of this analysis were not used to produce maps because so many TMS met the 20% criterion for the three most common substrate types: mud, mud/sand, and sand. For species and life stages that have an affinity with all three of these bottom types, the addition of substrate type as a third habitat variable in the GIS analysis failed to add any significant spatial resolution to habitat distributions that were based on depth and bottom temperature. Another problem was low sample size, i.e., life stages for some species were too poorly represented in the trawl survey to support a reliable analysis. For those life stages and species with acceptable results, TMS that contained at least 20% of any of the preferred substrates were added to the annual depth and temperature layer to produce the final habitat layer.

Table 12 – Results of substrate overlap analysis by species and lifestage

Species/Lifestage	*Sample Size*[1]			*Percent Overlap By Substrate Type*[2]							*Substrates Mapped?*		*Comments*
	0-25%	*25-50%*	*50-75%*	*Mud*	*M/S*	*Sand*	*M/S w Gr*	*Gr w M/S*	*Gr*	*Hard*	*Yes*	*No*	
American Plaice Juv	7	21	50	55.1	58.8	25.0	10.1	4.0	7.3	5.2	√		Did not use sand
American Plaice Adult	25	41	65	74.0	36.4	21.4	11.1	3.9	10.7	2.7	√		
Atlantic Cod Juv	7	25	60	18.0	31.4	62.6	25.3	13.1	26.0	6.4		√	Area too large
Atlantic Cod Adult	18	46	91	20.8	22.3	56.4	34.1	17.0	34.8	3.7	√		
Atlantic Halibut	1	2	25	85.3	4.0	6.7	8.0	4.0	12.0	20.7		√	Low sample size
Barndoor Skate Juv	15	26	42	17.4	27.4	84.7	25.0	6.2	5.9	0.0	√		
Barndoor Skate Adults	2	9	20	27.4	47.8	58.1	30.7	8.3	14.1	0.0	√		Low N, used juveniles
Clearnose Skate Juv	11	21	39	17.7	25.9	93.6	34.3	9.0	2.4	0.0	√		
Clearnose Skate Adult	15	25	39	14.1	22.9	95.7	38.2	3.4	2.2	0.0	√		Same as juveniles
Haddock Juv	16	34	73	7.4	9.5	79.1	34.8	15.2	19.5	0.5	√		Same as adults
Haddock Adult	8	20	71	10.8	15.2	54.6	40.6	33.9	38.2	0.9	√		
Little Skate Juv	44	73	115	8.3	12.9	95.4	14.6	4.1	9.0	3.9	√		
Little Skate Adult	32	53	85	10.2	10.0	90.1	17.4	13.0	17.1	0.8	√		
Monkfish Juvs	56	92	140	61.5	38.7	44.4	13.5	3.2	6.4	1.7		√	
Monkfish Adults	63	103	171	63.7	45.0	40.0	11.2	3.0	5.7	0.5		√	
Ocean Pout Juvs	24	47	81	26.9	30.5	67.0	22.8	9.1	10.7	3.6		√	Area too large
Ocean Pout Adults	32	62	124	22.1	29.1	80.8	20.0	4.8	8.2	4.7		√	Add mud, area too large
Offshore Hake Juv	3	10	20	52.8	83.3	44.4	1.7	1.7	0.0	0.0		√	Low N, area too large
Offshore Hake Adult	3	11	21	57.9	88.9	48.5	6.2	0.0	0.0	0.0		√	Low N, area too large
Pollock Juv	13	30	59	44.8	29.2	26.9	20.2	15.3	31.6	9.6		√	Area too large
Pollock Adult	11	36	73	39.6	31.2	29.1	37.2	22.5	24.8	0.5		√	Area too large
Red Hake Juv	60	116	193	44.3	30.4	61.6	17.7	6.4	8.1	1.6		√	Area too large
Red Hake Adult	41	79	130	65.3	40.7	40.0	15.9	5.8	6.2	1.3		√	Area too large

Species/Lifestage	***Sample Size[1]***			***Percent Overlap By Substrate Type[2]***							***Substrates Mapped?***		***Comments***
	0-25%	***25-50%***	***50-75%***	***Mud***	***M/S***	***Sand***	***M/S w Gr***	***Gr w M/S***	***Gr***	***Hard***	***Yes***	***No***	
Redfish Juv	15	34	56	61.3	28.8	21.9	22.8	14.8	21.5	3.2		√	Assume same as adults, area too large
Redfish Adult	8	21	44	53.4	28.5	27.9	26.1	23.5	23.2	0.8		√	Area too large
Rosette Skate Juv	7	11	20	31.6	44.1	74.5	27.3	1.7	0.0	0.0		√	Low N, area too large
Rosette Skate Adult	1	2	1	Not calculated – low sample size								√	Used juveniles
Sea Scallop	6	19	45	1.8	0.0	83.2	30.9	28.9	31.9	0.0	√		
Silver Hake Juv	43	84	141	75.8	31.4	22.5	14.2	7.4	11.2	2.8		√	Add sand, area too large
Silver Hake Adult	46	84	149	69.7	35.5	28.1	18.5	6.1	7.6	1.4		√	Area too large
Smooth Skate Juv	26	38	74	62.2	30.3	19.0	27.1	13.2	15.8	1.8		√	Add sand etc, area too large
Smooth Skate Adult	14	27	46	45.7	30.3	34.9	35.3	12.9	21.0	0.7		√	Area too large
Thorny Skate Juv	27	58	87	62.6	27.7	24.9	26.8	13.2	20.1	0.4		√	Area too large
Thorny Skate Adult	23	35	57	75.9	30.6	20.0	16.0	8.7	13.5	2.7		√	Add sand etc, area too large
White Hake Juv	26	47	97	73.3	24.7	22.1	12.9	6.7	15.4	8.1	√		
White Hake Adult	28	52	84	75.9	30.5	11.6	18.5	8.3	8.5	1.6	√		
Windowpane Juv	28	47	72	11.7	10.8	94.9	11.1	5.4	9.8	3.7	√		
Windowpane Adult	30	51	95	6.8	8.7	97.3	16.9	5.0	10.0	2.8	√		
Winter Flounder Juv	7	21	53	20.6	24.4	80.1	2.5	3.8	10.8	18.4		√	Add mud, sand/mud, area too large
Winter Flounder Adult	13	36	78	18.4	15.4	82.9	13.7	11.1	21.4	8.8	√		Add gravel
Winter Skate Juv	19	36	59	2.1	1.5	94.5	19.9	9.7	25.7	2.1	√		
Winter Skate Adult	11	24	40	1.7	2.2	93.3	23.6	13.0	39.0	0.0	√		
Witch Flounder Juv	13	29	64	82.6	31.3	14.6	3.8	4.1	10.4	7.5	√		
Witch Flounder Adult	22	40	75	77.8	25.1	20.3	16.7	9.0	13.6	1.7	√		
Yellowtail Juv	21	46	82	8.2	16.2	96.1	21.0	2.4	4.6	1.1	√		
Yellowtail Adult	28	47	81	7.5	21.5	91.7	19.9	3.7	5.0	0.7	√		

[1] Number of ten minute squares of latitude and longitude within three categories of decreasing abundance (average number of fish caught per tow)

[2] Averages of the percentages of ten minute squares with at least 20% of substrate samples in each substrate category across abundance categories
Note: Numbers in bold indicate substrate types that were used in EFH designation alternative 3 maps

3.2.3.3 **Continental slope and seamounts**

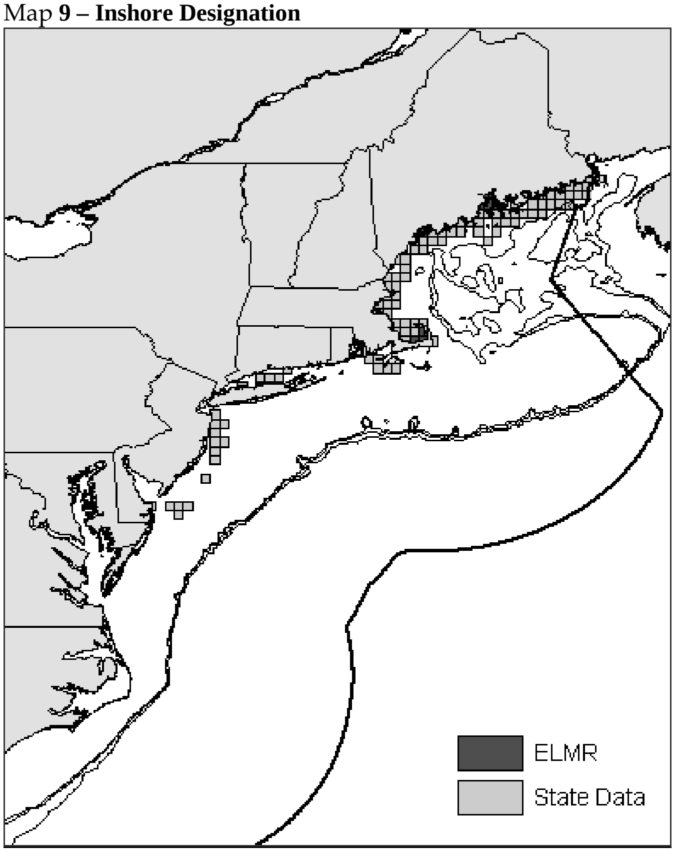
For benthic life stages, continental slope habitat distributions were added to the Alternative 3 maps based on level 1 maximum depth information included in the text descriptions and knowledge of the geographic range of the species. In all cases, species that extended beyond the edge of the shelf were known or assumed to inhabit slope habitats within the entire north-south range of the Northeast region, i.e., from the southern edge of Georges Bank (where the shelf break intersects the U.S.-Canada boundary) to approximately 34°N latitude, south of Cape Hatteras. Depth was defined by the NGDC Coastal Relief Model bathymetry.

3.2.3.4 **Map development example**

This section describes in detail the steps followed in creating the Alternative 3 EFH designation maps, using a hypothetical example.

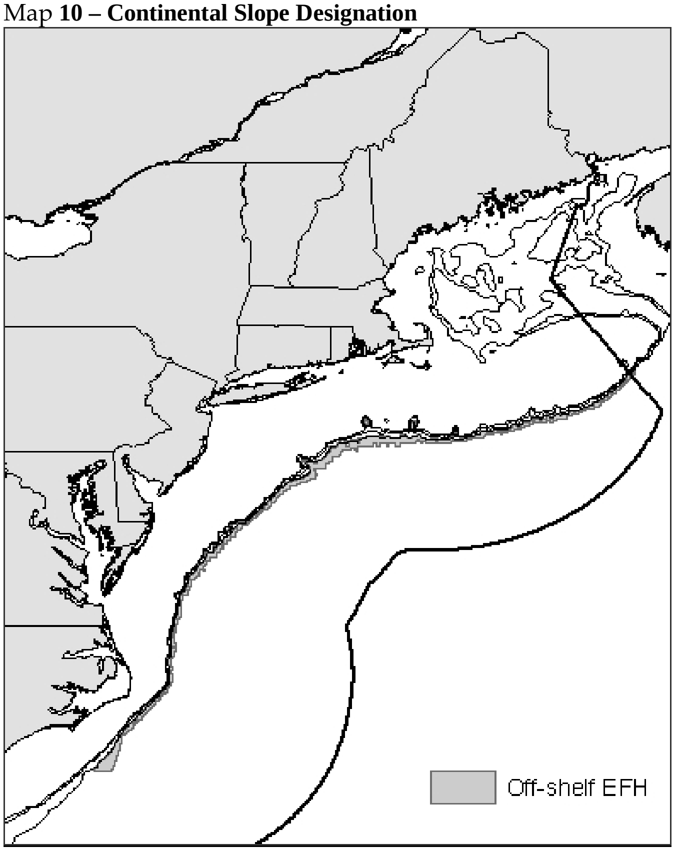
Step 1: The inshore coverage is mapped by overlaying the state survey data (TMS that satisfy the 10% frequency of occurrence criterion) and the ELMR data for species which occur inshore. M

Map **9 – Inshore Designation**



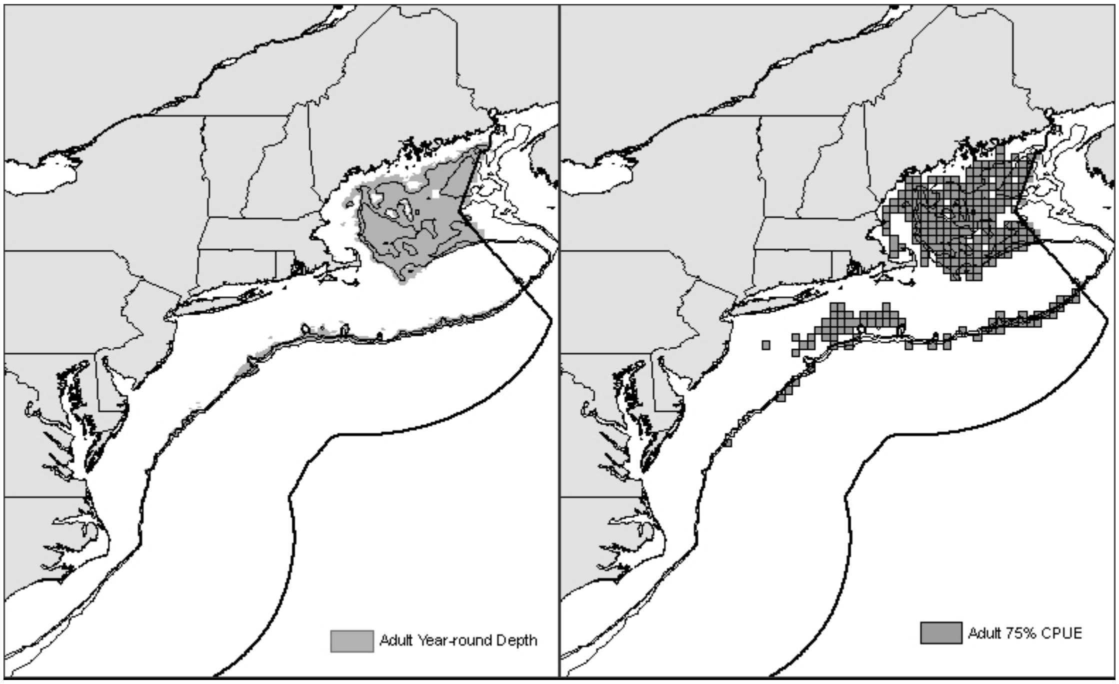
Step 2: The continental slope portion of the map is created by combining the maximum depth below 500 meters at which the species has been documented to be present with the known or inferred latitudinal range of the species.

Map **10 – Continental Slope Designation**

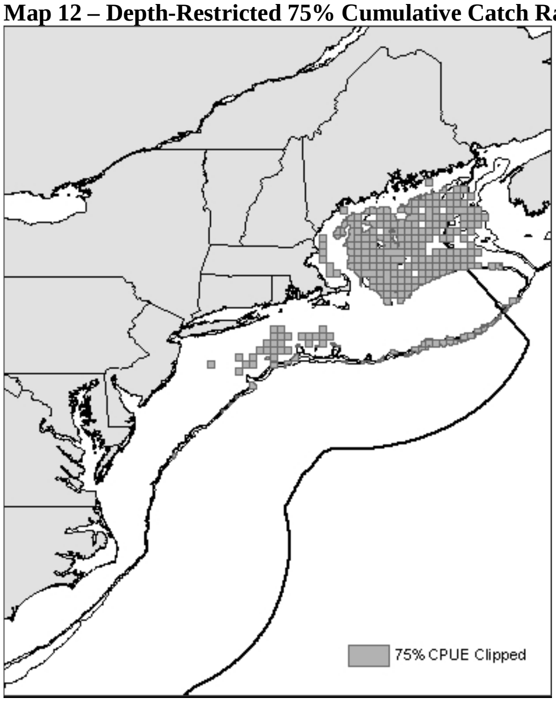


Steps 3 - 6: For the continental shelf, ten minute squares representing the 25, 50, 75, 90 percent cumulative catch rates are selected from the NEFSC trawl survey data. Portions of TMS with depths that are outside of the annual range determined in the analysis are removed, note that survey-defined TMS in southern New England and the southwestern Gulf of Maine remain intact, only those that overlap with depth range are clipped).

Map 11 – Year-round Depth Layer and 75% Cumulative Catch Rate

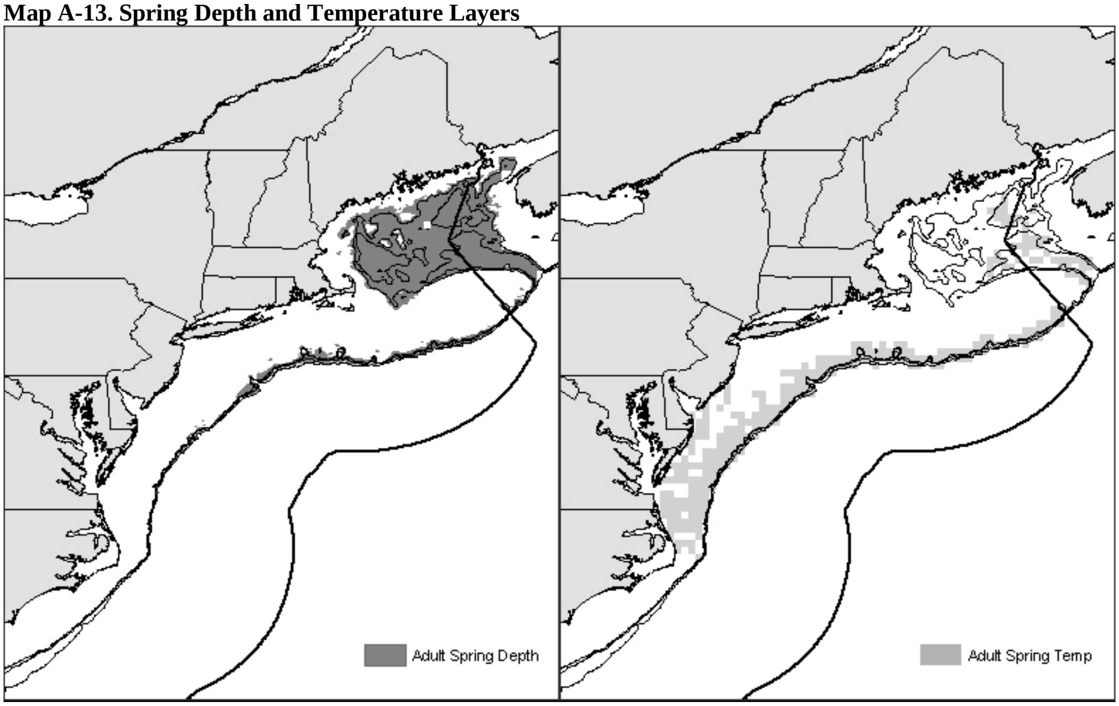


Map 12 – Depth-Restricted 75% Cumulative Catch Rate

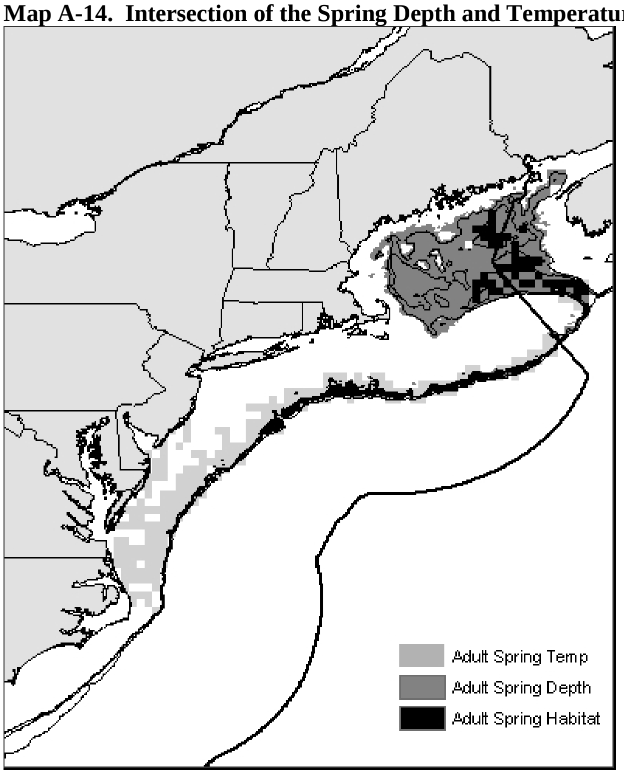


Steps 7-8: The intersection of the spring depth and temperature layer is created. This is repeated with the fall layers (steps 9-10, not shown).

Map A-13. Spring Depth and Temperature Layers

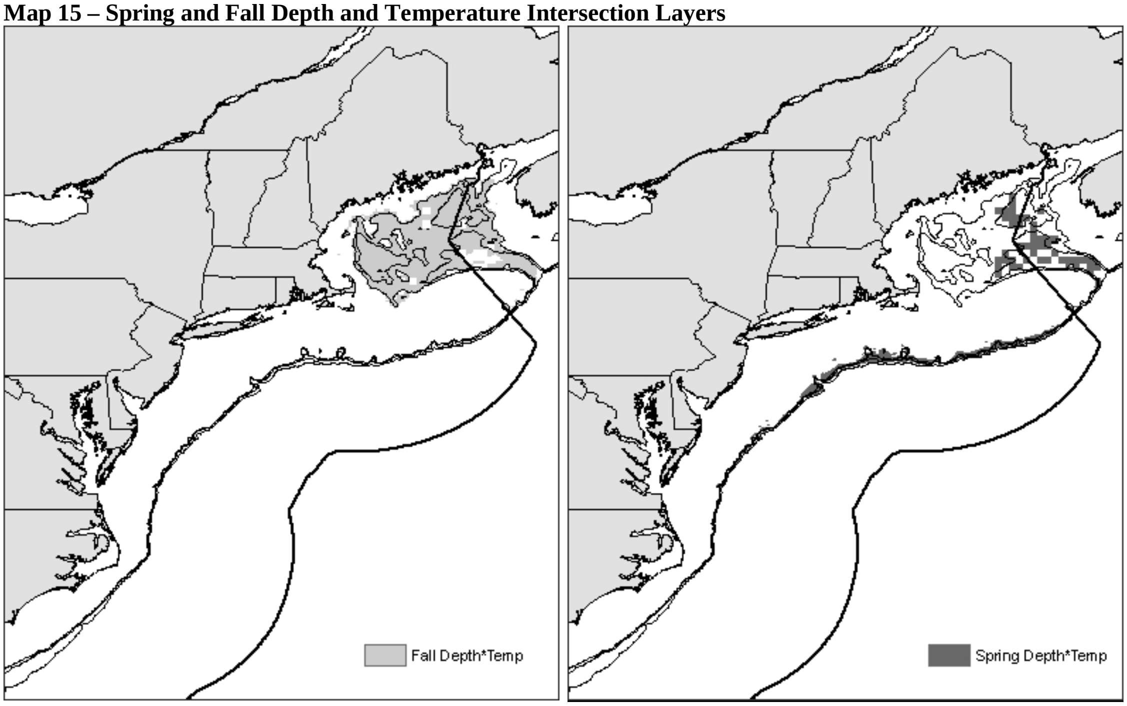


Map A-14. Intersection of the Spring Depth and Temperature Layers

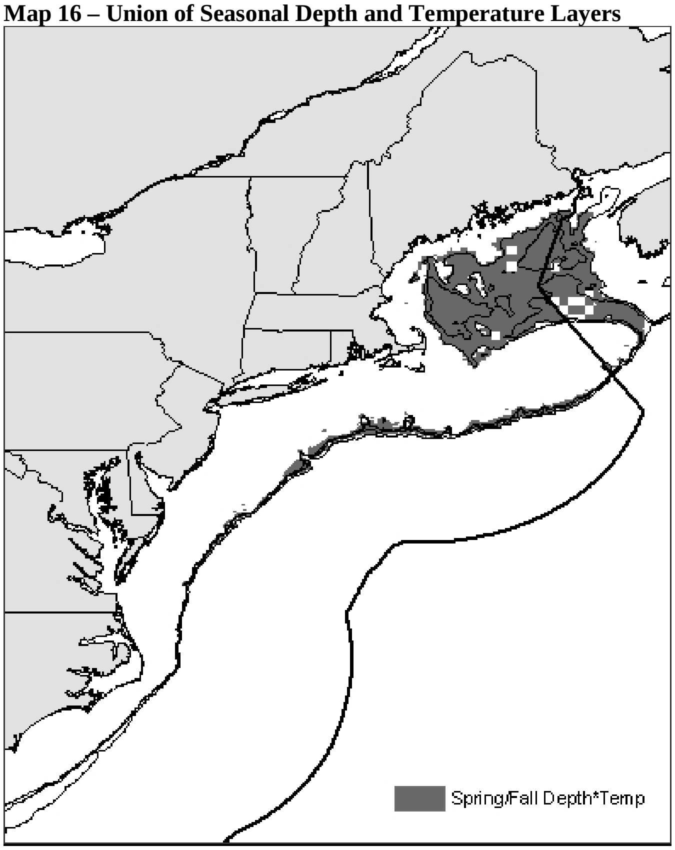


Step 11: The fall and spring depth and temperature intersection layers are overlaid to create a year round map.

Map 15 – Spring and Fall Depth and Temperature Intersection Layers

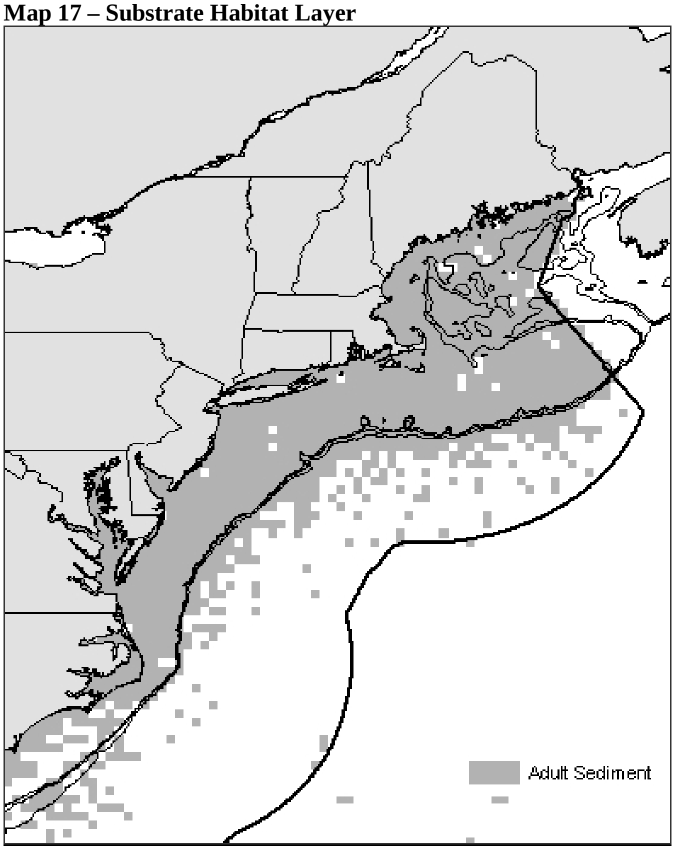


Map 16 – Union of Seasonal Depth and Temperature Layers



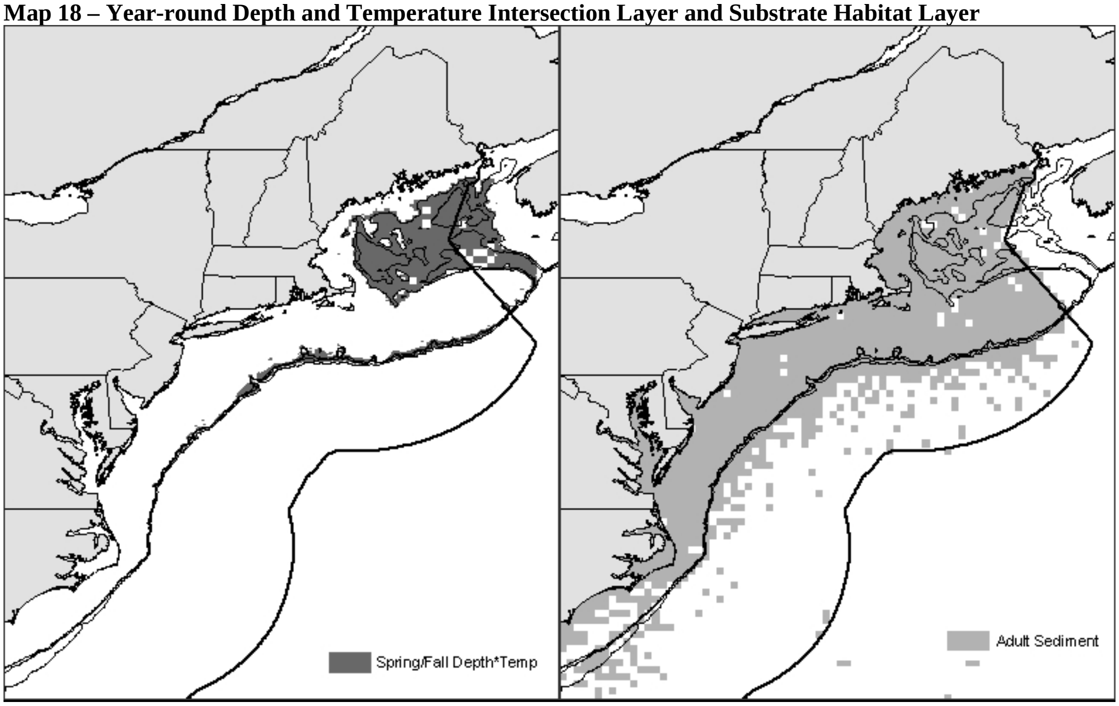
Step 12: The TMS where the combination of all correlated substrate classes for the species exceeds 20% of the total samples are selected.

Map 17 – Substrate Habitat Layer

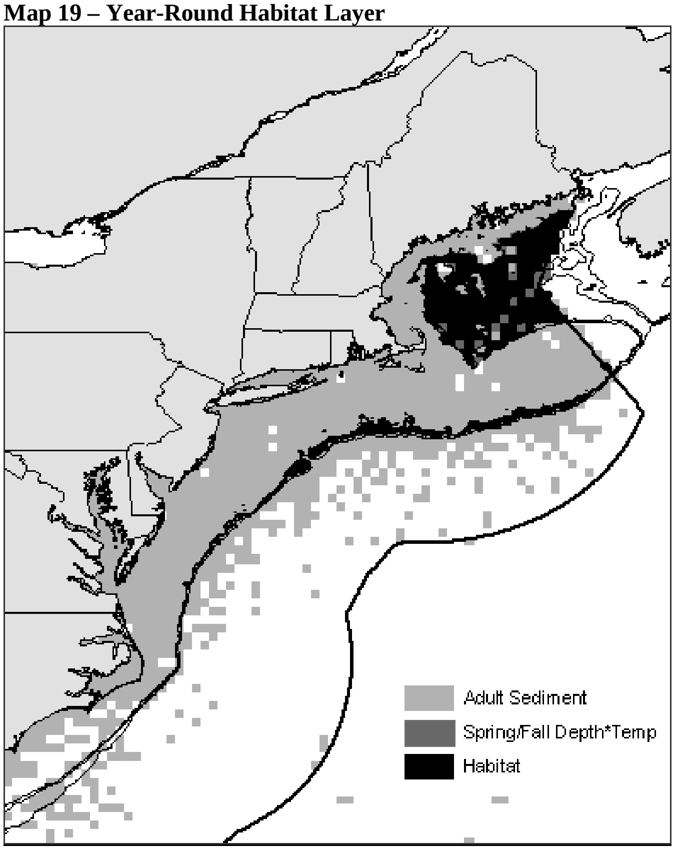


Step 13: The intersection of the year round depth and temperature intersection and the substrate layer creates the year-round habitat layer.

Map 18 – Year-round Depth and Temperature Intersection Layer and Substrate Habitat Layer

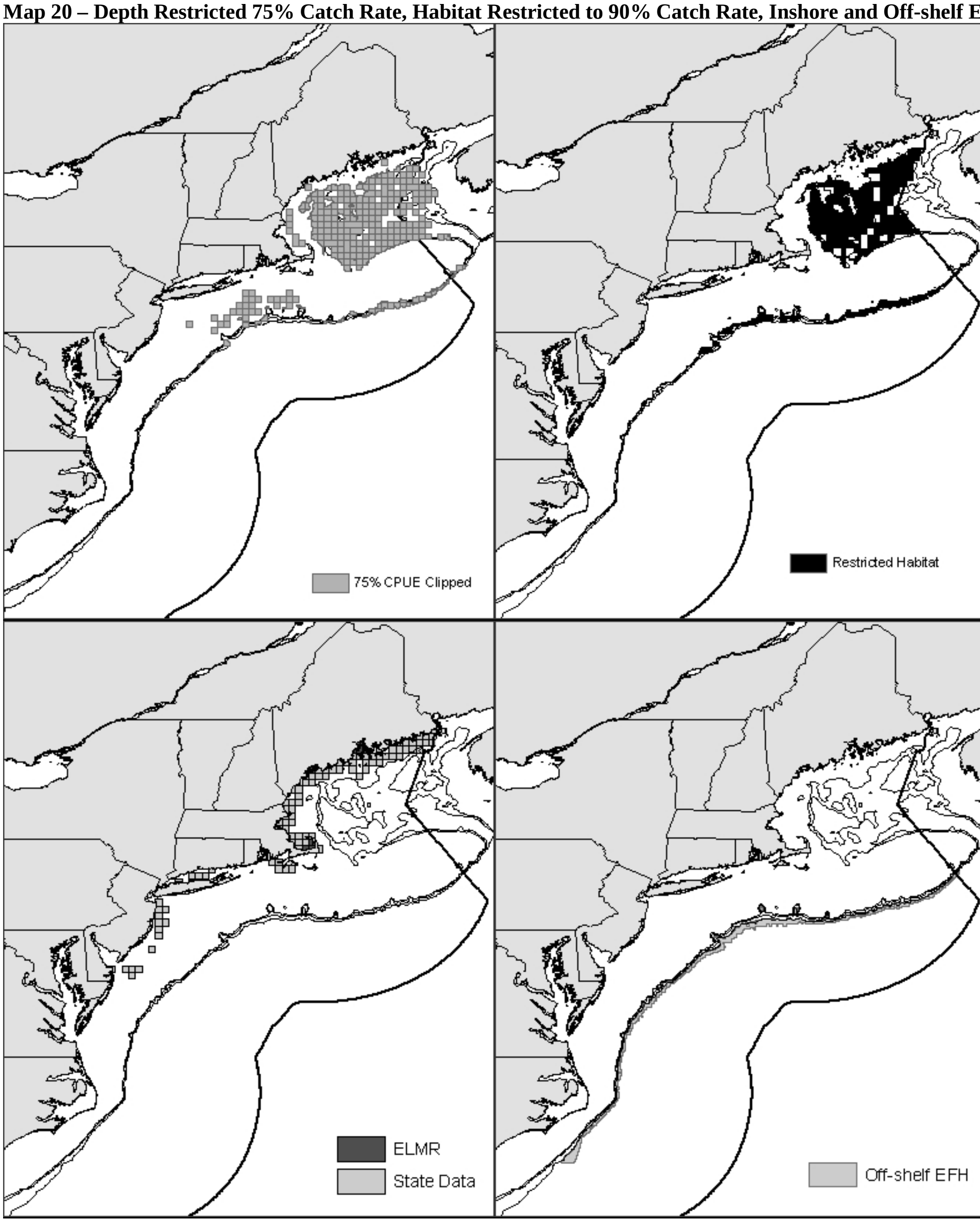


Map 19 – Year-Round Habitat Layer

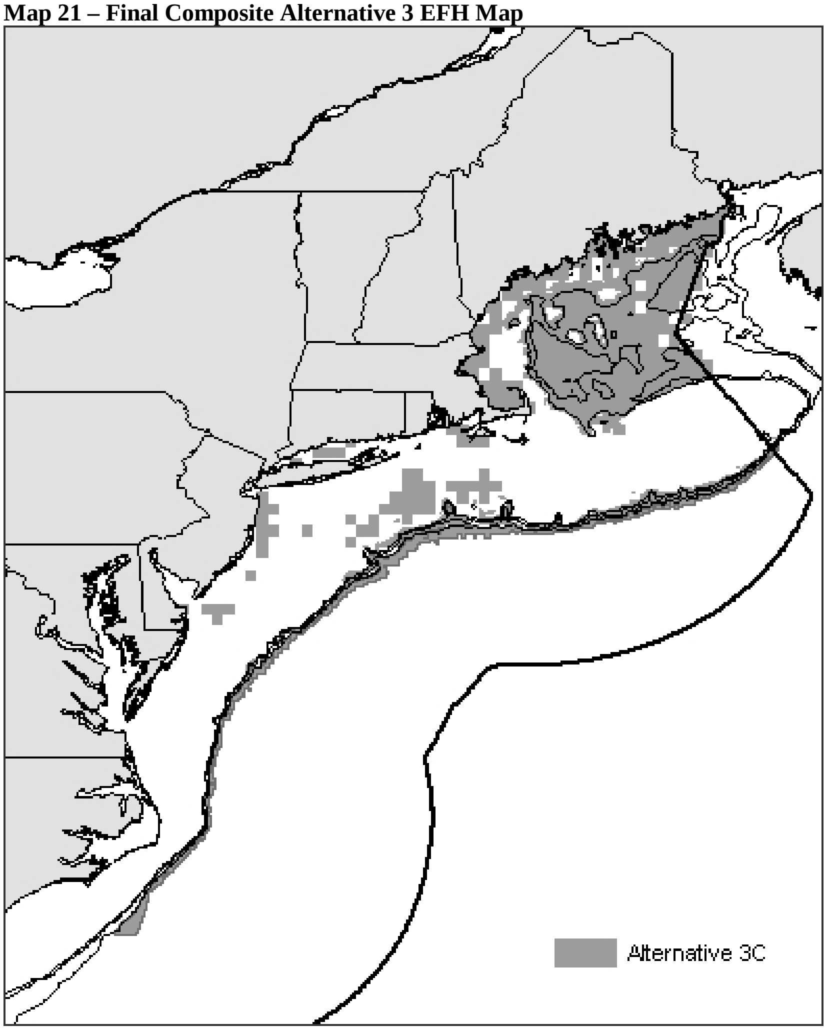


Step 14: The depth-restricted 75% cumulative catch rate NEFSC trawl survey layer is overlaid with the portions of the year-round habitat layer that fall within the 90% cumulative catch rate NEFSC trawl survey layer.(not shown). The result is overlaid with the inshore and continental slope data layers to create Alternative 3C.

Map 20 – Depth Restricted 75% Catch Rate, Habitat Restricted to 90% Catch Rate, Inshore and Off-shelf EFH



Map 21 – Final Composite Alternative 3 EFH Map



3.3 Species range method (Alternative 4 in 2007 DEIS)

The alternative designates EFH as the entire geographic range of any life stage and species. The spatial extent of EFH combines the GIS coverage for the inshore area developed for alternatives 2 and 3, the continental slope and seamount coverages for alternative 3, and the ten minute squares on the continental shelf that represent 100% of the catch rate data from the 1968-2005 spring and fall NEFSC trawl surveys. No habitat-defined GIS coverages were included in the EFH maps for this alternative. Since this alternative utilizes Level 1 information to map EFH, the text descriptions were modified to include broad ranges of depth, temperature, and salinity where a given lifestage and species is known to occur.

3.3.1 Text descriptions

For pelagic lifestages, the only new information that was included in the text descriptions for pelagic eggs and larvae in this alternative was level 1 information for species that have been found in continental slope waters. This information was used to supplement maximum depths recorded during the MARMAP surveys and is summarized in the species tables in Appendix B.[24]

For benthic life stages in inshore areas, leve1 1 information on minimum and maximum depths, bottom temperatures, and salinities was derived from data recorded during individual bottom trawl tows or seine hauls that were made in ten minute squares that met the 10% frequency of occurrence criterion (see Section 3.2.3.1). Data were compiled for each survey (see Table 6) and generalized for all ten minute squares in which the target life stage and species was caught in at least 10% of the state survey tows (or hauls). For the continental shelf, maximum depths at which any given life stage and species was caught during 1968-2005 NEFSC bottom trawl surveys were used to identify the upper limit of a depth range that in most cases included a minimum depth based on inshore survey data. For species and life stages with ranges that extend beyond the edge of the shelf, level 1 maximum depth information was derived from EFH source documents and up-date memos, reports of exploratory fishing projects conducted on the northeast continental slope, and from other relevant information sources. Ranges of bottom water temperatures and salinities for inshore and continental shelf areas were derived using the same method that was used for depth.[25] Substrate information was the same as in alternative 3. All the information that was available for use in developing the alternative 4 text descriptions is summarized in the species tables in Appendix B. Table 13 Even though this alternative was based solely on level 1 information, Level 2 information was available for most NEFMC-managed life stages and species. Table 13 identifies species and life stages with Alternative 4 EFH descriptions (and maps) that include the continental slope and which ones relied on other life stages as proxies.

Table 13 – Levels of information used for Alternative 4 EFH Designations

Species	*eggs*	*larvae*	*juveniles*	*adults*
American plaice	NAD	NAD	1	1
Atlantic cod	1[b]	1[b]	1	1
Atlantic halibut	NAD	NAD	1[a]	1[a]
Atlantic herring	NAD	NAD	1	1
Atlantic sea scallop	NAD	NAD	1	1
Barndoor skate	NAD	N/A	1[a]	1[a]
Clearnose skate	NAD	N/A	1	1
Haddock	NAD	NAD	1	1
Little skate	NAD	N/A	1	1
Monkfish	0[a,d]	1[a,d]	1[a]	1[a]
Ocean pout	0[e]	NAD	1	1
Offshore hake	NAD	NAD	1[a]	1[a]

[24] This information was collected for certain species during the 1995-1999 GLOBEC ichthyoplankton surveys on Georges Bank.
[25] As in the other action alternatives, minimum and maximum depths and temperatures were based on the lower or upper limits of data intervals such as illustrated in Figure A-1.

Species	***eggs***	***larvae***	***juveniles***	***adults***
Pollock	1[f]	1[f]	1	1
Red hake	0[a,c]	1[a,c]	1	1[a]
Redfish	N/A	1[a,c]	1[a]	1[a]
Rosette skate	NAD	N/A	1[a]	0[a],[b]
Silver hake	1[c]	1[c]	1	1[a]
Smooth skate	NAD	N/A	1[a]	1[a]
Thorny skate	NAD	N/A	1[a]	1[a]
White hake	0[a,f]	0[a,f]	1	1[a]
Windowpane flounder	NAD	NAD	1	1
Winter flounder	1[f]	1[f]	1	1
Witch flounder	NAD	NAD	1[a]	1[a]
Winter skate	NAD	N/A	1	1
Yellowtail flounder	NAD	NAD	1	1

[a]: a Level 1 continental slope designation is included in this alternative.
[b] juveniles were used as a proxy in combination with egg and/or larval survey data
[c]: juveniles were used as a proxy
[d]: adults were used as a proxy in combination with egg and/or larval survey data
[e]: a combination of juveniles AND adults were used as a proxy
[f] adults were used as a proxy
Level "**0**" indicates that there is very little information available for this life history stage.
N/A: indicates that this does not exist as a distinct life history stage for this species.
NAD: indicates No Alternative Designation due to lack of new information.

3.3.2 **Map representations**

For most pelagic species no maps were developed because no new information was available (see Table 13). Juvenile and/or adult distributions for inshore, continental shelf and slope areas were used as proxies for a few species. For these species, alternative 4 maps for the continental shelf were based on ten minute squares (TMS) that represented 100% of the 1968-2005 NEFSC spring and fall trawl survey data, sometimes in combination with MARMAP egg and larval survey data. EFH for the inshore and continental slope areas was mapped using the same GIS coverages that were developed for alternative 3.

Maps for benthic juveniles and adults in inshore and continental slope areas were based on the same GIS coverages that were used in alternative 3.[26] For the continental shelf, EFH was mapped as TMS that represented 100% of the 1968-2005 NEFSC spring and fall trawl survey data. The trawl survey data were compiled using the same methods that were used in alternatives 2 and 3. For two species with benthic eggs (ocean pout and winter flounder) distributions of adults or juveniles and adults were used as proxies.

[26] The juvenile and adult life stages of Atlantic herring are pelagic, but they are well represented in bottom trawl surveys. Herring eggs are benthic, but no alternative 4 designation was developed for them.

4.0 Atlantic salmon methods

4.1 No Action

Essential fish habitat for Atlantic salmon is described as all waters currently or historically accessible to Atlantic salmon within the streams, rivers, lakes, ponds, wetlands, and other water bodies of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island and Connecticut that meet the habitat requirement in the text description for each life stage. The EFH designations of estuaries and embayments under the No Action Alternative are based on the NOAA Estuarine Living Marine Resources (ELMR) program as supporting Atlantic salmon eggs, larvae, juveniles and adults at the "abundant", "common" or "rare" level.

4.2 Ten year presence

Under this alternative, those river systems and estuaries that are "current(ly)" or have "recent(ly)" supported Atlantic salmon in at least one of the last ten years (1996-2005) are included in the EFH designation. Use of a river or drainage system in any particular year is based on the presence of returning adult salmon, as documented in the 2006 Annual Report [to the North Atlantic Salmon Conservation Organization] of the U.S. Atlantic Salmon Assessment Committee (USASC 2006), and includes wild adults and hatchery-raised adults. "Presence" was based on the capture of one or more fish anywhere in a given river system.[27] EFH for the freshwater life history stages was defined to include all rivers and streams in each designated river system that exhibit the environmental conditions identified in the EFH text descriptions.

Text descriptions were based on new information obtained from the No Action EFH descriptions (NEFMC 1998), an unpublished and draft 2nd edition Atlantic salmon EFH source document, and other published sources. They were written in two different formats, one according to life history stages and another according to primary habitats types. The information included in each case was the same. Life history stages that were described included eggs, larvae (alevins), juveniles (fry, parr, smolts, and post-smolts), and adults (spawning and non-spawning). Fry were defined as less than 5 cm total length (TL), parr as 5-10 cm TL, and smolts as greater than 10 cm TL. Post-smolts were defined as oceanic-phase juveniles. Habitat types were fresh water spawning and rearing, emigration-immigration, and marine habitats. All the information that was utilized in developing the text descriptions for Atlantic salmon is summarized in Appendix B. This information includes habitat requirements by life stage for substrate, water depth, temperature, salinity, dissolved oxygen, current velocity, pH, and primary prey organisms.

Freshwater EFH text descriptions for eggs, larvae, fry and parr were defined to include 1st to 3rd or 4th order tributaries, and for smolts and spawning adults they included 1st to 5th order stream, rivers, and estuaries (i.e., entire riverine/estuarine drainage systems).[28] Lakes, ponds, and impoundments were also included in the text descriptions for smolts. Post-smolts were described as inhabiting near-surface waters in coastal and open ocean marine habitats. In addition to

[27] This was done because there was no way of knowing which tributaries might be utilized for spawning by adults that are captured as they enter the lower part of the main river. This approach was consistent with the method used to develop the No Action designations.

[28] 1st order streams refer to the headwaters of a river system and the numbering proceeds seaward until reaching 5th order rivers and estuaries.

freshwater and estuarine habitats, spawning and non-spawning adult EFH included coastal and open ocean marine habitats.

Three options were developed by the Habitat PDT for depicting the spatial extent of Atlantic salmon EFH. The freshwater portion of EFH was the same in each case. In option 1, there was no fully oceanic component. Coastal areas included in the map were limited to estuarine waters (salinities less than 25 ppt) of ELMR-designated bays and estuaries that form a direct connection between the designated rivers and the sea. In option 2, the map included an area adjacent to the mouth of each designated river out to the 3-mile limit.[29] In option 3, the entire U.S. EEZ was mapped north of 41 degrees north latitude, the presumed southern limit of the area that is potentially used by adults during their migrations to and from their summer feeding grounds in the North Atlantic Ocean (outside the U.S. EEZ).

4.3 Three year presence

This alternative was developed exactly the same way as the 10-year alternative, except that the only rivers and streams that were included were those where the presence of adult salmon was documented at least once during 2003-2005. Use of a 3-year instead of a 10-year time period resulted in the elimination of 12 rivers and seven coastal bays from the list of designated areas, all of which are located in Maine.

[29] Long Island Sound was excluded from this alternative because there was no obvious basis for defining which portion of the sound constitutes a migratory pathway for juvenile or adult salmon entering or leaving the Connecticut River.

5.0 Deep-Sea Red Crab methods

5.1 No Action

Text descriptions for this alternative were based on depths, substrates, bottom temperatures, salinities, and dissolved oxygen concentrations where juvenile and adult red crab are found on the continental slope, as described in the EFH Source Document for this species. Maps of the No Action EFH designations cover the geographic area of the continental slope included in the depth zones where deep-sea red crab is found between the U.S.-Canada border and Cape Hatteras. The methods used for defining this depth zone varied between life stages.

- Eggs: Based on known depth zone affinities for female adults (200-400 meters).
- Larvae: Based on the known depth zones as defined by the union of the full (female and male) adult and juvenile depth ranges (200-1800 meters).
- Juveniles: Based on known depth zone affinities for juveniles (700-1800 meters).
- Adults: Based on known depth zone affinities for all adults (200-1300 meters).

For the purpose of determining the geographic extent of EFH for this species (all life stages), its range was defined as continental slope waters (for larvae) and benthic habitats along the continental slope off the southern flank of Georges Bank and extending to Cape Hatteras, North Carolina. Information relating to depths, water temperatures, salinities, dissolved oxygen concentrations, and substrates used in the text descriptions was obtained from the EFH source document for this species and is included in the red crab species table in Appendix B. All the information used in the No Action EFH descriptions and maps for this species was level one (presence only).

5.2 Refined No Action

Alternative 2 includes the No Action text descriptions as revised for refined level 2 slope depth occurrences of deep-sea red crab and modifies the map representations to depict the new depth ranges on the continental slope. New depth ranges were based on relative abundance trawl survey data for juveniles, adults, and spawning adult females on the continental slope reported by Wigley et al. (1975). Text descriptions included revised information on substrate types, bottom water temperatures, and oxygen concentrations, and new information on prey. Maps were developed for eggs, larvae and juveniles, and adults.[30]

5.3 Refined No Action Plus Observed Seamounts

Alternative 3 includes the refined depth ranges for the continental slope used in Alternative 2 as well as a maximum depth (2000 meters) for juveniles and adults on two seamounts (Bear and Retriever) where deep-sea red crabs have been observed during bottom trawl and underwater video surveys. Two maps were generated, one showing the portions of these two seamounts that are within 2000 meters of the surface and the other feature-defined, each showing a "block" of the seafloor that includes the entire seamount. In either case, however, EFH would only apply to the portion of each seamount that is within 2000 meters of the surface. All seamount distribution

[30] As was done in Alternative 1, the depth range for larval EFH was assumed to include the extreme range designated for the species, which in this case was the same as the juvenile EFH depth range (adult EFH was limited to a narrower depth range), so both life stages were mapped together in this and the following alternatives.

information is Level 1 presence only information. Seamount bathymetry was defined using the UNH Center for Coastal and Ocean Mapping/Joint Hydrographic Center Law of the Sea multi-beam bathymetry dataset. This data provides the most accurate available bathymetric data for the seamount complex.

5.4 Refined No Action Plus Gulf of Maine

Alternative 4 includes the Alternative 2 continental slope designations as well as most of the Gulf of Maine where red crabs are reported in the EFH source document to be present in depths below 40 meters. The text descriptions for larvae, juveniles, and adults were revised accordingly. There was no information indicating that red crabs reproduce in the Gulf of Maine, so the text description for eggs was not modified.

5.5 Refined No Action, Observed Seamounts and Gulf of Maine

Alternative 5 includes the Alternative 2 continental slope, Alternative 3 seamount, and Alternative 4 Gulf of Maine designations. Maps for larvae and juveniles and for adults were developed for two options, 5A (depth-defined seamounts) and 5B (feature-defined seamounts).

5.6 Species Range

Alternative 6 designates EFH for deep-sea red crab in the Gulf of Maine, on the continental slope, and on three of the four seamounts located in the U.S. EEZ. Text descriptions and maps were based on the same level 2 information used in alternatives 2-5, but a third seamount (Physalia) was added because a very small portion of it is shallower than 2000 meters. So, even though red crabs have not been observed on this seamount, it seemed reasonable to assume that they are present there.

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OMNIBUS ESSENTIAL FISH HABITAT AMENDMENT 2
DRAFT ENVIRONMENTAL IMPACT STATEMENT

Appendix B: EFH supplementary tables, prey species information, and spawning information

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Table of contents

Tables

1.0 Introduction

To summarize the life history information necessary to understand the relationship of each species and life history stage to, or its dependence on, various habitats, using text, tables, and figures, as appropriate, the Council developed EFH designation text (text descriptions) for each species and life stage. The final text descriptions are provided in the body of the EIS. This appendix supplements those text descriptions with EFH supplemental tables, prey descriptions, and peak spawning descriptions. This information is organized by species in section 2.0.

Supplementary tables

As part of the process of developing the text descriptions, the Council created supplemental tables that include all the relevant habitat-related information that was compiled for each species and life stage. The tables summarize all available information on environmental and habitat variables that control or limit the distribution and abundance of each species and life stage, with some additional information on ecological factors limiting reproduction, growth, and survival. Sources of information are listed under each table: some of the information was derived from analyses of NMFS and state trawl survey data done as part of the EFH designation process for this amendment and some was provided in various state survey reports. Much of the information was available in the NMFS EFH Source Document series and in a number of recent revisions and update memos, and in Colette and Klein-MacPhee's Fishes of the Gulf of Maine (2002).

Prey species

Information on primary prey consumed by each species and life stage was also included in the text descriptions, and is detailed below. The EFH Final Rule (50 CFR 600) requires that Fishery Management Plans (FMPs) established or amended under the Sustainable Fisheries Act of 1996 defines essential fish habitat (EFH) as:

> "Those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity. For the purpose of interpreting the definition of essential fish habitat: ''Waters'' include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; ''substrate'' includes sediment, hard bottom, structures underlying the waters, and associated biological communities; ''necessary'' means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and ''spawning, breeding, feeding, or growth to maturity'' covers a species' full life cycle."

Further, the Rule requires that these FMPs *"list the major prey species for the species in the fishery management unit and discuss the location of prey species' habitat."* According to the Rule:

> "Loss of prey may be an adverse effect on EFH and managed species because the presence of prey makes waters and substrate function as feeding habitat, and the definition of EFH includes waters and substrate necessary to fish for feeding. Therefore, actions that reduce the availability of a major prey species, either through direct harm or capture, or through adverse impacts to the prey species' habitat that are known to cause a reduction in the population of the prey species, may be considered adverse effects on EFH if such actions reduce the quality of EFH. … Adverse effects on prey species and their habitats may result from fishing and non-fishing activities."

National Marine Fisheries Service has offered the Councils the following draft guidance (April 2006) on implementing the Prey Species Requirement of the EFH Final Rule as follows:

> The definition of EFH in the regulatory guidelines acknowledge that prey, as part of "associated biological communities", may be considered a component of EFH for a species and/or lifestage (50 CFR 600.10). However, including prey in EFH identifications and descriptions has considerable implications for the overall scope of EFH when those prey are considered during the EFH consultation process. It is important that prey do not become a vehicle for overly expansive interpretations of EFH descriptions. To avoid this pitfall, the following suggestions should be considered when including prey in an EFH description:
>
> 1. Prey species alone should not be described as EFH. Instead, prey should be included in EFH descriptions as a component of EFH (along with others components such as depth, temperature, sediment type).
>
> 2. If the FMP identifies prey as a component of EFH, the FMP should specify those prey species and how their presence "makes the waters and substrate function as feeding habitat" (50 CFR 600.815(a)(7)).
>
> 3. While prey may be considered a component of EFH, prey habitat should not be identified as EFH in FMPs unless it is also EFH for a managed species. Identifying prey habitat as EFH could be viewed as over-extending the scope of EFH which should consist of habitat necessary for the managed species (50 CFR Preamble). However prey species habitat should be discussed in the FMP (52 CFR 600.815 (a)(7)).

Accordingly, the New England Fishery Management Council has developed a description of the major prey types for each managed species under its jurisdiction. In addition, benthic invertebrate prey types and their vulnerability to fishing gear impacts are summarized in the Swept Area Seabed Impact approach appendix to this amendment.

The sources of information used to describe the primary prey for a managed species include the EFH species source documents (1st and 2nd editions) and the new EFH species update memos and references therein, plus a few published sources that were not included in the source documents or update memos. The major data source used for the prey information in these source documents is the NEFSC bottom trawl survey food habits database from 1963 to the present (see Link and Almeida [2000] for methods). This database has been used in many food habits studies and publications over the years, and these studies and publications often covered different years or subsets of the database. Generally, the results agree; it is often the details at a certain prey taxonomic level that may differ. The section of the prey tables that cover the continental shelf are largely based upon these various studies or publications, and because the use of these studies and publications often varied from one EFH species source document or update memo to another, this is reflected in the prey tables for each species. Generally, major prey phyla are defined as those prey items exceeding, depending on the study, the 5% threshold for one or several of the following measures in the stomachs of a managed species: percent frequency of occurrence, percent numerical abundance, percent stomach volume, and precent prey weight. It should be noted that prey species, families, etc. mentioned in the text or tables, depending on the study from which they came, are sometimes just examples of the primary prey within a phyla; thus, the tables, for example, should not be taken as an exhaustive list of prey items. See

2.0 Summary tables

Table 52, Table 53, and
Table 54 for a summary of these data.

Peak spawning periods

Finally, peak spawning periods were identified for each species. The sources of information used to describe the spawning periods for a managed species include the EFH species source documents (1st and 2nd editions) and the new EFH species update memos and references therein, and a few published sources that were not included in the source documents or update memos. Also presented, where applicable, are egg distribution and abundance information from the Northeast Fisheries Science Center (NEFSC) Marine Monitoring Assessment and Prediction (MARMAP) ichthyoplankton surveys (1978-1987) and the Georges Bank U.S. Global Ocean Ecosystems Dynamics (GLOBEC) ichthyoplankton surveys (1995-1999). See Table 55 for a summary of these data.

3.0 Northeast multispecies (groundfish)

3.1 Atlantic cod

3.1.1 Supplementary table

Table 1 – Summary of Habitat Information for Atlantic Cod

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Pelagic, in water column	Present 21-140 on shelf, common 21-140 Present 500-1000 off-shelf	Collected -2 to 20 inshore Present 1.5-15.5 on shelf, common 3.5-13.5 Lab studies: 5-8.3 optimum for hatching, high mortalities at 0; 2-8.5 optimum for incubation; upper limit for development 12; highest survival at hatching 2-10	Most collected 32-33 (GB, Nantucket Shoals) Lab studies: highest survival at hatching 28-36; high mortality 10-12.5
Larvae	Pelagic, in water column	Present 1-350 on shelf, common 21-120 Present 500-1000 off-shelf Abundant on southern flank GB in 50-100	Present 1.5-15.5 on shelf, common 3.5-12.5 Lab study: growth increased from 4 to 10	Most collected 32-33 (GB, NS)
Juveniles	Pelagic habitats during settlement Benthic habitats with substrates composed of *gravel*, sand, mud and sand, and/or mud and sand with *gravel* Inshore: more abundant in or near seagrass and macroalgae beds YOY: highest growth in seagrass, highest survival in cobble and rock reef habitats YOY on sand, gravelly sand, and pebble-gravel substrate (GB)	Present 4-85, common 6-55 (MA) Present 1-400 on shelf, common 31-120 YOY most abundant <27 in spring, 27-55 in fall; age 1+ most abundant 18-55 spring and 37-55 fall (MA) YOY 1-10 (inshore ME)	Present 1.5-19, common 5.5-12.5 (MA) Present 0.5-17.5 on shelf, common 2.5-11.5 Growth optimal near 10 YOY common 7-12 (inshore ME)	Present 28-34 (ME) Present 30.5-35.5 on shelf, common 32.5-33.5

Life Stage	***Habitat***	***Depth (m)****	***Temperature (ºC)*****	***Salinity (ppt)*****
	Lab studies: YOY prefer sand or gravel-pebble, cobble when predator present Decreased YOY mortality in high density sponge habitat vs. flat sand			
Adults	Benthic habitats with substrates composed of sand, *gravel*, and mud and sand with *gravel* Lab studies: prefer coarse sediments to mud Typically found along rocky slopes and ledges (SS) Also see juveniles	Present 5-85, common 21-75 (MA) Present 1-500, on and off shelf, common 31-140 Most abundant 10-150 Spawn near bottom, usually <73 (GB, GOM); also spawn in nearshore areas	Present 1.3-14.2, common 3.5-12.5 (MA) Present 0.5-19.5 on and off shelf, common 2.5-9.5 Can occur from near 0 to 20, usually <10 except in fall Spawn -1 to 12, optimum 5-7 (GB,GOM)	Present 31.2-34 (ME) Present 29.5-35.5 on shelf, common 32.5-33.5 Lab study: first mortalities at 2.7 Average 32 at spawning

*   *Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

<u>Note</u>: As used in the analysis of sediment associations, the term "gravel" refers to all grain sizes above a diameter of 2 mm, i.e., any sediment coarser than sand, and therefore includes pebbles, cobbles, and even boulders

Sources of information:

- **Eggs**: Shelf depth and temperature ranges derived from MARMAP and GLOBEC data in EFH Source Document (2nd ed), all other information from EFH Source Doc (2nd ed).
- **Larvae**: Shelf depth and temperature ranges derived from MARMAP and GLOBEC data in EFH Source Document (2nd ed), all other information from EFH Source Doc (2nd ed).
- **Juveniles**: <u>Inshore</u>: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; inshore depth and temperature ranges ("common") from analysis of MA trawl survey data in EFH Source Doc (2nd ed.). For the <u>continental shelf</u>: sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data and from information summarized in Stevenson et al. (2004); depth, temperature, and salinity ranges derived from NEFSC trawl survey data. Other information from EFH Source Document (2nd ed) and M. Lazzari (Maine DMR, pers. comm.).
- **Adults**: <u>Inshore</u>: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; inshore depth and temperature ranges ("common") from analysis of MA trawl survey data in EFH Source Doc (2nd ed.). <u>Continental shelf</u>: sediment types derived from GIS overlap analysis of NEFSC trawl

survey and USGS USSeabed sediment data and from information in EFH Source Document (2nd ed.); depth, temperature, and salinity ranges derived from NEFSC trawl survey data. Other information from EFH Source Document (2nd ed) and from Klein-MacPhee (2002).

3.1.2 Prey species

The main source of information on the prey consumed by the larval, juvenile and adult stages of Atlantic cod (*Gadus morhua*) comes from the EFH Source Document (Lough 2005 and references therein), Klein-MacPhee (2002), and Link and Garrison (2002). Larvae feed on copepods, changing from the naupliar and copepodite stages at smaller sizes (4-18 mm SL) to adult copopods at larger (> 18 mm) sizes. Common copepod prey on Georges Bank include *Pseudocalanus*, *Calanus*, and *Oithona*. Late pelagic juveniles on Georges Bank feed on calanoid copepods, mysid shrimp (*Neomysis americana*), harpacticoid copepods (*Tisbe* sp.) and hermit crab larvae. After settling to the bottom, age 0 juveniles (< 10 cm TL) feed on benthic prey, predominantly mysids. There is a rapid transition from pelagic to benthic prey at a size of 60-100 mm SL.

Older juvenile cod (10-35 cm TL) feed primarily on crustaceans, including amphipods, and to a lesser extent on pandalid shrimp, euphausiids, and the sand shrimp, *Crangon septemspinosa*. Small adult cod (35-50 cm TL) feed on crustaceans (including crabs, amphipods and pandalid shrimp), and fish (sand lance and silver hake). Medium-sized (50-90 cm TL) adults feed primarily on fish (herrings, silver hake, sand lance), and crabs (including *Cancer* sp.). Larger (90-120+ cm TL) adult cod feed on herring, other fish (including gadids, silver hake, other hakes, bluefish, mackerels, toadfish, redfish, and flatfish), *Cancer* crabs, and squid.

Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the NEFSC food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult cod include:
Atlantic herring (9%), herring (7%), silver hake (8%), other fish (16%), crangonid shrimp (8%), and decapod crabs (6%).

Table 2 – Major prey items of Atlantic cod

Life Stage	*Major Prey*	*Location*
Larvae (< 20-50 mm SL)		Georges Bank
Small (4-18 mm)	**Nauplii and Copepodite Stages of Copepods:** *Pseudocalanus* sp., *Calanus* sp., *Oithona* sp.	
--------------	---------------------	
Large (> 18 mm)	**Adult Copepods:** *Pseudocalanus* sp., *Calanus* sp., *Centropages* sp., *Paracalanus* sp.	
Juveniles (< 35 cm TL)		U.S. northeast continental shelf
Pelagic YOY (<10 cm TL)	**Crustaceans:** copepods and mysid shrimp (*Tisbe* sp., *Neomysis americana*)	
------	---------	
Benthic YOY	**Crustaceans:** mysid shrimp	

Life Stage	***Major Prey***	***Location***
(<10 cm TL) ------	 ---------	
Juveniles (10-35 cm TL)	**Crustaceans**: amphipods, decapods (pandalid shrimp, *Crangon septemspinosa*), euphausiids	
Adults (>35 cm TL)		U.S. northeast continental shelf
Small adults (35 - 50 cm TL) ------	**Crustaceans**: amphipods, decapods (crabs, pandalid shrimp) **Fish**: sand lance, silver hake --------	
Medium-sized adults (50-90 cm TL) ------	**Crustaceans:** *Cancer* sp. **Fish**: herrings, silver hake, sand lance --------	
Large adults (90-120+ cm TL)	**Crustaceans**: *Cancer* sp. **Mollusks**: squids **Fish**: herrings, gadids, silver hake, other hakes, bluefish, mackerels, redfish, toadfish, flatfish.	

3.1.3 Peak spawning

Information on the spawning periods of Atlantic cod (*Gadus morhua*) comes from the EFH Source Document (Lough 2005 and references therein).

On **Georges Bank**, an analysis of the MARMAP ichthyoplankton data set indicates that 60% of spawning occurs between February 23 and April 6, based on the abundance of Stage III eggs, back-calculated to spawning date. Ninety percent occurs between mid-November and mid-May, with a median date of mid-March (Colton *et al.* 1979; Page *et al.* 1998). Spawning begins along the **southern flank of Georges Bank** and progresses toward the north and west. It ends latest in the year on the **eastern side of the bank**. Historically, cod have spawned on both **eastern and western Georges Bank**. During the MARMAP period (1978-1987), spawning could either be split between **eastern and western Georges Bank**, **or occur predominantly on one side or the other** (Lough *et al*. 2002). Composite egg distributions indicate that the *most intense* spawning activity occurs on the **Northeast Peak of Georges Bank** (Page *et al.* 1998). Data from the more recent U.S. GLOBEC Georges Bank surveys (1995-1999) also indicated *peak* spawning occurs during the February-March period and mostly on the **Northeast Peak** (Mountain *et al*. 2003).

The results of the present compilation of egg distributions indicate that *most* spawning occurs not only on the **Northeast Peak of Georges Bank**, but also around the **perimeter of the Gulf of Maine, and over the inner half of the continental shelf off southern New England**. It occurs year-round, with a *peak* in winter and spring. *Peak* spawning is related to environmental conditions. It is delayed until spring when winters are severe and *peak*s in winter when they are mild (Smith *et al.* 1979; Smith *et al.* 1981). Spawning *peak*s in April on Browns Bank (Hurley and Campana 1989). Within the **Gulf of Maine**, cod generally spawn throughout the winter and early spring in most locations, but the period of *peak* spawning varies depending on location (Schroeder 1930). In general, spawning occurs later in the year in the more northerly regions. Within **Massachusetts Bay**, Fish (1928) reported *peak* spawning activity during January and February. Bigelow and Welsh (1924) noted that **north of Cape Ann, Massachusetts**, most spawning occurred between February and April and further north, between **Cape Elizabeth and Mt. Desert Island, Maine**, the *peak* spawning period was between March and May. Reproduction also occurs in **nearshore areas, such as Beverly-Salem Harbor, MA**, where eggs are found November through July (with a *peak* in April).

3.2 Haddock

3.2.1 Supplementary table

Table 3 – Summary of habitat information for haddock

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Pelagic, in water column	Present 1-1000 on and off shelf, common 41-200	Present 0.5-12.5 on and off shelf, common 3.5-7.5 Lab study: highest survival 4-10	Found 34-36
Larvae	Pelagic, in water column	Present 1-350 on shelf, common 41-160 Assume 1000 max (same as eggs)	Common 3.5-11.5 on shelf	Assume same as eggs
Juveniles	Pelagic habitats during settlement Benthic habitats composed of sand, and sand and mud with *gravel* Pebble gravel bottom	Present 7-84 inshore, common 31-85 (MA) Present 21-400 on shelf, common 41-120	Present 3-14.5 inshore, common 4.5-10.5 (MA) Present 0.5-15.5 on shelf, common 4.5-12.5	Present 31-34 inshore Present 30.5-35.5 on shelf, common 31.5-35.5, 32 optimal
Adults	Benthic habitats composed of *gravel*, sand, sand and mud with *gravel*, and *gravel* with sand and mud Prefer gravel, pebbles, clay, broken shells, and smooth, hard sand, esp between rocky patches Not common on rocks, ledges, kelp or soft mud	Present 31-83 inshore Present 21-400 on shelf, common 61-140	Present 3.2-11.5 inshore Present 0.5-15.5 on shelf, common 3.5-8.5 Spawn 2-7, optimum 4-6	Present 31-34 inshore Present 31.5-35.5 on shelf, common 32.5-33.5 Spawn 31.5-34

**   Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Note: As used in the analysis of sediment associations, the term "gravel" refers to all grain sizes above a diameter of 2 mm, i.e., any sediment coarser than sand, and therefore includes pebbles, cobbles, and even boulders

Sources of information:

- **Eggs**: Depth and temperature ranges derived from MARMAP and GLOBEC data in EFH Source Document (2nd ed), other information from EFH Source Doc (2nd ed).
- **Larvae**: Depth and temperature ranges derived from MARMAP and GLOBEC data in EFH Source Document (2nd ed.).
- **Juveniles**: Inshore: depth, temperature, and salinity ranges (presence only) based on MA and ME inshore trawl survey data in areas mapped as EFH; inshore depth and temperature ranges ("common") from MA trawl survey data in EFH Source Doc (2nd ed.). Continental shelf: sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data; additional substrate information from EFH Source Document (2nd ed.); depth, temperature, and salinity ranges derived from NEFSC trawl survey data. Other information from EFH Source Document (2nd ed.) and Mark Lazzari (Maine DMR, pers. comm.).
- **Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on MA and ME inshore trawl survey data in areas mapped as EFH; inshore depth and temperature ranges ("common") from MA trawl survey data in EFH Source Doc (2nd ed.). Continental shelf: sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data; additional substrate information from EFH Source Document (2nd ed.); depth, temperature, and salinity ranges derived from NEFSC trawl survey data. Other information from EFH Source Document (2nd ed.) and Klein-MacPhee (2002).

3.2.2 Prey species

The main source of information on the prey consumed by haddock (*Melanogrammus aeglefinus*) comes from the EFH Source Document (Brodziak 2005 and references therein). Haddock diet changes with life history stage. Pelagic larvae and small juvenile haddock feed on phytoplankton, copepods, and invertebrate eggs in the upper part of the water column. Juvenile haddock eat small crustaceans, primarily copepods and euphausiids, as well as polychaetes and small fishes. During the transition from pelagic to demersal habitat, juvenile diet changes to primarily benthic prey. Planktonic prey, such as copepods and pteropods decrease in importance after juveniles become demersal, while ophiuroids and polychaetes increase in importance. When juveniles reach 8 cm in length, they feed primarily on echinoderms, small decapods, and other benthic prey. Benthic juveniles above 30 cm and adults feed primarily on crustaceans, polychaetes, mollusks, echinoderms, and some fish. Regional variation in haddock food habits also exists. Echinoderms are more common prey items in the Gulf of Maine than on Georges Bank. In contrast, polychaetes are more common prey on Georges Bank than in the Gulf of Maine.

Food habits data collected during NEFSC bottom trawl surveys reveal that the species composition of haddock prey varies by haddock size class. Unidentified fish, amphipods, and euphausiids were the most common prey items by weight for small haddock less than 20 cm in length. The diet of haddock between 20 and 50 cm in length was more varied and included amphipods, ophiuroids, polychaetes, decapods, *Ammodytes* sp. (sand lance), and bivalves. Ophiuroids, amphipods, polychaetes, cnidarians, scombrids (mackerel), and *Ammodytes* sp. were the most common prey items of large haddock with lengths between 50-80 cm. Extra-large haddock over 80 cm in length fed primarily upon clupeids (herring), ophiuroids, amphipods, scombrids, and euphausiids. Overall, the NEFSC food habits data show that haddock diet includes more ophiuroids and becomes more varied as fish increase in size. It also shows that amphipods are an important prey item for all demersal life history stages and that fish are an important component of the diet of very large haddock. Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult haddock include: ophiuroids (22%), gammarid amphipods (14%), polychaetes (9%) and fish eggs (8%).

Table 4 – Major prey items of haddock

Life Stage	*Major prey*	*Location*
Larvae, small juveniles	**Phytoplankton, copepods, invertebrate eggs**	U.S. northeast continental shelf
Small juveniles	**Polychaetes; Crustaceans**: copepods, euphausiids, amphipods, decapods; **Echinoderms**: ophiuroids; **Fish**	U.S. northeast continental shelf
Large juveniles, small adults	**Polychaetes; Crustaceans**: amphipods, euphausiids, decapods; **Mollusks**: bivalves; **Echinoderms**: ophiuroids; **Fish**: *Ammodytes* sp. (sand lance)	U.S. northeast continental shelf
Large adults	**Cnidarians; Crustaceans**: amphipods, euphausiids; **Echinoderms**: ophiuroids; **Fish**: *Ammodytes* sp. (sand lance), scombrids (mackerel), clupeids (herring)	U.S. northeast continental shelf

3.2.3 Peak spawning

Information on the spawning periods of haddock (*Melanogrammus aeglefinus*) comes from the EFH Source Document (Brodziak 2005 and references therein). **Georges Bank** is the *principal* haddock spawning area in the northeast U.S. continental shelf ecosystem. Haddock spawning is concentrated on the **Northeast Peak** of Georges Bank. The western edge of Georges Bank also supports a smaller spawning concentration (Walford 1938).

Although the *vast majority* of reproductive output originates from **Georges Bank**, some limited spawning activity occurs on **Nantucket Shoals** (Smith and Morse 1985) and along the **South Channel** (Colton and Temple 1961). In the **Gulf of Maine**, **Jeffreys Ledge** and **Stellwagen Bank** are the two primary spawning sites (Colton 1972). In addition, Ames (1997) also reported numerous small, isolated spawning areas in **inshore Gulf of Maine waters**. Based on interviews with retired commercial fishers from Maine and New Hampshire, Ames (1997) identified 100 haddock spawning sites, covering roughly 500 square miles, from **Ipswich Bay to Grand Manan Channel.**

The timing of haddock spawning activity varies among areas. In general, spawning occurs later in more northerly regions (Page and Frank 1989; Lapolla and Buckley 2005). There is also inter-annual variation in the onset and *peak* of spawning activity. On **Georges Bank**, spawning occurs from January to June (Smith and Morse 1985), usually *peak*ing from February to early-April (Smith and Morse 1985; Lough and Bolz 1989; Page and Frank 1989; Brander and Hurley 1992; Lapolla and Buckley 2005) but the timing can vary by a month or more depending upon water temperature (Marak and Livingstone 1970; Page and Frank 1989). In the **Gulf of Maine**, spawning occurs from early February to May, usually *peaking* in February to April (Bigelow and

Schroeder 1953). Overall, cooler water temperatures tend to delay haddock spawning and may contract the duration of spawning activity (Marak and Livingstone 1970; Page and Frank 1989).

During 1978-1987, MARMAP ichthyoplankton surveys caught haddock eggs from **New Jersey to southwest Nova Scotia**. The highest densities were found on **Georges Bank** and Browns Bank, which are important haddock spawning areas (Colton and Temple 1961; Laurence and Rogers 1976; Brander and Hurley 1992). Eggs were collected from January through August. The *highest concentrations* occurred in April, followed by March and May. This pattern is consistent with the timing of peak spawning from March to May (Bigelow and Schroeder 1953; Page and Frank 1989; Brander and Hurley 1992). In particular, the *highest mean densities* of eggs occurred in April (77.3 eggs/10 m^2) and March (21.1 eggs/10 m^2). By July and August, mean densities had decreased substantially (< 0.1 eggs/10 m^2).

Data from the more recent U.S. GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) showed the *highest concentration* of eggs to be on the eastern, Canadian side of **Georges Bank**, with peaks occurring during February-March and into April.

3.3 Pollock

3.3.1 Supplementary table

Table 5 – Summary of habitat information for pollock

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Pelagic, in water column	Present 1-280 on shelf, common 41-120 Usually found 50-250	Present 2.5-13.5 on shelf, common 2.5-13.5 Optimum development 3.3-8.9	No information
Larvae	Pelagic, in water column	Present 1-280 on shelf, common 21-160 Normally from shore to 200, reported as deep as 1550	Present 1.5-17.5 on shelf, common 3.5-11.5 Larvae strong and active 3.3-8.9	No information
Juveniles	Pelagic habitats Benthic habitats with substrates composed of mud, sand, mixtures of mud and sand, and *gravel* Wide variety of substrates, including sand, mud, and rocky bottom with eelgrass and macroalgae	Present 4-83 inshore, common at min 6, max 70 (MA) Present 11-400 on shelf, common 41-180 YOY and age 1 utilize inshore subtidal and intertidal zones; common 1-10 in ME estuaries and bays	Present 1.6-17 inshore, common at min 5, max 12 (MA) Present 0.5-17.5 on shelf, common 2.5-9.5 Found 0-16	Present 28-33.7 inshore (ME) Present 31.5-35.5 on shelf, common 31.5-34.5 Prefer 31.5

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
		Age 2+ move offshore to 130-150		
Adults	Pelagic habitats Benthic habitats with substrates composed of mud, sand, mixtures of mud and sand, mud and sand mixed with *gravel*, and *gravel* Little preference for bottom type Spawn over hard, stony or rocky bottom	Present 1-400 on shelf, common 81-180 Range 35-365, most <137, prefer 100-125 Found further offshore than juveniles	Present 1.5-16.5 on shelf, common 5.5-9.5 on shelf Found 0-14, tend to avoid >11 and <3 Spawning begins <8, peaks 4.5-6 (MA Bay)	Common 32.5-35.5 on shelf Found 31-34 (SS) Spawn 32-32.8 (MA Bay)

**   Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Note: As used in the analysis of sediment associations, the term "gravel" refers to all grain sizes above a diameter of 2 mm, i.e., any sediment coarser than sand, and therefore includes pebbles, cobbles, and even boulders

Sources of information:

- **Eggs**: Shelf depth and temperature ranges derived from MARMAP data in EFH Source Document; other information from EFH Source Doc and Update Memo.
- **Larvae**: Shelf depth and temperature ranges derived from MARMAP data in EFH Source Document; other information from EFH Source Doc and Update Memo.
- **Juveniles**: Inshore: depth, temperature, and salinity ranges (present and "common") based on MA and ME inshore trawl survey data in areas mapped as EFH in EFH Source Doc Update Memo. Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types based on GIS overlap analysis of NEFSC trawl survey data and USGS USSeabed sediment data and EFH Source Document and Update Memo. Other information also obtained from EFH Source Document and Update Memo.
- **Adults**: Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types based on GIS overlap analysis of NEFSC trawl survey data and USGS USSeabed sediment data and EFH Source Document and Update Memo. Other information also obtained from EFH Source Document and Update Memo.

3.3.2 Prey species

The main source of information on the prey consumed by the juvenile and adult stages of pollock (*Pollachius virens*) comes from the EFH Update Memo and EFH Source Document (Essential Fish Habitat Source Document Update Memo: Pollock, *Pollachius virens*, Life History and Habitat Characteristics, 2004; Cargnelli *et al*. 1999, and references therein). The primary prey of small larvae (4-18 mm) is larval copepods while larger larvae (> 18 mm) feed primarily on adult copepods. The primary prey of juvenile pollock is crustaceans. Euphausiids, in particular

Meganyctiphanes norvegica, are the most important crustacean prey of juveniles. Fish and mollusks make up a smaller proportion of the juvenile diet; however, in some cases fish may play a more important role in the diet. For example, one study showed that the diet of subtidal juveniles in the Gulf of Maine was dominated by fish, especially young Atlantic herring (*Clupea harengus*). The diet of adults is comprised of, in order of decreasing importance, euphausiids, fish and mollusks. *M. norvegica* is the single most important prey item and Atlantic herring is the most important fish species. Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult pollock include: silver hake (19%); krill (14%); decapod shrimp (10%); sand lance (9%); crustacean shrimp (8%); and Atlantic herring (7%).

Bowman and Michaels (1984) found that the diet preferences of adults vary with size: crustaceans were the most important prey item among smaller adults (41-65 cm), fish were most important among medium size adults (66-95 cm), and mollusks (the squid *Loligo*) were the most important prey among the largest adults (> 95 cm). Bowman *et al*. (2000) summarized stomach contents, primarily from the NEFSC bottom trawl surveys from 1977-1980 by length. For fish < 31 cm, the main prey choices were chaetognatha and crustaceans; of the latter, the major identifiable crustacean was *Meganyctiphanes norvegica*. Crustacea often remain a major prey choice for larger pollock, but fish, particularly *Ammodytes*, become important for fish > 61 cm. Cephalopods are also important prey items for fish between 61-70 cm.

Table 6 – Major prey items of pollock

Life Stage	***Major prey***	***Location***
Larvae	**Larval and adult copepods**	U.S. northeast continental shelf
Juveniles, very small adults 1-40 cm	**Chaetognaths**: *Sagitta elegans;* **Crustaceans**: amphipods (*Ericthonius rubricornis*), euphausiids (*Meganyctiphanes norvegica*); **Mollusks**: squids	U.S. northeast continental shelf
Adults	**Nematodes; Crustaceans**: amphipods, euphausiids (*Meganyctiphanes norvegica*), decapods (*Crangon septemspinosa, Dichelopandalus leptocerus, Pandalus borealis*); **Mollusks**: squids (*Loligo* sp., *Illex* sp.); **Fish**: sand lance, Myctophidae, silver hake, Anarhichadidae, Atlantic herring	U.S. northeast continental shelf

3.3.3 Peak spawning

Information on the spawning periods of pollock (*Pollachius virens*) comes from the EFH Source Document (Cargnelli *et al*. 1999, and references therein).

The principal pollock spawning sites in the northwest Atlantic are in the **western Gulf of Maine, Great South Channel, Georges Bank**, and on the Scotian Shelf. In the **Gulf of Maine**, spawning is concentrated in **Massachusetts Bay, Stellwagen Bank, and from Cape Ann to the Isle of Shoals** (Steele 1963; Hardy 1978; Collette and Klein-MacPhee 2002). Spawning is believed to occur throughout the Scotian Shelf; Emerald, LaHave, and Browns banks are the principal sites (Mayo *et al.* 1989).

Spawning takes place from September to April. Spawning time is more variable in northern sites than in southern sites. In the **Gulf of Maine** spawning occurs from November to February (Steele 1963; Colton and Marak 1969), *peaking* in December (Collette and Klein-MacPhee 2002). On the Scotian Shelf, spawning occurs from September to April (Markle and Frost 1985; Clay *et al.* 1989) and *peak*s from December to February (Clay *et al.* 1989).

The 1978-1987 MARMAP offshore ichthyoplankton surveys collected eggs during October to June from off **Delaware Bay to southwest Nova Scotia**. *Highest monthly mean egg densities* occurred in November (24.4 eggs/10 m^2), December (36.8 eggs/10 m^2), January (86.1 eggs/10 m^2) and February (19.6 eggs/10 m^2) in **Massachusetts Bay, Georges Bank, and Browns Bank**. Egg densities were considerably lower in months prior to and after this period (≤ 1.40 eggs/m^2). This concurs with reports that *peak* spawning occurs during November to February (Hardy 1978; Fahay 1983; Clay *et al.* 1989).

3.4 White hake

3.4.1 Supplementary table

Table 7 – Summary of habitat information for white hake

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Pelagic, in water column	No information	No information	No information
Larvae	Pelagic, in water column	No information	No information	No information
Juveniles	Pelagic habitats during settlement	Present 5-99 inshore, common 21-80 (MA)	Present 1.3-20.7 inshore, common 2.5-12.5 (MA)	Present 13.4-34 inshore
	Benthic habitats with substrates composed of mud and/or eel grass	Present 1-500 on and off shelf, common 61-300	Present 0.5-18.5 on shelf, common 3.5-15.5	Present 29.5-35.5 on shelf, common 32.5-34.5
	Prefer fine grained, muddy substrates	YOY utilize estuarine nursery areas (1-10 coastal ME)		
Adults	Benthic habitats with substrates composed of mud and sand-mud	Present 25-84 inshore (36-84 in ME)	Present 1.9-13.1 inshore (3.5-16.5 ME)	Present 32-34 inshore
	Prefer fine grained, muddy substrates	Present 11- >500 on and off shelf, common 101-400	Present 1.5-21.5 on shelf, common 4.5-10.5 on shelf	Present 28.5-36.5 on shelf, common 33.5-35.5
		On slope to 2250		
		Spawn primarily on slope		

* Depth to bottom

** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages

<u>Note</u>: White hake eggs and larvae were not differentiated from eggs and larvae of red, spotted, and longfin hake in the MARMAP survey

Sources of information:

- **Juveniles**: Inshore: depth, temperature, and salinity ranges (presence only) based on MA and ME inshore trawl survey data from areas mapped as EFH; depth and temperature ranges ("common") derived from MA trawl survey data in EFH Source Document Update Memo. Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types based on GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data and information in EFH Source Document. Additional information provided by M. Lazzari (Maine DMR, pers. comm.).
- **Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on MA and ME inshore trawl survey data from areas mapped as EFH; depth and temperature ranges ("common") derived from ME trawl survey data. Continental shelf and slope: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types based on GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data and information in EFH Source Document; off-shelf depth data from Haedrich and Merrett (1988).

3.4.2 Prey species

The main source of information on the prey consumed by the juvenile and adult stages of white hake (*Urophycis tenuis*) comes from the EFH Update Memo and EFH Source Document (Essential Fish Habitat Source Document Update Memo: White hake, *Urophycis tenuis*, Life History and Habitat Characteristics, 2004; Cargnelli *et al*. 1999, and references therein).

Using the NEFSC food habits database from 1977-1980, Bowman *et al*. (2000) showed that the primary prey of juveniles < 21 cm were polychaetes and crustaceans. Crustacean prey included calanoid copepods, amphipods (*Anonyx sarsi*), and decapods (*Crangon septemspinosa*). Large juveniles/smaller adults 21-50 cm fed mostly on crustaceans, squids, and fish. Crustacean prey included decapods (*Crangon septemspinosa*; the pandalid shrimp *Dichelopandalus leptocerus* and *Pandalus borealis*), and euphausiids (*Meganyctiphanes norvegica*). Squids included *Loligo pealeii*. Fish prey included gadids, silver hake, and white hake (most likely juveniles). Adults > 50 cm also fed primarily on crustaceans, squid, and fish. Crustacean prey included euphausiids (*Meganyctiphanes norvegica)* and decapods (pandalid shrimp *Dichelopandalus leptocerus*). Squids included *Illex* sp. Fish prey included gadids, red hake, and silver hake. Regionally, fish dominated the diet in all locations sampled.

Using NEFSC diet data from 1973-1997, Garrison and Link (2000) observed an increasing amount of piscivory in white hake with increasing size. Euphausiids (12.8% of diet), crangonid shrimp (15.7%), pandalid shrimp (14.2%), and unclassified shrimp (19.9%) account for the majority of juvenile (< 20 cm) white hake diets. Larger juvenile/smaller adult white hake 20-50 cm had a large proportion of shrimp taxa in their diets, but unclassified fishes (25.5%) and silver hake (16.2%) were also important components. Large adults > 50 cm fed almost exclusively on fish taxa, with silver hake (21.7%), clupeids (7.1%), Atlantic herring (6.5%), argentines (6.6%), and unclassified fishes (33.5%) as major prey. Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult white hake include: other fish (32%), silver hake (22%), Atlantic herring (7%), and other herrings (6%).

Table 8 – Major prey items of white hake

Life Stage	*Major prey*	*Location*
Juveniles, < 20-21 cm	**Polychaetes; Crustaceans**: calanoid copepods, amphipods (*Anonyx sarsi*), decapods (*Crangon septemspinosa*, pandalid shrimp), euphausiids	U.S. northeast continental shelf
Larger juveniles/ smaller adults, 20-21 to 50 cm	**Crustaceans**: decapods (*Crangon septemspinosa*; the pandalid shrimp *Dichelopandalus leptocerus* and *Pandalus borealis*), euphausiids (*Meganyctiphanes norvegica*); **Mollusks**: squids (*Loligo pealeii*); **Fish**: gadids, silver hake, white hake (most likely juveniles)	U.S. northeast continental shelf
Larger adults, > 50 cm[1]	**Fish**: silver hake, clupeids, Atlantic herring, argentines	U.S. northeast continental shelf

[1]*Based on Garrison and Link (2000) only.*

3.4.3 Peak spawning

Information on the spawning periods of white hake (*Urophycis tenuis*) comes from the EFH Source Document (Cargnelli *et al*. 1999, and references therein). The northern stock of white hake spawns in late summer (August-September) in the southern Gulf of St. Lawrence and on the Scotian Shelf (Markle *et al*. 1982). The timing and extent of spawning in the **Georges Bank-Middle Atlantic Bight** stock has not been clearly determined. Based on the distribution and abundance of pelagic juveniles, as well as circulation patterns throughout the region, Fahay and Able (1989) suggested that the southern stock spawns in early spring (April-May) in **deep waters along the continental slope,** *primarily* off **southern Georges Bank and the Middle Atlantic Bight** (Lang *et al*. 1996). The spawning contribution of the **Gulf of Maine** population is negligible (Fahay and Able 1989).

3.5 American plaice

3.5.1 Supplementary table

Table 9 – Summary of habitat information for American plaice

Life Stage	**Habitat**	**Depth (m)***	**Temperature (ºC)****	**Salinity (ppt)****
Eggs	Pelagic, in water column	Present 21-240 on shelf, common 41-140	Present 1.5-8.5 on shelf, common 2.5-7.5 Highest growth and survival rates 2-6	No information
Larvae	Pelagic, in water column	Present 21-220 on shelf, common 41-120	Present 3.5-13.5 on shelf, common 4.5-8.5	No information
Juveniles	Pelagic habitats during settlement	Present 7-85 inshore, common 41-85 (MA)	Present 1-16 inshore, common 2.5-10.5 (MA)	Present 28-34 inshore Present 30.5-35.5, on

Life Stage	Habitat	Depth (m)*	Temperature (ºC)**	Salinity (ppt)**
	Benthic habitats with substrates composed of mud, and sand-mud mixtures	Present 1-500 on shelf, common 51-180	Present 0.5-16.5 on shelf, common 2.5-6.5	shelf, common 31.5-34.5
Adults	Benthic habitats with substrates composed of mud, and sand-mud mixtures	Present 8-85 inshore, common 41-85 (MA) Common 101-200 on shelf Present 1- >500 on and off shelf Normally occur 25-180, abundant 54-90 (GOM) Spawn <90	Present 1-14 inshore, common 2.5-10.5 (MA) Present 0.5-17.5 on shelf, common 2.5-7.5 Optimum spawning 3-6 Develop 1.7-7.7, but tolerate -1.5 Upper limit 10-13	Present 28-34 inshore Present 30.5-35.5 on shelf, common 31.5-34.5

**   Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Sources of information:

- **Eggs**: Shelf depth and temperature ranges derived from MARMAP and GLOBEC data in EFH Source Document (2nd ed); additional temperature data from EFH Source Doc (2nd ed).
- **Larvae**: Shelf depth and temperature ranges derived from MARMAP and GLOBEC data in EFH Source Document (2nd ed).
- **Juveniles**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; inshore depth and temperature ranges ("common") from analysis of MA trawl survey data in EFH Source Doc (2nd ed.). Continental shelf: sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data; depth, temperature, and salinity ranges derived from NEFSC trawl survey data.
- **Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; inshore depth and temperature ranges ("common") from analysis of MA trawl survey data in EFH Source Doc (2nd ed.). Continental shelf: sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data; depth, temperature, and salinity ranges derived from NEFSC trawl survey data. Other information from EFH Source Document (2nd ed.) and from Klein-MacPhee (2002).

3.5.2 Prey species

The main source of information on the prey consumed by the larval, juvenile and adult stages of American plaice (*Hippoglossoides platessoides*) comes from the EFH Source Document (Johnson 2004 and references therein). Larvae feed on plankton, diatoms, and copepods found in the upper water layers. Prior to settling, juveniles feed on small crustaceans, polychaetes, and cumaceans. According to the NEFSC food habits database, dominant (exceeds 5% weight threshold in fish stomachs) prey of smaller juveniles (< 20 cm) was ophiuroids and polychaetes (Fig. 2 in source document); Bowman and Michaels (1984) reported that polychaetes [including Nephtyidae (Bowman *et al*. 2000)] were especially important prey of plaice < 20 cm. Another important prey item of juveniles 21-25 cm appears to be nematodes (Bowman *et al*. 2000). Larger juveniles and smaller adults (20-40 cm) feed on echinoderms, especially ophiuroids (*Ophiura sarsi*) but also echinoids, crustaceans (decapods such as the sand shrimp *Crangon septemspinosa*, and euphausiids), and bivalves (Fig. 2 in source document, and Bowman *et al*. 2000). Previous studies suggest there are ontogenetic shifts in diet, with American plaice consuming fewer polychaetes as their body size increased. Smaller, mostly juvenile (< 16-30 cm) individuals fed predominately on polychaetes, crustaceans, and small brittle stars, while adults > 30 cm fed primarily on bivalve mollusks, brittle stars and other echinoderms, decapods, and fish.

Adult plaice are opportunistic feeders, flexible in their dietary habits, and will take whatever is most abundant or accessible. The stomach contents of plaice from the Gulf of Maine, Georges Bank, and southern New England are generally similar although the specific prey consumed can vary geographically. Dominant prey of adults 41-70 cm includes echinoderms (ophiuroids, such as *O. sarsi*; asteroids; and echinoids such as the sand dollar, *Echinarachnius parma*) and bivalves (including *Chlamys islandica* and *Cyclocardia borealis*) (Fig. 2 in source document, and Bowman *et al*. 2000).

In Sheepscot Bay, Maine, polychaetes, mysid shrimp, amphipods, sand shrimp (*Crangon septemspinosa*), and Atlantic herring are important prey; mysids generally decrease in importance with increasing fish size while polychaetes appear to increase.

Table 10 – Major prey items of American plaice

Life Stage	*Major prey*	*Location*
Larvae	**Diatoms, copepods,** other plankton	U.S. northeast continental shelf
Early juveniles (pre-settlement)	**Polychaetes; Crustaceans**: cumaceans	U.S. northeast continental shelf
Small juveniles (< 20 cm)	**Polychaetes**: *Nephtyidae*; **Echinoderms:** ophiuroids	U.S. northeast continental shelf
Large juveniles, small adults (20-40 cm)	**Nematodes** (*juveniles* 21-25 cm); **Crustaceans:** decapods (sand shrimp *Crangon septemspinosa*), euphausiids; **Mollusks:** bivalves; **Echinoderms**: ophiuroids (*Ophiura sarsi*), echinoids	U.S. northeast continental shelf
Larger adults (41-70 cm)	**Mollusks:** bivalves (*Chlamys islandica*, *Cyclocardia borealis*); **Echinoderms**: ophiuroids (*O. sarsi*), asteroids, echinoids, (sand dollar, *Echinarachnius parma*)	U.S. northeast continental shelf
	Polychaetes; Crustaceans: amphipods, mysid shrimp, sand shrimp (*Crangon septemspinosa*); **Fish:** Atlantic herring	Sheepscot Bay, ME

3.5.3 Spawning

Information on the spawning periods of American plaice (*Hippoglossoides platessoides*) comes from the EFH Source Document (Johnson 2004 and references therein).

In the northern part of its range (Canada), plaice spawn in the summer (Hebert and Wearing-Wilde 2002). In the southern part of its range in the **Gulf of Maine**, the spawning season extends from March through the middle of June, with *peak* spawning activity in April and May (Bigelow and Schroeder 1953; Colton *et al.* 1979; Smith *et al.* 1975). Nursery areas are found in coastal waters of the **Gulf of Maine** (Bigelow and Schroeder 1953).

The NEFSC MARMAP ichthyoplankton surveys (1978-1987) captured eggs throughout the year. During February and March, eggs were collected on **Stellwagen Bank**, **off Cape Ann, on Jeffreys Ledge, along coastal Maine, and on Georges Bank**. During April and May, the *highest* egg concentrations occurred along the **eastern edge of Georges Bank and along the coastal areas off eastern Massachusetts, the Gulf of Maine, southwest Nova Scotia, and Browns Bank**. From June through December, eggs were collected almost exclusively along the **coastal areas in the Gulf of Maine**; some eggs were collected on **Georges Bank** and the Scotian Shelf.

GLOBEC ichthyoplankton surveys on **Georges Bank** during 1995-1999 show that American plaice eggs were generally restricted to locations within depth zones $\geq$ 56 m. They were most abundant at greater depths on **Georges Bank** (56-110 m); **along the Great South Channel, the central and eastern part of the southern flank and the northern part of the Northeast Channel** where depths are > 185 m. Very few eggs were captured during January. Catches increased tenfold by February along the eastern part of the **Northeast Peak** reaching *peak* numbers by March. The occurrence of eggs extended eastward along the **southern flank of Georges Bank** and into the **eastern section of Georges Basin**. By April, the *high* concentrations shifted toward the **western part of the southern flank**. In May and June catches of eggs declined dramatically, with centers of abundance still along the **southern flank of Georges Bank**.

3.6 Atlantic halibut

3.6.1 Supplementary table

Table 11 – Summary of habitat information for Atlantic halibut

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Pelagic, in water column	No information (Assume same as juveniles and adults)	Lab study: optimum 5-7 (Assume same as juveniles and adults)	No information (Assume same as larvae)
Larvae	Pelagic, in water column	No information (Assume same as juveniles and adults)	No information (Assume same as juveniles and adults)	Prefer 30-35
Juveniles	Benthic habitats (for substrates types, see adults)	Present 21-400 on shelf, common 61-140 (juvs and adults) Most common 20-60	Present 1.5-14.5 on shelf, common 2.5-12.5 (juvs/adults) Survive sub-zero, but	Present 31.5-35.5 on shelf, common 31.5-34.5 (juvs/adults)

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
		(Canada) Occur as deep as 700 off-shelf (juvs/adults)	prefer >2	
Adults	Benthic habitats, usually on sand, gravel or clay, not on soft mud or rock Spawn over rough or rocky bottom	Range 37-1000, depth limit uncertain Spawn as deep as 700 Believed to spawn on continental slope and on offshore banks at depths of at least 183 Found mainly on banks (SS) and head of Bay of Fundy 165-229	Found -0.5 to 13.6, avoid <2.5; most caught 3-9, average 5-6 Spawn 4-7	Found 30.4-35.3 (SS) Spawn at 35 or less

** Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Note: As used in the analysis of sediment associations, the term "gravel" refers to all grain sizes above a diameter of 2 mm, i.e., any sediment coarser than sand, and therefore includes pebbles, cobbles, and even boulders

Sources of information:

- **Eggs and Larvae**: All information from EFH Source Document Update Memo.
- **Juveniles**: Depth and temperature ranges based on NEFSC trawl survey data in EFH Source Doc Update Memo; all other information also from EFH Source Doc Update Memo.
- **Adults**: All information from EFH Source Doc Update Memo.

3.6.2 Prey species

The main source of information on the prey consumed by the juvenile and adult stages of Atlantic halibut (*Hippoglossus hippoglossus*) comes from the EFH Update Memo (Essential Fish Habitat Source Document Update Memo: Atlantic Halibut, *Hippoglossus hippoglossus*, Life History and Habitat Characteristics, 2004, and references therein). Given the benthic occurrence of the eggs and larval development, no eggs were collected during the MARMAP (Marine Monitoring Assessment and Prediction) ichthyoplankton surveys and larvae were only collected at 2 out of 1,672 stations. Thus, we have no information on the food habits of the larvae. Larval exogeneous feeding occurs 28-35 days after hatching when the yolk sac has been completely absorbed at a size of roughly 11-13 mm (SL).

The range of lengths of Atlantic halibut collected in the NEFSC bottom trawl survey is 20-120 cm (TL), with most sizes less than 80-90 cm (TL). Since the length at maturity is 103 cm for females and 82 cm for males, most of the NEFSC food habits database is based upon juveniles and immature adults, and the limited information on the prey preferences of the juvenile/immature adult stages are combined in the prey table. Based on Fig. 3 in update memo, which is based on the NEFSC food habits database from 1973-2001, dominant (exceeds 5% weight threshold in fish stomachs) prey are fish (gadids, clupeids, eelpouts), squids, and decapod crustaceans. Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the fish stomachs include: longhorn sculpin (18%); other fish (10%); cod (8%); *Cancer* crabs (8%); pandalids (8%); silver hake (7%); and *Illex* squid (5%).

The diet of Atlantic halibut changes with increasing size. Fish up to 30 cm feed almost exclusively on invertebrates, mainly annelids and crustaceans (crabs, shrimps); those 30-80 cm in length feed on both invertebrates (mainly crustaceans, some mollusks) and fish; and those greater than 80 cm in length feed almost exclusively on fish (Kohler (967). However, Bowman *et al.* (2000) found that fish less than 31 cm had diets composed of mostly unidentified fishes (76.6%), as well as crustaceans (23.4%, mostly *Crangon septemspinosa*) (Table 2 in update memo). The most important prey of larger halibut during that same study were squid (*Illex*), crustaceans (pandalid shrimp, *Cancer* crabs), and fish including rock eel, silver hake, northern sand lance, ocean pout, and longhorn sculpin (Bowman *et al.* 2000; Table 2 in update memo). With the exception of the Scotian Shelf, fish were the major prey item in all regions sampled (Bowman *et al.* 2000; Table 3 in update memo). In an earlier study, Maurer and Bowman (1975) reported that 91% (by weight) of the stomach contents of juvenile and adult halibut were fish, of which greater than 50% were longhorn sculpin and its eggs, but also included cod and other gadids. Nickerson (1978) reported that the fish prey of halibut included cod, cusk, haddock, ocean perch, sculpins, silver hake, herring, capelin, skates, flounder, and mackerel.

Table 12 – Major prey items of Atlantic halibut

Life Stage	*Major Prey*
Juveniles and adults	**Crustaceans**: decapods (*Cancer* crabs, pandalid shrimp, *Crangon septemspinosa*); **Squid**: *Illex*; **Fish**: gadids (e.g., cod), clupeids, eelpouts (ocean pout), longhorn sculpin, silver hake, rock eel, northern sand lance

3.6.3 Peak spawning

Information on the spawning periods of Atlantic halibut (*Hippoglossus hippoglossus*) comes from the EFH Update Memo (Essential Fish Habitat Source Document Update Memo: Atlantic Halibut, *Hippoglossus hippoglossus*, Life History and Habitat Characteristics, 2004, and references therein).

Spawning in the western Atlantic is believed to occur on the **slopes of the continental shelf and on the offshore banks** (McCracken 1958; Nickerson 1978; Neilson *et al*. 1993), at depths of at least 183 m (Scott and Scott 1988), over rough or rocky bottom (Collins 1887). Spawning occurs during late winter and early spring (McCracken 1958; Scott and Scott 1988; Miller *et al*. 1991; Methven *et al*. 1992; Trumble *et al*. 1993), with *peak* spawning having been reported during November to December (Neilson *et al*. 1993). Kohler (1964) reported that spawning occurred during winter to early spring on the **Scotian Shelf**, during February to April in the **Gulf of St. Lawrence**, and during winter to late spring off **Newfoundland** (Kohler 1964). DFO

Canada (2003) reports that halibut in the **Gulf of St. Lawrence** appear to spawn from January to May. In northern Norway, spawning has been reported during December to March, with peak spawning from late January to early February (Haug 1990). However, historical descriptions of spawning have reported ripe halibut as late as August (Goode 1884).

Additional References

DFO Canada. 2003. DFO Can. Science Advis. Sec. Stock Status Rep. 2003/006.

3.7 Winter flounder

3.7.1 Supplementary table

Table 13 – Summary of habitat information for winter flounder

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Benthic habitats, attached to mud, sand, muddy sand, gravel, and submerged aquatic vegetation	Collected 0.3-8 inshore Spawn as deep as 72 (GB)	Collected 1-10 inshore Maximum survival at hatching 0-10	Found 10-32
Larvae	Pelagic, in water column	Present 1-180 on shelf, common 1-80	Most abundant 2-15 inshore, found 1-19.5 (NJ) Present 2.5-12.5 on shelf, common 2.5-12.5	Found 4-30 inshore, higher on GB (assume max is 33)
Juveniles	Pelagic habitats during settlement YOY found inshore on a variety of muddy and sandy substrates, with and without eelgrass and macroalgae (*Ulva* sp.), and in marsh creeks (NJ) Prefer muddy sediments with debris (shell, wood, leaves) to sandy sediments (CT) More abundant on mud and mud-sand than sand (LIS) Older juveniles in sandy benthic habitats on continental shelf	Present 0-86 inshore, common 7-24(RB), 16-50 (MA), and at min 7 (DBay) Present 1-300 on shelf, common 11-50 YOY collected 0.5-12 inshore, age 1+ to 27	Present 0-32 inshore, common 7.5-24.5 (RB) and 3.5-15.5 (MA), 1-14 (DB) Present 0.5-22.5 on shelf, common 1.5-16.5 Lab study: age 1+ prefer 18.5 (select 8-27) Maximum growth in field 16-18	Present 3-40 inshore, common 23.5-33.5 (RB) and min 9 (DB) Present 28.5-34.5 on shelf, common 31.5-33.5 Collected 19-21 (YOY 23-33) Optimum growth for YOY <24 (NJ) Lab study: avoid salinities <10 (YOY <5)
Adults	Sandy benthic habitats on continental shelf More abundant on mud and mud-sand than sand (LIS)	Present 2-86 inshore, common 7-24 (RB), 16-60 (MA), and at min 8 (DBay)	Present 0-24 inshore, common 5.5-12.5 (RB), 1-13 (DB), 5.5-15.5 (MA) Present 0.5-23.5 on	Present 8-36 inshore, common 23.5-33.5 (RB), and min 9 (DB)

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
	Spawn on sandy bottom Also see eggs	Present 1- >500 on and off shelf, common 11-60 Spawn as deep as 72 on GB and as shallow as 2-6 inshore Also see eggs	shelf, common 1.5-12.5 Prefer 13.5 (lab), 12-15 (field) Major egg production <3.3 in New England	Found 15-34.5, common 31.5-33.5 on shelf

** Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Sources of information:

- **Eggs**: All information from EFH Source Doc and Update Memo.
- **Larvae**: Temperature and depth ranges for continental shelf derived from MARMAP survey data in EFH Source Doc; other information from EFH Source Document.
- **Juveniles**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; depth, temperature, and salinity ranges ("common") based on MA and Raritan Bay trawl survey data in EFH Source Document and Update Memo and Delaware Bay trawl survey data in Morse (2000). Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data. Other information obtained from EFH Source Doc, Update Memo, Gottschall et al. (2002), and Manderson et al. (2002).
- **Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; depth, temperature, and salinity ranges ("common") based on MA and Raritan Bay trawl survey data in EFH Source Document and Update Memo and Delaware Bay trawl survey data in Morse (2000). Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data. Other information obtained from EFH Source Doc, Update Memo, and Gottschall et al. (2002).

3.7.2 Prey species

The main source of information on the prey consumed by the juvenile and adult stages of winter flounder (*Pseudopleuronectes americanus*) comes from the EFH Source Document and EFH Update Memo (Pereira *et al*. 1999; Pereira 2004, and references therein).

Pearcy (1962) investigated the food habits of winter flounder larvae from hatching through metamorphosis in the Mystic River, CT estuary. A large percentage of the stomach contents were unidentifiable but nauplii, harpacticoids, calanoids, polychaetes, invertebrate eggs, and phytoplankton were all present. Food item preference changed with larval size: smaller larvae (3-6 mm) ate more invertebrate eggs and nauplii while larger larvae (6-8 mm) preferred polychaetes and copepods. Plant material was found in larval stomachs but usually with other food items and was probably incidentally ingested (Pearcy 1962). Copepods and harpacticoids were important foods for metamorphosing and recently metamorphosed winter flounder. Amphipods and polychaetes gradually become more important for both YOY and yearling flounder (Pearcy 1962).

Winter flounder have been described as omnivorous or opportunistic feeders, consuming a wide variety of prey. Polychaetes and crustaceans (mostly amphipods; e.g., gammarids) generally make up the bulk of the diet (Link *et al*. 2002). The major prey items in the diet of juvenile/small adult winter flounder (≤ 30 cm), based on the NEFSC food habits database from 1973-1990, are amphipods (*Ericthonius* sp., *Unciola irrorata*, *Leptocheirus pinguis*, *Ampelisca agassizi*, *Byblis serrata*, *Aeginina longicornis*) and polychaetes (Ampharetidae, Sabellidae, Maldanidae, *Trichobranchus glacialis*, *Lumbrineris fragilis*, *Nereis* sp.), as well as hydroids. Adults ≥ 31 cm feed mostly on amphipods (*Pontogeneia inermis*, *Unciola irrorata*, *Leptocheirus pinguis*, *Aeginina longicornis*), cnidarians (anthozoans, hydroids, sea anemones), polychaetes, and mollusks (bivalves). Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult winter flounder include: polychaetes (39%), anemones/corals (16%), and gammarid amphipods (6%).

In the Navesink River and Sandy Hook Bay (NJ) estuary, ontogenetic shifts in dietary preferences suggest that winter flounder should be divided into three size classes (15-49 mm, 5.0-29.9 cm, and ≥ 30.0 cm) based on a cluster analysis of the winter flounder diet's (Stehlik and Meise 2000). The smallest group fed on spionid polychaetes and copepods, which were scarce in the diets of the two larger size groups. The intermediate size group fed on other polychaetes, amphipods, and bivalve siphons but increased consumption of sand shrimp (*Crangon septemspinosa*) in the summer and fall. The largest size group fed extensively on a bivalve (*Mya arenaria*) and glycerid polychaetes.

Winter flounder may modify their diet based on availability of prey, and degradation or improvement of environmental conditions causing shifts in benthic invertebrate populations may also cause shifts in prey selection such as eating the pollution-tolerant annelid *Capitella* or eating the pollution-sensitive amphipod, *Unciola irrorata*, once environmental conditions have improved. In addition, winter flounder are one of only a handful of species that consume planktonic hydroids (Avent *et al*. 2001). Twenty-eight percent of the winter flounder populations on Georges Bank eat planktonic hydroids, *Clytia gracilis*, but they compose only about 4.1% of the diet by weight. Hydroid consumption was not related to fish size and they were found in the stomachs of fish measuring approximately 100-400 mm in length (Avent *et al*. 2001).

For inshore diet studies, see Table, below.

Table 14 – Major prey items of winter flounder

Life Stage	*Major prey*	*Location*
Juveniles, small adults, ≤ 30 cm	**Cnidarians**: hydroids **Polychaetes**: Ampharetidae, Sabellidae, Maldanidae, *Trichobranchus glacialis*, *Lumbrineris fragilis*, *Nereis* sp. **Crustaceans**: amphipods (*Ericthonius* sp., *Unciola irrorata*,	U.S. northeast continental shelf

Life Stage	***Major prey***	***Location***
	Leptocheirus pinguis, *Ampelisca agassizi*, *Byblis serrata, Aeginina longicornis*)	
Adults, $\geq$ 31 cm	**Cnidarians**: anthozoans, hydroids, sea anemones **Polychaetes** **Crustaceans**: amphipods (*Pontogeneia inermis*, *Unciola irrorata*, *Leptocheirus pinguis*, *Aeginina longicornis*) **Mollusks**: bivalves	U.S. northeast continental shelf
Juveniles	**Crustaceans**: ostracods, copepods, amphipods, isopods, “shrimp”	Woods Hole harbor, MA (Linton 1921)
Juveniles, adults	**Polychaetes**: *Nereis* sp., *Glycera* sp., *Capitella* sp. **Crustaceans**: amphipods (*Ampelisca* sp.), decapods (*Pagurus* sp., *Crangon septemspinosa*) **Mollusks**: bivalves (*Macoma* sp., *Solemya* sp., *Mya* siphons)	Woods Hole harbor, MA (Lux *et al*. 1996)
Ages 1+	**Polychaetes; Crustaceans**: amphipods; **Mollusks**: bivalves (*Nucula proxima, Tellina agilis, Yoldia* sp.)	Buzzards Bay, MA (Frame 1974)
Ages 1+	**Cnidarians**: *Obelia* sp. ;**Crustaceans**: amphipods (*Unciola irrorata*, *Leptocheirus pinguis*)	Block Island Sound, RI (Smith 1950)
Juveniles, adults	**Cnidarians**: *Ceriantheopsis americanus* (tube anemone); **Polychaetes**: *Nephtys incisa, Pherusa affinis, Nereis* sp.	Narragansett Bay, RI (Bharadwaj 1988)
Juveniles	**Polychaetes**: *Nereis* sp., spionids; **Crustaceans**: amphipods (*Ampelisca* sp., *Lembos* sp.), isopods (*Edotea* sp.), tanaids (*Leptochelia* sp.)	Rhode Island coast (Mulkana 1966)
Juveniles	**Nematodes; Polychaetes; Crustaceans**: amphipods	Charles Pond, RI (Worobec 1984)
Larvae, metamporhosing, YOY, yearling	**Invertebrate eggs, nauplii** -- smaller larvae (3-6 mm): **Polychaetes, copepods --** larger larvae (6-8 mm): **Copepods, harpacticoids** -- metamorphosing and recently metamorphosed **Amphipods, polychaetes** -- YOY, yearling	Mystic River, CT estuary (Pearcy 1962)
Juveniles, adults	**Cnidarians**: hydroids; **Polychaetes**: *Streblospio* sp.; **Crustaceans**: amphipods (*Ampelisca abdita*), decapods (*Crangon septemspinosa*), mysid shrimp	New Haven Harbor, CT (Carlson 1991)
Juveniles	**Crustaceans**: amphipods *(Ampelisca abdita*)	Jamaica Bay, NY (Franz and Tanacredi 1992)
Juveniles	**Cnidarians**: hydroids; **Nemerteans; Polychaetes**: *Ampharete* sp., *Nereis succinea*, *Nephtys incise*, *Melinna cristata;* **Crustaceans**: amphipods (*Leptocheirus pinguis*), decapods (mysid shrimp *Neomysis americana*)	Long Island Sound (Richards 1963)
Juveniles	**Nematodes; Polychaetes; Crustaceans**: ostracods, copepods, amphipods, isopods	Southern Long Island, NY (Tressler and

Life Stage	***Major prey***	***Location***
		Bere 1938)
Juveniles, adults	**Polychaetes**: sabellids, terebelllids; **Crustaceans**: amphipods; **Mollusks**: bivalves (clam siphons)	Southern Long Island, NY (Kurtz 1975)
Juveniles	**Polychaetes**: *Asabellides oculata;* **Crustaceans**: amphipods (*Gammarus* sp.)	Raritan Bay, NY (Conover *et al*. 1985)
Juveniles, small adults, < 30 cm; adults, ≥ 30 cm	Juveniles, small adults; **Cnidarians**: hydroids; **Polychaetes**: *Glycera* sp.; **Crustaceans**: amphipods (*Ampelisca vadorum*, *Unciola* sp.), decapods (mysid shrimp *Neomysis americana*); **Mollusks**: bivalves (northern quahog siphons, Atlantic surfclam siphons, *Ensis directus*); Adults **Mollusks**: bivalves (northern quahog siphons, other bivalves) Other prey that may be important in the diet: **Nemerteans; Polychaetes**: *Asabellides oculata;* **Crustaceans**: amphipods (*Gammarus lawrencianus*, *Ampelisca abdita*, *Corophium* sp.), decapods (juvenile rock crab *Cancer irroratus*, *Crangon septemspinosa*); **Mollusks**: bivalves (blue mussel spat/juveniles)	Hudson-Raritan estuary (Steimle *et al*. 2000)
Juveniles, adults	**Polychaetes**: spionids, glycerids; **Crustaceans**: copepods (the calanoid *Eurytemora affinis*), amphipods (ampeliscid), decapods (*Crangon septemspinosa*), mysid shrimp; **Mollusks**: bivalves (*Mya* siphons)	Navesink River, Sandy Hook Bay (NJ) estuary (Stehlik and Meise 2000)
Juveniles, adults	**Nemerteans; Polychaetes; Crustaceans**: amphipods (*Ampelisca* sp.), decapods (*Palaemonetes* sp.); **Mollusks**: bivalves (clam siphons)	Little Egg Harbor, NJ (Festa 1979)
Juveniles, adults	**Polychaetes; Crustaceans**: amphipods, isopods, decapods (*Crangon septemspinosa*); **Mollusks**: bivalves	Hereford Inlet, NJ (Allen *et al*. 1978)
Juveniles, adults	**Cnidarians**: hydroids; **Polychaetes**: *Nereis succinea;* **Crustaceans**: decapods (*Crangon septemspinosa*); **Mollusks**: bivalves (clam siphons); **Fish**: sand lance	Manasquan River, NJ (Scarlett and Giust 1989)
Juveniles, adults	**Cnidarians**: hydroids; **Polychaetes**: *Nereis* sp., *Glycera* sp.; **Crustaceans**: isopods (*Cyathura* sp.); **Mollusks**: bivalves (clam siphons)	Central NJ estuaries (Scarlett 1986, 1988)
Juveniles	**Polychaetes; Crustaceans**: isopods (*Edotea* sp.)	Delaware Bay (de Sylva 1962)
	Polychaetes	Rehobeth Bay, DE (Timmons 1995)
Juveniles	**Polychaetes**: *Scolecolepides viridis*, *Nereis succinea;* **Crustaceans**: amphipods (*Corophium lacustra*); **Mollusks**: bivalves (*Macoma* sp.)	Chesapeake Bay (Homer and Boynton 1978)

3.7.3 Peak spawning

Information on the spawning periods of winter flounder (*Pseudopleuronectes americanus*) comes from the EFH Source Document and EFH Update Memo (Pereira *et al*. 1999; Pereira 2004, and references therein).

With the exception of the **Georges Bank** population, adult winter flounder migrate inshore in the fall and early winter and spawn in late winter and early spring. Winter flounder spawn from winter through spring, with *peak* spawning occurring during February and March in **Massachusetts Bay and south of Cape Cod** and somewhat later along the **coast of Maine** continuing into May (Bigelow and Schroeder 1953). Spawning occurs earlier (November to April) in the **southern part of the range** (Klein-MacPhee 2002). With the exception of **Georges Bank and Nantucket Shoals**, winter flounder eggs are generally collected from very shallow waters (less than about 5 m).

Data from recent U.S. GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) showed **Georges Bank** eggs occurred during March-June, with the highest numbers in March and May on the central and northern sections on the Bank. Winter flounder eggs have also been collected in standard plankton tows utilizing bongo nets by the NEFSC MARMAP survey. In some cases this was probably due to the nets accidentally hitting the bottom, but this explanation is not sufficient to explain the large numbers of eggs collected on **Georges Bank and Nantucket Shoals**, especially during April. The large numbers of eggs collected on **Georges Bank** are probably due to the unique hydrodynamic conditions found there. The water mass on **central Georges Bank** is characterized by lack of stratification at any time of year due to good vertical mixing (Backus and Bourne 1987). These same forces probably lift demersal eggs up into the water column and make them available to sampling by bongo net.

Pereira *et al*. (1999) and Pereira (2004) discuss **inshore locations** where winter flounder eggs have been found.

3.8 Windowpane flounder

3.8.1 Supplementary table

Table 15 – Summary of habitat information for windowpane flounder

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Pelagic, in water column	Present 1-200 on shelf, common 1-80	Present 2.5-24.5 on shelf, common 4.5-20.5	Found 18.2-30
Larvae	Pelagic, in water column	Present 1-200 on shelf, common 1-80	Present -0.5 to 25.5 on shelf, common 8.5-19.5	No information
Juveniles	Sandy benthic habitats Also mud (LIS, GOM) Lab study:	Present 3-82 inshore, common 8-24 (RBay), 6-18 (CBay), and 16-55 (MA) Present 1-300 on shelf, common 1-60	Present 0.1-30 inshore, common 13.5-23.5 (RB), 14-26 (CBay), and 7-19 (MA) Present 0.5-28.5 on shelf, common 2.5-18.5	Present 1-36 inshore, common 14.5-24.5 (RB), 24-32 (CBay) Present 26.5-35.5 on shelf, common 30.5-33.5

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
	prefer sand over mud			
Adults	Sandy benthic habitats Also mud (LIS,GOM)	Present 4-82 inshore, common 10-24 (RBay), 10-26 (CBay) and 6-35 (MA) Present 1-400 on shelf, common 1-70	Present 0.1-25, common 6.5-20.5 (RB), 4-18 (CBay), 3-15 (DBay), and 9-18 (MA) Present 0.5-25.5 on shelf, common 2.5-18.5 Tolerate 0-27 Spawn 6-21, mostly 8.5-13.5	Present 1-36 inshore, common 26.5-31.5 (RB), 22-32 (CBay), and 23-30 (DBay) Present 23.5-35.5 on shelf, common 30.5-33.5

** Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Sources of information:

- **Eggs**: Shelf depth and temperature ranges derived from MARMAP data in EFH Source Document; salinity data from Klein-MacPhee (2002).
- **Larvae**: Shelf depth and temperature ranges derived from MARMAP data in EFH Source Document.
- **Juveniles**: <u>Inshore</u>: depth, salinity, and temperature ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; inshore depth, temperature, and salinity ranges ("common") derived from Raritan Bay and MA trawl survey data in EFH Source Doc, and Chesapeake Bay trawl survey data in Geer (2002). <u>Continental shelf</u>: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types based on GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data and information in EFH Source Doc and Gottschall et al. (2002). Additional information obtained from EFH Source Document.
- **Adults**: <u>Inshore:</u> depth, salinity, and temperature ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; inshore depth, temperature, and salinity ranges ("common") derived from Raritan Bay and MA trawl survey data in EFH Source Doc and Chesapeake Bay trawl survey data in Geer (2002). <u>Continental shelf:</u> depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types based on GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data and on information in EFH Source Document and Gottschall et al. (2002). Additional information obtained from EFH Source Document.

3.8.2 Prey species

The main source of information on the prey consumed by the juvenile and adult stages of windowpane (*Scophthalmus aquosus*) comes from the EFH Update Memo and EFH Source Document (Essential Fish Habitat Source Document Update Memo: Windowpane, *Scophthalmus aquosus*, Life History and Habitat Characteristics, 2006; Chang *et al*. 1999, and references therein). The 1973-1990 NEFSC food habits database indicates windowpane feed on small crustaceans (e.g., mysid shrimp and decapod shrimp) and various fish larvae including hakes and tomcod, as well as their own species (Langton and Bowman 1981). Fish become more important in the diet of larger windowpane.

Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult windowpane include: mysids (18%), crangonidae (14%), gammarid amphipods (11%), sand lance (7%), other fish (6%), and pandalid shrimp (6%).

Bowman *et al*. (2000) summarized the diet composition of windowpane, based on the NEFSC bottom trawl surveys from 1977-1980 by both length and geographic area. Crustaceans, including amphipods, mysids (*Mysidopsis bigelowi* and *Neomysis americana*), and decapods (decapod larvae) were the dominant prey for juveniles up to 20 cm. Other important prey for windowpane 16-20 cm were polychaetes and fish. Large juveniles/adults ≥ 21 cm also fed primarily on crustaceans, including amphipods (*Gammarus annulatus*), mysids (*Neomysis americana*), and decapods (*Crangon septemspinosa*). Fish, including silver hake, sand lance, cusk, were also important prey items for that size class, especially for adults ≥ 36 cm, where they were the dominant prey items. Of the geographic areas sampled, decapod crustaceans made up 100% of the diet of windowpane found inshore south of Cape Hatteras. Fish, particularly sand lance, were the dominant prey items for fish in the Mid-Atlantic and on Georges Bank. Crustaceans dominated in southern New England and inshore north of Cape Hatteras.

A similar dietary analysis by Link *et al*. (2002) focused on flatfish of the northwest Atlantic taken during the NEFSC bottom trawl surveys from 1973-1998 for all seasons. In this study, the major portion of the windowpane diet was composed of shrimps (mysids, *Crangon septemspinosa*, pandalids) and benthic invertebrates. Fish were an important but secondary component of the diet. The study also noted that there was no significant change in the diet in the 25 years covered by the study.

Table 16 – Major prey items of windowpane flounder

Life Stage	*Major prey*	*Location*
Juveniles, ≤ 20 cm	**Crustaceans**: amphipods, mysids (*Mysidopsis bigelowi*, *Neomysis americana*), decapods (decapod larvae)	U.S. northeast continental shelf
Larger juveniles/adults, > 20 cm	**Crustaceans**: amphipods (*Gammarus annulatus*), mysids (*Neomysis americana*), decapods (*Crangon septemspinosa*, pandalid shrimp); **Fish**: silver hake, sand lance, cusk	U.S. northeast continental shelf
Juveniles, adults	**Crustaceans**: mysids	Johns Bay, Maine (Hacunda 1981)
Juveniles, adults	**Crustaceans**: decapods (*Crangon septemspinosa*), mysid shrimp (*Neomysis americana*); **Fish**: bay anchovy, goby, naked goby	New Haven Harbor, CT (Carlson 1991)
Juveniles, adults	**Crustaceans**: mysid shrimp (*Neomysis americana*); **Mollusks**: squid; **Fish**	Block Island Sound, RI (Smith 1950)
Juveniles, adults	**Chaetognaths; Crustaceans**: decapods (*Crangon septemspinosa*), mysid shrimp (*Neomysis americana*); **Fish**: larval sand lance and silver hake	Long Island/Block Island Sounds (Moore (1947)
Juveniles, adults	**Crustaceans**: decapods (*Crangon septemspinosa*), mysid shrimp	Long Island Sound

Life Stage	***Major prey***	***Location***
	(*Neomysis americana*)	(Richards 1963)
Juveniles, adults	**Crustaceans**: decapods (*Crangon septemspinosa*), mysid shrimp (*Neomysis americana*); **Fish**: eggs, larvae	Eastern Long Island Sound (Hickey 1975)
YOY to adult	**Crustaceans**: amphipods (*Gammarus lawrencianus*), decapods (*Crangon septemspinosa*), mysid shrimp (*Neomysis americana*);	Hudson-Raritan estuary (Steimle *et al*. 2000)
YOY to adult	**Crustaceans**: mysid shrimp (*Neomysis americana*)	New Jersey coast (Warkentine and Rachlin 1988)
YOY to adult	**Crustaceans**: decapods (*Crangon septemspinosa*), mysid shrimp (*Neomysis americana*); **Fish**: sand lance	Little Egg Harbor, NJ (Festa 1979)
YOY to adult	**Crustaceans**: amphipods, decapods (*Crangon septemspinosa*, crab larvae), mysid shrimp	Hereford Inlet, NJ (Allen *et al*. 1978)
YOY to adult	**Crustaceans**: copepods, decapods (*Crangon septemspinosa*), mysid shrimp (*Neomysis americana*)	Delaware Bay (de Sylva *et al*. 1962)
YOY to adult	**Crustaceans**: decapods (*Crangon septemspinosa*), mysid shrimp (*Neomysis americana*); **Fish**: bay anchovy	Mouth of Chesapeake Bay (Kimmel 1973)

3.8.3 Peak spawning

Information on the spawning periods of windowpane (*Scophthalmus aquosus*) comes from the EFH Source Document (Chang *et al*. 1999, and references therein). Gonadal development indices (Wilk *et al.* 1990) and egg and larval distributions (Colton and St. Onge 1974; Smith *et al.* 1975; Colton *et al*. 1979; Morse *et al.* 1987) indicate that spawning occurs throughout most of the year. Spawning begins in February or March in **inner shelf** waters, *peaks* in the **Middle Atlantic Bight** in May, and extends onto **Georges Bank** during the summer (Able and Fahay 1998). Spawning also occurs in the **southern portion of the Middle Atlantic Bight** in the autumn (Smith *et al*. 1975). There is a split spawning season in the **central Middle Atlantic Bight** with *peaks* in the spring and autumn (Morse and Able 1995; Able and Fahay 1998). Evidence for a split spawning season is available for **Virginia and North Carolina** (Smith *et al.* 1975), for **Long Island Sound**, **New York** (Wheatland 1956), and for **Great South Bay, New York** (Dugay *et al.* 1989; Monteleone 1992). Gonad development indicated that split spawning off **New Jersey and New York** *peaks* in May and in September (Wilk *et al.* 1990). However, neither Perlmutter (1939) nor Smith *et al.* (1975) found evidence for a split spawning season in **Long Island Sound** or in oceanic waters north of **Virginia**. Colton and St. Onge (1974) collected larvae on **Georges Ban**k from July to November but found no indication of a split spawning season.

Some spawning may occur in the **high salinity portions of estuaries in the Middle Atlantic Bight**, including **Great South Bay, New York** (Monteleone 1992), **Sandy Hook Bay, New Jersey** (Croker 1965), inside **Hereford Inlet, New Jersey** (Allen *et al.* 1978), and in the **coastal habitats of the Carolinas** (Wenner and Sedberry 1989).

Windowpane eggs have been collected in several studies (Colton and St. Onge 1974; Smith *et al.* 1975; Colton *et al.* 1979; Morse *et al.* 1987; Berrien and Sibunka 1999). During the MARMAP ichthyoplankton surveys, eggs were collected at 16% of the stations sampled; primarily at depths < 40 m between **Georges Bank** and **Cape Hatteras**. Eggs densities were generally low in the

Gulf of Maine. Eggs were collected in nearshore shelf waters in the **Middle Atlantic Bight** from February to November. Egg densities *peaked* in May and October. Eggs were present on **Georges Bank** from April through October and density *peaked* during July-August.

3.9 Witch flounder

3.9.1 Supplementary table

Table 17 – Summary of habitat information for witch flounder

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Pelagic, in water column	Present 1-1500 on and off shelf, common 1-160	Present 3.5-17.5 on and off shelf, common 4.5-12.5	No information
Larvae	Pelagic, in water column	Present 1-1500 on and off shelf, common 41-100	Present 3.5-20.5 on shelf, common 5.5-13.5 Maximum survival 15	No information
Juveniles	Benthic habitats with substrates composed of mud and mud mixed with sand	Present 5-99 inshore, common 51-85 (MA) Present 21-1500 on and off shelf, common 81-400	Present 1.5-12.6 inshore, common 3.5-10.5 (MA) Present 0.5-19.5 on shelf, common 3.5-13.5	Present 31.2-34 inshore Present 30.5-36.5 on shelf, common 32.5-34.5
Adults	Benthic habitats with substrates composed of mud and mud mixed with sand Mud, clay, silt, muddy sand substrates, rarely on other bottom types (also juveniles)	Present 6-99 inshore, common 36-85 (MA) Present 21-1500 on and off shelf, common 121-400 Found 20-1569, most 90-330 in U.S. waters (also juveniles)	Present 0.2-16.3 inshore, common 3.5-10.5 (MA) Present 0.5-21.5 on shelf, common 2.5-8.5 Found 0-15, most 2-9 (also juveniles) Spawn 0-10	Present 32.1-34 inshore Present 30.5-36.5 on shelf, common 32.5-35.5 Found 31-36 (also juveniles)

** Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Sources of information:

- **Eggs**: Shelf depth and temperature ranges derived from MARMAP data in EFH Source Document
- **Larvae**: Shelf depth and temperature ranges derived from MARMAP data in EFH Source Document; additional information also from EFH Source Document.
- **Juveniles**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore trawl surveys in areas mapped as EFH; depth and temperature ranges ("common") from MA inshore trawl survey data in EFH Source Doc Update Memo. Continental shelf and slope: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; additional depth information for slope from Moore et al. (2003);

sediment types based on GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data.

- **Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore trawl surveys in areas mapped as EFH; depth and temperature ranges ("common") from MA inshore trawl survey data in EFH Source Doc Update Memo. Continental shelf and slope: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; additional depth information for slope from EFH Source Document and Update Memo and from Moore et al. (2003); sediment types based on GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data, and information in EFH Source Doc and Update Memo.

3.9.2 Prey species

The main source of information on the prey consumed by the juvenile and adult stages of witch flounder (*Glyptocephalus cynoglossus*) comes from the EFH Update Memo and EFH Source Document (Essential Fish Habitat Source Document Update Memo: Witch Flounder, *Glyptocephalus cynoglossus*, Life History and Habitat Characteristics, 2006; Cargnelli *et al*. 1999, and references therein). The main food items in the witch flounder diet are polychaetes and crustaceans, although mollusks and echinoderms are also important. Overall, polychaetes were by far the most important food item, accounting for greater than 70% of the diet. However, there is a distinct ontogenetic shift in diet, with polychaetes increasing in importance and crustaceans decreasing in importance with age. By sexual maturity, polychaetes dominate the diet considerably, while crustaceans are far less important.

The 1973-1990 NEFSC food habits data for witch flounder verify that polychaetes are the most important food source of witch flounder. During 1973-1980, small (5-30 cm) witch flounder fed primarily on polychaetes (37%) and crustaceans (27%). Polychaetes remained the most important food source among larger (> 30 cm) individuals; however, crustaceans declined in importance, replaced in the diet by mollusks and echinoderms. The 1981-1990 data also show that polychaetes dominate the witch flounder diet. Again, an ontogenetic shift in diet is evident, although this shift contrasts with that described above: crustaceans increase in importance while polychaetes decrease in importance in larger fish.

Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the only prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult witch flounder was polychaetes (71%).

Bowman and Michaels (1984) reported that the major food items of smaller juveniles (< 20 cm) were crustaceans (74% of the diet), while polychaetes accounted for only 19%. However, larger juveniles (21-30 cm) fed primarily on polychaetes (45-65%) followed by crustaceans (15-37%). Mollusks and echinoderms were consumed in smaller quantities (0-5%) (Bowman and Michaels 1984). Adults 31-60 cm fed primarily on polychaetes (60-66%) and echinoderms (6-18%), with crustaceans, mollusks, and coelenterates accounting for a smaller part of the diet. Adults > 60 cm fed almost exclusively on polychaetes (98%) (Bowman and Michaels 1984). There is little variation in diet with geographic area. An exception is southern New England, where squid can be almost as important a food source as polychaetes.

Using the NEFSC food habits database from 1977-1980, Bowman *et al*. (2000) showed that in all areas sampled, polychaetes made up at least 75% of the stomach contents by weight. The primary prey of juveniles < 30 cm were polychaetes (Lumbrineridae, including *Lumbrineris fragilis*; Sternaspidae), followed by ascidians and crustaceans (amphipods). Polychaetes also dominated the diets of all the adult size classes; family/species included Lumbrineridae, including *Lumbrineris fragilis* and *Ninoe brevipes*; *Nephtys* sp.; *Glycera dibranchiata*, Goniadidae, including *Goniada* sp. and *Ophioglycera gigantea*; Terebellidae; and Capitellidae. Other important prey included bivalves (*Yoldia* sp.) for adults 36-40 cm, and echinoderms (sea cucumbers) for fish 56-60 cm.

Table 18 – Major prey items of witch flounder

Life Stage	***Major prey***	***Location***
Juveniles, < 30 cm	**Polychaetes**: (Lumbrineridae, including *Lumbrineris fragilis*; Sternaspidae); **Crustaceans**: amphipods	U.S. northeast continental shelf
Adults, $\geq$ 30 cm	**Polychaetes**: (Lumbrineridae, including *Lumbrineris fragilis* and *Ninoe brevipes*; *Nephtys* sp.; *Glycera dibranchiata*, Goniadidae, including *Goniada* sp. and *Ophioglycera gigantea*; Terebellidae; and Capitellidae)	U.S. northeast continental shelf

3.9.3 Peak spawning

Information on the spawning periods of witch flounder (*Glyptocephalus cynoglossus*) comes from the EFH Source Document (Cargnelli *et al*. 1999, and references therein).

Witch flounder spawn from March to November, with *peak* spawning occurring in summer. The general trend is for spawning to occur progressively later from south to north (Martin and Drewry 1978; Brander and Hurley 1992). In the **Gulf of Maine-Georges Bank** region, spawning occurs from April to November, and *peaks* from May to August (Bigelow and Schroeder 1953; Evseenko and Nevinsky 1975; Burnett *et al*. 1992; O'Brien *et al*. 1993). The **western and northern areas of the Gulf of Maine** tend to be the most active spawning sites (Burnett *et al*. 1992). In the **Middle Atlantic Bight**, spawning occurs from April to August, *peaking* in May or June (Smith *et al*. 1975; Martin and Drewry 1978), and the most important spawning grounds are off **Long Island** (Smith *et al*. 1975).

The MARMAP offshore ichthyoplankton surveys found eggs earlier in the **Middle Atlantic Bight** than in **New England**, where eggs were not found until May. This agrees with studies suggesting that spawning occurs later to the north (Martin and Drewry 1978; Brander and Hurley 1992). The highest egg densities appear to be in the **Gulf of Maine and Massachusetts Bay** in May and June. High densities of eggs occurred in May (monthly mean 5.7 eggs/10 m^2) in **Massachusetts Bay, along the south flank of Georges Bank and throughout the Middle Atlantic Bight**. The highest abundances occurred in June (monthly mean 8.0 eggs/10 m^2) off **New England**, particularly in the **Gulf of Maine and Georges Bank**. This concurs with reports that spawning peaks in May and June (Smith *et al*. 1975; Martin and Drewry 1978; Neilson *et al*. 1988).

3.10 Yellowtail flounder

3.10.1 Supplementary table

Table 19 – Summary of habitat information for yellowtail flounder

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Pelagic, in water column	Present 1-400 on shelf, common 21-100 Present 500-1000 off-shelf	Present 1.5-15.5 on shelf, common 3.5-10.5	No information
Larvae	Pelagic, in water column	Present 1-260 on shelf, common 21-120 Present 1000-1500 off-shelf	Present 4.5-17.5 on shelf, common 6.5-12.5 on shelf	No information
Juveniles	Sandy benthic habitats	Present 4-85, common 21-50 (MA) Present 1-400 on shelf, common 31-70 YOY: prefer 56-87 on shelf	Present 1.3-18, common 2.5-13.5 (MA) Present 0.5-18.5 on shelf, common 1.5-13.5	Present 28-33 inshore Present 30.5- 35.5 on shelf, common 32.5-33.5
Adults	Sandy benthic habitats Occur on any sandy bottom or mixture of sand and mud, but avoid rocks, stony ground, and soft mud	Present 4-85, common 26-65 (MA) Present 1-400 on shelf, common 31-80 Common 9-64 off Cape Cod	Present 1.3-17, common 4.5-12.5 (MA) Present 0.5-19.5 on shelf, common 2.5-12.5 Lab study: tolerate -1 to 18, max survival 8-14 Spawn 5-12	Present 28-35 inshore Present 30.5-36.5 on shelf, common 32.5-33.5 Lab study: maximum survival 32-38

** Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Sources of information:

- **Eggs and Larvae**: Shelf depth and temperature ranges, and off-shelf depths, derived from MARMAP and GLOBEC data in EFH Source Document and Update Memo.
- **Juveniles**: <u>Inshore</u>: depth, temperature, and salinity ranges (presence only) based on inshore trawl surveys in areas mapped as EFH; depth and temperature ranges ("common") from MA inshore trawl survey data in EFH Source Doc Update Memo. <u>Continental shelf</u>: depth, temperature, and salinity ranges derived from NEFSC trawl

survey data; sediment types based on GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data; other information from EFH Source Document.

- **Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore trawl surveys in areas mapped as EFH; depth and temperature ranges ("common") from MA inshore trawl survey data in EFH Source Doc Update Memo. Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types based on GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data, and from EFH Source Document, Update Memo, and Klein-MacPhee (2002). Additional information obtained from EFH Source Document, Update Memo, and Klein-MacPhee (2002).

3.10.2 Prey species

The main source of information on the prey consumed by the juvenile and adult stages of yellowtail flounder (*Limanda ferruginea*) comes from the EFH Update Memo and EFH Source Document (Essential Fish Habitat Source Document Update Memo: Yellowtail Flounder, *Limanda ferruginea*, Life History and Habitat Characteristics, 2006; Johnson *et al*. 1999, and references therein). The 1973-2001 NEFSC food habits database for yellowtail flounder shows that polychaetes comprised approximately 35% of the adult yellowtail diet. This was closely followed by amphipods (29%). Unidentified well-digested prey accounted for > 20% of the total diet, other items occurring in lower volumes include bivalves, cnidarians, decapods, and mysids. Other studies mention echinoderms (sand dollars, *Echinarachius parma*) as well. Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult yellowtail flounder include: polychaetes (38%), gammarid amphipods (19%), and other amphipods (6%).

Bowman *et al*. (2000) summarized the diet composition of yellowtail flounder, based on the NEFSC bottom trawl surveys from 1977-1980 by both length and geographic area. Juveniles 6-25 cm ate primarily polychaetes and crustaceans. Polychaete prey included *Ampharete arctica*, *Ophelia* sp. and Sigalionidae. Crustacean prey included amphipods (*Unicola irrorata*, Oedicerotidae) and decapods (*Crangon septemspinosa*). Large juveniles/small adults 26-30 also preyed primarily on polychaetes (*Spiophanes bombyx*, Nephtyidae) and crustaceans (amphipods, including *Unicola irrorata* and *Dulichia* sp.; the decapod *Crangon septemspinosa*); nemertians (phylum Rhynchocoela) were also significant in the diet. Adults ≥ 31 cm consumed primarily polychaetes and crustaceans, as well as tube anemones. Polychaete prey including mostly *Spiophanes bombyx*, but also *Drilonereis* sp. Crustacean prey was mostly amphipods, including *Leptocheirus pinguis*, *Ericthonius rubricornis,* and gammarids, including *Gammarus annulatus*. Of the geographic areas sampled, polychaetes were the most selected prey type on Georges Bank, followed by crustaceans. In southern New England and inshore north of Cape Hatteras, the most selected prey choice was crustaceans, followed by polychaetes. The decapod *Crangon septemspinosa* was only eaten in significant quantities inshore north of Cape Hatteras, while tube anemones were only important in southern New England.

A similar dietary analysis by Link *et al*. (2002) focused on flatfish of the northwest Atlantic taken during the NEFSC bottom trawl surveys from 1973-1998 for all seasons. In this study, juvenile and adult yellowtail flounder consumed primarily polychaetes, gammarid and other amphipods, and other benthic invertebrates. Unclassified amphipods and unidentified digested prey comprised 10% of the total diet. There were no significant ontogenetic shifts in diet across the 25-year time series.

Table 20 – Major prey items of yellowtail flounder

Life Stage	*Major prey*	*Location*
Juveniles, 6-25 cm	**Polychaetes**: *Ampharete arctica*, *Ophelia* sp., Sigalionidae **Crustaceans**: amphipods (*Unicola irrorata,* gammarids, Oedicerotidae), decapods (*Crangon septemspinosa*)	U.S. northeast continental shelf
Large juveniles/small adults, 26-30 cm	**Nemerteans; Polychaetes**: *Spiophanes bombyx*, Nephtyidae; **Crustaceans**: amphipods (*Unicola irrorata, Dulichia* sp., gammarids), decapods (*Crangon septemspinosa*)	U.S. northeast continental shelf
Adults, $\geq$ 31 cm	**Cnidarians**: tube anemones (Ceriantharia); **Polychaetes**: *Spiophanes bombyx*, *Drilonereis* sp.; **Crustaceans**: amphipods (*Leptocheirus pinguis*, *Ericthonius rubricornis*, *Gammarus annulatus*, gammarids)	U.S. northeast continental shelf

3.10.3 Peak spawning

Information on the spawning periods of yellowtail flounder (*Limanda ferruginea*) comes from the EFH Update Memo and EFH Source Document (Essential Fish Habitat Source Document Update Memo: Yellowtail Flounder, *Limanda ferruginea*, Life History and Habitat Characteristics, 2006; Johnson *et al*. 1999, and references therein).

Spawning generally occurs from March through August at temperatures of 5-12^{o}C (Fahay 1983). Collections from the MARMAP ichthyoplankton surveys (1977-1987) showed little or no spawning activity during February. By March and April, eggs appeared on the continental shelf off **New Jersey and Long Island, on Georges Bank, northwest of Cape Cod**, and on Browns Bank. The distribution and abundance of eggs expanded in **southern New England** in May. On **Georges Bank**, the distribution and abundance of eggs expanded in June and declined thereafter; spawning ended in August. Eggs were found in the **Gulf of Maine** from April to September. The densest egg concentrations occurred on the northeast and southwest part of **Georges Bank, west from Nantucket Shoals to New Jersey, northwest of Cape Cod along western Gulf of Maine**, and off southwest Nova Scotia. *Peak* abundances were from April to June.

During the **Georges Bank** GLOBEC ichthyoplankton surveys (1995-1999), yellowtail eggs were found in all months sampled (excluding January). They were most abundant at depths > 60 m, especially along the **Northeast Peak**, all regions of the **Southern Flank**, as well as the **Great South Channel**. Egg concentrations *peaked* in April and by May eggs extended into the **Southern Flank and central Georges Bank**. Fewer eggs were captured in June and even less in July.

3.11 Acadian redfish

3.11.1 Supplementary table

Table 21 – Summary of habitat information for redfish

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***

Life Stage	***Habitat***	***Depth (m)****	***Temperature (ºC)****	***Salinity (ppt)****
Larvae	Pelagic, in water column	Present 41- >2000 on and off shelf, common 81-260	Present 2.5-13.5 on shelf, common 3.5-9.5	No information
Juveniles	Pelagic habitats during settlement	Present 16-86 inshore	Present 1.5-12.6 inshore	Present 30.6-34 inshore
	Benthic habitats with a wide variety of sediment types, primarily mud	Present 31-400 on shelf, common 101-200	Present 1.5-19.5 on shelf, common 2.5-9.5	Present 30.5-36.5 on shelf, common 32.5-34.5
	YOY on boulder reefs; also associated with cerianthid anemone patches when larger (also adults)	Present 400-600 off-shelf		
Adults	Benthic habitats with a wide variety of sediment types, primarily mud	Present 35-99 inshore	Present 1.9-11 inshore	Present 31.7-33.6 inshore
	Most abundant over silt, mud, or hard bottom, rare over sand	Present 21-500 on shelf, common 141-200	Present 0.5-21.5 on shelf, common 3.5-9.5 on shelf	Present 31.5-35.5 on shelf, common 32.5-34.5
	Boulders, deep-water corals, other epifauna	Present 400-600 off-shelf		

**   Depth to bottom*

*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Note: Redfish bear live young (no egg stage). Also, the information in this table refers primarily to the Acadian redfish (Sebastes fasciatus) – which is more common in U.S. waters of the GOM and on GB, but deep-water redfish (Sebastes mentella) are also caught in trawl surveys and are not distinguished from Acadian redfish in the database.

Sources of information:

- **Larvae**: Shelf depth and temperature ranges derived from MARMAP data in EFH Source Document Update Memo.
- **Juveniles and Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore trawl survey data in areas mapped as EFH (MA and ME). Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types based on GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data and information in EFH Update Memo. Off-shelf depth information taken from and Moore et al. (2003).

3.11.2 Prey species

The main source of information on the prey consumed by the juvenile and adult stages of redfish (*Sebastes* spp.) comes from the EFH Update Memo (Essential Fish Habitat Source Document Update Memo: Acadian redfish, *Sebastes* spp., Life History and Habitat Characteristics, 2004, and references therein).

Redfish larvae feed on copepods, euphausiids, and fish and invertebrate eggs. Redfish feed on the pelagic calanoid-euphausiid assemblage throughout ontogeny and prey size is proportional to fish size. Small larvae eat larval copepods and eggs. Larger larvae and fry eat copepods and euphausiids.

The most frequently observed food items from the 1973-2001 NEFSC food habits database for both juvenile and adult redfish up to 50 cm, were crustaceans, mostly euphausiids, decapods, and larvaceans (subphylum Urochordata). Bowman *et al*. (2000), using the NEFSC food habits database from 1977-1980, also noted the dominance of crustaceans in the diet of all size classes of redfish and in all geographic locations sampled (Georges Bank, Gulf of Maine, and Scotian Shelf). Juveniles < 21 cm fed primarily on copepods (*Calanus* sp.) and the euphausiid, *Meganyctiphanes norvegica*. Large juveniles/adults 21-40 cm consumed mostly copepods (*Calanus* sp.), the euphausiid, *Meganyctiphanes norvegica*, and decapods (the latter for fish 36-40 cm). Adults 41-45 cm fed primarily on amphipods (*Parathemisto* sp.) and the euphausiid, *Meganyctiphanes norvegica*. Silver hake was the only fish prey of note, being a significant prey item of adults 31-35 cm in the Gulf of Maine. The proportion of fish in the diet is positively correlated with body size and depth. Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult redfish include: euphausiids, (28%), crustacean shrimp (19%), pandalid shrimp (18%), silver hake (10%), other fish (8%), and decapod shrimp (6%).

Table 22 – Major prey items of redfish

Life Stage	*Major prey*	*Location*
Larvae	**Larval and adult copepods, euphausiids, fish and invertebrate eggs**	U.S. northeast continental shelf
Juveniles, very small adults, ≤ 25 cm	**Crustaceans**: copepods (*Calanus* sp.), euphausiids (*Meganyctiphanes norvegica*), decapods; **Larvaceans (subphylum Urochordata)**	U.S. northeast continental shelf
Adults, > 25 cm	**Crustaceans**: copepods (*Calanus* sp.), amphipods (*Parathemisto* sp.), euphausiids (*Meganyctiphanes norvegica*), decapods (pandalid shrimp, other shrimp); **Larvaceans (subphylum Urochordata); Fish**: silver hake, other fish	U.S. northeast continental shelf

3.11.3 Peak spawning

Information on the spawning periods of redfish (*Sebastes* spp.) comes from the EFH Update Memo (Essential Fish Habitat Source Document Update Memo: Acadian redfish, *Sebastes* spp., Life History and Habitat Characteristics, 2004, and references therein).

Nothing is known about redfish breeding behavior, but eggs are fertilized internally and develop into larvae within the oviduct and are released near the end of the yolk sac phase (Klein-MacPhee and Collette 2002). Copulation probably occurs from October to January, but fertilization is delayed until February to April (Ni and Templeman 1985; Klein-MacPhee and Collette 2002). **Larvae are released throughout the range of the adults**, perhaps in mid-water, from April to August; the release of larvae lasts for 3-4 months with a *peak* in late May to early June (Steele

1957; Kelly and Wolf 1959; Kelly *et al.* 1972; Kenchington 1984; Klein-MacPhee and Collette 2002).

MARMAP surveys (1977-1987) collected larvae on the continental slope **south and east of Georges Bank** and throughout the **Gulf of Maine** from March through October. Only a few larvae were collected in March on the **slope southeast of Georges Bank**. These larvae are possibly a mix of *S. fasciatus* and *S. mentella*. [Kenchington (1984) reviewed evidence that larvae collected along the continental slope on the Scotian Shelf in early spring are *S. mentella*.] In April, larvae were more abundant on the slope and the first larvae appeared in the **Gulf of Maine** and in the **Northeast Channel**. In May, larvae were more dispersed on the slope and in the **Gulf of Maine**. In June and July, larvae were randomly distributed throughout the **Gulf of Maine** and in the **Great South Channel**. Larval abundance *peaked* in August, and by September, larvae were scarce and were found only in the **Gulf of Maine**. Only a few larvae were collected in October.

3.12 Ocean pout

3.12.1 Supplementary table

Table 23 – Summary of habitat information for ocean pout

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Benthic habitats in sheltered nests, sometimes in rocky crevices	No information (Assume same as spawning adults)	No information (Assume same as spawning adults)	No information
Larvae	Not applicable	Not applicable	Not applicable	Not applicable
Juveniles	Benthic habitats composed primarily of sand, with some mud and mud-sand Variety of substrates, including shells, rocks, algae, soft sediments, sand, and gravel	Present 7-82 inshore, common 21-65 (MA) Present 1-400 on shelf, common 41-70 Found along the shore at low tide (BOF) Few YOY 1-10 (ME)	Present 1.3-20.2 inshore, common 2.5-10.5 (MA) Present 1.5-18.5 on shelf, common 2.5-11.5	Present 31.8-33.1 inshore Present 30.5-36.5 on shelf, common 31.5-33.5
Adults	Benthic habitats composed primarily of sand, with some mud-sand Also see juveniles Spawn on hard bottom in sheltered areas	Present 5-86 inshore, common 26-80 (MA) Present 1-400 on shelf, common 41-100 Occur 27-363 on SS and in Bay of Fundy, (juvs and adults) Spawn <50	Present 1.3-18 inshore, common 3.5-10.5 (MA) Present 0.5-17.5 on shelf, common 1.5-11.5 Prefer 6-9, can tolerate 0-16 Spawn 10 or less	Present 3.3-33 inshore Present 29.5-36.5 on shelf, common 31.5-33.5 Prefer 32-34, but enter rivers in deeper, more saline water

** Depth to bottom*

*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Note: This species has no larval stage - ocean pout hatch as juveniles

Sources of information:

- **Eggs**: All information from EFH Source Document.
- **Juveniles**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; inshore depth and temperature ranges ("common") from MA inshore trawl survey data in EFH Source Doc Update Memo. Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey data and USGS USSeabed sediment data and from information in EFH Source Document and Update Memo. Additional information from EFH Source Document and Update Memo, Klein-MacPhee and Colette (2002), and M. Lazzari (Maine DMR, pers. comm.).
- **Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; inshore depth and temperature ranges ("common") from MA inshore trawl survey data in EFH Source Doc Update Memo. Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey data and USGS USSeabed sediment data and from information in EFH Source Document and Update Memo. Additional information from EFH Source Document and Update Memo and Klein-MacPhee and Colette (2002).

3.12.2 Prey species

The main source of information on the prey consumed by the juvenile and adult stages of ocean pout (*Macrozoarces americanus*) comes from the EFH Update Memo and EFH Source Document (Essential Fish Habitat Source Document Update Memo: Ocean Pout, *Macrozoarces americanus*, Life History and Habitat Characteristics, 2004; Steimle *et al*. 1999, and references therein). Crustaceans and echinoderms are the major prey items for almost all sizes of ocean pout. Bowman *et al*. (2000) showed that ocean pout 1-10 cm in length fed exclusively on the amphipod *Parathemisto* sp. Ocean pout 11-20 cm ate mostly polychaetes, followed by crustaceans, while those 21-30 cm fed on ophiuroids and crustaceans in equal proportions, followed by polychaetes. Echinoderms (ophiuroids and sand dollars) were the major prey items in the diet for larger ocean pout. In terms of the geographic areas sampled in the Bowman *et al*. (2000) study, crustaceans were the major prey items in New England and on the Scotian Shelf, while echinoderms dominated on Georges Bank, in the Gulf of Maine, and inshore north of Cape Hatteras. Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult ocean pout include: echinoids (44%); asteroids (20%); and C*ancer* crabs (9%).

Sand dollars (*Echinarachnius parma*) are a primary prey in waters of coastal Maine, Georges Bank, southern New England, Block Island Sound, and Middle Atlantic Bight; brittlestars and mollusks are also eaten. In the northern Gulf of Maine, ocean pout switch from crustaceans during the spring to mollusks and polychaetes during the summer and fall; off southern Maine, ocean pout primarily ate bivalve mollusks. Jonah crabs (*Cancer borealis*) constituted 76% of ocean pout diet (by total prey weight) off Nantucket shoals, while sand dollars and amphipods were dominant prey on Georges Bank. Juveniles on the sandy, mid- to outer-continental shelf (approximately 35-95 m) of the New York Bight fed primarily on gammarid amphipods and polychaetes. This is consistent with data in the NEFSC food habits database Many benthic species preyed upon by ocean pout are commercially valuable, including sea urchins, scallops, juvenile American lobsters, and crabs. Fish are rarely eaten, although demersal sculpin eggs are consumed when encountered.

Table 24 – Major prey items of ocean pout

Life Stage	*Major prey*	*Location*
Juveniles, very small adults 1-30 cm	**Polychaetes**: Aphroditidae, Cirratulidae **; Crustaceans**: amphipods (*Parathemisto* sp., *Leptocheirus pinguis*, *Unciola irrorata*); **Mollusks**: Pectinidae; **Echinoderms**: ophiuroids (*Ophiopholis aculeata*)	U.S. northeast continental shelf, coastal, inshore
Adults	**Crustaceans**: amphipods (*Leptocheirus pinguis*, *Unciola irrorata*), decapods (*Cancer borealis, Hyas coarctatus*); **Mollusks**: *Cerastoderma pinnulatum*, *Placopectin magellanicus;* **Echinoderms**: ophiuroids (*Ophiura sarsi*), echinoids (*Echinarachnius parma*)	U.S. northeast continental shelf, coastal, inshore

3.12.3 Peak spawning

Information on the spawning periods of ocean pout (*Macrozoarces americanus*) comes from the EFH Source Document (Steimle *et al*. 1999 and references therein). Spawning occurs in the late summer through early winter (*peak* in September-October) with earlier *peak*s (August-October) in the south (Wilk and Morse 1979). Spawning occurs on hard bottom, sheltered areas (Bigelow and Schroeder 1953), including artificial reefs and shipwrecks, at depths of < 50 m and temperatures of 10°C or less (Clark and Livingstone 1982). These spawning/nesting habitats **include the saline parts of New England estuaries** (Jury *et al.* 1994).

3.13 Atlantic wolffish

Atlantic wolffish range as far north as Davis Strait, south regularly to Cape Cod, less often west along southern New England, and exceptionally to NJ (Rountree 2002). West of the Scotian shelf, their abundance is highest in the southwestern Gulf of Maine from Jeffreys Ledge to the Great South Channel. They are also abundant on the northeast peak of Georges Bank, and on Browns Bank. Smaller concentrations appear off SW Nova Scotia and throughout the central Gulf of Maine.

The wolffish is a benthic, cold-water fish that changes its depth distribution seasonally to maintain a narrow temperature range (see Kulka et al. 2004, Keats et al. 1985, Scott 1982a, Nelson and Ross 1992 for information about their distribution in different regions and season). Distribution by depth was evaluated in the status review document. It should be noted that trawl gear is not very suitable for catching wolffish in rocky habitats. Recreational catches of wolffish in the party and charter data are greatest in the southwestern Gulf of Maine and in the Great South Channel, as well as in shallower water (<100 m) north of Closed Area I, on the northern edge of Georges Bank, and on Nantucket Shoals.

3.13.1 Prey species

Atlantic wolffish feed almost exclusively on hard-shelled benthic invertebrates such as mollusks, crustaceans and echinoderms (Rountree, 2002). Wolffish stomach contents include sea urchins, whelks, cockles, sea clams, brittle stars, crabs, scallops and other shellfish in addition to an occasional redfish (Rountree, 2002; Templeman, 1985). As an apex predator in the kelp forest ecosystem (Steneck et al. , 2004), the Atlantic wolffish is believed to be a key player in the regulation of the density and spatial distribution of lower trophic level organisms such as green sea urchins, crabs, and giant scallops (O'Dea and Haedrich, 2002). Although young Atlantic wolffish eat primarily echinoderms, mature wolffish eat mollusks and crustaceans as well as echinoderms. Travel between shelters and feeding grounds occurs during feeding periods as evidenced by crushed shells and debris observed in the vicinity of occupied shelters (Rountree, 2002; Pavlov and Novikov, 1993). Fasting does occur for several months, coincident with teeth replacement, spawning and nest guarding (Rountree, 2002).

3.13.2 Habitat associations and spawning

Rocky, nearshore habitats are plentiful in the Gulf of Maine and appear to provide critical spawning habitat for Atlantic wolffish. Auster and Lindholm (2005) analyzed data collected during submersible (July 1999) and ROV surveys (May-September 1993-2003) of deep boulder reefs in the Stellwagen Bank National Marine Sanctuary at depths of 50-100 meters. Nineteen single and paired Atlantic wolffish were observed in 110 hours of observation. All used crevices under and between boulders on deep boulder reefs. Shell debris from bivalves and crustaceans was scattered at crevice entrances, evidence of "central place foraging activities."

Based on the depth distribution information from the NEFSC trawl surveys in the Gulf of Maine region, the adults move into slightly shallower water in the spring where they have been observed with and without egg masses inhabiting shelters in deep boulder reefs in depths between 50 and 100 meters. Once they have finished guarding the eggs and resume feeding, adults move into deeper water where they have been collected over a variety of bottom types (sand and gravel, but not mud). Juvenile wolffish are found in a much wider variety of bottom habitats.

Similar associations with nearshore rocky spawning habitats have been observed in the Gulf of St. Lawrence and Newfoundland. However, the collection of "aggregations" of Atlantic wolffish eggs in bottom trawls fishing in 130 meters of water on LeHave Bank (Scotian Shelf) in March 1966 (Powles 1967; Templeman 1986) indicates that spawning is not restricted to nearshore habitats, and may not be restricted to rocky habitats.

In summary, attempts to relate catches of Atlantic wolffish in bottom trawl surveys to substrate types are of limited value and somewhat contradictory, but the data indicate that the juveniles do not have strong habitat preferences, and that adults are more widely distributed over a variety of bottom types once they leave their rocky spawning grounds.

3.14 Silver hake

3.14.1 Supplementary table

Table 25 – Summary of habitat information for silver hake

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Pelagic, in water column	Common 41-200 on shelf Present 1-1500 on and off shelf	Collected 14.8-21.4 (NBay) and 13-22 (MAB) Present 4.5-26.5 on and off shelf, common 5.5-23.5	No information
Larvae	Pelagic, in water column	Present 1-1500 on and off shelf Common 41-140 on shelf	Collected 12-22.4 (NBay) Present 4.5-26.5 on and off shelf, common 9.5-17.5	No information
Juveniles	Pelagic habitats (at night) Benthic habitats associated with mud, sand, and sand-mud mixtures Found mostly on flat sand, also sand wave crests, shells and depressions created by benthic organisms (MAB/SNE) YOY more abundant on silt-sand with amphipod tubes (NYB/MAB)	Present 5-99 inshore, common 41-80 (MA), 10-25 (RBay), 12-26 (CBay), and at 11-22 (DBay) Present 1- >500 on and off shelf, common 41-400 YOY most abundant 55 (MAB)	Present 0.2-22 inshore, common 1.5-11.5 (MA), 4.5-21.5 (RBay), 7-13 (CBay), and 5-16 (DBay) Present 0.5-22.5 on and off shelf, common 4.5-10.5	Present 13.4-36 inshore, common 26.5-33.5 (RB) and 26-33 (DB) Present 19.5-36.5 on and off shelf, common 32.5-34.5
Adults	Pelagic habitats (at night) Benthic habitats associated with mud, sand, and sand-mud mixtures Juvs/adults most abundant on mud and mud-sand (LIS) Found mostly on flat sand, also sand wave crests, shells and depressions created by benthic organisms (MAB/SNE)	Present 6-99 inshore, common 36-80 (MA) and at min 10 (DBay) Present 1- >500 on and off shelf, common 121-500 Prefer 40-200 (GB), 60-100 (MAB) Limited inshore spawning	Present 1.3-18 inshore, common 4.5-11.5 (MA) and at max 16 (DBay) Present 1.5-21.5 on and off shelf, common 5.5-13.5	Present 24-36 inshore, common 26.5-33.5 (RB) and 24-30 (DB) Present 31.5-36.5 on and off shelf, common 33.5-34.5

** Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Sources of information:

- **Eggs and Larvae**: Shelf and slope depth and temperature ranges derived from MARMAP data in EFH Source Document (2nd ed.), other information obtained from EFH Source Doc (2nd ed.).
- **Juveniles**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; depth, salinity, and temperature ranges ("common") from analysis of MA, Raritan Bay, Delaware Bay, and Chesapeake Bay trawl survey data in EFH Source Doc (2nd ed.) and Morse (2000). Continental shelf and slope: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFCS trawl survey data and USGS USSeabed sediment data and information in EFH Source Doc (2nd ed.). Other information from EFH Source Document (2nd ed.)
- **Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; depth, salinity, and temperature ranges ("common") from analysis of MA, Raritan Bay, and Delaware Bay trawl survey data in EFH Source Doc (2nd ed.) and Morse (2000). Continental shelf and slope: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFCS trawl survey data and USGS USSeabed sediment data, and information in EFH Source Doc (2nd ed.). Other information from EFH Source Document (2nd ed.)

3.14.2 Prey species

The main source of information on the prey consumed by the juvenile and adult stages of silver hake (*Merluccius bilinearis*) comes from the EFH Source Document (Lock and Packer 2004, and references therein). Variations in diet in diet of silver hake are dependent upon size, sex, season, migration, spawning, and age with size having the most influence on diet. Silver hake larvae feed on planktonic organisms such as copepod larvae and younger copepodites. The diet of young silver hake consists of euphausiids, shrimp, amphipods, and decapods. All silver hake are ravenous piscivores that feed on smaller hake and other schooling fishes such as young herring, mackerel, menhaden, alewives, sand lance**,** or silversides, as well as crustaceans and squids.

The 1973-2001 NEFSC food habits database for silver hake generally confirms previous studies. Several other studies, such as Garrison and Link (2000) and Tsou and Collie (2001a, b) use the same database, although the years differ. Garrison and Link (2000) found that small (< 20 cm) silver hake consumed large amounts of euphausiids, pandalids, and other shrimp species. The diet of medium sized (20-50 cm) silver hake consisted of fishes, squids, and shrimp taxa. The diet of large (> 50 cm) silver hake consisted of over 50% fish, including Atlantic herring, clupeids, Atlantic mackerel, and other scombrids. A higher proportion of cephalopods, sand lance, and amphipods are present in the diets of silver hake that occupy southern habitats (Southern Atlantic Bight, Mid- Atlantic Bight, Southern New England). Silver hake of northern regions (Gulf of Maine, Georges Bank, Scotian Shelf) prey more heavily on pelagic fishes, euphausiids, and pandalid shrimps. For example, euphausiids make up 25% of the diet for silver hake of the Gulf of Maine and 7.2% for the Middle Atlantic Bight. Atlantic herring comprise 0.2% of the Middle Atlantic Bight diet and 12.9% of the Georges Bank diet. Squids (*Loligo* sp. and cephalopods), sand lance, and butterfish accounted for 5-10% of silver hake diets in the

Middle Atlantic Bight and Southern New England compared to less than 1% in the Gulf of Maine and Southwestern Nova Scotian Shelf regions. Other studies confirm that silver hake is a major piscivore on Georges Bank, with an ontogenetic shift in diet towards increased piscivory.

Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult silver hake include: other fish (16%), Atlantic herring (9%), crangonids (8%), silver hake (8%), clupeids (7%), and decapod crabs (6%).

Bowman (1984) studied samples collected from 8 NEFSC Marine Resources Monitoring, Assessment, and Prediction (MARMAP) bottom trawl surveys conducted by NMFS between March 1973 and November 1976. These surveys were concentrated in the Middle Atlantic, Southern New England, and Georges Bank. It was found that 80% of the diet by weight was fish, 10.2% crustaceans, and 9.2% squid. Euphausiids consisted mainly of *Meganyctiphanes norvegica* and *Euphausia*. Decapod groups included Crangonidae (*Crangon septemspinosa* and *Sclerocrangon boreas*), Pandalidae (*Dichelopandalus leptocerus* and *Pandulus borealis*), and Pasiphaedae (*Pasiphaea multidentata*), as well as other unidentifiable decapods, which were mostly shrimp. Amphipods present in the stomachs of silver hake were mainly from the Ampeliscidae (*Ampelisca agaxxize, A. spinipes, A. vadorum*, and *Byblis serrata*), Oedicerotidae (*Manoculodes edwardsi* and *M. intermedius*), and Hyperiidea families. Other crustacean groups included the Mysidacea, Cumacea, and Copepoda. Additional stomach contents that were identified include cephalopods (*Loligo pealei* and *Rossia*), Polychaeta, and miscellaneous organisms such as Echinodermata, and Chaetognatha. The study also found that silver hake measuring less than 20 cm fork length (FL) ate mostly crustaceans, while those that were greater than 20 cm FL ate mostly fish and squid. Silver hake 3-5 cm FL contained the largest percentage of smaller crustacean forms, such as amphipods and copepods. Fish 6-20 cm FL ate decapods, euphausiids, and mysids.

Bowman (1984) found Cephalopoda to be another important prey group of silver hake. Fish in Southern New England ate the largest quantities of squid, 13.7% by weight. Squid comprised 6.7% of the silver hake diet of Georges Bank and 4.3% of the diet for Middle Atlantic. The percentage of euphausiids and squid in the diet tends to increase at deeper bottom depths, while the percent weight of fish in the diet shows a corresponding decrease. The trend is that fish sampled at deeper depths will have less food on average in their stomachs. Availability of prey is probably one of the most important factors in determining what type and how much food silver hake eat.

Cannibalism is common among silver hake. Conspecific juveniles contribute more than 10% to the adult diet and more than 20% to the total diet.Cannibalism can account for more than 50% of predation rates on Georges Bank, and was observed to be especially important to silver hake in the spring. Cannibalism is most common in adult silver hake, although it can occur at the early juvenile stage.

Migration results in seasonal and yearly variations in silver hake diet. The diet changes from fish in the spring and autumn to fish, crustaceans, and mollusks during the summer. Small fish

26-55 mm consume more food in October and November, while larger fish 86-115 mm experience increased food consumption by January. Tsou and Collie (2001a) used the NMFS food-habits database to identify trophic relationships for silver hake on Georges Bank for years 1978-1992. It was discovered that more fish were consumed in the autumn with herring being the major prey item during that season.
In terms of sex differences, male diets have the largest percentage of crustaceans, while female diets have the largest percentage of fish and squid. Crustaceans constitute 48% of the total weight of all prey in the diet of male silver hake. Fish consumption is half that of crustaceans and consists of mainly myctophids and other silver hake. Crustaceans rank highest in frequency of occurrence in the diet of female silver hake; however, weight contribution is less for males. Fish prey represent 53% of the female silver hake diet. Females generally consume twice the amount by weight of fish prey as males. The noted differences between the sexes in prey selection are associated with size. Because females are larger, hence faster, they are able to consume larger, highly mobile prey such as fish and squid. Males on the other hand tend to be smaller at age and therefore concentrate much of their feeding activity on crustaceans, which are abundant and easily obtained. After the age of 5, females constitute over 70% of the silver hake population, so it is expected that the diet of older silver hake will consist of larger prey.

Diet also differs between the northern and southern stocks. The northern stock primarily consumes euphausiids, Atlantic herring, silver hake, and other fish, while the southern stock consumes crangonid shrimp, squids, cephalopods, and sand lance. *Illex* sp. and *Loligo* sp. of squid are found in the diet of silver hake that live in southern habitats (Garrison and Link 2000).

For inshore diet studies, see Table, below.

Table 26 – Major prey items of silver hake

Life Stage	***Major prey***	***Location***
Larvae	**Copepod larvae and younger copepodites**	U.S. northeast continental shelf
Juveniles, ≤ 22 cm	**Crustaceans**: copepods, amphipods (Ampeliscidae, including *Ampelisca agaxxize, A. spinipes, A. vadorum*, *Byblis serrata*; Oedicerotidae, including *Manoculodes edwardsi*, *M. intermedius*; Hyperiidea), cumaceans, decapods (Crangonidae, including *Crangon septemspinosa*, *Sclerocrangon boreas*; pandalid shrimp, including *Dichelopandalus leptocerus*, *Pandulus borealis*; Pasiphaedae, including *Pasiphaea multidentata*), euphausiids (*Meganyctiphanes norvegica*, *Euphausia*), mysids	U.S. northeast continental shelf
Larger juveniles/adults, ≥ 20 cm	**Crustaceans**: copepods, amphipods (Ampeliscidae, including *Ampelisca agaxxize, A. spinipes, A. vadorum*, *Byblis serrata*; Oedicerotidae, including *Manoculodes edwardsi*, *M. intermedius*; Hyperiidea), cumaceans, decapods (Crangonidae, including *Crangon septemspinosa*, *Sclerocrangon boreas*; pandalid shrimp, including *Dichelopandalus leptocerus*, *Pandulus borealis*; Pasiphaedae, including *Pasiphaea multidentata*; crabs), euphausiids (*Meganyctiphanes norvegica*, *Euphausia*), mysids; **Mollusks**: squids (*Loligo* sp., *Rossia*); **Fish**: Atlantic herring, other clupeids, Atlantic mackerel, other scombrids, sand lance, butterfish, silversides, silver hake	U.S. northeast continental shelf
	Crustaceans: copepods, amphipods (*Leptocheirus pinguis*), decapods	Block Island

Life Stage	***Major prey***	***Location***
	(*Crangon septemspinosa*), mysid shrimp (*Neomysis americana*); **Mollusks**: squid; **Fish**: bay anchovy, sand lance, juvenile silver hake	Sound, RI (Smith 1950)
	Polychaetes: (*Glycera* sp.); **Crustaceans**: amphipods (*Ampelisca* sp.**,** *Leptocheirus pinguis*), decapods (*Crangon septemspinosa*), mysids (*Neomysis americana*, *Heteromysis Formosa*)	Long Island Sound (Richards 1963)
Mostly juveniles	**Crustaceans**: amphipods (*Gammarus lawrencianus*, *Ampelisca abdita*), decapods (*Crangon septemspinosa*), mysid shrimp (*Neomysis americana*); **Fish**: juvenile silver hake, Atlantic menhaden, anchovies	Hudson-Raritan estuary (Steimle *et al*. 2000)
Adults	**Crustaceans**: amphipods, decapods (*Crangon septemspinosa*), mysid shrimp; **Fish**: juvenile silver hake, blueback herring, silversides	New Jersey surf zone (Schaefer 1960)

3.14.3 Peak spawning

Information on the spawning periods of silver hake (*Merluccius bilinearis*) comes from the EFH Source Document (Lock and Packer 2004, and references therein).

Silver hake eggs and larvae have been collected in all months on the continental shelf in U.S. waters, although the onset of spawning varies regionally (Bigelow and Schroeder 1953; Marak and Colton 1961; Sauskan and Serebryakov 1968; Fahay 1974; Morse *et al*. 1987; Waldron 1988; Berrien and Sibunka 1999). The primary spawning grounds most likely coincide with concentrations of ripe adults and newly spawned eggs. These grounds occur **between Cape Cod, Massachusetts, and Montauk Point, New York** (Fahay 1974), on the **southern and southeastern slope of Georges Bank** (Sauskan 1964) and the **area north of Cape cod to Cape Ann**, Massachusetts (Bigelow and Schroeder 1953).

Spawning begins in January along the **shelf and slope in the Middle Atlantic Bight**. During May, spawning proceeds north and east to **Georges Bank**. By June spawning spreads into the **Gulf of Maine** and continues to be centered on **Georges Bank** through summer. In October, spawning is centered in **southern New England** and by December is observed again along the shelf and slope in the **Middle Atlantic Bight**. *Peak* spawning occurs May to June in the southern stock and July to August in the northern stock (Brodziak 2001). Over the U.S. continental shelf, significant numbers of eggs are produced beginning in May. Numbers increase through August and decline rapidly during September and October (Berrien and Sibunka 1999).

Silver hake eggs were found throughout the area surveyed during the NEFSC MARMAP ichthyoplankton surveys. They were most abundant in the deeper parts of **Georges Bank** (> 60 m) and the shelf off **southern New England**. Eggs were captured in all months of the year. From January to March, eggs occurred in small numbers in the deep waters of the **Middle Atlantic Bight**. By April, the occurrence of eggs extended eastward along the **southern edge of Georges Bank** and the total number of eggs increased slightly. During May and June the catches of eggs extended into the shelf and into nearshore waters of the **Middle Atlantic Bight and southern New England areas**. Some eggs were captured in the **western part of the Gulf of Maine**. By July and August the center of abundance had shifted east onto **Georges Bank with southern New England and the Gulf of Maine** continuing to show some catches of eggs. In September and October the occurrences of eggs began to decline with centers of abundance still on **Georges Bank** and extending into **southern New England**. Few eggs were captured in November or December, but those that were occurred in deeper waters of the **Middle Atlantic Bight**.

3.15 Red hake

3.15.1 Supplementary table

Table 27 – Summary of habitat information for red hake

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Pelagic, in water column	No information	No information	No information
Larvae	Pelagic, in water column	Present 1-1500 on shelf, common 21-120 Found 10-200 Most abundant 40-120 (MAB)	Present 7.5-23.5 on shelf, common 11.5-20.5 8-23, most 11-19 (MAB, Aug-Sept)	No information
Juveniles	Pelagic habitats during settlement Benthic habitats with substrates composed of mud, sand, and mud-sand mixtures YOY in depressions on open seabed and associated with eel grass and macroalgae Shelter is critical for older juveniles (e.g., shells, biogenic structure, bottom depressions, inside live scallops)	Present 4-99 inshore, common 26-65 (MA), 10-24 (RB), min 7 (DB), min 13 (CB) Present 1-500 on shelf, common 1-80 YOY 1-10 (ME)	Present 0.4-25 inshore, common 2.5-11.5 (MA), min 4.5, max 21.5 (RB), 4.5-12.5 (DB), 4-14 (CB) Present 1.5-22.5 on shelf, common 3.5-17.5	Present 1-36 inshore, common 26.5-33.5 (RB), 6.5-30.5 (DB), 22-32 (CB) Present 28.5-36.5 on shelf, common 31.5-33.5
Adults	Benthic habitats with substrates composed of mud, sand, and mud-sand mixtures Most common on soft sediments or shell beds, much less common on gravel or hard bottoms	Present 6-99 inshore, common 21-75 (MA) Present 1->500 on shelf, common 61-300 Present 400-750 off-shelf	Present 1.3-19.7 inshore, common 4.5-10.5 (MA) Present 1.5-21.5 on shelf, common 5.5-12.5 Spawn 5-10	Present 23-34.5 inshore Present 30.5-36.5 on shelf, common 32.5-34.5

** Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

<u>Note</u>: Red hake eggs were not differentiated from eggs of spotted and white hake in MARMAP survey.

Sources of information:

- **Larvae**: Depth and temperature ranges for shelf derived from MARMAP survey data and other information in EFH Source Doc (2nd ed).
- **Juveniles**: <u>Inshore</u>: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; depth, temperature, and salinity ranges ("common") based on MA and Raritan Bay trawl survey data in EFH Source Document Update Memo, Delaware Bay trawl survey data in Morse (2000), and Chesapeake Bay trawl survey data in Geer (2002). <u>Continental shelf</u>: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data and from information in EFH Update Memo. Other information on depth (for YOY juveniles) provided by M. Lazzari (Maine DMR, pers. comm.).
- **Adults**: <u>Inshore</u>: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; depth and temperature ranges ("common") based on MA trawl survey data in EFH Source Document. <u>Continental shelf</u>: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data and from information in EFH Source Doc Update Memo. Other information taken from EFH Update Memo and Haedrich and Merrett (1988).

3.15.2 Prey species

The main source of information on the prey consumed by the juvenile and adult stages of red hake (*Urophycis chuss*) comes from the EFH Update Memo (Essential Fish Habitat Source Document Update Memo: Red Hake, *Urophycis chuss*, Life History and Habitat Characteristics, 2004, and references therein). Larvae prey mainly on copepods and other micro-crustaceans. Juvenile red hake commonly prey on small benthic and pelagic crustaceans, including larval and small decapod shrimp and crabs, mysids, euphausiids, and amphipods. Based on the NEFSC food habits database (1973-2001), the primary prey items of juvenile hake ($\leq$ 20 cm) were amphipods, decapods, euphausiids, and polychaetes. Larger juveniles/small adult hake (21-40 cm) consumed mostly decapods and gadids, with each making up approximately 23% of the diet. Other major prey included amphipods, euphausiids, squids, and other fish. Bowman *et al*. (2000), using the NEFSC food habits database from 1977-1980, showed that the principal prey items of juveniles (< 26 cm) were polychaetes, amphipods (*Pontogeneia inermis*, *Leptocheirus pinguis*), decapods (*Crangon septemspinosa*, pagurid crabs, *Dichelopandalus leptocerus*), euphausiids (*Meganyctiphanes norvegica*), and fish (silver hake, searobins). Garrison and Link (2000) conducted a multivariate analysis on NEFSC diet data from over 12,000 red hake. The amount of fish consumed increased as the fish size increased. The diet of juvenile red hake < 20 cm consisted mainly of decapod shrimp (Crangonidae, Pandalidae), euphausiids, gammarid and other amphipods, and polychaetes. Larger juvenile/adult hake 20-50 cm consumed fish, decapod shrimp (Pandalidae), and euphausiids. In the Middle Atlantic Bight, amphipods, small decapods (e.g., the shrimp *Crangon septemspinosa*), and polychaetes are important prey of juveniles, but dominant prey can change seasonally and include copepods and chaetognaths.

The NEFSC food habits database from 1973-2001 shows that adult red hake > 40 cm fed primarily on fish (gadids, clupeids, and unidentified), followed by decapods and euphausiids. Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult red hake include: other fish (15%), pandalid shrimp (11%), euphausiids (11%), crustacean shrimp (9%), and silver hake (7%). Bowman *et al*. (2000), using the NEFSC food habits database from 1977-1980, showed that the principal prey items of adults were amphipods (*Leptocheirus pinguis*), euphausiids (*Meganyctiphanes norvegica*), decapods (*Dichelopandalus leptocerus*; the crab *Cancer irroratus* for hake > 35 cm, the shrimp *Pandalus borealis* for hake > 45 cm), mollusks (bivalves, squids), and fish (sand lance, silver hake). In the Garrison and Link (2000) study mentioned previously, fish such as clupeids and silver hake, decapod shrimp (Pandalidae), and euphausiids were important prey for large hake > 50 cm.

Bowman *et al*. (2000), using the NEFSC food habits database from 1977-1980, also enumerated diets from six principal offshore areas (offshore of Cape Hatteras, Middle Atlantic, Southern New England, Georges Bank, Gulf of Maine, and Scotian Shelf) and two inshore areas (inshore north of Cape Hatteras and inshore south of Cape Hatteras). Combined percentages of crustaceans, fish, and mollusks made up 70-80% of the total food composition for the Gulf of Maine, Scotian Shelf, and Georges Bank regions. In the Southern New England, Middle Atlantic, and inshore north of Cape Hatteras regions, diet composition was evenly divided among the three categories of mollusks, crustacean, and fish. Crustaceans and fish were also heavily consumed in Middle Atlantic and inshore areas. Garrison and Link (2000) showed that fish prey were generally more important in northern habitats. Euphausiids and pandalid shrimps typically accounted for > 10% of the diets on Georges Bank, the Gulf of Maine, and the southwest Scotian Shelf., and generally were < 5% of the diets in the Mid-Atlantic Bight and southern New England. Decapod larvae (8.5%), crangonid shrimp (9.1%), and C*ancer* crabs (8.7%) were important prey in the Mid-Atlantic Bight, while they accounted for < 1% of diets in the Gulf of Maine and southwest Scotian Shelf.

Garrison and Link (2000) also observed annual and seasonal trends in the diet of red hake. Euphausiid shrimp made up 30% from 1976-1980, but declined to 2% in 1996-1997, while the occurrence of pandalid shrimp increased from 4-8% in the 1970s to 12-15% in the 1990s. During the spring, euphausiids were the dominant prey, while pandalids were consumed primarily during summer (33%). In winter months, cephalopods (28%) and *Cancer* crabs (11%) were the dominant prey. Red hake preyed upon silver hake particularly during the winter months (13.5%); predation on silver hake decreased by spring and summer and they contributed to only a small part of the diet by autumn (3%).

For the inshore areas north of Cape Hatteras, Bowman *et al*. (2000) noted that crustaceans (decapods such as *Dichelopandalus leptocerus, Crangon septemspinosa*) and fish (silver hake, Atlantic mackerel) were heavily preyed upon. Other major prey included polychaetes. For a list of other inshore diet studies of red hake, see the table, below.

Table 28 – Major prey items of red hake

Life Stage	*Major prey*	*Location*

Life Stage	***Major prey***	***Location***
Larvae	**Copepods and other micro-crustaceans**	U.S. northeast continental shelf
Juveniles, < 26 cm	**Polychaetes; Crustaceans**: amphipods (*Pontogeneia inermis*, *Leptocheirus pinguis*), decapods (*Crangon septemspinosa*, pagurid crabs, *Dichelopandalus leptocerus*, other pandalid shrimp), euphausiids (*Meganyctiphanes norvegica*); **Fish**: silver hake, searobins	U.S. northeast continental shelf
Larger juveniles/smaller adults, 20-50 cm	**Crustaceans**: amphipods, decapods (Pandalid shrimp), euphausiids; **Mollusks**: squids; **Fish**: gadids	U.S. northeast continental shelf
Adults, ≥ 26 cm	**Polychaetes; Crustaceans**: amphipods (*Leptocheirus pinguis*), decapods (*Dichelopandalus leptocerus*, *Pandalus borealis*, *Cancer irroratus*), euphausiids (*Meganyctiphanes norvegica*); **Mollusks**: bivalves, squids; **Fish**: gadids, clupeids, silver hake, sand lance	U.S. northeast continental shelf
	Polychaetes: (*Glycera* sp.)' **Crustaceans**: amphipods (*Ampelisca* sp.**,** *Leptocheirus pinguis*), decapods (*Crangon septemspinosa*), mysids (*Neomysis americana*, *Heteromysis Formosa*)	Long Island Sound (Richards 1963)
Mostly juveniles	Crustaceans**: amphipods (*Gammarus lawrencianus*), decapods (*Crangon septemspinosa*), mysid shrimp (*Neomysis americana*)**	Hudson-Raritan estuary (Steimle *et al*. 2000)
Juveniles	**Crustaceans**: calanoid copepods, amphipods (*Unciola* sp., *L. pinguis*, *Monoculodes* sp., and *Ericthonius* sp.), decapods (*Crangon septemspinosa*), mysids	Coastal New Jersey (Luczkovich and Olla 1983)
Mostly juveniles	**Nematodes; Crustaceans**: copepods, amphipods, isopods, decapods (*Crangon septemspinosa*), mysids (*Neomysis americana*); **Fish**	Central New Jersey (Rachlin and Warkentine 1988)

3.15.3 Peak spawning

Information on the spawning periods of red hake (*Urophycis chuss*) comes from the EFH Update Memo (Essential Fish Habitat Source Document Update Memo: Red Hake, *Urophycis chuss*, Life History and Habitat Characteristics, 2004, and references therein).

Major spawning areas occur on the **southwestern part of Georges Bank** and on the **continental shelf off southern New England and eastern Long Island**; however, a nearly ripe female was collected during April in **Chesapeake Bay** (Hildebrand and Schroeder 1928). Spawning adults and eggs are also common in the **marine parts of most coastal bays between Narragansett Bay, Rhode Island, and Massachusetts Bay**, but rarely in coastal areas to the south or north (Jury *et al.* 1994; Stone *et al.* 1994). Based on condition of the gonads from red hake collected in the **New York Bight**, spawning occurs at temperatures between 5-10°C from April through November (Wilk *et al.* 1990). Approximate spawning seasons for red hake are March through October for **Middle Atlantic Bight and Southern New England** and May through September for **Georges Bank and Gulf of Maine** (Link and Burnett 2001). In the **Gulf of Maine**, spawning may not begin until June with a *peak* during July to August (Dery 1988; Scott and Scott 1988). In the **New York Bight and on Georges Bank**, spawning red hake are most abundant in May to June (Collette and Klein-MacPhee 2002). Eklund (1988) reported a *peak* in their gonadosomatic index (GSI) during May to July and the presence of ripe eggs in June to July off **Delaware**.

Hatching occurs in 3-7 days during May and September (Able and Fahay 1998).

3.16 Offshore hake

3.16.1 Supplementary table

Table 29 – Summary of habitat information for offshore hake

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Pelagic, in water column	Present 21-1500, common 101-1500, on continental shelf and slope	Present 4.5-20.5, common 7.5-19.5, on continental shelf and slope	No information
Larvae	Pelagic, in water column	Present 21-1500, common 61-1500, on continental shelf and slope	Present 4.5-19.5, common 4.5-18.5, on continental shelf and slope	No information
Juveniles	Pelagic habitats (at night) Benthic habitats with substrates composed of mud, sand, and sand-mud mixtures	Present 21-500, common 201-500, on continental shelf and slope Found 200-750	Present 2.5-16.5, common 8.5-12.5, on continental shelf and slope	Present 31.5-36.5, common 34.5-36.5, on continental shelf and slope
Adults	Pelagic habitats (at night) Benthic habitats with substrates composed of mud, sand, and sand-mud mixtures	Present 11->500, common 201-500, on continental shelf and slope Found 200-750 Spawn 330-550	Present 3.5-16.5, common 6.5-12.5, on continental shelf and slope	Present 31.5-36.5, common 34.5-36.5, on continental shelf and slope

* *Depth to bottom*
** *Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Sources of information:

- **Eggs**: Shelf and off-shelf depth and temperature ranges derived from MARMAP data in EFH Source Doc Update Memo.
- **Larvae**: Shelf and off-shelf depth and temperature ranges derived from MARMAP data in EFH Source Doc Update Memo.
- **Juveniles**: Depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types based on GIS overlap analysis of NEFSC trawl survey data and USGS USSeabed sediment data; other information from Haedrich and Merrett (1988).
- **Adults**: Depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types based on GIS overlap analysis of NEFSC trawl survey data and USGS USSeabed sediment data; other information from EFH Source Document and Haedrich and Merrett (1988).

3.16.2 Prey species

The main source of information on the prey consumed by the juvenile and adult stages of offshore hake (*Merluccius albidus*) comes from the EFH Update Memo and EFH Source Document (Essential Fish Habitat Source Document Update Memo: Offshore Hake, *Merluccius albidus*, Life History and Habitat Characteristics, 2004; Chang *et al*. 1999, and references therein). Offshore hake feed on pelagic invertebrates, e.g. euphausiids and other shrimps, and pelagic fish, including conspecifics.

Data from the NEFSC food habits database (1973-2001) show that offshore hake fed mostly on fish (gadids, hakes, and other fish), squids, and euphausiids. Analysis of samples from the same dataset from 1973-1997 by Garrison and Link (2000) showed decapod shrimp to be the primary prey of small (< 20 cm) juvenile *M. albidus*. Larger juveniles/small adults (20-50 cm) fed primarily on euphausiids and unclassified fish. Large-sized offshore hake (> 50 cm) were primarily piscivorous, feeding heavily on silver hake, its congener. Euphausiid prey have been identified as *Meganyctiphanes* sp. and *Thysanoessa raschi*; decapod prey includes pandalid shrimp, *Pandalus* sp. and *Dichelopandalus* sp., and pelagic shrimp, *Pasiphaea* sp. Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult offshore hake include: silver hake (26%), other fish (20%), *Illex* squid (14%), and cephalopods (9%).

Table 30 – Major prey items of offshore hake

Life Stage	***Major prey***	***Location***
Small juveniles, < 20 cm	**Crustaceans**: decapod shrimp (pandalid shrimp, *Pandalus* sp. and *Dichelopandalus* sp.; pelagic shrimp, *Pasiphaea* sp.)	U.S. northeast continental shelf, slope
Larger juveniles/small adults, 20-50 cm	**Crustaceans**: euphausiids (*Meganyctiphanes* sp., *Thysanoessa raschi*); **Mollusks**: squid (*Illex* sp.); **Fish**: gadids, hakes (especially silver hake)	U.S. northeast continental shelf, slope
Large adults, > 50 cm	**Crustaceans**: euphausiids (*Meganyctiphanes* sp., *Thysanoessa raschi*); **Mollusks**: squid (*Illex* sp.); **Fish**: gadids, hakes (especially silver hake)	U.S. northeast continental shelf, slope

3.16.3 Peak spawning

Information on the spawning periods of offshore hake (*Merluccius albidus*) comes from the EFH Update Memo (Essential Fish Habitat Source Document Update Memo: Offshore Hake, *Merluccius albidus*, Life History and Habitat Characteristics, 2004, and references therein).

There is little information available on the reproductive biology of offshore hake. Spawning appears to occur over a protracted period or even continually throughout the year from the **Scotian Shelf through the Middle Atlantic Bight**. For example, in New England, Cohen *et al*. (1990) indicates that spawning occurs from April to July at depths ranging from 330-550 m. Eggs and larvae have also been collected off of **Massachusetts** from April through July (Marak 1967). Smith *et al*. (1980) reported that eggs and larvae were also present from April through June **south of New England** and in February and March **south of Long Island, NY**. Colton *et al*. (1979) indicated that while there was some uncertainty in the timing of offshore hake spawning in the **Mid-Atlantic Bight**, it appears to extend from June through September. This is supported by results from the **New York Bight** where Wilk *et al*. (1990) showed that while mean gonadosomatic indices (GSI) were highest in June and July, females in various stages of gonadal development were collected from spring through late fall.

Offshore hake eggs were collected as part of the NEFSC MARMAP ichthyoplankton surveys from 1978-1987. They were most abundant along the continental shelf from **eastern Georges Bank to the Middle Atlantic Bight just south of Delaware Bay and infrequently off Cape Hatteras**. Egg densities exceeded 10 per 10 m^2 during the first four years of the survey, but declined to less than 5 per 10 m^2 during the final five years, with the exception of 1984 (Berrien and Sibunka 1999). Eggs were collected in every month of the year, although the catch varied seasonally.

In January and February, eggs were sparsely distributed with small numbers collected from off **Georges Bank to Delaware Bay and Cape Hatteras**. From March through June, eggs were collected in larger numbers as density increased along the outer margin of the continental shelf with abundance highest from **east of Georges Bank to off the Hudson Canyon**, although small numbers were collected from **south of Delaware Bay to as far north as the Northeast Channel**. From July through September, the numbers of eggs dropped sharply and were irregularly distributed from southeast of **Georges Bank to Delaware Bay**. Abundance rose again in October with a distribution similar to that in April, ranging from the **Northeast Channel to the Mid-Atlantic Bight off the Hudson Canyon**. Abundance decreased again during November and December with a distribution generally similar to that in January and February.

4.0 Monkfish

4.1 Supplementary table

Table 31 – Summary of habitat information for monkfish

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Pelagic, in upper water column	18-40 (NJ) Collected within 1 meter of shore See larvae	Most at 10-20 Upper limit for normal development 17-18	No information
Larvae	Pelagic, in water column	Found in surf zone and near-shore habitats (NJ) Present 1-1500 on and off shelf, common 1-160 on shelf	Present 6.5-20.5 on shelf, common 8.5-17.5 on shelf	No information
Juveniles	Pelagic habitats during settlement Benthic habitats with substrates composed of mud,	Present 8-100 inshore, common 31-85 (MA) Present 1-1000 on and off shelf (YOY at 900),	Present 1.5-13 inshore, common 3.5-10.5 (MA) Present 1.5-24.5 on shelf, common 4.5-13.5	Present 31-33.6 inshore Present 29.5-36.5 on shelf, common 30.5-

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
	sand, and mixtures of mud and sand Also see adults	common 51-400 on shelf Common 91-182 (GOM)		36.5
Adults	Benthic habitats with substrates composed of mud, sand, and mixtures of mud and sand Found on hard sand, pebbly bottoms, gravel and broken shells, and soft mud Prefer clay and mud over sand and gravel (SS)	Present 8-84 inshore, common 21-65 (MA) Present 1-1000 on and off shelf, common 51-400 on shelf	Present 1.9-16.5 inshore, common 5.5-11.5 (MA) Present 0.5-21.5 on shelf, common 4.5-15.5	Present 30-34 inshore Present 29.5-36.5, common 33.5-35.5 on shelf

** Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Sources of information:

- **Eggs**: Depth information from EFH Source Document (2nd ed.) and Caruso (2002); temperature data from EFH Source Document (2nd ed.)
- **Larvae**: Shelf depth and temperature ranges derived from MARMAP survey data in EFH Source Document; other information from EFH Source Document (2nd ed.)
- **Juveniles**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; inshore depth and temperature ranges ("common") from MA trawl survey data in EFH Source Doc (2nd ed.). Continental shelf: sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data; depth, temperature, and shelf salinity ranges from NEFSC trawl survey data. Other depth information derived from EFH Source Document (2nd ed.) and Moore et al. (2003).
- **Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; inshore depth and temperature ranges ("common") from MA trawl survey data in EFH Source Doc (2nd ed.). Continental shelf: sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data; depth, temperature, and shelf salinity ranges from NEFSC trawl survey data. Other depth and substrate information derived from EFH Source Document (2nd ed.) and Moore et al. (2003).

4.2 Prey species

The main source of information on the prey consumed by the juvenile and adult stages of monkfish (goosefish) (*Lophius americanus*) comes from the EFH Update Memo (Essential Fish Habitat Source Document Update Memo: Goosefish, *Lophius americanus*, Life History and Habitat Characteristics, 2006, and references therein). Monkfish are opportunistic feeders; prey found in their stomachs include a variety of benthic and pelagic species. Diets can vary regionally and seasonally, depending on what is available as prey. Larger monkfish eat larger prey and often have empty stomachs. Monkfish eat spiny dogfish, *Squalus acanthias,* skates, *Raja* spp., eels, sand lance, Atlantic herring, Atlantic menhaden, *Brevoortia tyrannus*, smelt, *Osmerus mordax*, mackerel, *Scomber* spp., weakfish, *Cynoscion regalis*, cunner, tautog, *Tautoga onitis*, black sea bass, *Centropristis striata*, butterfish, pufferfish, sculpins, sea raven, *Hemitripterus americanus*, searobins, *Prionotus* spp., silver hake, *Merluccius bilinearis*, Atlantic tomcod, *Microgadus tomcod,* cod, *Gadus morhua*, haddock, *Melanogrammus aeglefinus*, hake, *Urophycis* spp., witch and other flounders, squid, large crustaceans, and other benthic invertebrates. They even have been known to prey on sea birds and diving ducks.

Larvae feed on zooplankton, including copepods, crustacean larvae, and chaetognaths. Pelagic YOY juveniles consume chaetognaths, hyyperiid amphipods, calanoid copepods, and ostracods. Small benthic juveniles (5-20 cm TL) start eating fish, such as sand lance (*Ammodytes* spp.), soon after they settle to the bottom, but invertebrates, especially crustaceans such as red (bristle-beaked) shrimp (*Dichelopandalus leptocerus*) and squid, can make up a large part of their diet. The consumption of invertebrates decreases among larger juveniles (20-40 cm TL) and monkfish > 40 cm TL (larger juveniles and adults) eat comparatively few invertebrates.

The 1973-2001 NEFSC food habits database showed that monkfish consumed primarily fish, as well as squids, and the type of prey consumed varied with the size of the monkfish. Gadids are always a dominant component, but small to medium size monkfish also consume relatively large amounts of clupeids and squid. Flatfish and scombrids also contribute significantly to the diets of larger monkfish. Bowman *et al*. (2000), using the same NEFSC food habits database, but only for the years 1977-1980, also found the same general trends in changing prey consumption with size, with the addition of skates being important in the diet of larger monkfish. Regionally, Bowman *et al*. (2000) showed that fish dominated the diet in the Mid-Atlantic, southern New England, Gulf of Maine, and on the Scotian Shelf, while squids, particularly *Illex*, dominated at inshore North of Cape Hatteras. Fish (including, and especially, skates) and squids co-dominated on Georges Bank. Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult monkfish include: other fish (32%); silver hake (6%) and Atlantic herring (5%).

Cannibalism (non-kin, inter-cohort) may be important and perhaps explains the apparent high mortality of smaller males although the reported occurrence of cannibalism is low. In 2001, only nine incidences of cannibalism were detected among 2160 stomachs examined (0.42%) by the NEFSC. All of the cannibals were females 63-105 cm TL, and the size of the prey was 45-49 cm.

Table 32 – Major prey items of monkfish

Life Stage	*Major prey*	*Location*
Larvae	**Zooplankton**: copepods, crustacean larvae, chaetognaths.	U.S. northeast continental shelf
YOY juveniles	**Zooplankton**: chaetognaths, hyperiid amphipods, calanoid copepods, ostracods.	U.S. northeast continental shelf
Juveniles 1-40 cm	**Mollusks**: squids; **Fish**: sand lance, silver hake, fourbeard rockling, witch flounder	U.S. northeast continental shelf

Life Stage	*Major prey*	*Location*
Large juveniles, small adults 41-50 cm	**Mollusks**: squids (*Illex* sp.); **Fish**: silver hake, flounders	U.S. northeast continental shelf
Adults > 50 cm	**Mollusks**: squids (*Illex* and *Loligo* sp.); **Fish**: e.g., spiny dogfish, skates, eels, sand lance, Atlantic herring, Atlantic menhaden, smelt, mackerel, weakfish, cunner, tautog, black sea bass, butterfish, pufferfish, sculpins, sea raven, searobins, silver hake, other hakes, Atlantic tomcod, cod, haddock, witch flounder, other flounders.	U.S. northeast continental shelf

4.3 Peak spawning

Information on the spawning periods of monkfish (goosefish) (*Lophius americanus*) comes from the EFH Update Memo (Essential Fish Habitat Source Document Update Memo: Goosefish, *Lophius americanus*, Life History and Habitat Characteristics, 2006, and references therein).

Spawning occurs from spring through early fall with a *peak* in May-June (Wood 1982; Armstrong *et al*. 1992) although pelagic individuals (larvae and juveniles) have been reported for all months of the year except December, suggesting that spawning occurs at some level for most months of the year **within the species' geographic range**. Regionally, goosefish has been reported to spawn in the early spring off the **Carolinas**, in May-July off of **New Jersey**, in May-June in the **Gulf of Maine**, and into September in Canadian waters (Scott and Scott 1988; Hartley 1995). *Peak* gonadosomatic indices (GSI) occurred in March-June for males and in May-June for females (Armstrong *et al*. 1992). Spawning locations are not well known but are thought to be on inshore shoals to offshore (Connolly 1920; Wood 1982; Scott and Scott 1988).

Eggs were only occasionally caught (N = 28) in the NEFSC MARMAP ichthyoplankton surveys from the Gulf of Maine to North Carolina. Eggs were not collected in **Sandy Hook Bay** by Croker (1965) and were only rarely found in **Long Island Sound** by Merriman and Sclar (1952) and Wheatland (1956). Egg veils were reported from late May through late July in waters (18-40 m depth) off of **Barnegat Light, New Jersey** (R.C. Chambers, NMFS/NEFSC/James J. Howard Marine Sciences Laboratory, unpublished data). Eggs have been reported in open coastal bays and sounds in low numbers (Smith 1898; Herman 1963; Caruso 2002).

5.0 Skates

5.1 Winter skate

5.1.1 Supplementary table

Table 33 - Summary of habitat information for winter skate

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	No information	No information	No information	No information
Larvae	Not applicable	Not applicable	Not applicable	Not applicable
Juveniles	Benthic habitats with sand and *gravel*	Present 4-81 inshore, common 6-25 (MA)	Present 0.1-21.8 inshore, common 8.5-16.5 (MA) and	Present 15-36 inshore, common at

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
	substrates Also see adults	Present 1-400 on shelf, common 11-80 Also see adults	3.5-13.5 (RB) Present 0.5-21.5 on shelf, common 1.5-17.5 Also see adults	min 15.5 (RB) Present 28.5-35.5 on shelf, common 31.5-33.5
Adults	Benthic habitats with sand and *gravel* substrates	Present 5-65 inshore, common 6-45 (MA), 7-19 (j/a DB)	Present 2.4-19.4 inshore, common 7.5-15.5 (MA), min 4.5 max 17.5 (j/a DB)	Present 27.2-36 inshore, common 20.5-34.5 (j/a DB)
	Sandy and gravelly bottoms, also on mud in Penobscot Bay (GOM) Most abundant on sand (j/a LIS)	Present 1-400 on shelf, common 31-60 Most abundant 46-64 (GOM), found 15-46 (SNE) and 33-113 (MAB), rare <2-7	Present 0.5-20.5 on shelf, common 1.5-16.5 Found 2-15 (southern NS to Cape Hatteras), 20 in summer to 1-2 in winter (coastal MA), 10-12 (MAB in winter)	Present 29.5-36.5 on shelf, common 31.5-33.5

* Depth to bottom
** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages

Note: As used in the analysis of sediment associations, the term "gravel" refers to all grain sizes above a diameter of 2 mm, i.e., any sediment coarser than sand, and therefore includes pebbles, cobbles, and even boulders

Sources of information:

- **Juveniles**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data for areas mapped as EFH; depth, temperature, and salinity ranges ("common") based on Raritan Bay and MA trawl survey data in EFH Source Document. Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; information on substrates derived from GIS overlap analysis of NEFSC survey and USGS USSeabed sediment data.
- **Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data for areas mapped as EFH; depth, temperature, and salinity ranges ("common") based on Raritan Bay, Delaware Bay, and MA trawl survey data in EFH Source Document. Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data in EFH Source Document; information on substrates from analysis of NEFSC survey and USGS USSeabed sediment data and from information in EFH Source Doc. All other information from EFH Source Document.

Note: Delaware Bay data were applied to juveniles and adults – winter skates caught during survey were not distinguished by life stage.

5.1.2 Prey species

The main source of information on the prey consumed by winter skate (*Leucoraja ocellata*) comes from the EFH Source Document (Packer *et al*. 2003 and references therein). Generally, polychaetes and amphipods are the most important prey items in terms of numbers or occurrence, followed by decapods, isopods, bivalves, and fishes. Hydroids are also ingested. In terms of weight, amphipods, decapods and fish can be most important; fish are especially prevalent in the larger winter skate. Bigelow and Schroeder (1953) reported rock crabs and squid as favorite prey, other items included polychaetes, amphipods, shrimps, and razor clams. The fishes that were eaten included smaller skates, eels, alewives, blueback herring, menhaden, smelt, sand lance, chub mackerel, butterfish, cunners, sculpins, silver hake, and tomcod.

McEachran (1973) studied skates collected from Nova Scotia to Cape Hatteras during 1967-1970; the following diet descriptions are from him and McEachran *et al*. (1976). *Nephtys* spp., *Nereis* spp., *Lumbrineris fragilis*, *Ophelia denticulata*, and maldanids (mostly *Clymenella torquata*) were the most abundant polychaetes in the Mid-Atlantic Bight and Georges Bank stomachs. *Nephtys* spp., *Pectinaria* sp., *O. denticulata*, and *Aphrodite hastata* were the most frequently consumed prey in the Gulf of Maine and on the Nova Scotian shelf. Haustoriids, *Leptocheirus pinguis*, *Monoculodes* sp., *Hippomedon serratus*, ampeliscids, *Paraphoxus* sp., and *Tmetonyx* sp. were the most frequently eaten amphipods over the survey area. *Crangon septemspinosa* was the most abundant decapod in the diet. *Cancer irroratus*, *Dichelopandalus leptocerus*, *Pagurus acadianus*, and *Hyas* sp. were consistently eaten but in small numbers. Among the minor prey items included *Cirolana* (= *Politolana*?) *polita*, which was the dominant isopod. Other isopods eaten included *Chiridotea tuftsi* and *Edotea triloba*, but they contributed little to the overall diet. The only identifiable bivalves eaten were *Solemya* sp. and *Ensis directus*. The most frequently eaten fish was sand lance, while yellowtail flounder and longhorn sculpin were occasionally eaten. Winter skate from Georges Bank had the most diverse diet and those from the Mid-Atlantic Bight the least diverse diet. There was no significant change in the diet with increase in skate size; however, the numbers of polychaetes gradually increased and amphipods gradually decreased with increasing skate size. The number of fish and bivalves also increased with predator size and the two taxa were a major part of the diet of skate > 79 cm TL. The ingestion of decapods was independent of skate size.

The 1973-1990 NEFSC food habits database for winter skate generally confirms the McEachran (1973) and McEachran *et al*. (1976) studies. Crustaceans made up > 50% of the diet for skate < 61 cm TL, while fish dominated the diet of skate > 91 cm TL. Overall crustaceans declined in importance with increasing skate size (includes both amphipods and decapods) while the percent occurrence of polychaetes increased with increasing skate size until the skate were about 81 cm TL. Amphipods occurred more frequently than decapods until the skates were > 71 cm TL. Among the most frequently occurring prey species for almost all sizes of skate included the decapods *C. septemspinosa* and *Cancer* and pagurid crabs, the isopod *Cirolana* (= *Politolana*?) *polita*, and sand lance. The following is a detailed description of the diet from the NEFSC food habits database broken down by winter skate size class.

For winter skate 21-30 cm TL, 74-84% of the diet consisted of crustaceans, with 38-43% of the diet consisting of identifiable amphipods. The most abundant amphipod species included *Unciola irrorata*, *Byblis serrata*, and *H. serratus*. Identifiable decapods made up 23-25% of the diet, most of which were species such as *C. septemspinosa* and *C. irroratus*. Identifiable polychaete species (9-13% of the diet) included *Ampharete arctica*. Identifiable isopod species (9% of the diet) included *Cirolana* (= *Politolana*?) *polita*. Nematodes, bivalves, and fish were included in the "other prey phyla" category (3-17% of the diet).

For skate 31-40 cm TL, 72-76% of the diet consisted of crustaceans, with 37-39% of the diet consisting of identifiable amphipods. Major amphipod species included *B. serrata*, *U. irrorata*, *H. serratus*, and several unidentified haustoriids. Identifiable decapods made up 17-23% of the diet, most of which were *C. septemspinosa* and *C. irroratus*. Identifiable polychaetes (12-17% of the diet) included *Scalibregma inflatum*, *L. fragilis*, and unidentified maldanids. Identifiable isopods (5-8% of the diet) included *Cirolana* (= *Politolana*?) *polita*. Miscellaneous items (6-9% of the diet) included nematodes and bivalves. Among the identifiable fish present in the diet (3-4%) were sand lance, yellowtail flounder, and hakes.

The percentage of crustaceans in the diet of winter skate 41-50 cm TL dropped to 62-69%, although identifiable amphipods still made up the major portion (33-35%) followed by decapods (14-22%). Identifiable polychaetes made up 19-23% of the diet; other prey species (including mollusca), 6-9% of the diet; identifiable isopods, 7% of the diet; and identifiable fish, 3-8% of the diet. All the major prey species (except for the lack of the polychaete *S. inflatum*) were similar to the 31-40 cm TL size class, with the additions of several more *Unciola* species, *L. pinguis* (an amphipod), unidentified pagurid crabs, and nephtyid polychaetes.

The percent occurrence of crustaceans in the diet of winter skate 51-60 cm TL dropped further, down to 53-54%, with identifiable amphipods making up only 26-32% of the overall diet. Some of the dominant identifiable amphipods included *Psammonyx nobilis*, unidentified oedicerotids, *H. serratus*, and unidentified haustoriids. Identifiable decapods made up only 9-12% of the diet; *C. septemspinosa* was again the dominant decapod prey, followed by *C. irroratus* and pagurid crabs. *Cirolana* (= *Politolana*?) *polita* was again one of the major identifiable isopods, which all together made up 7-12% of the diet. The percent occurrence of identifiable polychaetes continued to increase in the diet, up to 26-29%; several of the more numerous species present were in the genera *Nephtys* and *Nereis*. Identifiable fish also increased in the diet, up to 6-13%, with sand lance the dominant species. Other prey phyla, including bivalves and nematodes, accounted for 9-11% of the diet.

The percent occurrence of crustaceans in the diet continued to decline for winter skate 61-70 cm TL: down to 38-44%, with identifiable amphipods making up only 13-20% of the diet, while identifiable decapods made up 11-12%. Major amphipod species included *M. edwardsi*, *U. irrorata*, *H. serratus*, and unidentified haustoriids and oedicerotids. *C. septemspinosa* continued to be the dominant decapod prey, followed by *Cancer* and pagurid crabs. Identifiable isopods again made up 7-12% of the diet; *Cirolana* (= *Politolana*?) *polita* continued to be one of the major prey species. The percent occurrence of identifiable polychaetes in the diet increased, up to 28-32%; species in the genera *Nephtys* and *Nereis* were again dominant. The percent occurrence of identifiable fish in the diet continued to increase also, up to 11-24%, most of which were sand lance. Nine percent of the diet consisted of identifiable mollusks, with bivalves being dominant.

While the percent occurrence of crustaceans dropped to 29-36% for winter skate 71-80 cm TL, the percent occurrence of identifiable decapods was greater than the percent occurrence of amphipods: 11-13% versus 7-12%. The former were dominated by *C. septemspinosa*, *Cancer* and pagurid crabs, and *D. leptocerus*, while several haustoriid species and *U. irrorata* were some of the major amphipod prey. Identifiable isopods made up 8-9% of the diet, the dominant species continued to be *Cirolana* (= *Politolana*?) *polita*. Identifiable polychaetes (25-35% of the diet) included *L. fragilis* and several *Nephtys* and *Nereis* species. The percent occurrence of identifiable fish in the diet varied widely between the two sampling periods, from 16-36%, although sand lance was still the dominant species. Identifiable mollusks made up 9-10% of the diet, most of which were bivalves.

Fish as prey items became increasingly important for winter skate 81-90 cm TL. They made up 29-42% of the overall diet. As usual sand lance were the dominant fish prey, other species ingested included other skate, longhorn sculpin, and silver hake. Crustaceans in the diet declined to 19-30%. The major identifiable decapod species (8-11% of the diet) continued to be *C. septemspinosa* and *Cancer* and pagurid crabs as well as pandalid shrimp and *Ovalipes ocellatus*. The major identifiable amphipod species (3-8% of the total diet) were several haustoriid species. *Cirolana* (= *Politolana*?) *polita* was once again the dominant identifiable isopod (all isopods together made up 5-7% of the diet). Several *Nephtys* species were the major identifiable polychaetes ingested, all polychaetes together made up 22-28% of the diet. Bivalves, particularly of the familiy Solenidae, were the dominant identifiable molluscan prey ingested, with all mollusks together accounting for 7-17% of the diet.

Identifiable fish made up >50% of the diet of winter skate 91-100 cm TL. Sand lance was the overwhelming dominant, some of the minor fish prey included silver hake, herring, and butterfish. Crustaceans were down to 12-23% of the diet. Identifiable decapods made up 5-10% of the diet, *C. septemspinosa*, *Cancer* and pagurid crabs, *D. leptocerus*, and pandalid shrimp were some of the major decapods ingested. Identifiable amphipods made up only 4-5% of the total diet, with few conspicuous species. Identifiable polychaetes accounted for 10-13% of the diet, with the genus *Nephtys* the most notable. “Other prey phyla” and identifiable mollusks together accounted for 10-12% of the diet, bivalves and nematodes dominated this category.

Finally, identifiable fish made up > 60% of the diet of 101-110 cm TL winter skate from the 1981-1990 NEFSC trawl surveys. Most were sand lance. Mollusks were 14% of the diet, polychaetes were 13% of the diet, and crustaceans were down to 11% of the diet.

Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult winter skate include: sand lance (17%), bivalve mollusks (13%), polychaetes (12%), other fish (8%), and gammarid amphipods (7%).

Using NEFSC data from 1977-1980, Bowman *et al*. (2000) found that in terms of percent weight, crustaceans were dominant in the diet of skate < 31-50 cm TL, while fish, mostly sand lance, were dominant in the diet of skate 51-110 cm TL. For skate < 31 cm TL, amphipods dominated, especially *L. pinguis*. For skate 31-50 cm TL, decapods dominated, especially *C. septemspinosa* and *C. irroratus*. On Georges Bank Tsou and Collie (2001a), using NEFSC dietary data from 1989-1990, also showed that fish, especially sand lance, were most important for winter skate > 50 cm TL. Other noted fish prey included sliver hake, mackerel, and herring (see also Tsou and Collie 2001b).

Table 34 – Major prey items of winter skate

Life Stage	***Major prey***	***Location***
Juveniles, < 81 cm[1]	**Nematodes; Polychaetes**: *Ampharete arctica*, Nephtyidae, *Scalibregma inflatum*, *Lumbrineris fragilis*, unidentified maldanids, Nereidae; **Crustaceans**: amphipods (*Unciola irrorata* and spp., *Psammonyx nobilis*, *Monoculodes edwardsi*, *Leptocheirus pinguis*, *Hippomedon serratus*, *Byblis* serrata, unidentified haustoriids, unidentified oedicerotids, unidentified gammarids), isopods (*Cirolana* [= *Politolana*?] *polita*), decapods (*Crangon septemspinosa*, pagurid crabs, *Cancer irroratus* crabs, the pandalid shrimp *Dichelopandalus leptocerus*); **Mollusks**: bivalves; **Fish**: sand lance	U.S. northeast continental shelf
Very large juveniles, adults, ≥ 81 cm[1]	**Nematodes; Polychaetes**: Nephtyidae; **Crustaceans**: amphipods (unidentified haustoriids, unidentified gammarids), isopods (*Cirolana* [= *Politolana*?] *polita*), decapods (*Crangon septemspinosa*, pagurid crabs, *Cancer* crabs, the lady crab *Ovalipes ocellatus*, pandalid shrimp including *Dichelopandalus leptocerus*); **Mollusks**: bivalves (Solenidae); **Fish**: sand lance, other skate, longhorn sculpin, silver hake, herring, butterfish	U.S. northeast continental shelf
Very large juveniles, adults, ≥ 81 cm[1]	**Polychaetes**: *Nephtys incisa*, *Nereis* sp., *Lumbrineris* sp.; **Crustaceans**: amphipods (*Leptocheirus pinguis*, *Monoculodes edwardsi*), decapods (*Crangon septemspinosa*, *Cancer irroratus;* **Mollusks**: *Ensis directus*	Block Island Sound, RI (Smith 1950)
Juveniles	**Crustaceans**: decapods (*Crangon septemspinosa*, *Cancer irroratus*, the lady crab *Ovalipes ocellatus;* **Fish**: sand lance, longhorn sculpin, Atlantic herring, winter flounder	Hudson-Raritan estuary (Steimle *et al*. 2000)

[1]From NEFSC food habits database in Packer et al. (2003) and Figure 3 therein, and J. Link (pers. comm.). For a list of other major prey species from other studies, see text.

5.1.3 Peak spawning

Information on the spawning periods of winter skate (*Leucoraja ocellata*) comes from the EFH Source Document (Packer et al. 2003, and references therein).

Bigelow and Schroeder (1953) report egg deposition to occur during summer and fall off Nova Scotia and, quoting Scattergood, probably in the **Gulf of Maine** as well. They also state that egg deposition continues into December and January off **southern New England**.

A recent study by Sulikowski et al. (2004) in the **Gulf of Maine off New Hampshire** indicates that several morphological parameters and steroid hormones have been shown to peak in female winter skates during the summer, and egg-case production is highest in the fall. However, the presence of reproductively capable females during most months of the year and spermatocysts within the male testis year round implies that reproduction could occur at other times of the year. Thus, the Sulikowski et al. (2004) study, combined with the criteria described by Wourms (1977) and Hamlett and Koob (1999), collectively support the conclusion that winter skate display a partially defined reproductive cycle with a single peak (Sulikowski et al. 2004).

Additional References

Hamlett, W.C. and T.J. Koob. 1999. Female reproductive system. In: Hamlett, W.C., editor. Sharks, skates and rays; the biology of elasmobranch fish. Baltimore, MD: Johns Hopkins University Press.

Sulikowski J.A., P.C.W. Tsang, and W. Huntting Howell. 2004. An annual cycle of steroid hormone concentrations and gonad development in the winter skate, Leucoraja ocellata, from the western Gulf of Maine. Mar. Biol. 144: 845−853.

Wourms, J.P. 1977. Reproduction and development in chondrichthyan fishes. Am. Zoo 17: 379–410.

5.2 Little skate

5.2.1 Supplementary table

Table 35 – Summary of habitat information for little skate

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Sandy benthic habitats	<27 (GOM)	Embryos begin growing >7-8	No information
Larvae	Not applicable	Not applicable	Not applicable	Not applicable
Juveniles	Sandy benthic habitats Also see adults	Present 4-80 inshore, common 16-30 (MA), at min 8 (RB) Present 1-400 on shelf, common 11-70	Present 0-24 inshore, common 7.5-18.5 (MA), 3.5-18.5 (RB) Present 0.5-24.5 on shelf, common 1.5-21.5	Present 15-36 inshore, common 22.5-32.5 (RB) Present 25.5-36.5 on shelf, common 29.5-33.5
Adults	Sandy benthic habitats Generally on sandy or gravelly bottoms, but also on mud (GOM) Biogenic depressions and flat sand (SNE) Sand and sand-mud (LIS)	Present 4-78 inshore, common 16-30 (MA), 7-19 (j/a DB) Present 1-400 on shelf, common 31-100 Generally found <111, occ >183, 15-46 (SNE), as deep as 329 on GB, 384 off NJ	Present 2.2-21.6 inshore, common 6.5-16.5 (MA), 7.5-22.5 (j/a DB) Present 1.5-21.5 on shelf, common 1.5-15.5 Generally found 1-21, most 2-15	Present 13.4-35 inshore, common 24.5-34.5 (j/a DB) Present 28.5-36.5 on shelf, common 32.5-33.5

** Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Sources of information:

- **Eggs**: EFH Source Document
- **Juveniles**: <u>Inshore</u>: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; depth, temperature, and salinity ranges ("common") based on Raritan Bay and MA trawl survey data in EFH Source Document. <u>Continental shelf</u>: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data.

- **Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; depth, temperature, and salinity ranges ("common") based on Delaware Bay and MA trawl survey data in EFH Source Document. Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data and from information in EFH Source Doc. Other information obtained from EFH Source Document.

5.2.2 Prey species

The main source of information on the prey consumed by little skate (*Leucoraja erinacea*) comes from the EFH Source Document (Packer *et al*. 2003 and references therein). Generally, invertebrates such as decapod crustaceans (e.g.; crabs and sand shrimp, *Crangon septemspinosa*) and amphipods are the most important prey items, followed by polychaetes. Isopods, bivalves, and fishes are of minor importance. The fishes that are eaten included sand lance, alewives, herring, cunners, silversides, tomcod, and silver hake. Hydroids, copepods, ascidians and squid are also ingested.

McEachran (1973) studied skates collected from Nova Scotia to Cape Hatteras during 1967-1970; the following diet descriptions are from him and McEachran *et al*. (1976).

Crangon septemspinosa, *Pagurus acadianus*, *Cancer irroratus*, and *Dichelopandalus leptocerus* were the most frequently eaten decapods in the Mid-Atlantic Bight and on Georges Bank. *C. septemspinosa* was the most numerous decapod in the stomachs while *P. acadianus* and *C. irroratus* accounted for most of the stomach volume. In the Gulf of Maine and on the Nova Scotian shelf *Pagurus pubescens*, *C. septemspinosa*, *Hyas* sp., and *Eualus pusiolus* were the most frequently eaten decapods.

The most frequently consumed amphipods in the Mid-Atlantic Bight and on Georges Bank were *Monoculoides* sp., *Unciola* sp., *Leptocheirus pinguis*, ampeliscids, haustoriids, and *Dulichia* (= *Dyopedos*) *monacantha*. *L. pinguis* predominated in the Mid-Atlantic Bight and *Monoculodes* sp. and *Unciola* predominated in little skate from Georges Bank. Haustoriid amphipods were abundant only in the little skate from Georges Bank and contributed significantly to the stomach contents only during the autumn survey. *Pleustes panoplus*, *L. pinguis*, *Hippomedon serratus*, *Monoculodes* sp., and *Unciola* sp. were the most frequently eaten amphipods in the Gulf of Maine and on the Nova Scotian shelf.

Eunice pennata and *Nereis* spp. were the most numerous polychaetes, with *E. pennata* abundant only on the Nova Scotian shelf and *Nereis* spp. numerous only in the Mid-Atlantic Bight. Other major polychaetes consumed in the Mid-Atlantic Bight and on Georges Bank were *Nepthys* spp., *Lumbrineris fragilis*, *Aphrodite hastata*, maldanids, (mostly *Clymenella torquata*), *Glycera* spp., and *Pherusa affinis*. *A. hastata* contributed most to the stomach volume. The polychaetes *Ophelia denticulata*, *Nothria conchylega*, and *Pectinaria* sp. predominated in stomachs from the Gulf of Maine and the Nova Scotian shelf.

McEachran (1973) and McEachran *et al*. (1976) showed that the diet of little skate is size-dependent. Skate < 41 cm TL consumed considerably fewer decapods and more amphipods than those that were ≥ 41 cm TL. Most decapods eaten by skates ≤ 30 cm TL were *C. septemspinosa*. Haustoriid amphipods were almost never found in skates > 30 cm TL. Cumaceans and copepods were also limited to the smaller skates. All sizes fed on fishes, but the frequency of occurrence increased with the size of the skate. Polychaetes were eaten by all sizes.

The 1973-1990 NEFSC food habits database for little skate generally confirms the McEachran (1973) and McEachran *et al*. (1976) studies. Crustaceans dominated the diet overall, but declined in importance with increasing skate size while the percent occurrence of polychaetes increased with increasing skate size. Amphipods occurred more frequently than decapods until the skates were > 41 cm TL. *C. septemspinosa* was the major decapod prey for all sizes of skate. The following is a description of the diet from the NEFSC food habits database broken down by little skate size class.

For juvenile little skate 1-10 cm TL, 97% of the diet consisted of crustaceans, with 42% of the diet consisting of identifiable amphipods. The most abundant amphipod species included *B. serrata*, *U. irrorata*, *Monoculodes intermedius*, *Synchelidium* sp., as well as several unidentifiable Gammaridea. Identifiable cumaceans made up 27% of the diet, notable species included *Cyclaspis varians* and *Diastylis* spp. Identifiable decapods made up only 8% of the diet, all of which were either *C. septemspinosa* or classified as unidentifiable Crangonidae.

For juveniles 11-20 cm TL, 90% of the diet consisted of crustaceans, and at least half of the diet consisted of identifiable amphipods. Major amphipod species included *B. serrata*, *U. irrorata*, *L. pinguis*, *Ericthonius rubricornis*, and several unidentifiable gammarids, ampeliscids, oedicerotids, and caprellids. Identifiable decapods made up 18-20% of the diet, most of which were *C. septemspinosa*; other important decapods included pagurid and *Cancer* crabs.

The percentage of crustaceans in the diet of juvenile little skate 21-30 cm TL dropped to 83%, although almost half of the diet still consisted of identifiable amphipods. The major amphipod prey species were similar to the 11-20 cm TL size class, with the addition of *M. edwardsi*. Identifiable decapods again made up 18-20% of the diet, the majority of which were again *C. septemspinosa* along with *Cancer* and pagurid crabs. Identifiable polychaetes made up only 10-11% of the diet, most of which were terebellids.

The percent occurrence of crustaceans in the diet of juveniles 31-40 cm TL dropped further, down to 73-78%, with identifiable amphipods making up only 32-36% of the overall diet. The usual amphipods were dominant; in order of abundance they were *U. irrorata*, *L. pinguis*, unidentifiable gammarids, *B. serrata*, unidentifiable ampeliscids, *M. edwardsi*, and unidentifiable caprellids, haustoriids, and oedicerotids. Identifiable decapods made up 25-28% of the diet; *C. septemspinosa* was again the dominant decapod prey, followed by *Cancer* and pagurid crabs, and *Dichelopandalus leptocerus*. Identifiable polychaetes made up only 14-15% of the diet; the majority were terebellids and maldanids.

The percent occurrence of crustaceans in the diet continued to decline for juvenile/small adult little skate 41-50 cm TL: down to 66-71%, with identifiable amphipods making up only 22-28% of the diet, while identifiable decapods made up 29-32%. The usual amphipods were dominant, especially *L. pinguis* and *U. irrorata*, followed by the others previously mentioned. *C.*

septemspinosa continued to be the dominant decapod prey, followed by *Cancer* and pagurid crabs. Identifiable polychaetes made up 17-18% of the diet, with the dominant family being the Terebellidae. Other abundant families included the Nephtyidae, Maldanidae, Aphroditidae, and the Flabelligeridae.

Finally, the percent occurrence of crustaceans in the diet declined to 64-69% for adult skate 51-60 cm TL, with identifiable amphipods making up only 19-22% of the diet, while identifiable decapods 29-34%. *L*. *pinguis* was the dominant amphipod; *C*. *septemspinosa*, *Cancer*, and pagurid crabs were the dominant decapods. Identifiable polychaetes made up 19-20% of the diet, with the dominant family being the Terebellidae.

Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult little skate include: gammarid amphipods (15%), decapod crabs and shrimps (12%), *Cancer* crabs (11%), polychaetes (11%), *C*. *septemspinosa* (7%), and bivalves (6%).

Other authors also show similar size-dependent trends in the diet of little skate. Bowman and Michaels (1984) and Bowman *et al*. (1987) reported that while crustaceans were the dominant prey of all sizes of little skate, juvenile skate < 35 cm TL preyed mostly on amphipods (including *Unciola*) and those > 35 cm TL ate large quantities of decapods (including *C. septemspinosa*). Polychaetes, mollusks, and fish were found primarily in little skate > 20 cm TL. Again, using NEFSC data from 1977-1980, Bowman *et al*. (2000) also found that in terms of percent weight, crustaceans were important for all size classes of skate. Juvenile skate < 15-30 cm TL fed mostly on amphipods, including *L*. *pinguis*, *Unciola* spp, *Gammarus annulatus*, and Oedicerotidae. Juvenile and small adult skate 36 to > 51 cm TL fed mostly on decapods, including *C*. *irroratus*, *C*. *borealis*, *P*. *acadianus*, and *C*. *septemspinosa* [although, as in the McEachran (1973) and McEachran *et al*. (1976) studies, *C*. *septemspinosa* was eaten mostly by juvenile skates ≤ 30 cm TL]. On Georges Bank, Nelson (1993) discovered that colonial amphipods and small epibenthic decapods dominated the diets of juvenile little skate < 39 cm TL at both of his study sites, but species composition was site and size dependent. At one site, *Ericthonius fasciatus* and *U. inermis* comprised the largest portions of the diet of juvenile skates < 39 cm TL. As skate length increased, *E*. *fasciatus* declined while *U*. *inermis* became increasingly important in the diets. For skates > 40 cm TL, the epibenthic decapods *C*. *septemspinosa* and young-of-the-year *C*. *irroratus* and the isopod *C. polita* were large components of the diet. The polychaete *Glycera dibranchiata* and young-of-the-year hakes (eaten mostly in summer) also increased in the diet. At a second site, the dominant prey items for juvenile skate < 39 cm TL was *C*. *septemspinosa*, followed by (except for juvenile skates 10-19 cm TL) the amphipod *Protohaustorius wigleyi*. Other notable amphipods were *Monoculodes edwardsi*, *Rhepoxynius hudsoni*, *Pontogeneia inermis*, and *Aeginina longicornis; C*. *polita* and *C*. *irroratus* were the most important epibenthic arthropods. For skates > 40 cm TL, *M*. *edwardsi*, *C*. *septemspinosa*, *C*. *polita*, and *P*. *inermis* were dominant; the cnidarian *Cerianthus* spp. dominated in terms of weight.

Information and citations for the inshore studies can be found in the Little Skate EFH Source Document (Packer *et al*. 2003). In Sheepscot Bay, Maine, little skate ate a variety of prey, but seemed to focus most on crustaceans and Atlantic herring. *C*. *septemspinosa*, the jonah crab

Cancer borealis, the amphipods *L. pinguis* and *U. inermis*, and several other varieties of crustaceans were important in the diet, followed by polycheates such as *Nephtys* spp. In Johns Bay, Maine, little skate fed primarily on the decapod crustaceans *C. septemspinosa* and *C. irroratus*, followed by the amphipods *L. pinguis*, *Unciola* spp. and *Monoculodes* spp. Polychaetes were the next major prey group. In Block Island Sound, *L. pinguis* was most abundant in the diet, followed by *C. irroratus*, *C. septemspinosa*, *Upogebia affinis* (a mud shrimp), *Glycera dibranchiata*, *Byblis serrata* (an amphipod), *Unciola irrorata*, *Nephtys incisa*, and *E. directus*. Decapods made up 76% of the diet by weight in New Haven Harbor. *C. septemspinosa* and *C. irroratus* were the most important prey items, followed by mantis shrimp, *Squilla empusa*. Fish were the next major group, but only made up 10% of the diet by weight and only 4% by number. In the Hudson-Raritan estuary, he most frequently found prey, overall, was *Crangon septemspinosa* at a frequency of occurrence of 82.8%. This prey was followed by juvenile or small Atlantic rock crabs at a frequency of occurrence of 49.5%, then by the mysid shrimp, *Neomysis americana*), at a frequency of occurrence of 16.3%, and finally the lady crab, *Ovalipes ocellatus*, at a frequency of occurrence of 10.9% (Steimle *et al*. 2000). In Delaware Bay, *C. septemspinosa* made up > 70% of the diet, followed by *E. directus* and *Euceramus praelongus* (a burrowing crab).

In Sheepscot Bay, a study by Packer and Langton (unpublished manuscript) again indicated that the percentage of crustacean prey in the diet decreased as the skate size increased. This was due to decreases in amphipods, cumaceans, and *C. septemspinosa*. Polychaetes (including *Nephtys* spp.) were a small but important part of the diet for juvenile skate > 20 cm TL. Atlantic herring occurred only in the stomachs of fish > 40 cm TL, but were only prominent in terms of percent weight. In Long Island Sound, Richards (1963) found that amphipods and *C. septemspinosa* were more important to smaller skates. Tyler (1972) also noted that smaller skates (≤ 44 cm TL) ate mysids and amphipods and larger skate consumed decapods, euphausids, and polychaetes.

In the inshore diet studies mentioned above, the skates generally depended more on a few major prey species than skates from the McEachran (1973) and McEachran *et al*. (1976) studies. This may be attributable to the benthic faunal composition in these inshore areas; these areas have a less diverse fauna than the wide region sampled as part of the McEachran (1973) and McEachran *et al*. (1976) studies. But it is clear that the food habits of little skate are fairly generalized, and it is an opportunistic predator.

Table 36 – Major prey items of little skate

Life Stage	***Major prey***	***Location***
Juveniles, ≤ 40 cm[1]	**Polychaetes**: terebellids, maldanids; **Crustaceans**: amphipods (*B. serrata*, *U. irrorata*, *Monoculodes intermedius*, *Synchelidium* sp., *L. pinguis*, *Ericthonius rubricornis*, *M. edwardsi*, unidentifiable gammarids, ampeliscids, haustoriids, oedicerotids, caprellids), cumaceans (*Cyclaspis varians*, *Diastylis* spp.), decapods (*C. septemspinosa*, pagurid and *Cancer* crabs, *Dichelopandalus leptocerus*), isopods; **Mollusks; Fish**	U.S. northeast continental shelf
Large juveniles, very small adults, 41- 50 cm[1]	**Polychaetes**: Terebellidae, Nephtyidae, Maldanidae, Aphroditidae, Flabelligeridae; **Crustaceans**: amphipods (*L. pinguis*, *U. irrorata*, etc.), decapods (*C. septemspinosa*, *Cancer* and pagurid crabs), isopods; **Mollusks; Fish**	U.S. northeast continental shelf
Adults, 51-60	**Polychaetes**: Terebellidae; **Crustaceans**: amphipods (*L. pinguis*), decapods	U.S. northeast

Life Stage	***Major prey***	***Location***
cm[1]	(*C. septemspinosa*, *Cancer* and pagurid crabs), isopods; **Fish**	continental shelf
	Polychaetes: e.g., *Nephtys* spp.; **Crustaceans**: amphipods (*L. pinguis*, *U. inermis*), decapods (*C. septemspinosa*, *Cancer borealis*); **Fish**: Atlantic herring	Sheepscot Bay, Maine
	Polychaetes: e.g., *Nephtys* spp.; **Crustaceans**: amphipods (*L. pinguis*, *U. inermis*, *Monoculodes* spp.), decapods (*C. septemspinosa*, *Cancer irroratus*)	Johns Bay, Maine
	Polychaetes: *Glycera dibranchiata*, *Nephtys incisa* **Crustaceans**: amphipods (*L. pinguis*, *Byblis serrata*, *Unciola irrorata*), decapods (*C. septemspinosa*, *Cancer irroratus*, the mud shrimp *Upogebia affinis*); **Mollusks**: *Ensis directus*	Block Island Sound, RI
	Crustaceans: decapods (*C. septemspinosa*, *Cancer irroratus*, mantis shrimp *Squilla empusa*); **Fish**	New Haven Harbor
Mostly adults	**Crustaceans**: decapods (*C. septemspinosa*, *Cancer irroratus,* the lady crab, *Ovalipes ocellatus*), the mysid shrimp *Neomysis americana*	Hudson-Raritan estuary
	Crustaceans: decapods (*C. septemspinosa*, the burrowing crab *Euceramus praelongus*); **Mollusks**: *Ensis directus*	Delaware Bay

[1]From NEFSC food habits database in Packer et al. (2003) and Figure 3 therein, and J. Link (pers. comm.). For a list of other major prey species from other studies, see text.

5.2.3 Peak spawning

Information on the spawning periods of little skate (*Leucoraja erinacea*) comes from the EFH Source Document (Packer *et al*. 2003 and references therein). Egg cases are found partially to fully developed in mature females year-round but several authors report that they are most frequently encountered from late October-January and from June-July (Fitz and Daiber 1963; Richards *et al*. 1963; Scott and Scott 1988); Bigelow and Schroeder (1953) also mention that eggs are taken off **southern New England** mostly from July to September.

In **Block Island Sound**, Johnson (1979) also reported pregnant little skate were present during all months of the year, but the seasonal percentages of pregnant females varied. *Periods of relatively high pregnancy-frequency* were October-December and April-May, while low periods occurred in August-September and February-March. *Peaks* in egg production were in November and May when 34% and 44% of the females examined were pregnant, respectively. The lowest levels of production came in September and March when approximately 1% of the females were pregnant.

Johnson (1979) found the mean number of mature and maturing eggs per fish increased significantly prior to and during the spawning *peaks*, reaching maxima in October and May. The average number of mature and maturing eggs decreased significantly between what appears to be two spawning seasons with minima in August and January. The greatest ovarian production occurred in the spring. In **Delaware Bay**, Fitz and Daiber (1963) also showed that the greatest ovarian production occurred in the spring, while the size and number of eggs was at a minimum in February and March.

Johnson (1979) reported that ovarian weight also increased significantly during two spawning seasons. Comparison of the female gonad weight expressed as a percentage of total body weight demonstrated two seasonal *peaks* with maxima occurring in October and May; these seasonal peaks represented and increase in ovarian production. After the height of spawning, the female gonad weight dropped off significantly, reaching a minima in January and August.

Rate of egg laying in Johnson's (1979) study varied from 0.20-0.67 eggs/d, with an average rate of 0.39 eggs/d. Johnson (1979) suggests that an average female little skate which spawns twice annually (once during fall and spring) produces approximately 30 eggs/yr. Bigelow and Schroeder (1953) observed that eggs in aquaria were laid at intervals of from five days to several weeks, and were partially buried in sand.

Gestation is at least six months or more. Aquarium studies mentioned by Bigelow and Schroeder (1953) showed that eggs laid in May-July hatched between the end of November and beginning of January, about 5-6 months. Richards *et al*. (1963) also determined that eggs spawned in the late spring and early summer required five to six months to hatch. Since the water temperature of the aquarium in which the eggs were kept was slightly above that of the natural environment, it is possible that the incubation time was underestimated. Perkins (1965) in a study conducted at **Boothbay Harbor, Maine**, found under aquarium conditions where the water temperature closely approximated that of the inshore waters, eggs deposited in November and December hatched after twelve months of incubation. Johnson (1979) performed flow-through seawater system studies using ambient temperatures resembling those of the **inshore waters of Block Island Sound** at 20 m. The incubation period ranged from 112-366 d and was dependent on month of deposition. Eggs deposited in September 1975 hatched after an average of 360 d. Incubation time decreased progressively from September, and eggs deposited in July 1977 developed and hatched in an average of 122 d. The rate of embryonic growth appeared to be directly related to temperature. In Perkins (1965) study, incubation of eggs deposited in November and December showed the first embryonic activity in March when the water temperature had risen to 7EC.

5.3 Smooth skate

5.3.1 Supplementary table

Table 37 – Summary of habitat information for smooth skate

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	No information	No information	No information	No information
Larvae	Not applicable	Not applicable	Not applicable	Not applicable
Juveniles	Benthic habitats associated primarily with mud, but also mud and sand, and mud and sand mixed with *gravel* Found mostly on soft mud in deeper areas, but also on sand, broken shells, gravel, and pebbles on	Present 12-99 inshore Present 31-500 on shelf, common 121-400 Found 31-874, most abundant 110-457, min 46 on offshore banks	Present 3.2-10 inshore Present 1.5-16.5 on shelf, common 3.5-9.5 Found 2-10	Present 32.1-33.3 inshore Present 31.5-35.5, common 32.5-35.5

Life Stage	***Habitat***	***Depth (m)****	***Temperature (ºC)*****	***Salinity (ppt)*****
	offshore banks in GOM	(GOM) Occurs 46-956 NC to Grand Banks	southern Nova Scotia to GB	
Adults	Benthic habitats associated with mud, sand, mud and sand, and mud and sand mixed with *gravel* Also see juveniles	Present 31-400 on shelf, common 121-300 Also, see juveniles	Present 2.5-21.5 on shelf, common 3.5-8.5	Present 31.5-35.5 on shelf, common 32.5-35.5

** Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Note: As used in the analysis of sediment associations, the term "gravel" refers to all grain sizes above a diameter of 2 mm, i.e., any sediment coarser than sand, and therefore includes pebbles, cobbles, and even boulders

Sources of information:

- **Juveniles**: Inshore: depth, temperature, and salinity ranges (presence only) derived from ME trawl survey data in areas mapped as EFH. Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data plus information in EFH Source Document. Other information obtained from EFH Source Document. Presence on shelf slope based on NEFSC deep-water trawl survey data and information in Moore et al. (2003)
- **Adults**: depth, temperature, and salinity ranges for continental shelf derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data.

Note: Information on off-shelf depth distribution in Moore et al. (2003) is not specific to juveniles or adults, nor is substrate information in the EFH Source Document.

5.3.2 Prey species

The main source of information on the prey consumed by smooth skate (*Malacoraja senta*) comes from the EFH Source Document (Packer *et al*. 2003 and references therein). Generally, the diet of smooth skate is limited to epifaunal crustaceans. Decapod shrimps and euphausiids are the primary food items although amphipods and mysids are also important. Larger smooth skate also feed on small fish.

McEachran (1973) studied skates collected from Nova Scotia to Cape Hatteras during 1967-1970; the following diet description is from him and McEachran *et al*. (1976).

On Georges Bank, *Pagurus pubescens*, *Dichelopandalus leptocerus*, *Crangon septemspinosa*, and *Eualus pusiolus* were the major decapods eaten, while on the Nova Scotian shelf, *P. pubescens*, *Pandulus* spp., and *C. septemspinosa* were the most numerious decapod prey consumed. *Meganyctiphanes norvegica* was the only euphausiid eaten, and was eaten more frequently during the winter than during the autumn. *Monoculodes* sp. was the major amphipod eaten on Georges Bank and *Dulichia* (= *Dyopedos*) *monacantha* and *Pontogeneia inermis* were the most frequently eaten amphipods eaten in the Gulf of Maine and on the Nova Scotian shelf. The mysids *Erythrops erythrophthalma* and *Neomysis americana* were also consumed in large numbers.

As smooth skate grow, the diet shifts from amphipods and mysids to decapods, and euphausiids appear to be directly correlated to the size of the skate (McEachran *et al*. 1976). Using NEFSC data from Georges Bank and the Gulf of Maine from 1977-1980, Bowman *et al*. (2000) reported that that in terms of percent weight, the major decapods consumed by skate 36-51 cm TL included *Pandalus borealis* and *D. leptocerus*. Skate 51-55 cm TL consumed pagurid crabs. *M. norvegica* was eaten by skate 56-60 cm TL, but also by skate < 31 cm TL.

The 1981-1990 NEFSC food habits database for smooth skate generally confirms the McEachran (1973) and McEachran *et al*. (1976) studies, even though the sample sizes are often quite small. Decapods and crustaceans are the major components of the skates' diet, particularly for skates > 21 or 31 cm TL. Several fish species are minor, but important components of the diet of skates > 31 cm TL. Amphipods, which are a major part of the diet of skates 11-20 cm TL, rapidly decrease in occurrence for larger skates. However, there doesn't seem to be a remarkable increase in the occurrence of decapods or euphausiids with increasing skate size. It is interesting to note though the rather high (54%) occurrence of euphausiids in the stomachs of skates 21-30 cm TL, this may mirror the previously mentioned presence of *M. norvegica* in skate < 31 cm TL as reported by Bowman *et al*. (2000).

The following is a description of the diet from the NEFSC food habits database broken down by smooth skate size class.

For smooth skate 11-20 cm TL, 39% of the diet consisted of identifiable amphipods. Identifiable euphausiids made up 23% of the diet, while pagurid crabs and pandalid shrimp, both decapods, together made up 15% of diet. Identifiable mysids and isopods each made up only 8% of the diet. For skate 21-30 cm TL, 54% of the diet consisted of identifiable euphausiids, and 23% of the diet identifiable amphipods.

The percent occurrence of identifiable amphipods in the diet of smooth skate 31-40 cm TL dropped to 17% and identifiable euphausiids dropped to 29% of the diet. Identifiable decapods made up 21% of the diet; they included pagurid crabs, pandalid shrimp, and *C. septemspinosa*. Identifiable fish made up 13% of the diet, among which were a yellowtail flounder and a hake. Minor prey items included polychaetes (4%) and stomatopods (4%).

The percent occurrence of identifiable euphausiids in the diet of skate 41-50 cm TL increased to 38%, while identifiable amphipods continued to decrease, down to 7%. Identifiable decapods, including pandalid shrimp and *C. septemspinosa*, made up 21% of the diet. Identifiable fish increased to 17% of the diet, species included silver hake and witch flounder.

The percent occurrence of identifiable euphausiids in the diet of 51-60 cm TL skate decreased to 32%, while identifiable amphipods dropped down to 2%. Identifiable decapods, including pagurid crabs, pandalid shrimp, and *C. septemspinosa*, increased to 29%. Identifiable fish, including silver hake and sand lance, made up 13% of the diet.

Finally, for smooth skate 61-70 cm TL, identifiable euphausiids made up 38% of the diet, identifiable pandalid shrimp 25% of the diet, identifiable fish 13%, and identifiable polychaetes 13%. However, only 7 skate stomachs were examined, making any conclusions about diet preference for this size class suspect.

Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult smooth skate include: pandalid shrimp (27%), euphausiids (14%), crustacean shrimp (13%), silver hake (5%), other fish (5%), and decapod crabs (5%).

Table 38 – Major prey items of smooth skate

Life Stage	*Major prey*	*Location*
Juveniles, ≤ 50 cm[1]	**Crustaceans**: amphipods (gammarid), isopods, mysids, euphausiids, decapods (*C. septemspinosa*, pagurid crabs, pandalid shrimp); **Fish**: yellowtail flounder, silver hake, witch flounder	U.S. northeast continental shelf
Large juveniles, adults > 50 cm[1]	**Polychaetes**: [for skate 61-70 cm, but small sample size makes this suspect] ;**Crustaceans**: euphausiids, decapods (*C. septemspinosa*, pagurid crabs, pandalid shrimp) ; **Fish**: silver hake, sand lance	U.S. northeast continental shelf

[1]From NEFSC food habits database in Packer et al. (2003) and Figure 2 therein, and J. Link (pers. comm.). For a list of other major prey species from other studies, see text.

5.3.3 Peak spawning

Smooth skate (*Malacoraja senta*) appears to spawn year round. Females with fully formed egg capsules are found both in summer and winter (McEachran 2002). Sulikowski *et al*. (2007) examined the reproductive condition of male and female skates in the **Gulf of Maine.** Their data indicate that at least in the Gulf of Maine, the species is reproductively active year round. See Packer *et al*. 2003 and references therein for additional information.

Additional References

Sulikowski, J.A., J. Kneebone, S. Elzey, P. Danley, W.H. Howell and P.W.C. Tsang. 2007. The reproductive cycle of the smooth skate, *Malacoraja senta*, in the Gulf of Maine. Marine and Freshwater Research 58(1) 98-103.

5.4 Thorny skate

5.4.1 Supplementary table

Table 39 – Summary of EFH information for thorny skate

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	No information	No information	No information	No information
Larvae	Not applicable	Not applicable	Not applicable	Not applicable
Juveniles	Benthic habitats associated primarily with mud, also mud and sand, sand, and mud and sand mixed with *gravel* Found on wide variety of bottom types from sand, gravel, broken shell, pebbles, to soft mud	Present 11.5-84 inshore, common 36-75 (MA) Present 11-500 and >500 on and off shelf, common 71-400 Also see adults	Present 2.5-13.4 inshore, common 2.5-10.5 (MA) Present 0.5-25.5 on shelf, common 0.5-8.5	Present 31.7-34 inshore (ME) Present 30.5-36.5, common 32.5-34.5
Adults	Benthic habitats associated primarily with mud, also mud and sand Also see juveniles	Present 31-500 on shelf, common 121-300 Found 18-183 on shelf, as deep as 786-896 off NY, to 699 off SNE, 300-1200 off VA	Present 1.5-14.5 on shelf, common 2.5-7.5	Present 31.5-35.5 on shelf, common 32.5-34.5

** Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Note: As used in the analysis of sediment associations, the term "gravel" refers to all grain sizes above a diameter of 2 mm, i.e., any sediment coarser than sand, and therefore includes pebbles, cobbles, and even boulders

Sources of information:

- **Juveniles**: Inshore: depth, temperature, and salinity ranges (presence only) based on ME and MA trawl survey data from areas mapped as EFH; depth, temperature, and salinity ranges ("common") based on MA trawl survey data in EFH Source Document. Continental shelf and slope: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data plus information in EFH Source Document.
- **Adults**: Depth, temperature, and salinity ranges for continental shelf and slope derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data plus information in EFH Source Document; other information also from EFH Source Doc.

Note: Information on maximum depths and substrates in EFH Source Document is not specific to life stage. Adults of this species are not caught in inshore trawl surveys.

5.4.2 Prey species

The main source of information on the prey consumed by thorny skate (*Amblyraja radiata*) comes from the EFH Source Document (Packer *et al*. 2003 and references therein). Prey of thorny skate in the western North Atlantic includes hydrozoans, aschelminths, gastropods, bivalves, squids, octopus, polychaetes, pycnogonids, copepods, stomatopods (larvae), cumaceans, isopods, amphipods, mysids, euphausids, shrimps, hermit crabs, crabs, holothuroideans, and fishes. The feeding habits of thorny skate are size-dependent, but it is also an opportunistic feeder on the most abundant and available prey species in an area.

McEachran (1973) studied skates collected from Nova Scotia to Cape Hatteras during 1967-1970; the following diet descriptions are from him and McEachran *et al*. (1976). Polychaetes and decapods were the major prey items eaten, followed by amphipods and euphausids. Fishes and mysids contributed little to the diet. *Nephtys* spp. and *Glycera* spp. were the most frequently eaten polychaetes on Georges Bank while *Nephtys* spp., *Eunice pennata,* and *Aphrodite hastata* were the most abundant polychaetes eaten in the Gulf of Maine and on the Nova Scotian shelf. *Orchomonella minuta* and *Leptocheirus pinguis* were the most numerous amphipod prey in the Mid-Atlantic Bight, while *L*. *pinguis*, ampeliscids, and *Orchomonella* sp. were the most frequently eaten amphipods on Georges Bank. *Pontogeneia inermis* and *Tmetonyx* sp. were the most abundant amphipods eaten in the Gulf of Maine, while on the Nova Scotian shelf ampeliscids and *L*. *pinguis* were the most frequently eaten amphipods. On Georges Bank, *Hyas* sp., *Eualus pusiolus*, *Dichelopandalus leptocerus*, and *Crangon septemspinosa* were the most frequently eaten decapods. *Pandalus* spp., *Pagurus pubescens*, *Axius serratus*, and *Pasiphaea* sp. were the dominant species eaten in the Gulf of Maine. *Hyas* sp., *P*. *pubescens*, *E*. *pusiolus*, *A*. *serratus* were the major decapod prey eaten on the Nova Scotian shelf. *Meganctiphanes norvegica* was the only euphausid in the diet. The mysids eaten were *Neomysis americana* and *Erythrops erythrophthalma*. The most commonly eaten fishes were sand lance, longhorn sculpin, and Atlantic hagfish.

McEachran (1973) and McEachran *et al*. (1976) found that the diet of thorny skate was size dependent. Fish ≤ 40 cm TL fed mostly on amphipods while fish > 40 cm TL fed mostly on polychaetes and decapods. Mysids decreased in the diet while fishes increased with increase in size of the skate. Fishes were a major component of the diet of skates > 70 cm TL. Consumption of euphausids was independent of skate size (McEachran 1973; McEachran *et al*. 1976).

The 1973-1990 NEFSC food habits database for thorny skate generally confirms the previous studies. Overall, crustaceans declined in importance with increasing skate size. Amphipods, which included species such as *Psammonyx nobilis* and *L. pinguis,* decreased with increasing skate size, while the percent occurrence of decapods, which included *C*. *septemspinosa*, *Cancer* and pagurid crabs, and pandalid shrimp, generally did not change with skate size. The percent occurrence of polychaetes, which included those from the Nephtyidae and Aphroditidae families, increased with increasing skate size until the skate were about 60 cm TL. Fish became noticeable in the diet of the larger skates, around > 50-60 cm TL, but were never a major component of the diet (at least as measured here in terms of percent occurrence).

The following is a detailed description of the diet from the NEFSC food habits database broken down by thorny skate size class.

For thorny skate 11-20 cm TL, 61-78% of the diet consisted of crustaceans, with 24-48% of the diet consisting of identifiable amphipods. The most abundant amphipod species included *Ericthonius rubricornis*, *Psammonyx nobilis*, *Monoculodes edwardsi*, and several unidentifiable gammarid amphipods. Identifiable decapods (11% of the diet during the 1973-1980 study period) included *C. septemspinosa* and *Cancer* and *Pagurus* crabs. Euphausids (*M. norvegica*), mysids (*E. erythrophthalma*), and cumaceans were also eaten. Identifiable polychaetes (15-34% of the diet) included those from the Nephtyidae and Aphroditidae families.

For skate 21-30 cm TL, 56-66% of the diet consisted of crustaceans, with 23-34% of the diet consisting of identifiable amphipods. Major amphipod species included *L. pinguis*, *Melita dentata*, and *Hippomedon serratus*. Identifiable decapods (5-10% of the diet) again included *C. septemspinosa* and *Cancer* and pagurid crabs. *Cirolana* (= *Politolana*?) *polita* was one of the identifiable isopods. Identifiable polychaetes made up 18-39% of the diet and included those from the Aphroditidae and Terebellidae families.

The percentage of crustaceans in the diet of thorny skate 31-40 cm TL dropped to 44-52%. Some of the more numerous identifiable amphipods (10-26% of the diet) included *P. nobilis*, *L. pinguis*, and *Byblis serrata*. *C. septemspinosa*, pagurid crabs, and *E. pusiolus* were the major identifiable decapod prey (8-15% of the diet). Identifiable polychaete prey (38-48% of the diet) included members of the families Aphroditidae, Nephtyidae, Lumbrineridae, as well as the species *Sternaspis scutata*.

The percent occurrence of crustaceans in the diet of thorny skate 41-50 cm TL was between 42-59%. Identifiable decapods (5-11% of the diet) included *C. septemspinosa*, pandalid shrimp, and *E. pusiolus*. Identifiable amphipods, which decreased to 8-17% of the diet, included *L. pinguis*, while identifiable euphausids (10% of the diet during the 1981-1990 study period) included *M. norvegica*. Identifiable polychaetes made up 35-50% of the diet; major families included the Aphroditidae and Nephtyidae.

The percent occurrence of crustaceans in the diet for skate 51-60 cm TL declined to 37-41%. Identifiable decapods (13-15% of the diet) included *E. pusiolus*, pandalid shrimp, pagurid crabs, and *D. leptocerus*. *M. norvegica* was a dominant euphausid (7% of the diet during the 1981-1990 study period). Among the polychaetes, which were 40-48% of the diet, were found members of the Nephtyidae (e.g., *N. discors*) and Aphroditidae (e.g., *A. hastata*) families, as well as *E. pennata*. The percent occurrence of identifiable fish in the diet increased to 5-11%.

The percent occurrence of crustaceans dropped to 34-40% for skate 61-70 cm TL. Among the identifiable decapods (13-23% of the diet) were pagurid crabs, pandalid shrimp, *Hyas* sp., *D. leptocerus*, and *C. septemspinosa*. Identifiable polychaetes (36-49% of the diet) again included members of the Nephtyidae and Aphroditidae families. The percent occurrence of identifiable fish in the diet increased to 10-14%.

For skate 71-80 cm TL, crustaceans made up 25-42% of the diet. Major identifiable decapods (16-18% of the diet) again included pagurid crabs, pandalid shrimp, *Hyas* sp., and *D. leptocerus*. Identifiable polychaetes made up 38-47% of the diet and included members of the Aphroditidae, Nephtyidae, Nereidae, Sabellidae, and Opheliidae families. The percent occurrence of identifiable fish in the diet increased to 13-17% and included sand lance, wrymouth, and silver hake.

Finally, the percent occurrence of crustaceans in the diet for skate 81-90 cm TL declined to 34-35%. Identifiable decapods (12-16% of the diet) included pandalid shrimp, *Hyas* sp., *Cancer* crabs, and *D. leptocerus*. *M. norvegica* was a dominant euphausid. Identifiable polychaetes comprised 31-35% of the diet, most of which were in the Nephtyidae, Aphroditidae, and Nereidae families. Identifiable fish, which made up 10-22% of the diet, included hagfish, wrymouth, and herring.

Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult thorny skate include: polychaetes (21%), other fish (13%), Atlantic herring (7%), wrymouth (6%), and decapod crabs (5%).

Using NEFSC data from 1977-1980, Bowman *et al*. (2000) found that in terms of percent weight, crustaceans and polychaetes were dominant in the diet of skate < 31-60 cm TL, while fish, including herring, sand lance, and wrymouth were dominant in the diet of skate 61-90 cm TL. Squid and herring dominated the diet of skate > 90 cm TL.

Table 40 – Major prey items of thorny skate

Life Stage	***Major prey***	***Location***
Juveniles, < 81 cm[1]	**Polychaetes**: Nephtyidae (e.g., *N. discors*), Aphroditidae (e.g., *A. hastata*), Terebellidae, Lumbrineridae, Nereidae, Sabellidae, and Opheliidae, *Sternaspis scutata*, *Eunice pennata;* **Crustaceans**: amphipods (*Ericthonius rubricornis*, *Psammonyx nobilis*, *Monoculodes edwardsi*, *Leptocheirus pinguis*, *Melita dentata*, *Hippomedon serratus*, *Byblis* serrata, unidentifiable gammarids), cumaceans, isopods (*Cirolana* [= *Politolana*?] *polita*), decapods (*Crangon septemspinosa*, pagurid crabs, *Cancer* crabs, spider crabs *Hyas* sp., *Eualus pusiolus*, pandalid shrimp including *Dichelopandalus leptocerus*), euphausiids (*Meganctiphanes norvegica*), mysids (*Erythrops erythrophthalma*); **Mollusks; Fish**: sand lance, wrymouth, silver hake	U.S. northeast continental shelf
Very large juveniles, adults, ≥ 81 cm[1]	**Polychaetes**: Nephtyidae, Aphroditidae, Nereidae; **Crustaceans**: decapods (*Cancer* crabs, spider crabs *Hyas* sp., pandalid shrimp including *Dichelopandalus leptocerus*), euphausiids (*Meganctiphanes norvegica*); **Mollusks; Fish**: hagfish, wrymouth, Atlantic herring.	U.S. northeast continental shelf

[1]From NEFSC food habits database in Packer et al. (2003) and Figure 3 therein, and J. Link (pers. comm.). For a list of other major prey species from other studies, see text.

5.4.3 Peak spawning

Information on the spawning periods of thorny skate (*Amblyraja radiata*) comes from the EFH Source Document (Packer *et al*. 2003 and references therein). Females with fully formed egg capsules are captured over the entire year (Templeman 1982a), although the percentage of mature females with capsules is higher during the summer (McEachran 2002). A recent study by Sulikowski et al. (2005) in the **Gulf of Maine off New Hampshire** indicates that thorny skate have a reproductive cycle that is continuous throughout the year. Bigelow and Schroeder (1953a) reported that females with ripe eggs have been taken in Nova Scotian waters or in the **Gulf of Maine** in April, June, July, and September.

Additional References

Sulikowski, J.A., J. Kneebone, S. Elzey, P. Danley, W.H. Howell and P.W.C Tsang. 2005. The reproductive cycle of the thorny skate, *Amblyraja radiata*, in the Gulf of Maine. Fish. Bull. (U.S.) 103: 536-543.

5.5 Barndoor skate

5.5.1 Supplementary table

Table 41 – Summary of habitat information for barndoor skate

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	No information	No information	No information	No information
Larvae	Not applicable	Not applicable	Not applicable	Not applicable
Juveniles	Benthic habitats with substrates composed primarily of sand, but also sand and mud, and sand and mud with *gravel* Also see adults	Present 21-400 on shelf, common 51-160 Assumed present 400-750 (see adults)	Present 2.5-18.5 on shelf, common 2.5-11.5	Present 31.5-36.5 on shelf, common 32.5-34.5
Adults	Found on mud as well as sand and gravel	Present 21-400 on shelf, common 61-400 Range from shoreline to about 750, most abundant <150	Present 3.5-16.5 on shelf, common 4.5-16.5	Present 31.5-36.5 on shelf, common 32.5-34.5 Observed in mouth of CBay where salinity is 21-24 and in "brackish" water in Delaware R

** Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

<u>Note</u>*: As used in the analysis of sediment associations, the term "gravel" refers to all grain sizes above a diameter of 2 mm, i.e., any sediment coarser than sand, and therefore includes pebbles, cobbles, and even boulders*

Sources of information:

- <u>Juveniles and adults</u>: Depth, temperature, and salinity ranges based on NEFSC trawl survey data in EFH Source Document; sediment types derived from analysis of NEFSC trawl survey and USGS USSeabed sediment data plus information in EFH Source Document; other information from EFH Source Document.

5.5.2 Prey species

The main source of information on the prey consumed by barndoor skate (*Dipturus laevis*) comes from the EFH Source Document (Packer *et al*. 2003 and references therein). Food of the barndoor skate consists of benthic invertebrates and fishes. Prey includes polychaetes, gastropods, bivalve mollusks, squids, crustaceans, hydroids, and fishes. Smaller individuals apparently subsist mainly on benthic invertebrates, such as polychaetes, copepods, amphipods, isopods, the shrimp *Crangon septemspinosa*, and euphausiids, while larger skate eat larger and more active prey such as razor clams (*Ensis directus*), large gastropods, squids, crabs (*Cancer* spp. and spider crabs), lobsters and fishes. Fish prey includes spiny dogfish, alewife, Atlantic herring, menhaden, hakes, sculpins, cunner, tautog, sand lance, butterfish, and various flounders.

Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult barndoor skate include: *Cancer* crabs (23%); decapod crabs (18%); other fish (10%); Atlantic herring (9%); pandalid shrimp (8%); and silver hake (7%).

Table 42 – Major prey items of barndoor skate

Life Stage	*Major Prey*	*Location*
Juveniles and Adults	Smaller individuals **Polychaetes; Crustaceans**: copepods, amphipods, isopods, the sand shrimp *Crangon septemspinosa*, euphausiids Larger individuals **Crustaceans**: decapods (*Cancer* spp., spider crabs, lobsters); **Mollusks**: razor clams (*Ensis directus*), large gastropods, squids; **Fish**: Atlantic herring, hakes (esp. silver), spiny dogfish, alewife, menhaden, sculpins, cunner, tautog, sand lance, butterfish, various flounders	U.S. northeast continental shelf

5.5.3 Peak spawning

Information on the spawning periods of barndoor skate (*Dipturus laevis*) comes from the EFH Source Document (Packer *et al*. 2003 and references therein).

Females containing fully formed egg capsules have been taken in December and January (Vladykov 1936; Bigelow and Schroeder 1953), although it is not known if egg capsule production and deposition is restricted to the winter (McEachran 2002).

5.6 Rosette skate

5.6.1 Supplementary table

Table 43 – Summary of habitat information for rosette skate

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	No information	No information	No information	No information
Larvae	Not applicable	Not applicable	Not applicable	Not applicable
Juveniles	Benthic habitats primarily composed of sand, with some mud, mud and sand, and mud and sand with *gravel*	Present 10-500 on shelf, common 71-300	Present 4.5-25.5 on shelf, common 9.5-17.5	Present 30.5-36.5 on shelf, common 34.5-36.5
	Sand to mud bottoms	Found 33-530, most	Found 5.3-15	

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
		common 74-274		
Adults	Assume same as juveniles	Not caught in trawl surveys, see juveniles	Not caught in trawl surveys, see juveniles	Not caught in trawl surveys, see juveniles

**   Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Note: As used in the analysis of sediment associations, the term "gravel" refers to all grain sizes above a diameter of 2 mm, i.e., any sediment coarser than sand, and therefore includes pebbles, cobbles, and even boulders

Sources of information:

- **Juveniles**: Shelf depth, temperature, and salinity ranges derived from NEFSC trawl survey data; information on substrates from GIS overlap analysis of NEFSC survey and USGS USSeabed sediment data and from EFH Source Document; other information also from EFH Source Document.

5.6.2 Prey species

The main source of information on the prey consumed by rosette skate (*Leucoraja garmani virginica*) comes from the EFH Source Document (Packer *et al*. 2003 and references therein). The major prey items of juvenile and adult rosette skate are crustaceans, followed by polychaetes. Crustacean prey includes copepods, amphipods, cumaceans, and decapods such as the shrimp *Crangon septemspinosa* and *Cancer* and galatheoid crabs. Other prey include cephalopods such as squids and octopods, and small fishes. Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult rosette hake include: decapod crabs (15%), polychaetes (14%), *Cancer* crabs (10%), other crabs (7%), and gammarid amphipods (6%).

Table 44 – Major prey items of rosette skate

Life Stage	*Major prey*	*Location*
Juveniles and adutls	**Polychaetes; Crustaceans**: gammarid amphipods, decapods (*Cancer* crabs, other crabs)	U.S. northeast continental shelf

5.6.3 Peak spawning

Information on the spawning periods of rosette skate (*Leucoraja garmani virginica*) comes from the EFH Source Document (Packer *et al*. 2003 and references therein). North of Cape Hatteras the egg capsules are found in mature females year-round but are most frequent during the summer (McEachran 1970).

5.7 Clearnose skate

5.7.1 Supplementary table

Table 45 – Summary of habitat information for clearnose skate

Life Stage	Habitat	Depth (m)*	Temperature (ºC)**	Salinity (ppt)**
Eggs	No information	No information	No information	No information
Larvae	Not applicable	Not applicable	Not applicable	Not applicable
Juveniles	Benthic habitats with substrates composed primarily of sand, also mud and sand with and without *gravel* Found on soft bottoms, but also on rocky or gravelly bottoms	Present 2.7-76 inshore, common min 5 (RB) Present 1-300 on shelf, common 1-30	Present 2.8-27.2 inshore, common 14.5-22.5 (RB) Present 3.5-27.5 on shelf, common 14.5-21.5	Present 19-35 inshore, common 19.5-31.5 (RB) Present 25.5-36.5 on shelf, common 30.5-36.5
Adults	Benthic habitats with substrates composed primarily of sand, also mud and sand with and without *gravel* Found on soft bottoms, but also on rocky or gravelly bottoms	Present 4-76 inshore, common min 5 (RB) Present 1-300 on shelf, common 1-30	Present 4-25.4 inshore, common 14.5-22.5 (RB), 11.5-22.5 (j/a DB), 10-24 (j/a CB) Present 3.5-25.5 on shelf, Common 13.5-21.5 Found 9-30, mostly 9-20 in north, 19-30 NC	Present 19.6-35 inshore, common 19.5-31.5 (RB), 21.5-34.5 (j/a DB), 22-32 (j/a CB) Present 25.5-36.5 on shelf, common 30.5-36.5

* Depth to bottom

** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages

Note: As used in the analysis of sediment associations, the term "gravel" refers to all grain sizes above a diameter of 2 mm, i.e., any sediment coarser than sand, and therefore includes pebbles, cobbles, and even boulders

Sources of information:

- **Juveniles**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; depth, temperature, and salinity ranges ("common") based on Raritan Bay trawl survey data in EFH Source Document. Continental shelf: depth, temperature, and salinity ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data and from information in EFH Source Doc.
- **Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl survey data in areas mapped as EFH; depth, temperature, and salinity ranges ("common") based on Raritan Bay, Delaware Bay, and Chesapeake Bay trawl survey data in EFH Source Document. Continental shelf: depth, temperature, and salinity

ranges derived from NEFSC trawl survey data; sediment types derived from GIS overlap analysis of NEFSC trawl survey and USGS USSeabed sediment data and from information in EFH Source Doc.

Note: Delaware Bay and Chesapeake Bay temperature and salinity data were applied to juveniles and adults – clearnose skates caught during these two surveys were not distinguished by life stage. Also, the substrate information in the EFH Source Document is common to both life stages.

5.7.2 Prey species

The main source of information on the prey consumed by clearnose skate (*Raja eglanteria*) comes from the EFH Source Document (Packer *et al*. 2003 and references therein). Clearnose skate appear to feed mostly on crustaceans and fish. Crustacean prey include amphipods, mysid shrimps (e.g. *Neomysis americana*), the shrimp *Crangon septemspinosa*, mantis shrimps, crabs including *Cancer*, mud, hermit, and spider crabs, and *Ovalipes ocellatus* (lady crab). Fish prey include soles, weakfish, butterfish, and scup. Other prey include polychaetes and mollusks (bivalves, e.g. *Ensis directus*; squids). Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult clearnose skate include: other fish (20%); decapod crabs (16%); *Cancer* or rock crabs (16%); *Loligo* squids (14%); and tonguefish or *Symphurus* sp.(6%).

In the Hudson-Raritan estuary, crustaceans (*Crangon septemspinosa*, juvenile or small Atlantic rock crabs, *Ovalipes ocellatus*), fish (conger eel, juvenile winter flounder, juvenile windowpane), and mollusks (*Ensis directus*) were most frequently found in the stomachs (Steimle *et al*. 2000). In Delaware Bay, crustaceans (*Crangon septemspinosa*, mud crabs, *Neomysis americana*) dominated the diet (Fitz and Daiber 1963). Kimmel (1973) examined juveniles (< 44 cm TL) from the mouth of Chesapeake Bay and found crustaceans (*Crangon septemspinosa*; mud shrimp, *Upogebia affinis*) and mollusks (*Ensis directus*) dominated the diet. This is consistent with the prey that Hildebrand and Schroeder (1928) noted in the few clearnose skate that they examined from inside Chesapeake Bay. In North Carolina, fish prey included striped anchovy, croaker, spot, and blackcheek tonguefish (Schwartz 1996).

Table 46 – Major prey items of clearnose skate

Life Stage	***Major Prey***	***Location***
Juveniles and Adults	**Crustaceans**: amphipods, mysid shrimps (*Neomysis americana*), the shrimp *Crangon septemspinosa*, mantis shrimps, crabs including *Cancer*, mud, hermit, and spider crabs, lady crab (*Ovalipes ocellatus*); **Mollusks**: squids (*Loligo*); **Fish**: soles, weakfish, butterfish, scup, tonguefish	U.S. northeast continental shelf
Juveniles	**Crustaceans**: *Crangon septemspinosa*, mud shrimp (*Upogebia affinis*); M**ollusks**: razor clams (*Ensis directus*)	Mouth of Chesapeake Bay
Juveniles and Adults	**Crustaceans**: *Crangon septemspinosa*, juvenile or small Atlantic rock crabs, *Ovalipes ocellatus*, mud crabs, *Neomysis Americana;* **Mollusks**: razor clams (*Ensis directus*); **Fish**: conger eel, juvenile winter flounder, juvenile windowpane, striped anchovy, croaker, spot, and blackcheek tonguefish.	Hudson-Raritan estuary, Delaware Bay, North Carolina

5.7.3 Peak spawning

Information on the spawning periods of clearnose skate (*Raja eglanteria*) comes from the EFH Source Document (Packer *et al*. 2003 and references therein). The patterns of estradiol concentrations and follicle dynamics indicate the presence of a well-defined annual reproductive cycle, in which mating and egg deposition take place from December to mid May (Rasmussen *et al*. 1999). **North of Cape Hatteras** the egg cases are deposited in the spring and summer; in **Delaware Bay**, Fitz and Daiber (1963) reported spawning to occur only in the spring. Off the central west coast of Florida, egg deposition occurs from December through mid-May (Luer and Gilbert 1985).

Additional References

Rasmussen L E., L, D. L. Hess, and C.A. Luer. 1999. Alterations in serum steroid concentrations in the clearnose skate, *Raja eglanteria*: correlations with season and reproductive status. J. Exp. Zool. 284: 575–585.

6.0 Atlantic sea scallop

6.1 Supplementary table

Table 47 – Summary of Habitat Information for Atlantic Sea Scallop

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Benthic habitats	No information	No information	No information
Larvae	Pelagic and benthic habitats Spat survival enhanced on sedentary branching plants or animals, or any hard surface (e.g., shells, small pebbles); do not survive on shifting sand	No information	Lab study: viable 12-18 (mass mortalities >18)	Lab study: viable as low as 10.5, 16.9-30 preferred
Juveniles	Benthic habitats associated with sand, gravel, and mixtures of gravel, mud, and sand Attach to shells and bottom debris, including gravel and small rocks, most abundant on gravel Currents stronger than 10 cm/s retard feeding and growth	Common 41-120 on shelf (not including GOM), present 21-160 Typically 18-110, but also found as shallow as 2 inshore (GOM) (also adults) Most abundant 62-91 (GB) Found primarily 45-75 in south, less common 25-45 (too warm) Not common >110, but occur as deep as 170-	Present 0.5-20.5, common 5.5-10.5, on shelf (in summer) Lab studies: maximum survival 1.2-15 or <18	Lab study: maximum survival >25

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
		180 in GOM		
Adults	Benthic habitats associated with sand, gravel, and mixtures of gravel, mud, and sand Found on firm sand, gravel, shells, and rock, most abundant on gravel Strong tidal currents (> 25 cm/s) inhibit feeding	Same as juveniles Common or abundant in coastal GOM bays and estuaries (ELMR) (juveniles and adults) Found from low tide level to ~100 m	Optimal growth 10-15, >21 lethal Spawn 6.5-16 Otherwise, same as juveniles	Prefer full strength seawater, <16.5 lethal

**   Depth to bottom*
*** Bottom water temperatures and salinities for benthic life stages and water column temperatures and salinities for pelagic life stages*

Sources of information:

- **Larvae**: All information obtained from EFH Source Document (2nd ed.)
- **Juveniles**: Shelf depth and temperature ranges derived from NEFSC summer scallop dredge survey data (all sizes); sediment associations based on GIS overlap analysis of USGS USSeabed sediment data and NEFSC scallop dredge survey data; other information on substrates, depths, temperatures, and salinities from EFH Source Document (2nd ed.).
- **Adults**: Sediment associations based on analysis of USGS USSeabed sediment data and NEFSC scallop dredge survey data; other information on substrates, temperatures, and salinities from EFH Source Doc (2nd ed.).

Note: Eggs are slightly heavier than seawater and probably remain on the sea floor as they develop into free-swimming larvae which settle to bottom (as "spat") before metamorphosing into juveniles. Juveniles and adults inhabit similar habitats, so information on depth and bottom temperatures in the table is common to both life stages. The NEFSC scallop dredge survey does not include the Gulf of Maine and is only done in summer.

6.2 Prey species

The main source of information on the prey consumed by the larval, juvenile, and adult stages of the Atlantic sea scallop (*Placopecten magellanicus*) comes from the EFH Source Document (Hart *et al*. 2004 and references therein). The Atlantic sea scallop is a pelagic filter feeder in the larval stage and benthic suspension feeders as juveniles/adults. Their diet primarily consists of phytoplankton and microzooplankton (such as ciliated protozoa), but particles of detritus can also be ingested, especially during periods of low phytoplankton concentrations. Dissolved organic matter (absorbed through the tissues) has been suggested as an additional minor source of nutrition, particularly for scallop larvae. Palp-pedal feeding (using the ciliated end of the foot to bring organic matter from biofilms to the labial palps) as well as DOM absorption may also be used by post-settlement scallops, during the time that feeding structures on the gill develop. It is presumed that DOM is a minor nutritional source despite its high concentration, since much of it is found as refractory organic carbon.

Atlantic sea scallops in coastal areas and embayments digest detritus from seaweeds and sea grasses and may be exposed periodically to significant amounts of resuspended inorganic material, while offshore scallops consume primarily phytoplankton and resuspended organic matter. Phytoplankton appears necessary to meet scallop energetic demands, although seaweed detritus may be an important food supplement in nearshore environments. One study showed that a scallop population in shallow water (20 m) fed equally on pelagic and benthic food species, while a deep water population (180 m) fed primarily on benthic species. In both populations, seasonal variations in food items occurred and coincided with bloom periods of individual algal species. The gut contents generally reflected the available organisms in the surrounding habitat, indicating that sea scallops are opportunistic filter feeders which take advantage of both benthic and pelagic food. A total of 27 species of algae, ranging in size from 10-350 μm were identified, plus a number of miscellaneous items including pollen grains, ciliates, zooplankton tests, detrital material, and bacteria.

Table 48 – Major prey items of Atlantic sea scallop

Life Stage	*Major Prey*	*Location*
Pre-settlement (larvae: trochophore and veliger stages)	**Phytoplankton ;Microzooplankton; Detritus**	U.S. northeast continental shelf
Post-settlement (spat, juveniles, adults)	**Phytoplankton; Microzooplankton; Detritus**	U.S. northeast continental shelf
Post-settlement (spat, juveniles, adults)	**Phytoplankton; Seaweed, seagrass detritus; Resuspended inorganic material**	Nearshore, bays and embayments

6.3 Peak spawning

Information on the spawning periods of the Atlantic sea scallop (*Placopecten magellanicus*) comes from the EFH Source Document (Hart *et al*. 2004 and references therein).

Shumway *et al.* (1988) summarized the gametogenic cycle of sea scallops from **Maine**. Spawning takes place in September/October and the animals enter a reproductively quiescent or rest period. Barber *et al.* (1988) found that spawning and reabsorption of mature ova was evident in September and to a greater extent in October, after which the animals underwent a period of recovery (December/January).

Spawning generally occurs synchronously when males extrude sperm and the females release eggs en masse into the water, but it may occur over a more protracted period of time depending on environmental conditions. It has been suggested that year-class strength may correlate with the degree of spawning synchrony, rather than fecundity per se (Langton *et al.* 1987).

A *major annual spawning period* occurs during late summer to fall (August to October) (Parsons *et al.* 1992a) although spring or early summer spawning can also occur, especially in the **Mid-Atlantic** (Barber *et al.* 1988; DuPaul *et al.* 1989; Schmitzer *et al.* 1991; Davidson *et al.* 1993; Almeida *et al.* 1994; Dibacco *et al.* 1995). The timing of spawning can vary with latitude, starting in summer in southern areas and in fall in the northern areas. MacKenzie *et al.* (1978) reported that **off the coast of North Carolina and Virginia**, spawning generally occurred as early as July and that further north on the **Mid-Atlantic shelf** spawning occurred in August. However, there are exceptions to this pattern. MacDonald and Thompson (1988) report that scallops off of **New Jersey** spawned up to two months later than scallops from Newfoundland (September-November versus late August-early September). They found no clearly identifiable latitudinal trends in the timing of spawning. A biannual spawning cycle on the **Mid-Atlantic shelf** has been reported south of the **Hudson Canyon**, with spawning occurring both in the spring and fall (DuPaul *et al.* 1989; Schmitzer *et al.* 1991; Davidson *et al.* 1993). Kirkley and DuPaul (1991) found that *spring spawning in the* **Mid-Atlantic** *is the more predictable and dominant spawning event*, while fall spawning is minor, temporally irregular, and sometimes does not occur. Schmitzer *et al.* (1991) also reported that the *spring spawning was of longer duration and the scallops showed greater fecundity than in the fall*.

North of the Hudson Canyon there is generally a single annual spawning event starting in late summer or early fall. However, there are some reports of biannual spawning (spring and fall) in the **Gulf of Maine** and **Georges Bank**, with the *fall spawning being dominant* (Barber *et al.* 1988; Almeida *et al*. 1994, DiBacco *et al.* 1995). On **Georges Bank** fall spawning generally occurs in late September or early October (Posgay and Norman 1958; MacKenzie *et al.* 1978; McGarvey *et al.* 1992; DiBacco *et al.* 1995). In **Cape Cod Bay**, spawning occurs in late September and early October (Posgay 1950). In the **Gulf of Maine** spawning occurs in August and September (Drew 1906; Welch 1950; Baird 1953; Culliney 1974; Robinson *et al.* 1981; Barber *et al.* 1988). In the Bay of Fundy the spawning period extends from late July to November (Stevenson 1936; Dickie 1955; Beninger 1987; MacDonald and Thompson 1988; Dadswell and Parsons 1992).

Scallops beds generally spawn synchronously in a short time, going from completely ripe to completely spent in less than a week (Posgay and Norman 1958; Posgay 1976). "Dribble spawning" over an extended time period has been reported in scallops from Newfoundland coastal waters (Naidu 1970) and possibly in the **Gulf of Maine** (Langton *et al*. 1987) and in **New Jersey** in June and July (MacDonald and Thompson 1988). A rapid temperature change, the presence in the water of gametes from other scallops, agitation, or tides may trigger scallop spawning (Parsons *et al.* 1992a).

7.0 Atlantic herring

7.1 Supplementary table

Table 49 – Summary of habitat information for Atlantic herring

Life Stage	*Habitat*	*Depth (m)**	*Temperature (ºC)***	*Salinity (ppt)***
Eggs	Benthic habitats with boulders, coarse sand, cobble/pebble, gravel, and/or macroalgae Not on mud or fine sand	5-90 inshore and on shelf	Bottom temperatures over egg beds 7-15 Normal development 1-22	Spawn 32-33 in GOM/GB

Life Stage	***Habitat***	***Depth (m)****	***Temperature (ºC)*****	***Salinity (ppt)*****
	Strong bottom currents enhance survival			
Larvae	Pelagic, in water column	Present 1-1500 on and off shelf, common 41-220 Inshore: minimum 20	Present -0.5 to 14.5 on and off shelf, common 1.5-12.5 Lab study: tolerate -1.8 to 24	Lab study: survived 2.5-52.5 for 7 days (assume max=35)
Juveniles	Pelagic, in water column	Present 4-99 inshore, common 11-65 (MA), 9-17 (RBay), 9-21 (DBay), 4-16 (CBay) Present 1-400 on shelf, common 21-300 on shelf YOY caught in beach seines	Present 0-28 inshore, common 3.5-14.5 (MA), 13.5-21.5 (RBay), 5-13 (DBay), 10-22 (CBay) Common 2.5-10.5 on shelf Can survive -1.1 Lab study: prefer 8-12	Present 5-36.5 inshore, common 20.5-31.5 (RBay), 11-26 (DBay), 18-28 (CBay) Common 30.5-34.5 on shelf YOY can tolerate salinities as low as 5 for a short time; older juveniles avoid brackish water Lab study: prefer 28-32
Adults	Pelagic, in water column; spawn on bottom	Present 4-84 inshore, common 31-85 (MA), 7-16 (RBay), 10-21 (DBay) Present 1-400 on shelf, common 11-300 Spawn 5-90 (see eggs)	Present 0-20 inshore, common 1.5-10.5 (MA), 1.5-9.5 (RBay), 0-11 (DBay) Common 2.5-10.5 on shelf Prefer 5-9 during spawning season (GB)	Present 16-36, common 18.5-33.5 (RBay), 11-29 (DBay) Common 29.5-35.5 on shelf Rarely found in low salinities; lower limit 28 Spawn 32-33

** Depth to bottom*
*** Bottom water temperatures and salinities for eggs and water column temperatures and salinities for larvae, juveniles, and adults*

Note: Information based on bottom trawl survey data cited in this table were not used to map EFH for this species, since it is a pelagic species.

Sources of information:

- **Eggs**: All information on eggs obtained from EFH Source Document (2nd ed).
- **Larvae**: Shelf depth and temperature ranges derived from MARMAP data in EFH Source Document (2nd ed.); other information from EFH Source Document (2nd ed.) and Lazzari and Stevenson (1992).

- **Juveniles**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl surveys in areas mapped as EFH; depth, temperature, and salinity ranges ("common") from analysis of MA, Chesapeake Bay, and Raritan Bay trawl survey data in EFH Source Doc (2nd ed.) and Delaware Bay trawl survey data in Morse (2000). Continental shelf: depth and temperature ranges derived from NEFSC bottom trawl survey data. All other information from EFH Source Document (2nd ed.) and from reports on seine surveys conducted in NH, RI, MD, and VA.
- **Adults**: Inshore: depth, temperature, and salinity ranges (presence only) based on inshore seine and trawl surveys in areas mapped as EFH; depth, temperature, and salinity ranges ("common") from analysis of MA and Raritan Bay trawl survey data in EFH Source Doc (2nd ed.) and Delaware Bay trawl survey data in Morse (2000). Continental shelf: depth and temperature ranges derived from NEFSC bottom trawl survey data. All other information from EFH Source Document (2nd ed.) and Munroe (2002).

7.2 Prey species

The main source of information on the prey consumed all life stages of Atlantic herring (*Clupea harengus*) comes from the EFH Source Document (Stevenson and Scott 2005 and references therein). Atlantic herring prey upon a variety of planktivorous organisms. All life stages of herring are opportunistic feeders, and will take advantage of whatever prey of the appropriate size is available. As they grow and the size of their jaws increases, they consume larger organisms. Their diet therefore varies with season, their age and size, and location.

Newly-hatched larvae (7-20 mm) in coastal waters of central Maine feed primarily on the small, early developmental stages of copepods; during the winter, larger larvae (21-30 mm) feed on the adult stages of small copepods as well. During the spring, when a wider variety of planktonic organisms are available and the larvae are larger, their diet includes organisms such as barnacle larvae, crustacean eggs, copepods, and free-swimming ciliate protozoans (tintinnids). Three copepod species preyed upon by larval herring on Georges Bank are *Pseudocalanus* sp., *Paracalanus parvus*, and *Centropages typicus*.

Juveniles feed on up to 15 different groups of zooplankton; the most common are copepods, decapod larvae, barnacle larvae, cladocerans, and molluscan larvae. Adults have a diet dominated by euphausiids, chaetognaths, and copepods. The most important prey items of adults herring collected on Georges Bank were chaetognaths (*Sagitta elegans*, 43% by weight), euphausiids (*Meganyctiphanes norvegica*, 23%; *Thysanoessa inermis*, 6.1%), pteropods (*Limacina retroversa*, 6.2%), and copepods (3%). The copepod *Calanus finmarchicus* is a common prey item. In addition, adults also consume fish eggs and larvae, including larval herring, sand lance, and silversides.

Food habits data collected during NEFSC bottom trawl surveys reveal that the most abundant identifiable prey items (percent by weight) for Atlantic herring include amphipods, copepods, and euphausiids. Jason Link (NOAA/NMFS/NEFSC, Woods Hole Laboratory, personal communication) has updated the food habits database from 1973-2005 and reports that the prey exceeding the 5% by weight threshold in the stomachs of juvenile and adult Atlantic herring include: euphausiids (18%), copepods (16%), and gammarid amphipods (7%).

Table 50 – Major prey items of Atlantic herring

Life Stage	*Major Prey*	*Location*
Larvae		Central Gulf of Maine, Georges Bank
Newly hatched (7-20 mm)	**Copepods**: small, early developmental stages	
--------------	------------	
Large (21-30 mm)	**Copepods**: adult stages of small copepods (e.g.; are *Pseudocalanus* sp., *Paracalanus parvus*, and *Centropages typicus* are *Pseudocalanus* sp., *Paracalanus parvus*, and *Centropages typicus*)	
-------------	------------	
Larger (> 30 mm)	**Barnacle larvae, crustacean eggs, copepods, free-swimming ciliate protozoans (tintinnids)**	
Juveniles (< 25 cm TL)	**Zooplankton: copepods, decapod larvae, barnacle larvae, cladocerans, molluscan larvae.**	U.S. northeast continental shelf
Adults (≥ 25 cm TL)	**Chaetognaths**: *Sagitta elegans;* **Crustaceans**: euphausiids (*Meganyctiphanes norvegica*, *Thysanoessa inermis*), amphipods, copepods; **Mollusks**: pteropods (*Limacina retroversa*)	U.S. northeast continental shelf; Georges Bank

7.3 Peak spawning

Information on the spawning periods of Atlantic herring (*Clupea harengus*) comes from the EFH Source Document (Stevenson and Scott 2005 and references therein).

In the northwest Atlantic, herring spawn from **Labrador to Nantucket Shoals**. Spawning occurs in the spring, summer, and fall in more northern latitudes, but summer and fall spawning predominates in the **Gulf of Maine-Georges Bank region** (Haegele and Schweigert 1985).

In U.S. waters of the **Gulf of Maine**, herring eggs have been observed along the **eastern Maine coast**, at several **other locations along the Maine coast** (e.g., outer Penobscot Bay and near Boothbay), on Jeffreys Ledge and Stellwagen Bank, and on **eastern Georges Bank**. **Nantucket Shoals** is known to be an important spawning ground based on the concentrations of recently-hatched larvae that were repeatedly collected there during the 1970s and 1980s (Grimm 1983; Smith and Morse 1993). High concentrations of recently-hatched larvae have also been collected in the vicinity of **Cultivator Shoals on western Georges Bank**, in the vicinity of **Stellwagen Bank and Jeffreys Ledge**, and on the **outer continental shelf in southern New England** (Grimm 1983; Smith and Morse 1993). High densities of recently-hatched larvae have also been observed in **Saco Bay and Casco Bay on the southern Maine coast** (Graham *et al*. 1972b, *et al*. 1973).

The spawning season in the **Gulf of Maine-Georges Bank** region begins in July and lasts until December. Spawning begins earlier in the northern areas of the **Gulf**. Off southwestern Nova Scotia, spawning occurs from July to November and *peak*s in September-October (Boyar 1968; Das 1968, 1972) Spawning in **eastern Maine coastal waters** during 1983-1988 extended from late July through early October, with *peak* spawning in late August (Stevenson 1989), but more recent egg bed surveys (1997-2002) in the same area indicated that spawning did not start until late August and lasted until October 21 (Neal and Brehme 2001; Neal 2003). Based on larval surveys, Graham *et al*. (1972b) concluded that spawning *peak*s in mid-September to mid-October in **eastern Maine** and in October in **western Maine**. Boyar *et al*. (1973) reported that spawning on **Jeffreys Ledge** in 1972 started in early September and *peak*ed during the first three weeks of October. On **Georges Bank**, spawning occurs from late August to December (Boyar 1968; Berenbeim and Sigajev 1978; Lough *et al*. 1980) with a *peak* in September-October (Boyar 1968; Pankratov and Sigajev 1973; Grimm 1983). On **Nantucket Shoals**, spawning *peak*s from October to early November, 1-2 weeks later than on **Georges Bank** (Lough *et al*. 1980; Grimm 1983). Larval surveys conducted during 1971-1975 indicated that spawning on **Georges Bank** started on the **Northeast Peak** of the Bank in September and extended southwest to **Nantucket Shoals** in October, declined in November and was absent in December (Grimm 1983).

8.0 Deep-sea red crab

8.1 Prey species

The main source of information on the prey consumed by red deepsea crab [*Chaceon (Geryon) quidquedens*] comes from the EFH Source Document (Steimle *et al*. 2002 and references therein). No information is known on the natural diets of red crab larvae, but it is probably zooplanktivorous, as they were found to thrive on rotifers, brine shrimp, and chopped mollusk meats in laboratory cultures.

Red crabs are opportunistic feeders. Post-larval, benthic red crabs eat a wide variety of infaunal and epifaunal benthic invertebrates (e.g. bivalves) that they find in the silty sediment or pick off the seabed surface. Smaller red crabs eat sponges, hydroids, mollusks (gastropods and scaphopods), small polychaetes and crustaceans, and possibly tunicates. Larger crabs eat similar small benthic fauna and larger prey, such as demersal and mid-water fish (*Nezumia* and myctophids), squid, and the relatively large, epibenthic, quill worm (*Hyalinoecia artifex*).They can also scavenge deadfalls (e.g., trawl discards) of fish and squid, as they are readily caught in traps with these as bait and eat them when held in aquaria.

Table 51 – Major prey items of deep-sea red crab

Life Stage	***Major Prey***	***Location***
Larvae (4 zoeal and 1 megalopa stages)	**Zooplankton**	U.S. northeast continental shelf/slope
Juveniles and Adults	Smaller **Sponges; Hydroids; Polychaetes; Mollusks**: gastropods, scaphopods Larger **Sponges; Hydroids; Annelids**: polychaetes, quill worm (*Hyalinoecia artifex*); **Mollusks**: gastropods, scaphopods, squids; **Fish**: *Nezumia*, myctophids	U.S. northeast continental shelf/slope

8.2 Peak spawning

Information on the spawning periods of red deepsea crab [*Chaceon (Geryon) quidquedens*] comes from the EFH Source Document (Steimle *et al*. 2002 and references therein). Erdman *et al*. (1991) suggested that the egg brooding period may be about nine months, at least for the Gulf of Mexico population, and larvae are hatched in the early spring there. There is no evidence of any restricted seasonality in spawning activity in any geographic region of the population, although a mid-winter *peak* is suggested as larval releases are reported to extend from January to June (Wigley *et al*. 1975; Haefner 1978; Lux *et al*. 1982; Erdman *et al*. 1991; Biesiot and Perry 1995). Laboratory studies also found hatching to occur from April to June (Perkins 1973). Gerrior (1981), however, suggested that red crab egg hatching occurred later, between July and October, based on the ratio of egg-bearing to non-egg-bearing crabs.

9.0 Atlantic salmon

9.1 Peak spawning

Information on the spawning periods of Atlantic salmon (*Salmo salar*) comes from the EFH Source Document (Maltz et al., in draft, and references therein).

Spawning in freshwater occurs in late October through November. U.S. Atlantic salmon populations are typically spring run with the majority of fish entering rivers in June through August. Therefore, depending upon their date of return, these fish may spend 1-6 months in the river prior to spawning. Incubation time may be 4-7 months in **Maine rivers** (DeCola 1970).

10.0 Summary tables

Table 52 – Summary of pelagic prey consumed by managed species

Prey group	Pelagic genera or species	American plaice	Atlantic cod	Atlantic halibut	Atlantic herring	Atlantic sea	Barndoor skate	Clearnose skate	Deep-sea red	Haddock	Little skate	Monkfish	Ocean Pout	Offshore hake	Pollock	Redfish	Red hake	Rosette skate	Silver hake	Smooth skate	Thorny skate	White hake	Witch flounder	Windowpane	Winter flounder	Winter skate	Yellowtail	Count
Plankton	**Plankton, total**	x	x		x	x	x		x	x		x			x	x	x		x			x		x	x			15
	Phytoplankton					x				x									x									3
	Microzooplankton					x																						1
	Zooplankton								x			x																2
	Copepods	x	x		x		x			x		x			x	x	x		x			x		x	x			13
	Diatoms	x																										1
	Decapod larvae				x							x												x				3
	crustacean eggs				x																				x			2
Chaetognaths	**Chaetognaths, total**				x							x			x									x				4
	Sagitta elegans				x										x													2
Mollusks	**Mollusks, total***	x	x	x	x		x	x	x	x	x	x	x	x	x		x		x		x	x		x	x	x		20
	pteropods				x																							1
	cephalopods (squids)		x	x			x	x	x			x		x	x		x		x			x		x				12
	Illex			x								x		x	x													4
	Loligo							x				x			x				x			x						5
	Rossia																		x									1
Fish	**Fish, total***	x	x	x			x	x	x	x	x	x		x	x	x	x		x	x	x	x		x	x	x		20
	Atlantic herring	x									x	x			x				x		x					x		7
	Herring		x				x			x																x		4
	Blueback herring																		x									1
	Alewife						x																					1
	Bay anchovy																		x					x				2
	Striped anchovy							x																				1
	Menhaden						x					x							x									3
	Clupeids			x						x							x		x			x						5

Prey group	Pelagic genera or species	American plaice	Atlantic cod	Atlantic halibut	Atlantic herring	Atlantic sea	Barndoor skate	Clearnose skate	Deep-sea red	Haddock	Little skate	Monkfish	Ocean Pout	Offshore hake	Pollock	Redfish	Red hake	Rosette skate	Silver hake	Smooth skate	Thorny skate	White hake	Witch flounder	Windowpane	Winter flounder	Winter skate	Yellowtail	Count
	Bluefish		x																									1
	Mackerels		x							x		x							x									4
	Butterfish						x	x				x							x							x		5
	Myctophids								x						x													2
	Silversides																		x									1
	Argentines																					x						1
* totals include benthic and pelagic species																												

Table 53 – Summary of benthic invertebrate prey consumed by managed species

Prey group	Subgroups (order or family)	Genera or species	American plaice	Atlantic cod	Atlantic halibut	Atlantic herring	Atlantic sea	Barndoor skate	Clearnose skate	Deep-sea red	Haddock	Little skate	Monkfish	Ocean Pout	Offshore hake	Pollock	Redfish	Red hake	Rosette skate	Silver hake	Smooth skate	Thorny skate	White hake	Witch flounder	Windowpane	Winter flounder	Winter skate	Yellowtail	Count
Sponges										x																			1
Urochordates																	x												1
Nemerteans																										x		x	2
Cnidarians	**Cnidarians, all**									x	x															x		x	4
		Hydroids								x																x			2
		Anthozoans																								x		x	2
Nematodes			x													x		x								x	x		5
Polychaetes	**Polychaetes, all**		x					x		x	x	x		x				x	x	x	x	x	x	x		x	x	x	16
	Oenonidae	**Oenonids, all**																										x	1
		Drilonereis sp.																										x	1
	Sigalionidae	**Sigalionids, all**																											0
	Opheliidae	**Opheliids, all**																										x	1

Prey group	Subgroups (order or family)	Genera or species	American plaice	Atlantic cod	Atlantic halibut	Atlantic herring	Atlantic sea	Barndoor skate	Clearnose skate	Deep-sea red	Haddock	Little skate	Monkfish	Ocean Pout	Offshore hake	Pollock	Redfish	Red hake	Rosette skate	Silver hake	Smooth skate	Thorny skate	White hake	Witch flounder	Windowpane	Winter flounder	Winter skate	Yellowtail	Count
		Ophelia sp.																										x	**1**
	Scalibregmatidae	**Scalibrematids, all**																									x		**1**
		Scalibregma inflatum																									x		**1**
	Spionidae	**Spionids, all**																								x		x	**2**
		Streblospio sp.																								x			**1**
		Marenzelleria viridis																								x			**1**
		Spiophanes bombyx																										x	**1**
	Capitellidae	**Capitellids,all**																						x		x			**2**
		Capitella sp.																								x			**1**
	Cirratulidae	**Cirratulids, all**												x															**1**
	Nephtyidae	**Nephytids, all**	x									x										x		x		x	x	x	**7**
		Nephtys spp.										x												x					**2**
		Nephtys incisa										x														x	x		**3**
		Nephtys discors																				x							**1**
	Terebellids	**Terebellids, all**										x										x		x					**3**
	Maldanids	**Maldanids, all**										x														x	x		**3**
	Aphroditidae	**Aphroditids, all**										x										x							**2**
		Aphrodite hastata																				x							**1**
	Flabelligeridae	**Flabelligerids, all**										x														x			**2**
		Pherusa affinis																								x			**1**
	Glyceridae	**Glycerids, all**										x						x		x				x		x			**5**
		Glycera dibranchiata										x												x					**2**
		Glycera sp.																x		x						x			**3**
	Lumbrineridae	**Lumbrinerids, all**																				x		x		x	x		**4**
		Lumbrineris fragilis																						x		x	x		**3**
		Lumbrineris sp.																									x		**1**
		Ninoe brevipes																						x					**1**
	Nereidae	**Nereids, all**																				x				x	x		**3**

Prey group	Subgroups (order or family)	Genera or species	American plaice	Atlantic cod	Atlantic halibut	Atlantic herring	Atlantic sea	Barndoor skate	Clearnose skate	Deep-sea red	Haddock	Little skate	Monkfish	Ocean Pout	Offshore hake	Pollock	Redfish	Red hake	Rosette skate	Silver hake	Smooth skate	Thorny skate	White hake	Witch flounder	Windowpane	Winter flounder	Winter skate	Yellowtail	Count
		Nereis sp.																								x	x		**2**
		Nereis succinea																								x			**1**
	Sabellidae	**Sabellids, all**																				x				x			**2**
	Ophelidae	**Ophelids, all**																				x							**1**
	Sternaspidae	**Sternaspids, all**																				x		x					**2**
		Sternaspis scutata																				x							**1**
	Eunicidae	**Eunicids, all**																				x							**1**
		Eunice pennata																				x							**1**
	Goniadidae	**Goniadids, all**																						x					**1**
		Goniada sp.																						x					**1**
		Ophioglycera gigantea																						x					**1**
	Ampharetidae	**Ampharetids, all**																								x	x	x	**3**
		Ampharete arctica																									x	x	**2**
		Ampharete sp.																								x			**1**
	Ampharetidae	*Melinna cristata*																								x			**1**
		Asabellides oculata																								x			**1**
	Trichobranchidae	*Trichobranchids, all*																								x			**1**
		Trichobranchus glacialis																								x			**1**
Crustaceans	**Crustaceans, all**		x	x	x	x		x	x		x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	**23**
	Amphipods, all		x	x		x		x	x		x	x		x		x	x	x		x	x	x	x	x	x	x	x	x	**20**
	Aoridae (gammarid)	**Aoridae, all**										x		x				x		x		x				x		x	**7**
		Unciola irrorata										x		x												x	x	x	**5**
		Unciola inermis										x																	**1**
		Unciola sp.																x								x	x		**3**
		Lembos sp.																								x			**1**

Prey group	Subgroups (order or family)	Genera or species	American plaice	Atlantic cod	Atlantic halibut	Atlantic herring	Atlantic sea	Barndoor skate	Clearnose skate	Deep-sea red	Haddock	Little skate	Monkfish	Ocean Pout	Offshore hake	Pollock	Redfish	Red hake	Rosette skate	Silver hake	Smooth skate	Thorny skate	White hake	Witch flounder	Windowpane	Winter flounder	Winter skate	Yellowtail	Count
		Leptocheirus pinguis										x		x				x		x		x				x	x	x	**8**
	Ischyroceridae (gammarid)	**Chyroceridae, all**										x				x		x				x				x			**5**
		Ericthonius rubricornis										x				x						x						x	**4**
		Ericthonius sp.																x								x			**2**
	Ampeliscids (gammarid)	**Ampeliscids, all**										x						x		x		x				x	x		**6**
		Byblis serrata										x								x		x				x	x		**5**
		Ampelisca sp.																x		x						x			**3**
		Ampelisca agassizi																		x						x			**2**
		Ampelisca spinipes																		x									**1**
		Ampelisca vadorum																		x						x			**2**
		Ampelisca abdita																		x						x			**2**
	Haustoriids (gammarid)	**Haustoriids, all**										x															x		**2**
	Oedicerotids (gammmarid)	**Oedicerotids, all**										x						x		x		x					x	x	**6**
		Monoculodes intermedius										x								x									**2**
		Monoculodes spp.										x						x											**2**
		Monoculodes edwardsi										x								x		x					x		**4**
		Synchelidium sp.										x																	**1**
	Eusiridae (gammarid)	**Eusiridids, all**																x								x			**2**
		Pontogeneia inermis																x								x			**2**
	lysianassidae (gammarid)	**lysianassids, all**																				x					x		**2**
		Psammonyx nobilis																				x					x		**2**
		Hippomedon serratus																				x					x		**2**
	Melitidae (gammarid)	**Melitids, all**																				x							**1**
		Melita dentata																				x							**1**
	Uristidae	**Uristids, all**																					x						**1**

Prey group	Subgroups (order or family)	Genera or species	American plaice	Atlantic cod	Atlantic halibut	Atlantic herring	Atlantic sea	Barndoor skate	Clearnose skate	Deep-sea red	Haddock	Little skate	Monkfish	Ocean Pout	Offshore hake	Pollock	Redfish	Red hake	Rosette skate	Silver hake	Smooth skate	Thorny skate	White hake	Witch flounder	Windowpane	Winter flounder	Winter skate	Yellowtail	Count
	(gammarid)	*Anonyx sarsi*																					x						**1**
	Corophiidae	**Corophids, all**																								x			**1**
		Corophium sp.																								x			**1**
		Corophium lacustre																											**0**
	Podoceridae (gammarid)	**Podocerids, all**																										x	**1**
		Dulichia sp.																										x	**1**
	Gammeridae (gammarid)	**Gammarids, all**																x		x					x	x		x	**5**
		Gammarus lawrencianus																x		x					x	x			**4**
		Gammarus annulatus																							x			x	**2**
		Gammarus sp.																								x			**1**
	Other gammarids	Unidentified gammarids										x							x		x	x					x	x	**6**
	Caprellids	**Caprellids, all**										x														x			**2**
		Aeginina longicornis																								x			**1**
	Hyperiids	**Hyperiids, all**												x			x			x									**3**
		Parathemisto sp.												x			x												**2**
	Cumaceans	**Cumaceans, all**	x									x								x		x							**4**
	Isopods	**Isopods, all**						x				x						x			x	x				x	x		**7**
		Cirolana [= *Politolana?] polita*																				x					x		**2**
	Decapods, all		x	x	x			x	x		x	x		x	x	x	x	x	x	x	x	x	x		x	x	x	x	**21**
	Other decapods	*Eualus pusiolus*																				x							**1**
		mud shrimp (*Upogebia affinis*)							x			x																	**2**
		Pasiphaea sp.													x					x									**2**
		Crangon septemspinosa	x	x	x			x	x			x				x		x		x	x		x		x	x	x	x	**15**

Prey group	Subgroups (order or family)	Genera or species	American plaice	Atlantic cod	Atlantic halibut	Atlantic herring	Atlantic sea	Barndoor skate	Clearnose skate	Deep-sea red	Haddock	Little skate	Monkfish	Ocean Pout	Offshore hake	Pollock	Redfish	Red hake	Rosette skate	Silver hake	Smooth skate	Thorny skate	White hake	Witch flounder	Windowpane	Winter flounder	Winter skate	Yellowtail	Count
		Sclerocrangon boreas																		x									1
		Palaemonetes sp.																								x			1
		Mantis shrimps							x			x																	2
	Pandalid shrimp	**Pandalid shrimp, all**		x	x							x			x	x	x	x		x	x	x	x		x		x		13
		Dichelopandalus leptocerus										x			x	x		x		x		x	x				x		8
		Pandalus borealis														x				x			x						3
	Crabs	**Crabs, all**		x	x			x	x			x		x				x	x	x	x	x				x	x		13
		Cancer spp.		x	x			x	x			x		x				x	x			x				x	x		11
		mud crabs							x																				1
		spider crabs/*Hyas*						x	x					x								x							4
		hermit/pagurid							x			x						x			x	x				x	x		7
		lady crab (*Ovalipes ocellatus*)							x			x															x		3
		Lobster						x																					1
	Euphausids	**Euphausiids, all**	x	x		x		x			x				x	x	x	x		x	x	x	x						13
		Meganyctiphanes norvegica				x									x	x	x	x		x		x	x						8
		Thysanoessa inermis				x																							1
		Thysanoessa raschi													x														1
	Mysid shrimp	mysid shrimp, all	x	x					x			x						x		x	x	x			x	x			10
		Neomysis americana		x					x			x						x		x					x	x			7
		Heteromysis formosa																x		x									2
		Erythrops																				x							1

Prey group	Subgroups (order or family)	Genera or species	American plaice	Atlantic cod	Atlantic halibut	Atlantic herring	Atlantic sea	Barndoor skate	Clearnose skate	Deep-sea red	Haddock	Little skate	Monkfish	Ocean Pout	Offshore hake	Pollock	Redfish	Red hake	Rosette skate	Silver hake	Smooth skate	Thorny skate	White hake	Witch flounder	Windowpane	Winter flounder	Winter skate	Yellowtail	Count
		erythrophthalma																											
		Mysidopsis bigelowi																							x				**1**
Mollusks	**Mollusks, all**		x	x	x	x		x	x	x	x	x	x	x	x	x		x		x		x	x		x	x	x		**20**
	Bivalves	**Bivalves, all**	x					x	x		x	x		x				x								x	x		**9**
		razor clam *(Ensis directus)*						x	x			x														x	x		**5**
		Chlamys islandica	x																										**1**
		Cyclodardia borealis	x																										**1**
		Pectinidae												x															**1**
		Cerastoderma pinnulatum												x															**1**
		clam siphons																								x			**1**
		blue mussels																								x			**1**
		Macoma sp.																								x			**1**
		Solemya sp.																								x			**1**
		Nuculla proxima																								x			**1**
		Tellina agilis																								x			**1**
		Yoldia sp.																								x			**1**
		Solenidae																									x		**1**
	Gastropods	*gastropods*						x		x																			**2**
	Scaphalopods	*scaphalopods*								x																			**1**
Echinoderms	**Echinoderms, all**		x								x			x															**3**
	Ophiuroids	**Ophiuroids, all**	x								x			x															**3**
		Ophiura sarsi	x											x															**2**
		Ophiopholis aculeata												x															**1**
	Echinoids	**Echinoids, all**	x											x															**2**
		Echinarachnius parma	x											x															**2**

Prey group	Subgroups (order or family)	Genera or species	American plaice	Atlantic cod	Atlantic halibut	Atlantic herring	Atlantic sea	Barndoor skate	Clearnose skate	Deep-sea red	Haddock	Little skate	Monkfish	Ocean Pout	Offshore hake	Pollock	Redfish	Red hake	Rosette skate	Silver hake	Smooth skate	Thorny skate	White hake	Witch flounder	Windowpane	Winter flounder	Winter skate	Yellowtail	Count
	Asteroids	**Asteroids, all**	x																										**1**

Table 54 – Summary of benthic fish prey consumed by managed species

Benthic fish species	American plaice	Atlantic cod	Atlantic halibut	Atlantic herring	Atlantic sea	Barndoor skate	Clearnose skate	Deep-sea red	Haddock	Little skate	Monkfish	Ocean Pout	Offshore hake	Pollock	Redfish	Red hake	Rosette skate	Silver hake	Smooth skate	Thorny skate	White hake	Witch flounder	Windowpane	Winter flounder	Winter skate	Yellowtail	Count
Silver hake		x	x			x					x		x	x	x	x		x	x	x	x		x		x		**14**
White hake																					x						**1**
Other hakes		x				x					x		x														**4**
Cod			x								x																**2**
Haddock											x																**1**
Tomcod											x																**1**
Other gadids		x	x										x			x					x						**5**
Fourbeard rockling											x																**1**
Redfish		x																									**1**
Toadfish		x																									**1**
Windowpane							x																				**1**
Winter flounder							x																		x		**2**
Witch flounder											x								x								**2**
Yellowtail flounder																			x								**1**
Flatfish/flounder		x				x	x				x																**4**
Eelpouts/Ocean pout			x																								**1**
Longhorn sculpin			x																						x		**2**
Sculpins						x					x																**2**
Rock eel			x																								**1**

Benthic fish species	American plaice	Atlantic cod	Atlantic halibut	Atlantic herring	Atlantic sea	Barndoor skate	Clearnose skate	Deep-sea red	Haddock	Little skate	Monkfish	Ocean Pout	Offshore hake	Pollock	Redfish	Red hake	Rosette skate	Silver hake	Smooth skate	Thorny skate	White hake	Witch flounder	Windowpane	Winter flounder	Winter skate	Yellowtail	Count
Sand lance		x	x			x			x		x			x		x		x	x	x			x	x	x		13
Cunner						x					x																2
Tautog						x					x																2
Weakfish							x				x																2
Scup							x																				1
Tonguefish							x																				1
Conger eel							x																				1
Croaker							x																				1
Spot							x																				1
Nezumia/grenadier								x																			1
Cusk																							x				1
Gobies																							x				1
Black sea bass											x																1
Sea raven											x																1
Searobins											x					x											2
Wolffish														x													1
Wrymouth																				x							1
Spiny dogfish						x					x																2
Hagfish																				x							1
Skates											x														x		2

Table 55 – Peak spawning periods.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Notes
American plaice			M	P	P	M							GLOBEC: Georges Bank peak egg abundance also in March.
Atlantic cod, GB	M	P	P	P	M						M	M	GLOBEC: peak February-March, mostly on Northeast Peak.
Atlantic cod, GOM	P	P	P	P	P	M					M	M	Peak spawning period varies depending on location; spawning occurs later in year in more northerly regions.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Notes
Atlantic halibut (Can.)	M	M	M	M	M						P	P	Spawning on slopes of continental shelf and offshore banks.
Atlantic herring, GB							M	P	P	P	M		Includes Nantucket Shoals.
Atlantic herring, GOM								M	P	P	P	M	Coastal areas, includes Jeffreys Ledge.
Atlantic salmon										M	M		Spawn in freshwater; no peak periods given.
Haddock, GB	M	P	P	P	M	M							Concentrated on Northeast Peak.
Haddock, GOM		P	P	P	M								Two primary spawning sites are Jeffreys Ledge, Stellwagen Bank.
Monkfish			M	M	P	P	M	M	M				
Ocean pout								P	P	P	M	M	Earlier peak spawning (August-October) in the south.
Offshore hake		M	M	M	M	M	M	M	M	M			No peak periods given; spawning occurs over a protracted period or continually throughout the year.
Pollock	P	P	M	M					M	M	P	P	Spawning time more variable in north than in south.
Redfish				M	P	P	P	P					Eggs fertilized internally, larvae released. MARMAP: peak August.
Red hake, GOM					M	M	P	P	M				
Red hake, GB					P	P	M	M	M				
Red hake, MAB/SNE			M	M	M	M	M	M	M	M			No peak periods given.
Red hake, NYB					P	P	M	M	M	M	M		
Silver hake					P	P	P	P	M	M			Peak May-June in southern stock, July-August in northern stock.
White hake, southern stock				M	M								Deep waters along continental slope, primarily off southern Georges Bank and Mid-Atlantic Bight. No peak periods given.
Windowpane, GB				M	M	M	P	P	M	M			MARMAP.
Windowpane, MAB		M	M	M	P	M	M	M	P	P	M		Split spawning season. MARMAP data included.
Winter flounder	M	P	P	P	P						M	M	Spawning occurs earlier in southern part of range. Peak: February, March in Mass. Bay and south of Cape Cod and somewhat later along coast of Maine continuing into May. GB peak (MARMAP/GLOBEC egg collections): March-May.

Species	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Notes**
Witch flounder, GB/GOM				M	P	P	P	P	M	M	M		Spawning occurs progressively later from south to north.
Witch flounder, MAB			M	M	P	P	M	M					Spawning occurs progressively later from south to north.
Yellowtail flounder			M	P	P	P	M	M					

M: Major spawning months
P: Peak spawning months
Information obtained from EFH Source Documents and Update Memos.
Table does not include Atlantic sea scallops, barndoor skate, clearnose skate, deep-sea red crab, little skate, rosette skate, smooth skate, thorny skate, winter skate.

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OMNIBUS ESSENTIAL FISH HABITAT AMENDMENT 2 DRAFT ENVIRONMENTAL IMPACT STATEMENT

Appendix C: EFH designation map representations as approved in June 2007, with corrections

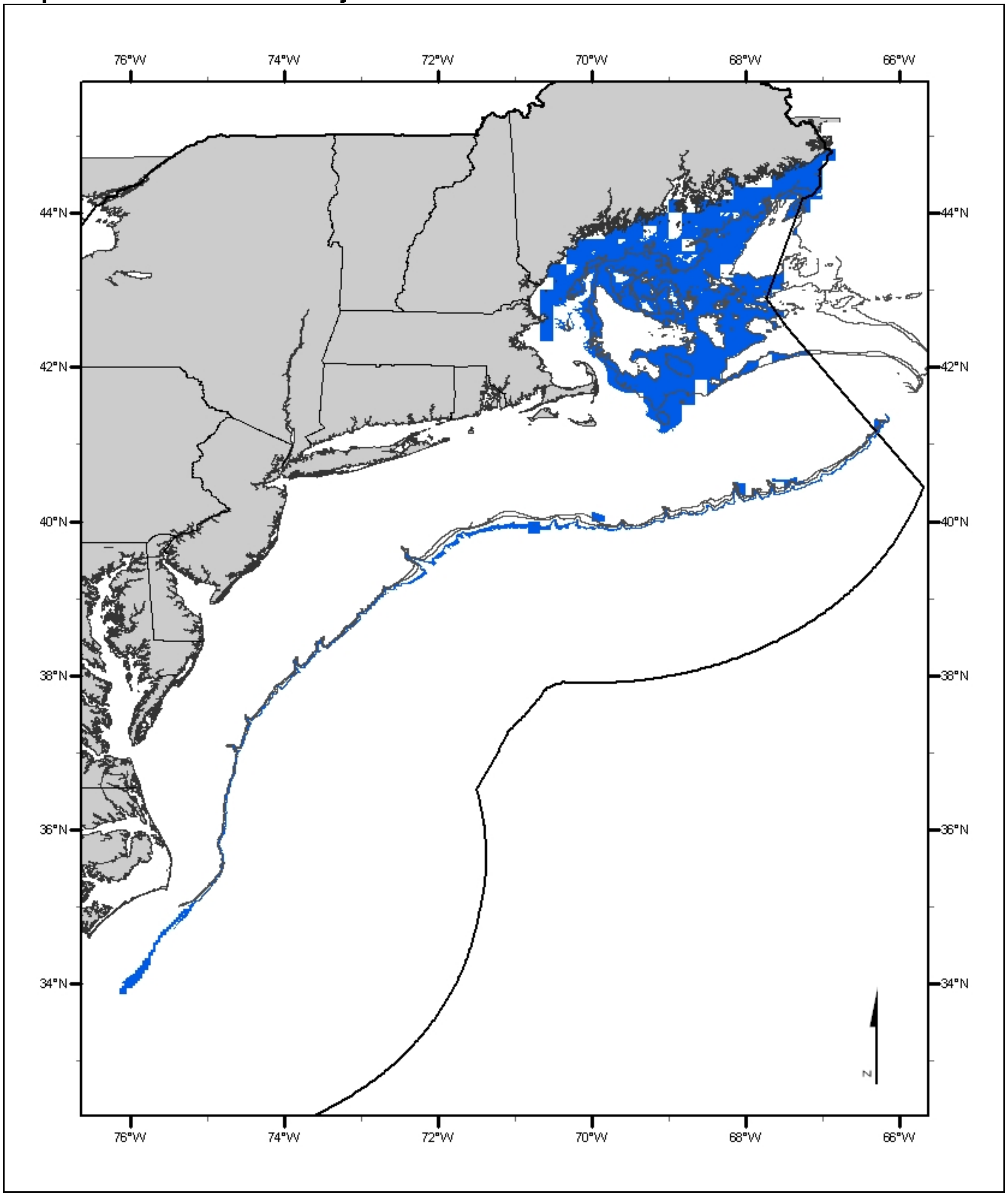
Contents

Maps

1.0 Northeast multispecies (groundfish)

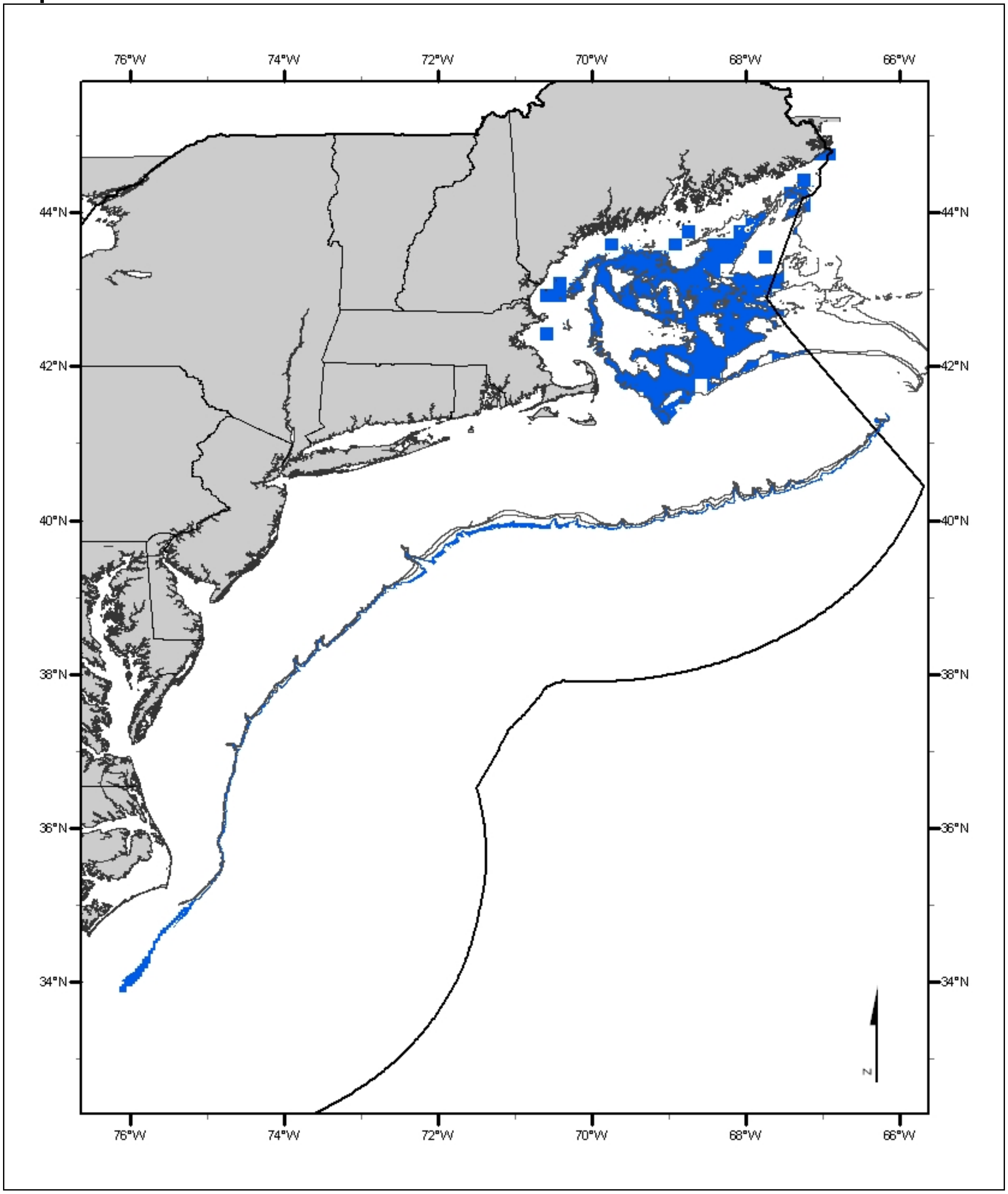
1.1 Acadian redfish (*Sebastes fasciatus*)

Map 1. Redfish larvae and juveniles



The Alternative 3D EFH designation for redfish larvae and juveniles on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore and off-shelf areas where juvenile redfish were determined to be present, based on 10% frequency of occurrence in state trawl surveys and off-shelf depth and geographic ranges.

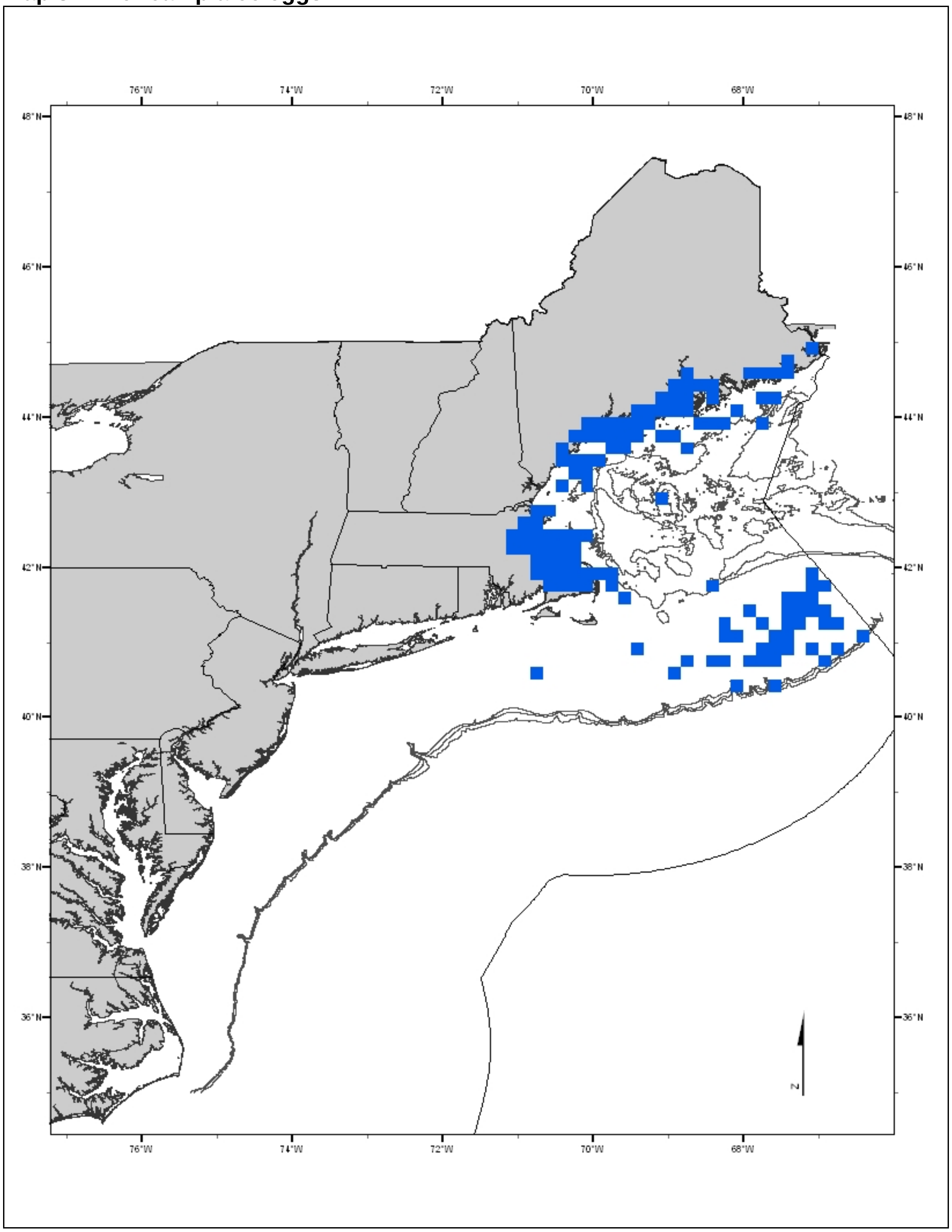
Map 2. Redfish adults



The Alternative 3D EFH designation for redfish adults on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore and off-shelf areas where adult redfish were determined to be present, based on 10% frequency of occurrence in state trawl surveys and off-shelf depth and geographic ranges.

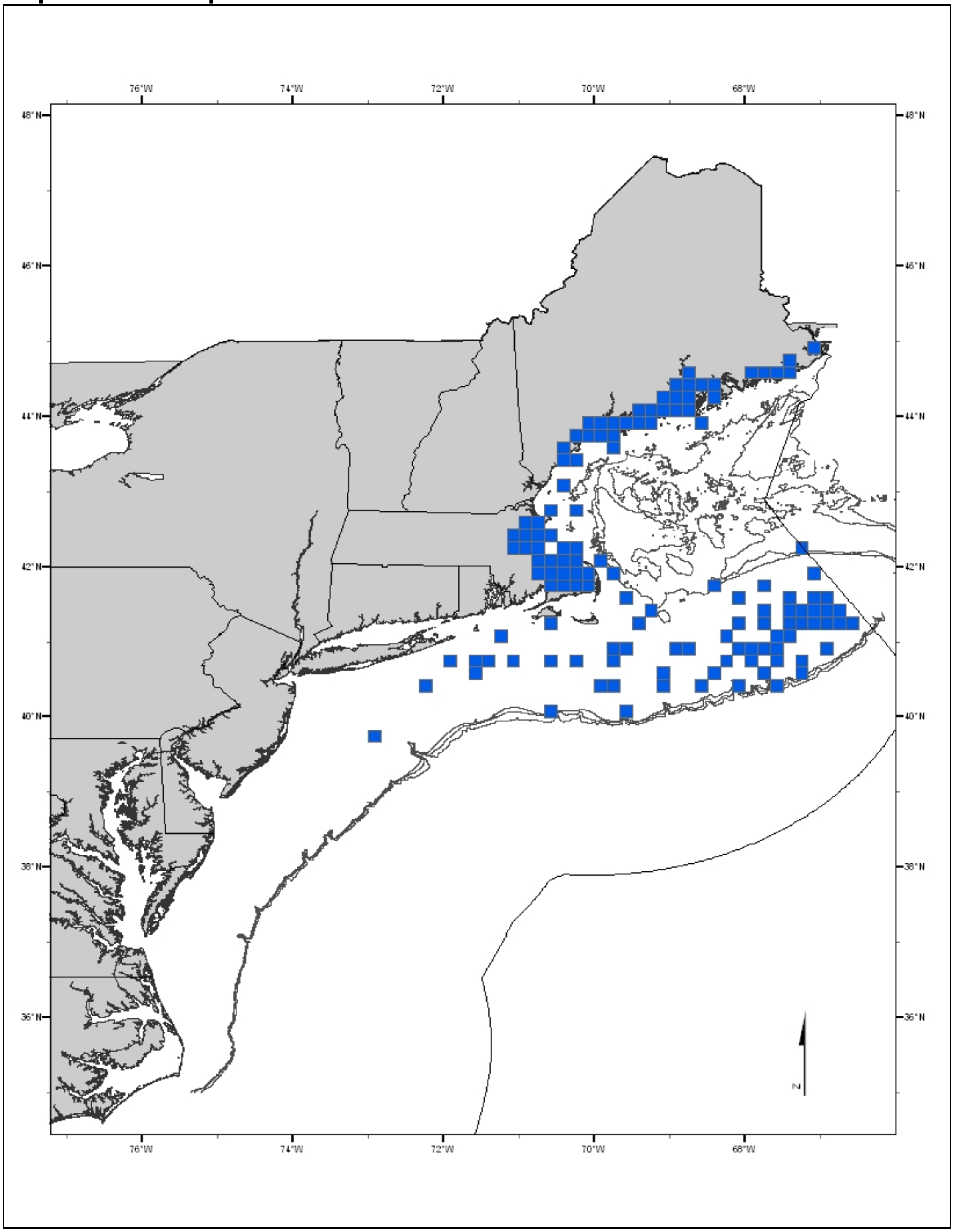
1.2 American plaice (*Hippoglossoides platessoides*)

Map 3. American plaice eggs



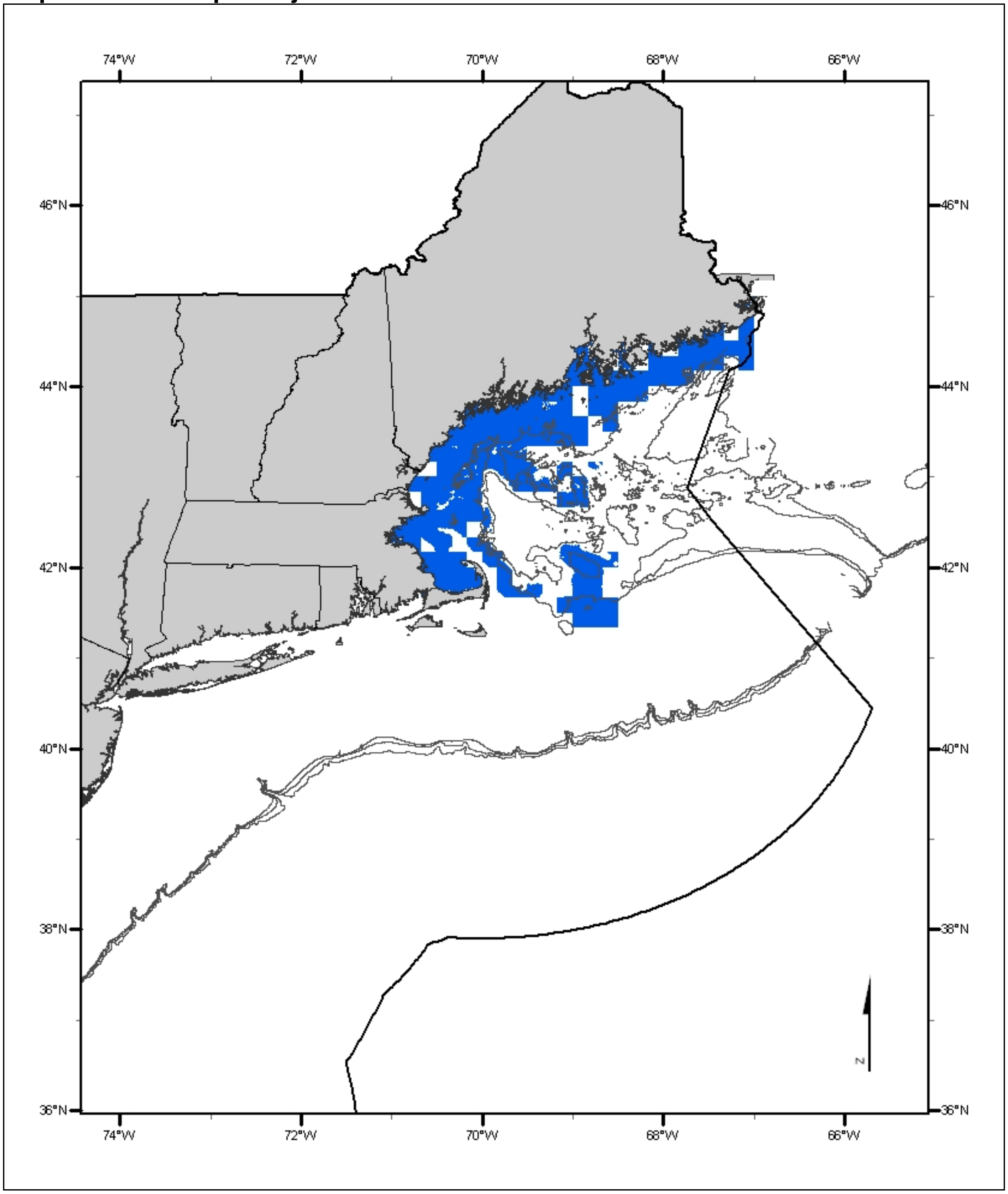
The EFH designation for American plaice eggs is the status quo designation, which was based on the ten minute squares corresponding to the top 75% of the observed range in the 1978-1987 MARMAP survey data. This designation also includes those bays and estuaries identified by the NOAA ELMR program as supporting American plaice eggs at the "common" or "abundant" level. .

Map 4. American plaice larvae



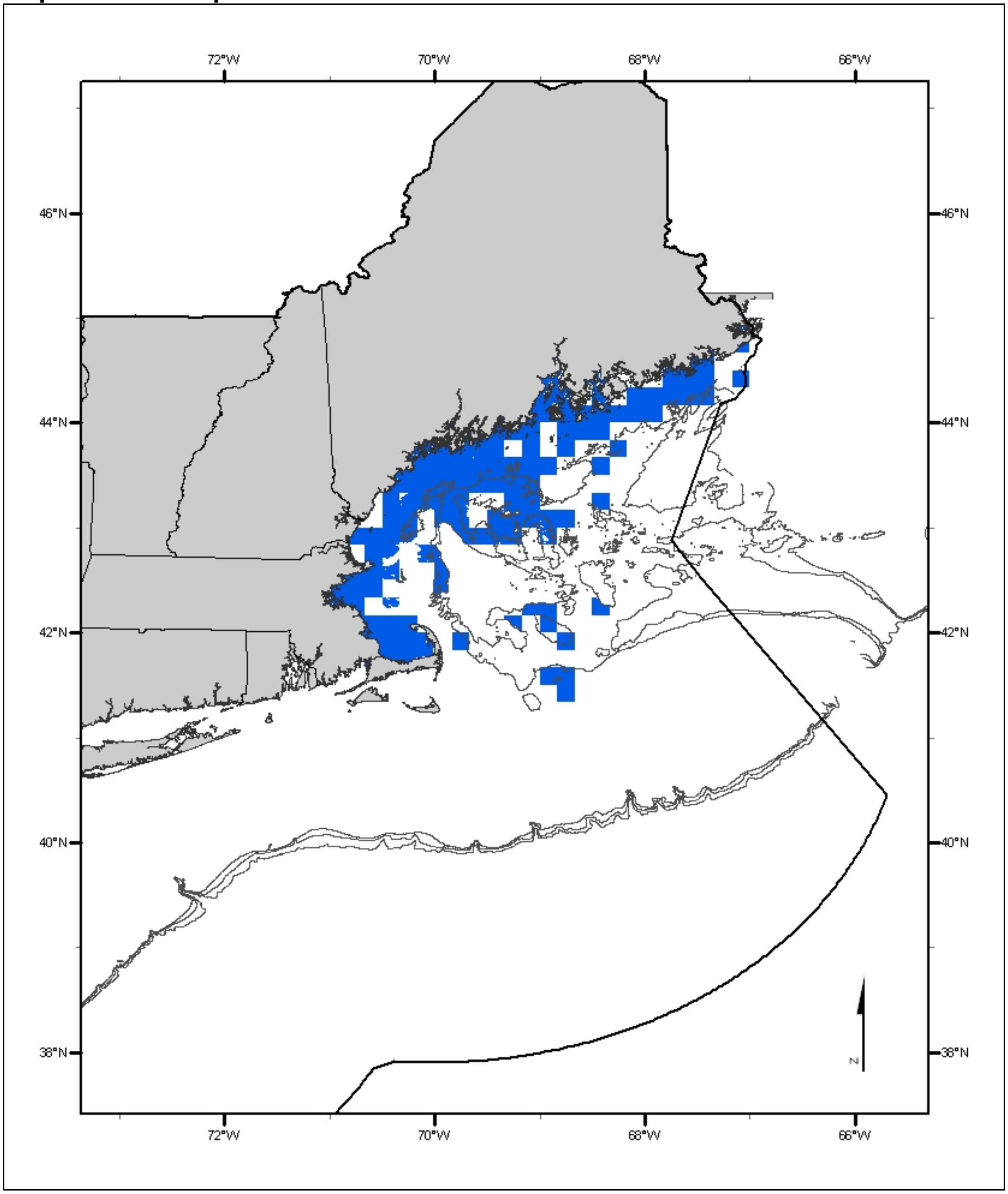
The EFH designation for American plaice larvae is the status quo designation, which was based on the ten minute squares corresponding to the top 75% of the observed range in the 1978-1987 MARMAP survey data. *This designation also includes those bays and estuaries identified by the NOAA ELMR program as supporting American plaice larvae at the "common" or "abundant" level.*

Map 5. American plaice juveniles



The EFH designation for juvenile American plaice on the continental shelf is based on the distribution of substrate types, depths, and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level and includes inshore areas where juvenile American plaice were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

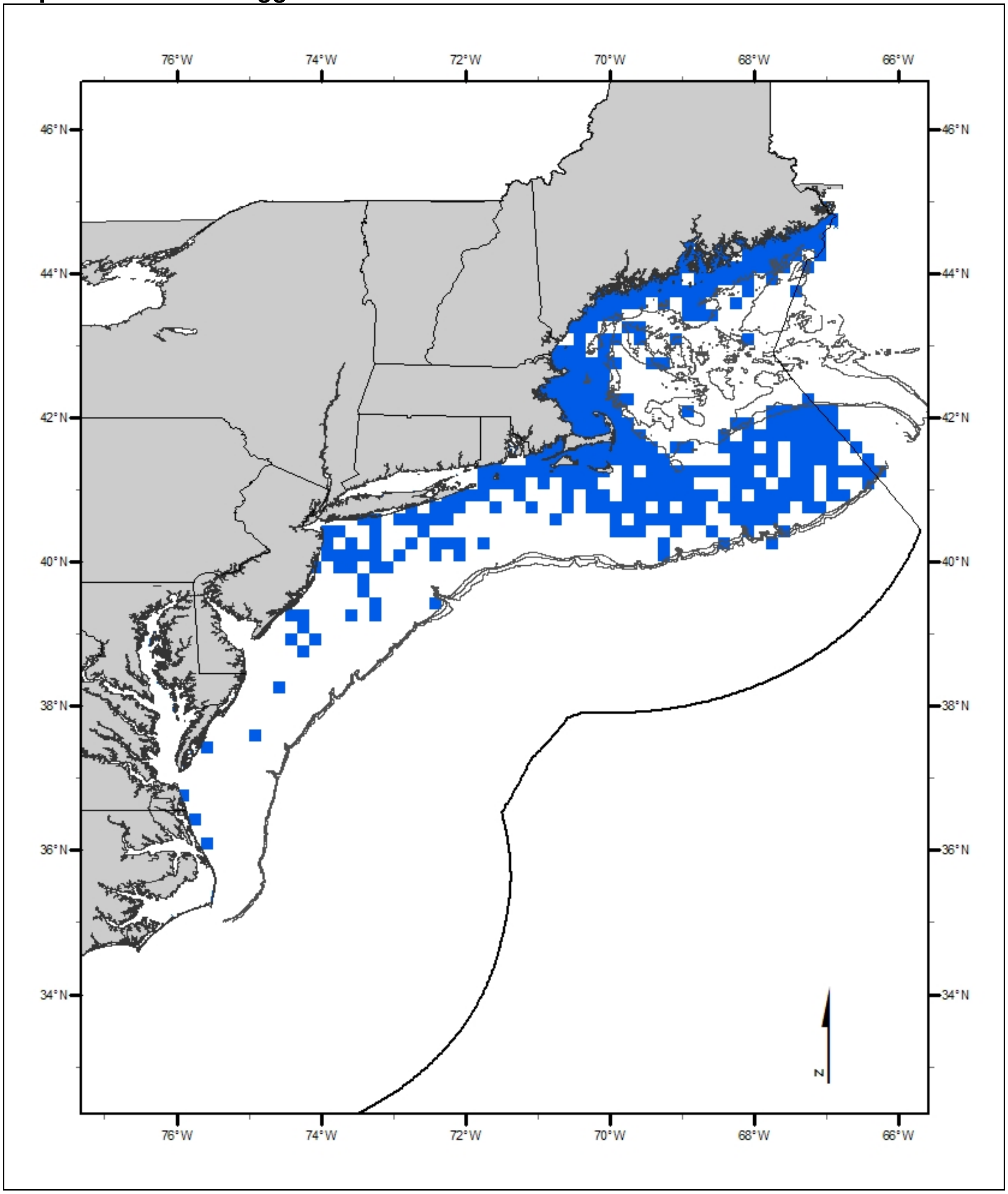
Map 6. American plaice adults



The Alternative 3C EFH designation for adult American plaice on the continental shelf is based on the distribution of substrate types, depths, and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level and includes inshore areas where adult American plaice were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

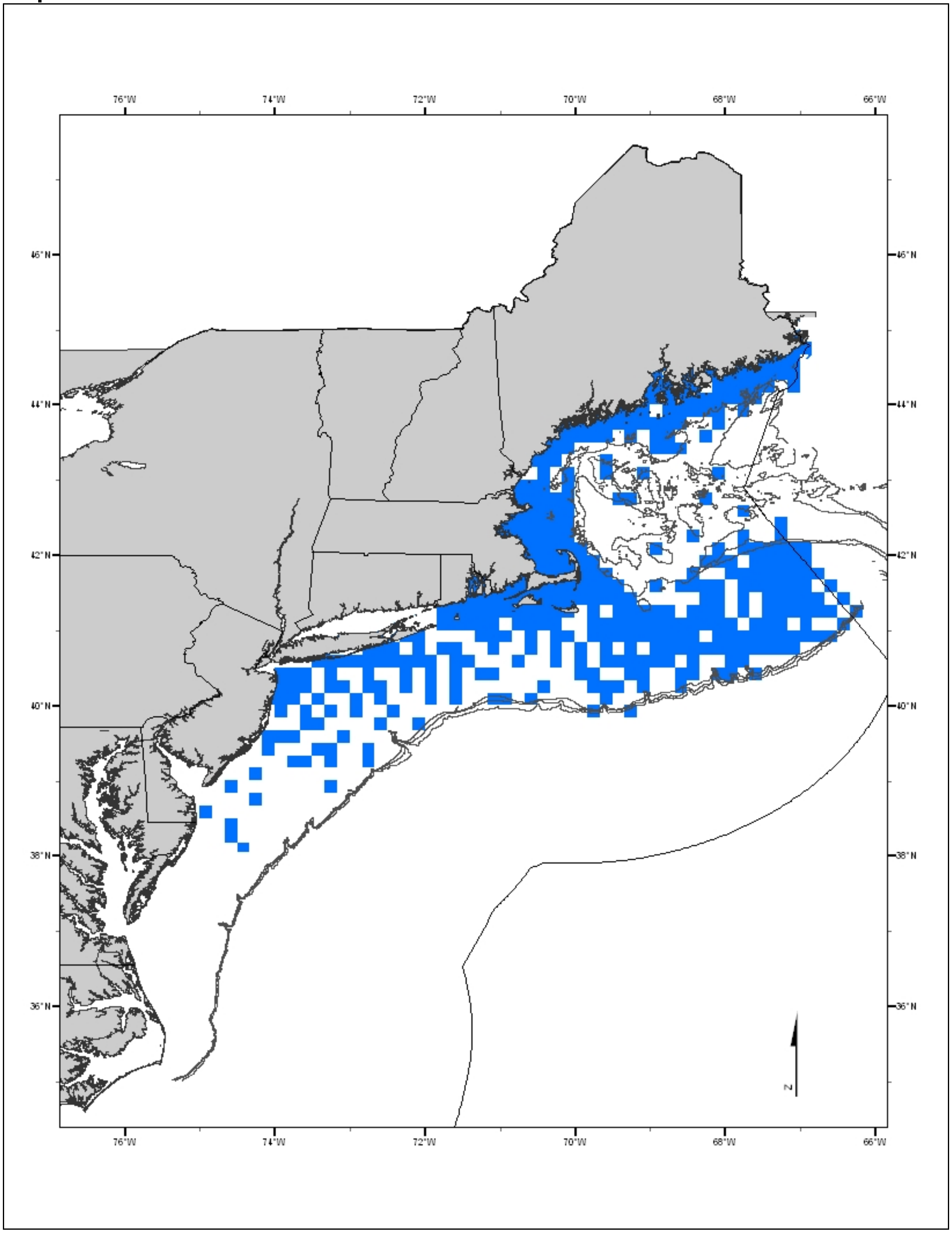
1.3 Atlantic cod (*Gadus morhua*)

Map 7. Atlantic cod eggs



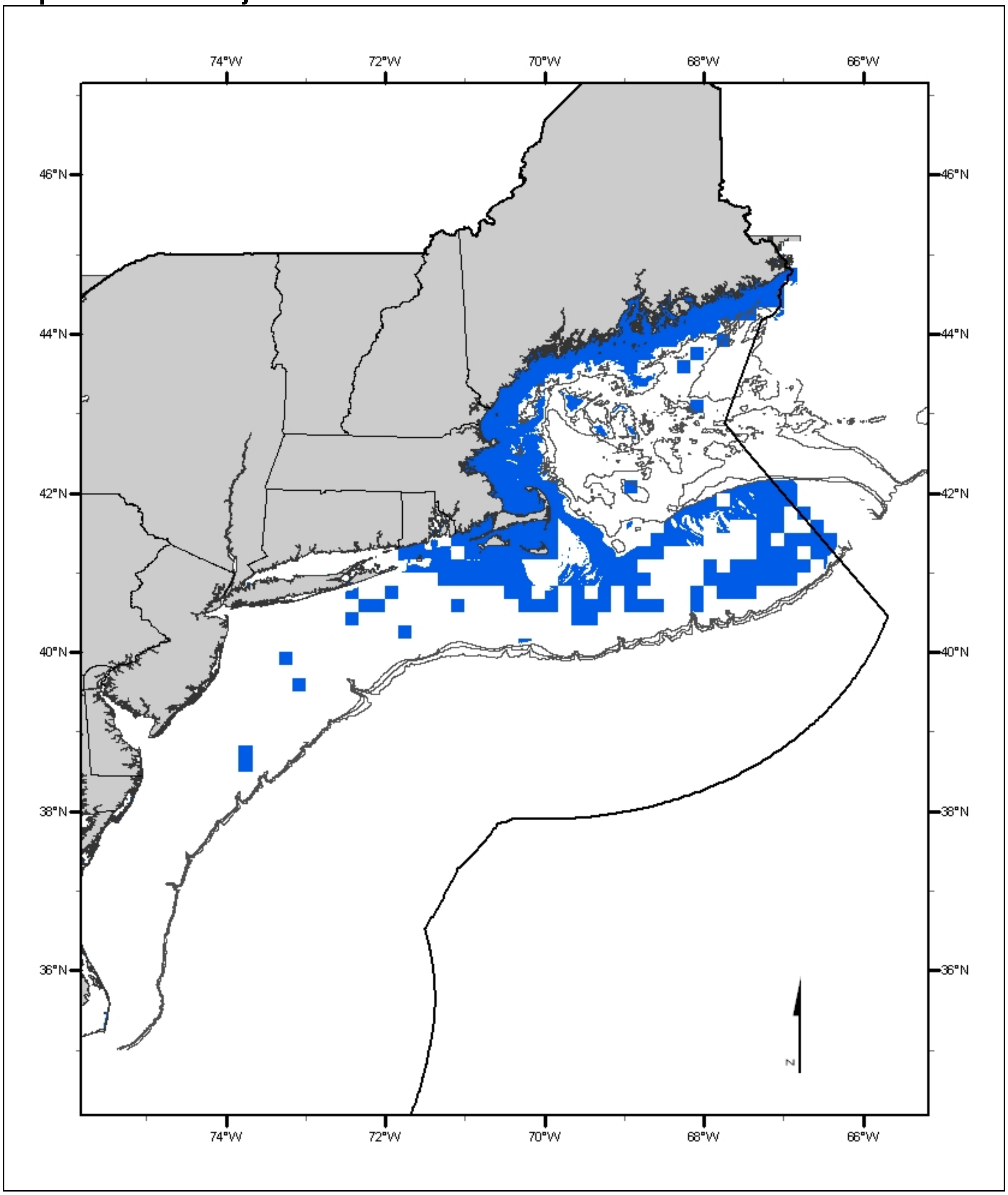
The Alternative 2E EFH designation for Atlantic cod eggs on the continental shelf is based upon the relative abundance of juveniles during 1968-2005 in the fall and spring NMFS trawl survey at the 90% cumulative percentage catch level and the relative abundance of eggs during 1978-1987 in the NMFS MARMAP ichthyoplankton survey at the 90% cumulative percentage area level. Ten minute squares located south of 38°N latitude were not included. This alternative also includes those bays and estuaries identified by the NOAA ELMR program where Atlantic cod eggs were "common" or "abundant."

Map 8. Atlantic cod larvae



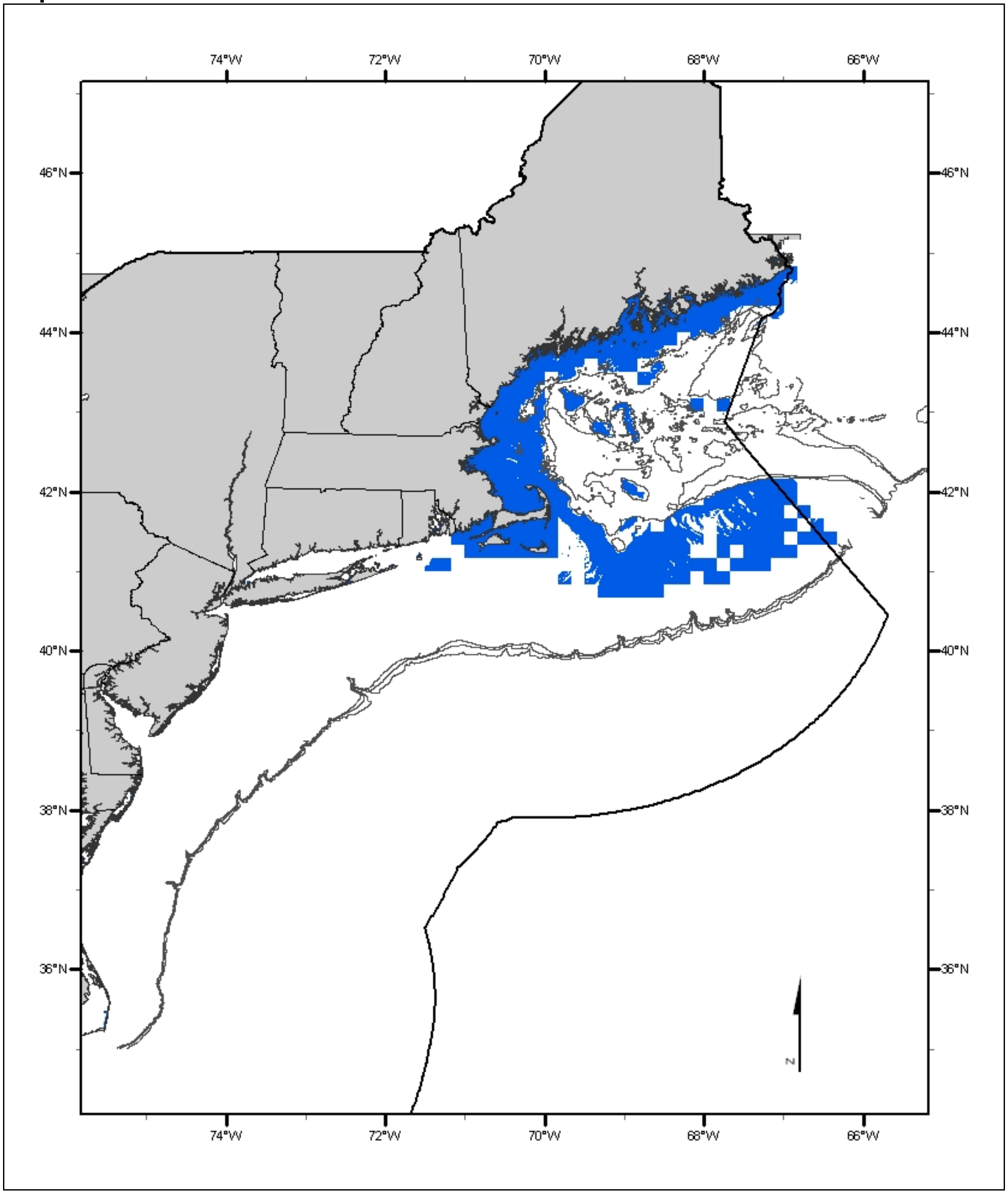
The Alternative 2E EFH designation for Atlantic cod larvae on the continental shelf is based upon the relative abundance of juveniles during 1968-2005 in the fall and spring NMFS trawl survey at the 90% cumulative percentage catch level and the relative abundance of larvae during 1978-1987 in the NMFS MARMAP ichthyoplankton survey at the 90% cumulative percentage area level. Ten minute squares located south of 38°N latitude were not included. This alternative also includes those bays and estuaries identified by the NOAA ELMR program where Atlantic cod larvae were "common" or "abundant."

Map 9. Atlantic cod juveniles



The Alternative 3E EFH designation for juvenile Atlantic cod on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore areas where juvenile Atlantic cod were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information. In addition, 3E includes ten minute squares that were "filled in" along the MA, NH, and ME coasts, including the islands and portions of the Stellwagen Bank National Marine Sanctuary.

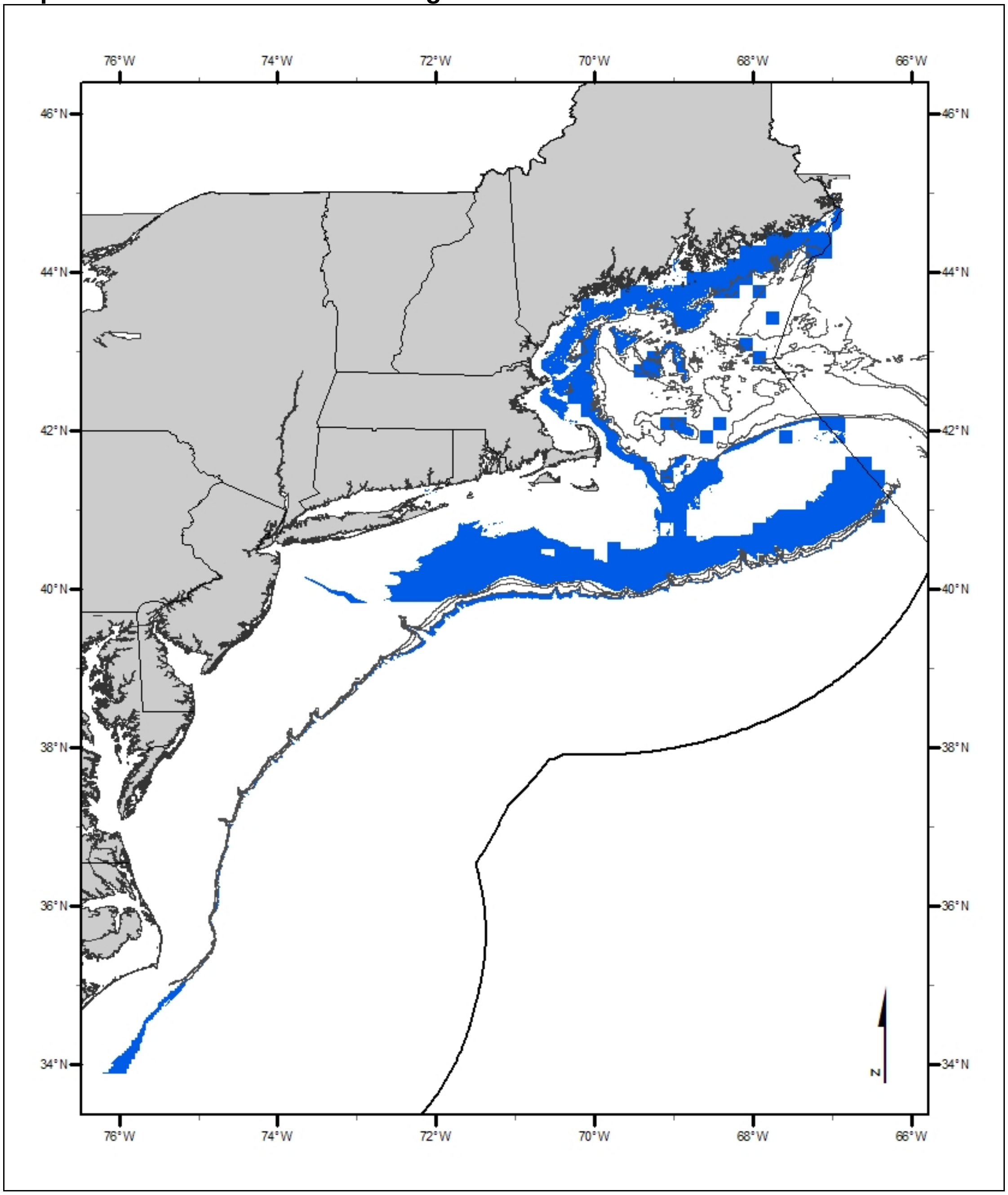
Map 10. Atlantic cod adults



The Alternative 3E EFH designation for adult Atlantic cod on the continental shelf is based on the distribution of substrate types, depths, and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore areas where adult Atlantic cod were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information. In addition, 3E includes ten minute squares that were "filled in" along the MA, NH, and ME coasts, including the islands and portions of the Stellwagen Bank National Marine Sanctuary.

1.4 Atlantic halibut (*Hippoglossus hippoglossus*)

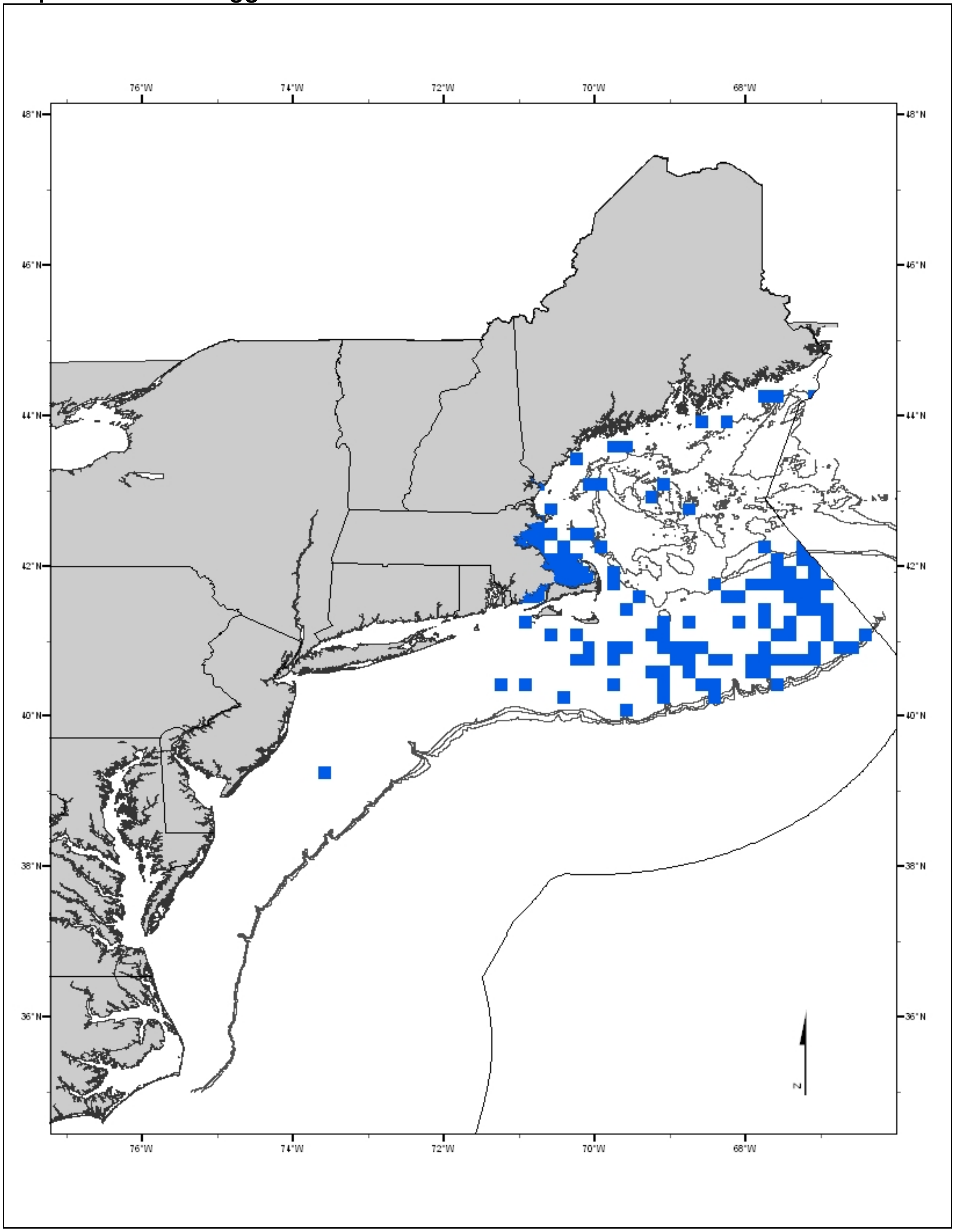
Map 11. Atlantic halibut all life stages



The Alternative 3 EFH designation for juvenile and adult Atlantic halibut on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of juveniles or adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles or adults in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore and off-shelf areas where juvenile or adult Atlantic halibut were determined to be present, based on 10% frequency of occurrence in state trawl surveys, ELMR information, and off-shelf depth and geographic ranges.

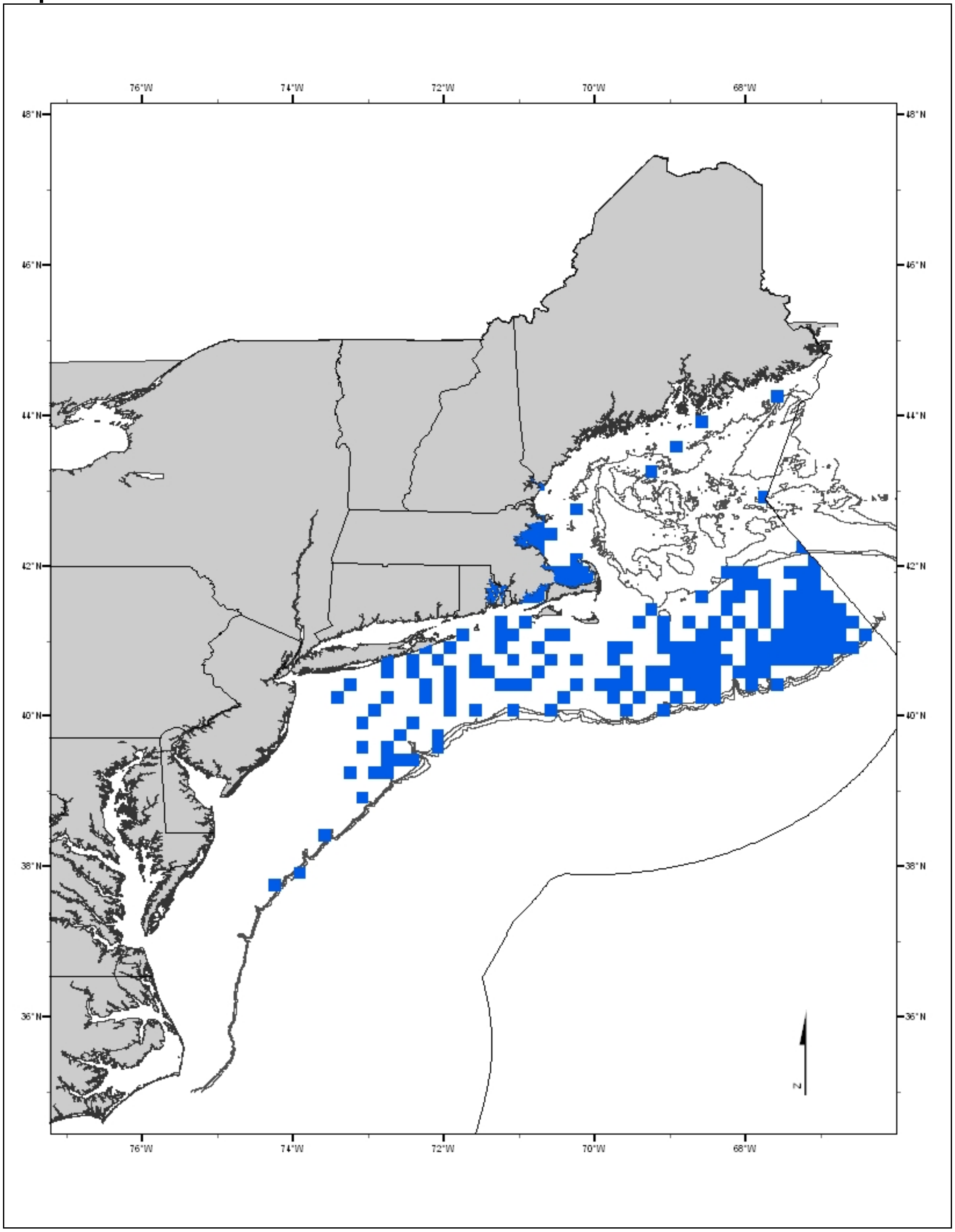
1.5 Haddock (*Melanogrammus aeglefinus*)

Map 12. Haddock eggs



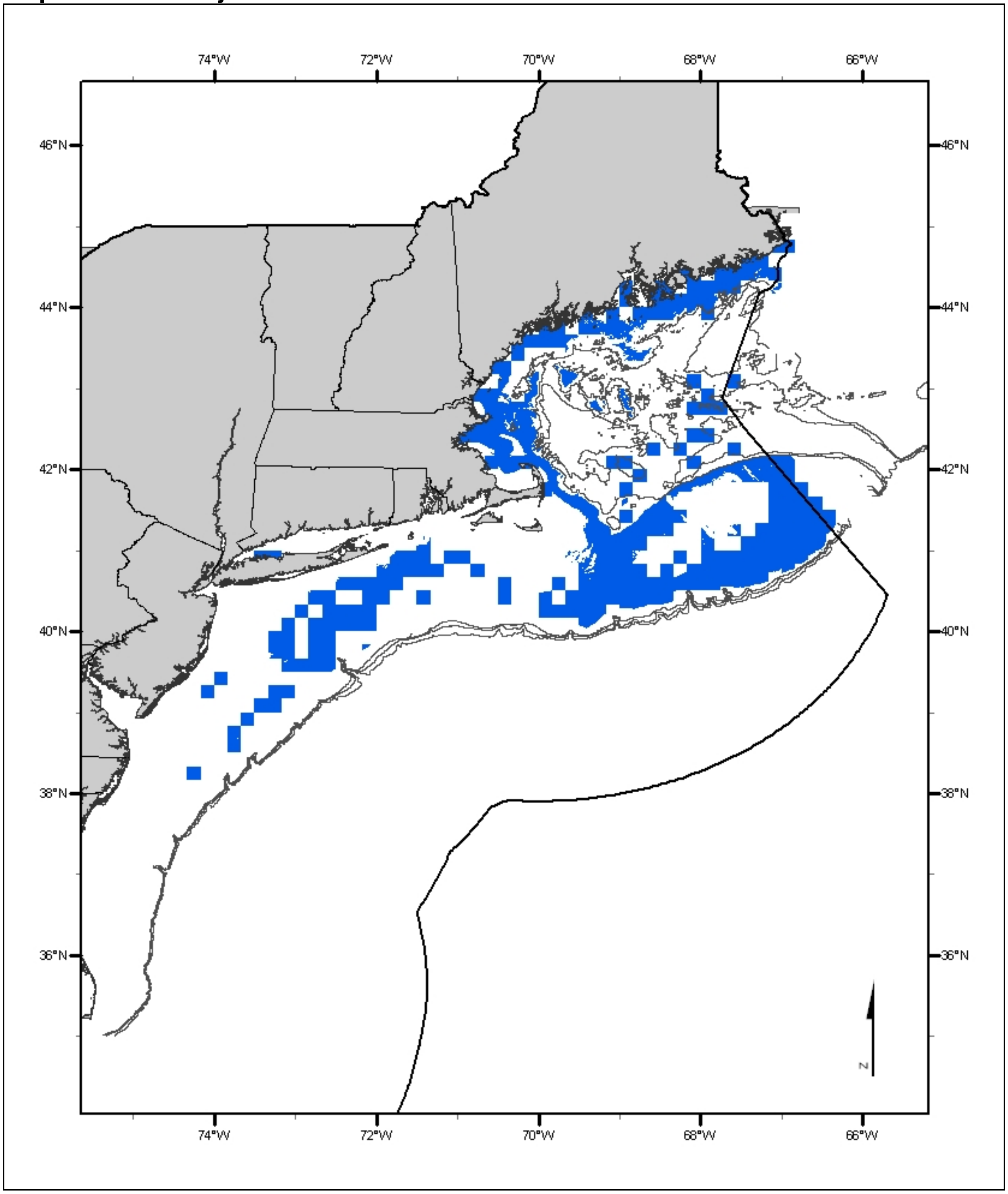
The EFH designation for haddock eggs is the status quo designation, which was based on the ten minute squares corresponding to 100% of the observed range in the 1978-1987 MARMAP survey data. *In addition it includes those bays and estuaries identified in the NOAA ELMR program as supporting haddock eggs at the "rare", "common", or "abundant" level.*

Map 13. Haddock larvae



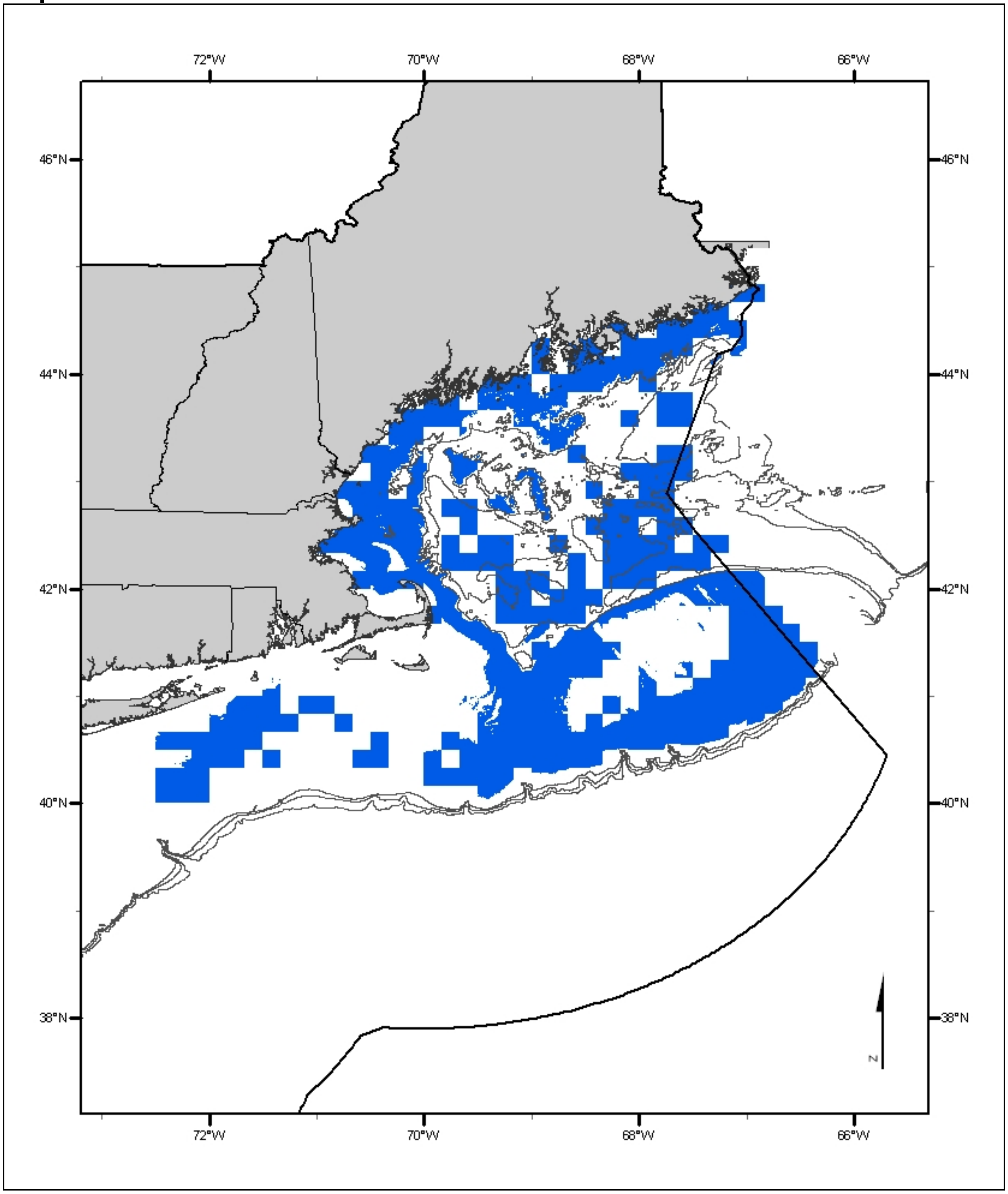
The EFH designation for haddock larvae is the status quo designation, which was based on the ten minute squares corresponding to 100% of the observed range in the 1978-1987 MARMAP survey data. *In addition it includes those bays and estuaries identified in the NOAA ELMR program as supporting haddock larvae at the "rare", "common", or "abundant" level.*

Map 14. Haddock juveniles



The Alternative 3D EFH designation for juvenile haddock on the continental shelf is based on the distribution of substrate types, depths and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore areas where juvenile haddock were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

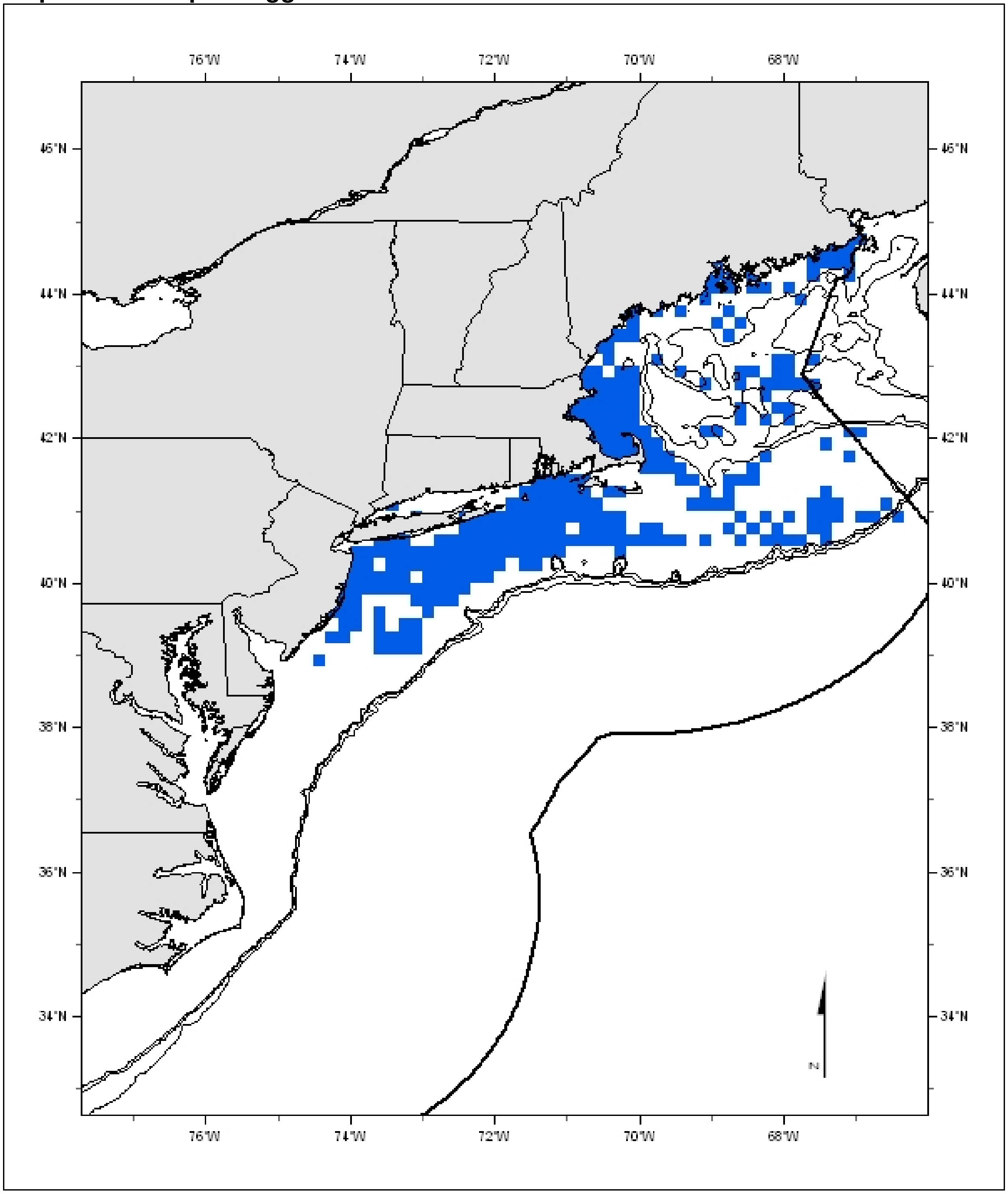
Map 15. Haddock adults



The Alternative 3E EFH designation for adult haddock is the union of the 3D designation for juvenile haddock and the 3D designation for adult haddock, bounded at the western and southern extent of the adult 3D map.

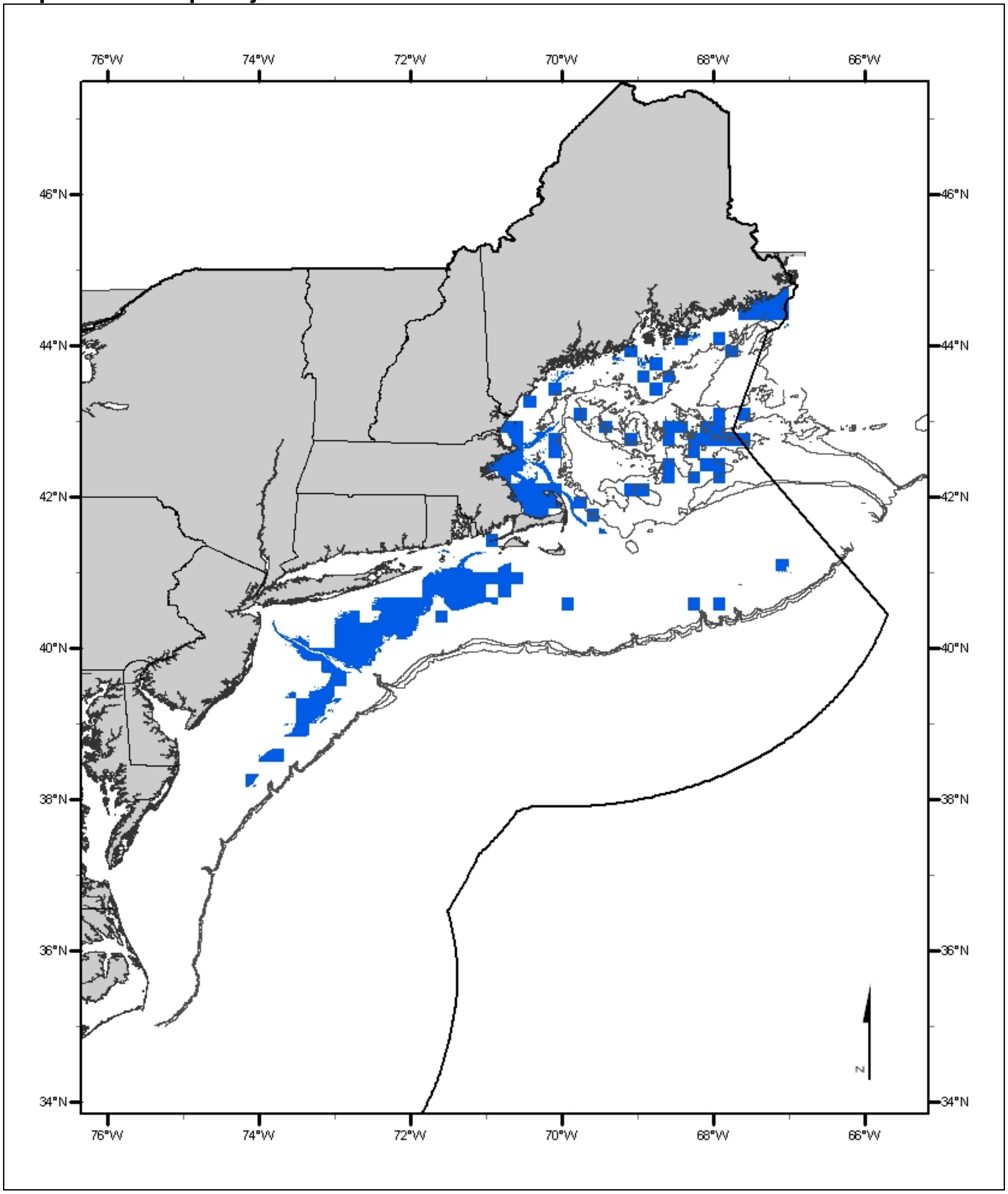
1.6 Ocean pout (*Macrozoarces americanus*)

Map 16. Ocean pout eggs



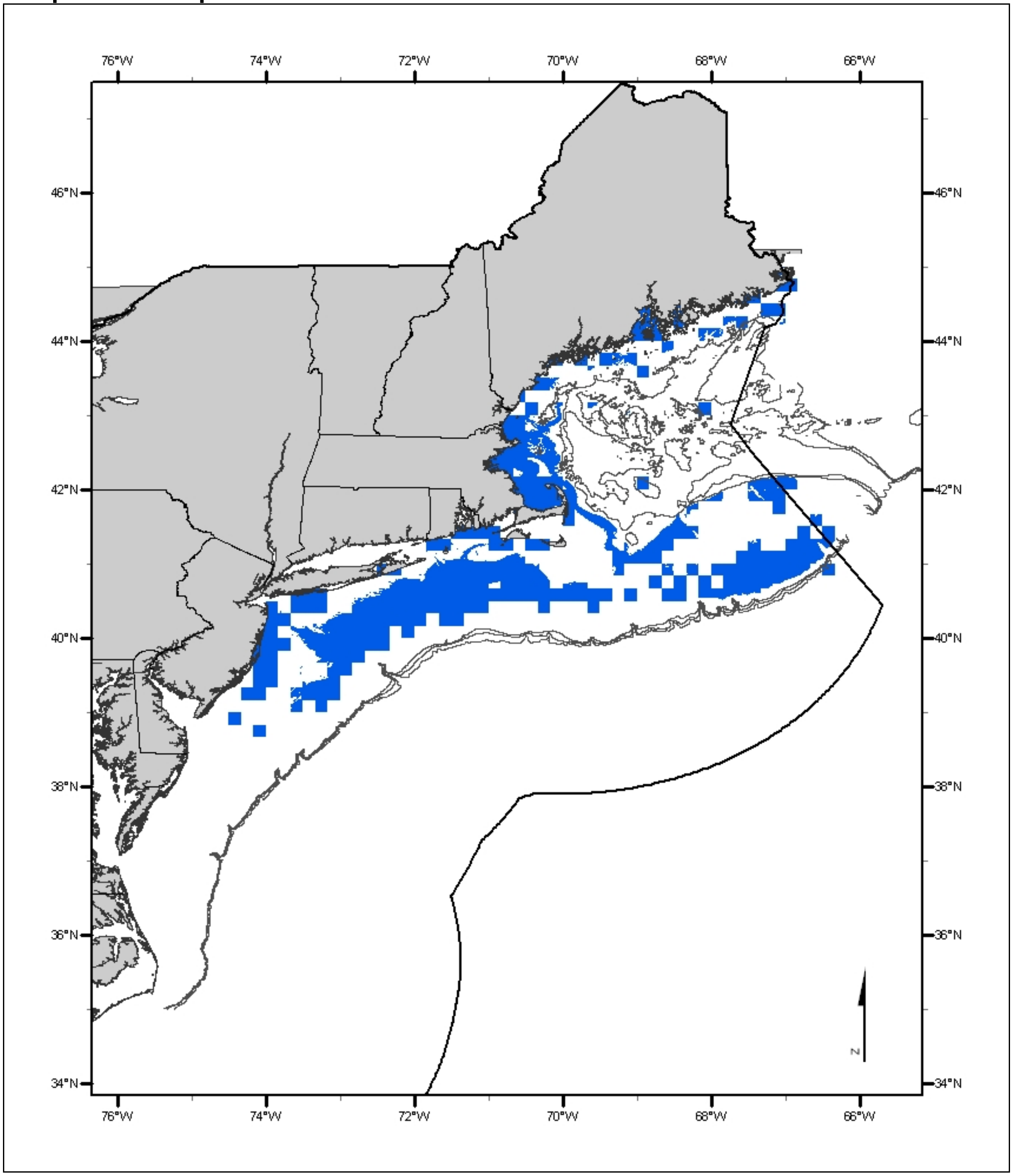
The Alternative 2C EFH designation for ocean pout eggs on the continental shelf is based upon the relative abundance of juveniles and adults during 1968-2005 in the fall and spring NMFS trawl survey at the 75% cumulative percentage level. This alternative also includes ten minute squares in inshore areas where juvenile or adult ocean pout were caught in state trawl surveys in more than 10% of the tows, as well as those bays and estuaries identified by the NOAA ELMR program where ocean pout juveniles or adults were "common" or "abundant."

Map 17. Ocean pout juveniles



The Alternative 3C EFH designation for juvenile ocean pout on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level and includes inshore areas where juvenile ocean pout were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

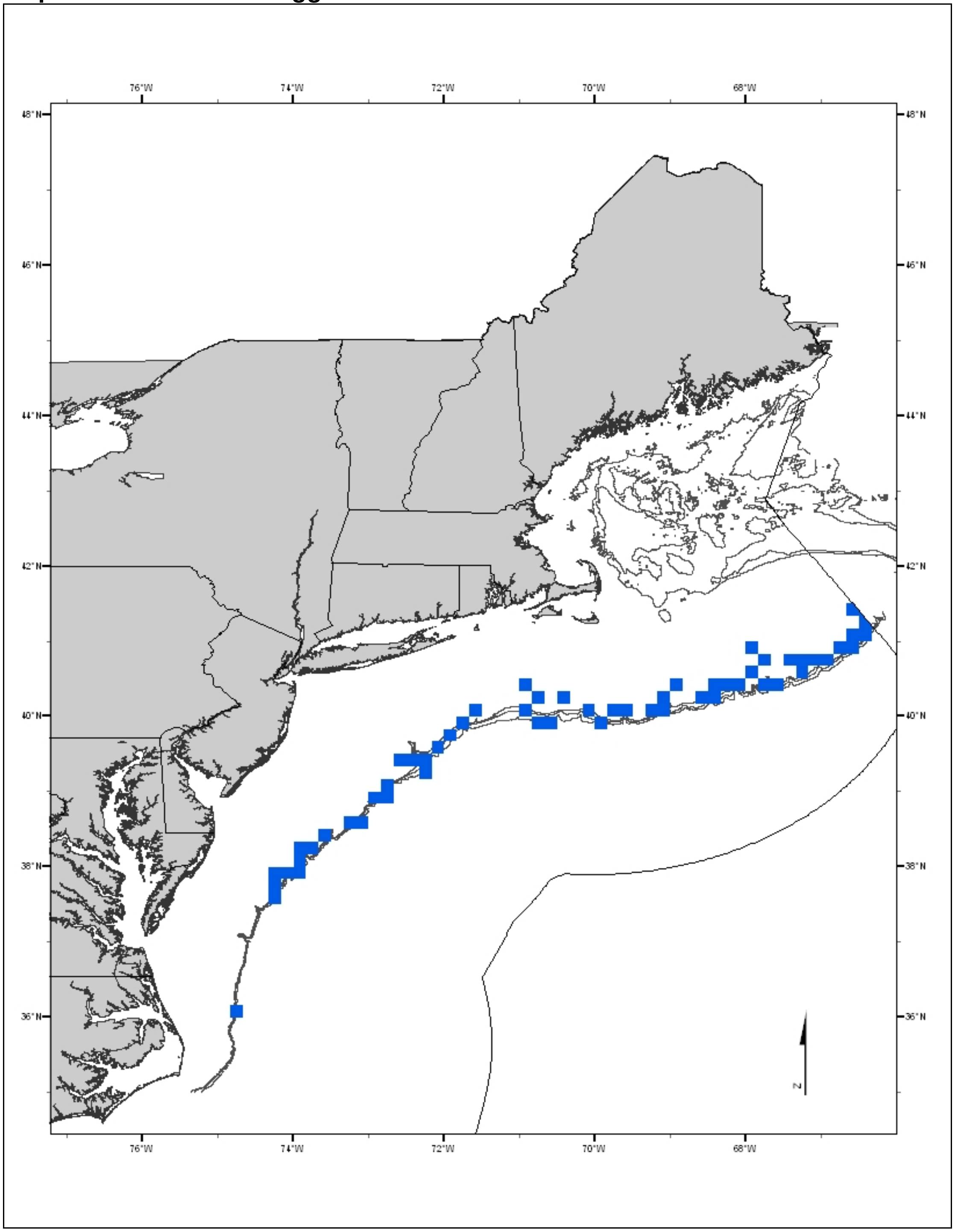
Map 18. Ocean pout adults



The Alternative 3C EFH designation for adult ocean pout on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level and includes inshore areas where adult ocean pout were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

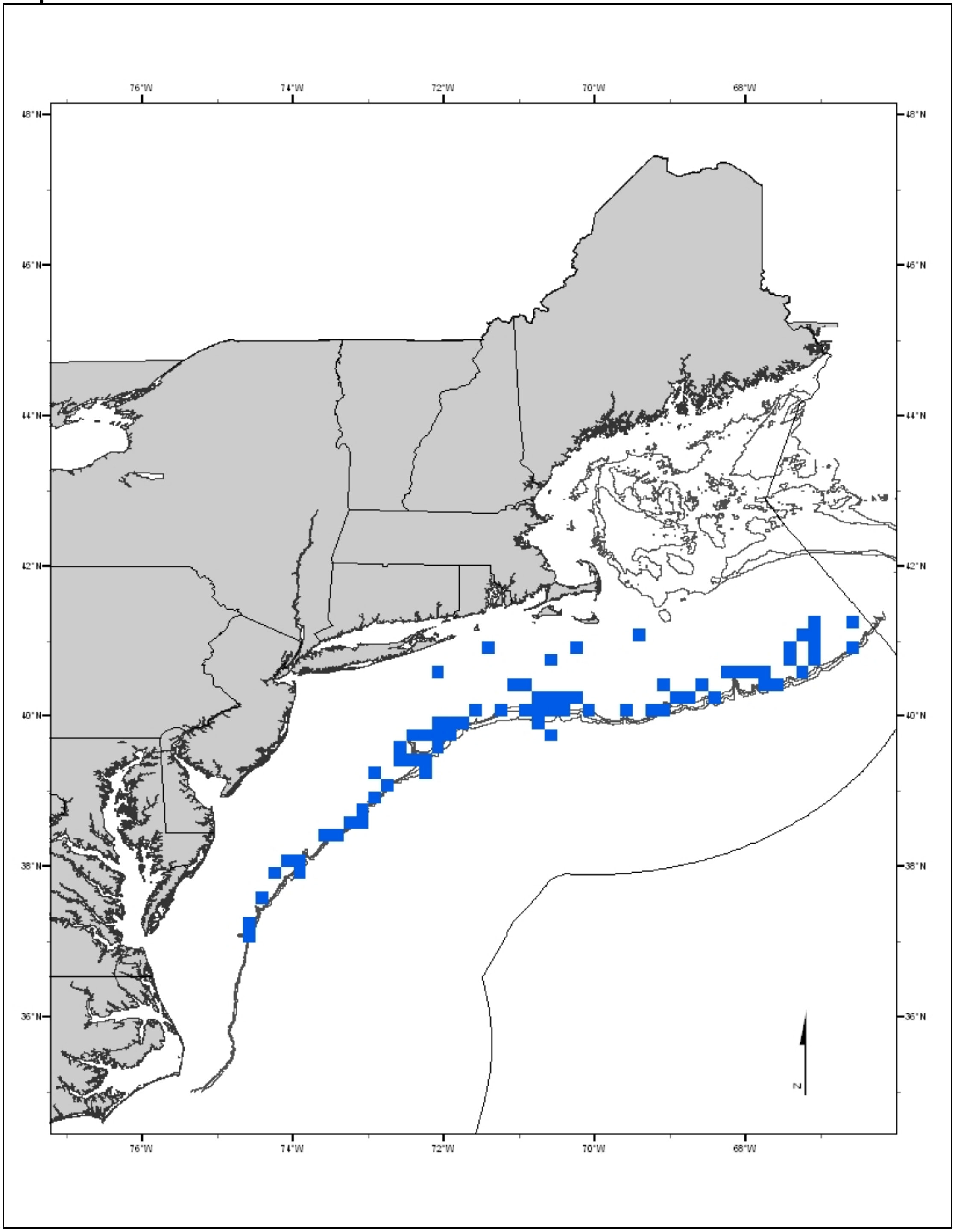
1.7 Offshore hake (*Merluccius albidus*)

Map 19. Offshore hake eggs



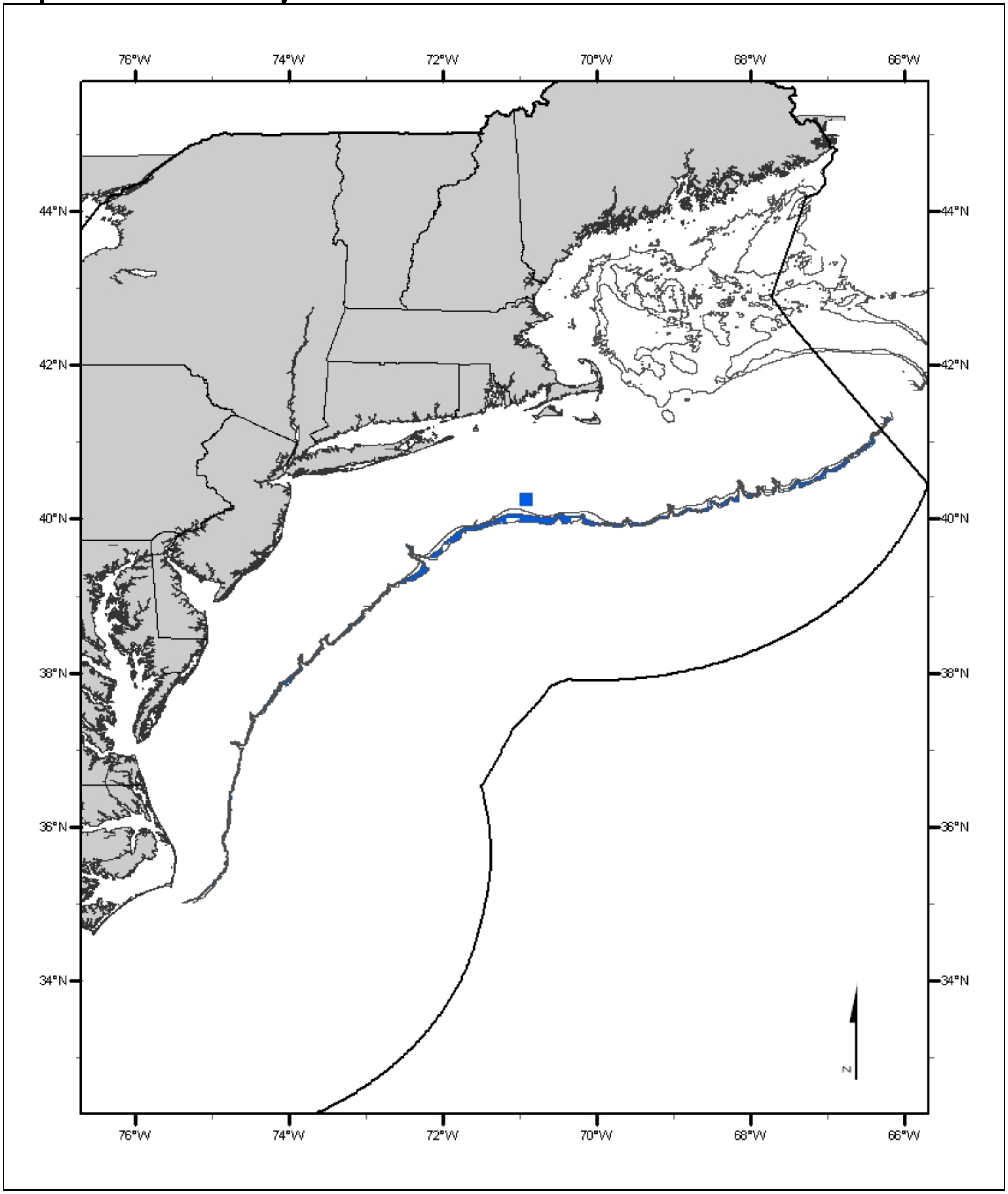
The EFH designation for offshore hake eggs is the status quo alternative which was based on the ten minute squares corresponding to the top 75% of the observed range in the 1978-1987 MARMAP survey data.

Map 20. Offshore hake larvae



The EFH designation for offshore hake larvae is the status quo alternative which was based on the ten minute squares corresponding to the top 75% of the observed range in the 1978-1987 MARMAP survey data.

Map 21. Offshore hake juveniles and adults

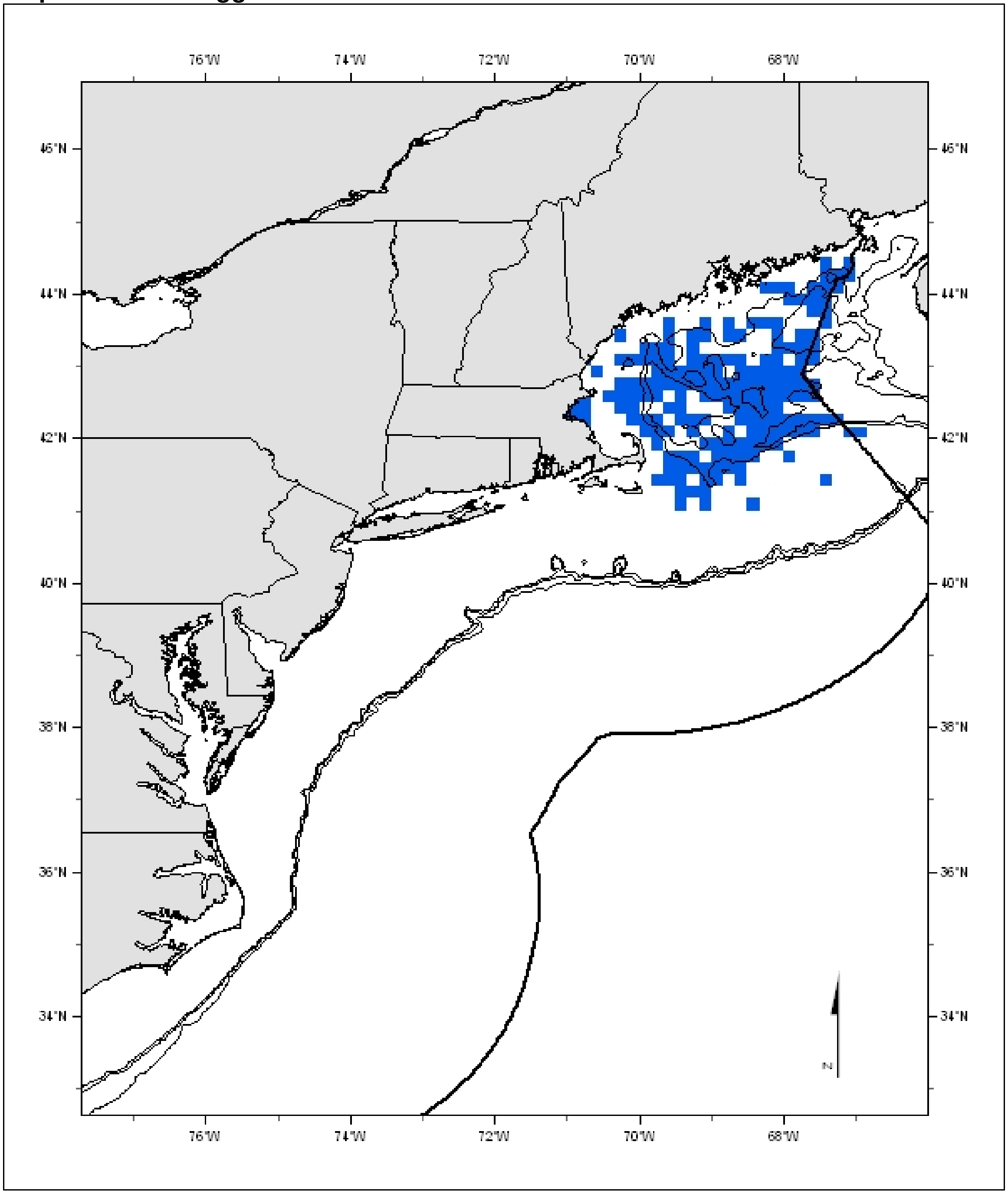


The Alternative 5 EFH designation for juvenile and adult offshore hake combines Alternative 3E for juveniles and 3D for adults. This alternative is based on off-shelf areas where juvenile and adult offshore hake were determined to be present, based on depth and geographic ranges, and also includes one ten minute square where the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys reached the 90% cumulative percentage of catch level.

NOTE: The correct map was never created – this is the juvenile offshore hake map.

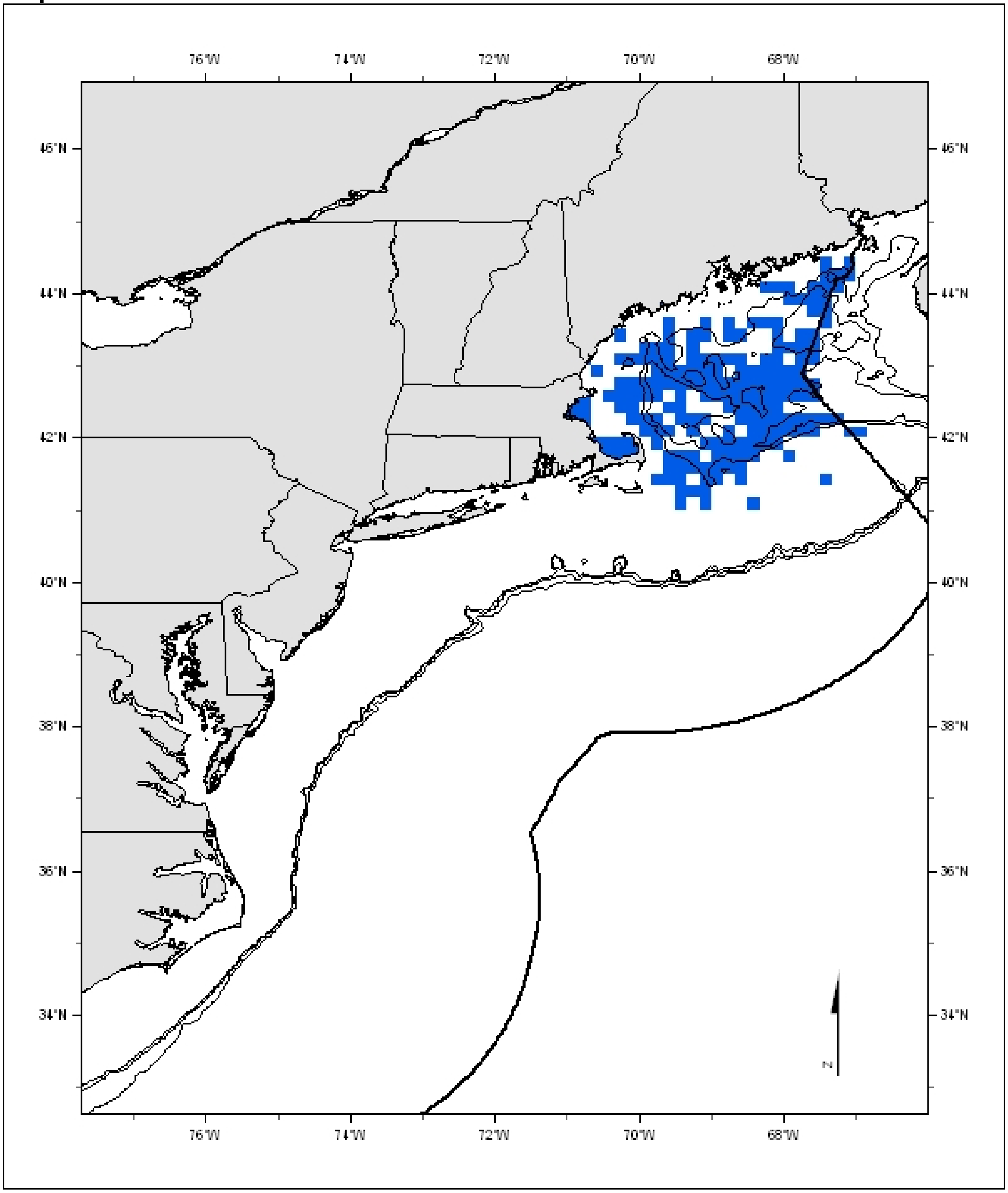
1.8 Pollock (*Pollachius virens*)

Map 22. Pollock eggs



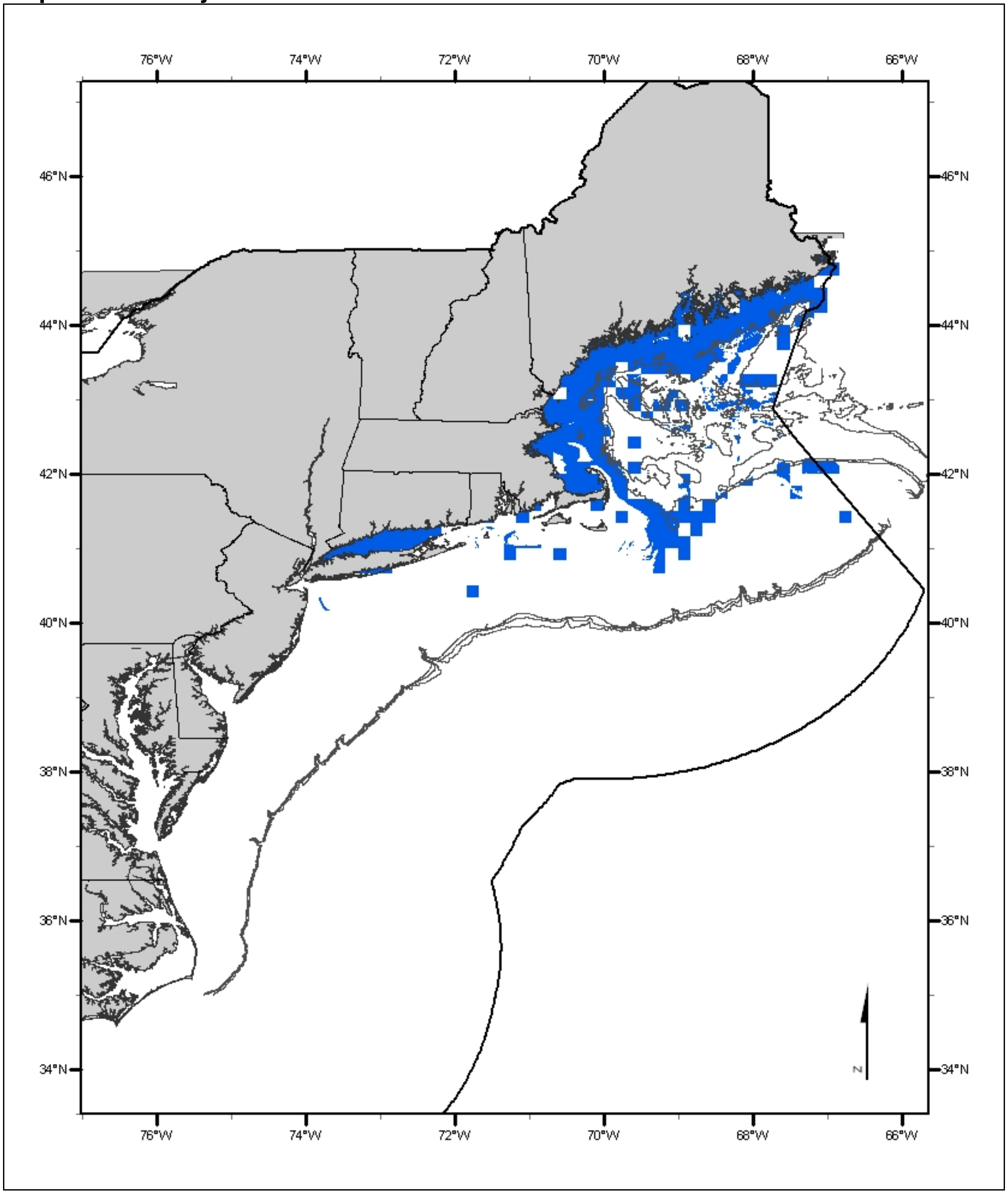
The Alternative 2D EFH designation for pollock eggs on the continental shelf is based upon the relative abundance of adult pollock during 1968-2005 in the fall and spring NMFS trawl survey at the 90% cumulative percentage level. This alternative also includes ten minute squares in inshore areas where adult pollock were caught in state trawl surveys in more than 10% of the tows, as well as those bays and estuaries identified by the NOAA ELMR program where pollock eggs were "common" or "abundant."

Map 23. Pollock larvae



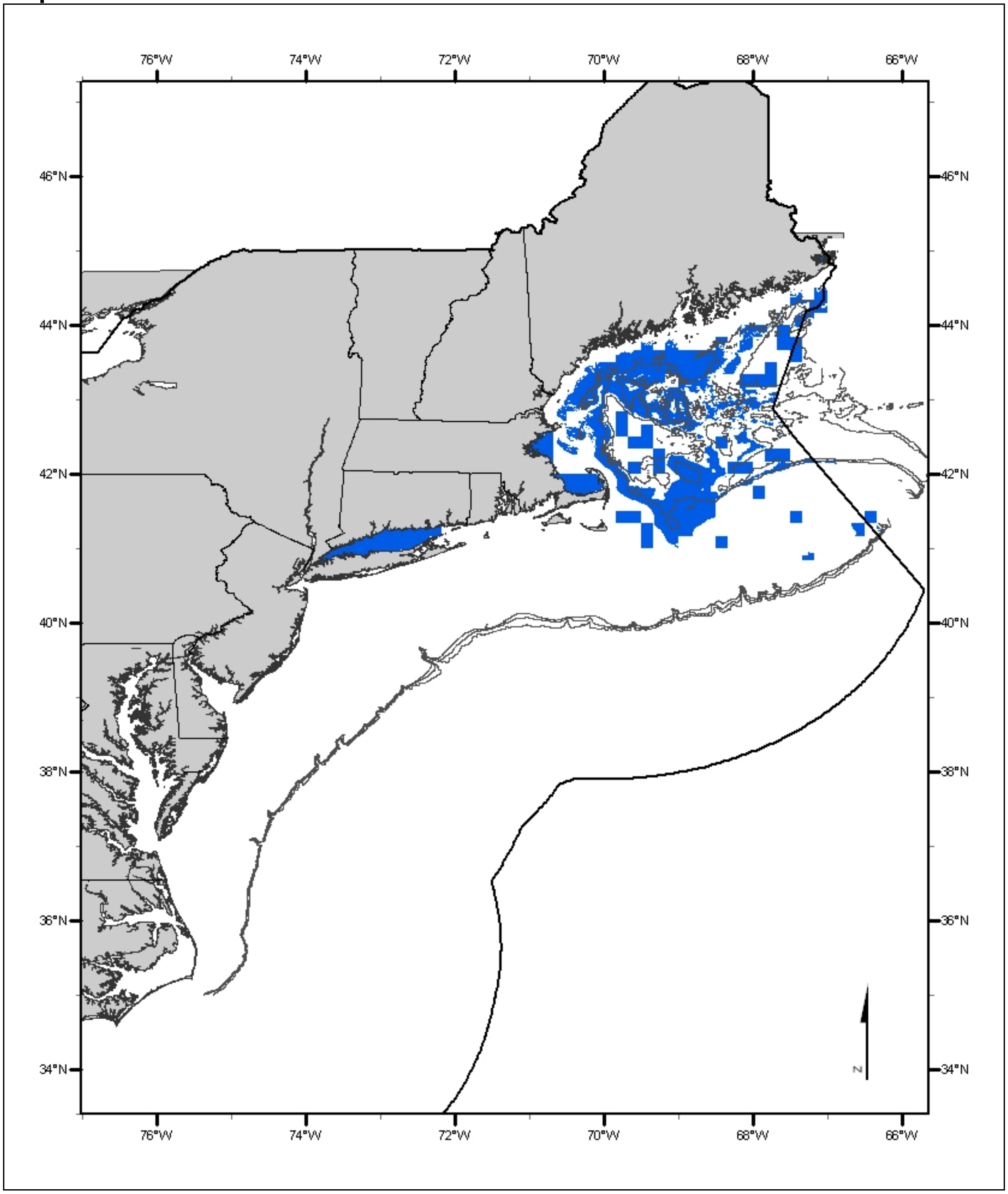
The Alternative 2D EFH designation for pollock larvae on the continental shelf is based upon the relative abundance of adult pollock during 1968-2005 in the fall and spring NMFS trawl survey at the 90% cumulative percentage level. This alternative also includes ten minute squares in inshore areas where adult pollock were caught in state trawl surveys in more than 10% of the tows, as well as those bays and estuaries identified by the NOAA ELMR program where pollock larvae were "common" or "abundant."

Map 24. Pollock juveniles



The Alternative 3D EFH designation for juvenile pollock on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore areas where juvenile pollock were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

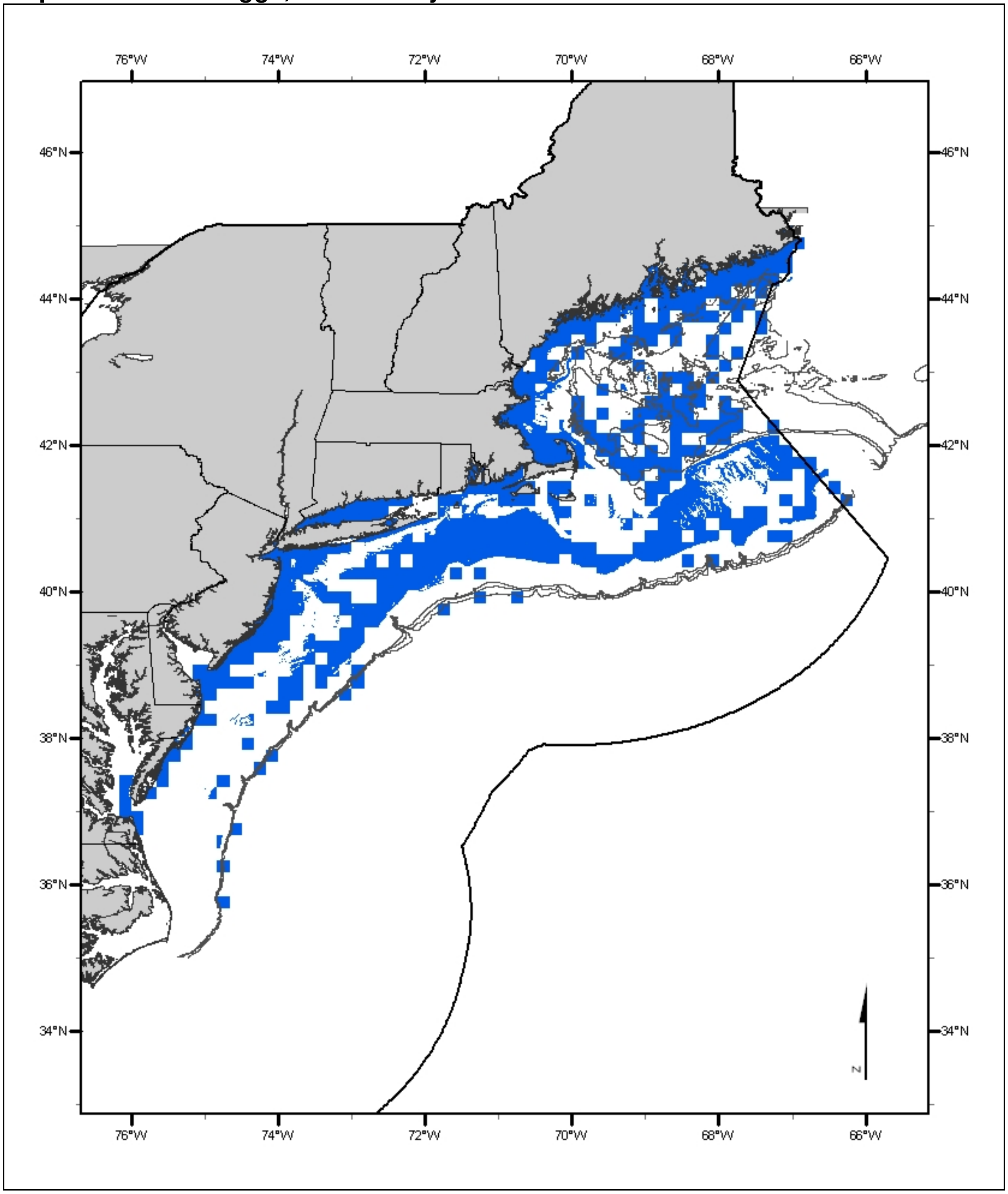
Map 25. Pollock adults



The Alternative 3D EFH designation for adult pollock on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore areas where adult pollock were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

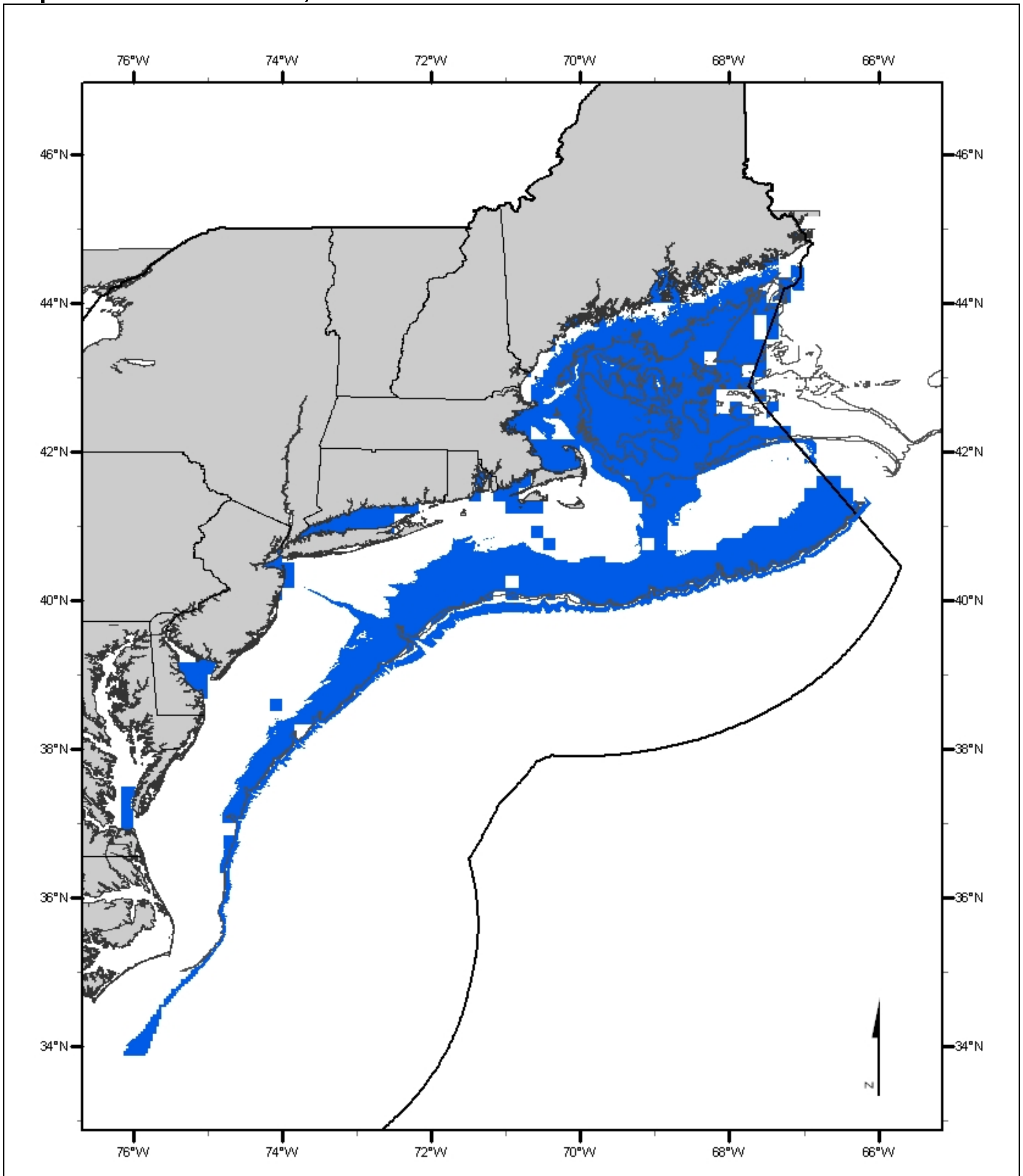
1.9 Red hake (*Urophycis chuss*)

Map 26. Red hake eggs, larvae and juveniles



The Alternative 3C EFH designation for red hake eggs, larvae, and juveniles on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level and includes inshore areas where juvenile red hake were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

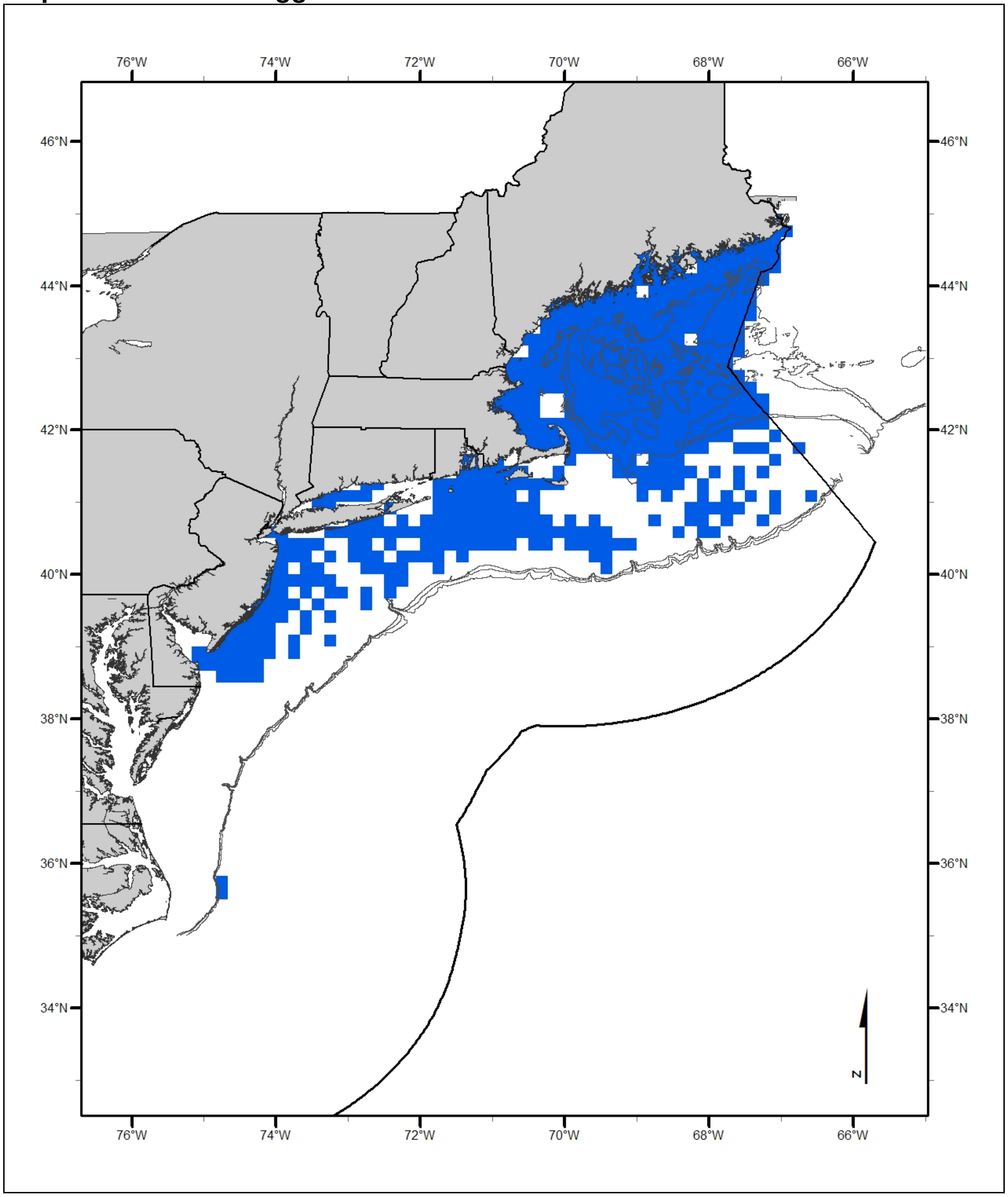
Map 27. Red hake adults, Alternative 3D



The Alternative 3D EFH designation for adult red hake on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore and off-shelf areas where adult red hake were determined to be present, based on 10% frequency of occurrence in state trawl surveys, ELMR information, and off-shelf depth and geographic ranges.

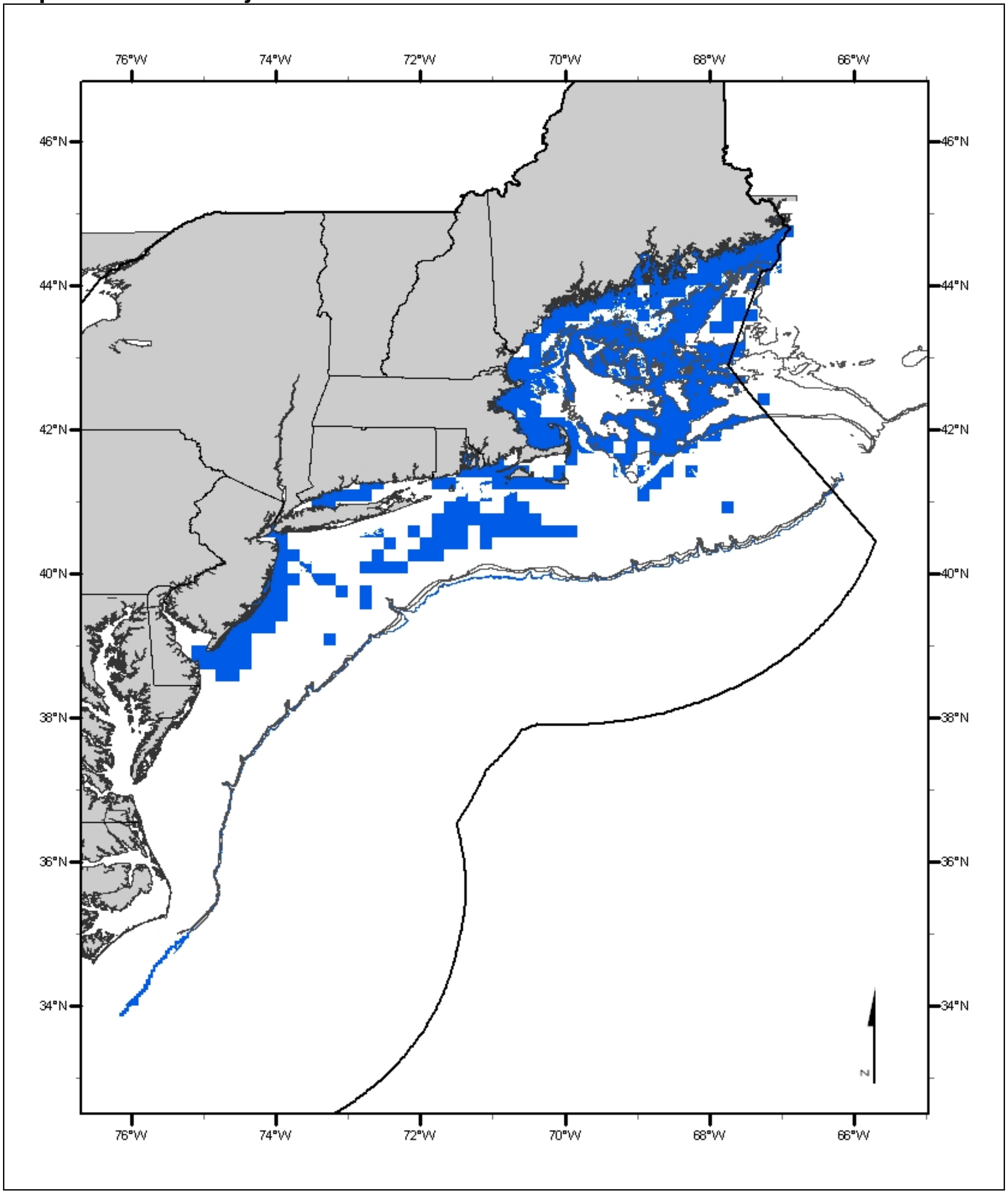
1.10 Silver hake (*Merluccius bilinearis*)

Map 28. Silver hake eggs and larvae



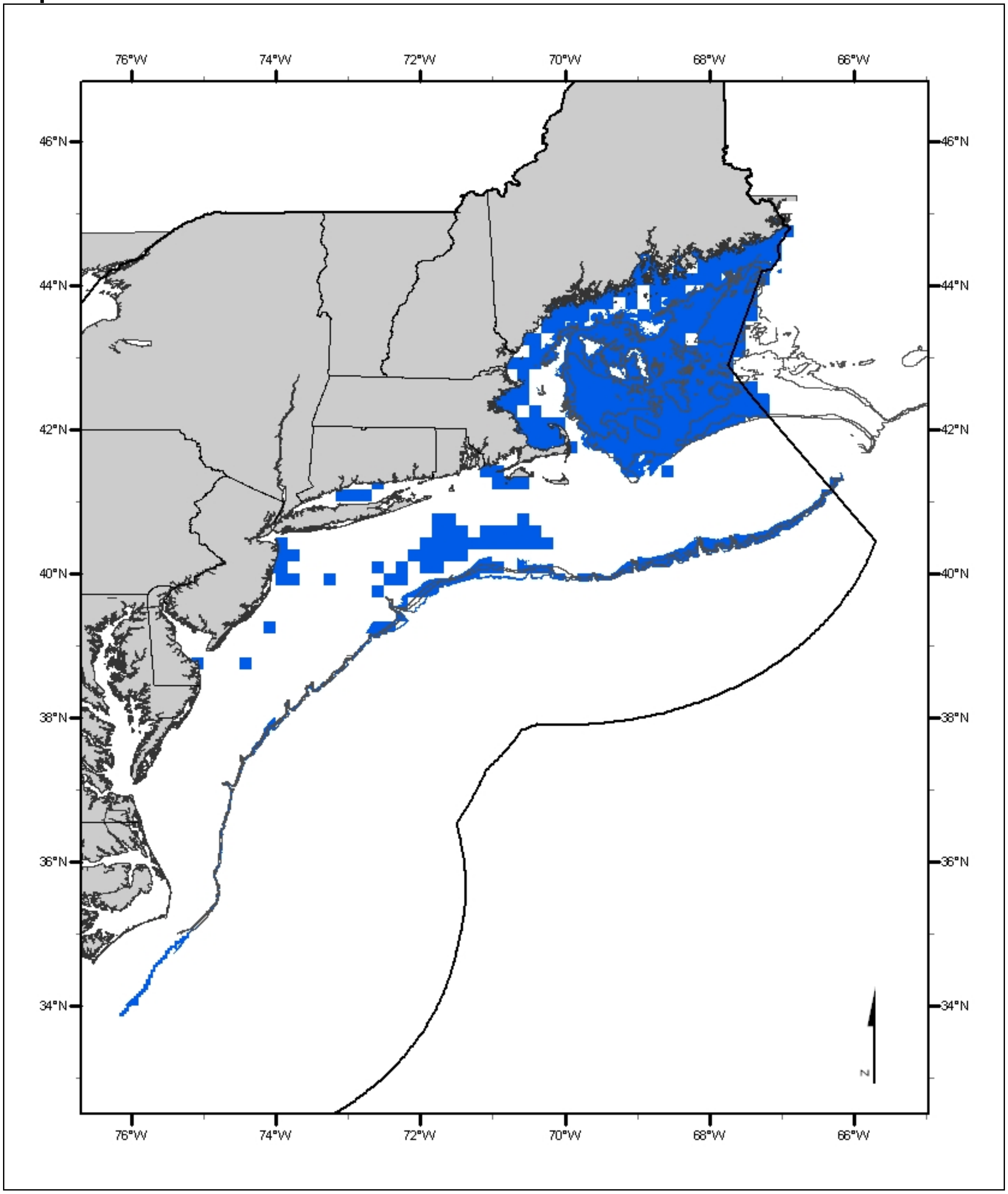
The Alternative 2D EFH designation for silver hake eggs and larvae on the continental shelf is based upon the relative abundance of juvenile silver hake during 1968-2005 in the fall and spring NMFS trawl survey at the 90% cumulative percentage level. This alternative also includes ten minute squares in inshore areas where juvenile silver hake were caught in state trawl surveys in more than 10% of the tows and those bays and estuaries identified by the NOAA ELMR program where silver hake eggs and larvae were "common" or "abundant."

Map 29. Silver hake juveniles



The Alternative 3C EFH designation for juvenile silver hake on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level and includes inshore areas where juvenile red hake were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

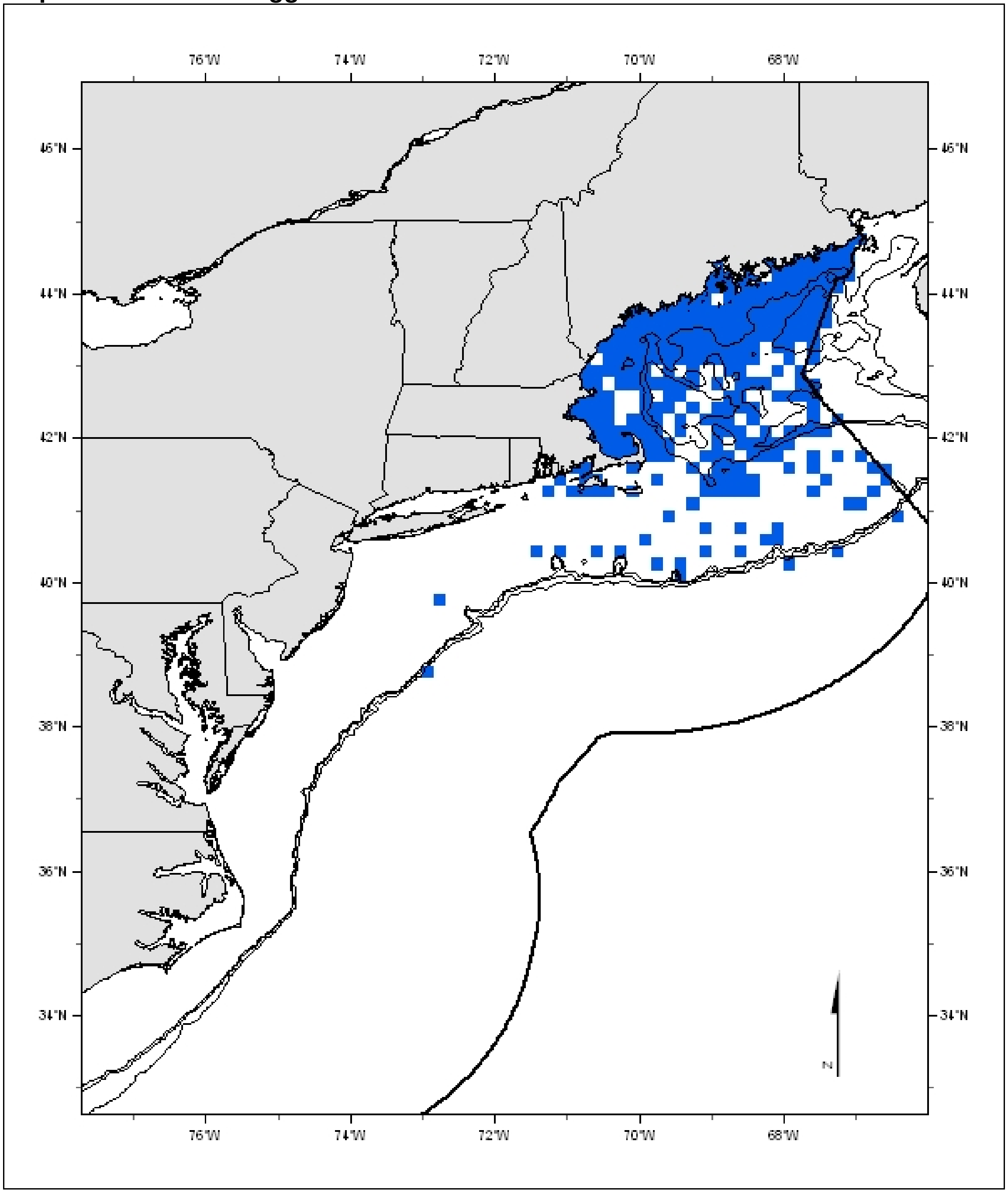
Map 30. Silver hake adults



The Alternative 3C EFH designation for adult silver hake on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level and includes inshore and off-shelf areas where adult silver hake were determined to be present, based on 10% frequency of occurrence in state trawl surveys, ELMR information, and off-shelf depth and geographic ranges.

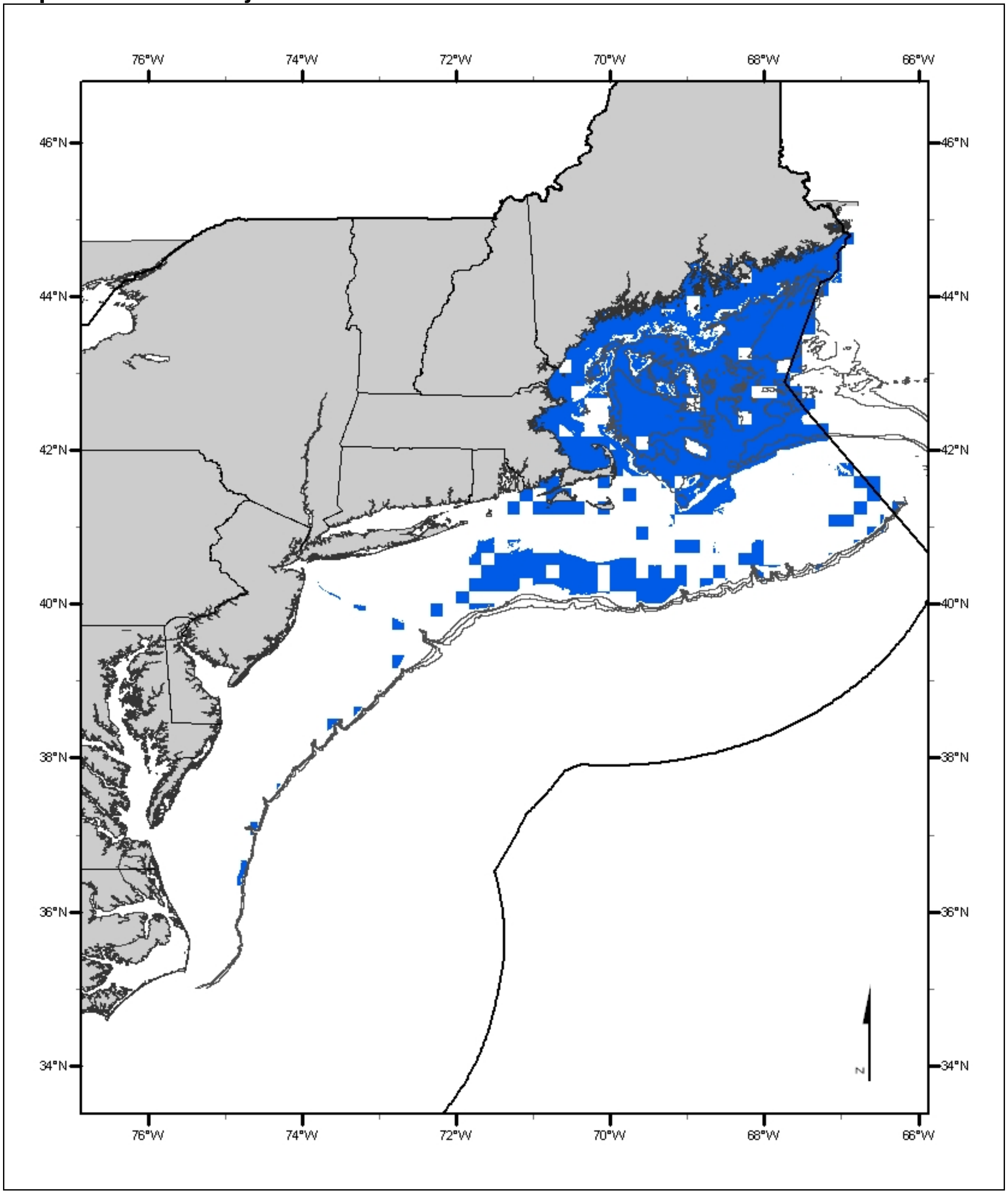
1.11 White hake (*Urophycis tenuis*)

Map 31. White hake eggs and larvae



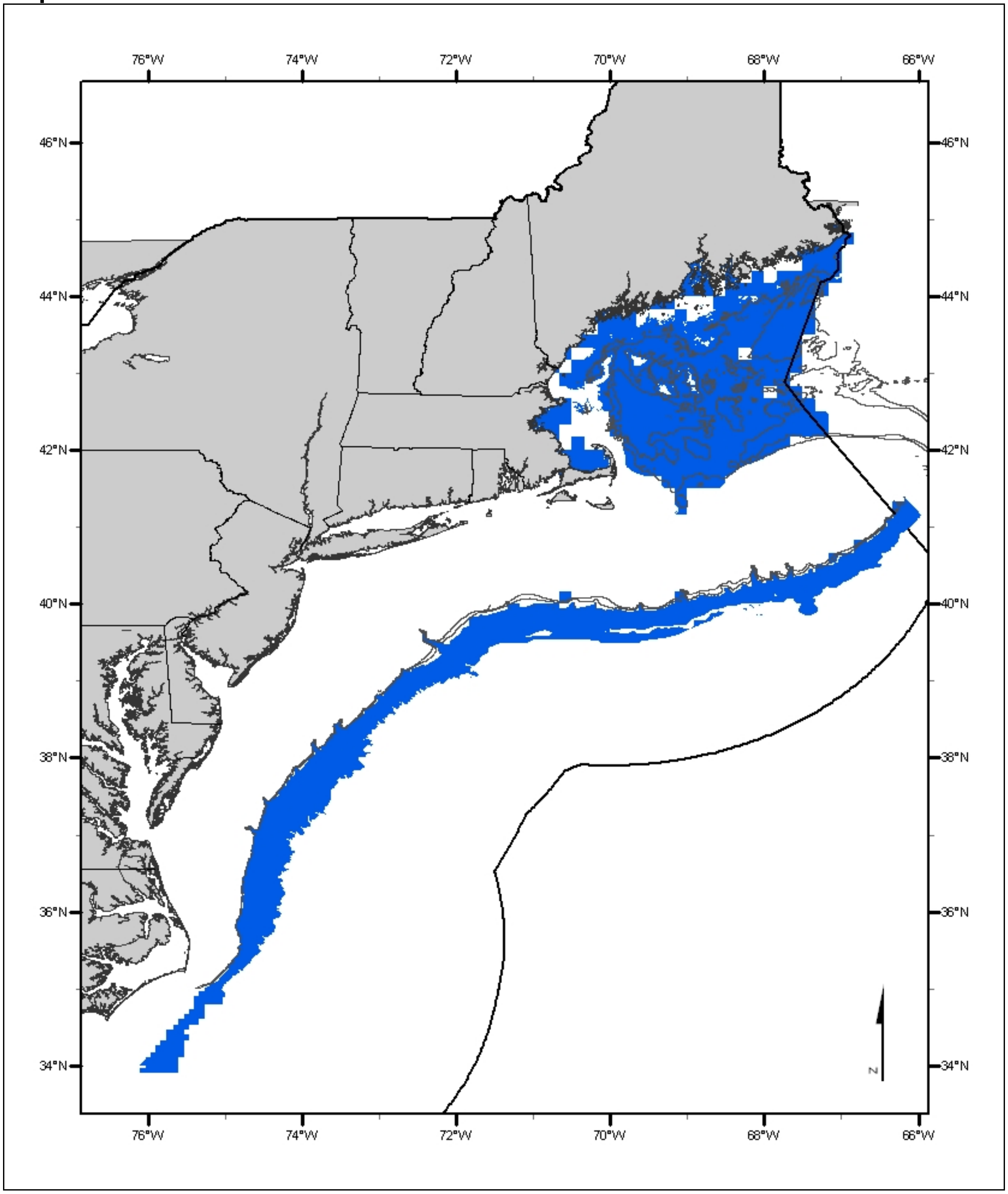
The Alternative 2D EFH designation for white hake eggs and larvae on the continental shelf is based upon the relative abundance of juveniles during 1968-2005 in the fall and spring NMFS trawl survey at the 90% cumulative percentage level. This alternative also includes ten minute squares in inshore areas where juvenile white hake were caught in state trawl surveys in more than 10% of the tows and those bays and estuaries identified by the NOAA ELMR program where white hake eggs or larvae were "common" or "abundant."

Map 32. White hake juveniles



The Alternative 3D EFH designation for juvenile white hake on the continental shelf is based on the distribution of substrate types, depths, and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore areas where juvenile white hake were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

Map 33. White hake adults

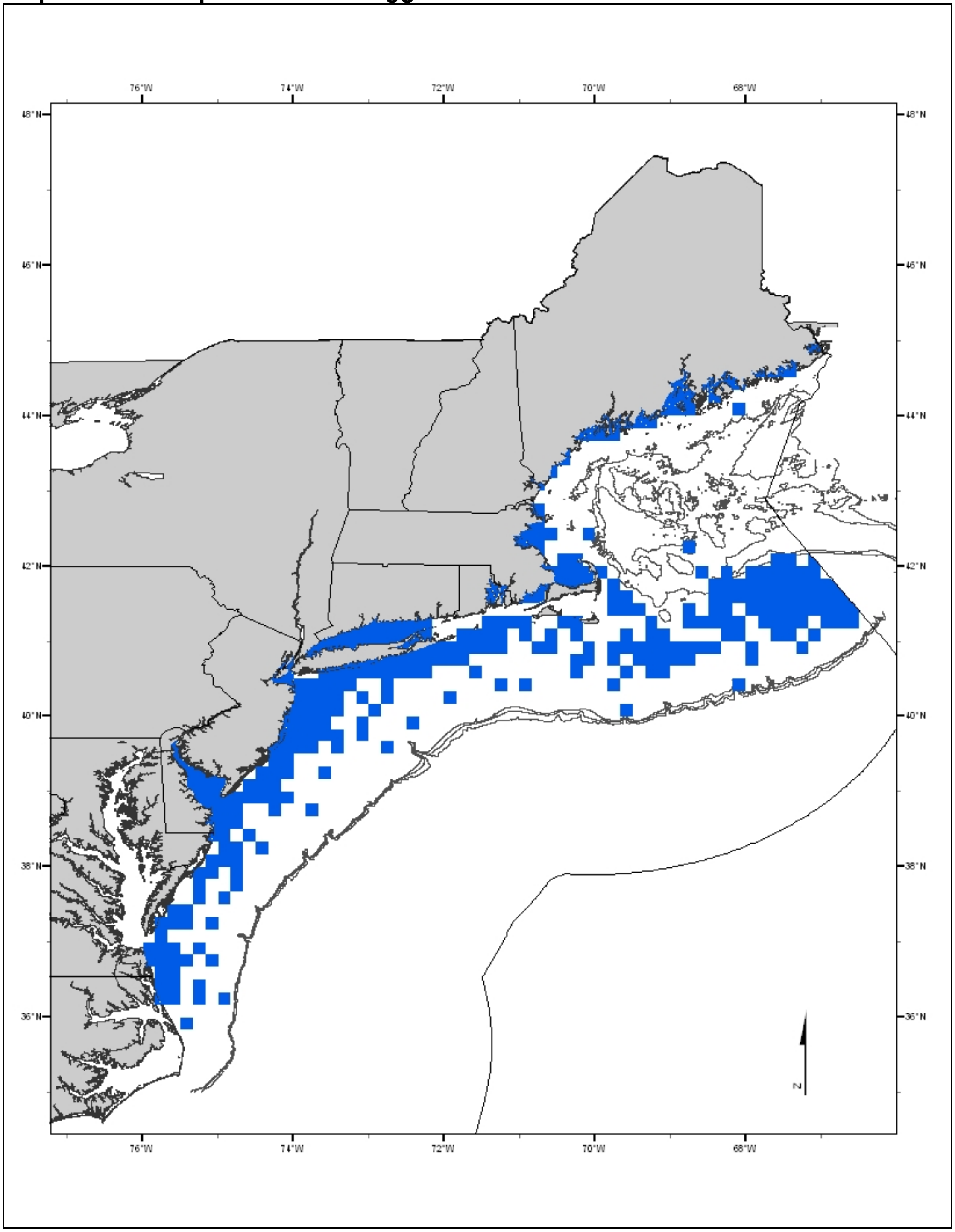


The Alternative 3D EFH designation for adult white hake on the continental shelf is based on the distribution of substrate types, depths, and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore and off-shelf areas where adult white hake were determined to be present, based on 10% frequency of occurrence in state trawl surveys, ELMR information, and off-shelf depth and geographic ranges.

NOTE: The maximum depth on the slope was incorrectly mapped at 2250 m – it should be 900m.

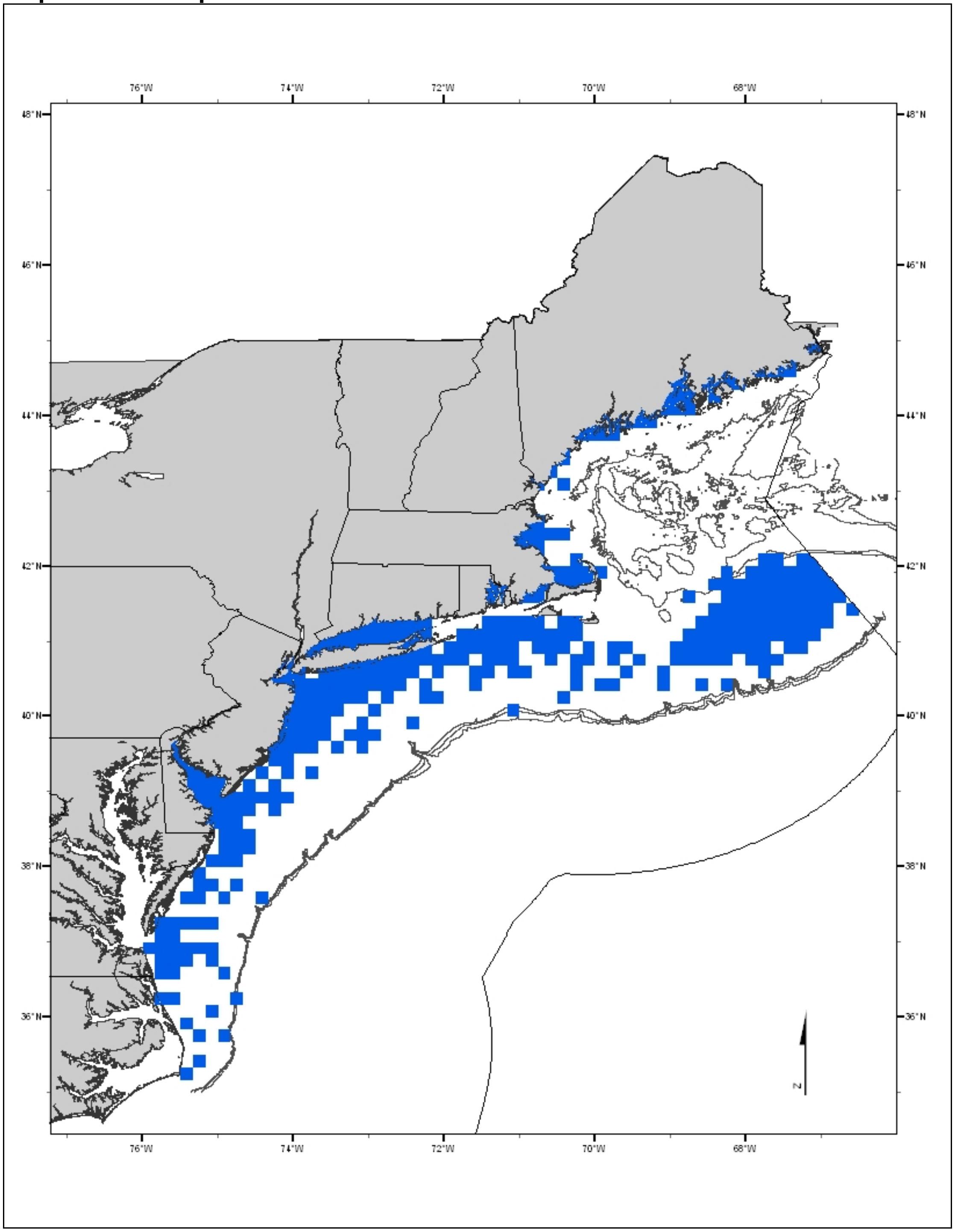
1.12 Windowpane flounder (*Scophthalmus aquosus*)

Map 34. Windowpane flounder eggs



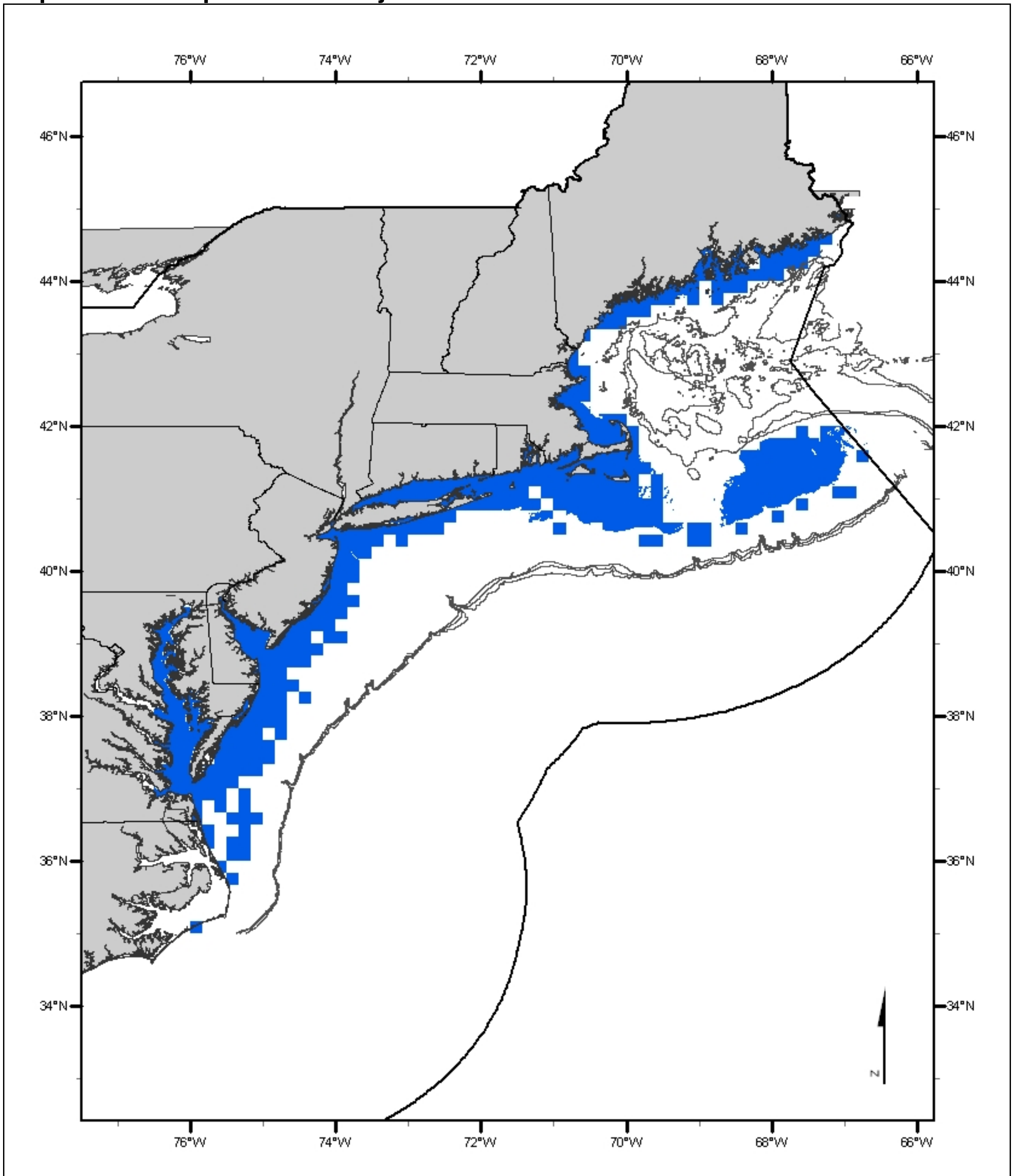
The EFH designation for windowpane flounder eggs is the status quo alternative which was based on the ten minute squares corresponding to the top 90% of the observed range in the 1978-1987 MARMAP survey data. *The EFH designation also includes those bays and estuaries identified by the NOAA ELMR program as supporting windowpane flounder eggs at the "common" or "abundant" level.*

Map 35. Windowpane flounder larvae



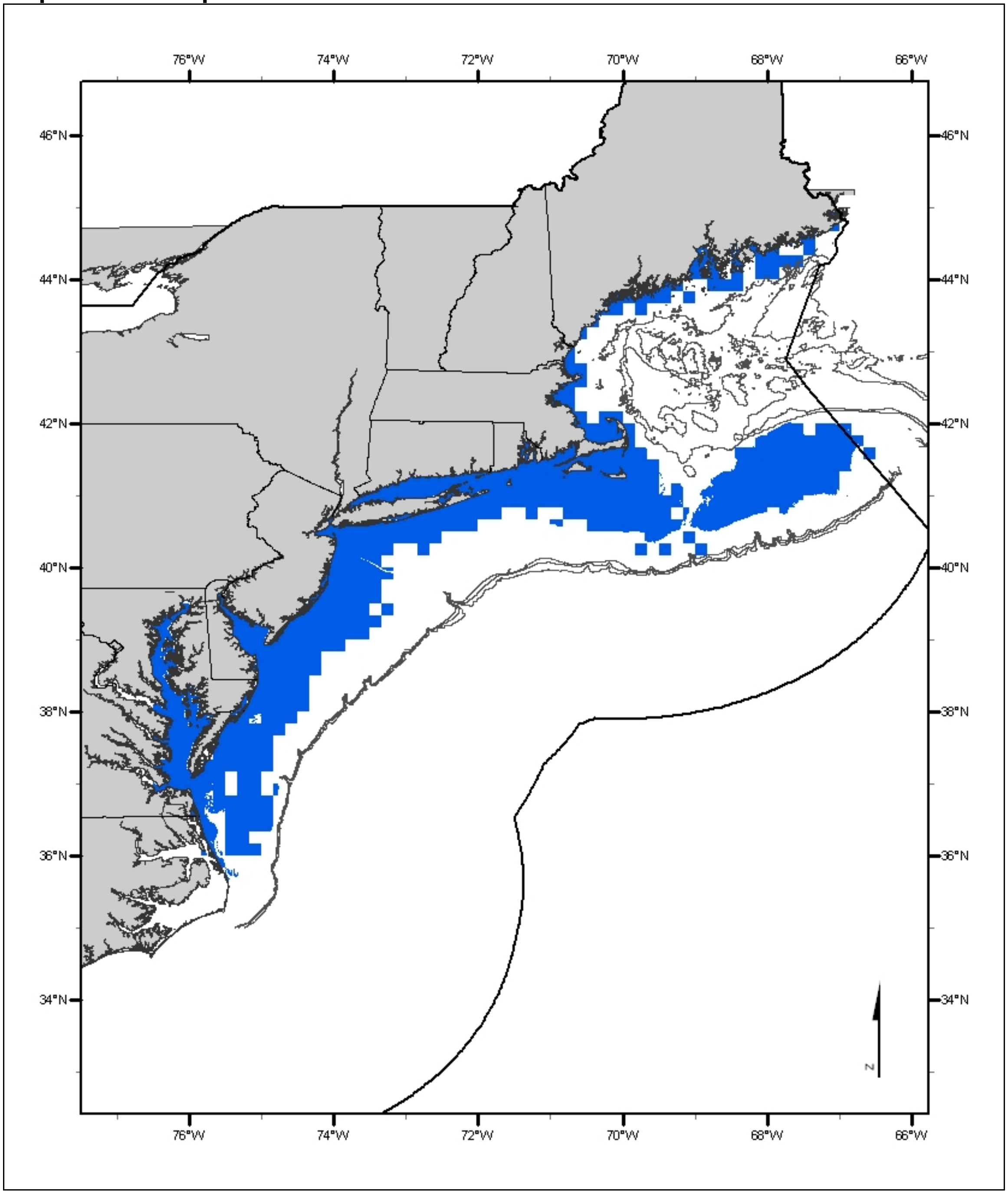
The EFH designation for windowpane flounder larvae is the status quo alternative which was based on the ten minute squares corresponding to 100% of the observed range in the 1978-1987 MARMAP survey data. *The EFH designation also includes those bays and estuaries identified by the NOAA ELMR program as supporting windowpane flounder larvae at the "common" or "abundant" level.*

Map 36. Windowpane flounder juveniles



The Alternative 3E EFH designation for juvenile windowpane flounder is the same as the 3D Alternative for juvenile windowpane flounder with the addition of ten minute squares along the RI and CT coasts and southeast of Nantucket Island where there are no survey data.

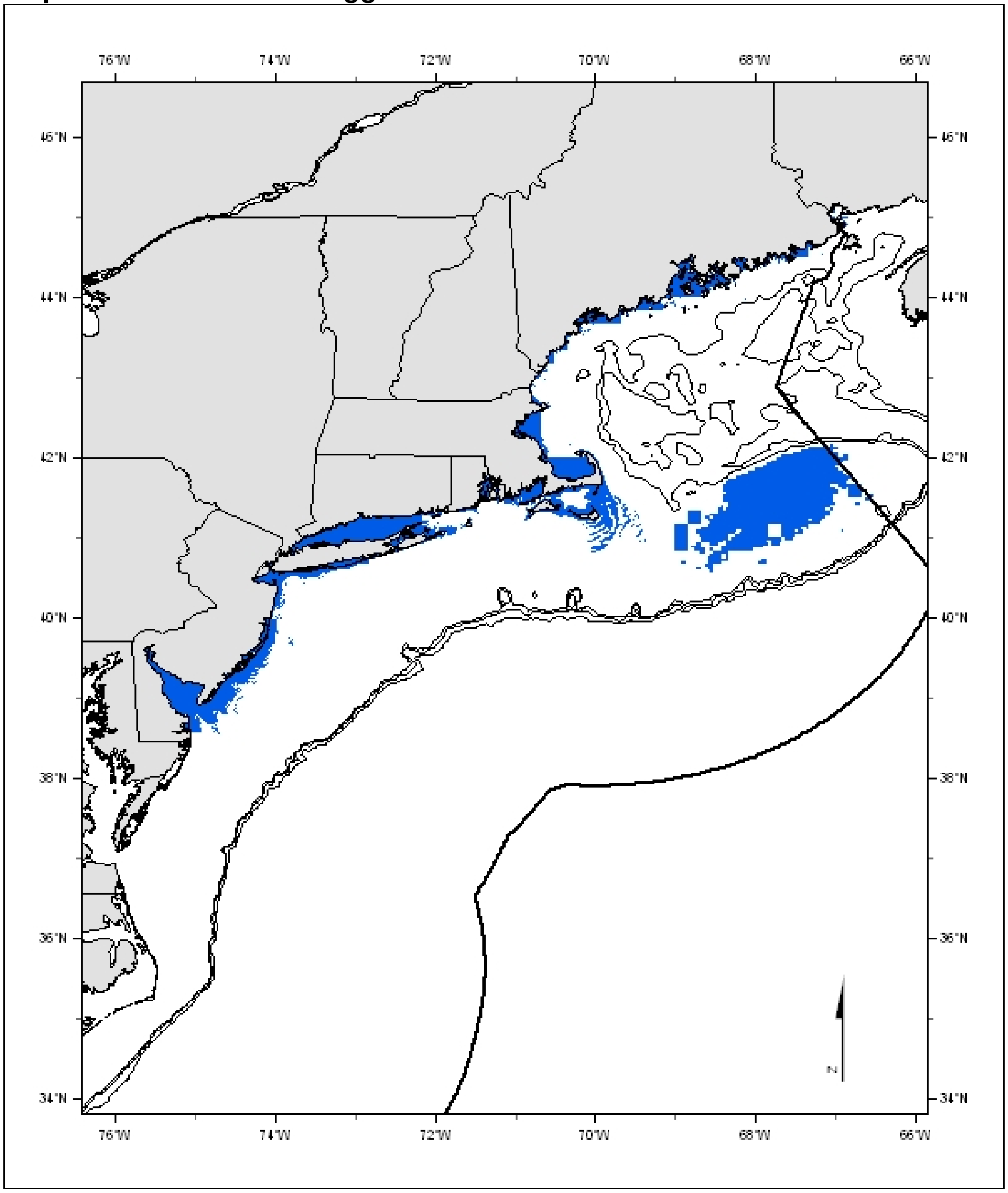
Map 37. Windowpane flounder adults



The Alternative 3E EFH designation for adult windowpane flounder is the same as the 3D Alternative for adult windowpane flounder with the addition of ten minute squares along the RI and CT coasts and southeast of Nantucket Island where there are no survey data for this species.

1.13 Winter flounder (*Pseudopleuronectes americanus*)

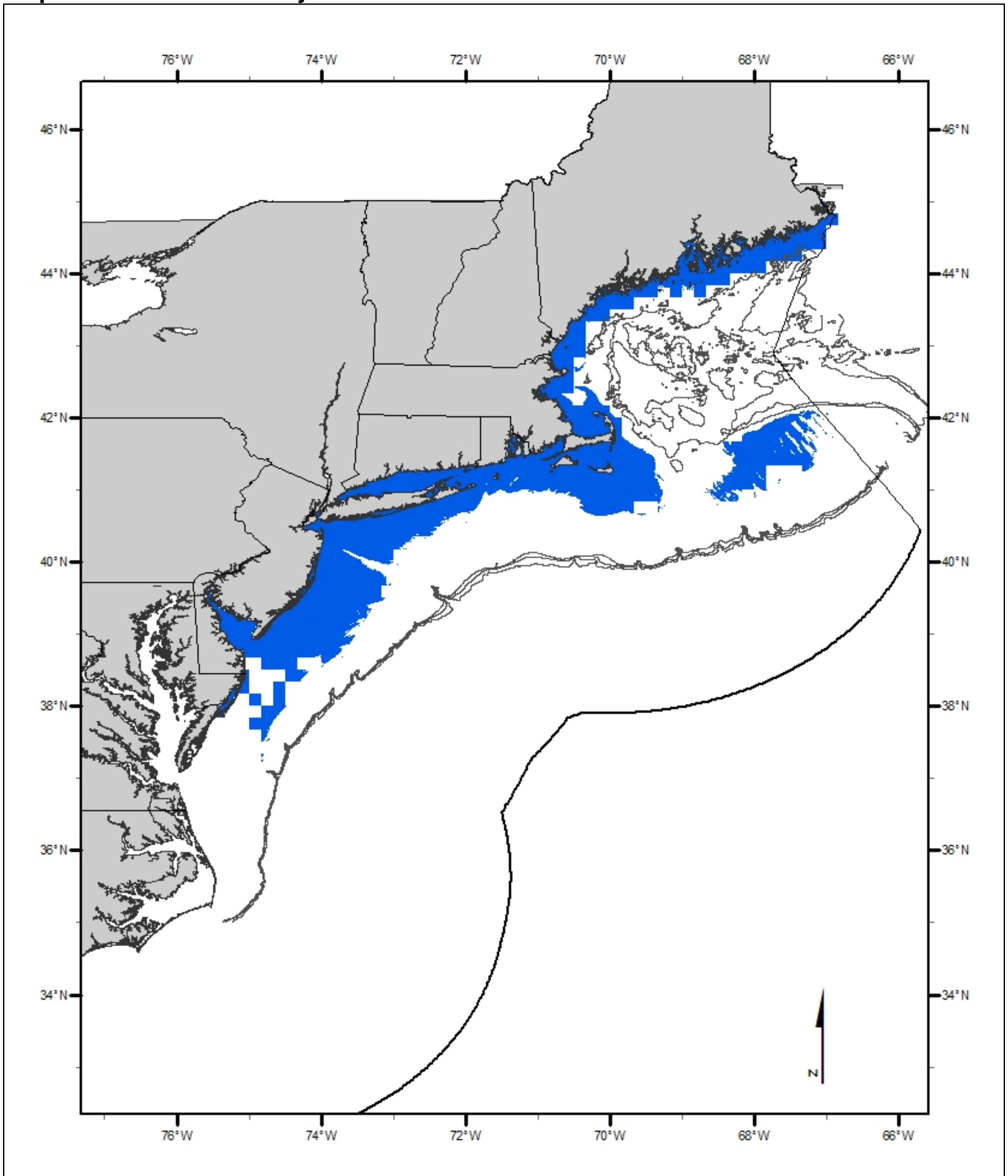
Map 38. Winter flounder eggs and larvae



The Alternative 5A EFH designation for winter flounder eggs and larvae is the same as the Alternative 3 designation for eggs and larvae, except that areas in Nantucket Sound deeper than 20 meters have been removed. The Alternative 3 designation includes coastal waters out to a maximum depth of 20 meters within the range of spawning adults (eastern Maine to Delaware Bay) plus bays and estuaries identified in the NOAA ELMR program where winter flounder eggs and larvae are "common" or "abundant." It also includes spawning areas on Georges Bank to a maximum depth of 72 meters, as identified in the EFH Source Document.

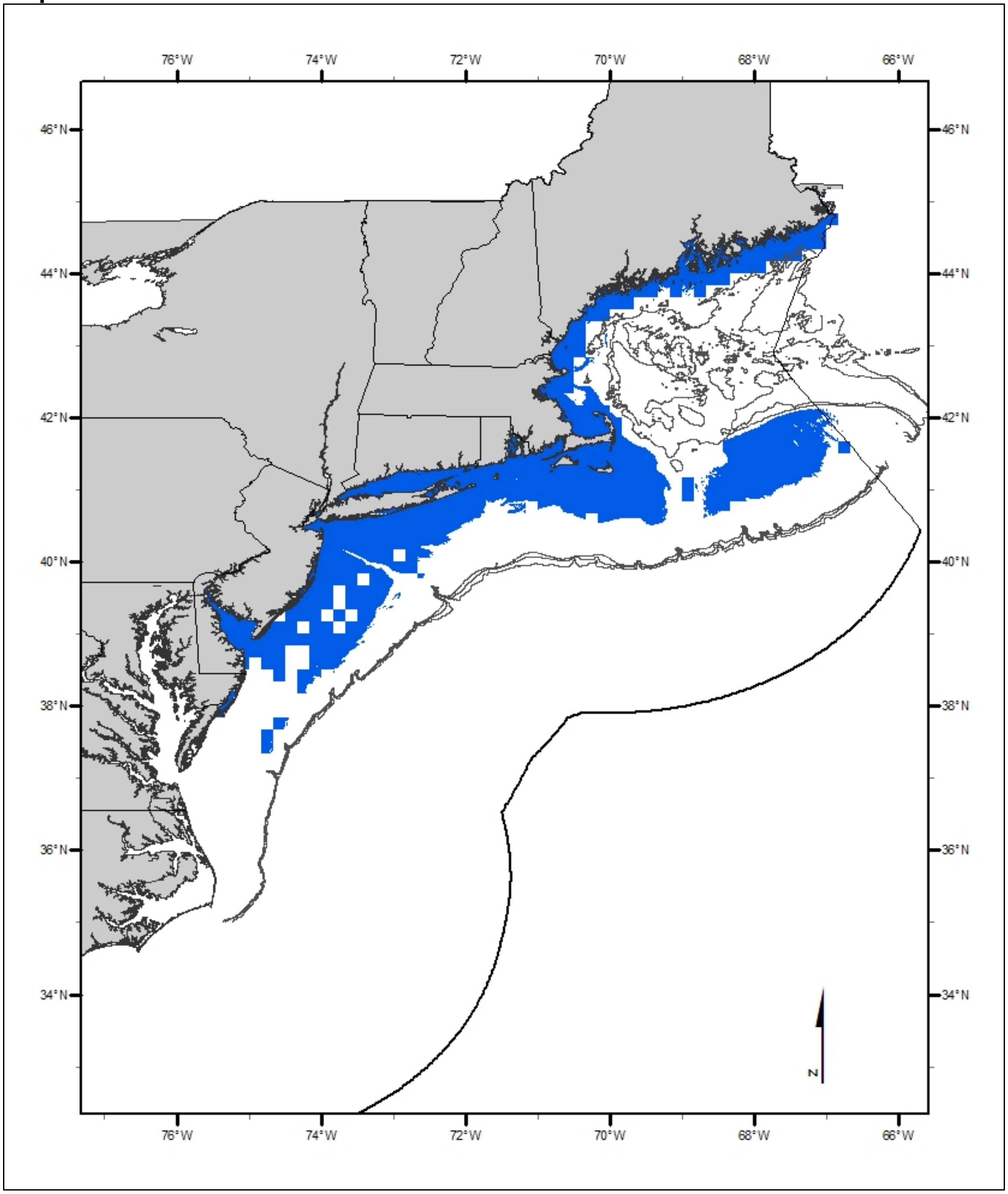
NOTE: The maximum depth on Georges Bank was incorrectly set at 60 meters – it should be 70 meters.

Map 39. Winter flounder juveniles



The Alternative 3E EFH designation for juvenile winter flounder is based on the Alternative 3D designation for juvenile winter flounder with "filled in" ten minute squares along the ME, NH, RI, and CT coasts and east and south of Nantucket Island.

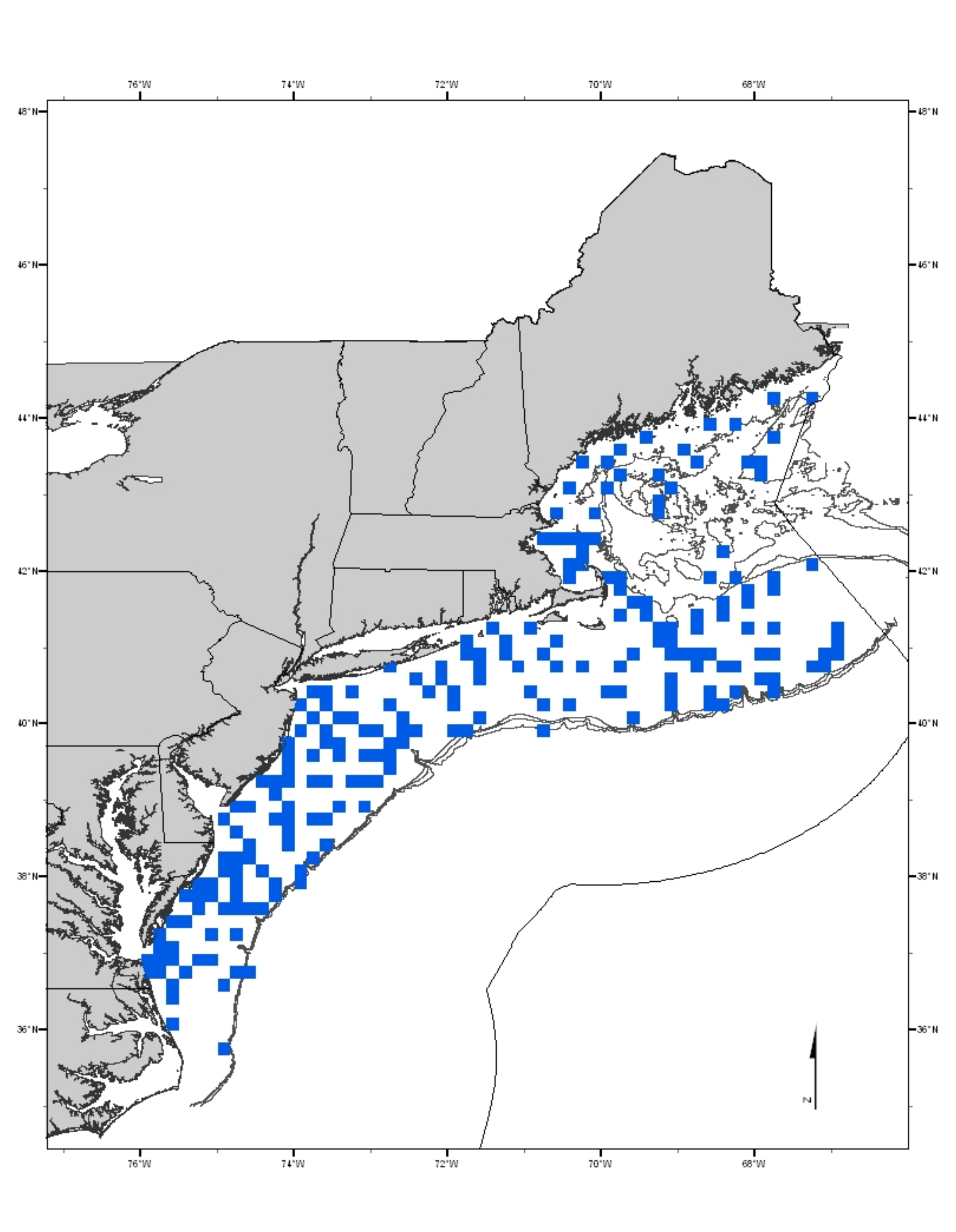
Map 40. Winter flounder adults



The Alternative 3E EFH designation for adult winter flounder is based on the Alternative 3D designation for adult winter flounder with "filled in" ten minute squares along the ME, NH, RI, and CT coasts and east and south of Nantucket Island.

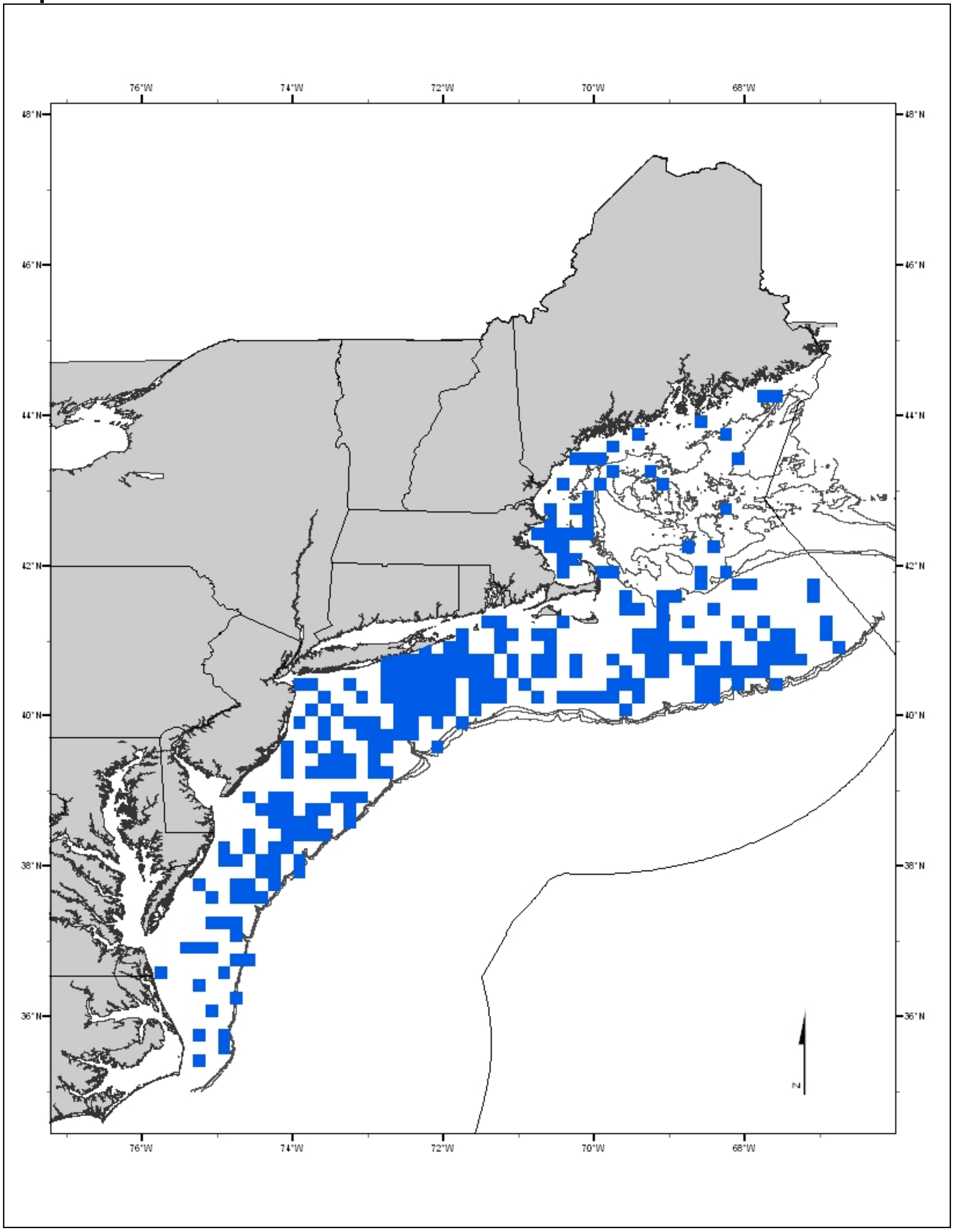
1.14 Witch flounder (*Glyptocephalus cynoglossus*)

Map 41. Witch flounder eggs



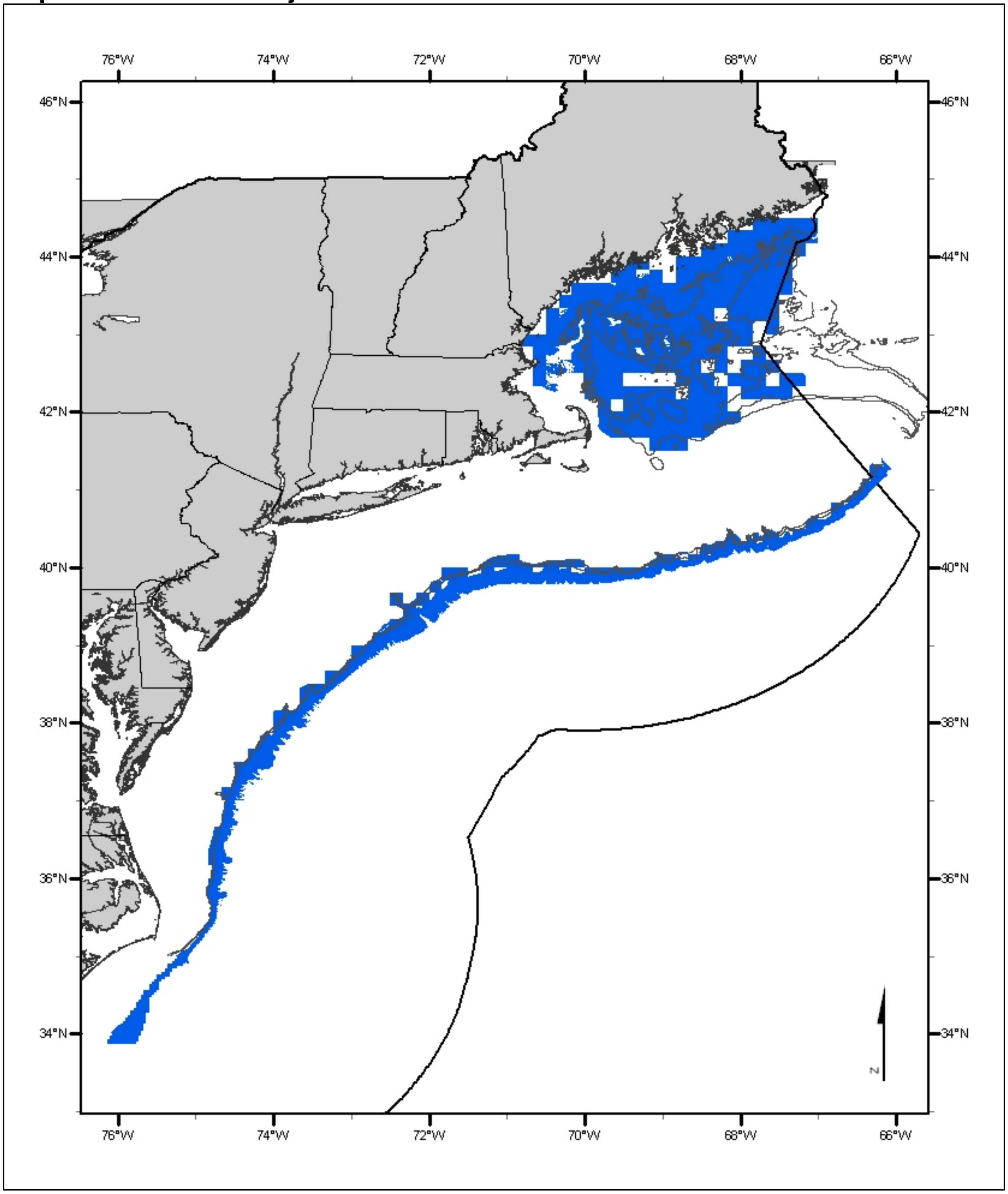
The EFH designation for witch flounder eggs is the status quo alternative which was based on the ten minute squares corresponding to 100% of the observed range in the 1978-1987 MARMAP survey data.

Map 42. Witch flounder larvae



The EFH designation for witch flounder larvae is the status quo alternative which was based on the ten minute squares corresponding to 100% of the observed range in the 1978-1987 MARMAP survey data.

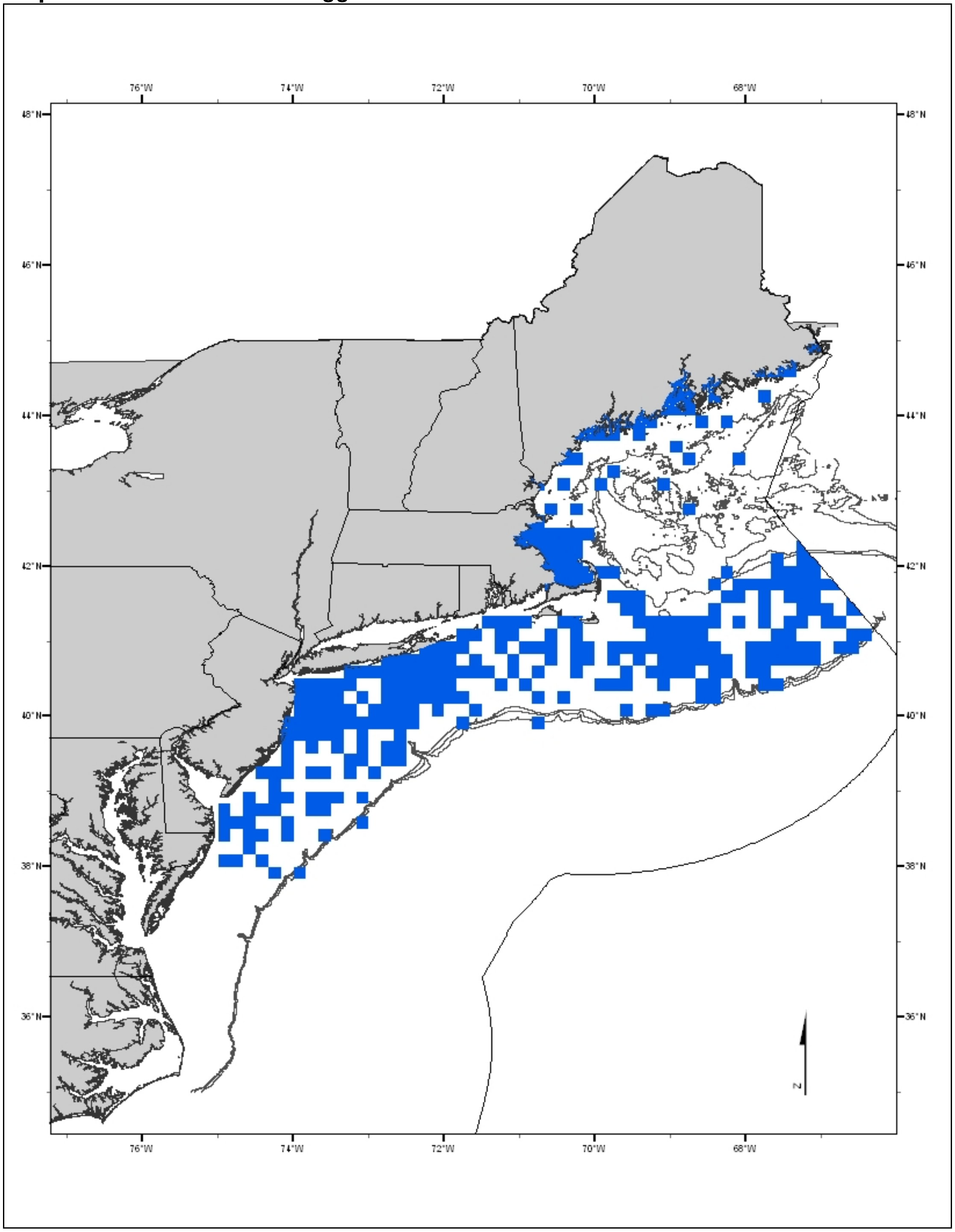
Map 43. Witch flounder juveniles and adults



The Alternative 3D EFH designation for juvenile and adult witch flounder on the continental shelf is based on the distribution of substrate types, depths, and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore and off-shelf areas where juvenile witch flounder were determined to be present, based on 10% frequency of occurrence in state trawl surveys and off-shelf depth and geographic ranges.

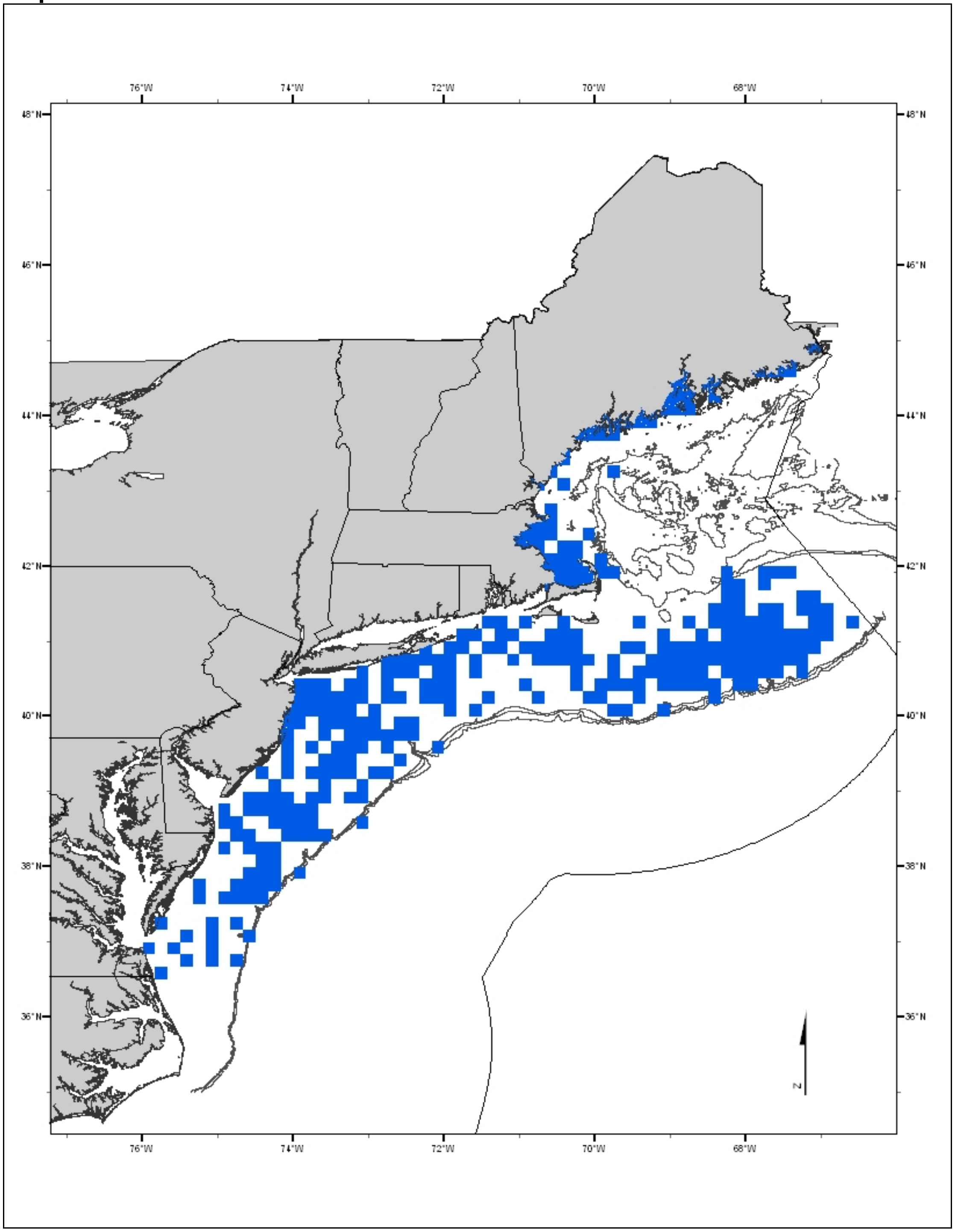
1.15 Yellowtail flounder (*Limanda ferruginea*)

Map 44. Yellowtail flounder eggs



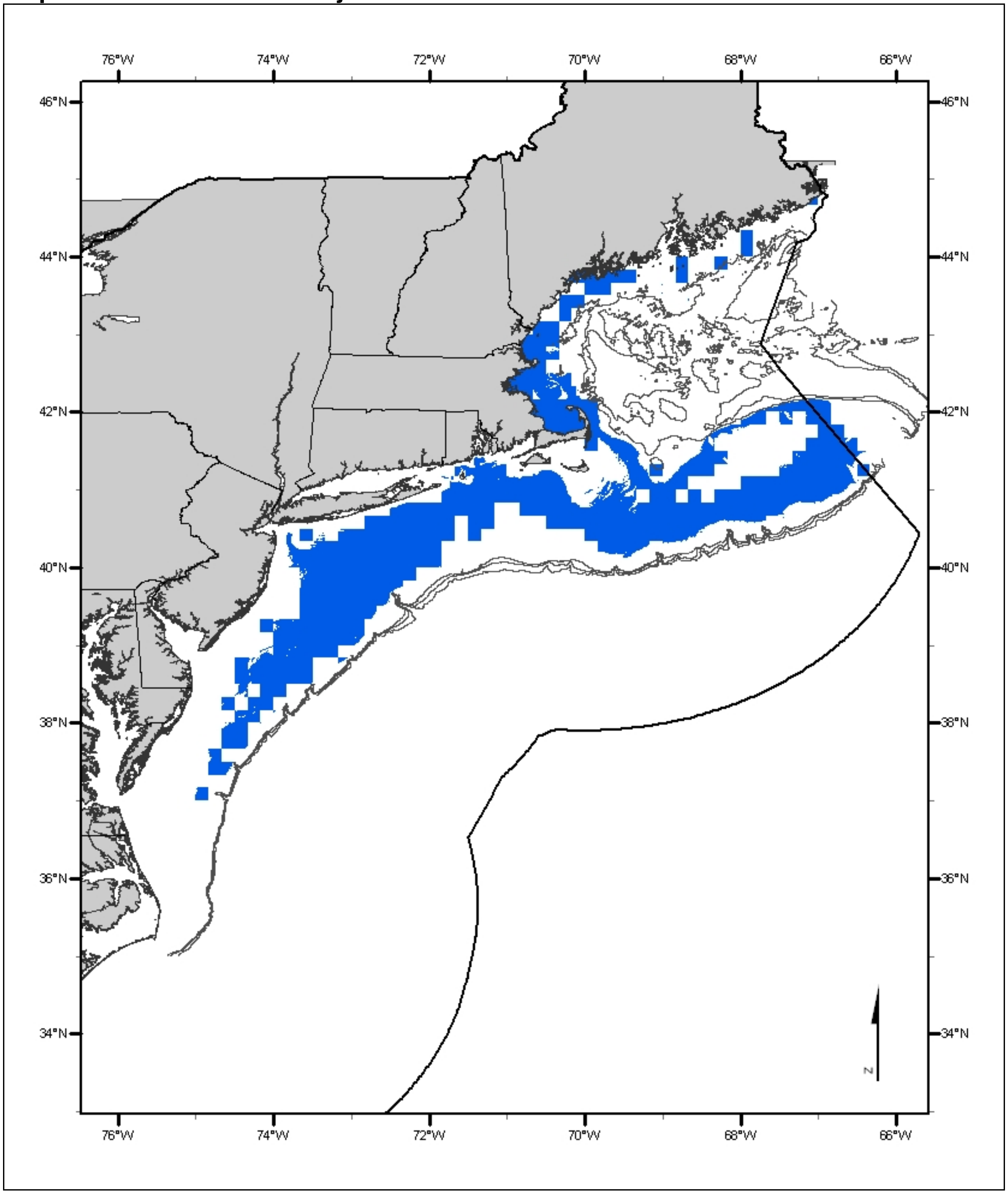
The EFH designation for yellowtail flounder eggs is the status quo alternative which was based on the ten minute squares corresponding to 100% of the observed range in the 1978-1987 MARMAP survey data. *In addition, this designation includes those bays and estuaries identified in the NOAA ELMR program as supporting yellowtail flounder eggs at the "rare", "common", or "abundant" level.*

Map 45. Yellowtail flounder larvae



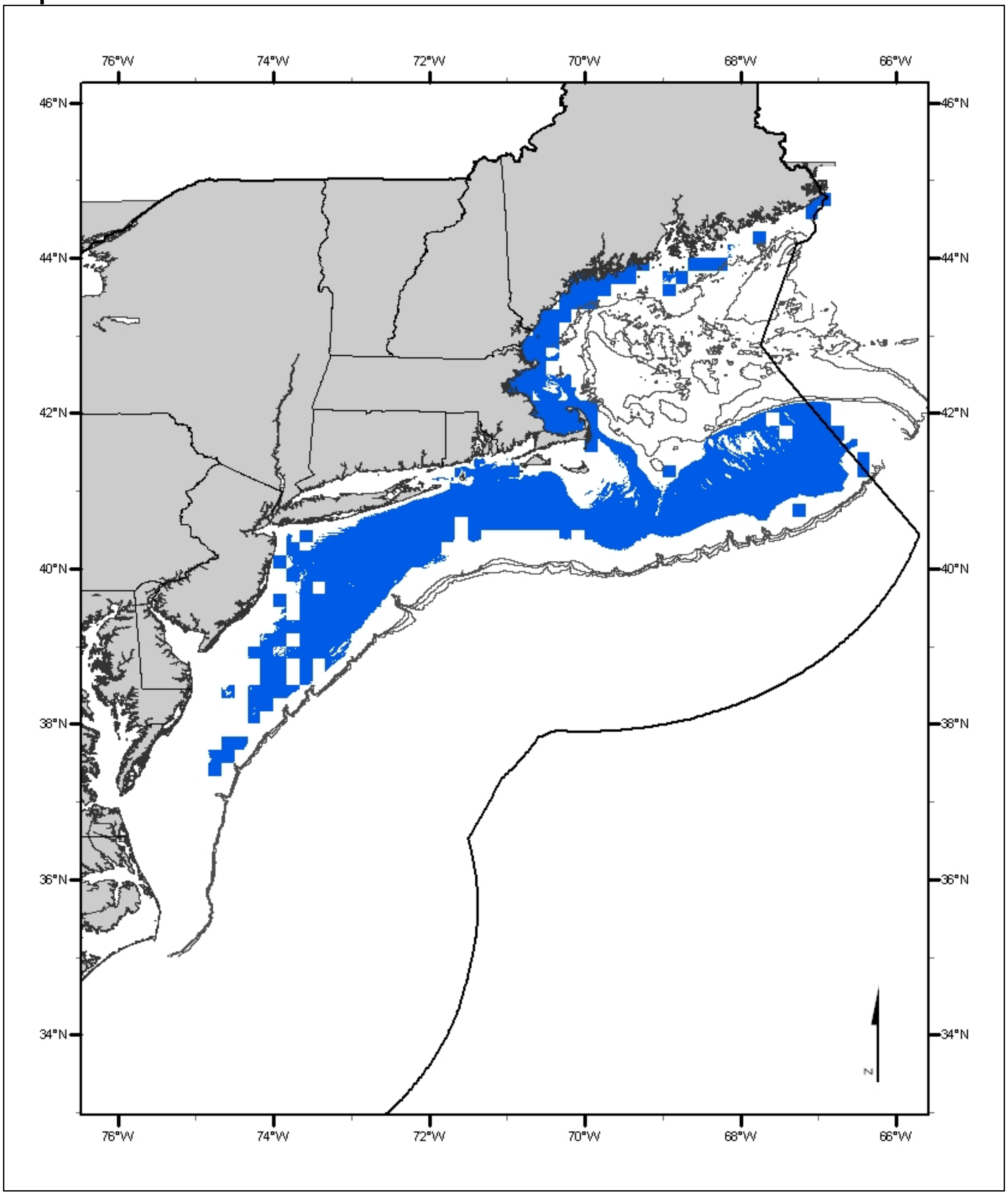
The EFH designation for yellowtail flounder larvae is the status quo alternative which was based on the ten minute squares corresponding to 100% of the observed range in the 1978-1987 MARMAP survey data. *In addition, this designation includes those bays and estuaries identified in the NOAA ELMR program as supporting yellowtail flounder larvae at the "rare", "common", or "abundant" level.*

Map 46. Yellowtail flounder juveniles



The Alternative 3D EFH designation for juvenile yellowtail flounder on the continental shelf is based on the distribution of substrate types, depths and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore areas where juvenile yellowtail flounder were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

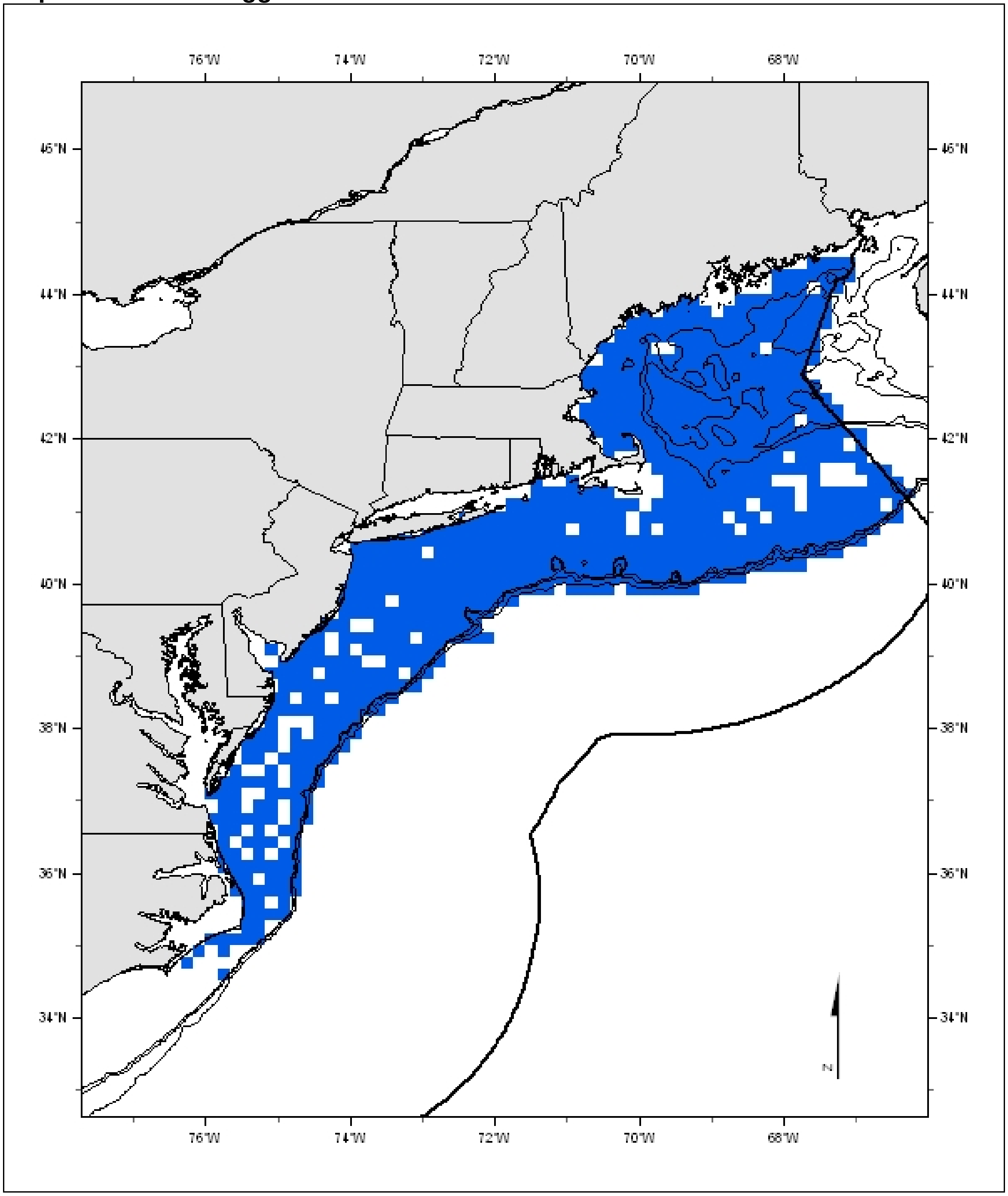
Map 47. Yellowtail flounder adults



The Alternative 3D EFH designation for adult yellowtail flounder on the continental shelf is based on the distribution of substrate types, depths and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore areas where adult yellowtail flounder were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

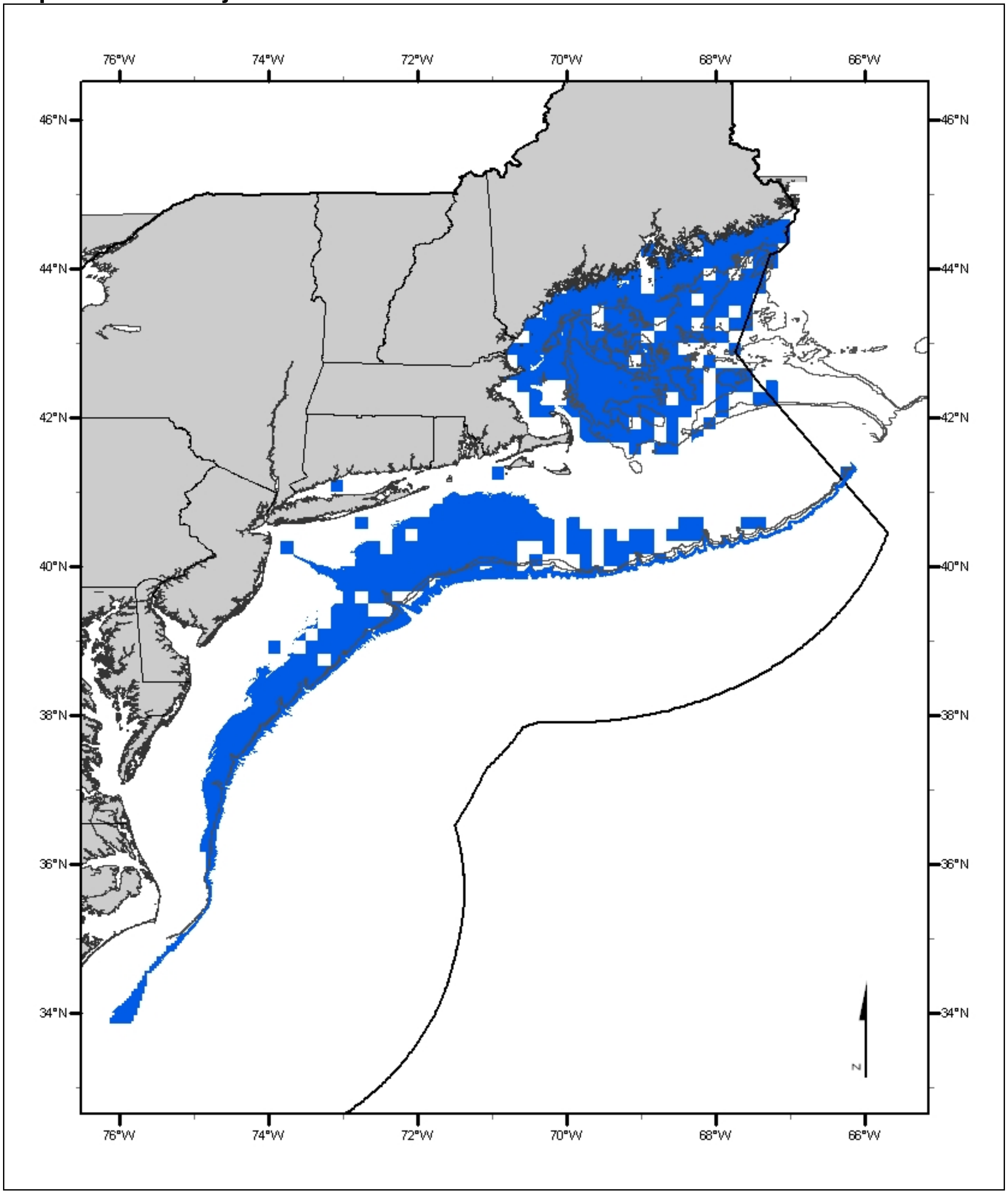
2.0 Monkfish (*Lophius americanus*)

Map 48. Monkfish egg and larvae



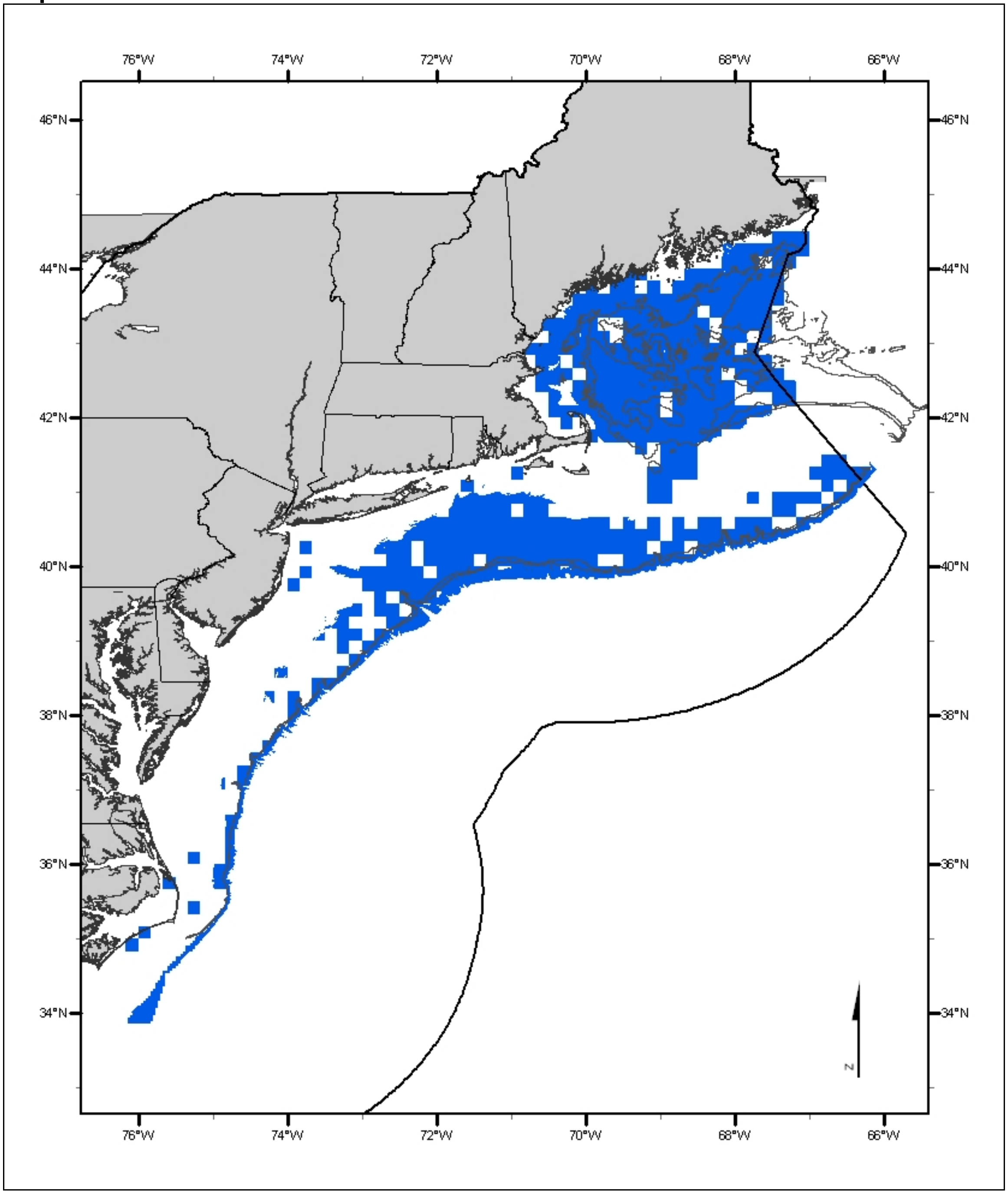
The Alternative 4 EFH designation for monkfish eggs and larvae on the continental shelf includes all the ten minute squares where adult monkfish were caught during 1968-2005 in the fall and spring NMFS trawl survey plus all the ten minute squares where monkfish larvae were collected during 1978-1987 in the NMFS MARMAP ichthyoplankton survey. Inshore, this alternative includes ten minute squares where adult monkfish were caught in state trawl surveys in more than 10% of the tows. This alternative also includes the area beyond the continental shelf where monkfish larvae are known or presumed to be present.

Map 49. Monkfish juveniles



The Alternative 3C EFH designation for juvenile monkfish on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level and includes off-shelf areas where juvenile or adult monkfish were determined to be present, based on depth and geographic ranges.

Map 50. Monkfish adults

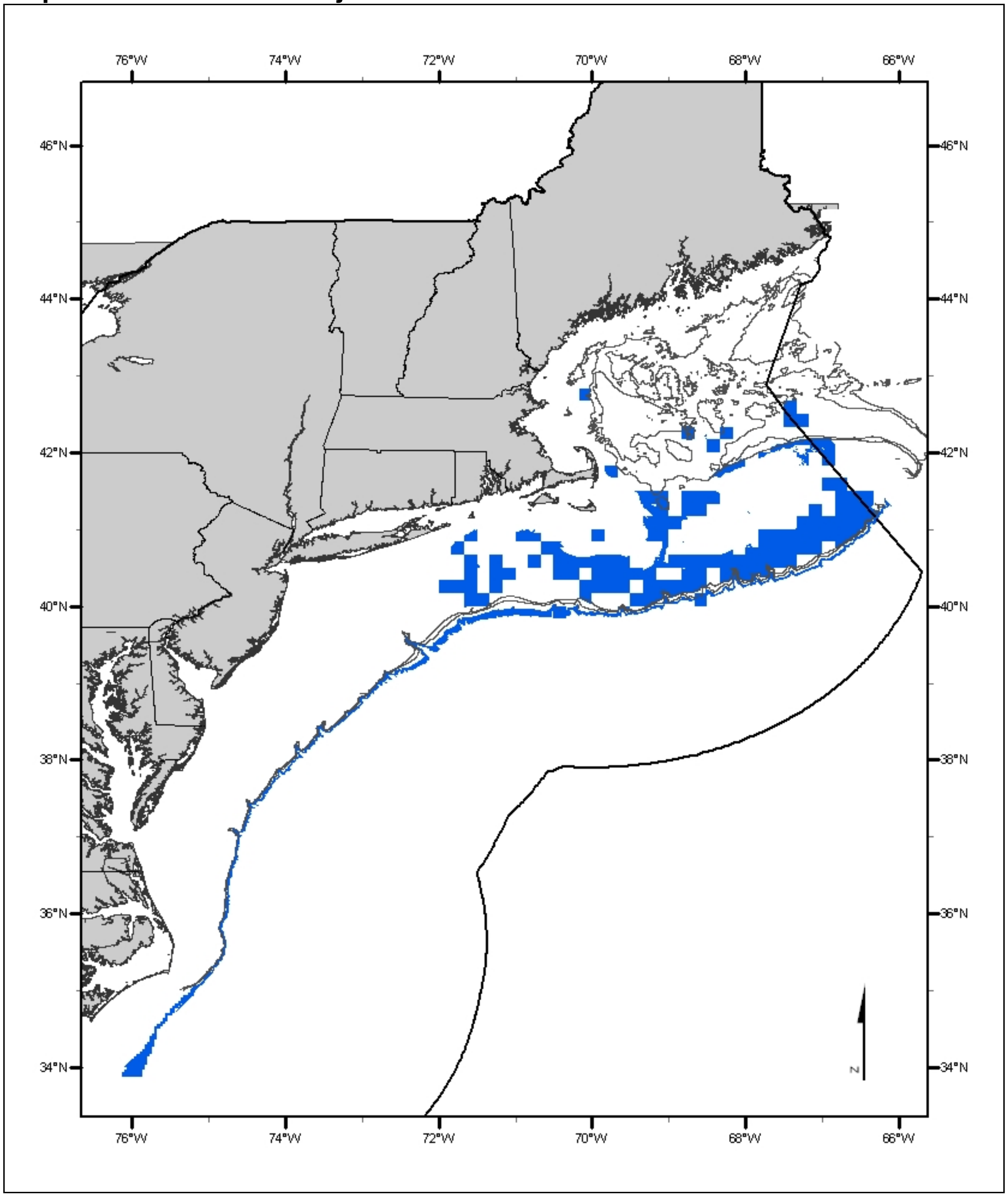


The Alternative 3C EFH designation for adult monkfish on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level and includes off-shelf areas where adult or adult monkfish were determined to be present, based on depth and geographic ranges.

3.0 Skates

3.1 Barndoor skate (*Dipturus laevis*)

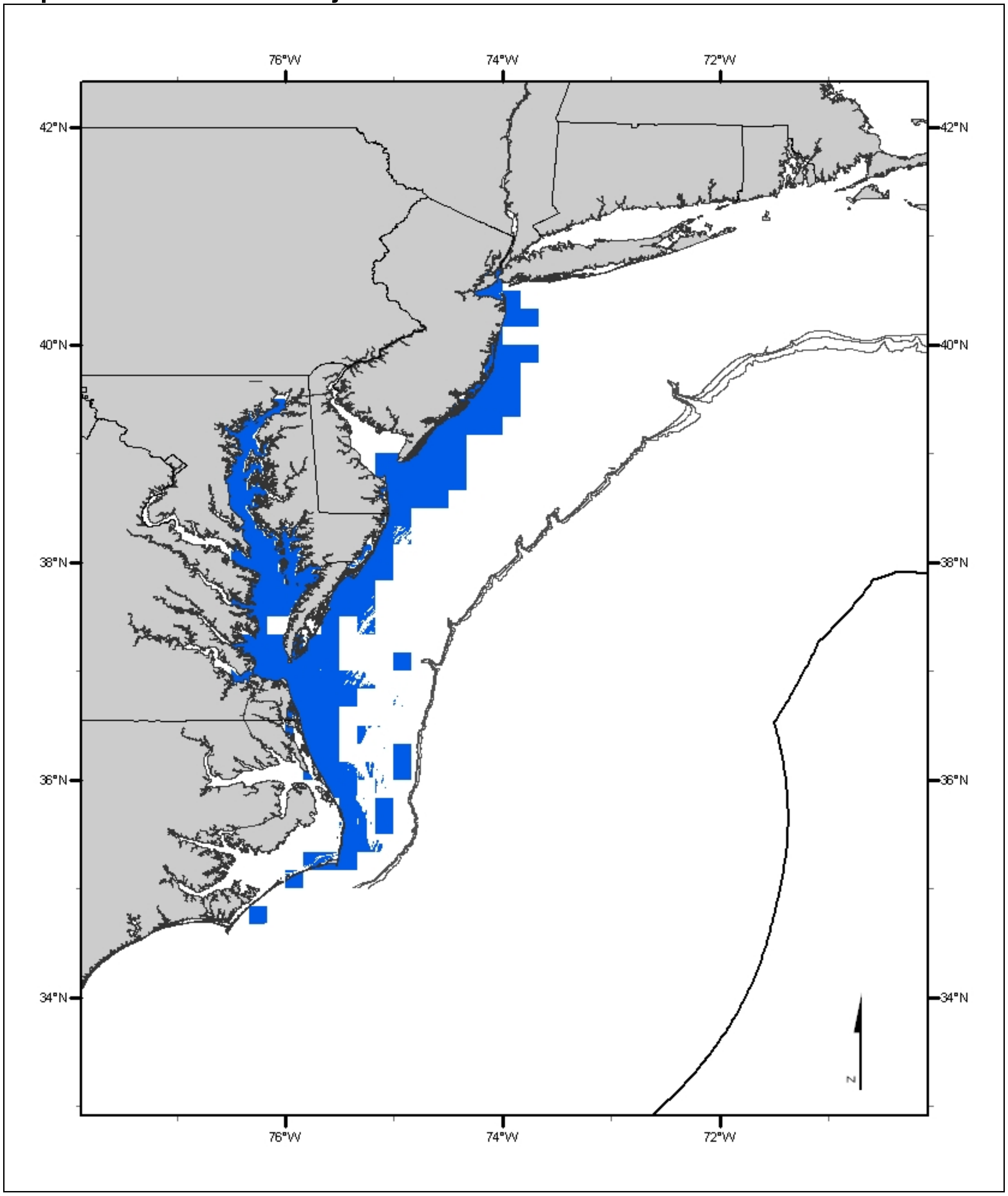
Map 51. Barndoor skates juveniles and adults



The Alternative 3D EFH designation for juvenile and adult barndoor skate on the continental shelf is based on the distribution of substrate types, depths, and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes off-shelf areas where juvenile and adult barndoor skate were determined to be present, based on off-shelf depth and geographic ranges.

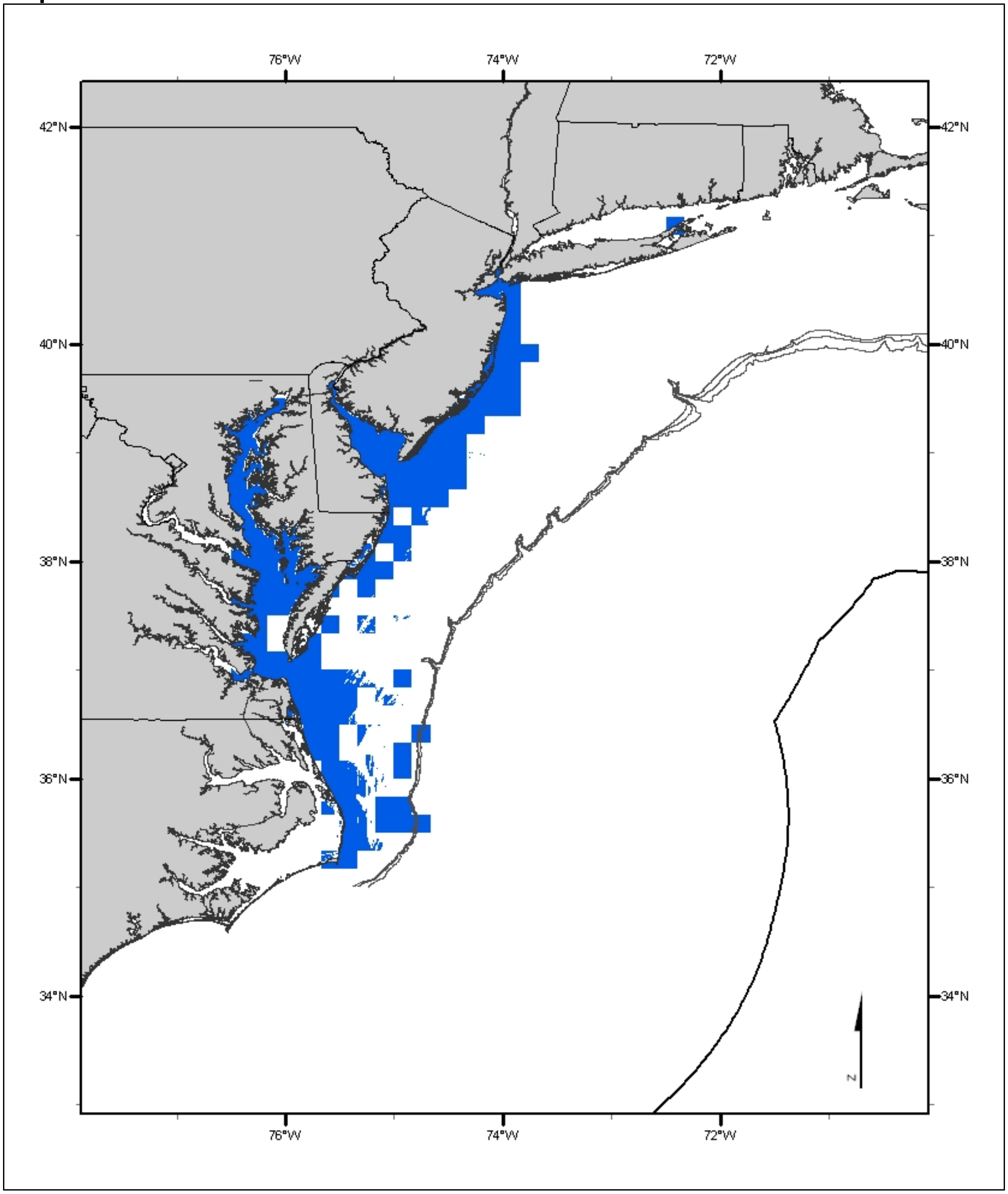
3.2 Clearnose skate (*Raja eglanteria*)

Map 52. Clearnose skates juveniles



The Alternative 3C EFH designation for juvenile clearnose skate on the continental shelf is based on the distribution of substrate types, depths and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level and includes inshore areas where juvenile clearnose skate were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

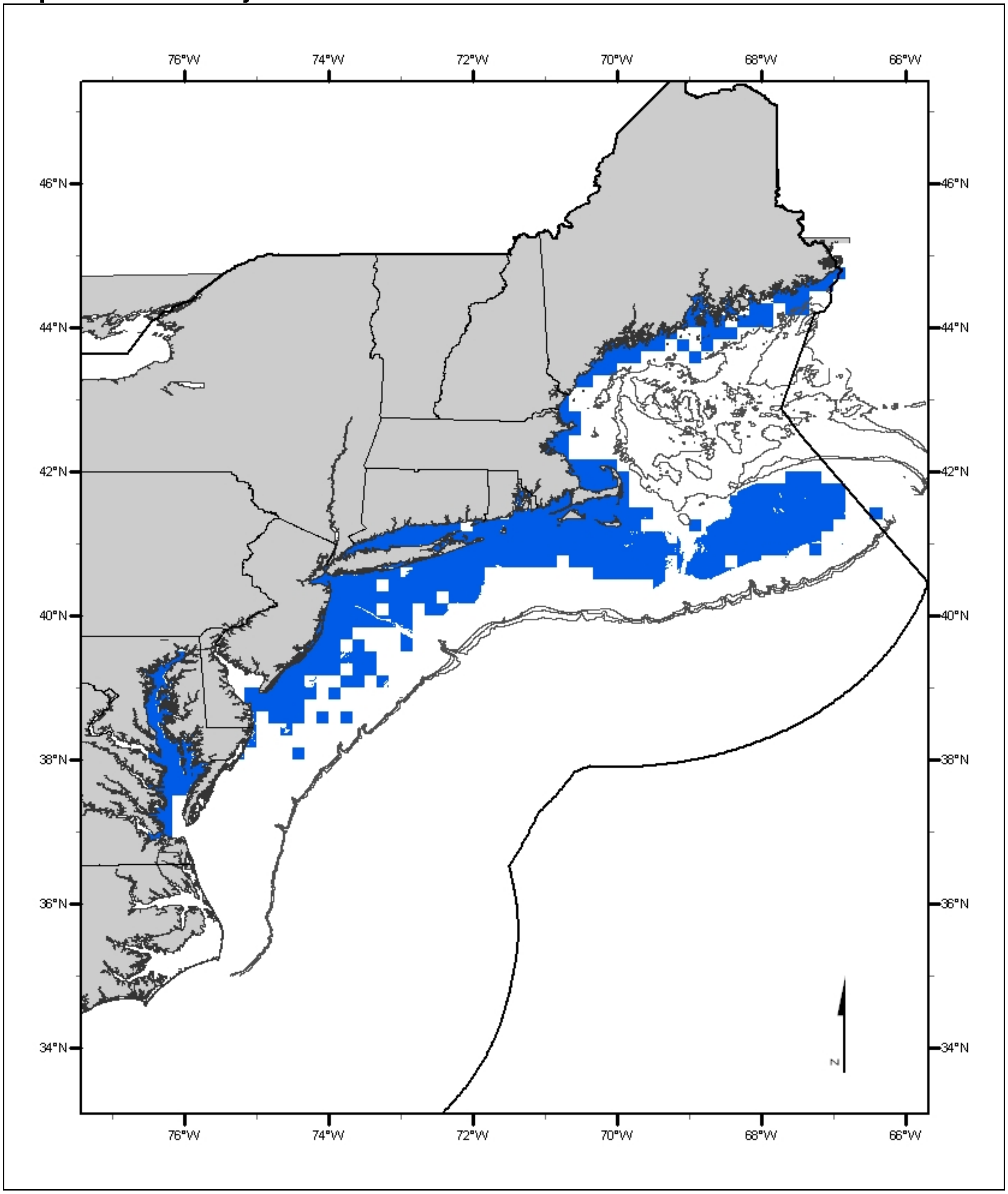
Map 53. Clearnose skates adults



The Alternative 3C EFH designation for adult clearnose skate on the continental shelf is based on the distribution of substrate types, depths and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level and includes inshore areas where adult clearnose skate were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

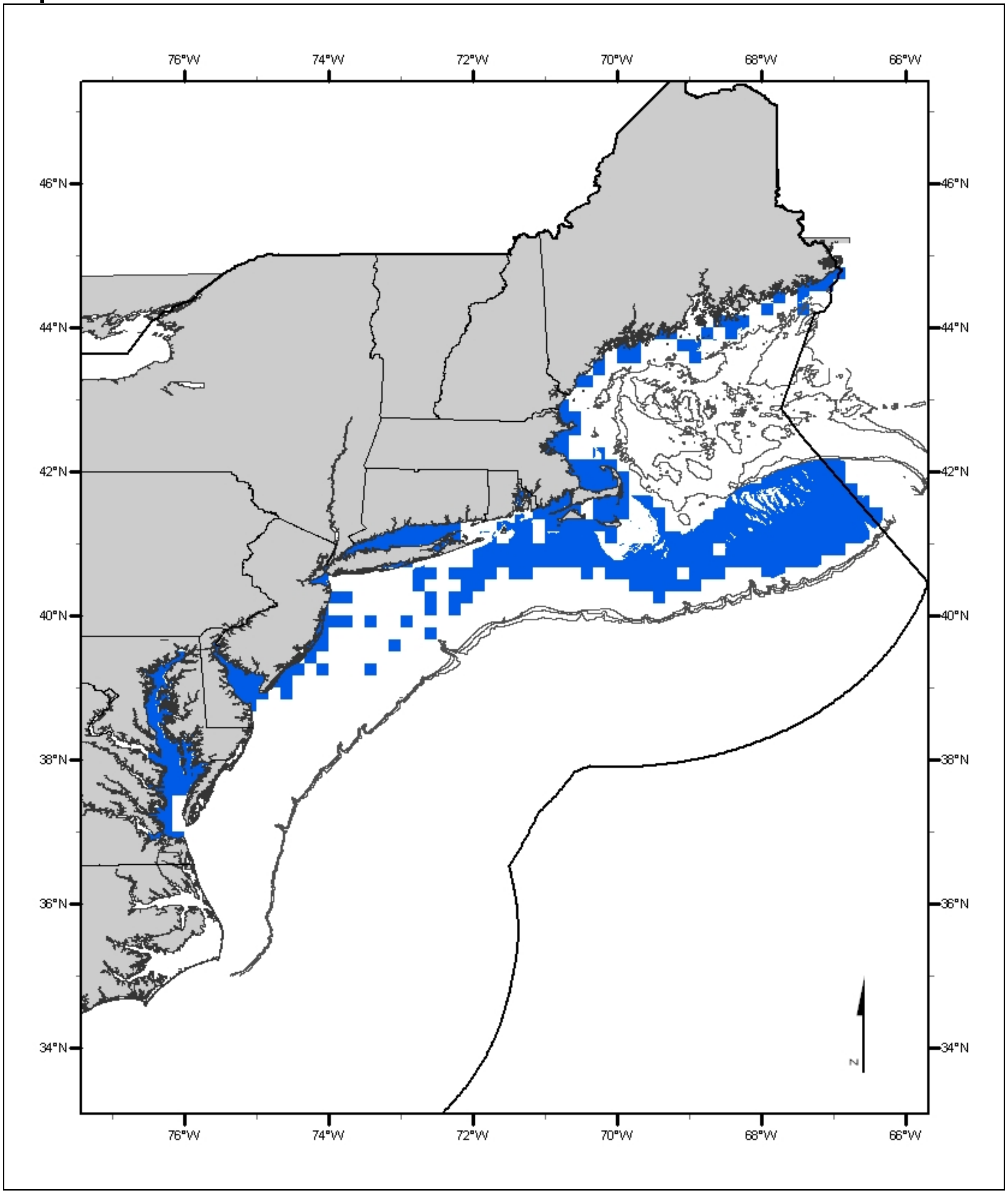
3.3 Little skate (*Leucoraja erinacea*)

Map 54. Little skate juveniles



The Alternative 3E EFH designation for juvenile little skate is based on the 3C Alternative for juvenile little skate with the addition of ten minute squares along the RI and CT coasts and east of Nantucket Island where there are no survey data for this species.

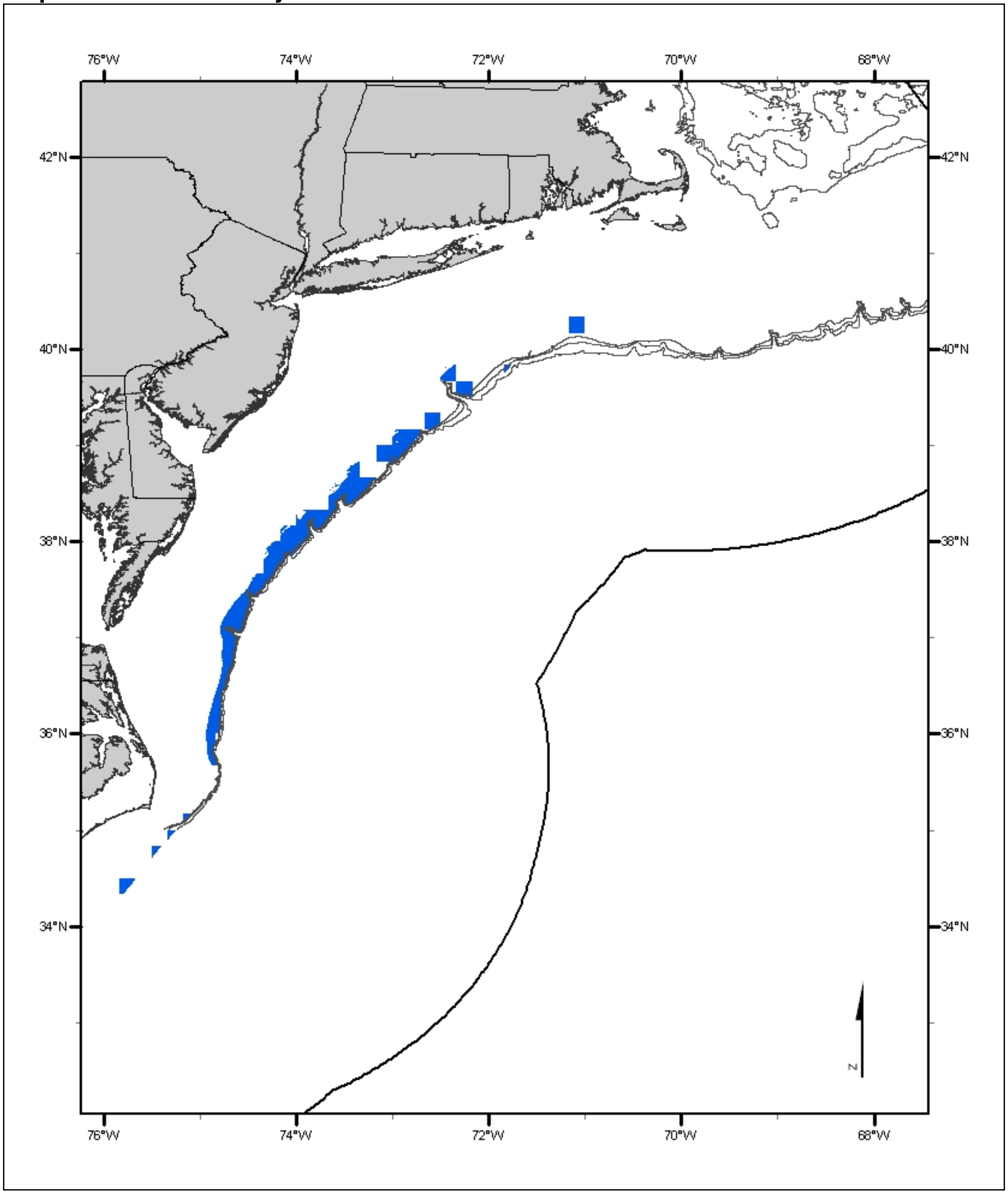
Map 55. Little skate adults



The Alternative 3C EFH designation for adult little skate on the continental shelf is based on the distribution of substrate types, depths and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level and includes inshore areas where adult little skate were determined to be present, based on 10% frequency of occurrence in state trawl surveys and ELMR information.

3.4 Rosette skate (*Leucoraja garmani*)

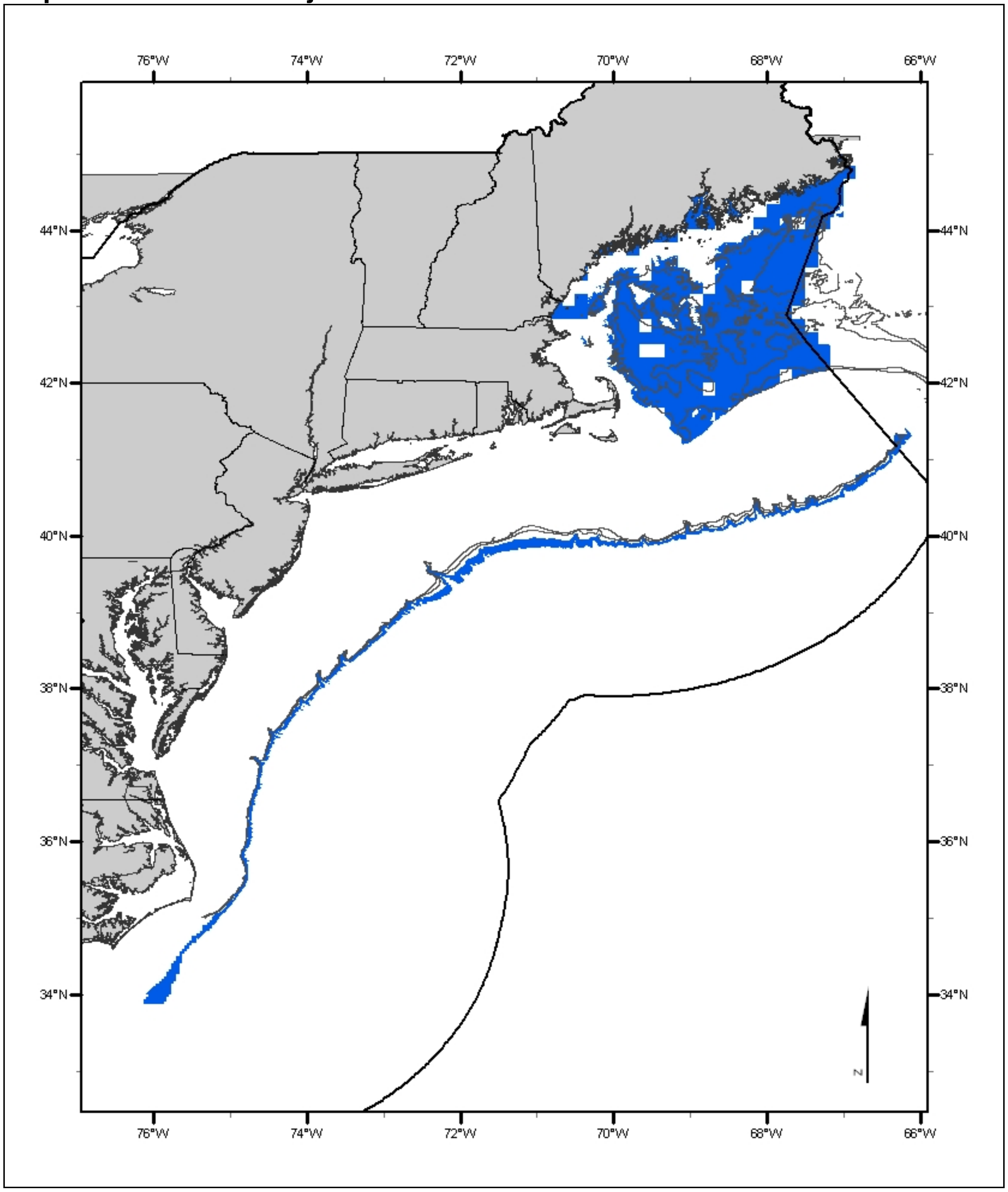
Map 56. Rosette skate juveniles and adults



The Alternative 3C EFH designation for juvenile and adult rosette skate on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level.

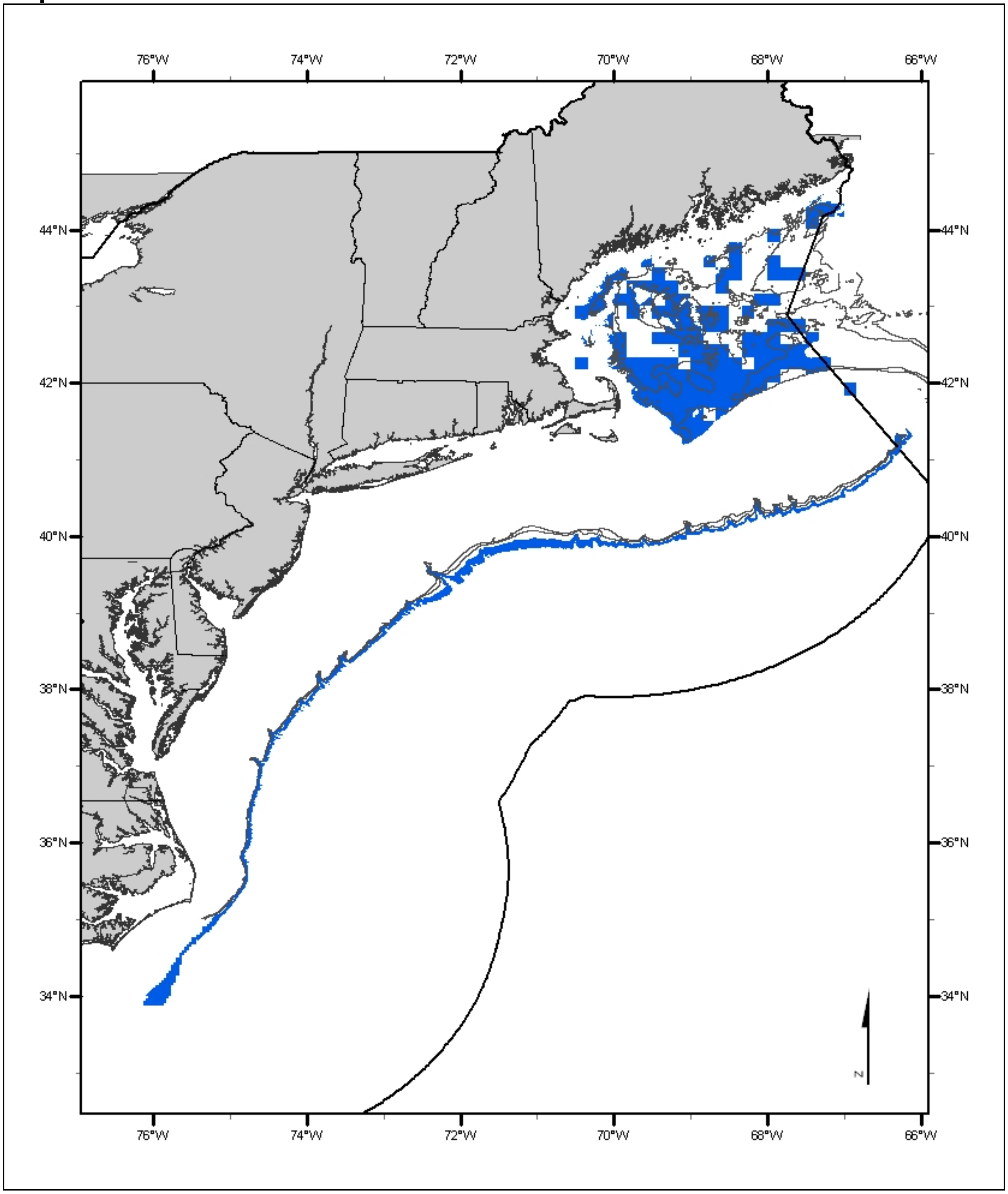
3.5 Smooth skate (*Malacoraja senta*)

Map 57. Smooth skate juveniles



The Alternative 3D EFH designation for juvenile smooth skate on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore and off-shelf areas where juvenile smooth skate were determined to be present, based on 10% frequency of occurrence in state trawl surveys and off-shelf depth and geographic ranges.

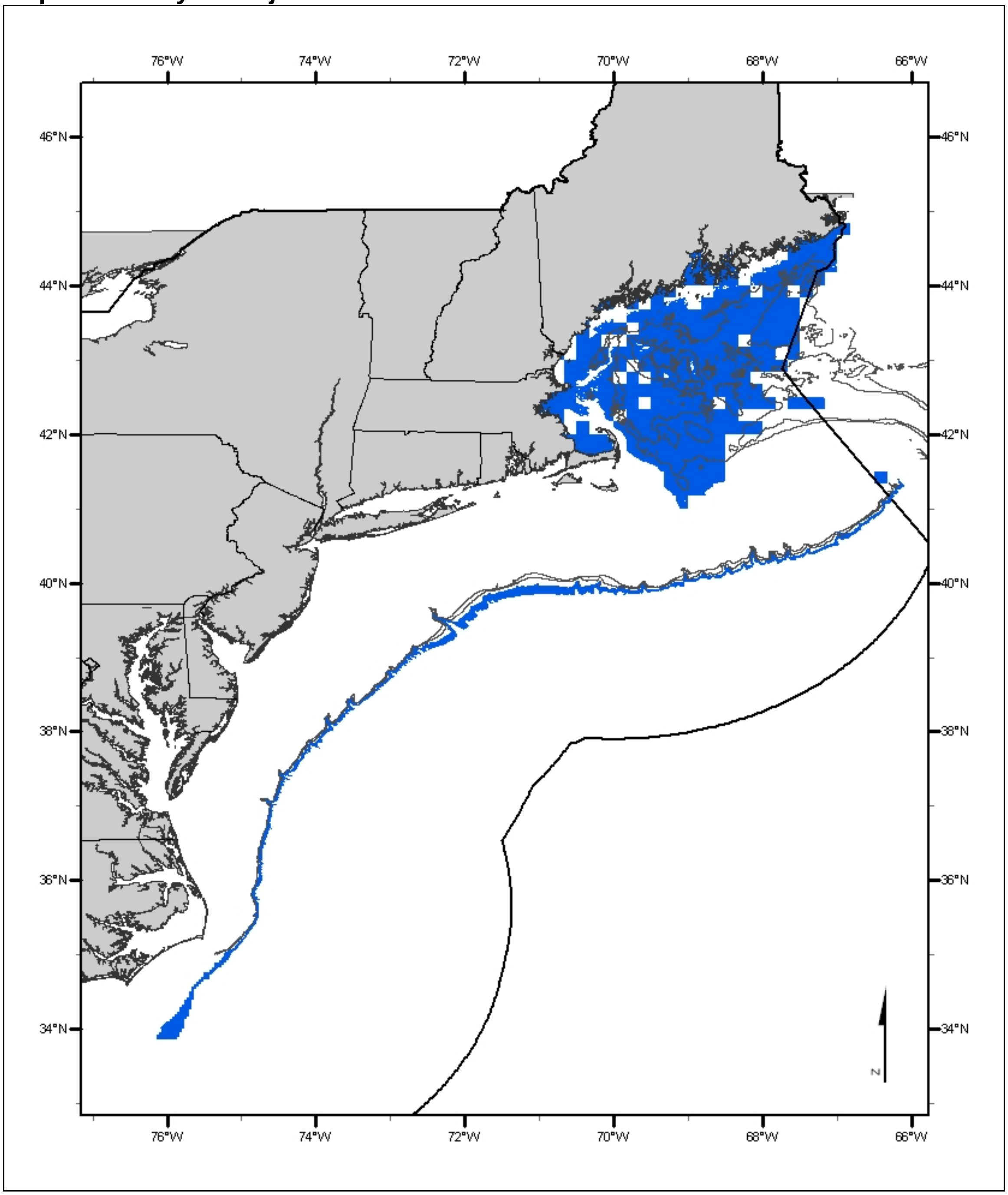
Map 58. Smooth skate adults



The Alternative 3D EFH designation for adult smooth skate on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore and off-shelf areas where adult smooth skate were determined to be present, based on 10% frequency of occurrence in state trawl surveys and off-shelf depth and geographic ranges.

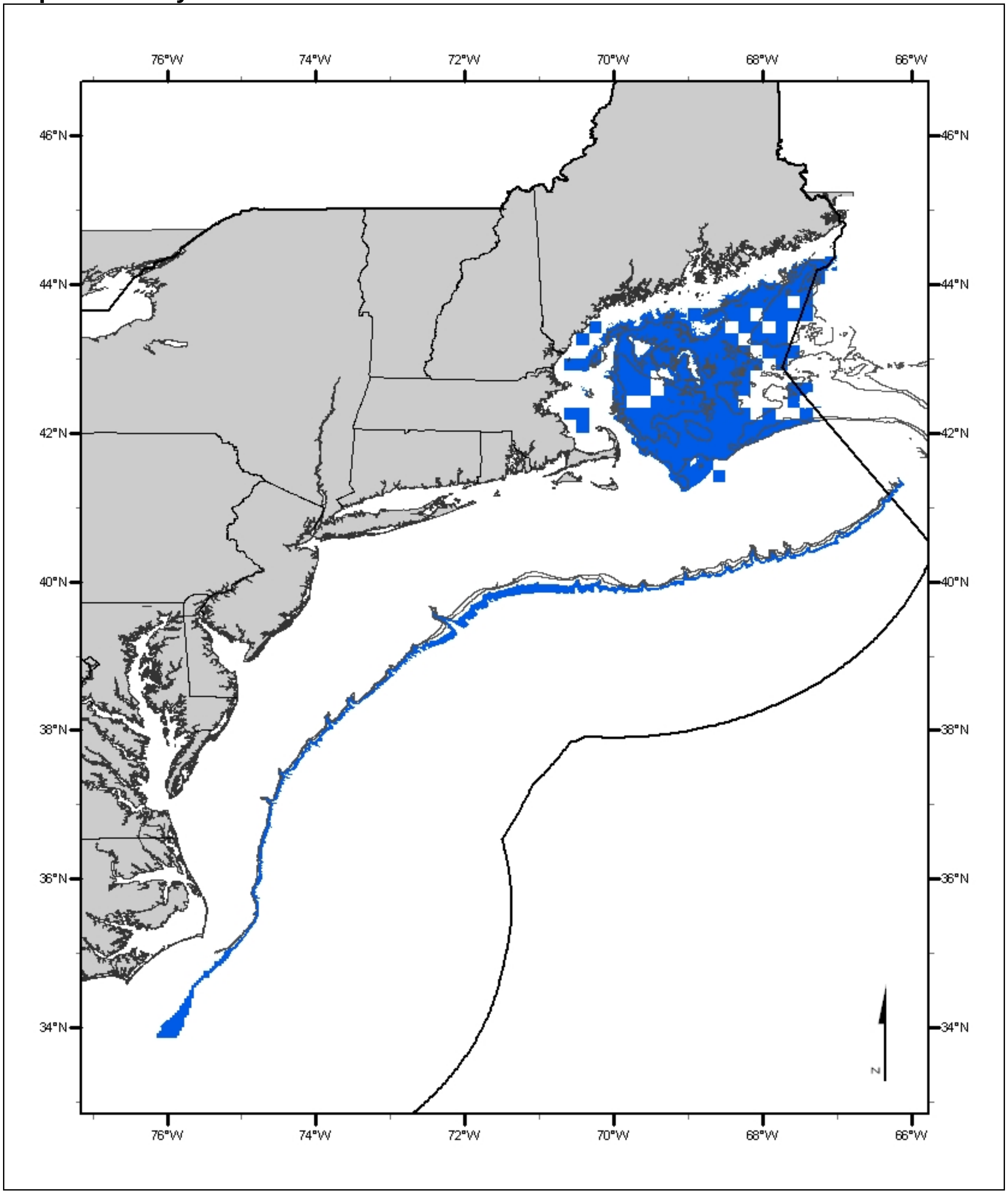
3.6 Thorny skate (*Amblyraja radiata*)

Map 59. Thorny skate juveniles



The Alternative 3C EFH designation for juvenile thorny skate on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of juveniles in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of juveniles in the 1968-2005 spring and fall NMFS trawl surveys at the 75% cumulative percentage of catch level and includes inshore and off-shelf areas where juvenile thorny skate were determined to be present, based on 10% frequency of occurrence in state trawl surveys and off-shelf depth and geographic ranges.

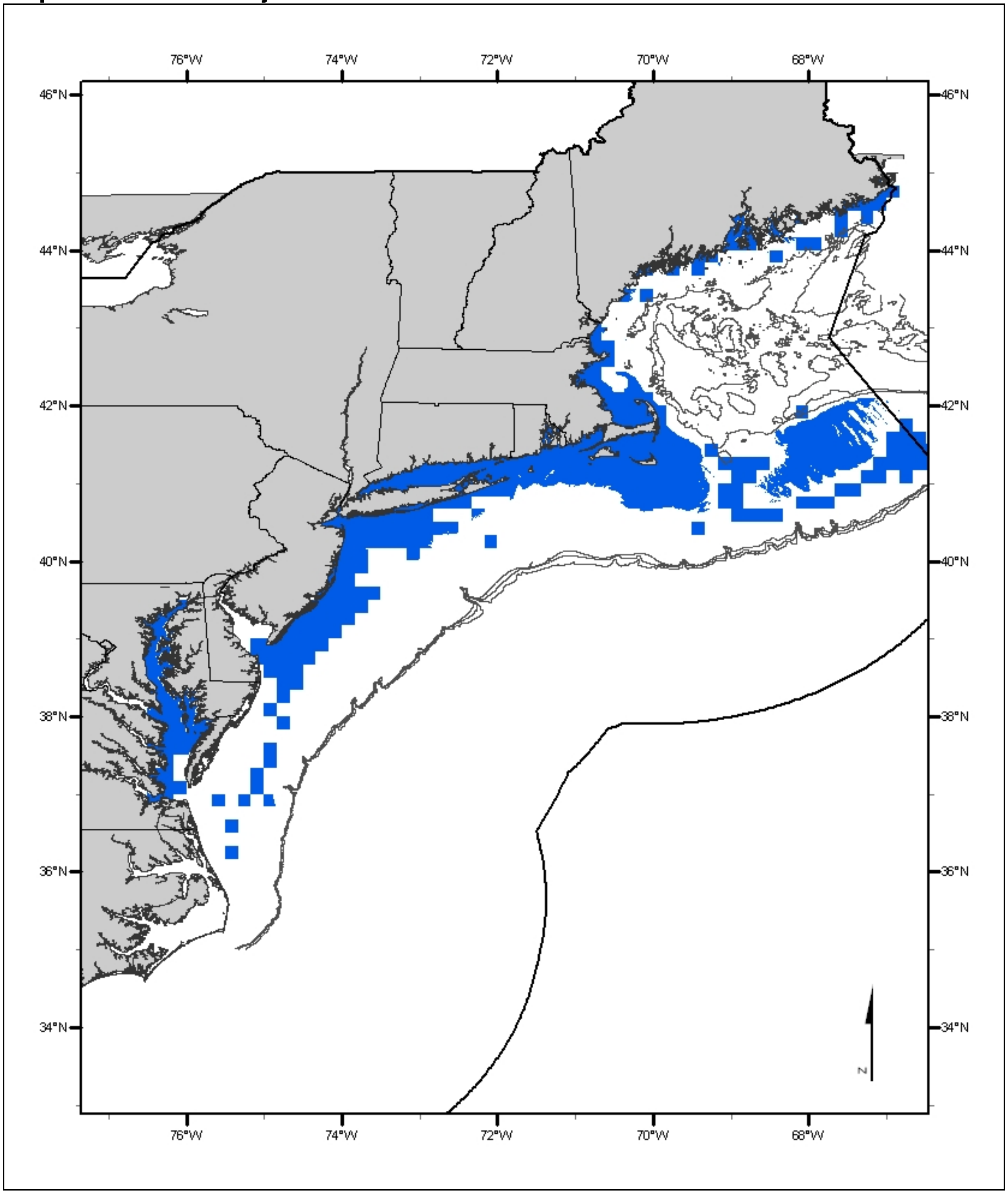
Map 60. Thorny skate adults



The Alternative 3D EFH designation for adult thorny skate on the continental shelf is based on the distribution of depths and bottom temperatures that are associated with high catch rates of adults in the 1963-2003 spring and fall NMFS trawl surveys or identified in the EFH Source Document for this species. This alternative is also based on the abundance of adults in the 1968-2005 spring and fall NMFS trawl surveys at the 90% cumulative percentage of catch level and includes inshore and off-shelf areas where adult thorny skate were determined to be present, based on 10% frequency of occurrence in state trawl surveys and off-shelf depth and geographic ranges.

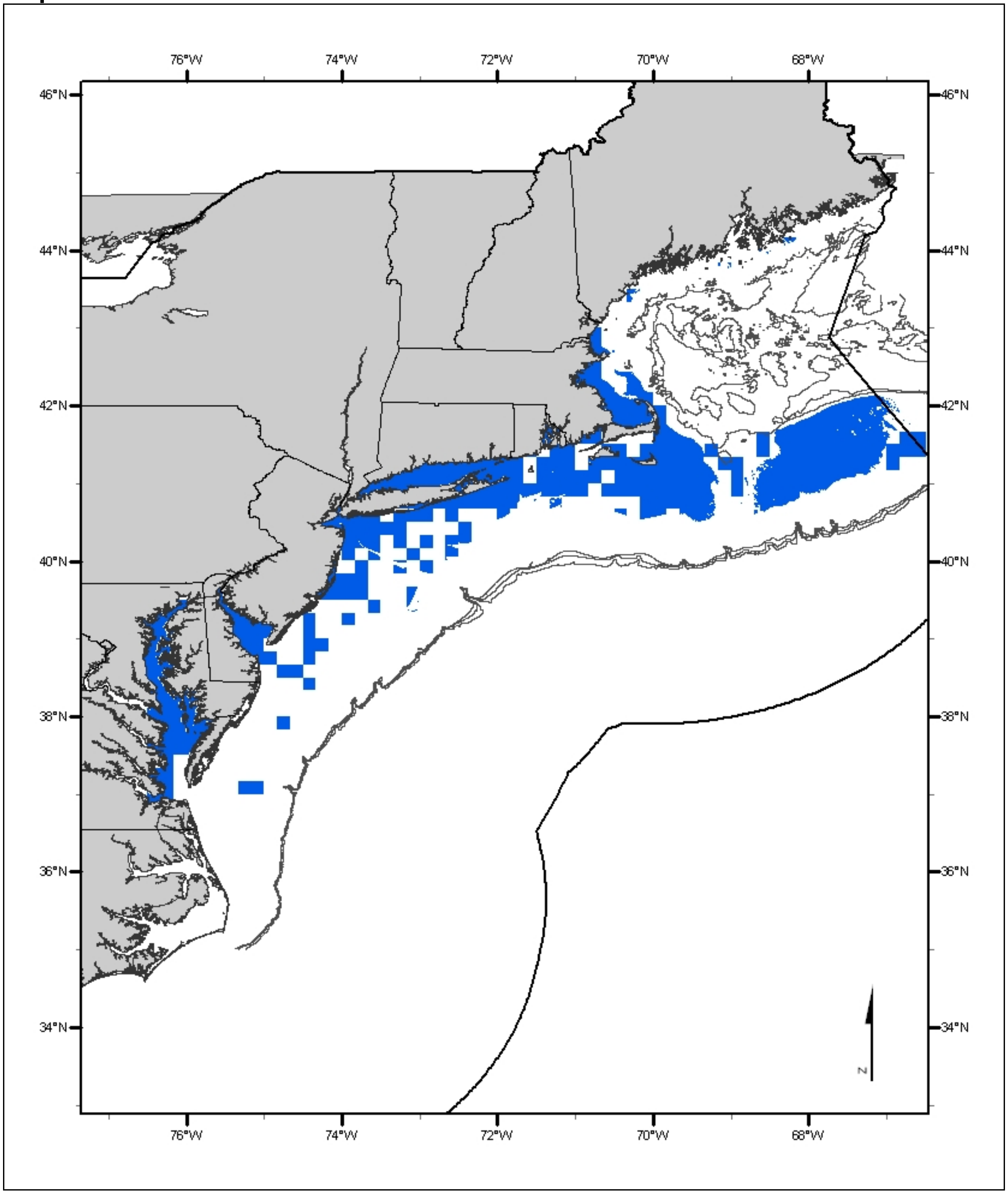
3.7 Winter skate (*Leucoraja ocellata*)

Map 61. Winter skate juveniles



The Alternative 3E EFH designation for juvenile winter skate is based on the Alternative 3D designation for juvenile winter skate with the addition of ten minute squares along the RI and CT coasts and southeast of Nantucket Island where there are no survey data for this species.

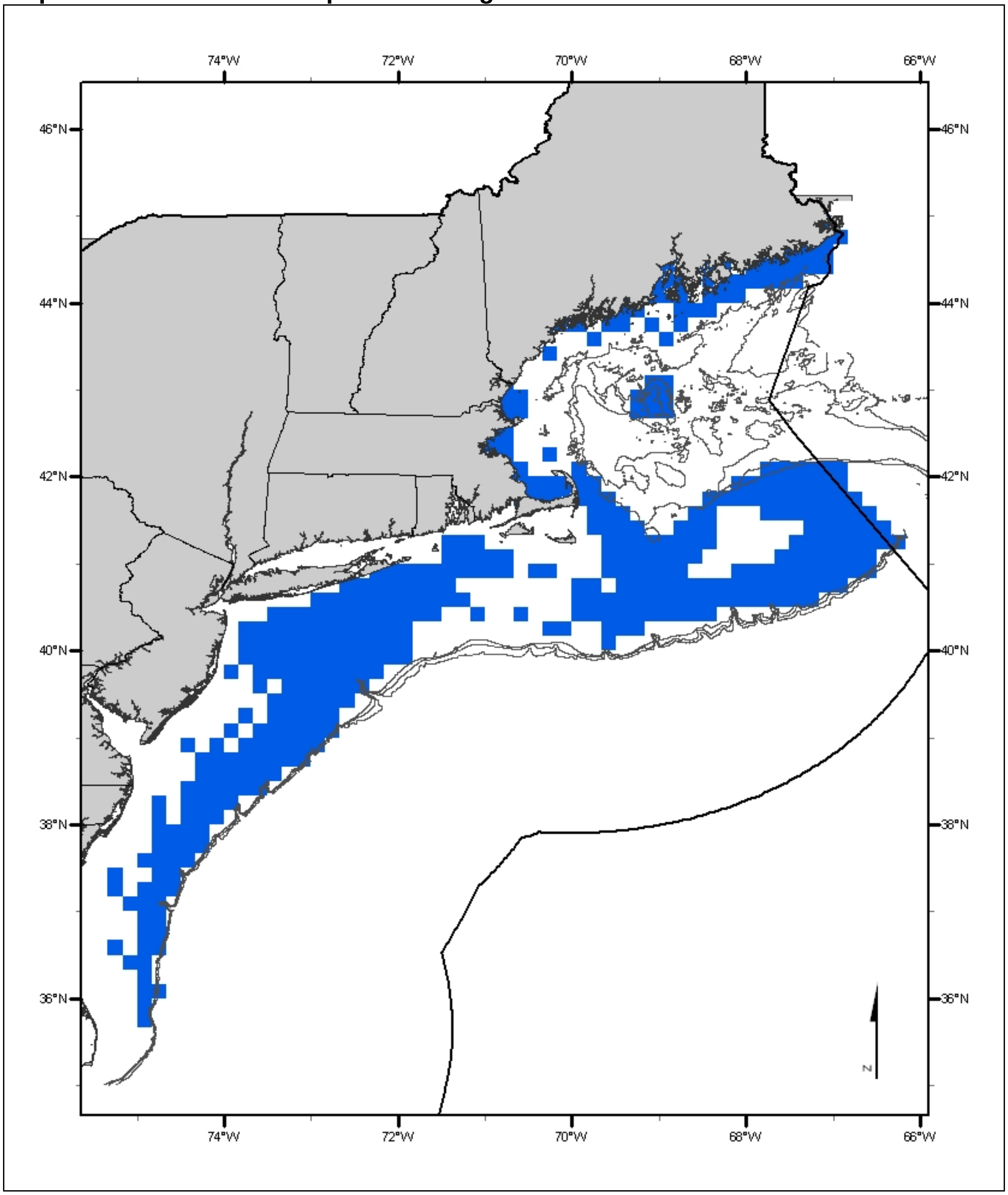
Map 62. Winter skate adults



The Alternative 3E EFH designation for adult winter skate is based on the Alternative 3D designation for adult winter skate with the addition of ten minute squares along the RI and CT coasts and southeast of Nantucket Island where there are no survey data for this species.

4.0 Atlantic sea scallop (*Placopecten magellanicus*)

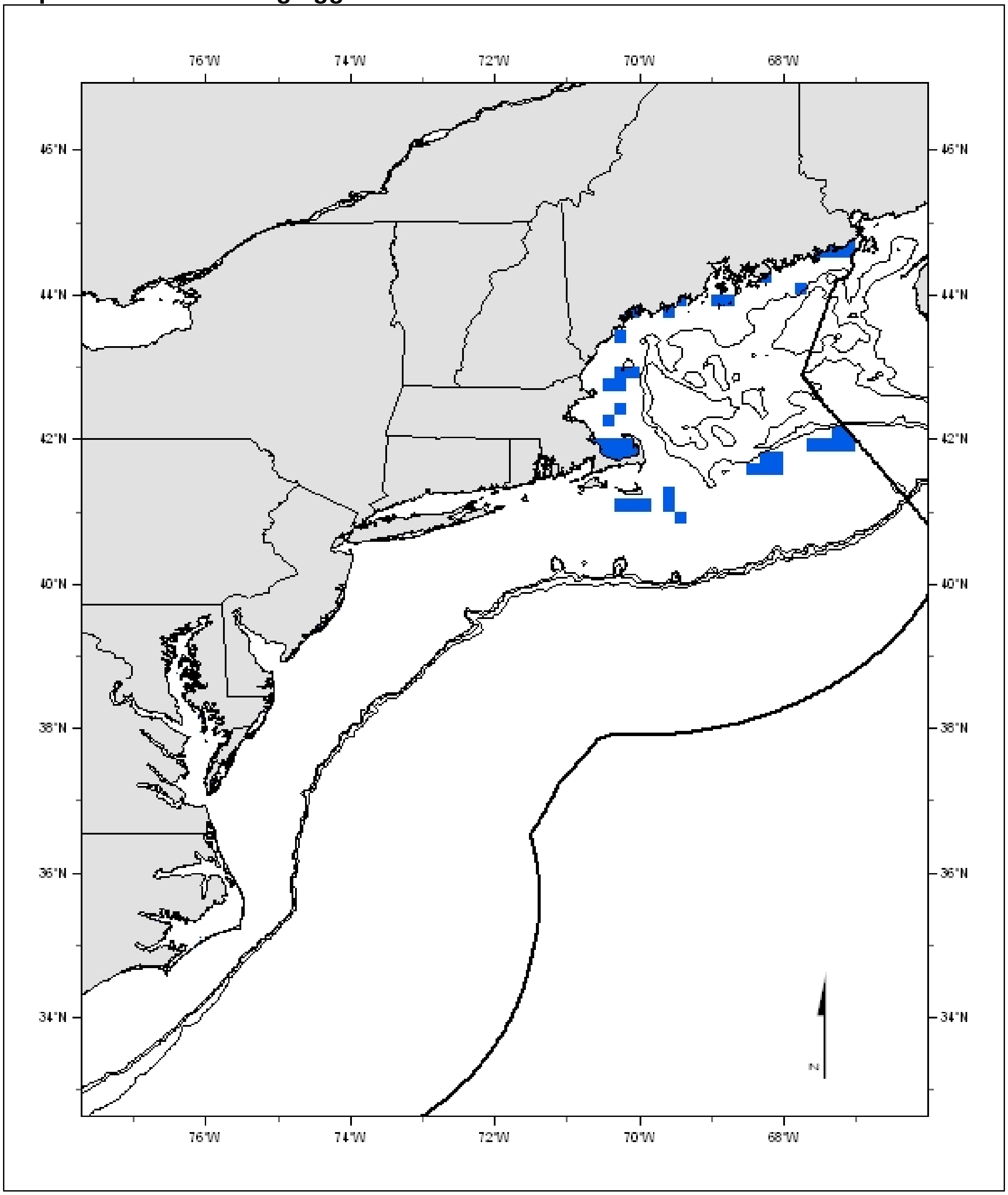
Map 63. Atlantic sea scallops all life stages



The Alternative 5 EFH designation for juvenile and adult Atlantic sea scallops is the same as the Alternative 4 designation, with the addition of ten minute squares on Fipennies Ledge and in eastern Maine that are not well represented in state surveys of the Gulf of Maine. The Alternative 4 EFH designation includes all the ten minute squares where juveniles or adults were caught during 1982-2005 in the summer NMFS sea scallop dredge survey and ten minute squares in the Gulf of Maine where juveniles or adults were caught in state trawl surveys in more than 10% of the tows, as well as those bays and estuaries identified by the NOAA ELMR program where juvenile or adult Atlantic sea scallops were "common" or "abundant."

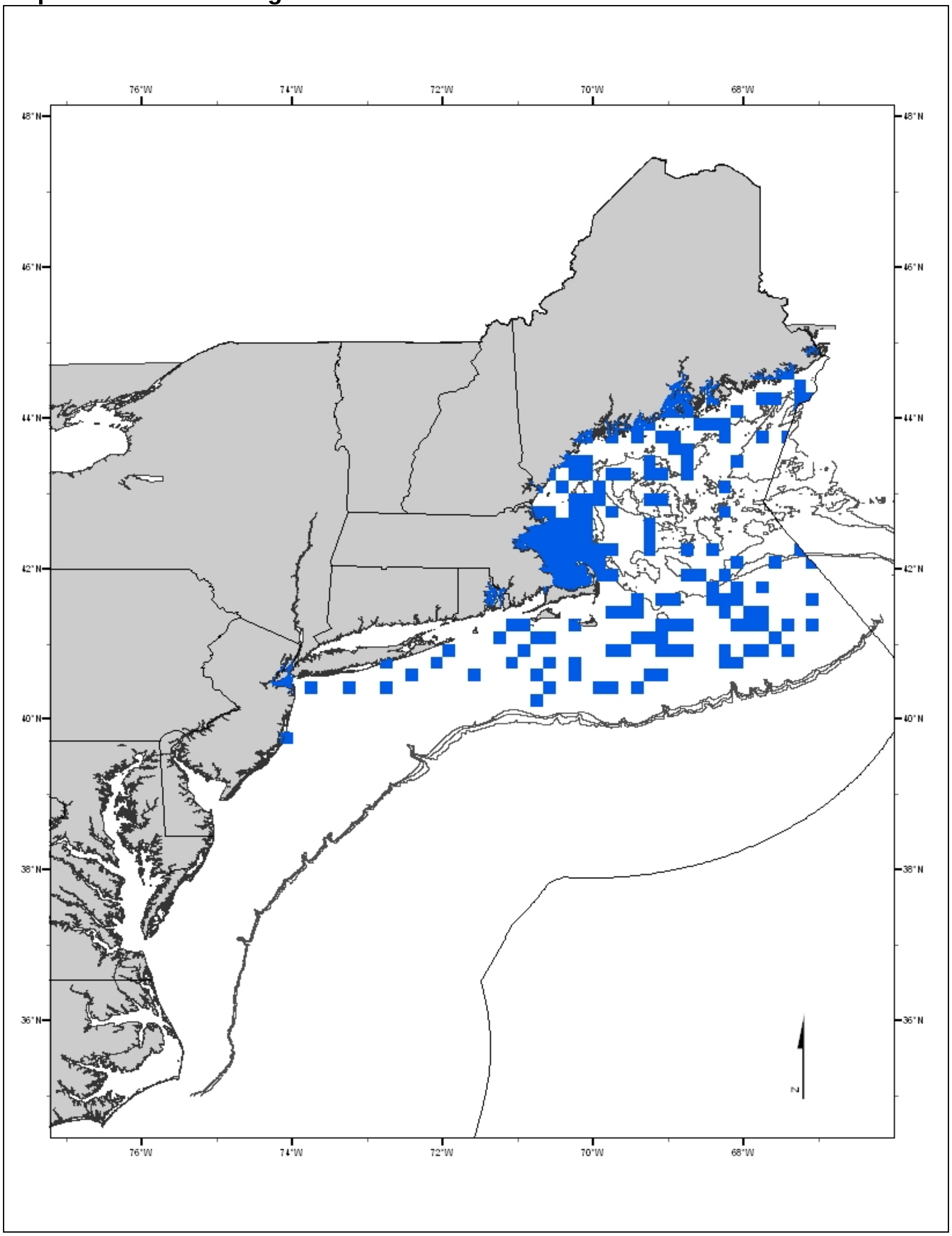
5.0 Atlantic herring (*Clupea harengus*)

Map 64. Atlantic herring eggs



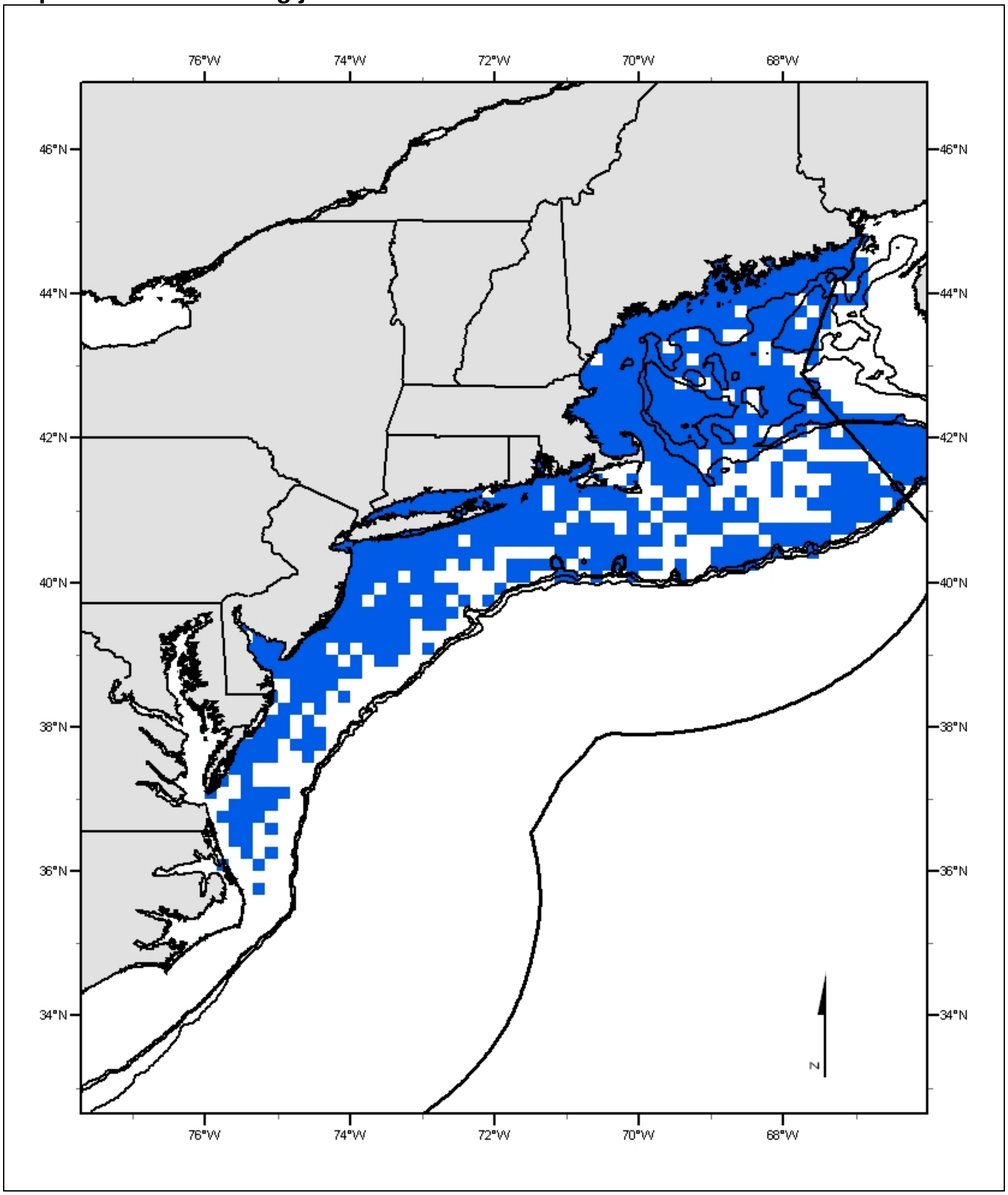
The Alternative 2 EFH designation for Atlantic herring eggs represents 100% of the known Atlantic herring egg beds. These egg beds were identified based on a review of all available information on current and historical herring egg bed locations. In addition, this alternative includes those bays and estuaries identified in the NOAA ELMR program where herring eggs were "rare", "common", or "abundant" and other ten minute squares on the continental shelf that are included in the No Action alternative where eggs have never been observed, but where recently-hatched larvae have been observed during larval herring surveys.

Map 65. Atlantic herring larvae



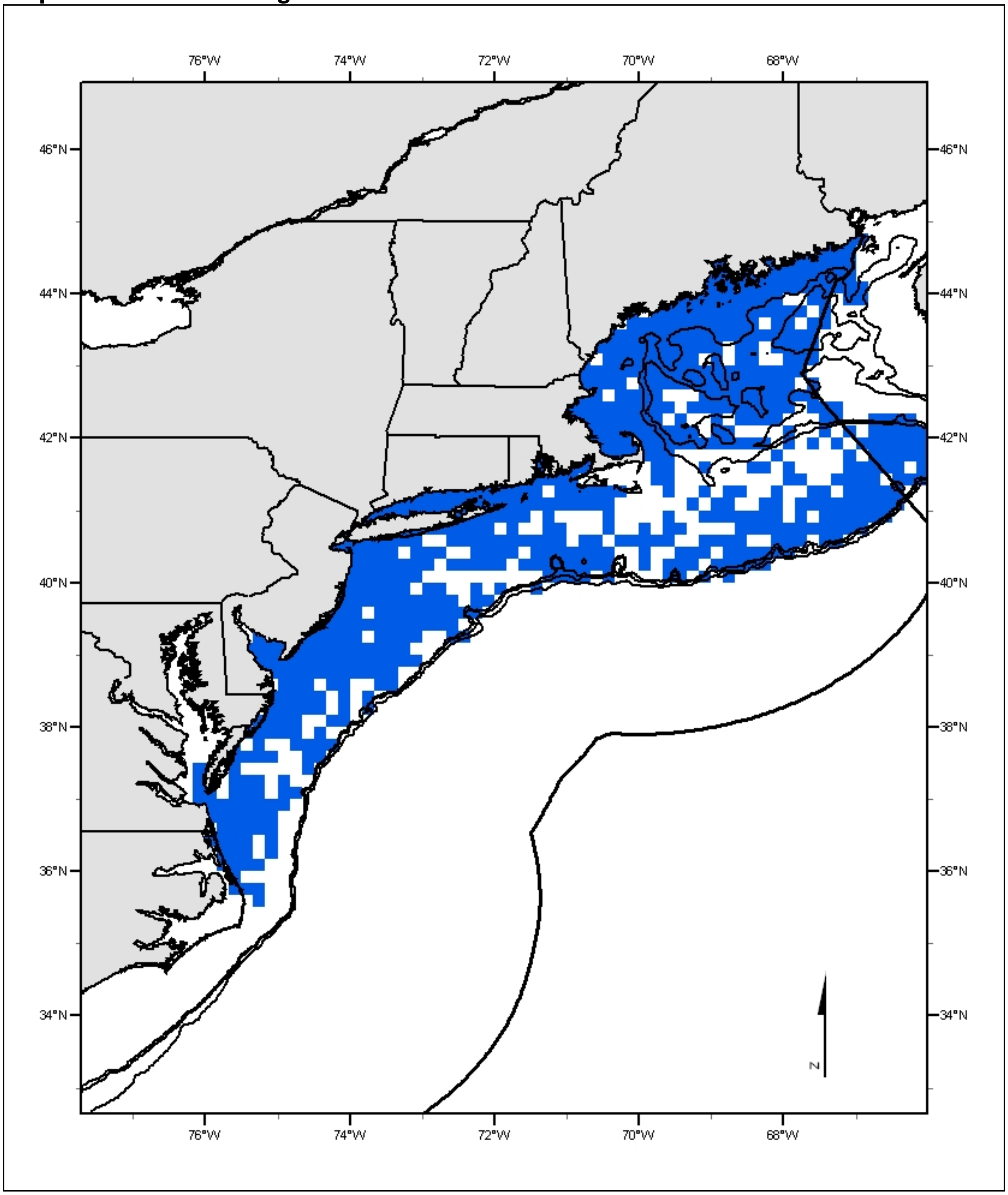
The EFH designation for Atlantic herring larvae is the status quo designation, which was based on the ten minute squares corresponding to the top 75% of the observed range in the 1978-1987 MARMAP survey data. *This designation also includes those bays and estuaries identified by the NOAA ELMR program as supporting Atlantic herring larvae at a "common" or "abundant" level.*

Map 66. Atlantic herring juveniles



The Alternative 2E EFH designation for juvenile Atlantic herring on the continental shelf is based upon relative abundance during 1968-2005 in the fall and spring NMFS trawl survey at the 75% cumulative percentage level plus additional ten minute squares that were "filled in" along the CT and RI coasts . Relative abundance was calculated on a percent of area rather than a percent of catch basis. This alternative also includes ten minute squares in inshore areas where juvenile Atlantic herring were caught in state trawl surveys in more than 10% of the tows, as well as those bays and estuaries identified by the NOAA ELMR program where Atlantic herring juveniles were "common" or "abundant."

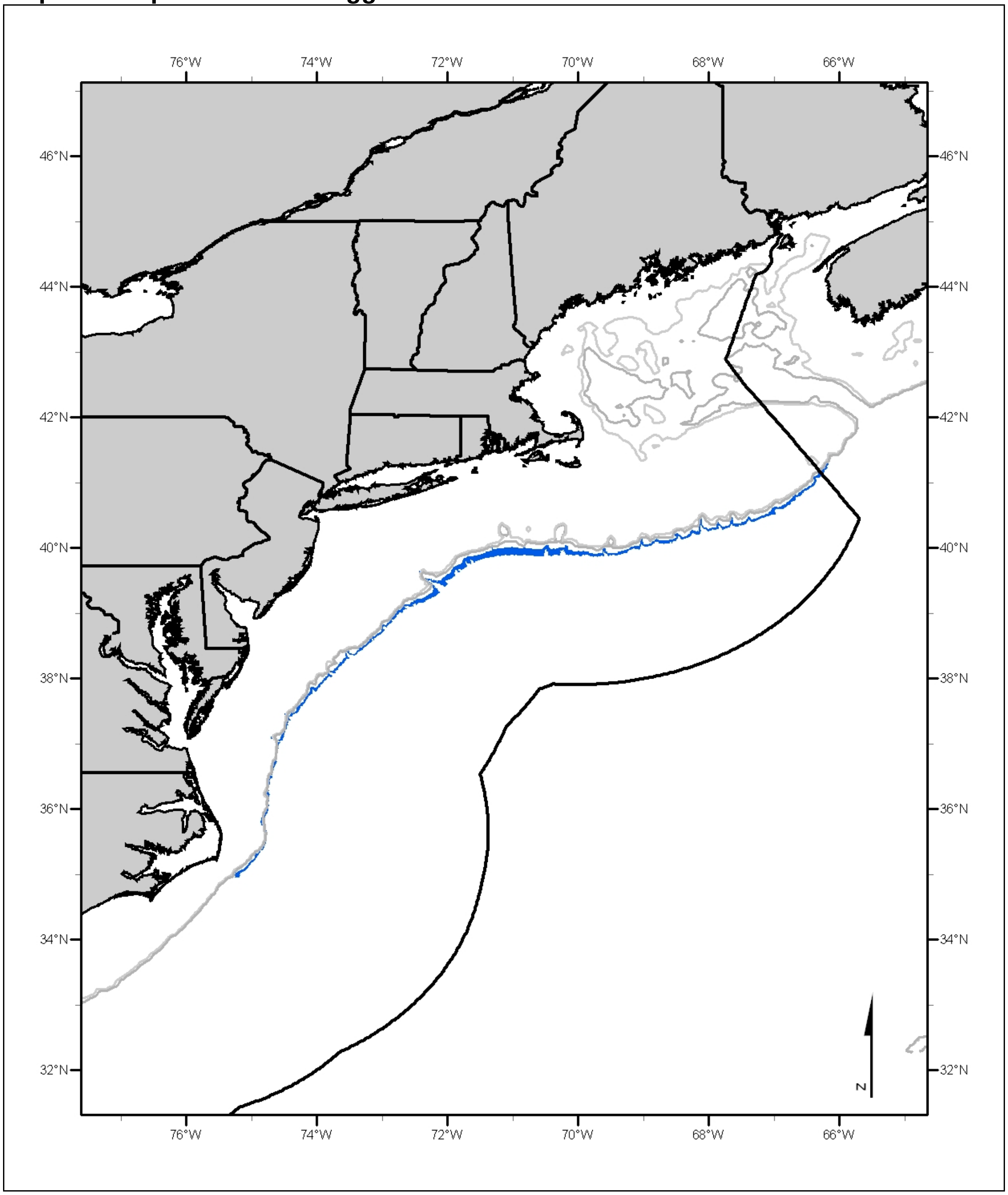
Map 67. Atlantic herring adults



The Alternative 2E EFH designation for adult Atlantic herring on the continental shelf is based upon relative abundance during 1968-2005 in the fall and spring NMFS trawl survey at the 75% cumulative percentage level plus additional ten minute squares that were "filled in" along the ME, CT, and RI coasts . Relative abundance was calculated on a percent of area rather than a percent of catch basis. This alternative also includes ten minute squares in inshore areas where juvenile Atlantic herring were caught in state trawl surveys in more than 10% of the tows, as well as those bays and estuaries identified by the NOAA ELMR program where Atlantic herring juveniles were "common" or "abundant."

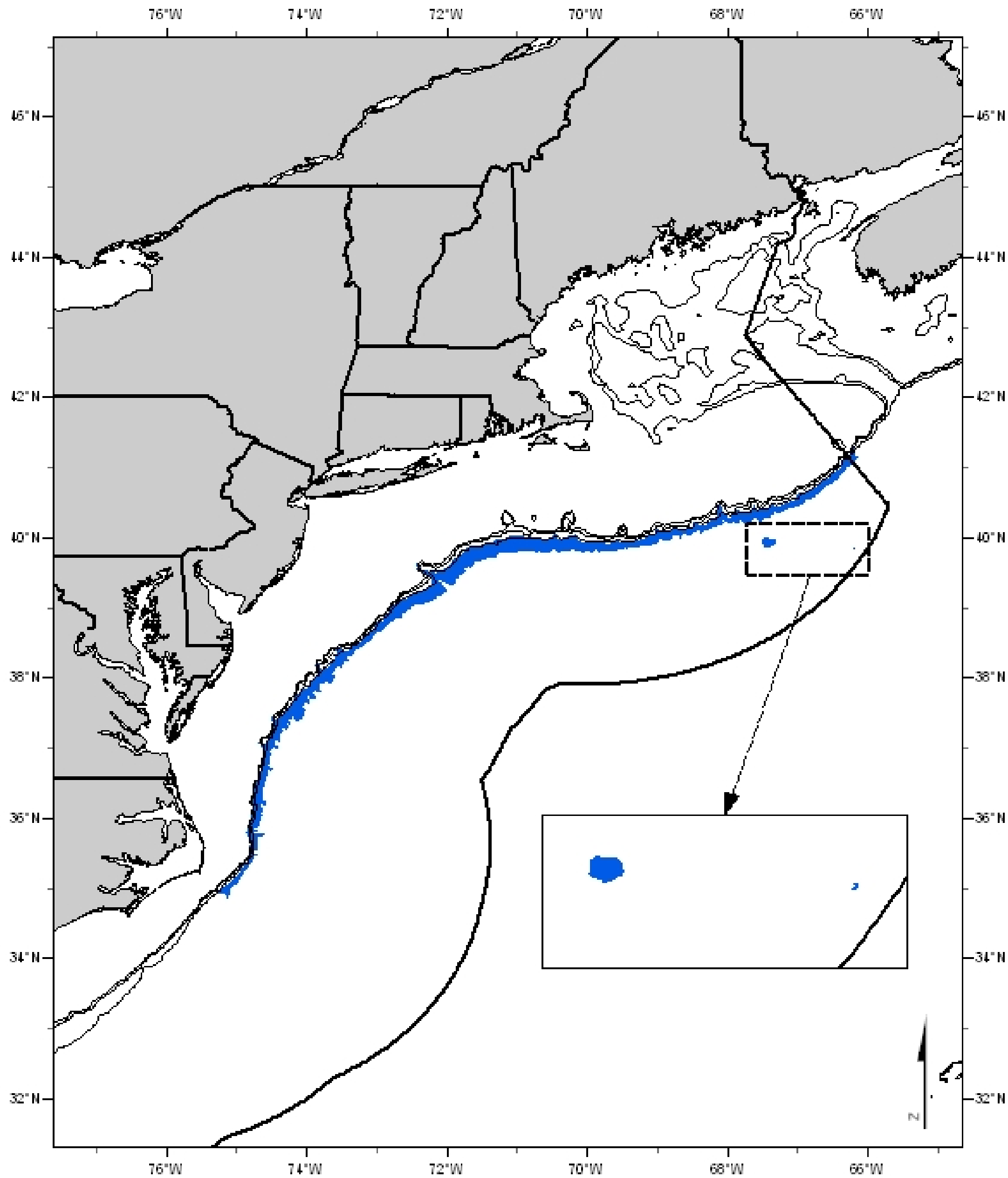
6.0 Deep-sea red crab (*Chaceon quinquedens*)

Map 68. Deep-sea red crab eggs



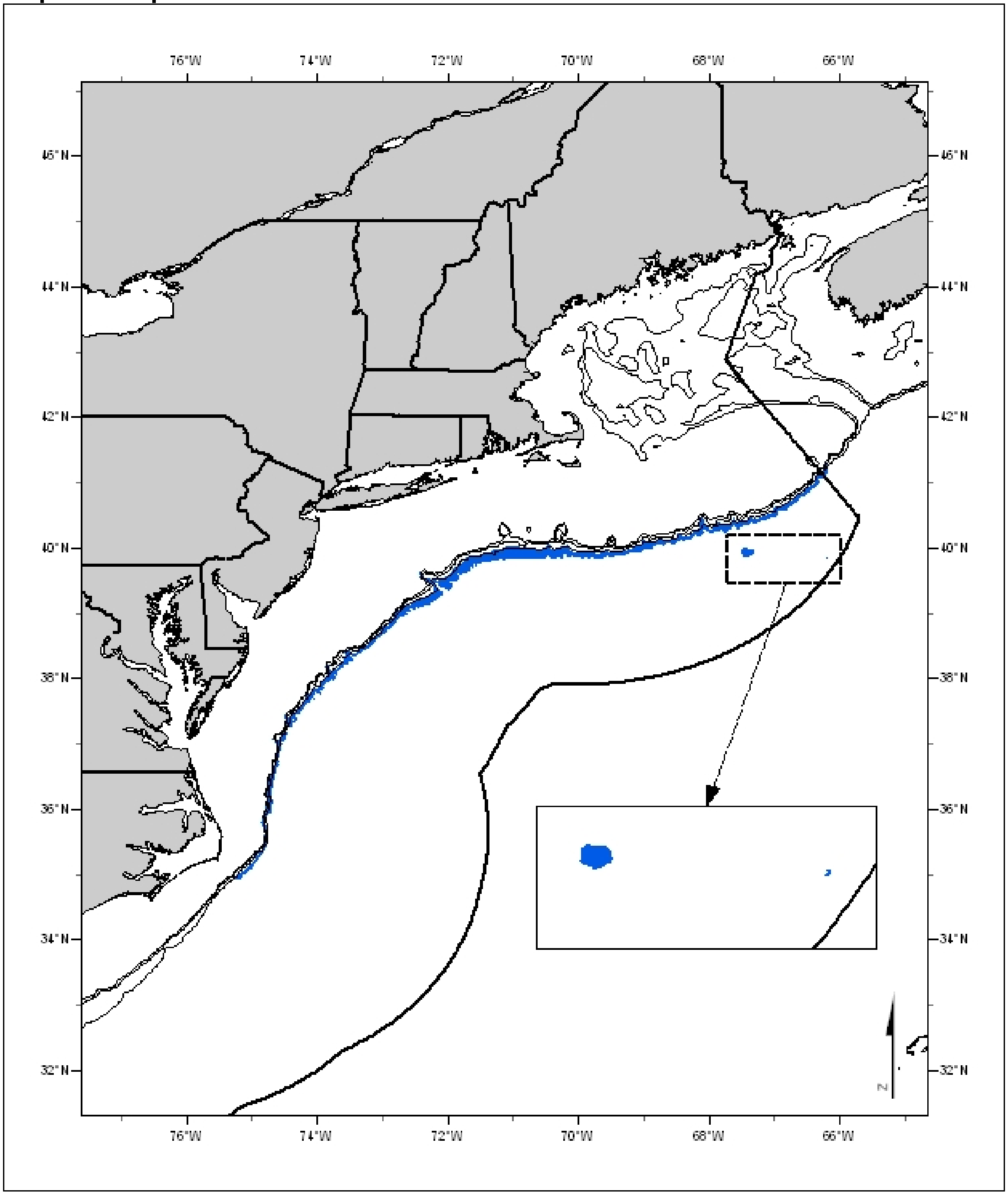
The Alternative 2 EFH designation for red crab eggs on the continental slope is based on the depth range for spawning females as described in Wigley et al. (1975).

Map 69. Deep-sea red crab larvae and juveniles



The Alternative 3A EFH designation for red crab larvae and juveniles is based on the maximum depth range for this species on the continental slope as described in Wigley et al. (1975) and on the maximum depth where red crabs have been observed on two seamounts. The seamounts are mapped according to this maximum depth (2000 meters).

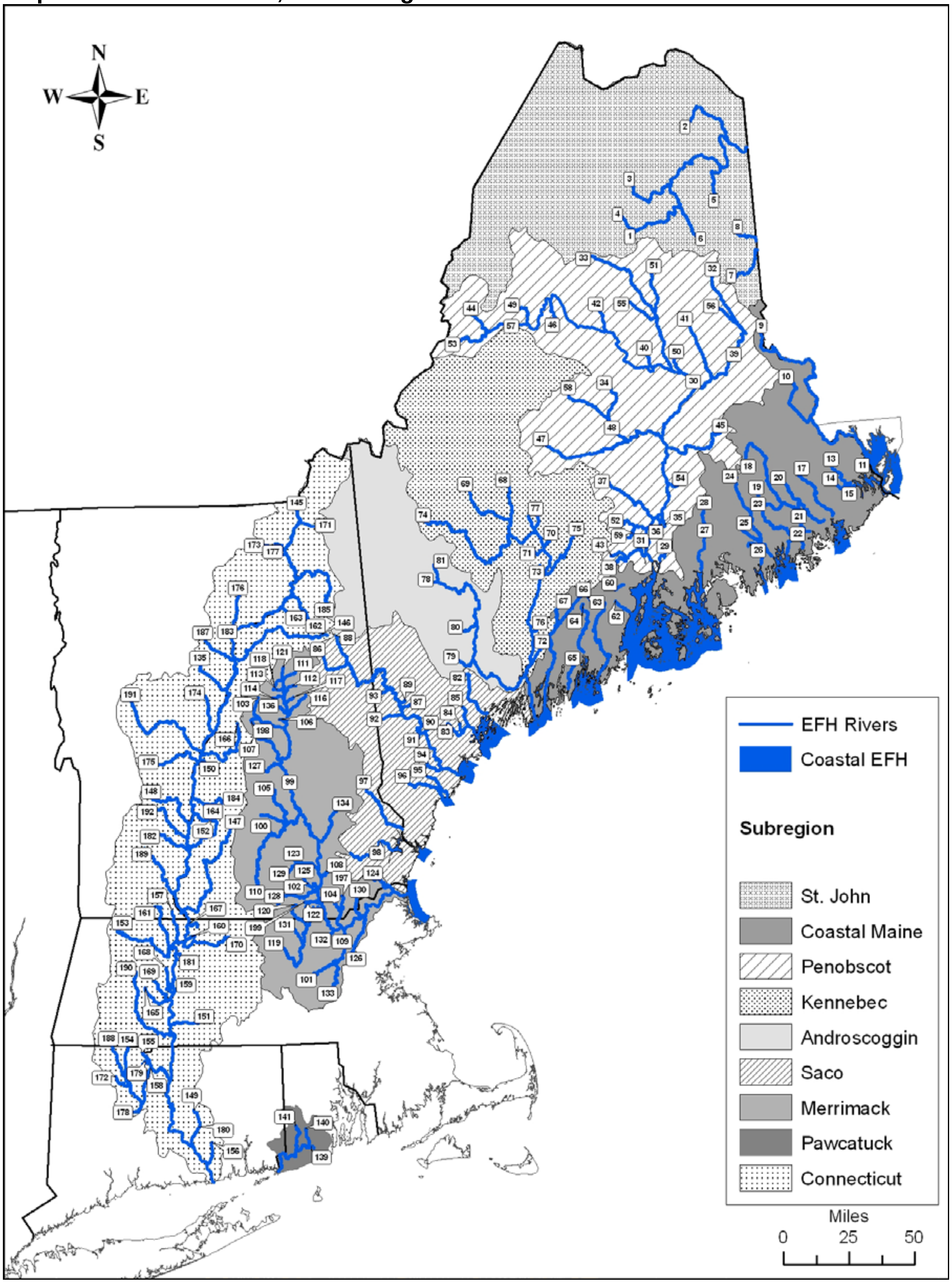
Map 70. Deep-sea red crab adults



The Alternative 3A EFH designation for red crab adults is based on the maximum depth range for adults on the continental slope as described in Wigley et al. (1975) and on the maximum depth where red crabs have been observed on two seamounts. The seamounts are mapped according to this maximum depth (2000 meters).

7.0 Atlantic salmon (*Salmo salar*)

Map 71. Atlantic salmon, all life stages



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OMNIBUS ESSENTIAL FISH HABITAT (EFH) AMENDMENT 2 DRAFT ENVIRONMENTAL IMPACT STATEMENT

Appendix D: The Swept Area Seabed Impact (SASI) approach: a tool for analyzing the effects of fishing on Essential Fish Habitat

This document was prepared by the following members of the NEFMC Habitat Plan Development team, with feedback from the NEFMC Habitat Oversight Committee, NEFMC Habitat Advisory Panel, and interested members of the public.

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1.0 Overview of the Swept Area Seabed Impact model

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) requires fishery management plans to minimize, to the extent practicable, the adverse effects of fishing on fish habitats. To meet this requirement, fishery managers would ideally be able to quantify such effects and visualize their distributions across space and time. The Swept Area Seabed Impact (SASI) model provides such a framework, enabling managers to better understand: (1) the nature of fishing gear impacts on benthic habitats, (2) the spatial distribution of benthic habitat vulnerability to particular fishing gears, and (3) the spatial and temporal distribution of realized adverse effects from fishing activities on benthic habitats.

SASI increases the utility of habitat science to fishery managers via the translation of susceptibility and recovery information into quantitative modifiers of swept area. The model combines area swept fishing effort data with substrate data and benthic boundary water flow estimates in a geo-referenced, GIS-compatible environment. Contact and vulnerability-adjusted area swept, a proxy for the degree of adverse effect, is calculated by conditioning a nominal area swept value, indexed across units of fishing effort and primary gear types, by the nature of the fishing gear impact, the susceptibility of benthic habitats likely to be impacted, and the time required for those habitats to return to their pre-impact functional value. The various components of the SASI approach fit together as described in Figure 1.

The vulnerability assessment and associated literature review were developed over an approximately two year period by members of the New England Fishery Management Council's Habitat Plan Development Team. The assessment serves two related purposes: (1) a review of the habitat impacts literature relevant to Northeast US fishing gears and seabed types, and (2) a framework for organizing and generating quantitative susceptibility and recovery parameters for use in the SASI model.

The vulnerability assessment only considers adverse (vs. positive) effects and effects on habitat associated with the seabed (vs. the seabed and the water column). This bounding does not preclude the possibility of positive impacts from fishing on seabed structures or fauna, nor is it intended to indicate that the water column is not influential habitat for fish. The former is possible, and the latter is likely. However, as per the EFH Final Rule, only adverse effects are considered and, because fishing gears do not substantively alter the water column, effects from fishing on the pelagic water column are assumed to be negligible.

As a model parameterization tool, the vulnerability assessment quantifies both the magnitude of the impacts that result from the physical interaction of fish habitats and fishing gears, and the duration of recovery following those interactions. This vulnerability information is used to condition area swept (i.e. fishing effort) in the SASI model via a series of susceptibility and recovery parameters.

A critical point about the vulnerability assessment and accompanying SASI model is that they consider EFH and impacts to EFH in a holistic manner, rather than separately identifying impacts to EFH designated for individual species and lifestages. This is consistent with the EFH final rule, which indicates "adverse effects to EFH may result from actions occurring within EFH or outside of [designated] EFH and may include site-specific or habitat-wide impacts, including individual, cumulative, or synergistic consequences of actions" (§600.810). To the extent that key features of species' EFH can be related to the features in the vulnerability assessment, post-hoc analysis of SASI model outputs can be conducted to better evaluate the vulnerability of a particular species' essential habitat components to fishing gear effects.

This document contains detailed information about the various aspects of SASI, as follows:

Defining habitat (2.0), which describes the structural components and their constituent features. Fish habitat is divided into two components, geological and biological, which are further subdivided into structural features. Structural features identified include bedforms, biogenic burrows, sponges, macroalgae, etc. (see sections 2.1 and 2.2 related to geological and biological features, respectively). These features may either provide shelter for managed species directly, or provide shelter for their prey. The geological and biological features, weighted equally in the model, are distinguished as being non-living and living, respectively. While both components (geological, biological) are assumed to occur in every habitat type, the presence or absence of particular features is assumed to vary based on substrate type and natural disturbance (energy) regime. Thus, habitat types in the vulnerability assessment are distinguished by dominant substrate, level of natural disturbance, and the presence or absence of various features. The substrate and energy classifications used are described in the introduction to section 2.0.

Gear impacts literature review (3.0), which summarizes the fishing impacts literature that forms the basis of the vulnerability assessment. To facilitate use of the literature in matrix evaluations, research relevant to regional habitats and fishing gears is summarized in a database. Each study in the database is coded according to the habitat components evaluated, features evaluated, whether recovery is examined, etc. This coding is detailed in section 4.1, and the literature is summarized in section 4.2. Both the literature review database and the matrix values can be updated as new information becomes available.

Matrices (section 5.0), which describes the process used to estimate the susceptibility and recovery of features to/from fishing impacts and presents S and R scores in tabular format. The vulnerability assessment matrices organize and present estimates of susceptibility and recovery for each feature by fishing gear type. Both susceptibility and recovery are scored from 0-3. Values are assigned using knowledge of the fishing gears and habitat features combined with results from the scientific literature on gear impacts. Susceptibility is defined as the percentage of total habitat features encountered by fishing gear during a hypothetical single pass fishing event that have their functional value reduced. Recovery is defined as the time in years that would be required for the functional value of that habitat feature to be restored.

Fishing gears (section 3.0), which identifies the gears evaluated by the model and describes how they are fished. SASI models the seabed impacts of bottom tending gear types, both static and mobile. The gear types include demersal otter trawls (subdivided into four types), New Bedford-style scallop dredges (subdivided into two classes), hydraulic clam dredges, demersal longlines, sink gillnets, and traps. These gears account for approximately 95% of the landings in federal waters of the Northeast region.

Estimating contact-adjusted area swept (section 6.0), which summarizes how fishing effort data is converted to area swept. The annual area of seabed swept for each gear type is used as the starting point for estimating the adverse effects from fishing. To generate these estimates, for each of the gear types, gear dimensions are estimated and a linear effective width is calculated for each gear component individually and for the gear as a whole. This linear effective width is multiplied by the length of the tow to generate a nominal area swept in km^2. Next, assumptions about the amount of contact each gear component has with the seabed during normal fishing operations are used to convert nominal area swept to contact-adjusted area swept (denoted as A). In practice, these contact adjustments are applied to trawl gears only, as all the components of all other gears are assumed to have full contact with the seabed. Area swept is calculated individually for each tow, and the resulting contact-adjusted area swept values are then summed by trip, year, gear type, etc.

Defining habitats spatially/model grid (section 0), which describes the substrate and energy layers used in the model. Two classes of data, substrate and energy environment, are used to define habitats. These combine to form the underlying surface onto which gear-specific habitat vulnerability information and contact-adjusted area-swept data are added. Two data sources are used to create the substrate surface: the usSEABED dataset from the U.S. Geological Survey, and the University of Massachusetts Dartmouth School for Marine Science and Technology (SMAST) video survey. Based on empirical observations from these two sources, substrates are classed by particle size using the Wentworth scale for five substrate classes: mud, sand, granule/pebble, cobble, and boulder. The raw substrate data are mapped using a Voronoi tessellation procedure which calculates an unstructured grid around each individual data point. These grid cells vary in shape and size depending on the spatial arrangement of samples. As the grid is easily updated, new substrate data can be added to the model as it becomes available. Next, each of these grid cells are classified as having a high or low natural disturbance (energy) regime using a combination of shear stress and bottom depth. Finally, a 100 km^2 grid is overlaid on the unstructured grid, and the substrate composition of each 100 km^2 grid cell is calculated based on the size of the unstructured cells contained within each of the 100 km^2 grid cells. Geological and biological seabed features are inferred within each of the 100 km^2 grid cells based on the substrate and energy mosaic. Based on a literature review, susceptibility and recovery scores for each habitat feature are coded as described in section 5.0.

Spatially estimating adverse effects from fishing on fish habitat: the SASI model (section 8.0), which describes how fishing effort data are integrated with susceptibility and recovery estimates in a spatial context. The SASI model combines contact-adjusted area swept estimates with the substrate and energy surfaces and the assigned susceptibility and recovery scores for each of the seabed features to calculate the vulnerability-adjusted area swept (measured in km^2), represented by the letter Z. This value is the estimate of the adverse effects from fishing on fish habitat. The model can be used to estimate adverse effects based either on a simulated hypothetical amount of fishing area swept (Z_∞ outputs), or the realized area swept estimated from fishery-dependant data ($Z_{realized}$ outputs). The former estimate is intended to represent underlying habitat vulnerability, while the latter can be used to understand change in adverse effects over time. The latter approach can also be used to forecast the impacts of future management actions, given assumptions about shifts in the location and magnitude of area swept. Sensitivity analyses are also presented in this section.

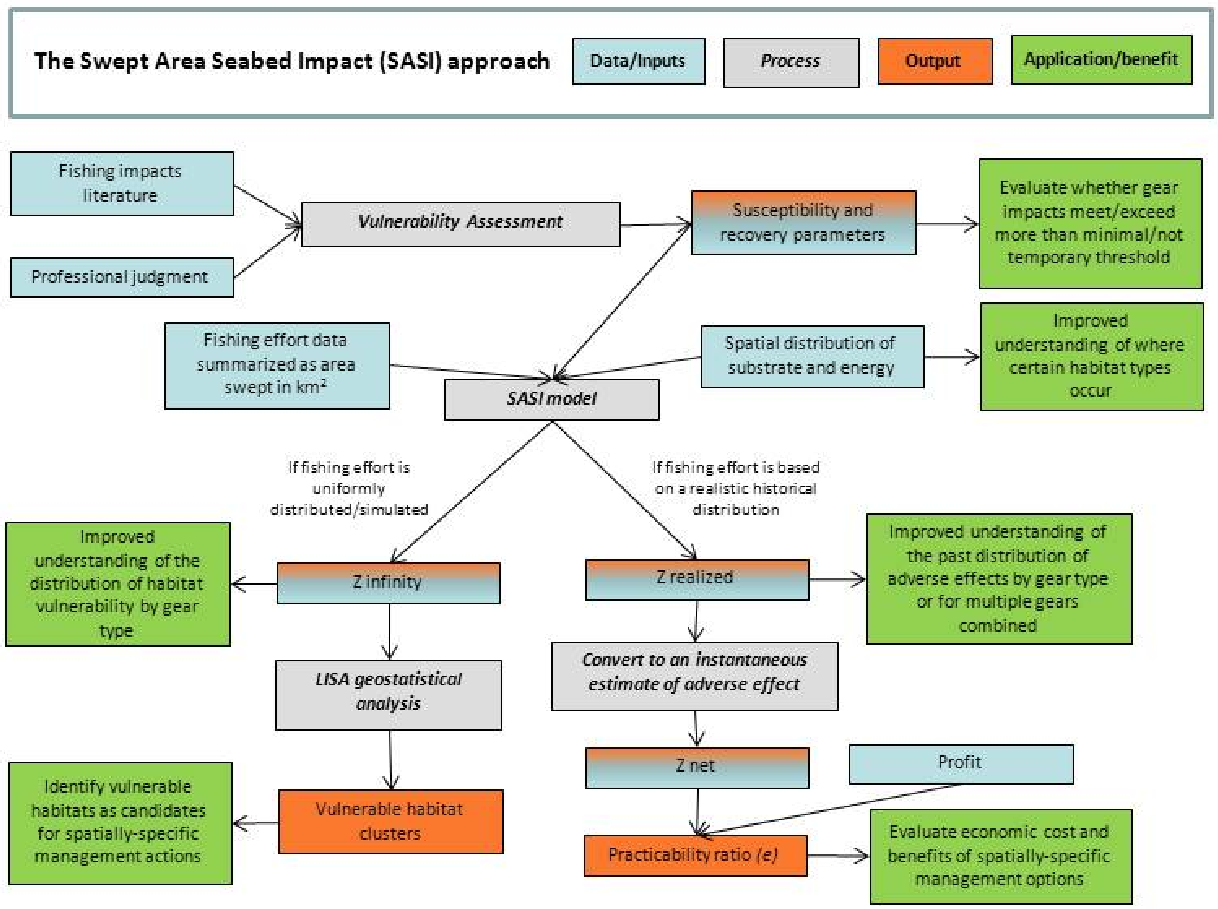
Spatial analyses (section 9.0). One way in which Z_∞ (adverse effect) estimates are evaluated is through formal spatial analysis. The objectives of the SASI spatial clustering analysis are to (explore the spatial structure of the asymptotic area swept (Z_∞), and to define clusters of high and low Z_∞ for each gear type. The analysis is intended to focus the Habitat Committee and Council's attention on areas with clusters of high vulnerability grid cells, as one starting point for developing spatially based alternatives to minimize adverse effect. Local Indicators of Spatial Association (LISA) statistics developed by Anselin (1995), which are designed to test individual sites for membership in clusters, are used.

Practicability analyses (section 10.0). Z_{net} is an instantaneous variant of $Z_{realized}$ that can be compared with trip level profit estimates to generate a practicability ratio, *e*. For gears with high habitat impact relative to profit, the *e* ratio is large, while for gears with a low habitat impact relative to revenue, the *e* ratio is small, approaching zero for some gear types. Z_{net} and *e* are developed for evaluating the relative practicabilty of various management alternatives, as the Council has expressed interest in optimizing its adverse effects minimization strategy across different gear types, fisheries, and areas.

Finally, **application of results to fishery management decision making (section 11.0)**, describes the assumptions and limitations of the model, and its potential applications to fishery management.

Section 12.0, research needs, lists habitat related research needs identified during model development. **Section 13.0, references**, includes acronyms used in the document, a glossary of key terms, and a literature cited section.

Figure 1 – SASI model flowchart



2.0 Defining habitat

Essential Fish Habitat is defined by the Magnuson Stevens Act as:

> "…those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity. For the purpose of interpreting the definition of essential fish habitat: ''Waters'' include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; ''substrate'' includes sediment, hard bottom, structures underlying the waters, and associated biological communities; ''necessary'' means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and ''spawning, breeding, feeding, or growth to maturity'' covers a species' full life cycle."

Fish habitat as defined above is thus an amalgamation of all the living and non-living aquatic features used by managed species throughout their lives. However, impacts to fish habitat conceptualized in this collective sense are difficult to summarize quantitatively and represent spatially. Therefore, in order to evaluate more concretely the interaction between fishing activity and fish habitat, a vulnerability assessment is developed to estimate the impacts of fishing on "substrate" as it is described above. For this assessment, "structures underlying the waters and associated biological communities" are specified as individual features that occur in areas identified as having particular "sediment" and "hard bottom" compositions. Individual features are chosen based on their known or assumed importance to managed species, and are differentiated to the extent required to capture broad differences in their susceptibility to and recovery from fishing disturbance. For a particular species of interest, the features and substrates than constitute its essential fish habitat can be inferred from both the EFH text description and also the EFH source documents, to the extent that the species dependence on such features and substrates is known.

For the purpose of this assessment, habitat features are divided into two components: geological structures and biological structures. Prey features and a special case class of biological features, deep-sea corals, were discussed extensively but ultimately not incorportated into the assessment. Structural features are defined as the living and non-living seabed structures used by managed species or their prey for shelter, and are classed as either geological (non-living), or biological (living). The number of different features defined attempted to strike a balance between simplifying the analysis while allowing for expected differences in the susceptibility of features to fishing gears. For example, the biological features 'burrowing anemones' and 'actinarian anemones' are differentiated because they have different abilities to retract into the seabed and thus avoid fishing gears that skim the surface.

Features described in the following sections are exclusively benthic. While recognizing the importance of the water column as fish habitat, SASI addresses physical changes to seafloor substrates and biological communities exclusively, as it is assumed that fishing gear does not alter the water itself in any substantive way. Similarly, only bottom tending gear types are modeled.

The various geological and biological features are inferred to one or more seafloor substrate classes (mud, sand, granule-pebble, cobble, boulder - Table 1) and one or more energy environments (high or low - Table 2). The various substrate and energy combinations map directly to the model grids.

Table 1 – Substrate classes by particle size range (based on Wentworth, 1922)

Substrate	*Particle size range*	*Corresponding Wentworth class*
Mud	< 0.0039-0.0625 mm	Clay (< 0.0039 mm) and silt (0.0039 – 0.0625mm)
Sand	0.0625 – 2 mm	Sand (0.0625 – 2 mm)
Granule-pebble	2-64 mm	Granule (2-4 mm) and pebble (4-64 mm)
Cobble	64 – 256 mm	Cobble (64 – 256 mm)
Boulder	> 256 mm	Boulder (> 256 mm)

Table 2 – Critical shear stress model components

Condition	*Data source*	*Parameterization*	
		High energy	*Low energy*
Shear stress	The max shear stress magnitude on the bottom in $N{\cdot}m^{-2}$ derived from the M2 (principal lunar semidiurnal) and S2 (solar) tidal components only	High = shear stress ≥ 0.194 $N{\cdot}m^{-2}$ (critical shear stress sufficient to initiate motion in coarse sand)	Low = shear stress < 0.194 $N{\cdot}m^{-2}$
Depth	Coastal Relief Model depth data	High = depths ≤ 60m	Low = depths > 60m

The inference of features to the five substrate and two energy classes defines 10 basic physical habitat types. In reality, seabed habitats cannot be classed so simplistically, and there are certainly areas which contain a greater or lesser diversity of features than those listed below. In addition, the various features will differ in their relative abundances between areas. The possible biases that may be introduced into the spatial SASI model as a result of characterizing habitat in this way are discussed in section 5.3.

The following sections describe the structural features evaluated, highlighting: (1) characteristics of the features that would likely influence their susceptibility to fishing-induced disturbance and their recovery times following disturbance, (2) the importance of natural disturbance (i.e. high or low energy environment) in creating or maintaining geological features, and (3) the distribution of features by substrate type. In addition, for biological features, the taxonomic bounds of each feature are specified, and species commonly found in the Northeast region are noted.

2.1 Geological habitat component

Geological habitat features include non-living seafloor structures that can be used for shelter by managed species or their prey (Table 3). These eight features may be created and maintained via physical oceanographic processes or by benthic organisms.

Table 3 – Geological habitat features and their inferred distribution by substrate and energy.

Feature	*Mud high*	*Mud low*	*Sand high*	*Sand low*	*Granule pebble high*	*Granule pebble low*	*Cobble high*	*Cobble low*	*Boulder high*	*Boulder low*
Sediments, surface/subsurface	X	X	X	X						
Biogenic burrows	X	X	X	X						
Biogenic depressions	X	X	X	X						
Bedforms			X							
Gravel, scattered					X	X	X	X	X	X
Gravel pavement					X		X			
Gravel piles							X	X	X	X
Shell deposits			X	X	X	X				

2.1.1 Sediments, surface and subsurface

A surface and subsurface sediment feature is evaluated for high and low energy mud, and high and low energy sand. Gear effects on these features include resuspension, compression, geochemical effects, and sorting/mixing. Surface sediments are defined as the top few centimeters of sediment, while subsurface sediments are defined as the top few feet of soft sediments that provide habitat for various burrowing prey species.

2.1.2 Biogenic depressions and burrows

Biogenic depressions and burrows are generated by benthic species including fishes, crabs, or lobsters, and may be used by other species for shelter. Depressions are shallower, and burrows are deeper. Gear effects on these features include filling and collapsing. Impacts to these features are evaluated separately from impacts to the organisms that create them or may live on them. As they are of biological origin, recovery depends on the continued presence of the organism that created the feature, with timing dependent on the complexity of the feature: shorter for depressions, and longer for burrows. Biogenic depressions and burrows are found throughout the region in mud and sand substrates. More complex burrows are likely to be found in mud substrates, which are more cohesive than sand. One specialized type of biogenic structure is a tilefish burrow[1]. However, because of their very specific affinity for clay outcrops, and their limited spatial distribution, vulnerability of tilefish burrows to fishing is not carried forward into the matrices and spatial SASI model.

2.1.3 Bedforms

Sedimentary bedforms include ripples, megaripples, and waves. Twichell (1983) defines these features by size (Table 4). Bedforms are created by the action of waves and tides over the seabed. The susceptibility and recovery of bedforms to gear impacts are assumed to relate to both bedform size and energy environment. Bottom tending fishing gear can smooth bedforms of various sizes. Ripples can occur in high-energy mud or sand, although mud ripples are considered rare and therefore not carried forward into the matrices or spatial SASI model. Megaripples and waves are inferred to high-energy sand.

Table 4 – Bedform classification (after Twichell 1983)

Bedform	*Wavelength*	*Height*	*Found in*
Ripple	< 0.6 m		Mud, sand
Megaripple	1-15 m	Less than 1 m	Sand
Wave	50-1000 m	1-25 m	Sand

2.1.4 Gravel and gravel pavements

'Scattered gravel in sand' refers to areas with scattered granules/pebbles, cobbles, or boulders in a sand matrix, while 'gravel pavement' refers to areas covered or nearly covered with granules/pebbles or cobbles. Gear effects on gravel and gravel pavements include burial in underlying soft substrates, displacement, and resorting. Gravel pavements are found in high-energy environments where tidal or wave-generated disturbance removes finer grained sand and mud and leaves larger gravel particles behind. Scattered gravel surrounded by mud or sand is inferred to both high and low-energy environments.

[1] Various authors, including Twichell et al. (1985), Able et al. (1982, 1993), Grimes et al. (1986, 1987), and Cooper et al. (1987), have studied the burrows and their use by the tilefish; this research is summarized in Steimle et al. 1999. Tilefish burrow may be tubular or funnel shaped. They range in size, but the largest are up to 5 meters wide and several meters deep. It is believed that either tilefish (Grimes et al. 1986, 1987) or crustaceans (Grimes et al. 1986, 1987, Cooper et al. 1987) form the burrows initially. The burrows may be created over the lifetime of the tilefish (Twichell et al. 1985); the maximum observed ages for female and male tilefish respectively are 46 and 39 years (Nitschke 2006). If completely destroyed, tilefish burrows would have a longer recovery time than other biogenic burrows.

2.1.5 Cobble and boulder piles

When glaciers extended over what is now submerged continental shelf, larger size classes of gravel (i.e. cobbles and boulders) are deposited as glacial till, sometimes occurring in piles on the seafloor. Fishing gear may smooth these piles and displace the cobbles and boulders they are made of. For boulder dominated habitats, redistribution will reduce availability of deep crevices that are utilized by fish, such as Acadian redfish, for shelter. Because of the size of cobbles and boulders, these features will not reform naturally due to wave action.

2.1.6 Shell deposits

Shell deposits are the non-living remains of mollusks distributed in windrows (due to wave and current energy), along the base of steep slopes, and as continuous pavements, and may form as the result of fishing activities, predation, senescence, or all factors. These aggregations provide interstices for small organisms that serve as prey for managed species as well as directly providing cover for juvenile fishes. Such deposits are distinguished from occasional shells or shell pieces (i.e. shell debris). Gear effects on shell deposits include burial, breakage/crushing, or displacement. Recovery is possible if the organisms that generate the shells, such as scallops, razor clams, quahogs, surfclams, or mussels, remain in or recolonize the area following disturbance. Empty shells may aggregate to form deposits as a result of storm events. Shell deposits are inferred to high and low energy sand and gravel habitats.

2.2 Biological habitat component

Biological habitat features are macrofauna that attach to, emerge from, or rest on top of the substrate, and provide physical structure for managed species (Table 5). The functional roles of such habitats are to increase growth rates and survivorship, and to enhance reproduction. Generally, these biological features are broad taxonomic or functional groupings at family and higher levels, as opposed to individual species. Although differential susceptibility and recovery due to variation in life history or form is intuitive and has been demonstrated in various studies (e.g. Tillen et al. 2006), much of the fishing impacts literature considers impacts on a species- or taxon-specific basis. For example, impacts to sponges are considered, rather than impacts to erect, soft, long-lived epifauna.

Table 5 – Biological habitat features and their inferred distribution by substrate and energy.

Feature	*Mud high*	*Mud low*	*Sand high*	*Sand low*	*Granule pebble high*	*Granule pebble low*	*Cobble high*	*Cobble low*	*Boulder high*	*Boulder low*
Amphipods	X	X	X	X						
Anemones, actinarian					X	X	X	X	X	X
Anemones,	X	X	X	X	X	X				

cerianthid										
Ascidians			X	X	X	X	X	X	X	X
Brachiopods					X	X	X	X	X	X
Bryozoans					X	X	X	X	X	X
Corals, sea pens		X		X						
Hydroids	X	X	X	X	X	X	X	X	X	X
Macroalgae					X		X		X	
Mollusks, mussels	X	X	X	X	X	X	X	X	X	X
Mollusks, scallop			X	X	X	X	X	X		
Polychaetes, *F implexa*					X	X	X	X	X	X
Polychaetes, other					X	X	X	X	X	X
Sponges			X	X	X	X	X	X	X	X

2.2.1 Amphipods – tube-dwelling

A number of marine amphipod species construct temporary or permanent burrows, tunnels, or tubes. A variety of materials, including mud, clay, sand grains, and shell and plant fragments may be used to form the tubes. The material is usually bound together with a cementing secretion produced by the animal. All amphipods belonging to the family Ampeliscidae, with the exception of those living on hard substrate, are tube-dwelling. They are common in marine sediments throughout the world and certain species may occur at very high densities in coastal sediments, forming tube beds or mats (Sheader 1998). Another species – *Erichthonius* sp., belonging to the family Corophiidae – has also been reported to form tube mats on Fippennies Ledge, in the Gulf of Maine, that are susceptible to damage by fishing gear (Langton and Robinson 1990). This species has also been observed in deep water in Jordan Basin on undisturbed mud bottom (Watling 1998). Many amphipod species in the Northeast region are tube-dwelling, but do not create tubes that extend above the sediment surface (Steimle and Caracciolo 1981).

The vulnerability assessment for structure-forming amphipods is based on the susceptibility and recovery potential of the most common east coast ampeliscid species, *Ampelisca abdita*. This species ranges from Maine to at least Florida and produces dense masses of tubes in soft sediments at depths ranging from shallow, sub-tidal waters to about 60 meters. In Raritan Bay, New Jersey, dense *A. abdita* tube mats are common in mud and fine sand, covering mud surfaces at certain times of year so completely that the mud surface is not visible (MacKenzie et al. 2006). The tubes are about 3.5 cm long and flattened laterally, and are composed of nonchitinous, pliable organic material. About two-thirds (2-2.5 cm) of the tube extends vertically into the water. In Raritan Bay, the tube mats are covered with a continuous layer of brown fecal pellets and finer particles held in place by mucous secreted by the amphipods. Tube mat formation is highly seasonal because *A. abdita* has three breeding seasons per year. In Raritan Bay, new generations settle onto the bottom and construct new tubes in May-June, September-October, and December-January. Several weeks after the new tubes are constructed, they slowly begin to disintegrate and lay flat on the bottom.

Amphipod tube mats also occur further offshore on the continental shelf. Auster et al. (1991) identified flat sand with amphipod tubes (species not identified) as one of four microhabitats utilized by fish at a low relief outer continental shelf site (55 m) in southern New England. This microhabitat type was found to support the highest density of young-of-year silver hake at various locations on the southern New England continental shelf on silt-sand bottoms at depths of 47-82 m (Auster et al. 1997). Lindholm et al. (2004) also identified a sand dominated habitat with amphipods and polychaete tubes that extended approximately 2 cm above the sediment surface on eastern Georges Bank, in depths >60 meters.

Tube-dwelling amphipods are inferred to high and low energy mud and sand-dominated habitats.

2.2.2 Anemones – actinarian and cerianthid

Anemones are members of the class Anthozoa, a very large and diverse group of Cnidarians that also includes corals. Anemones are soft-bodied and flexible, consisting of a ring or rings of tentacles atop a base or column. For the purpose of the vulnerability assessment, burrowing (order Ceriantharia) and non-burrowing anemones (order Actinaria) are differentiated. Whereas Actinarians (true) anemones are able to retract their oral disk and tentacles, cerianthids cannot. However, cerianthids can withdraw very rapidly into permanent, semi-rigid tubes buried in the substrate that are constructed of specialized cnidae and mucus, with adhering substrate debris (Shepard et al. 1986). Available information for four actinarian species and the two cerianthids known to exist in the region is summarized in Table 4. Sources used to compile this information are Shepard et al. (1986, Sebens (1998), the Marine Life Encyclopedia [on-line], Wikipedia [on-line], and the website actiniaria.com.

Actinarian anemones in the region include the northern red anemone *Urticina (Tealia) felina (=Urticina crassicornis?)*, the frilled anemone *Metridium senile*, *Bolocera tueidae*, and *Stomphia coccinea* (Table 4). Actinarians adhere to the substrate with a pedal disk, and are thus restricted to hard substrates including larger size classes of gravel and biogenic structures. In the British Isles, both *U. felina* and *M. senile* are found in areas with varying tidal flows and wave exposures (Jackson and Hiscock 2008, Hiscock and Wilson 2007). *U. felina* and *M. senile* are present on Ammen Rock, in the central Gulf of Maine, at depths of 30-65 m (Witman and Sebens 1988) and *B. tueidae* has been observed on hard substrates in the central and eastern Gulf of Maine (Langton and Uzmann 1989). *U. felina* has also been observed on settlement panels deployed on the northern edge of Georges Bank (Collie et al. 2009).

Burrowing anemones in the Northeast region include *Cerianthus borealis* and *Ceriantheopsis americanus*. *C. borealis* is found from the Arctic to Cape Hatteras at depths of 10-500 m, while *C. americanus* has a more southerly and shallow distribution, ranging from Cape Cod to Florida at depths between 0-70 m. Other unclassified cerianthids have been sampled from deeper waters of the continental slope (Shepard et al. 1986). Between Nova Scotia and Cape Hatteras, cerianthids are most common on the shelf off Nova Scotia, between 40-41° N latitude, and between 37-38° N latitude (Shepard et al. 1986). Shepard et al. found that cerianthid distribution was independent of sediment type, although they are not found in areas with 100% gravel or bedform-dominated coarse sand substrates. Langton and Uzmann (1989) reported that *C. borealis* in the central and eastern Gulf of Maine were most abundant in mixed sandy substrates and in silt, but entirely absent from 100% sand and gravel substrates. Tubes inhabited by *C. americanus* remain entirely in the substrate (Peter Auster, personal communication) whereas the tubes of *C. borealis* extend 15 cm above the sediment surface (Valentine et al. 2005). Under certain conditions, *C. borealis* are found in dense aggregations (up to 10 animals per m^2) in the Gulf of Maine (Valentine et al. 2005).

Cerianthids are important ecologically. For example, Shepard et al. (1986) found a positive relationship between the abundance of hydroids, sponges, anemones, blackbelly rosefish, and redfish and cerianthids in deeper waters (137-183 m) of Block Canyon. Acadian redfish as well as other fish species use dense patches of cerianthids for shelter (Auster et al. 2003). Pandalid shrimp are known to aggregate around the base of anemones and may serve to concentrate crustacean prey. In addition, cerianthids are known prey of cod, haddock, flounder, scup, and skates, which may consume whole juveniles or the tentacles of adults, and they serve as a substrate for epifaunal and infaunal organisms (Shepard et al. 1986). Both cerianthid and actinarian anemones are carnivorous, feeding primarily on zooplankton.

Generally, both types of anemones are long-lived and slow growing, and like other cnidarians, many species reproduce both asexually and sexually. Anemones are solitary, but show a gregarious distribution, which might be expected due to the importance of sexual reproduction. Both *U. felina* and *M. senile* are gonochoristic (separate males and females, Jackson and Hiscock 2008, Hiscock and Wilson 2007), while cerianthids are protandric hermaphrodites (sequentially male then female, Shepard et al. 1986). However, for many species, it seems that few details are known about growth rates, age at maturity, longevity, or fecundity.

Actinarian anemones are inferred to high and low energy granule-pebble, cobble, and boulder substrates, while cerianthid anemones are inferred to high and low energy mud, sand, and granule-pebble substrates.

Table 6 – Actinarian and cerianthid anemones of the Northeast Region.

Species	*Range*	*Size*	*Form*	*Habitats*
Bolocera tuediae	Arctic to North Carolina	25 cm high, base 25 cm wide	Solitary	Rock and shell substrates, 20-1000 m, rarely to 2000 m
Cerianthus borealis	Arctic to Cape Hatteras	Semi-rigid tube extends 15 cm above seabed	Solitary, burrowing	Mud, stable sand, or gravelly substrates (<50% gravel cover), 10-500 m
Ceriantheopsis americanus	Cape Cod to Florida	Animal extends above sediment, but not tube	Solitary, burrows up to 45 cm into sediment,	Muddy or sandy bottom, up to 70 m
Metridium senile	Arctic to Delaware Bay	Large, to 30 cm, base 15 cm wide	Solitary, very common	Rock outcrop, large gravel or biogenic structure, intertidal to 166 m
Stomphia coccinea	Circumarctic boreal, to Cape Cod	Moderate, height and diameter to 7 cm	Solitary, can detach easily from substrate	Surfaces of stones and rocks, on shells, 5-400 m
Urticina (Tealia) felina (crassicornis)	Just below Cape Cod to Arctic	Large, base up to 70 cm diameter when expanded	Solitary	Cobble or gravel, 2 to >300 m

2.2.3 Ascidians

Ascidians are a class of tunicates, and as such are members of the phylum Chordata, along with fish, birds, and mammals. They are suspension feeders; water and food enter through an incurrent siphon, are filtered through a U-shaped gut, and exit through an excurrent siphon. The ascidian's outer covering, or tunic, may range from soft and gelatinous to thick and leathery, depending on the species. A few ascidians live interstitially or attached to soft sediments, but most require a hard surface for attachment. Ascidians reproduce both asexually and sexually; in the latter case the larval stage is typically very short, ranging from hours to days.

Ascidians may be solitary (often gregarious), social (individuals are vascularly attached at the base), or compound/colonial (many individuals live within a single gelatinous matrix). However, only the solitary species are considered in the vulnerability assessment. Compound, or colonial, ascidians (genera like *Didemnum* and *Botryllus*) are not included because they spread out over the substrate and do not create any appreciable vertical structure. All of the eight species listed in Table 7 reach maximum heights >2 cm, and four of them grow up to 5-7.5 cm tall. One species, (*Molgula arenata*) does not attach to the substrate, and one (*Boltenia ovifera*) is attached by a stalk. Only two species (*M. arenata* and *M. manhattensis*) occur in the Mid-Atlantic region. Very little is known about the deep-water species *Ascidia prunum*. *Molgula* spp. (sea grapes) live in soft bottom habitats, but the others attach to hard substrates.

Ascidians are inferred to all substrate and energy environments except for high and low energy mud.

Table 7 – Structure-forming solitary ascidians of the Northeast Region

Species	***Range***	***Height***	***Form***	***Habitats***
Ascidia callosa	Arctic south to Cape Cod	To 50 mm	Attached	Subtidal
Ascdia prunum	?	?	Attached	Deep water only
Boltenia ovifera	Arctic to Cape Cod, rarely to Rhode Island	Body to 75 mm, stalk 2-4 times longer (smaller near shore)	Attached, on stalk	generally subtidal to great depths (?), on rock outcrop, gravel, seagrasses
Boltenia echinata	Arctic south to Cape Cod, rarely beyond	To 34 mm	Cactuslike cushion, attached, no stalk	Lower intertidal to subtidal, shallow
Ciona intestinalis	Arctic south to Cape Cod, rarely to Rhode Island	To 62 mm	Attached, tall and slender	In shallow water on pilings, etc.
Halocynthia pyriformis	Subarctic to Massachusetts Bay, uncommon south of eastern Maine	To 62 mm, often only half that size	Attached, large, barrel-shaped	Usually subtidal, Rock outcrop, gravel, seagrasses
Molgula arenata	Bay of Fundy to Cape May	To 19 mm	Unattached, globular	On sand or mud, subtidal, 5-22 m
Molgula manhattensis	Bay of Fundy to Gulf of Mexico	To 34 mm	Attached, globular	Intertidal to subtidal in shallow water

2.2.4 Brachiopods

Brachiopods – also known as lamp shells – resemble bivalve mollusks, but belong to an entirely separate phylum. The resemblance is only superficial: they do possess a calcareous shell with two valves, and are approximately the same size as many bivalve mollusks, but one valve is typically larger than the other and the larger valve is attached to the substrate directly or by means of a short, cord-like stalk. All brachiopods are marine, and most live on the continental shelf. Most species live attached to rocks or other hard substrate. They have very thin, light shells and some species are very long-lived (up to 50 years).

The common species in the Northwest Atlantic is *Terebratulina septentrionalis*. It is locally common from Labrador south at least to Cape Cod in the lower intertidal zone in the northern part of its range, but is resticted to deep water at its southern limit (Gosner 1978). It is a common epifaunal organism on rocky bottom in the Bay of Fundy, on Western Bank (Scotian shelf), and on Browns Bank and Jeffreys Ledge in the Gulf of Maine (Kenchington et al. 2006/2007, Kostylev et al. 2001, and D. Stevenson, pers. comm.). The shells of this species are small, ranging from 12-30 mm in size (Gosner 1978). Unlike other brachiopod species, it is relatively short-lived, with a lifespan ranging from 1-5 years (Witman and Cooper 1983).

Brachiopods are inferred to high and low energy granule-pebble, cobble, and boulder substrates.

2.2.5 Bryozoans

The bryozoans (Greek, meaning moss animals), are a highly diverse group of colonial animals found in both fresh and saltwater. Marine bryozoans have been found at nearly all depths and latitudes, primarily on hard substrates; they are almost always sessile. They may be calcified or soft, and encrusting or erect. Each colony is comprised of hundreds to millions of tiny individuals called zooids; individual zooids may be specialized for feeding, cleaning, providing structure to the colony, etc. The soft parts of each zooid are typically enclosed in a tiny calcified 'house', or cystid. Bryozoans suspension feed using a lophophore, which is a ring of tentacles surrounding the mouth that can be protracted and retracted through a pore in the cystid. As colonial organisms, asexual reproduction via budding is an important strategy for bryozoans. The directionality of budding (e.g. circular or chainlike) varies by species, and helps to determine the structure of the larger colony. As for sexual reproduction, most bryozoans are hermaphroditic, and the eggs may be brooded or released and externally fertilized depending on the species. The bryozoan larva, which may be mobile for several months in some species, settles, and then a new colony forms asexually by budding (Gosner 1971).

Only erect (or "bushy") bryozoans are considered structural habitat for fish or their prey and included in the vulnerability assessment. These bryozoans are anchored via a holdfast (Gosner 1971). Some are calcified, others are not. Some species that occur in the Northeast region are quite large, reaching heights of 30 cm, but the majority are <10 cm high. *Eucratea loricata* grows to a height of 25 cm and is found in shallow and deep water from the Arctic to Cape Cod. *Bugula turrita* and *Alcyonidium* spp. can reach 30 cm and are found in shallow water. Other erect species that inhabit deeper water are *Crisia eburnea, Dendrobaenia murrayana, Flustra foliacea, Idmonea atlantica, Cabrera ellisi,* and

Tricellaria ternata. The information in Table 8 was compiled from Gosner (1978), Stokesbury and Harris (2006), Henry et al. (2006), and Witman and Sebens (1988).

F. foliacea biology was summarized by Tyler-Walters and Ballerstedt (2007). The species lives between 5-10 years, and growth rate estimates range from 1-3 cm per year. Growth has been shown to vary seasonally, annually, by colony age, and according to the degree of fouling by other bryozoans, hydroids, polychaetes, barnacles, ascidians, etc. The holdfast is thickened and strengthened as the colony ages. *F. foliacea* is able to recover from grazing damage within a few days. *F. foliacea* settles on any hard substrate and seems to prefer high-flow conditions.

Bryozoans are inferred to high and low energy granule-pebble, cobble, and boulder substrates.

Table 8 – Erect bryozoans (>1.5 cm high) of the Northeast Region.

Species	***Range***	***Height***	***Form***	***Substrate***
Aeverrillia spp.	Mostly south of Cape Cod; A. armata estuarine, reported north to Casco Bay	10 cm	Horny but not calcified	Shallow water
Alcyonidium spp.	Three species, one boreal, one south of Cape Cod, and one whole coast	To 30 cm or more	Rubbery or gelatinous, not calcified	Shallow water
Amathia convoluta and *vidovici*	*A. convoluta* south of MD, *A. vidovici* south of Cape Cod	50 and 150 mm	Not calcified	Variety of substrates in shallow water
Anguinella palmata	Cape cod to Brazil, abundant Delaware Bay and south	65 mm	Soft, grows in palmate, branching tufts	Shallow; can be found in estuaries
Bugula turrita	Bay of Fundy to Florida	Usually <75mm but sometimes to 30 cm	Lightly calcified, bushy, thickly tufted	At shallower depths, can be found in estuaries
Bugula simplex	South shore of Cape Cod to Maine	To 25 mm	Lightly calcified, thick, fan-shaped tufts and whorls	Shallow water
Cabrera ellisi	Cape Cod north to Arctic	?	Branching	Usually offshore on pebbles and shells
Crisia eburnea and *cribaria*	*C. eburnea* Arctic to Cape Hatteras, *C. cribaria* north of Cape Cod only	To 19 mm	Calcified, in twiggy tufts	*C. eburnea* to 300+ m, can be found in estuaries
Dendrobaenia murrayana	*Dendrobaenia* sp. common colonial epifauna on Scotian shelf, on Ammen Rock	To 38 mm	Leafy, in narrow to broad fans or ribbons	On pebble-cobble-boulder substrate on Scotian shelf

Species	Range	Height	Form	Substrate
	(central Gulf of Maine)			
Eucratea loricata	Arctic to Cape Cod	To 25 cm	Calcified; some colonies short and stiff, others bushier	Subtidal, shallow to deep (in mixed sand, gravel, and boulders
Flustra foliacea	Arctic south to Georges Bank	100 mm +	Calcified, erect, leafy, broad-lobed fronds	Attached to rocks, seaweed, etc., at 52-70 m on Georges Bank
Idmonea atlantica	Arctic to Cape Cod	25 mm or more	Antler-like colonies	On rocky substrate at 30-65 m on Ammen Rock, central Gulf of Maine)
Tricellaria ternata	Present on western part of Georges Bank	To 16 mm?	Calcified	In 52-70 m on GB, mixed sand, gravel, and boulders

2.2.6 Sea pens

Sea pens are members of the phylum Cnidaria[2], a large and diverse group whose benthic, structure-forming species include the hydroids, sea anemones, and corals. They belong to the Class Anthozoa, along with corals and sea anemones, and are placed under the Subclass Octocorallia (Alcyonaria), or octocorals. Unlike most other corals, sea pens live in muddy and sandy sediments, anchored in place by a swollen, buried peduncle. Some species are capable of retracting into the sediment when disturbed.

Records of sea pens were drawn from Smithsonian Institution collections and the Wigley and Theroux benthic database (Packer et al. 2007). Nearly all materials from the former source were collected either by the U.S. Fish Commission (1881-1887) or for the Bureau of Land Management (BLM) by the Virginia Institute of Marine Sciences (1975-1977) and Battelle (1983-1986). These latter collections heavily favor the continental slope fauna. The Wigley and Theroux collections (1955-1974) were made as part of a regional survey of all benthic species (Theroux and Wigley 1998), heavily favoring the continental shelf fauna. A list of 21 sea pen species representing ten families was compiled from these sources for the northeastern U.S. The majority of these species have been reported exclusively from continental slope depths (200-4300 m), although two uncommon species have been recorded from shallow depths (e.g., < 30 m) off the North Carolina coast.

[2] Cnidarians are distinguished by their cnidae, or stinging cells, for which jellies in particular are commonly known.

Sea pens are evaluated as structural biological features in the matrix-based vulnerability assessment because of two sea pen species which are fairly common in continental shelf waters. In contrast, other cold-water coral species are less abundant in shallower, more commonly fished waters. The most common and fairly widespread species found in this region in the deeper parts of the continental shelf (80-200 m) are *Pennatula aculeata* (common sea pen) and *Stylatula elegans* (white sea pen). *P. aculeata* is common in the Gulf of Maine (Langton et al. 1990), and there are numerous records of *Pennatula* sp. on the outer continental shelf as far south as the Carolinas in the Theroux and Wigley database. *S. elegans* is abundant on the Mid-Atlantic coast outer shelf (Theroux and Wigley 1998). Given the 51 m minimum depth in the region, sea pens are only inferred to low energy mud and sand environments.

Table 9 – Common sea pen species on the continental shelf of the Northeast Region

Species	*Range*	*Form*	*Habitats*
Pennatula aculeata	Newfoundland to Virginia	Solitary	Mud or sand, 119-3316 m; also in sand with scattered gravel
Stylatula elegans	New York to Florida	Solitary	Mud or sand, 20-812 m, 51 m minimum depth in NE region; also in sand with scattered gravel

2.2.7 Hydroids

Hydroids are also Cnidarians within the Class Hydrozoa. Most hydroids are colonial, branching, and live attached to the substrate directly or to another organism. Each branch of the colony terminates in an individual polyp, or zooid. Most marine hydroids are encased in an exoskeleton made of chitin or calcium carbonate; when this structure extends around the polyp in a cup-shape, the species is considered thecate, which is an important identifying characteristic. Within a colony, individual polyps are modified for different functions, which may include reproduction, feeding, and defense.

Hydroids reproduce both asexually and sexually. In the case of sexual reproduction, the reproductive, or gonozooids produce gonophores, which may either remain attached to the colony or detach as a free medusae (the upside-down bell-shaped form commonly associated with jellyfish). Some of these medusae may live for several months and feed on their own, thus allowing for wide dispersal. Eggs and sperm released by the attached or detached reproductive structures come together to produce a planula larvae. These larvae have varying degrees of dispersal, ranging from attached to the mother colony, to crawling along the seafloor, to detached but floating in the currents, to free swimming (Boero 1984). Generally, hydroid species living in estuarine environments tend to have free medusae, while hydroids living in colder, saltier waters tend to have gonophores that remain attached (Calder 1992). Some species (e.g., *Sertularella polyzonias*) reproduce asexually and can rapidly recolonize new substrates by using terminal tendrils located at the distal ends of each hydroid plume (Henry et al. 2003).

Hydroids settle precociously on hard bottoms, and then also settle on top of the algae, sponges, polychaetes, barnacles, bryozoans, mollusks, and ascidians that succeed them (Boero 1984). In fact, some hydroids have fairly exclusive preferences for settlement on other epifaunal species (Boero 1984). In soft bottom environments, they are less common in shallow waters, but increase in importance below 40-50 m depth (Boero 1984). Auster et al. (1996), for example, observed dense growth of *Corymorpha pendula* on coarse sand on Stellwagen Bank (southwest Gulf of Maine) in depths of 32-43 meters and Henry et al. (2006) identified 30 species of colonial hydroids at 70 meters on a mixed pebble, cobble, boulder, and sand bottom on Western Bank (Scotian shelf).

Generally, hydroids tend to grow quickly, and some show pronounced seasonal cycles, particularly in areas where temperatures vary at different times of year (Boero 1984). Hydroid polyps filter food from the water column, and as such are sensitive to suspended sediment. In high-flow areas, this is generally not an issue, but in low-flow areas hydroids tend to 'climb' on other organisms, presumably to increase their distance from the seabed (a phenomenon known as acrophily) (Boero 1984). Species in low-flow areas also tend to be thinner, so that less surface area is available to collect suspended sediment (Boero 1984). Hydroids tend to orient their colonies perpendicular to the dominant flow direction (Boero 1984).

Hydroid colonies are generally relatively low relief, such that they are unlikely to be used directly by fish for shelter, but they do provide complex structure that can be used by other smaller epifauna, some of which are prey for managed species. For example, at two different Irish Sea sites, samples with abundant hydroids had significantly higher abundances of some other epifaunal species (Bradshaw et al. 2003). Three types of associations were found between the hydroid colonies and other species: (1) species that settle on the hydroids directly (e.g. amphipods, *Erichthonius punctatus*, and scallops, *Pecten maximus*), (2) species that shelter amidst the upright structure of the hydroids, and (3) species that shelter at the base of the hydroids. For example, high densities of pandalid shrimp were differentially distributed within hydroid patches on Stellwagen Bank (Auster et al. 1996), influencing the distribution of an important prey resource for crustacean-eating fishes.

Many species of hydroids do not reach maximum sizes that are sufficient to (potentially) provide shelter for managed species of fish. Therefore, the habitat vulnerability assessment focused on species known to occur in the region that exceed 2 cm in height (see Table 10 for details). The identified genera and species are derived from information for the Atlantic coast from the Bay of Fundy to Cape Hatteras (Gosner 1978) and by Calder (1975), based on a survey of Cape Cod Bay. Additional information for Georges Bank and the Gulf of Maine (Stellwagen Bank) was derived from Stokesbury and Harris (2006) and Auster et al. (1996).

Calder (1992) examined the distribution of hydroids in the western North Atlantic by comparing species diversity at sites that were reasonably well-studied. He found that the hydroid assemblage changes significantly around Cape Hatteras, somewhere between Chesapeake Bay and Beaufort, NC. Hydroid assemblages from the Canadian Arctic to the Mid Atlantic Bight were distinct from those found from Beaufort, NC south to the Caribbean. In particular, the hydroid assemblage in Cape Cod Bay was more similar to the assemblages found in the Canadian Maritimes, while the assemblage from Woods Hole was more similar to the one from Chesapeake Bay.

Hydroids are inferred to all ten substrate and energy environments.

Table 10 –Hydroids (>2 cm) in the Northeast Region

Species	***Range***	***Height***	***Habitat***
Abietinaria spp.	Arctic to Cape Cod	To 30 cm	Usually subtidal, common on seaweeds, rocks, pilings
Aglantha digitale	Arctic south to Chesapeake Bay	To 28 mm	Mainly subtidal (> 15 m), year-round in Gulf of Maine, winter-spring southward
Bougainvillia carolinensis	Central Maine to Florida	To 30 cm	Lower intertidal to subtidal in shallow water
Bougainvillia superciliaris	Arctic south to Cape Cod	To 5 cm	Lower intertidal to subtidal in shallow water
Bougainvillia rugosa	Chesapeake Bay south	To 25 cm	Shallow water
Capanularia spp.	Four conspicuous species, two mainly boreal, two along entire coast	Two species 25-35 cm, two 32 mm	Rocks, shells, pilings in shallow water
Clytia edwardsi	Chesapeake Bay north	To 25 mm	Lower intertidal to subtidal in shallow water on rocks, shells, pilings
Corymorpha (Hybocodon) pendula	Gulf of St. Lawrence to Rhode Island	To 10 cm	Deep water, in sand at 32-43 m in SW Gulf of Maine
Diphasia spp.	Arctic to Rhode Island	To 10 cm	Common on seaweeds, rocks, pilings from lower intertidal to subtidal at considerable depths
Eudendrium spp.	Whole coast, 10 species, most conspicuous are *E. carneum* and *E. ramosum, E. capillare on Georges Bank*	To 15 cm	Most in shallow water on a wide variety of substrates; E. capillare on mixed sand and gravel in 52-70 m
Garveia spp.	Whole coast	To 15 cm	
Gonothyraea loveni	Chesapeake Bay north	To 32 mm	Lower intertidal to subtidal in shallow water, on rocks, shells, pilings
Halecium spp.	Numerous species, mostly boreal	To 75 mm	Lower intertidal to subtidal at depths of 12 m or more

Species	***Range***	***Height***	***Habitat***
Hybocodon (Corymorpha) pendula	Chiefly boreal	To 10 cm	Present in SW Gulf of Maine in coarse sand at 32-43 m, abundant in Cape Cod Bay in sand and mud
Lovenella spp.	Whole coast (distribution uncertain)	16-50 mm	Some species subtidal in shallow water, others only in deep
Obelia bicuspidata	Whole coast	To 25 mm	Lower intertidal to subtidal in shallow water, on rocks, shells, pilings
Obelia commissuralis	Whole coast	To 20 cm	Lower intertidal to subtidal in shallow water, on rocks, shells, pilings
Obelia longissima	N. Canada to Chesapeake Bay	15 cm	On mud and sand in Cape Cod Bay
Opercularella spp.	Whole coast (distribution uncertain)	16-50 mm	Some species subtidal in shallow water, others only in deep
Pennaria tiarella	Maine south to West Indies	To 15 cm	Common on eelgrass, pilings, and other substrates in summer-early fall
Schizotricha tenella	Casco Bay to Caribbean	To 10 cm	On pilings, seaweeds, and other substrata to shallow depths
Sertularella polyzonias	N. Canada to Georgia	20 mm	
Sertularia cupressina	Labrador to New Jersey	11.5 cm	Common on sand and mud in Cape Cod Bay
Sertularia argentea	Northern Canada to North Carolina	To 30 cm	Chiefly a winter species, common on seaweeds, rocks, pilings to considerable depths, on sand and mud in Cape Cod Bay
Sertularia latiuscula	Gulf of St. Lawrence to Virginia	8.5 cm	Common in Cape Cod on sand and mud
Sertularia pumila	Labrador to Long Island Sound	To 50 mm	Common on seaweeds, rocks, pilings to considerable depths
Tubularia spp.	Whole coast, several species (*T. crocera* common south of Cape Cod, *T. larynx* north of Long Island Sound)	15 cm	From lower intertidal to subtidal at shallow depths

2.2.8 Macroalgae

A wide variety of macroalgae can be found in coastal areas of the Northeast region, but fewer species have been documented in deeper, offshore waters. Because macroalgae are photosynthetic, their distribution is restricted to the photic zone. They require a hard substrate for attachment. The most important species of macroalgae, in terms of providing habitat for fish, are the kelps, brown algae belonging to the order Laminariales. This order includes the largest and most structurally complex of all the algae. They are an important floristic component of the lower littoral and sublittoral zones on almost any rocky coast in temperate or polar seas (Bold and Wynne 1978). On the east coast of North America they range southward to Long Island Sound (Table 11). All the species found in the Northeast Region are perennials. The blades of these kelps slough off after reproduction and a new blade is produced at the beginning of the next growing season (Bold and Wynne 1978). Owing to their large size (up to 10 meters in length), these plants provide habitats for a variety of pelagic and benthic marine invertebrates and fish. There are also a number of larger red algal species that grow in subtidal waters in the region (Table 11). Five of the 17 red algal taxa identified as inhabiting subtidal waters in the region, and reaching sufficient sizes to provide three-dimensional structure, reach lengths of 30-60 cm. Because of differences in their photosynthetic pigments, red algae occur in deeper water than brown algae. Four of those listed range southward from Cape Cod and Long Island Sound, five northward, and eight are common to both areas. Information in Table 11 was based primarily on Gosner (1978), with some supplementary information from Sears and Cooper (1978), Schneider (1976), and Vadas and Steneck (1988).

Macroalgae are inferred to high energy granule-pebble, cobble, and boulder substrates.

Table 11 – Brown and Red Macroalgae (>5 cm high) in the Northeast Region

Species	***Type***	***Range***	***Height***	***Habitat***
Alaria (5 species?)	Brown	Arctic to Cape Cod, A. esculenta sparingly to Long Island Sound	Stalked, with lateral bladelets, main blade to 3 m	Primarily subtidal, sometimes in lower intertidal zone
Agarum cribrosum	Brown	Arctic to Cape Cod	Single broad blade, to 1.8 m, sometimes twice that	Chiefly subtidal, present at 24-40 on Ammen Rock, central Gulf of Maine
Laminaria digitata	Brown	Arctic to Long Island Sound	Wide blade split into 6-30 or more "fingers," to 1.1 m	In extreme lower intertidal on exposed rocks, subtidal southward
Laminaria longicruris	Brown	Arctic to Cape Cod, locally to Long Island Sound	Long stalk, usually to 4.5 m, but to 10 m or more in deep water	Present (with an unidentified species of Laminaria) at 24-40 on Ammen Rock, central Gulf of Maine
Laminaria saccharina (form of *L. agardhii*?)	Brown	Northern Massachusetts to Arctic		
Laminaria agardhii	Brown	Long Island Sound and off NY Harbor to Gulf of Maine (only common long-bladed	To 3 m	

Species	Type	Range	Height	Habitat
		kelp south of Cape Cod)		
Champia parvula	Red	Cape Cod to tropics	Bushy, branched, to 75 mm	Chiefly subtidal in quiet water, often epiphytic, at 17-27 m in North Carolina
Chondria spp.	Red	Nova Scotia to tropics, four species	Bushy, branched, 10-25 cm	Lower intertidal to subtidal in summer, found at 14-60 m in NC
Cystoclonium purpureum	Red	Long Island Sound to Newfoundland	Bushy, to 60 cm	Abundant, mainly subtidal on sandy or shelly bottoms in protected and exposed locations
Dasya spp.	Red	Maine or Nova Scotia to tropics	Furry strands to 60 cm	*D. baillouviana* found at 18-40 m in NC
Gracilaria spp.	Red	Cape Cod to tropics, two species, one locally north to central Maine and one to Prince Edward Island	Coarsely bushy, to 30 cm	Common in shallow bays and sounds south of Cape Cod
Griffithsia globulifera	Red	Two species , one from Cape Cod to tropics, the other to Virginia	Bushy, with branches, fragile, to 20 cm	Subtidal in quiet water, 17-47 m in NC
Grinnellia americana	Red	Northern MA south at least to the Carolinas	Thin, undivided leaf up to 60 cm	Subtidal, appears and disappears abruptly during summer, little more than a month in north, longer in south, 15-50 m in NC
Hypnea musciformis	Red	Cape Cod to tropics	Delicate, mosslike bushy weed, to 45 cm	Subtidal, in warm coves from Cape Hatteras to Cape Cod, at 21 m in NC
Lomentaria spp.	Red	Two species, New England to tropics	Small and delicate, to 75 mm	Subtidal in shallow protected waters, 15-40 m in NC
Membranoptera spp.	Red	Two species, one Arctic to northern MA, one to Long Island Sound	Finely divided lacy thalli, to 20 cm	Usually subtidal, *M. alata* at 24-40 m on Ammen Rock, central Gulf of Maine
Neoagardhiella baileyi	Red	Cape Cod south to tropics, locally north to central Maine	A coarsely bushy red weed, to 30 cm	In warm bays and sounds south of Cape Cod, attaches to shells and stones, found at 29-45 m

Species	Type	Range	Height	Habitat
				in NC
Phycodrys rubens	Red	Arctic to Cape Cod, less common to NY Harbor	Leafy, deeply-lobed, to 15 cm	Subtidal in deep water southward, present 24-50 m in southwest Gulf of Maine and on Ammen Rock, central Gulf of Maine
Phyllophora spp.	Red	Delaware to subarctic, two common species	10-15 cm	Chiefly subtidal, *P. truncata* at 24-40 m in southwest Gulf of Maine and on Ammen Rock, central Gulf of Maine
Polysiphonia spp.	Red	Two species, one from New England to North Carolina, the other New England to the Caribbean	Bushy with fine filaments, up to 40 cm	Present 15-48 m in NC
Ptiloda serrata	Red	Arctic to Cape Cod, rarely and in deep water south to Long Island Sound	Bushy, main branches flat and fernlike, to 15 cm	Subtidal, on rocky substrates 24-50 m in SW Gulf of Maine and Ammen Rock
Rhodymenia palmata	Red	Long Island Sound to Arctic	Broad bladed with small stalk, to 30 cm	Lower mid-littoral to deep water
Spyridia filamentosa	Red	Cape Cod to tropics	Bushy with fine filaments, to 30 cm	20-32 m in NC, chiefly in summer

2.2.9 Mollusks, epifaunal bivalve

While many bivalve mollusks live in the sediment or bore into hard substrates, some are epifaunal, including the scallops, oysters, and mussels. In our region, three epifaunal species are commonly found offshore in deeper water, the blue mussel, *Mytilus edulis,* the horse mussel, *Modiolus modiolus*, and the Atlantic sea scallop, *Placopecten magellanicus*. Mussels and scallops are considered as two separate habitat features because of differences in attachment and factors contributing to recovery rates.

Sea scallops provide direct shelter for juvenile red hake, which can be found between the shell valves amidst the scallop's tissues. They also provide a settlement substrate for other epifauna including hydroids, bryozoans, and sponges. Mussels also provide a settlement substrate for other epifauna. All three species are solitary, but have a contagious distribution. This is particularly true of the mussels. Blue mussels occur as far south as South Carolina and are common in shallow, nearshore waters. They attach by means of byssal threads to any type of firm substrate and often form shoals or "beds," even on muddy tidal flats. They also occur on the continental shelf to depths of several hundred feet (Gosner 1978). The horse mussel is a boreal species that is reported to occur as far south as Cape Hatteras (Coen and Grizzle 2007), but may be scarce south of Cape Cod (Gosner 1978). It mainly inhabits deeper waters (to 70 meters) and most commonly occur partially buried in soft sediments, or attached by byssal threads to hard substrates where it forms clumps or extensive beds that vary in size, density, thickness, and form (ASMFC 2007). In prime habitats, blue mussels can reach full growth within a year; elsewhere 2-5 years are needed (Gosner 1978). *M. modiolus* is a long-lived species, with some individuals living for 25 years or more (ASMFC 2007). *P. magellanicus* may reach 20 years of age.

Mussels are inferred to all substrate and energy environments, while scallops are only inferred to high and low energy sand, granule-pebble, and boulder substrates.

Table 11 –Structure-forming epifaunal bivalves of the Northeast Region

Species	*Range*	*Size*	*Form*	*Habitats*
Modiolus modiolus	Circumpolar, south in NW Atlantic to New York	Largest may be >22 cm	Solitary, gregarious; attached to substrate	Muddy sand, sand, any hard substrates; adapted to live semi-infaunally; subtidal, to 70 m (280 m in Europe)
Mytilus edulis	Arctic to South Carolina	To 10 cm	Solitary, gregarious; attached to substrate	Cling to any firm substrate, form beds, even on mud; in estuaries and offshore to several hundred feet deep
Placopecten magellanicus	Labrador to Cape Hatteras	To 20 cm wide, < 2 in deep	Solitary, gregarious; adults unattached to substrate, lie "flat" on bottom, often in depressions	Generally found on firm sand, gravel, shells and cobble substrate to 180 m (deeper waters south)

2.2.10 Polychaetes – tube-dwelling

Two different tube-dwelling polychaete features are included in the assessment. *Filograna implexa* is considered as its own feature in the vulnerability assessment because of its unique clump-forming morphology. It is commonly called the lacy tube worm because it lives colonially in calicified tubes. Although many other polychaetes form calcified tubes, *F. implexa* is unusual in that it forms large clumps. These occur when individual worms divide asexually, and one worm bores out of the tube and forms a new tube adjacent to the first. *F. implexa* is found on all types of hard substrates, including shell and sand, and encrusting other organisms as well (Richards 2008). It is distributed from Newfoundland to Cape Cod at depths of 33-55 m (ten Hove et al. 2009).

A few other non-colonial tube-dwelling polychaetes also form bottom structure that could provide shelter for managed species of fish. They are known commonly as feather-duster or fanworms and are considered a separate feature from *F. implexa* in the vulnerability assessment because of differences in their morphology and life histories (see Table 12). Many common tube-dwelling polychaetes (e.g., the fanworm *Myxicola infundibulum, Sabella* spp. and *Spirorbis* spp.) either occupy tubes that do not extend above the sediment surface at all, or are found encrusting rocks and shells and, therefore, do not create shelter for juvenile fish. Two of the structure-forming species listed below (*P. reinformis* and *P. tubularia*) are found on granule-pebble pavement on the northern edge of Georges Bank, and are more abundant in deeper (90 m versus 40 meters) sites undisturbed by scallop dredging and trawling (Collie et al. 1997, 2000). Another species, *Thelepus cincinnatus*, reported to be one of three top-ranking species for biomass on Western Bank (Scotian shelf), builds tubes that can exceed 10 cm in diameter out of shell debris, granules, and bryozoans and are attached to rocks and cobbles (Kenchington et al. 2006).

Both polychaete features, *Filograna implexa* and other tube-dwelling species, were inferred to high and low energy granule-pebble, cobble, and boulder substrates.

Table 12 – Tube-dwelling polychaetes of the Northeast Region

Species	***Range***	***Size***	***Form***	***Substrate***
Filograna implexa	Newfoundland to Cape Cod	Calcified tubes several inches long	Colonial, tubes in tangled masses, twisted together	All types of hard substrates, including shell and sand
Potamilla reinformis	Eastern coast of North America from Maine to North Carolina	In leathery tubes approx 4 inches long	Solitary, attached to substrate	Rocks and shells, common fouling animals on pilings, buoys, etc.
Potamilla neglecta	Penobscot Bay south to at least Chesapeake Bay	Same as P. reinformis ?	Solitary, attached to substrate	Rocks and shells, common fouling animals on pilings, buoys, etc.
Protula tubularia	In UK, on lower shore and sublittoral zones to depths of 100 m Northwest Atlantic?	Forms a white, calcareous tube	Solitary, attached to substrate	Hard substrates such as stones and rocks
Thelepus cincinnatus	Arctic Ocean, warmer and colder parts of the Atlantic	Tough tubes made out of shell debris, granules, etc	Solitary, attached to substrate	Rocks and cobbles

2.2.11 Sponges

Sponges (phylum Porifera) are sessile animals that come in a variety of forms, colors, and sizes. Forms vary from encrusting to ball-shaped, vase-shaped, and fan-shaped. Some forms branch or even anastomose[3], others are stalked. Some sponges have calcareous skeletons (composed of spicules), but most have siliceous skeletons. The siliceous spicules of some sponges in the group Hexactinellida (glass sponges) have fused spicules providing a rigid structure. Sponges range in size from minute to in excess of one meter. They can be found on both hard and soft substrates, but hard substrates appear to be favored by a majority of species. Sponges suspension feed by pulling water through pores on their surface, and are thus very sensitive to suspended sediment.

It is thought that all sponges are likely capable of regeneration from fragments. Sexual reproduction often involves sequential hermaphroditism, although other strategies are used as well. Fertilization is typically external, although internal fertilization occurs in some species, and the larval period is short. Sponges are typically long-lived. Growth rates vary widely from fast for the annual sponges (larvae to adult in months), to much slower for the perennial sponges. There are numerous examples of symbioses between sponges and other species.

There are numerous species of sponges in the Northeast region. For the purposes of this assessment, the species of primary importance are those that are large enough that they could provide shelter for managed species of fish, especially juveniles that seek refuge from predators. Information on the geographic range (or locations where present), size, morphological form, and habitats (depth and substrates) is compiled for 12 potential structure-forming species that are found in the region (Table 13). Encrusting species or species that do not extend very far above the seafloor are not included. Information sources included Gosner (1978), the Marine Life Information Network, the Stellwagen Bank National Marine Sanctuary [on-line], the European Marine Life Network, the Marine Life Encyclopedia website, Georgia Southern University [on-line], the Chesapeake Bay Program website, Fuller et al. (1998), Stokesbury and Harris (2006), Steimle and Zetlin (2000), and Witman and Sebens (1988).

Examples of species found on Georges Bank include *Suberites ficus* (Johnston, 1842) (fig sponge), *Haliclona oculata* (Pallas, 1759) (finger sponge), *Halichondria panicea* (Pallas, 1766) (breadcrumb sponge), *Isodictya palmata* (Lamarck, 1814) (palmate sponge), *Microciona prolifera* (Ellis & Solander, 1786) (red beard sponge), and *Polymastia robusta* (Bowerbank, 1860) (encrusting sponge) (Almeida et al. 2000; Stokesbury and Harris 2006).

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[3] Anastomose – when branches reconnect to form a web or network

The larger species that inhabit deeper water are probably the most susceptible to the adverse effects of fishing. These include the large form of the boring sponge *Cliona celata*, the "bread-crumb" sponge *Halichondria panicea*, the finger sponge *Haliclona oculata*, the palmate sponge *Isodictya palmata*, *Mycale lingua,* and the fig sponge *Suberites ficus*. All of these species attach to some form of hard substrate or shell. *Suberites ficus* is very common on sandy bottom habitats on Georges Bank where it attaches to small shell fragments and provides cover for fish and crustaceans (Lindholm et al. 2004). As it grows, the substrate on which it originally attached can no longer be seen and the sponge often is rolled along the bottom by currents and wave action. The other species are more common in hard bottom habitats. Based on the available information, only two of the species – *Cliona celata* and *Haliclona oculata* – listed in Table 13 are known to occur south of southern New England (also see Van Dolah et al. 1987). This may reflect the fact that natural rocky bottom habitats are rare south of New York Harbor (Steimle and Zetlin 2000). Other structure-forming species of sponge are undoubtedly present in the Mid-Atlantic region, but are either found on the continental slope (e.g., in canyons) or on the shelf attached to gravel, scallop shells, and shell fragments in predominantly sandy habitats.

Sponges are inferred to all substrate and energy environments except high and low energy mud.

Table 13 –Structure-forming sponges of the Northeast Region

Species	***Range***	***Height***	***Form***	***Habitats***
Cliona celata	Gulf of Mexico to Long Island Sound, locally to Gulf of St. Lawrence	Up to 1 m, 60 cm diameter	Two growth forms, boring into shells and large "barrel" shape, firm with tough outer layer, embeds rocks and sediments into tissue	On rock to 200 m; begins life by boring into limestone, shells, or calcareous red algae
Halichondria panicea	Arctic south to Cape Cod, rarely beyond	Up to 30 cm	Encrusting, globular, or branched	Cobbles, boulders, bedrock, shells, algae down to 60 m (570 m in Europe), esp abundant in strong tidal flows
Halichondria parma	Range unknown, found in SW Gulf of Maine	Up to several ft in diameter	Encrusting, in many shapes with cone-shaped bulges	On rocks, pilings
Haliclona oculata	Labrador to Long Island, rarely to North Carolina, but	Up to 45 cm	Short stalk with flat to rounded finger-like branches, very flexible, not fragile	Sandy, rocky substrates, often attached to stones, to 150 m

Species	***Range***	***Height***	***Form***	***Habitats***
	present in Georgia			
Haliclona ureolus	Range unknown, found in Bay of Fundy	To 15 cm, stalk typically <half body length	Tubular, even bell shaped, with thin, hard, flexible stalk	On rock, shell fragments, etc.
Isodctya deichmannae	Newfoundland to Rhode Island			
Isodictya palmata	Nova Scotia to Gulf of Maine, Georges Bank	Up to 35 cm	Large, palmate with finger-like branches	Deep water on rocks, 52-70 m in sand and gravel on Georges Bank
Microciona prolifera	Nova Scotia to Florida and Texas	Up to 20 cm	At first encrusting, then forms small clumps with fingerlike branches	Shells, pilings, hard surfaces, in shallow to moderate depths (52-70 m on Georges Bank)
Mycale lingua	Range unknown, found in the Gulf of Maine	Up to 30 cm high with variable width and depth	In mounds, sometimes in erect, flattened form with base narrower than apex	Between 30-2460 m on rocky bottom
Myxilla fimbriata	Range unknown, found in GOM		mounds	
Polymastia robusta	Range unknown, found on Georges Bank, in the Gulf of Maine and southern New England	Volume of 40 cm^3	Globular with thick base, body is soft	Most common on upward facing rock or boulder tops, as deep as 2300 m (in Europe)
Suberites ficus	Arctic south to Rhode Island, possibly to Virginia	10-40 cm diameter	Variable, lobed or globular cushion, rolls over bottom if it outgrows its substrate	Attaches to rocks and to small stones, empty shells, in sandy or muddy bottom, from 15 to 200 m

3.0 Fishing gears evaluted

Many types of fishing gears are used throughout the region. To make the scope of this analysis more manageable, only seabed impacts from bottom-tending gears that account for significant landings, revenue, and/or days at sea are evaluated.

Key fishing gears are identified out of 45 gear types associated with landings of federal or state-managed species as reported in National Marine Fisheries Service Vessel Trip Reports (VTR) from 1996-2008. By gear type and year, landed pounds, percent of total landed pounds, revenue, percent of total revenue, days absent, and percent of total days absent are summarized (Table 14, Table 15, Table 16, Table 18, Table 19, Table 20). Eight gear types individually accounted for roughly 1% or greater of landings, revenues and/or days absent: ocean quahog/surf clam dredge, sea scallop dredge, sink gillnet, bottom longline, bottom otter trawl (combining fish, scallop, and shrimp), midwater otter trawl, lobster pot, and purse seine. Of these, midwater otter trawls and purse seines are not evaluated in the Vulnerability Assessment due to low or no bottom contact.

Table 21 relates the gear types evaluated in the Vulnerability Assessment to gear type names from the VTR database. In some cases, two separate VTR gear types are combined to create one Vulnerability Assessment category, while in other cases VTR gear types are disaggregated due to trip characteristics.

Table 14 – Landed pounds by gear type (1,000 lbs, source: NMFS vessel trip reports)

GEARNM	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CARRIER VESSEL	0	0	0	0	0	0	0	0	0	0	0	0	69
CASTNET	0	0	0	0	5	1	0	15	142	479	60	93	3
DIVING GEAR	443	259	245	181	132	132	82	34	23	12	1	3	1
DREDGE, SCALLOP-CHAIN MAT	0	0	0	0	0	0	0	0	0	37	151	3,981	3,529
DREDGE, URCHIN	152	192	206	246	185	151	103	71	72	191	117	25	145
DREDGE,MUSSEL	383	352	17	27	1	0	0	0	0	60	236	570	6
DREDGE,OCEAN QUAHOG/SURF CLAM	6,377	619	4,704	686	1,845	1,580	1,183	538	1,066	1,079	979	862	533
DREDGE,OTHER	373	438	341	486	468	593	350	370	395	321	148	263	243
DREDGE,SCALLOP,SEA	19,180	18,303	16,985	25,245	31,935	45,529	50,169	54,404	62,008	54,664	53,257	55,352	43,766
FYKE NET	0	0	0	0	0	0	0	0	36	1	2	1	0
GILL NET,DRIFT,LARGE MESH	86	84	83	66	125	21	25	380	593	904	888	1,290	922
GILL NET,DRIFT,SMALL MESH	409	535	1,018	874	1,352	1,396	1,228	464	604	354	175	357	148
GILL NET,RUNAROUND	161	79	565	448	635	508	538	855	642	685	666	362	354
GILL NET,SINK	50,253	47,034	50,396	44,430	39,060	37,950	37,109	41,421	37,067	32,726	25,083	99,100	38,104
HAND LINE/ROD & REEL	2,353	2,071	2,645	2,337	2,561	3,622	2,935	2,177	1,939	1,402	953	1,441	893
HAND RAKE	0	0	0	0	20	4	0	184	55	115	146	150	70
HARPOON	119	71	93	102	250	107	50	53	15	8	7	6	8
HAUL SEINE	0	0	0	0	0	0	10	7	2	0	0	2	0
LONGLINE, PELAGIC	430	537	395	130	210	209	241	191	339	87	23	135	100
LONGLINE,BOTTOM	9,245	10,081	9,481	9,626	7,197	6,522	4,267	3,366	4,782	4,326	2,648	3,174	2,768
MIXED GEAR	624	487	608	81	55	0	0	0	0	0	0	0	0
OTHER GEAR	8,296	7,205	1,914	230	956	33	5	1	1	1	0	14	0
OTTER TRAWL, BEAM	1	0	2	7	40	144	523	529	1,182	776	269	640	477
OTTER TRAWL,BOTTOM,FISH	235,333	229,592	250,298	220,968	215,631	225,020	200,721	198,906	247,918	196,598	161,113	166,036	164,161
OTTER TRAWL,BOTTOM,OTHER	323	790	828	438	634	27	0	0	0	0	0	0	32
OTTER TRAWL,BOTTOM,SCALLOP	1,395	935	2,063	2,060	2,395	3,547	3,660	3,367	3,072	1,854	956	1,345	1,039
OTTER TRAWL,BOTTOM,SHRIMP	18,159	15,212	9,162	6,140	9,104	4,447	3,261	3,142	5,080	4,347	4,300	9,820	10,576
OTTER TRAWL,MIDWATER	122,712	107,547	107,606	92,927	93,445	101,565	74,885	67,292	56,550	58,375	56,250	32,207	13,145
PAIR TRAWL,BOTTOM	43	81	127	374	45	49	113	0	9	711	18	0	240
PAIR TRAWL,MIDWATER	1,942	18,231	37,783	45,639	83,675	139,422	136,552	193,334	217,663	199,218	188,610	118,141	145,731
POT, CONCH/WHELK	464	504	841	1,191	1,817	1,850	1,834	2,210	1,503	1,400	952	3,543	1,632
POT, EEL	0	0	0	0	0	0	0	0	0	0	0	2	0
POT, HAG	3,447	3,401	2,493	3,759	3,767	3,251	2,416	1,950	3,396	1,479	796	2,541	4,961
POT,CRAB	1,052	1,052	869	698	1,546	3,963	3,517	3,567	4,251	3,953	2,525	3,062	2,317
POT,FISH	1,283	1,643	1,709	2,081	1,668	862	1,239	2,404	1,195	1,442	1,264	1,380	836
POT,LOBSTER	20,362	22,221	21,493	24,847	26,015	24,589	23,321	21,087	21,559	20,577	14,757	20,005	21,197
POT,OTHER	242	101	321	503	158	10	4	2	3	3	0	169	259
POT,SHRIMP	72	18	12	26	574	266	111	286	84	202	129	202	273
POTS, MIXED	105	92	88	75	5	0	0	0	0	0	0	0	0
PURSE SEINE	81,689	110,605	58,520	83,012	83,307	78,248	66,817	55,910	47,509	50,838	51,868	101,744	111,240
SEINE, STOP	0	0	0	0	0	0	3	23	11	5	5	4	0
SEINE,DANISH	6,121	10,444	10,217	7,896	1,950	1,631	4,985	2,294	3,034	8	1,876	755	234
SEINE,SCOTTISH	269	268	221	135	235	278	125	170	104	11	0	0	0
TRAP	2,189	1,684	835	907	492	633	1,273	858	598	334	455	821	203
WEIR	0	0	50	326	262	278	570	271	330	0	0	19	0
total	*596,087*	*612,768*	*595,234*	*579,204*	*613,757*	*688,438*	*624,225*	*662,133*	*724,832*	*639,583*	*571,683*	*629,617*	*570,215*

Table 15 – Percent of total landed pounds by gear type (source: NMFS vessel trip reports)

GEARNM	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CARRIER VESSEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CASTNET	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
DIVING GEAR	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE, SCALLOP-CHAIN MAT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.6%
DREDGE, URCHIN	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE,MUSSEL	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
DREDGE,OCEAN QUAHOG/SURF CLAM	1.1%	0.1%	0.8%	0.1%	0.3%	0.2%	0.2%	0.1%	0.1%	0.2%	0.2%	0.1%	0.1%
DREDGE,OTHER	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
DREDGE,SCALLOP,SEA	3.2%	3.0%	2.9%	4.4%	5.2%	6.6%	8.0%	8.2%	8.6%	8.5%	9.3%	8.8%	7.7%
FYKE NET	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
GILL NET,DRIFT,LARGE MESH	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%
GILL NET,DRIFT,SMALL MESH	0.1%	0.1%	0.2%	0.2%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.0%	0.1%	0.0%
GILL NET,RUNAROUND	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
GILL NET,SINK	8.4%	7.7%	8.5%	7.7%	6.4%	5.5%	5.9%	6.3%	5.1%	5.1%	4.4%	15.7%	6.7%
HAND LINE/ROD & REEL	0.4%	0.3%	0.4%	0.4%	0.4%	0.5%	0.5%	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%
HAND RAKE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HARPOON	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HAUL SEINE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LONGLINE, PELAGIC	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LONGLINE,BOTTOM	1.6%	1.6%	1.6%	1.7%	1.2%	0.9%	0.7%	0.5%	0.7%	0.7%	0.5%	0.5%	0.5%
MIXED GEAR	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTHER GEAR	1.4%	1.2%	0.3%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTTER TRAWL, BEAM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.1%	0.0%	0.1%	0.1%
OTTER TRAWL,BOTTOM,FISH	39.5%	37.5%	42.1%	38.2%	35.1%	32.7%	32.2%	30.0%	34.2%	30.7%	28.2%	26.4%	28.8%
OTTER TRAWL,BOTTOM,OTHER	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTTER TRAWL,BOTTOM,SCALLOP	0.2%	0.2%	0.3%	0.4%	0.4%	0.5%	0.6%	0.5%	0.4%	0.3%	0.2%	0.2%	0.2%
OTTER TRAWL,BOTTOM,SHRIMP	3.0%	2.5%	1.5%	1.1%	1.5%	0.6%	0.5%	0.5%	0.7%	0.7%	0.8%	1.6%	1.9%
OTTER TRAWL,MIDWATER	20.6%	17.6%	18.1%	16.0%	15.2%	14.8%	12.0%	10.2%	7.8%	9.1%	9.8%	5.1%	2.3%
PAIR TRAWL,BOTTOM	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
PAIR TRAWL,MIDWATER	0.3%	3.0%	6.3%	7.9%	13.6%	20.3%	21.9%	29.2%	30.0%	31.1%	33.0%	18.8%	25.6%
POT, CONCH/WHELK	0.1%	0.1%	0.1%	0.2%	0.3%	0.3%	0.3%	0.3%	0.2%	0.2%	0.2%	0.6%	0.3%
POT, EEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POT, HAG	0.6%	0.6%	0.4%	0.6%	0.6%	0.5%	0.4%	0.3%	0.5%	0.2%	0.1%	0.4%	0.9%
POT,CRAB	0.2%	0.2%	0.1%	0.1%	0.3%	0.6%	0.6%	0.5%	0.6%	0.6%	0.4%	0.5%	0.4%
POT,FISH	0.2%	0.3%	0.3%	0.4%	0.3%	0.1%	0.2%	0.4%	0.2%	0.2%	0.2%	0.2%	0.1%
POT,LOBSTER	3.4%	3.6%	3.6%	4.3%	4.2%	3.6%	3.7%	3.2%	3.0%	3.2%	2.6%	3.2%	3.7%
POT,OTHER	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POT,SHRIMP	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POTS, MIXED	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PURSE SEINE	13.7%	18.1%	9.8%	14.3%	13.6%	11.4%	10.7%	8.4%	6.6%	7.9%	9.1%	16.2%	19.5%
SEINE, STOP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SEINE,DANISH	1.0%	1.7%	1.7%	1.4%	0.3%	0.2%	0.8%	0.3%	0.4%	0.0%	0.3%	0.1%	0.0%
SEINE,SCOTTISH	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TRAP	0.4%	0.3%	0.1%	0.2%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%
WEIR	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 16 **– Revenue by gear type (1,000 dollars, all values converted to 2007 dollars; source: NMFS vessel trip reports)**

GEARNM	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CARRIER VESSEL	0	0	0	0	0	0	0	0	0	0	0	0	10
CASTNET	0	0	0	0	3	1	0	7	56	281	123	61	1
DIVING GEAR	371	356	177	175	147	94	81	78	81	58	12	8	5
DREDGE, SCALLOP-CHAIN MAT	0	0	0	0	0	0	0	0	0	343	1,411	25,507	22,934
DREDGE, URCHIN	112	128	127	208	153	114	67	52	57	105	109	22	104
DREDGE,MUSSEL	201	292	11	18	1	0	0	0	0	53	180	408	3
DREDGE,OCEAN QUAHOG/SURF CLAM	8,075	565	4,002	684	1,450	1,565	880	667	1,549	4,560	5,199	3,933	1,564
DREDGE,OTHER	1,240	1,546	1,307	2,736	1,731	880	401	770	867	931	107	841	1,142
DREDGE,SCALLOP,SEA	131,362	119,704	94,851	145,839	183,848	210,929	241,939	271,784	354,412	441,855	375,956	357,267	294,304
FYKE NET	0	0	0	0	0	0	0	0	33	2	1	1	0
GILL NET,DRIFT,LARGE MESH	71	165	96	97	113	8	12	294	89	627	419	863	325
GILL NET,DRIFT,SMALL MESH	349	397	870	807	1,144	1,048	872	295	548	239	124	267	64
GILL NET,RUNAROUND	83	48	364	246	368	292	326	508	430	576	230	318	284
GILL NET,SINK	39,512	36,256	41,337	47,440	51,961	48,154	45,766	47,559	41,851	43,885	37,653	40,061	36,401
HAND LINE/ROD & REEL	8,325	5,110	5,580	5,925	6,860	8,996	7,331	4,153	2,885	1,752	1,721	2,088	1,059
HAND RAKE	0	0	0	0	12	2	0	160	26	210	66	400	55
HARPOON	945	509	568	646	1,945	735	315	311	61	31	41	11	28
HAUL SEINE	0	0	0	0	0	0	3	4	1	0	0	1	0
LONGLINE, PELAGIC	1,213	1,377	819	412	809	592	469	342	807	99	106	199	172
LONGLINE,BOTTOM	8,172	8,228	8,932	8,356	5,446	5,327	4,166	3,296	5,092	5,483	3,916	4,092	2,660
MIXED GEAR	408	501	339	122	50	0	0	0	0	0	0	0	0
OTHER GEAR	6,859	5,419	2,783	534	1,426	107	6	0	1	0	3	9	0
OTTER TRAWL, BEAM	16	0	4	16	50	153	529	743	1,278	1,108	413	449	616
OTTER TRAWL,BOTTOM,FISH	226,763	204,184	219,144	207,375	207,206	218,814	201,782	197,663	208,425	195,431	164,913	161,524	137,823
OTTER TRAWL,BOTTOM,OTHER	388	835	1,409	556	1,171	34	0	0	0	0	0	0	14
OTTER TRAWL,BOTTOM,SCALLOP	10,700	6,458	8,727	12,013	13,055	15,155	14,690	13,319	13,276	10,163	6,160	5,787	4,176
OTTER TRAWL,BOTTOM,SHRIMP	19,461	20,154	12,458	12,308	17,184	8,906	7,607	5,117	3,922	3,295	3,804	10,393	10,206
OTTER TRAWL,MIDWATER	14,874	13,815	13,853	9,682	10,877	9,085	7,667	7,802	6,541	7,142	9,572	4,299	1,722
PAIR TRAWL,BOTTOM	220	371	162	482	178	182	228	0	22	109	15	3	510
PAIR TRAWL,MIDWATER	146	1,343	3,837	3,581	6,436	10,716	12,850	19,184	23,303	22,325	27,302	12,650	16,625
POT, CONCH/WHELK	179	218	425	791	1,005	1,111	1,261	1,022	724	1,087	825	1,597	649
POT, EEL	0	0	0	0	0	0	0	0	0	0	2	2	0
POT, HAG	1,492	1,716	1,404	2,300	1,898	2,127	1,459	1,134	894	1,062	613	1,807	2,103
POT,CRAB	716	786	603	681	1,138	2,647	1,697	2,083	2,198	2,613	1,458	2,679	916
POT,FISH	2,078	3,100	3,116	3,539	2,823	1,724	2,337	3,335	2,741	3,415	3,812	3,355	2,041
POT,LOBSTER	85,360	84,729	75,724	98,900	94,390	85,325	83,106	77,726	76,865	82,172	74,433	67,879	51,629
POT,OTHER	178	147	257	285	163	38	16	3	5	16	0	261	175
POT,SHRIMP	49	19	15	34	572	311	147	247	60	158	67	78	132
POTS, MIXED	193	231	139	128	12	0	0	0	0	0	0	0	0
PURSE SEINE	10,895	13,188	9,672	12,660	13,717	17,850	14,744	12,172	5,925	14,564	9,310	30,185	18,841
SEINE, STOP	0	0	0	0	0	0	1	10	9	4	4	4	0
SEINE,DANISH	2,219	5,137	4,763	4,228	1,110	1,211	2,670	978	1,364	5	630	437	51
SEINE,SCOTTISH	369	354	334	187	230	265	163	174	110	17	0	0	0
TRAP	1,629	1,001	473	840	582	628	1,021	714	410	519	636	604	181
WEIR	0	0	15	112	135	206	326	202	181	0	0	14	0
total	*585,223*	*538,387*	*518,697*	*584,943*	*631,399*	*655,332*	*656,935*	*673,908*	*757,099*	*846,295*	*731,346*	*740,364*	*609,525*

Table 17 – Percent of total revenues by gear type (source: NMFS vessel trip reports)

GEARNM	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CARRIER VESSEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CASTNET	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DIVING GEAR	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE, SCALLOP-CHAIN MAT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	3.4%	3.8%
DREDGE, URCHIN	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE,MUSSEL	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
DREDGE,OCEAN QUAHOG/SURF CLAM	1.4%	0.1%	0.8%	0.1%	0.2%	0.2%	0.1%	0.1%	0.2%	0.5%	0.7%	0.5%	0.3%
DREDGE,OTHER	0.2%	0.3%	0.3%	0.5%	0.3%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%	0.2%
DREDGE,SCALLOP,SEA	22.4%	22.2%	18.3%	24.9%	29.1%	32.2%	36.8%	40.3%	46.8%	52.2%	51.4%	48.3%	48.3%
FYKE NET	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
GILL NET,DRIFT,LARGE MESH	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%
GILL NET,DRIFT,SMALL MESH	0.1%	0.1%	0.2%	0.1%	0.2%	0.2%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
GILL NET,RUNAROUND	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
GILL NET,SINK	6.8%	6.7%	8.0%	8.1%	8.2%	7.3%	7.0%	7.1%	5.5%	5.2%	5.1%	5.4%	6.0%
HAND LINE/ROD & REEL	1.4%	0.9%	1.1%	1.0%	1.1%	1.4%	1.1%	0.6%	0.4%	0.2%	0.2%	0.3%	0.2%
HAND RAKE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
HARPOON	0.2%	0.1%	0.1%	0.1%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HAUL SEINE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LONGLINE, PELAGIC	0.2%	0.3%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
LONGLINE,BOTTOM	1.4%	1.5%	1.7%	1.4%	0.9%	0.8%	0.6%	0.5%	0.7%	0.6%	0.5%	0.6%	0.4%
MIXED GEAR	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTHER GEAR	1.2%	1.0%	0.5%	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTTER TRAWL, BEAM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.1%
OTTER TRAWL,BOTTOM,FISH	38.7%	37.9%	42.2%	35.5%	32.8%	33.4%	30.7%	29.3%	27.5%	23.1%	22.5%	21.8%	22.6%
OTTER TRAWL,BOTTOM,OTHER	0.1%	0.2%	0.3%	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTTER TRAWL,BOTTOM,SCALLOP	1.8%	1.2%	1.7%	2.1%	2.1%	2.3%	2.2%	2.0%	1.8%	1.2%	0.8%	0.8%	0.7%
OTTER TRAWL,BOTTOM,SHRIMP	3.3%	3.7%	2.4%	2.1%	2.7%	1.4%	1.2%	0.8%	0.5%	0.4%	0.5%	1.4%	1.7%
OTTER TRAWL,MIDWATER	2.5%	2.6%	2.7%	1.7%	1.7%	1.4%	1.2%	1.2%	0.9%	0.8%	1.3%	0.6%	0.3%
PAIR TRAWL,BOTTOM	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
PAIR TRAWL,MIDWATER	0.0%	0.2%	0.7%	0.6%	1.0%	1.6%	2.0%	2.8%	3.1%	2.6%	3.7%	1.7%	2.7%
POT, CONCH/WHELK	0.0%	0.0%	0.1%	0.1%	0.2%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.2%	0.1%
POT, EEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POT, HAG	0.3%	0.3%	0.3%	0.4%	0.3%	0.3%	0.2%	0.2%	0.1%	0.1%	0.1%	0.2%	0.3%
POT,CRAB	0.1%	0.1%	0.1%	0.1%	0.2%	0.4%	0.3%	0.3%	0.3%	0.3%	0.2%	0.4%	0.2%
POT,FISH	0.4%	0.6%	0.6%	0.6%	0.4%	0.3%	0.4%	0.5%	0.4%	0.4%	0.5%	0.5%	0.3%
POT,LOBSTER	14.6%	15.7%	14.6%	16.9%	14.9%	13.0%	12.7%	11.5%	10.2%	9.7%	10.2%	9.2%	8.5%
POT,OTHER	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POT,SHRIMP	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POTS, MIXED	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PURSE SEINE	1.9%	2.4%	1.9%	2.2%	2.2%	2.7%	2.2%	1.8%	0.8%	1.7%	1.3%	4.1%	3.1%
SEINE, STOP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SEINE,DANISH	0.4%	1.0%	0.9%	0.7%	0.2%	0.2%	0.4%	0.1%	0.2%	0.0%	0.1%	0.1%	0.0%
SEINE,SCOTTISH	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TRAP	0.3%	0.2%	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%
WEIR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 18 – Days absent by gear type (source: NMFS vessel trip reports)

GEARNM	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CARRIER VESSEL	0	0	0	0	0	0	0	0	0	0	0	0	1
CASTNET	0	0	0	0	21	3	0	11	13	135	28	53	6
DIVING GEAR	219	131	136	116	80	112	79	58	64	28	10	15	14
DREDGE, SCALLOP-CHAIN MAT	0	0	0	0	0	0	0	0	0	34	119	4,320	3,894
DREDGE, URCHIN	107	115	135	157	131	91	54	47	32	17	14	13	24
DREDGE,MUSSEL	58	54	34	39	2	1	0	0	0	2	10	32	1
DREDGE,OCEAN QUAHOG/SURF CLAM	702	396	373	507	468	894	746	336	496	1,979	2,176	2,553	1,865
DREDGE,OTHER	1,624	1,363	2,002	1,973	872	331	190	253	208	216	186	257	220
DREDGE,SCALLOP,SEA	109,552	92,014	117,521	97,355	82,237	75,244	76,528	74,358	70,777	68,084	65,721	78,181	55,904
FYKE NET	0	0	0	0	0	0	1	0	28	4	8	6	0
GILL NET,DRIFT,LARGE MESH	403	103	434	49	82	10	13	379	658	591	546	809	407
GILL NET,DRIFT,SMALL MESH	360	513	985	1,401	1,276	1,057	666	306	462	206	94	224	103
GILL NET,RUNAROUND	179	70	434	489	685	476	648	800	683	506	429	443	486
GILL NET,SINK	61,044	48,126	53,873	57,506	65,451	69,240	55,734	54,454	50,288	45,468	33,627	41,899	41,166
HAND LINE/ROD & REEL	6,282	6,533	8,559	7,654	7,016	9,065	8,752	7,542	6,609	5,251	4,023	6,243	3,570
HAND RAKE	0	0	0	0	40	35	14	46	25	36	50	43	17
HARPOON	78	88	115	159	225	243	143	93	19	7	7	16	12
HAUL SEINE	0	0	0	0	0	0	12	4	5	0	0	5	0
LONGLINE, PELAGIC	3,564	2,450	2,061	730	1,675	1,657	1,785	1,271	1,964	704	127	831	914
LONGLINE,BOTTOM	13,108	12,749	16,061	10,894	7,575	6,713	6,832	5,411	5,986	5,881	3,993	5,373	4,355
MIXED GEAR	1,834	398	509	253	104	0	0	0	0	0	0	0	0
OTHER GEAR	9,698	6,955	5,267	580	1,611	144	24	1	3	2	1	13	0
OTTER TRAWL, BEAM	9	3	162	48	134	347	912	2,121	2,805	1,576	485	522	852
OTTER TRAWL,BOTTOM,FISH	437,190	376,357	400,592	399,583	367,867	394,397	355,604	329,149	314,677	315,865	233,359	266,620	239,546
OTTER TRAWL,BOTTOM,OTHER	1,002	1,838	2,448	381	852	112	0	0	0	0	0	0	16
OTTER TRAWL,BOTTOM,SCALLOP	3,654	4,119	5,802	5,211	3,991	4,327	4,234	3,976	4,395	5,052	3,493	3,656	1,723
OTTER TRAWL,BOTTOM,SHRIMP	13,677	18,956	15,949	17,802	16,790	11,428	9,406	5,178	6,717	4,418	4,611	9,756	10,235
OTTER TRAWL,MIDWATER	4,859	4,475	4,005	2,651	3,219	3,527	2,830	1,733	1,761	2,157	1,475	1,132	784
PAIR TRAWL,BOTTOM	140	478	298	474	151	410	570	0	37	12	52	0	1,317
PAIR TRAWL,MIDWATER	39	419	652	1,191	1,842	3,514	3,118	4,184	4,142	4,626	3,488	2,335	3,331
POT, CONCH/WHELK	212	212	300	326	591	653	620	564	519	524	401	665	618
POT, EEL	0	0	0	0	0	0	0	0	0	0	0	2	0
POT, HAG	489	591	420	523	615	579	463	257	257	287	197	495	761
POT,CRAB	212	312	341	402	566	822	507	701	1,084	953	706	844	607
POT,FISH	1,603	1,995	2,644	2,705	1,887	1,587	1,882	2,662	2,502	2,932	2,331	3,030	1,967
POT,LOBSTER	39,561	39,198	41,904	43,058	43,225	42,503	38,609	38,713	38,910	33,631	25,351	35,547	32,904
POT,OTHER	89	156	93	202	58	23	8	3	6	3	0	79	84
POT,SHRIMP	78	41	11	16	246	200	95	108	121	76	75	92	89
POTS, MIXED	256	213	247	174	27	0	0	0	0	0	0	0	0
PURSE SEINE	1,791	2,496	1,599	1,166	1,513	997	1,143	922	968	775	606	1,480	1,768
SEINE, STOP	0	0	0	0	0	0	2	6	7	6	4	3	0
SEINE,DANISH	36	72	63	60	15	17	27	10	28	4	12	13	2
SEINE,SCOTTISH	442	499	470	479	467	378	229	176	207	34	2	0	0
TRAP	741	561	777	492	221	284	667	1,136	966	855	750	1,272	170
WEIR	0	0	5	60	80	102	119	104	76	0	0	29	0
total	714,892	625,049	687,281	656,866	613,908	631,523	573,266	537,073	518,505	502,937	388,567	468,901	409,733

Table 19 – Percent of days absent by gear type (source: NMFS vessel trip reports)

GEARNM	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CARRIER VESSEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CASTNET	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DIVING GEAR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE, SCALLOP-CHAIN MAT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.9%	1.0%
DREDGE, URCHIN	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE,MUSSEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE,OCEAN QUAHOG/SURF CLAM	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.4%	0.6%	0.5%	0.5%
DREDGE,OTHER	0.2%	0.2%	0.3%	0.3%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
DREDGE,SCALLOP,SEA	15.3%	14.7%	17.1%	14.8%	13.4%	11.9%	13.3%	13.8%	13.7%	13.5%	16.9%	16.7%	13.6%
FYKE NET	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
GILL NET,DRIFT,LARGE MESH	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%
GILL NET,DRIFT,SMALL MESH	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
GILL NET,RUNAROUND	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
GILL NET,SINK	8.5%	7.7%	7.8%	8.8%	10.7%	11.0%	9.7%	10.1%	9.7%	9.0%	8.7%	8.9%	10.0%
HAND LINE/ROD & REEL	0.9%	1.0%	1.2%	1.2%	1.1%	1.4%	1.5%	1.4%	1.3%	1.0%	1.0%	1.3%	0.9%
HAND RAKE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HARPOON	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HAUL SEINE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LONGLINE, PELAGIC	0.5%	0.4%	0.3%	0.1%	0.3%	0.3%	0.3%	0.2%	0.4%	0.1%	0.0%	0.2%	0.2%
LONGLINE,BOTTOM	1.8%	2.0%	2.3%	1.7%	1.2%	1.1%	1.2%	1.0%	1.2%	1.2%	1.0%	1.1%	1.1%
MIXED GEAR	0.3%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTHER GEAR	1.4%	1.1%	0.8%	0.1%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTTER TRAWL, BEAM	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.4%	0.5%	0.3%	0.1%	0.1%	0.2%
OTTER TRAWL,BOTTOM,FISH	61.2%	60.2%	58.3%	60.8%	59.9%	62.5%	62.0%	61.3%	60.7%	62.8%	60.1%	56.9%	58.5%
OTTER TRAWL,BOTTOM,OTHER	0.1%	0.3%	0.4%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTTER TRAWL,BOTTOM,SCALLOP	0.5%	0.7%	0.8%	0.8%	0.7%	0.7%	0.7%	0.7%	0.8%	1.0%	0.9%	0.8%	0.4%
OTTER TRAWL,BOTTOM,SHRIMP	1.9%	3.0%	2.3%	2.7%	2.7%	1.8%	1.6%	1.0%	1.3%	0.9%	1.2%	2.1%	2.5%
OTTER TRAWL,MIDWATER	0.7%	0.7%	0.6%	0.4%	0.5%	0.6%	0.5%	0.3%	0.3%	0.4%	0.4%	0.2%	0.2%
PAIR TRAWL,BOTTOM	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
PAIR TRAWL,MIDWATER	0.0%	0.1%	0.1%	0.2%	0.3%	0.6%	0.5%	0.8%	0.8%	0.9%	0.9%	0.5%	0.8%
POT, CONCH/WHELK	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%
POT, EEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POT, HAG	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.1%	0.1%	0.1%	0.2%
POT,CRAB	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	0.2%	0.1%
POT,FISH	0.2%	0.3%	0.4%	0.4%	0.3%	0.3%	0.3%	0.5%	0.5%	0.6%	0.6%	0.6%	0.5%
POT,LOBSTER	5.5%	6.3%	6.1%	6.6%	7.0%	6.7%	6.7%	7.2%	7.5%	6.7%	6.5%	7.6%	8.0%
POT,OTHER	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POT,SHRIMP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POTS, MIXED	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PURSE SEINE	0.3%	0.4%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.4%
SEINE, STOP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SEINE,DANISH	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SEINE,SCOTTISH	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TRAP	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.1%	0.2%	0.2%	0.2%	0.2%	0.3%	0.0%
WEIR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 20 - Fishing gears used in estuaries and bays, coastal waters, and offshore waters of the EEZ, from Maine to North Carolina. The gear is noted as bottom tending, federally regulated, and/or evaluated using SASI.

Gear	***Estuary or Bay***	***Coastal 0-3 Miles***	***Offshore 3-200 Miles***	***Contacts Bottom***	***Federally Regulated***	***SASI evaluated?***
Bag Nets	X	X	X		X	
By Hand	X	X			X	
Cast Nets	X	X	X			
Clam Kicking	X			X		
Diving Outfits	X	X	X			
Dredge Clam	**X**	**X**	**X**	**X**	**X**	**Yes**
Dredge Conch	X			X		
Dredge Crab	X	X		X		
Dredge Mussel	X	X		X		
Dredge Oyster, Common	X			X		
Dredge Scallop, Bay	X			X		
Dredge Scallop, Sea		**X**	**X**	**X**	**X**	**Yes**
Dredge Urchin, Sea		X	X	X		
Floating Traps (Shallow)	X	X		X	X	
Fyke And Hoop Nets, Fish	X	X		X		
Gill Nets, Drift, Other			X		X	
Gill Nets, Drift, Runaround			X		X	
Gill Nets, Sink/Anchor, Other	**X**	**X**	**X**	**X**	**X**	**Yes**
Gill Nets, Stake	X	X	X	X	X	
Haul Seines, Beach	X	X		X		
Haul Seines, Long	X	X		X		
Haul Seines, Long(Danish)		X	X	X	X	
Hoes	X			X		
Lines Hand, Other	X	X	X		X	
Lines Long Set With Hooks		**X**	**X**	**X**	**X**	**Yes**
Lines Long, Reef Fish		X	X	X	X	
Lines Long, Shark		X	X		X	
Lines Troll, Other		X	X		X	
Lines Trot With Baits		X	X		X	
Otter Trawl Bottom, Crab	X	X	X	X		
Otter Trawls, Beam	X	X	X	X	X	
Otter Trawl Bottom, Fish	**X**	**X**	**X**	**X**	**X**	**Yes**
Otter Trawl Bottom, Scallop		**X**	**X**	**X**	**X**	**Yes**
Otter Trawl Bottom, Shrimp	**X**	**X**	**X**	**X**	**X**	**Yes**
Otter Trawl Midwater		X	X		X	
Pots And Traps, Conch	X	X		X		
Pots and Traps, Crab, Blue Peeler	X	X		X		
Pots And Traps, Crab, Blue	X	X		X		
Pots And Traps, Crab, Other	**X**	**X**	**X**	**X**	**X**	**Yes**
Pots And Traps, Eel	X	X		X		
Pots and Traps, Lobster Inshore	X	X		X		

Gear	*Estuary or Bay*	*Coastal 0-3 Miles*	*Offshore 3-200 Miles*	*Contacts Bottom*	*Federally Regulated*	*SASI evaluated?*
Pots and Traps, Lobster Offshore			**X**	**X**	**X**	**Yes**
Pots and Traps, Fish	X	X	X	X	X	
Pound Nets, Crab	X	X		X		
Pound Nets, Fish	X	X		X		
Purse Seines, Herring		X	X		X	
Purse Seines, Menhaden		X	X			
Purse Seines, Tuna		X	X		X	
Rakes	X			X		
Reel, Electric or Hydraulic		X	X		X	
Rod and Reel	X	X	X		X	
Scottish Seine		X	X	X	X	
Scrapes	X			X		
Spears	X	X	X			
Stop Seines	X			X		
Tongs and Grabs, Oyster	X			X		
Tongs Patent, Clam Other	X			X		
Tongs Patent, Oyster	X			X		
Trawl Midwater, Paired		X	X		X	
Weirs	X			X		

Table 21 – Bottom-tending gear types evaluated in the Vulnerability Assessment.

Vulnerability assessment gear type	***Fishing vessel trip report gear type(s)***
Generic otter trawl	Otter trawl, bottom, fish; Otter trawl, scallop; Otter trawl, haddock separator; Otter trawl, other
Squid trawl*	Otter trawl, bottom, fish; Otter trawl, other
Raised-footrope trawl*	Otter trawl, bottom, fish; Otter trawl, other
Shrimp trawl	Otter trawl, bottom, shrimp
New Bedford-style scallop dredge	Dredge, scallop, se; Dredge, scallop-chain mat
Hydraulic clam dredge	Dredge, ocean quahog/surf clam
Lobster and deep-sea red crab trap	Pot, crab; Pot, lobster
Demersal longline	Longline, bottom
Sink gill net	Gill net, sink

*Effort related to squid and raised footrope trawl trips was disaggregated based on composition of landings.

The following Vulnerability Assessment gear types are described in this section: demersal otter trawl (including a generic otter trawl category plus shrimp, squid, and raised footrope trawls), New Bedford-style scallop dredge, hydraulic clam dredge, lobster and deep-sea red crab trap, sink gill net, and demersal longline. Unless otherwise noted, the following descriptions are based on Sainsbury (1996), DeAlteris (1998), Everhart and Youngs (1981), and the report of a panel of science and fishing industry representatives on the effects of fishing gear on marine habitats in the region (NREFHSC 2002), updated in Stevenson et al. (2004). Additional amplifying information was provided by the Council's Habitat Advisory Panel. In practice, there is nearly infinite variety in the ways in which gear can be rigged and fished, so these descriptions are necessarily an oversimplification.

3.1 Demersal otter trawls

Demersal, or bottom, otter trawls are towed along the seafloor to catch a variety of species throughout the region. They account for a higher proportion of the catch of federally-managed species than any other gear type. Use of demersal otter trawls in the region is managed under several federal FMPs developed by the NEFMC and MAFMC, including Northeast Multispecies; Atlantic Sea Scallop; Monkfish; Small Mesh Multispecies; Atlantic Mackerel, Squids, and Butterfish; Dogfish; Skates; and Summer Flounder, Scup, and Black Sea Bass. Otter trawling is also managed under various interstate FMPs developed by the ASMFC, including Northern Shrimp.

Trawl gear components include the warps, which attach the gear to the vessel; the doors, which hold the net open under water, the ground cables and bridles, which attach the door to the wings of the net; and the net itself. The top opening of the net, or headrope, is rigged with floats, and the lower opening, or groundrope, is rigged with a sweep, which varies in design depending on the target species (*e.g.*, whether they are found on or off the bottom) as well as the roughness and hardness of the bottom. The net terminates in a codend, which has a drawstring opening that can be untied easily to dump the catch on deck. Three components of the otter trawl typically come in contact with the seafloor: the doors; the ground cables and lower bridles; and the footrope and sweep. Chafing gear may be attached to the codend to avoid damage caused by seabed contact, although this is not believed to be a regular occurrence (S. Eayrs, personal communication).

The traditional otter board, or door, is a flat, rectangular wooden structure with steel fittings and a steel "shoe" along the leading and bottom edges that prevents damage as the door drags over the bottom. In the Northeast Region, wooden doors have been largely replaced by more hydrodynamically efficient, steel doors. Two types of steel doors commonly used in the region are the V-shaped "Thyboron" door and the cambered (or curved) "Bison" door. Either type of door can be slotted to allow some water to flow through the door, reducing drag in the water. Steel "shoes" can be added at the bottom of the door to aid in keeping it upright and take the wear from bottom contact. The sizes and weights of trawl doors used in the Northeast region vary according to the size and type of trawl, and the size and horsepower of the vessel. Large steel doors 43-54 ft^2 (4-5 m^2) weigh between 1500-2200 lb (700-1000 kg) at the surface. The effective weight (buoyancy) of the doors on the seabed during fishing is somewhat less due to hydrostatic forces acting on the doors.

The attachment point of the warps on the doors creates the towing angle, which in turn generates the hydrodynamic forces needed to push the door outward and downward, thus spreading the wings of the net. The non-traditional door designs increase the spreading force of the door by increasing direct pressure on the face of the door and/or by creating more suction on the back of the door. On fine-grained sediments, the doors create a silt cloud that aids in herding fish into the mouth of the net. On rocky or more irregular bottom, trawl doors impact rocks in a jarring manner and can jump distances of 3-6 ft (1-2 m) (Carr and Milliken 1998).

Steel ground cables attach the doors to the wings of the net. Each ground cable runs from a door to the upper and lower bridles, which attach to the top and bottom of the net wing. Thus, both the ground cables and the lower bridles contact the bottom. In New England, fixed rubber roller disks (sometimes called cookies) are attached to the ground cables and lower bridles to assist the passage of the trawl over the bottom. Depending upon bottom conditions, towing speed, and fish behavior, ground cables and bridles vary in length.

As mentioned above, sweep type varies by target species and substrate. In New England, two types of sweep are used on smooth bottom (Mirarchi 1998). In the traditional chain sweep, loops of chain are suspended from a steel cable, with only 2-3 links of the chain touching bottom. Contact of the chain with the bottom allows the trawl to skim a few inches above the bottom to catch species such as squid and scup. Another type of smooth bottom sweep uses a heavy chain with rubber cookies instead of a cable, and is used to catch flounder. The cookies vary in diameter from 4 to 16 in (10 to 41 cm) and do not rotate (Carr and Milliken 1998). This type of sweep is always in contact with the bottom.

On rough bottoms, roller and rockhopper sweeps are used (Carr and Milliken 1998). On the roller sweeps, vertical rubber rollers as large as 36 in (91 cm) in diameter are placed at intervals along the sweep. Although the rollers are free to rotate, because the sweep is shaped in a curve, only the rollers that are located at or near the center of the sweep actually "roll" over the bottom; the others are oriented at increasing angles to the direction of the tow and do not rotate freely as they are dragged over the bottom. In New England, roller sweeps have been largely replaced with rockhopper sweeps that use larger diameter fixed rollers, and are designed to "hop" over rocks as large as 1 m in diameter. Small rubber "spacer" disks are placed in between the larger rubber disks in both types of sweep. Rockhopper gear is no longer used exclusively on hard bottom habitats, but is actually quite versatile and used in a variety of habitat types (Carr and Milliken 1998).

A number of different types of bottom otter trawls are designed to catch certain species of fish on specific bottom types and at particular times of year. Bottom trawls designed to catch groundfish, scallops, shrimp, and squid are differentiated below. The raised footrope trawl is also described.

3.1.1 Generic otter trawls (including groundfish and scallop trawls)

The generic otter trawl category includes groundfish trawls and scallop trawls. Groundfish trawls can be divided into two classes, those rigged to target flatfish, and those rigged to target fish that rise off bottom. Flatfish trawls are designed with a low net opening between the headrope and the footrope and more ground rigging (i.e., rubber cookies and chain) on the sweep (Mirarchi 1998). This design allows the sweep to follow the contours in the bottom in order to encourage flatfish, which lie in contact with the seafloor, to swim off the bottom and into the net. It is used on smooth mud and sand. A high-rise or fly net with larger mesh has a wide net opening and is used to catch demersal fish that rise higher off the bottom, e.g. haddock and cod (NREFHSC 2002). Trawls used on gravel or rocky bottom, or on mud or sand bottom with occasional boulders, may be rigged with rockhopper gear, intended to get the sweep over irregularities in the bottom without damaging the net.

Scallop trawls are used on sandy bottoms, typically in waters from Long Island south to the Virginia coast. Vessels typically use wooden doors, and fishing usually occurs in waters less than 40 fathoms (approximately 75 m) deep. Cable lengths vary from 3:1 to 5:1 ratios of cable to depth. Typical scallop trawls are 55 or 65 ft (17 or 20 m) two seam nets with body and wings constructed of 5 in, 4mm or 5mm braided poly webbing. Wings are 20 to 25 ft (6-8 m) long cut on an 8:1 or 10:1 taper, while the body and belly sections are 20 to 23 ft (6-7 m) long and are cut on a 10:1 taper. Body and belly sections are identical with no overhang and both top and bottom lines are hung on 5/8 inch combination cable. Varying numbers of 8 inch (20 cm) hard plastic floats are used on the headrope, while the footrope is lined with 0.375 in to 0.5 in (1-1.3 cm) loop chain either single or double looped along the entire length. Some fishermen also use tickler chains ahead of the trawl to help kick up scallops from the seabed. No trawl extensions are used and the tailbag sections are 60 meshes around by 50 meshes deep and are constructed of 5 in^2, 4mm or 5mm, braided, double poly webbing. A whisker-type chaffing gear is used along the underside of the trawl and bag to reduce wear. Scallop trawls are not disaggregated in the Vulnerability Assessment; scallop trawl effort is evaluated together with groundfish trawls under the groundfish trawl matrix.

3.1.2 Shrimp trawls

The northern shrimp trawl fishery is prosecuted primarily in the western Gulf of Maine on mud and muddy sand substrates in depths between 20 and 100 fathoms (37-183 m). The fishery is seasonal, beginning in December and extending as late as May. Gear used in the northern shrimp fishery is required by regulation to include a finfish excluder device (Nordmore grate) to minimize bycatch of other bottom dwelling species, and is generally thought to be rigged for lighter contact on bottom (also for bycatch reduction). Northern shrimp trawls use 1 ¾ and 2 in mesh in the codend and the body of the net, respectively. This is smaller than the minimum requirement in the Northeast Multispecies regulated mesh areas, but they are exempt from these areas based on use of a properly configured fish excluder device. Also, regulations require that northern shrimp trawls may not be used with ground cables and that the “legs” of the bridles not exceed 90 ft (27 m). Footrope length is not regulated, but they range in length from 40-100 ft (12-30 m), although most are 50-90 ft (15-27 m). Shrimp trawls may use rollers or rockhoppers, in some cases greater than 12 in (30.5 cm) in size. The inshore roller gear restricted area previously applied to all trawl gears, including shrimp vessels, but it currently applies to vessels fishing on a Northeast Multispecies DAS or sector trip only. Trawling is generally restricted to daylight hours, when shrimp are lower in the water column. Tow times may typically be two hours.

3.1.3 Squid trawls

Bottom otter trawls used to catch species like squid and scup that swim over the bottom are rigged very lightly, with loops of chain suspended from the sweep (Mirarchi 1998). This gear is designed to skim along the seafloor with only two or three links of each loop of chain touching the bottom.

3.1.4 Raised footrope trawls

The raised-footrope trawl is designed capture small mesh species (silver hake, red hake, and dogfish). Raised-footrope trawls can be rigged with or without a chain sweep. If no sweep is used, drop chains must be hung at defined intervals along the footrope. In trawls with a sweep, chains connect the sweep to the footrope. Both configurations are designed to make the trawl fish about 0.45 - 0.6 m (1.5 - 2 ft) above the bottom (Carr and Milliken 1998). Although the doors of the trawl still ride on the bottom, underwater video and observations in flume tanks have confirmed that the sweep in the raised footrope trawl has much less contact with the sea floor than does the traditional cookie sweep that it replaces (Carr and Milliken 1998).

Floats of approx 8 in (20 cm) in diameter are attached to the entire length of the headrope, with a maximum spacing of 4 ft (1.2 m) between floats. The ground gear is bare wire. The top and bottom legs are equal in length, and net fishes with no extensions. The total length of ground cables and legs must not be greater than 240 ft (73 m) from the doors to wing ends. The sweep and its rigging, including drop chains, must be made entirely of bare chain with a maximum diameter of 0.3 in (0.8 cm). No wrapping or cookies are allowed on the drop chains or sweep.

3.2 New Bedford-style scallop dredges

The New Bedford-style scallop dredge is the primary gear used in the Georges Bank and Mid-Atlantic sea scallop fishery. The use of scallop dredges in federal waters of the Northeast Region is managed under the federal Atlantic Sea Scallop FMP, developed by the NEFMC in consultation with the MAFMC.

In the Northeast Region, scallop dredges are used in high- and low-energy sand environments, and high-energy gravel environments. Although gravel exists in low-energy environments of deepwater banks and ridges in the GOM, the fishery is not prosecuted there.

A New Bedford-style scallop dredge consists of a chain bag and a steel towing frame. The bag is made of two sheets of 4 in (10 cm) metal rings. The upper portion of the bag includes a 10 in mesh twine top designed to allow fish to escape, and the lower portion is rigged with chafing gear. During fishing, the bag drags on the substrate. The frame consists of a flat steel cutting bar and a pressure plate mounted above it which run parallel to the direction of the tow, and a triangular frame which connects the cutting bar and pressure plate to the single towing wire. The pressure plate generates hydrodynamic pressure, while the cutting bar rides along the surface of the substrate. Shoes on the right and left sides of the cutting bar ride along the substrate surface and are intended to take much of the wear. A sweep chain is attached to each shoe and to the forward portion of the bottom panel of the ring bag (Smolowitz 1998). Tickler chains run from side to side between the frame and the ring bag, and, in hard-bottom scalloping, a series of rock chains run from front to back to prevent large rocks from getting into the bag.

New Bedford-style dredges are typically 15 ft (4.5 m) wide; one or two of them are towed by single vessels at speeds of 4-5 knots (7.4-9.3 $km \cdot hr^{-1}$). Towing times are highly variable, depending on the density of marketable-sized sea scallops at any given location, and may be as short as 10 minutes or as long as an hour. New Bedford-style dredges used along the Maine coast are typically smaller than those used elsewhere in the fishery, and dredges used on hard bottoms are heavier and stronger than dredges used on sand.

3.3 Hydraulic clam dredges

Hydraulic clam dredges have been used in the Atlantic surfclam (*Spisula solidissima*) fishery for over five decades, and in the ocean quahog (*Arctica islandica*) fishery since its inception in the early 1970s. Use of this gear in the region is managed under the federal FMP for surf clams and ocean quahogs developed by the MAFMC. The gear is also used in state waters in the Mid-Atlantic region.

Hydraulic clam dredges can be operated in areas of large-grain sand, fine sand, sand with small-grain gravel, sand with small amounts of mud, and sand with very small amounts of clay. Most tows are made in large-grain sand. Surfclam/ocean quahog dredges are not fished in clay, mud, pebbles, rocks, coral, large gravel >0.5 in (> 1.25 cm), or seagrass beds.

The typical dredge is 12 ft (3.7 m) wide and about 22 ft (6.7 m) long, and uses pressurized water jets to wash clams out of the seafloor. Towing speed at the start of the tow is about 2.5 knots (4.6 $km \cdot hr^{-1}$), and declines as the dredge accumulates clams. The dredge is retrieved once the vessel speed drops below about 1.5 knots (2.8 $km \cdot hr^{-1}$), which can be only a few minutes in very dense beds. However, a typical tow lasts about 15 minutes. The water jets penetrate the sediment in front of the dredge to a depth of about 8-10 in (20-25 cm) and help to "drive" the dredge forward. The water pressure required to fluidize the sediment varies from 50 $lb \cdot in^{-2}$ (psi) in coarse sand to 110 psi in finer sediments. The objective is to use as little pressure as possible since too much pressure will blow sediment into the clams and reduce product quality. The "knife" (or "cutting bar") on the leading bottom edge of the dredge opening is 5.5 in (14 cm) deep for surfclams and 3.5 in (9 cm) for ocean quahogs. The knife "picks up" clams that have been separated from the sediment and guides them into the body of the dredge ("the cage").

3.4 Demersal longlines

A longline is a long length of line, often several miles long, to which short lengths of line ("gangions") carrying baited hooks are attached. Demersal longlining is used to catch a wide range of species on continental shelf areas and offshore banks.

Bottom longline fishing in the Northeast Region is conducted using hand-baited gear that is stored in tubs before the vessel goes fishing and by vessels equipped with automated "snap-on" or "racking" systems. The gangions are 15 in (38 cm) long and spaced 3-6 ft (0.9-1.8 m) apart. The mainline, hooks, and gangions all contact the bottom. In the Cape Cod longline fishery, up to six individual longlines are strung together, for a total length of about 1500 ft (460 m), and are deployed with 20-24 lb (9-11 kg) anchors. Each set consists of 600 to 1200 hooks. In tub trawls, the mainline is parachute cord; stainless steel wire and monofilament nylon gangions are used in snap-on systems (Leach 1998). The gangions are snapped on to the mainline as it pays off a drum and removed and rebaited when the wire is hauled. In New England, longlines are usually set for only a few hours at a time in areas with attached benthic epifauna. Longlines used for tilefish are deployed in deep water, may be up to 25 mi (40 km) long, and are set in a zigzag fashion. The mainline is stainless steel or galvanized wire. These activities are managed under federal fishery management plans.

3.5 Sink gill nets

A gill net is a large wall of netting which may be set at or below the surface, on the seafloor, or at any depth between. They are equipped with floats at the top and lead weights along the bottom. Sink, or bottom gill nets are anchored or staked in position. Fish are caught as they try to pass through the net meshes. Gill nets are highly selective because the species and sizes of fish caught are highly dependant on the mesh size of the net. They are used to catch a wide variety of species, including many federally-managed species. Bottom gill net fishing occurs in the Northeast Region in nearshore coastal and estuarine waters as well as offshore on the continental shelf. The use of sink gill nets in federal waters is managed under federal fishery management plans. The use of gill nets is restricted or prohibited in some state waters in the region.

Gill nets have three components: leadline, netting, and floatline. Leadlines used in New England are 65 lb (30 kg) per net; leadlines used in the Mid-Atlantic are slightly heavier. The netting is monofilament nylon, and the mesh size varies, depending on the target species. Nets are anchored at each end using Danforth anchors. Anchors and leadlines have the most contact with the bottom. Individual gill nets are typically 300 ft (91 m) long and 12 ft (3.6 m) high. Strings of nets may be set out in straight lines, often across the current, or in various other configurations (e.g., circles), depending upon bottom and current conditions.

In New England, bottom gill nets are fished in strings of 5-20 nets attached end to end. They are fished in two different ways, as "stand up" and "tie-down" nets (Williamson, 1998). Stand-up nets are used to catch cod, haddock, pollock, and hake and are soaked for 12-24 hrs. Tie-down nets are set with the float line tied to the lead line at 1.8 m (6 ft) intervals so the float line is close to the bottom and the net forms a limp bag in between each tie. They are left in the water for 3-4 days and used to catch flounders and monkfish. Bottom gill nets in New England are set in relation to changes in bottom topography or bottom type where fish are expected to congregate. Other species caught in bottom gill nets in New England are spiny dogfish, and skates.

In the Mid-Atlantic, sink gill nets are fished singly or in strings of just 3-4 nets. The Mid-Atlantic fishery is more of a "strike" type fishery in which nets are set on schools of fish or around distinct bottom features and retrieved the same day, sometimes more than once. They catch species such as bluefish (*Pomatomus saltatrix*), Atlantic croaker (*Micropogonias undulates*), striped bass (*Morone saxatilis*), spot (*Leiostomus xanthurus*), mullet (*Mugii* spp.), spiny dogfish (*Squalus acanthias*), smooth dogfish (*Mustelus canis*), and skates (*Leucoraja ocellata*, *Leucoraja erinacea, Raja eglanteria, Leucoraja garmani*).

3.6 Traps

Traps are used to capture lobsters, crabs, black sea bass, eels, and other bottom-dwelling species seeking food or shelter. Trap fishing can be divided into two general classifications: 1) inshore trapping in estuaries, lagoons, inlets, and bays in depths up to about 75 m (250 ft); and 2) offshore trapping using larger and heavier vessels and gear in depths up to 730 m (2400 ft) or more.

Originally, traps used to harvest American lobster (*Homarus americanus*) were constructed of wooden laths with single, and later, double, funnel entrances made from net twine. Today, roughly 95% are made from coated wire mesh. They are rectangular and are divided into two sections, the "kitchen" and the "parlor." The kitchen has an entrance on both sides of the pot and is baited. Lobsters enter either chamber then move to the parlor through a long, sloping tunnel to the parlor. Escape vents are installed in both areas of the pot to minimize the retention of sub-legal-sized lobsters. Rock crabs (*Cancer* spp.) are also harvested in lobster pots.

Lobster traps are fished as either a single trap per buoy, 2 or 3 traps per buoy, or strung together in "trawls" of up to 100 traps. Trawls are used on flatter types of bottom. Traps in trawls are connected by "mainlines" which either float off the bottom, or, in areas where they are likely to become entangled with marine mammals, sink to the bottom. Single traps are often used in rough, hard bottom areas where lines connecting traps in a trawl line tend to become entangled in bottom structures.

Soak time for lobster traps depends on season and location, ranging from 1-3 days in inshore waters in warm weather, up to several weeks in colder waters. Offshore traps are larger (>1.2 m (4 ft) long) and heavier (~45 kg (100 lb)) than inshore traps with an average of about 40 traps per trawl. They are usually deployed for a week at a time. Although the offshore component of the fishery is regulated under federal rules, American lobster is not managed under a federal fishery management plan.

Currently, three large (average 98 ft. 30 m) vessels are engaged in the deep-sea red crab (*Geryon quinquedens*) fishery, which is managed by the NEFMC (NEFMC 2010). Traditional deep-sea red crab traps are wood and wire traps that are 48 in long, 30 in wide, and 20 in high (1.20 x 0.75 x 0.5 m) with a top entry funnel or opening. A second style of trap, which is now used exclusively, is conical in shape, 4 ft (1.3 m) in diameter at the base and 22 in (0.45 m) high with a top entry funnel or opening. Vessels use an average of 560 traps that are deployed in trawls of

75-180 traps per trawl along the continental slope at depths of 1300-2600 ft (400-800 m) (NEFMC 2002).

4.0 Gear impacts literature review

A goal of the vulnerability assessment is to base estimates of susceptibility and recovery of features to gear impacts on the scientific literature to the extent possible. Thus, after identifying fishing gears (section 3.0), and key habitat features (section 2.0), the next step is to summarize the scientific literature that examines interactions between the two[4]. Studies were selected for evaluation based on their broad relevance to Northeast Region habitats and fishing gears. Synthesis papers and modeling studies are excluded from the review, but the research underlying these publications is included when relevant. Most of the studies reviewed are published as peer-reviewed journal articles, but conference proceedings, reports, and theses are considered as well. Studies that examined gear types very different from those used in the Northeast Region are not evaluated. Also, studies conducted in habitats very different from those found in the Northeast Region are not evaluated.

4.1 Methods: database and coding

A Microsoft Access database, described in detail below, was developed to organize the review and to identify in detail the gear types and habitat features evaluated by each study. In addition to identifying gear types and features, the database included fields to code for basic information about study location and related research; study design, relevance and appropriateness to the vulnerability assessment; depth and energy environment; whether recovery of features is addressed; and substrate types found in the study area. Analysts interacted with the database via a form (Figure 2). Table 22 summarizes each of the fields.

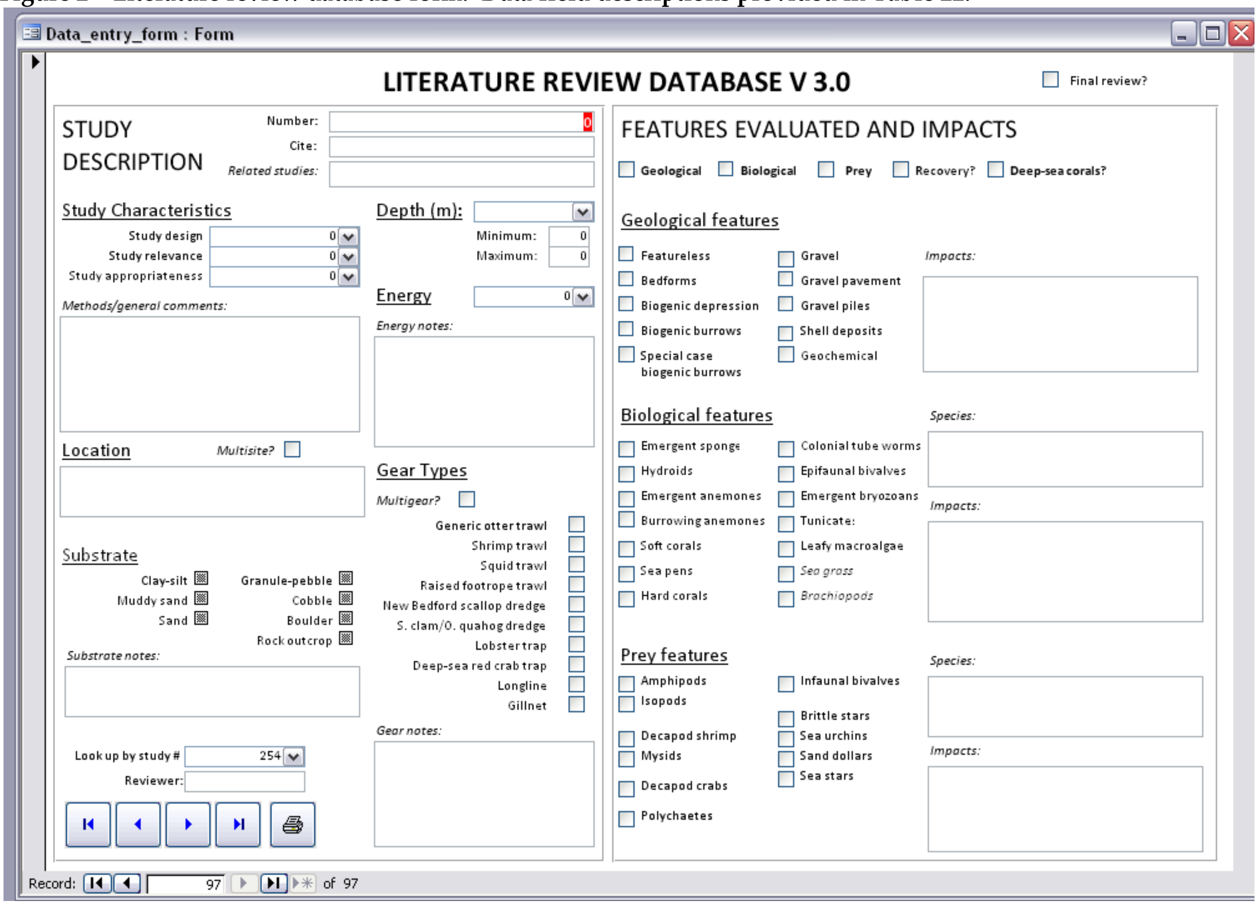
Most studies were read and coded by a single team member initially, and then the coding was reviewed by one or more additional team members at a later time. The process of coding the database was somewhat iterative, as the matrix-based approach, SASI model implementation, and literature review were developed contemporaneously. For example, each study's high/low energy coding was reviewed and updated as necessary when the depth threshold for the unstructured model grid was adjusted.

The database is intended to serve as a legacy product, so some features are coded but not used in the current analysis. For example, if prey feature susceptibility and recovery matrices are developed in the future, the database could be queried to determine the studies relevant to each S/R evaluation. The long-term intention is to create new records in the database as additional gear impacts studies are published.

[4] For readers familiar with NOAA Technical Memorandum NMFS-NE-181, this review builds on but is distinct from that report and subsequent updates, and includes many of the same studies.

For easy reference, a list of citations by study number is provided on the last page of this document (Table 83). Nearly 100 studies are evaluated, although additional literature referenced in the previous section on feature descriptions was used in some cases to inform recovery scores, and not all of the studies are used equally to inform the matrix-based vulnerability assessment.

Figure 2 – Literature review database form. Data field descriptions provided in Table 22.



Data_entry_form : Form

LITERATURE REVIEW DATABASE V 3.0

Final review?

STUDY DESCRIPTION

Number: 0

Cite:

Related studies:

Study Characteristics

Study design 0

Study relevance 0

Study appropriateness 0

Methods/general comments:

Location

Multisite?

Substrate

Clay-silt, Muddy sand, Sand, Granule-pebble, Cobble, Boulder, Rock outcrop

Substrate notes:

Look up by study # 254

Reviewer:

Depth (m):

Minimum: 0

Maximum: 0

Energy 0

Energy notes:

Gear Types

Multigear?

Generic otter trawl, Shrimp trawl, Squid trawl, Raised footrope trawl, New Bedford scallop dredge, S. clam/O. quahog dredge, Lobster trap, Deep-sea red crab trap, Longline, Gillnet

Gear notes:

FEATURES EVALUATED AND IMPACTS

Geological, Biological, Prey, Recovery?, Deep-sea corals?

Geological features

Featureless, Bedforms, Biogenic depression, Biogenic burrows, Special case biogenic burrows, Gravel, Gravel pavement, Gravel piles, Shell deposits, Geochemical

Impacts:

Biological features

Emergent sponge, Hydroids, Emergent anemones, Burrowing anemones, Soft corals, Sea pens, Hard corals, Colonial tube worms, Epifaunal bivalves, Emergent bryozoans, Tunicate:, Leafy macroalgae, *Sea grass*, *Brachiopods*

Species:

Impacts:

Prey features

Amphipods, Isopods, Decapod shrimp, Mysids, Decapod crabs, Polychaetes, Infaunal bivalves, Brittle stars, Sea urchins, Sand dollars, Sea stars

Species:

Impacts:

Record: 97 of 97

Table 22 – Literature review database fields

Database field	***Coding options***	***Purpose of coding***	***Coding guidelines***
Study design	Choice of: observational, comparative, or experimental	The design of a particular study influences the way in which analysts might interpret the results.	**Observational** refers to studies where fished sites were characterized in terms of the distribution and status of habitat features, without an unfished reference site for comparison. **Comparative** refers to studies that assessed impacts to otherwise similar fished and unfished areas. **Experimental** refers to studies that either: evaluated the experimental use of fishing gear in comparison with an unfished control, or used a before-after control-impact design to study the effects of either experimental use of fishing gear or actual fishing effort.
Study relevance	Choice of: (1) Similar gears or habitats but geographically remote study area (2) Geographically similar (though non-NE) study area, similar gears/habitats (3) Study area overlaps with NE area (incl. CA side of Georges) and uses similar gears (4) Study performed in NE area with NE gears	This field was intended to provide some indication of the types of studies considered; although the results of those receiving a higher score were weighted explicitly during evaluation of susceptibility and recovery.	All studies used or observed the effects of gears similar to those used in the Northeast U.S. in similar habitats. A score of (1) would indicate that the study met these basic criteria. A score of (4) would indicate that they study was conducted in Northeast U.S. waters and evaluated the impacts of Northeast U.S. gear types. Values of (2) and (3) fall between these two extremes.
Study appropriateness (to Vulnerability Assessment)	Choice of: study (1) tangentially supports, (2) supports, or (3) is perfectly aligned with the vulnerability assessment	This field was intended to provide some indication of how well the study fit the gear impacts/feature/substrate assessment approach. Studies with higher appropriateness values were more straightforward to incorporate into the matrix-based assessment.	Regardless of relevance, studies that specifically examine the effects of particular gear types on particular habitat components should receive the highest appropriateness values. Studies that are more general, perhaps aggregating multiple gear types or impacts, or that do not provide clear information on the substrate, depth, or energy, would receive lower values.
Gear type, multiple gear types checkbox	One or more of the following: generic otter trawl, shrimp trawl, squid trawl, raised footrope trawl, New Bedford scallop dredge, surfclam/ocean quahog dredge, lobster trap, deep-sea red crab trap, demersal longline, sink gill net	The susceptibility and recovery of features estimated in the matrix assessment was disaggregated by gear type. Therefore, an understanding of which gear types were used to create the impacts studied was key to the assessment.	Multiple gear types could be checked as applicable, with details summarized in the comments section. If the study area was subject to the impact of two or more gear types and these could not be fully distinguished, the multiple gear types checkbox was selected.

Database field	***Coding options***	***Purpose of coding***	***Coding guidelines***
Energy	Choice of: (1) high author stated, (2) high inferred, (3) low author stated, (4) low inferred, or (5) not specified	Feature recovery was assumed to vary by environmental energy, so it was important to know what type of environment a particular study occurred in.	Energy environment was determined based on the shear stress and depth criteria for high and low energy used in the SASI model
Depth	Choice of four ranges: (1) 0-50m, (2) 51-100m, (3) 101-200 m, (4) deeper than 200m	Depth information helped to determine energy environment and also relates to feature distributions.	Additional space was provided to input minimum and maximum study depths.
Location	Text box	Gives a better sense for the study environment than the relevance column alone	Space to indicate where the study was conducted.
Related studies	Text box	Allows analyst to compare results easily between studies at the same or similar sites, or to review studies done by the same or similar authors	Space to indicate if the study was directly related to other studies reviewed (i.e. a follow up study, or a similar study in the same area conducted by the same group of authors).
Recovery addressed	True/false	Estimates of recovery times were based on study results whenever possible, and absent results to draw from, on descriptions of the features themselves	'True' indicates that the study addressed the recovery of habitat components from disturbance.
Deep-sea corals	True/false	The MSRA allows for explicit protection of deep-sea corals independent of Essential Fish Habitat impacts. While some cold-water coral species are found in shallower areas and are included in the matrix-based assessment as a biological habitat component, other studies were specific to deep-sea species; this code allowed those deep-sea coral studies to be easily distinguished.	'True' indicates that the study referred to any deep-sea coral species, whether impacts to corals are evaluated separately or if they are simply mentioned as a biological habitat component in the study area. In the Northeast, deep-sea corals include five Anthozoan orders: Scleratinia (stony corals), Alcyonacea (soft corals), Antipatharia (black corals), Gorgonacea (sea fans), and Pennatulacea (sea pens).
Substrate	Choice of: clay-silt, muddy-sand, sand, granule-pebble, cobble, boulder, rock outcrop,	The spatial grid on which habitat sensitivity and fishing effort are overlaid is based on dominant (modal) substrate data, so the substrate present in a particular study area was key to determining to which grid cells the study results applied.	This section indicates when a particular substrate type was present in the study area.
Geological habitat components	True/false for overall evaluation and for each feature, 256 character text boxes for impacts	Geological habitat components indicates that fishing gear effects on non-living seafloor structures were evaluated as part of the study	'Geological' was checked when the study assessed impacts to substrate subclasses or features. Checkboxes in this section indicated when impacts to and/or recovery of specific geological habitat features were evaluated. There was an additional checkbox for geochemical effects. A text box was used to summarize gear impacts.

Database field	***Coding options***	***Purpose of coding***	***Coding guidelines***
Biological habitat components	True/false for overall evaluation and for each feature, 256 character text boxes for species and impacts	Biological habitat components indicates that fishing gear effects on living seafloor structures were evaluated as part of the study	'Biological' was checked if fishing impacts to the various biological features were studied. Checkboxes in this section indicated when impacts to and/or recovery of specific biological habitat features were evaluated. A text box was used to summarize gear impacts and another text box was used to list particular species.
Prey habitat components	True/false for overall evaluation and for each feature, 256 character text boxes for species and impacts	Prey habitat components indicates that fishing gear effects on prey were evaluated as part of the study	'Prey' was checked if prey features were mentioned in the study. Checkboxes in this section were used to indicate when impacts to and/or recovery specific prey features was evaluated. A text box was used to summarize gear impacts and another text box was used to list particular species.
General comments	256 character text box	Provide additional information to help analysts understand study design.	This section was used to note any details about gear used, provide additional information about the study methods, or to state caveats as to the usefulness of the study for the Vulnerability Assessment.

4.2 Tabular summary of literature

The tables that follow reproduce the contents of the literature review database in a format amenable to a written document. They list, by study, attributes (Table 23), gears evaluated (Table 24), physical environment (Table 25), geological features evaluated (Table 26), and biological features evaluated (Table 27). The database file itself is available upon request.

Table 23 – Study attributes. Columns shown below are described in Table 22. MS column indicates a multi-site study; MG column indicates a multi-gear study. Relevance values are coded as follows: 1 – similar gears, different habitats; 2 – similar gears, similar habitats; 3 – similar gears, overlapping habitats; 4 – Northeast gears, Northeast habitats. Appropriateness values are coded as follows: 1 – Study tangentially supports VA evaluation; 2 – Study supports VA evaluation; 3 – Study perfectly aligned with VA evaluation.

Citation	*Related studies*	*MS*	*MG*	*D*	*R*	*A*	*Summary/notes*
Asch and Collie 2007 (404)	69, 70, 71, 158	-	X	Comp	4	3	386 photos (rep 100 m^2 total) analyzed for percent cover of colonial epifauna and abundance of non-colonial organisms at shallow & deep disturbed/undisturbed sites. Good data/discussion on recovery rates of different epifaunal taxa (also see #71).
Auster et al 1996 (11)	-	X	X	Comp	4	3	Video transects in/outside SI closed area (10 yr); sonar and video observations of trawl/scallop dredge impacts (individual tows) on SB in 1993; JB site surveyed before (1987) and after (1993) trawling
Ball et al 2000 (17)	-	-	-	Comp	2	2	Exp fish at 35 m (light fishing=LF) and 70 m (heavy fishing=HF) sites, with shipwrecks used as controls; sampled 24 hr after. Both areas in prawn trawl fishing ground. Effects of exp trawling could not be evaluated.
Bergman and VanSantbrink 2000 (21)	-	-	-	Exp	2	3	Estimated mortality of large, sedentary megafauna due to damage/predation within 24-48 hrs after single trawl tows in fishing grounds, (beam trawl data not included in this summary), mortality of animals caught in net was minor
Blanchard et al 2004 (24)	-	-	-	Comp	2	2	Sampled invert megafauna and demersal fishes with a beam trawl in areas w/ 3 levels of fishing by var otter trawl types. Tested hypotheses about community-level indicators under different effort regimes. Effort data at ICES stat rectangle resolution.
Boat Mirarchi and CR Environmental 2003 (408)	409	-	-	Exp	4	2	Evaluated immediate effects of 6 replicate tows in 2 lanes at 2 locations, one heavily and one lightly trawled (HT/LT) locations, with controls, using SS sonar, grab samples, benthic dredge, and video cameras.
Boat Mirarchi and CR Environmental 2005 (409)	408	-	-	Exp	4	2	Follow up (2nd yr) to Mirarchi and CR Env 2003 (#408); additional tows (aver 1.3x per wk for 4 mos) in same lanes at two locations to evaluate temporal changes and cumulative effects, SPI camera added to sampling array
Brown et al 2005a (34)	35	-	-	Exp	2	3	Compared macrofauna in area closed for 10 yrs with an area recently reopened using divers (core samples) and video transects, also examined immediate effects of exp trawling (10 parallel tows in 4km2) at 11 stations (2 controls) in closed area
Brown et al 2005b (35)	34	-	-	Exp	2	3	Same study design (compared chronically trawled and untrawled area/exp fishing in closed area) as in #34, focus on grain size and labile carbon dist in sediments; compared trawling effects to wave disturbance.
Burridge et al 2003 (38)	Poiner et al 1998, 285	-	-	Exp	1	3	Depletion experiment, n=6 sites, 3 deep-35m, 3 shallow-20 m. Goal: achieve 90% depletion at conclusion of trials. Lack of perfect coincidence in trawls may have incr var in depletion rate - used simulations to test magnitude of this effect (see p 249 results).
Caddy 1968 (42)	-	-	-	Obs	2	2	Direct observations of gear impacts by divers attached to dredge during two 5-min tows made at 2 knots.

Citation	Related studies	MS	MG	D	R	A	Summary/notes
Caddy 1973 (43)	-			Obs	2	2	Submersible observations inside/outside of tow tracks 1 hr after single dredge tows
Clark and O'Driscoll 2003 (64)	541, 209	-	-	Comp	1	1	Comparison of seamounts at similar depths that are fished and unfished; developed fishing importance index to rate sites as to use by fishermen
Coggan et al 2001 (414)	--	X	-	Exp	1	2	Good discussion of trawl effects, with interesting pictures. Distinctions btwn high, med and low fishing intensity are unclear. Good info on classification of functional groups and sediments.
Collie et al 1997 (69)	70, 71, 158, 404	-	X	Comp	4	3	Benthic macrofaunal collected and counted in video transects at 4 deep and 2 shallow sites classified as disturbed (D) or undisturbed (U) by trawls and scallop dredges; data collected during two 1994 cruises using 1 m Naturalists dredge
Collie et al 2000 (70)	69, 71, 158, 404	-	X	Comp	4	3	Follow-up publication to #69 based on analysis of video images and still photos at 3 deep (80-90m) and 2 shallow (42-37m) sites, some disturbed (D) and some undisturbed by trawls and dredges
Collie et al 2005 (71)	69, 70, 158, 404	-	-	Comp	4	3	Data collected during 1994-2000 at 2 deeper sites in Canada (heavily and lightly fished, HF and LF); recovery monitored at shallower, previously disturbed US site after CAII was closed to trawling and dredging in 1995, rel to 2 sites outside CAII.
De Biasi 2004 (88)	-	-	-	Exp	1	2	14 1 hr tows in 24 hrs at each of 5 stations in an unfished area, effects evaluated rel to landward and seaward control sites after, 24/48 hrs and 1 mo after trawling with side scan sonar and box core samples
de Juan et al 2007a (89)	90	-	-	Comp	2	2	Changes in functional components of benthos analyzed rel to seasonal variability and variations in fishing intensity during 1 yr study comparing a chronically trawled location and an area closed to fishing for 20 yrs
de Juan et al 2007b (90)	89	-	-	Comp	2	1	compared diets of starfish and flatfish from fished and unfished locations to relative abundance of their prey, some study areas as de Juan et al 2007a (study #89)
DeAlteris et al 1999 (92)	-	-	-	Obs	4	2	Diver obs of persistence of hand-dug trenches and modeling of bottom hydrodynamic and sediment transport processes
Dellapenna et al 2006 (406)	-	-	-	Exp	1	2	Pre- and post-trawl sediment and water column profiling in small, heavily-fished area, 3 exp tows on 2 occasions
Drabsch et al 2001 (97)	360	-	-	Exp	2	2	Effects of 2 passes of trawl evaluated at 3 sites (2 in sand, 1 mud) in area with no trawling for 15 yrs, compared to control areas, effects on infauna assessed after 1 week (at one sand and mud site) and 3 mos (other sand site), core sampling
Engel and Kvitek 1998 (101)	-	-	-	Comp	2	2	Multi-year study comparing adjacent lightly trawled (LT) and heavily trawled (HT) areas using a submersible (video transects/still photos) and bottom grabs.
Eno et al 2001 (102)	-	X	-	Exp	2	3	Short term study. - sea pen recovery assessed. Some depths not well specified.
Fossa et al 2002 (108)	-	-	X	Obs	1	1	Two goals: estimate extent of L. pertusa reefs in Norweigen waters, and examine fishing-related impacts at some of the sites; one method found very valuable was to ask fishermen to document coral locations on charts
Freese 2001 (110)	111	-	-	Exp	2	3	Follow up to 111, examining recovery of seafloor ans sponges a year after experimental trawling
Freese et al 1999 (111)	110	-	-	Exp	2	3	Submersible obs (with control transects) 2 hr-5 days after single trawl passes, in area with little or no commerial trawling for 20 yrs - 8 trawl and 8 reference video transects
Frid et al 1999 (113)	-	-	-	Comp	2	2	Related changes in benthic fauna in a lightly trawled (LT) and heavily trawled (HT) location to low, mod, and high fishing activity and primary production over 27 yrs; organisms grouped according to predicted responses to fishing
Gibbs et al 1980 (119)	-	-	-	Exp	2	2	Grab sampling in 3 treatment sites and 1 control site prior to and imm after 1 wk of repeated exp tows before

Citation	Related studies	MS	MG	D	R	A	Summary/notes
							opening of fishing season, more sampling at end of season, control area not fished
Gilkinson et al 1998 (120)	120	-	-	Obs	2	3	This study was conducted in a flume tank; habitat is meant to simulate northeastern edge of Grand Banks, which would be high energy; Characterizes shell damages in 4 categories: No damage, minor damage, moderate, and major; animals were already dead
Gilkinson et al 2003 (121)	122, 123	-	-	Exp	2	3	BACI study, recovery of physical habitat features monitored 1,2 and 3 yrs after initial disturbance in previously un-dredged area on Scotian Shelf; good description of how gear fishes, rel betwn fishing and natural disturbance discussed
Gilkinson et al 2005a (122)	121, 123	-	-	Exp	2	2	BACI study, recovery of macrobenthic community monitored immediately aftrer and 1 and 2 yrs after initial disturbance in previously un-dredged area on Scotian Shelf
Gilkinson et al 2005b (123)	121, 122	-	-	Exp	2	3	Efffects of dredging on abundance of soft coral Gersemia rubiformis evaluated on Scotian shelf (see Gilkinson et al. 2003 and 2005a - based on same study).
Gordon et al 2005 (128)	192, 291, 325	-	-	Exp	2	3	Summary of research in studies 192, 291, and 325 (see them for details)
Grehan et al 2005 (136)	108, 146, 393 (NE Atlantic coral studies)	X	X	Obs	1	1	Part of Atlantic Coral Ecosystem Study. Video and sonar mapping. Magnitude of fishing effort not really quantified; evidenced from ghost gear and physical marks on seabed.
Hall et al 1990 (140)	-	-	-	Exp	2	1	Escalator dredge using water pressure to harvest razor clams in highly dynamic, shallow-water environment in Scotland.
Hall et al 1993 (141)	-	-	-	Comp	2	2	Sampled benthic infauna from a fishing ground in the North Sea using distance from a shipwreck as a proxy for changes in trawling intensity.
Hall-Spencer et al 2002 (146)	Norway sites similar to #108	X	-	Obs	2	1	Analyzed coral bycatches from two French trawlers over a two year period in W. Ireland; examined two Norweigan sites (fished/unfished) using video for coral damage
Hansson et al 2000 (149)	407, 313, 575	-	-	Exp	2	2	Exp trawling for 1 yr (2 tows/wk, 24 tows per unit area) in area closed to fishing for 6 yrs, effects evaluated during last 5 mos of experiment, 3 control and 3 treatment sites
Henry et al 2006 (157)	193, 194	-	-	Exp	2	3	12-14 tows (all in 1 day) along same trawl line in 3 consecutive yrs in closed area (10 yrs), videograb sampling of colonial epifauna before and 1-5 days after trawling each year along trawled and multiple (3) control lines.
Hermsen et al 2003 (158)	69, 70, 71, 404	-	X	Comp	4	3	Compared secondary production rates at heavily fished and lightly fished (HF/LF) sites and changes in production over time after CAII was closed to mobile, bottom-tending gear - see #71 for more details.
Hinz et al 2009 (658)	292	-	-	Exp	2	2	Quantified response of macrofaunal community along a gradient of otter trawling effort, epifauna sampled with beam trawl at 20 sites (15 sites analyzed), infauna with grab samplers
Hixon and Tissot 2007 (164)	-	-	-	Comp	2	1	Submersible obs on edges of rocky, offshore bank, 2 transects in untrawled (UT) area (183-215m) and 4 in heavily trawled (HT) area (274-361m), as evidenced by trawl tracks; densities of fish and benthic inverts
Kaiser et al 2000 (184)	-	-	X	Comp	2	1	Compared benthic communities in areas of low, medium and high fishing effort, three habitat types (depth/sediments) at each site, sampling with grab, beam trawl, and anchor dredge
Kenchington et al 2001 (192)	same site as 128, 291, 325	-	-	Exp	2	3	See #325 for description of exp design - this 3 yr study evaluated grab samples for short-term (imm after trawling) and long-term (1-2 yrs later) effects of trawling on benthic community, trawling effects dwarfed by natural decline
Kenchington et al 2005 (193)	157, 194	-	-	Exp	2	3	12-14 tows along same trawl line in one day of experimental fishing in 3 consecutive yrs in closed area (10 yrs) - compared stomach contents of 22 fish species between first 2 tows (time 1) and subsequent tows (time 2)
Kenchington et al 2006 (194)	157, 193	-	-	Exp	2	3	Same experimental design and sampling gear as Henry et al (2006) - study #157. Analysis of impacts to much broader range of epifaunal and infaunal taxa.

Citation	Related studies	MS	MG	D	R	A	Summary/notes
Knight 2005 (203)	-	-	-	Comp	4	2	Extent of shrimp trawling in WGOM closure prior to 2004?
Koslow et al 2001 (209)	541, 64	-	-	Comp	1	1	Good basic description of why seamounts have high biodiversity, study examined effects of trawling on benthic macrofauna, but depth and fishing effects confounded; trawl logbook data assumed accurate because vessels have VMS (?)
Koulouri et al 2005 (211)	-	-	-	Comp	1	1	Study used 3-level experimental sledge to collect hyperbenthos (small 0.5-20 mm inverts living very close to or on seabed); sledge used with and w/o groundrope (disturbed/undist) before and during trawling season in an actively fished area
Kutti et al 2005 (214)	-	-	-	Exp	2	3	Short-term effects (but recovery addressed as part of larger study); study area not fished since 1978 but adj. to fishing grounds; one transect trawled 10 times along same center line, epibenthic sled used for sampling.
Langton and Robinson 1990 (217)	-	-	-	Comp	4	2	Two sites - Jeffreys (one set of dives) and Fippennies (fishing at latter which was undist prior to study for 5-7 yr, dives before and after fishing); spp associations and densities varied at Jeff, Fipp before, Fipp after
Lindegarth et al 2000 (575)	313 ,407, 149	-	-	Exp	2	1	BACI design with multiple before and after samples (see Hansson et al 2000, study #149), area closed to shrimp trawling for 5 years
Lindholm et al 2004 (225)	228	-	X	Comp	4	2	Compared relative abundance of 7 microhabitats at 32 stations inside/outside area closed to mobile, bottom-tending gear for 4.5 yrs, video and still photos taken along transects
Link et al 2005 (228)	225	-	X	Comp	4	3	Evaluation of effects of area closures on nekton (fish) and benthic community composition in a variety of habitat types, benthos sampled with grab, still photos to quantify microhabitat dists and dist of sand ripples/dunes
MacKenzie 1982 (232)	-	-	-	Comp	4	2	Compararive study of an actively fished, recently fished, and never fished area off NJ.
Mayer et al 1991 (236)	-	-	X	Exp	4	3	Single tow of scallop dredge at 8m site/trawl at 20 m site, sediment core samples to 18 cm inside and outside drag lines the day after dragging
McConnaughey et al 2000 (238)	239	-	-	Comp	2	2	Compared abundance of epifauna caught in small-mesh trawl inside and outside area closed to trawling for ca 40 yrs
McConnaughey et al 2005 (239)	238	-	-	Comp	2	1	Analyzed mean size (wt) of 16 invert taxa in 42 paired trawl samples from inside and outside closed area
Medcof and Caddy 1971 (244)	-	-	-	Obs	3	3	SCUBA and submersible obs during and after two tows with a cage dredge in a shallow (7-12 m) coastal inlet in southern Nova Scotia
Meyer et al 1981 (245)	-	-	-	Exp	4	3	South shore of Long Island, direct obs (divers) of physical impacts during and after a single tow with a cage dredge, samples inside and outside of dredge track compared, recovery noted after 2 and 24 hrs.
Morais et al 2007 (247)	-	-	-	Obs	1	1	Submarine obs along 5 transects near head and on flanks of a canyon; occurence of large epifauna and epi-benthic organisms quantified using video
Moran and Stephenson 2000 (248)	-	-	-	Exp	2	3	Compared demersal and semi pelagic trawl effects on macrobenthos. Video surveys of benthos before/during/after 4 exp trawling events (one tow per unit area) at 2-day intervals in unexploited area
Morello et al 2005 (249)	-	-	-	Exp	2	1	
Mortensen et al 2005 (254)	-	-	X	Obs	3	2	Video survey to det dist of deepwater corals and extent of damage. 52 transects, totalling 32 km - divided into 1751 video sequences. Corals classed as intact, broken, tilted, or dead. To rep fishing effort, 5 yrs logbook data agg into 1 min sq.
Murawski and Serchuk 1989 (256)	-	-	-	Obs	4	2	Submersible obs following dredge tows at various locations on continental shelf in Mid-Atlantic Bight.

Citation	*Related studies*	*MS*	*MG*	*D*	*R*	*A*	*Summary/notes*
Nilsson and Rosenberg 2003 (407)	575, 149	-	-	Exp	2	1	Sediment Profile Images (SPI's) used to describe seabed before and after trawling in area closed to shrimp trawling for 6 yrs, using a benthic habitat quality (BHQ) index . BHQ = f(surface structures, structures in sediment, and redox potential)
Palanques et al 2001 (277)	-	-	-	Exp	1	1	7 repeated sets at 30m and 14 at 40m in unfished area, before and after changes in bottom morphology monitored with side scan sonar, also eval turbidity, sediment comp in trawl lines before and at various times after trawling
Pilskaln et al 1998 (283)	-	-	-	Obs	4	1	Focus on sediment resusp as evid by infaunal worms in sediment traps 25-35 m off bottom; ; good disc of pros and cons of fishing on bottom geochemistry, but prelim study with few specifics
Pranovi and Giovanardi 1994 (287)	-	-	-	Exp	2	1	Study conducted in a coastal lagoon (Adriatic Sea) in dredged and undredged areas where variety of clams are harvested (not surfclams), recovery monitored after 20, 40, and 60 days
Prena et al 1999 (291)	same site as 128, 192, 325	-	-	Exp	2	3	See #325 for description of exp design - this study focused on trawl bycatch and effects on epifauna (and some infauna), used epibenthic sled for sampling
Probert et al 1997 (541)	64, 209	X	-	Comp	1	1	Evaluated bycatch in hill sites and flat sites during a survey for orange roughy.
Queiros et al 2006 (292)	658,368	-	-	Exp	2	2	Evaluated effects of diff levels of chronic trawling dist on community biomass and production and comm bio size spectra at two sites (North Sea, Irish Sea); only Irish Sea results should be used due to gear types
Rosenburg et al 2003 (313)	407	X	-	Comp	2	2	Sediment Profile images to evaluate macrofaunal biomass and abundance, sediment relief, redox profile discontinuity (variation in oxidation) in 2 locations.
Sanchez et al 2000 (320)	-	-	-	Exp	2	3	Exp study in trawled area at 2 sites swept once and twice in one day, effects on infauna evaluated after 24, 72, 102, and 150 hrs
Schwinghamer et al 1998 (325)	same site as 128, 192, 291	-	-	Exp	2	3	Experimental trawling (12 tows in 3 corridors, 3-6 tows per unit area, in 5 days) in area closed to trawling 1 yr previous to study and lightly fished for ca 10 yrs, repeated for 3 yrs; this study assessed physical impacts only
Sheridan and Doerr 2005 (330)	-	-	-	Comp	2	1	Compared sediments and benthos in 2 adjacent areas, one closed to shrimp trawling for 7 mos, core samples collected by divers
Simboura et al 1998 (599)	-	-	-	Comp	2	1	Assessed the structure of the benthic communities in relation to natural and anthropogenic factors; two sites compared, one w/o fishing and one fished, results componded by differences in sediment composition
Simpson and Watling 2006 (333)	-	-	-	Comp	4	2	Block exp design comparing habitat/macrofaunal community structure in trawled and untrawled areas at 2 sites before, during, and after shrimp trawling season using video and box core samples; trawling only occurred at inshore (84m) site during study.
Smith et al 1985 (334)		-	-	Comp	4	1	Used diver obs to estimate effect of trawling on lobsters and lobster habitat (summary on page v).
Smith et al 2000 (335)	336	-	X	Comp	1	2	Compared 2 stations inside a commercial trawling lane with 2 outside, video and grab sampling for 11 mos starting before 8 mo trawling season and ending well after
Smith et al 2003 (336)	335	X	X	Exp	1	1	Sediment profile imagery used to analyze sed penetration and roughness, plus a number of sediment attributes in trawled and untrawled areas at 2 sites; exp trawling in shallow-water site (13 tows during 2days)
Sparks-McConkey and Watling 2001 (338)	-	-	-	Exp	4	3	4 tows along one line (?) in one day at 2 stations, Pen Bay closed to trawling for 20 yrs, pre-trawl sampling of sediments/infauna for 1.5 yrs before trawling at exp stations and 7 reference stations, and 5d, 3.5mo and 5 mo after trawling
Stokesbury and Harris 2006 (352)	-	-	-	Exp	4	3	BACI study (video survey) in open and closed areas on GB: exp 1 compared CAII (closed) with NLCA (open) and exp 2 compared open and closed portions of CAI
Stone et al 2005 (355)	-	-	-	Comp	2	2	Examination of 'chronic' effects of trawling on epifauna inside and outside 2 areas closed to fishing for 11-12

Citation	*Related studies*	*MS*	*MG*	*D*	*R*	*A*	*Summary/notes*
							years, data collected along video transects by a submersible; analysis of key taxa and functional groups (prey, sedentary, low/high mobility)
Sullivan et al 2003 (359)	-	-	-	Exp	3	2	Submersible used to conduct pre-dredge and post-dredge surveys (2d, 3mo, 1 yr after dredging) and sample infaunal prey of YT flounder at 3 sites (2 deeper sites in Hudson Canyon closed area), multiple control and dredge treatments at each site
Tanner 2003 (360)	97	-	-	Exp	2	2	Anaysis of video images of sessile epifauna in treatment and control quadrats before and 1 wk/3 mos after trawling (2 tows) in 1 mud site and 2 sand sites in unfished area (15-20 yrs). Recruitment of major taxa also monitored - very good paper!
Tillin et al 2006 (368)	292	X	X	Comp	2	2	Large scale/long term impact of varying trawling intensity on functional composition of benthic invertebrate communities. Life-history based, multivariate assessment; large spatial scale study that fits well with feature-based approach
Tuck et al 1998 (372)	-	-	-	Exp	2	2	Repeated tows (10 tows, aver 1.5/unit area) 1d/mo for 16 mos in area closed to fishing for >25 yrs, infaunal surveys in trawled and ref site prior to, and after 5,10,16 mos of trawling, and 6,12,18 mos after trawling ended
Tuck et al 2000 (373)	-	-	-	Exp	2	1	Samples collected inside and outside of dredge tracks, recovery evaluated after 1 day, 5 days, and 11 wks, cage dredge designed to harvest razor clams, study site in Outer Hebrides (Scotland)
Van Dolah et al 1987 (382)	-	-	-	Exp	1	2	Diver counts of large sponges and corals (>10 cm high) in trawled and untrawled transects before, imm after, and 12 mos after a single tow in an unexploited area
Wassenberg et all 2002 (387)	-	-	-	Exp	2	1	Survey to determine depth/spatial dist of sponges, also quantified catch and damage of sponges and soft corals using a video camera in the net (McKenna demersal wing trawl) during 6 indiv trawl tows - net not used in NE region.
Watling et al 2001 (391)	-	-	-	Exp	1	2	Very shallow river-estuary. Maybe best example of gear impacts on completely undistrurbed muddy river bed. Divers collected bottom samples in control and exp plots before, imm after, and 4/6 mo after dredging (23 tows in 1 day)
Wheeler et al 2005 (393)	108, 136, 146	-	-	Comp	0	0	Seabed mapping with side scan sonar. Still, video imagery of trawled and untrawled mounds to id benthic organisms, estimate % coral cover.

Table 24 – Gears evaluated, by study. Note that all trawl types and both trap types were grouped for the matrix-based assessment.

Citation	*Generic otter trawl*	*Shrimp trawl*	*Squid trawl*	*Raised footrope trawl*	*Scallop dredge*	*Hydraulic dredge*	*Lobster trap*	*Deep-sea red crab trap*	*Longline*	*Gillnet*	*Gear notes*
Asch and Collie 2007 (404)	X	-	-	-	X	-	-	-	-	-	Scallop and otter trawl effort overlapping in study area.
Auster et al 1996 (11)	X	-	X	-	X	-	-	-	-	-	Impacts of single dredge and trawl tows observed on SB and at SI
Ball et al 2000 (17)	-	-	X	-	-	-	-	-	-	-	Exp Nephrops trawl with a light tickler chain.
Bergman and VanSantbrink 2000 (21)	X	-	-	-	-	-	-	-	-	-	Comm flatfish trawl, 20 cm rollers
Blanchard et al 2004 (24)	X	-	-	-	-	-	-	-	-	-	-
Boat Mirarchi and CR Environmental 2003 (408)	X	-	-	-	-	-	-	-	-	-	Smooth bottom (flatfish) trawl: 350 kg doors, 2.5 in rubber cookies on ground cables/bridles, sweep 0.5 in chain with continuous string of 6 in cookies
Boat Mirarchi and CR Environmental 2005 (409)	X	-	-	-	-	-	-	-	-	-	Two vessels used for exp trawling using flatfish trawls (see #408),area trawled/dredged between yr 1 and yr 2 of study
Brown et al 2005a (34)	X	-	-	-	-	-	-	-	-	-	Victory trawl, footrope rigged w 36 cm rubber diks, 13 cm rubber disks on bottom bridle and sweep lines, high lift doors 5.5 m2 weighing 1250 kg in water.
Brown et al 2005b (35)	X	-	-	-	-	-	-	-	-	-	Same gear as study 34.
Burridge et al 2003 (38)	-	-	X	-	-	-	-	-	-	-	Gear: a single 12-fathom (21.9 m) "Florida Flyer" prawn (=shrimp) trawl with a ground chain. Possible illegal fishing in closed area, but authors deemed unlikely based on distance offshore/uncharted waters (conf by Gribble and Robertson 1998).
Caddy 1968 (42)	-	-	-	-	X	-	-	-	-	-	2.4 meter wide chain-sweep dredge modified to reduce weight (forward drag bars replaced with chains)
Caddy 1973 (43)	-	-	-	-	X	-	-	-	-		2.4 m wide chain-sweep dredge
Clark and O'Driscoll 2003 (64)	X	-	-	-	-	-	-	-	-	-	-
Coggan et al 2001 (414)	X	X	X	X	-	-	-	-	-	-	-
Collie et al 1997 (69)	X	-	-	-	X	-	-	-	-	-	Authors note there was a gradient in dredging disturbance from least dist to most dist sites; degree of dist based on SS sonar evidence of gear tracks, video obs of epifauna, and VTR data of scallop dredging by TNMS in US waters
Collie et al 2000 (70)	X	-	-	-	X	-	-	-	-	-	See #69
Collie et al 2005 (71)	X	-	-	-	X	-	-	-	-	-	Fishing patterns (trawl and dredge) at study sites based on US and Canadian logbook data, VMS data for US scallop vessels
De Biasi 2004 (88)	X	-	-	-	-	-	-	-	-	-	Trawl gear - footrope with 1 kg lead weights (no chains), 2 oval, iron doors weighing 250 kg each; parallel tows spaced 160 m apart
de Juan et al 2007a (89)	X	-	-	-	-	-	-	-	-	-	-
de Juan et al 2007b (90)	X	-	-	-	-	-	-	-	-	-	-
DeAlteris et al 1999 (92)	X	-	-	-	-	-	-	-	-	-	combined gear used in area 95% trawl, 5% mussel dredge

Citation	***Generic otter trawl***	***Shrimp trawl***	***Squid trawl***	***Raised footrope trawl***	***Scallop dredge***	***Hydraulic dredge***	***Lobster trap***	***Deep-sea red crab trap***	***Longline***	***Gillnet***	***Gear notes***
Dellapenna et al 2006 (406)	-	X	-	-	-	-	-	-	-	-	1.5 x 2.5 m >50kg doors, tickler chain on footrope
Drabsch et al 2001 (97)	-	-	X	-	-	-	-	-	-	-	Triple prawn (shrimp) trawl with chain sweeps, each door 1x2 m/200 kg - more approp for squid trawl evaluation?
Engel and Kvitek 1998 (101)	X	-	-	-	-	-	-	-	-	-	HT area fished commercially for >100 yrs and exposed to 12 x more trawling than LT area which is inside 3 mi no trawling zone, but was open in one yr as a "refuge site" in bad weather
Eno et al 2001 (102)	-	-	-	-	-	-	X	-	-	-	Gear: pots (H. gammarus, C. pagurus, B. undatum); creels (N. norvegicus).
Fossa et al 2002 (108)	X	-	-	-	-	-	-	-	X	X	-
Freese 2001 (110)	X	-	-	-	-	-	-	-	-	-	-
Freese et al 1999 (111)	X	-	-	-	-	-	-	-	-	-	60 cm rubber tires at center of footrope, 45 cm rockhopper/steel bobbins on wings, trawl similar to those used in rockfish fishery
Frid et al 1999 (113)	-	-	X	-	-	-	-	-	-	-	Deep water site located in prawn trawl fishing ground
Gibbs et al 1980 (119)	-	-	X		-	-	-	-	-	-	Prawn trawl with 1 x 0.5 m flat doors
Gilkinson et al 1998 (120)	X	-	-	-	-	-	-	-	-	-	-
Gilkinson et al 2003 (121)	-	-	-	-	-	X	-	-	-	-	-
Gilkinson et al 2005a (122)	-	-	-	-	-	X	-	-	-	-	-
Gilkinson et al 2005b (123)	-	-	-	-	-	X	-	-	-	-	-
Gordon et al 2005 (128)	X	-	-	-	-	-	-	-	-	-	Otter trawl with rock hopper gear.
Grehan et al 2005 (136)	X	-	-	-	-	-	-	X	X	X	Typical gears described on p 820.
Hall et al 1990 (140)	-	-	-	-	-	X	-	-	-	-	-
Hall et al 1993 (141)	X	-	-	-	-	-	-	-	-	-	-
Hall-Spencer et al 2002 (146)	X	-	-	-	-	-	-	-	-	-	-
Hansson et al 2000 (149)	-	X	-	-	-	-	-	-	-	-	Commercial shrimp trawl with leaded ground rope and 125 kg doors
Henry et al 2006 (157)	X	-	-	-	-	-	-	-	-	-	Rockhoppers on footrope
Hermsen et al 2003 (158)	X	-	-	-	X	-	-	-	-	-	-
Hinz et al 2009 (658)	X	-	X	-	-	-	-	-	-	-	Nephrops and gadid trawl fisheries, trawling intensity ranged from 1.3 to 18.2 times trawled/yr, area fished for >100 yrs
Hixon and Tissot 2007 (164)	X	-	-	-	-	-	-	-	-	-	-
Kaiser et al 2000 (184)	X	-	-	-	-	-	X	-	-	-	Fishing effort defined as low=pots only, medium=seasonal trawl use, high=trawling year-round
Kenchington et al 2001 (192)	X	-	-	-	-	-	-	-	-	-	See #325
Kenchington et al 2005 (193)	X	-	-	-	-	-	-	-	-	-	Rockhopper gear.

Citation	***Generic otter trawl***	***Shrimp trawl***	***Squid trawl***	***Raised footrope trawl***	***Scallop dredge***	***Hydraulic dredge***	***Lobster trap***	***Deep-sea red crab trap***	***Longline***	***Gillnet***	***Gear notes***
Kenchington et al 2006 (194)	X	-	-	-	-	-	-	-	-	-	See p. 252 for info re how often grab-sampled locations were swept by trawl (average 4-8 times yrs 1-2 by some part of trawl, 1-4 x just rock hoppers and net)
Knight 2005 (203)	X	-	-	-	X	-	-	-	-	-	-
Koslow et al 2001 (209)	X	-	-	-	-	-	-	-	-	-	-
Koulouri et al 2005 (211)	X	-	-	-	-	-	-	-	-	-	-
Kutti et al 2005 (214)	X	-	-	-	-	-	-	-	-	-	Gear: commercial trawl equipped with 2300 kg otter boards and 21 in rockhoppers.
Langton and Robinson 1990 (217)	-	-	-	-	X	-	-	-	-	-	-
Lindegarth et al 2000 (575)	-	X	-	-	-	-	-	-	-	-	Detailed description of gear in Hansson et al (2000)
Lindholm et al 2004 (225)	X	-	-	-	X	-	-	-	-	-	Open area impacted by bottom trawls and scallop dredges
Link et al 2005 (228)	X	-	-	-	X	-	-	-	-	-	-
MacKenzie 1982 (232)	-	-	-	-	-	X	-	-	-	-	-
Mayer et al 1991 (236)	X	-	-	-	X	-	-	-	-	-	Trawl footrope with tickler chain and 90 kg doors
McConnaughey et al 2000 (238)	X	-	-	-	-	-	-	-	-	-	Flatfish Trawl used for Yellowfin sole.
McConnaughey et al 2005 (239)	X	-	-	-	-	-	-	-	-	-	-
Medcof and Caddy 1971 (244)	-	-	-	-	-	X	-	-	-	-	-
Meyer et al 1981 (245)	-	-	-	-	-	X	-	-	-	-	-
Morais et al 2007 (247)	-	X	X	-	-	-	-	-	-	-	Area heavily fished by crustacean trawlers (shrimp, prawns), but mostly outside canyon (<200m?)
Moran and Stephenson 2000 (248)	X	-	-	X	-	-	-	-	-	-	"Light" bottom trawl, 20 cm diameter disks separated by 30-60 cm long spacers of 9 cm diameter on footrope (may have lifted over some benthic organisms w/o removing them)
Morello et al 2005 (249)	-	-	-	-	-	X	-	-	-	-	-
Mortensen et al 2005 (254)	X	-	-	-	-	-	-	-	X		-
Murawski and Serchuk 1989 (256)	-	-	-	-	-	X	-	-	-	-	-
Nilsson and Rosenberg 2003 (407)	-	X	-	-	-	-	-	-	-	-	-
Palanques et al 2001 (277)	X	-	-	-	-	-	-	-	-	-	Fishing done by two commercial trawlers - lead weights in footropes

Citation	Generic otter trawl	Shrimp trawl	Squid trawl	Raised footrope trawl	Scallop dredge	Hydraulic dredge	Lobster trap	Deep-sea red crab trap	Longline	Gillnet	Gear notes
Pilskaln et al 1998 (283)	X	-	-	-	-	-	-	-	-		-
Pranovi and Giovanardi 1994 (287)	-	-	-	-	-	X	-	-	-		-
Prena et al 1999 (291)	X	-	-	-	-	-	-	-	-		See #325
Probert et al 1997 (541)	X	-	-	-	-	-	-	-	-		O. roughy trawl has 600 mm steel bobbins.
Queiros et al 2006 (292)	X	-	X	-	-	-	-	-	-		Beam trawls used on Dogger Bank, otter trawls in Irish Sea (Nephrops fishery).
Rosenburg et al 2003 (313)	X	-	-	-	-	-	-	-	-		Exp fishing in fjord (site a) - see #407- data collected at 4 locations at site b exposed to unknown levels of fishing, no controls
Sanchez et al 2000 (320)	X	-	-	-	-	-	-	-	-		No info
Schwinghamer et al 1998 (325)	X	-	-	-	-	-	-	-	-		Engel 145 bottom trawl with 1250 kg doors and 46 cm rockhopper gear
Sheridan and Doerr 2005 (330)	-	X	-	-	-	-	-	-	-		-
Simboura et al 1998 (599)	X	-	-	-	-	-	-	-	-		Gear types fishing in Petalioi not well specified (=bottom trawlers).
Simpson and Watling 2006 (333)	-	X	-	-	-	-	-	-	-		
Smith et al 1985 (334)	X	-	-	-	-	-	-	-	-		Gear: otter trawl with 1.8 m door and 1 cm footrope chain.
Smith et al 2000 (335)	X	X	-	-	-	-	-	-	-		Commercial fishing for hake and shrimp (no description of gear)
Smith et al 2003 (336)	X	X	-	-	-	-	-	-	-		Commercial fishing for hake and shrimp at 200 m, no description of trawl used for exp fishing at shallow-water site
Sparks-McConkey and Watling 2001 (338)	-	X	-	-	-	-	-	-	-		Modified commercial silver hake net (increased mesh size and decreased diameter of float rollers) to reduce impacts to seafloor (to mimic impacts of shrimp trawl)
Stokesbury and Harris 2006 (352)	-	-	-	-	X	-	-	-	-		-
Stone et al 2005 (355)	X	-	-	-	-	-	-	-	-		Site 1 open area for trawling and scallop dredging, site 2 just for trawls (?)
Sullivan et al 2003 (359)	-	-	-	-	X	-	-	-	-		Impact "boxes" thoroughly dredged with paired NB-style dredges (4.6 m wide, 89mm ring size)
Tanner 2003 (360)	-	X	X	-	-	-	-	-	-		Triple prawn (shrimp) trawl with chain sweeps, each door 1x2 m/200 kg - more approp for squid trawl evaluation?
Tillin et al 2006 (368)	X	-	X	-	-	-	-	-	-		Beam trawls used in southern North Sea, OT in north (FG and LF fishing grounds) for Nephrops and gadoids, low energy for prawn trawls (mud), high for OT (sand, gr-p)
Tuck et al 1998 (372)	X	-	-	-	-	-	-	-	-		No net (??), modified rockhopper ground gear
Tuck et al 2000 (373)	-	-	-	-	-	X	-	-	-		-

Citation	Generic otter trawl	Shrimp trawl	Squid trawl	Raised footrope trawl	Scallop dredge	Hydraulic dredge	Lobster trap	Deep-sea red crab trap	Longline	Gillnet	Gear notes
Van Dolah et al 1987 (382)	X	-	-	-	-	-	-	-	-	-	"Roller" trawl with 30 cm rubber rollers on footrope separated by 15 cm rubber discs
Wassenberg et all 2002 (387)	X	-	-	-	-	-	-	-	-	-	Groud gear with 60/80 mm diameter bobbins or rubber discs and lead weights, suspended by drop chains from footrope, allowing leading part of net to clear bottom
Watling et al 2001 (391)	-	-	-	-	X	-	-	-	-	-	2 meter wide chain-sweep dredge towed at 2 knots
Wheeler et al 2005 (393)	X	-	-	-	-	-	-	-	-	-	-

Table 25 – Study environment. For the matrices, the following categories were combined to designate studies belonging in particular cells: If energy was listed as high, high-inferred, both, or unknown, the study was added to the high energy column; similarly, low, low-inferred, both, or unknown was added to the low energy column. For substrate, clay-silt and muddy sand were assigned to mud; muddy sand and sand were assigned to sand. Rock outcrop was assigned to boulder.

Citation	*Location*	*Energy*	*Energy notes*	*Depth range*	*Clay-silt*	*Muddy sand*	*Sand*	*Granule-pebble*	*Cobble*	*Boulder*	*Rock outcrop*	*Substrate notes*
Asch and Collie 2007 (404)	Northern Edge (in and around Closed Area II), Eastern Georges Bank, US/CAN	High	All sites high energy, author's notes confirmed by output of critical shear stress model	42-90				X	X			Only examined sites dominated by gravel substrate (as identified by Valentine et al 1993)
Auster et al 1996 (11)	Gulf of Maine: Swans Island (SI), Jeffreys Bank (JB), Stellwagen Bank (SB)	High	SI - 30-40m; JB - 94; SB - 20-55m; high energy at SB and SI, low at JB	20-94	X		X	X	X	X		SI - sand, cobble, shell; JB - mud draped gravel and large boulders; SB - gravel, sand, shell
Ball et al 2000 (17)	Irish Sea	Both	Deeper site low energy, shallow site high energy (?)	35-75	X	X						Sandy silt at deeper site (44% fine sand, 55% silt-clay), muddy sand at shallow site (55/40%).
Bergman and VanSantbrink 2000 (21)	Southern North Sea, Dutch Coast	High, inf	inferred from depth and location	20-45		X	X					Silty sand (offshore, <30-40m) and sand (inshore, 40-50m), silty sand 3-10% silt
Blanchard et al 2004 (24)	Bay of Biscay, France	Low, inf	Low, based on depth - samples collected around 100 m to "avoid strong natural disturbances"	106-129	X	X	X					Mud (muddy sand and sandy mud (10-35% silt)) sampled with Reineck corer
Boat Mirarchi and CR Environmental 2003 (408)	Gulf of Maine, MA coast	High, inf	inferred based on shallow depth	36-48		X	X					HF - muddy sand; LF - sand
Boat Mirarchi and CR Environmental 2005 (409)	Gulf of Maine, MA coast	High	inferred based on shallow depth; description of site as high natural disturbance, storm prior to last sampling date (Nov) eroded finer sediments and created sand waves	36-48		X	X					See #408: shallow (36m) site sand, deeper site (48m) muddy sand
Brown et al 2005a (34)	Bristol Bay, eastern Bering Sea	High	Persistent wave disturbance to study area (see Brown et al 2005b, which modeled energy)	20-30		X	X					Fine sand
Brown et al 2005b (35)	Bering Sea	High	modeled wave energy of seabed	20-30		X	X					

Citation	***Location***	***Energy***	***Energy notes***	***Depth range***	***Clay-silt***	***Muddy sand***	***Sand***	***Granule-pebble***	***Cobble***	***Boulder***	***Rock outcrop***	***Substrate notes***
Burridge et al 2003 (38)	A large closed area in the Far Northern Great Barrier Reef off Queensland, Australia. Towed in lagoon/shoal area between mainland and reef. Used prev BACI study to choose tow sites w/ typical sponge, gorgonian, coral fauna, but avoid reefs.	High, inf	Inferred based on depth.	20-35			X	X				Assumed. However, Poiner et al show substantial variation in sed comp and biol comm in same area.
Caddy 1968 (42)	Northumberland Strait, Gulf of St. Lawrence, CAN	High, inf	Tidal currents up to 0.7 knots	20-20	X	X	X					substrate patchy with mud and sand areas
Caddy 1973 (43)	Chaleur Bay, Gulf of St. Lawrence, CAN	High, inf	Energy inferred from depth	40-50			X	X	X	X		Gravel over sand, with occ boulders
Clark and O'Driscoll 2003 (64)	New Zealand seamounts - N Chatham Rise, Graveyard Hills (one heavily fished one lightly fished per seamount)	Low, inf	low based on depth	748-1100								
Coggan et al 2001 (414)	Clyde Sea and Aegean Sea	Low, inf	Clyde Sea site depths ranged 30-100 m, water column remains stratified much of year; Aegean Sea sites 70-250 m	30-250	X	X	X					Clyde Sea -mud, muddy-sand, or sandy-mud at all depths; Aegean Sea - sand/maerl at shallower depths, mud at deeper depths
Collie et al 1997 (69)	Eastern Georges Bank (US and Canada)	High	All sites high energy, author's notes confirmed by output of critical shear stress model	42-90			X	X	X	X		pebble-cobble pavement with some overlying sand, <5% scattered boulders create obstacles to fishing
Collie et al 2000 (70)	Eastern Georges Bank (US and Canada)	High	All sites high energy, author's notes (in #69) confirmed by output of critical shear stress model	42-90			X	X	X	X		pebble-cobble pavement with some overlying sand and scattered boulders (see #69)
Collie et al 2005 (71)	Eastern Georges Bank (US and Canada)	High	All sites high energy, author's notes (in #69) confirmed by output of critical shear stress model	47-84			X	X	X	X		pebble-cobble pavement with some overlying sand and boulders (see #69,70)
De Biasi 2004 (88)	Tyrrhenian Sea, Mediterannean	Unk	energy regime not described - discussion alludes to expectation of quick recovery in shallow-water disturbed environments	32-34	X							
de Juan et al 2007a (89)	Coast of Spain, Mediterranean Sea	Low, inf	study done in same area as Palanques et al (2001) and near Gulf of Lions, where mud sediment at this depth was in low energy portion of shelf	30-80	X							95% muddy sediment

Citation	***Location***	***Energy***	***Energy notes***	***Depth range***	***Clay-silt***	***Muddy sand***	***Sand***	***Granule-pebble***	***Cobble***	***Boulder***	***Rock outcrop***	***Substrate notes***
de Juan et al 2007b (90)	Coast of Spain, Mediterranean Sea	Low, inf	study done in same area as Palanques et al (2001) and near Gulf of Lions, where mud sediment at this depth was in low energy portion of shelf	30-80	X							-
DeAlteris et al 1999 (92)	Naraganett Bay, Rhode Island, USA	High, inf	Inferred based on depth	7-14	X		X					Sand at 14 m, mud at 7 m
Dellapenna et al 2006 (406)	Galveston Bay, Texas, USA	High, inf	Inferred based on depth: episodic high energy, re wind/weather; very shallow 2-3 m	2-3	X							-
Drabsch et al 2001 (97)	Gulf of St Vincent, S. Australia	Low, inf	Depths >20m in central gulf, GSV protected from high wave activity by large,offshore island, depositional environment (see Tanner et al 2003, study #360)	20-20	X		X					Medium-coarse sand and shell fragments at sites 1 and 3, fine silt at site 2, all sites at same depth
Engel and Kvitek 1998 (101)	Monterey Bay Natl Marine Sanctuary, central California, USA	Low, inf	Inferred based on depth	180-180	X		X	X	X	X		No signif difference in pct comp of any grain size category between areas
Eno et al 2001 (102)	Great Britain: (a) off Scotland (B) Lyme Bay (c) Greenala Point	Unk	Depths (A) - uncertain, but divable (B,C) - no deeper than 23 m. Energy - examining norway lobster fishery; spp lives in soft mud - but depths are rel. shallow, so coded as unknown.	-	X				X	X	X	Clay-silt substrate described as "soft mud".
Fossa et al 2002 (108)	Off west Norway	Low, inf	Most corals dist between 200-400 m	200-400						X	X	Corals most common on 'substrate of morainic origin' - not sure if this indicates rock outcrops or gravel piles
Freese 2001 (110)	Gulf of Alaska	Low, inf	Inferred based on depth	206-274				X	X	X		93% pebble, 5% cobble, 2% boulder
Freese et al 1999 (111)	Gulf of Alaska	Low, inf	Inferred based on depth	206-274				X	X	X		93% pebble, 5% cobble, 2% boulder - occ in large piles
Frid et al 1999 (113)	North Sea (NE England)	Both	Shallow site high, deep site low??? No info in paper	55-80	X		X					55 m site (Station M1) has 20% silt clay; 80 m site has > 50% silt clay, of which 20% is faecal pellets - both sites have brittle-star dominated community
Gibbs et al 1980 (119)	Botany Bay, New South Wales, Australia	High, inf	Inferred based on location (a shallow estuary) although no specific depth given	-		X						Sand with 0-30% silt-clay

Citation	Location	Energy	Energy notes	Depth range	Clay-silt	Muddy sand	Sand	Granule-pebble	Cobble	Boulder	Rock outcrop	Substrate notes
Gilkinson et al 1998 (120)	flume tank to sim Grand Banks off Newfoundland	High	Simulated habitat in a flume tank	-			X					-
Gilkinson et al 2003 (121)	Scotian Shelf	Low	low energy zone (defined by Amos and Fader 1988); adjacent Eastern Shoal is high energy	70-80			X					Sand with shell deposits
Gilkinson et al 2005a (122)	Scotian Shelf	Low	same site as study 121	70-80			X					Sand with shell deposits
Gilkinson et al 2005b (123)	Scotian Shelf	Low	same site as study 121	70-80			X					-
Gordon et al 2005 (128)	Grand Banks off Newfoundland	Low	sediment thought to be below depth of wave induced sediment transport (Amos and Judge 1991 cited by authors))	120-146			X					-
Grehan et al 2005 (136)	NE Atlantic - carbonate mounds in Irish Porcupine Seabight and Rockall Trough	Low, inf	current speeds > 40 cm/s close to mounds	500-1200								-
Hall et al 1990 (140)	Loch Garloch, Scotland	High		7-7			X					Fine sand
Hall et al 1993 (141)	North Sea	Unk		80-80			X					-
Hall-Spencer et al 2002 (146)	off West Ireland and off West Norway	Low, inf	Also shallower sites (200 m) W. Norway	840-1300								-
Hansson et al 2000 (149)	Fjord off W. Sweden	Low, inf	bottom water described as stagnant; turns over in spring; assumed low energy from setting, depth, and substrate	75-90	X							substrate features not described
Henry et al 2006 (157)	Western Bank (Scotian Shelf)	High		70-70			X	X	X	X		Pebbles/cobbles overlaying medium to gravelly sand with some sand and boulders
Hermsen et al 2003 (158)	N. Edge Georges Bank, US/CAN sides	High	All sites high energy, author's notes (in #69) confirmed by output of critical shear stress model	47-90			X	X	X	X		pebble-cobble pavement with some overlying sand and boulders
Hinz et al 2009 (658)	Northeastern Irish Sea off the Cumbrian coast (same area as #292)	High, inf	shear stress at 15 sites that were analyzed averaged 0.21 N/m2 (based on 2D hydrographic model): 0.21 N/m2 is moderate energy	31-31	X	X						mostly fine sand and muddy sediment deposits, average 67% (+-14%) silt and clay at 15 analyzed sites
Hixon and Tissot 2007 (164)	Oregon Coast, USA (Coquille Bank)	Low, inf	inferred by depth - authors describe "minimal water motion" in study area	183-361	X							-

Citation	***Location***	***Energy***	***Energy notes***	***Depth range***	***Clay-silt***	***Muddy sand***	***Sand***	***Granule-pebble***	***Cobble***	***Boulder***	***Rock outcrop***	***Substrate notes***
Kaiser et al 2000 (184)	South Devon Coast, England	High, inf	one inshore site (15-18 m), two offshore (53-70 m), deeper sites "less likely" to be affected by wave action, but assumed high energy given depth and exposure	15-70			X					discriminated between fine, medium/fine, coarse/medium sand; also stone (size not specified) at deeper sties and shell debris at all sites
Kenchington et al 2001 (192)	Grand Banks, Newfoundland, CAN	Low	See #325	120-146			X					See #325
Kenchington et al 2005 (193)	Western Bank (Scotian Shelf)	High	See 194	70-70			X	X	X			Pebbles/cobbles overlaying medium to gravelly sand
Kenchington et al 2006 (194)	Western Bank, Scotian Shelf	High	"Moderate levels of natural dist with major perturbations induced by storms, esp in winter"	70-70			X	X	X	X		Pebbles/cobbles overlaying medium to gravelly sand with some sand and boulders
Knight 2005 (203)	Gulf of Maine	Low, inf	defined based on depth and shear stress model	100-130	X	X	X	X				-
Koslow et al 2001 (209)	South of Tasmania	Low, inf	deep water	714-1580								-
Koulouri et al 2005 (211)	Crete, Mediterannean Sea	Unk		50-50	X							-
Kutti et al 2005 (214)	Barents Sea, Norway; 9 nm west of Bear Island	Low, inf	Inferred based on depth	85-101			X		X	X		bottom substrate at site is dom by shell debris mixed to varying degrees with finer sed, agg of boulders at several locations
Langton and Robinson 1990 (217)	Jeffreys and Fippennies Ledges, Gulf of Maine, USA	Low, inf	defined by depth and shear stress estimates	80-100		X	X	X	X	X		Grain size analysis on Fipp showed that 84% of sediment to 5 cm was sand, with some gravel; shell hash, small rocks also present
Lindegarth et al 2000 (575)	Gullmarsfjorden, Sweden-	Low, inf	inferred from depth and sediment type	75-90	X							study area is described in Hansson et al (2000)
Lindholm et al 2004 (225)	Eastern Georges Bank - southern part of Closed Area II	High, inf	coded as high energy, but lower influence of tidal and storm driven currents at deeper stations as compared to shallower stations	40-95			X					Microhabitats all sandy, gravelly sand, or shell fragments with and w/o emergent epifauna
Link et al 2005 (228)	Closed Area I and southern part of Closed Area II, Georges Bank, USA	High	CAI (55-110m) exposed to strong storm/tidal currents, CAII (35-90m) higher energy in shallower, NW portion of study area, but all impacted by intermittent storm currents	35-90		X	X	X	X			CAI divided into 3 zones based on energy and substrates, CA II into 2 zones; substrate highly variable in CAI, sand in CAII

Citation	***Location***	***Energy***	***Energy notes***	***Depth range***	***Clay-silt***	***Muddy sand***	***Sand***	***Granule-pebble***	***Cobble***	***Boulder***	***Rock outcrop***	***Substrate notes***
MacKenzie 1982 (232)	East of Cape May, NJ, USA	High, inf	No indication of energy regime, only depth -	37-37			X					Very fine to medium sand
Mayer et al 1991 (236)	Gulf of Maine, Coastal ME, USA	High, inf	8 m site in a channel among coastal islands, well flushed by tidal currents. 20 m site protected from open ocean waves by rock ledge	8-20	X							8m site poorly sorted mud with abundant shell hash, 20m site fine-grained mud. Sand and mud below sediment surface at 8m.
McConnaughey et al 2000 (238)	Eastern Bering Sea, AK, USA	High	Site in similar location as compared to studies 34, 35; author describes site as 'high tidal currents'	44-52			X					Sand with ripples
McConnaughey et al 2005 (239)	Bristol Bay, Eastern Bering Sea, AK, USA	High	Site in similar location as compared to studies 34, 35; author describes site as 'high tidal currents', Flow >1m/s	44-52			X					Same study area as #238
Medcof and Caddy 1971 (244)	Southern Nova Scotia, CAN	High, inf	inferred based on shallow depth	7-12		X	X					-
Meyer et al 1981 (245)	Long Island, NY, USA	High, inf	inferred based on depth	11-11		X	X					Fine to medium sand covered by silt layer
Morais et al 2007 (247)	Canyon south of Portugal	Low		120-286	X	X	X	X		X	X	Multiple substrates
Moran and Stephenson 2000 (248)	Northwest Australia	High, inf	high energy inferred from depth (see study #387	50-55			X	X				Sand and gravel INFERRED, but not stated explicitly
Morello et al 2005 (249)	Coastal Adriatic Sea, heavily dredged for bivalve Chamelea gallina	High, inf	inferred based on depth	6-6			X					-
Mortensen et al 2005 (254)	Northeast Channel, Nova Scotia, Between Georges Bank and Browns Bank	High, inf	Strong currents, 40-50 cm/s 16 m off bottom	190-500		X	X	X				Thick till - unstrat glacial dep with mix of gravel, sand, silt, clay; % cover of subst types est for each video sequence
Murawski and Serchuk 1989 (256)	Mid-Atlantic Bight, USA	High, inf	No info re depths or energy levels. High inferred - most shellfish resources shallower than depth threshold in spatial model?	-	X	X	X	X				-
Nilsson and Rosenberg 2003 (407)	Fjord, W coast Sweden	Low, inf	fairly deep, muddy sediments; low energy inferred from depth and sed type	75-90	X							See Hansson et al (2000) for description of study area

Citation	***Location***	***Energy***	***Energy notes***	***Depth range***	***Clay-silt***	***Muddy sand***	***Sand***	***Granule-pebble***	***Cobble***	***Boulder***	***Rock outcrop***	***Substrate notes***
Palanques et al 2001 (277)	NW Mediterranean Sea	Low	study done in summer when shear stress from bottom currents and wave action was not energetic enough to suspend muddy sediments	30-40	X							> 80% clay and silt
Pilskaln et al 1998 (283)	Jordan and Wilkinson Basins, Gulf of Maine, USA	Low, inf	250 meters	-	X							Mud bottom inferred from depth and observed turbidity
Pranovi and Giovanardi 1994 (287)	Venice Lagoon (coastal), Adriatic Sea, Italy	Low	Environment described as med/low energy, but subject to strong env and anthropogenic stresses (eg temp changes, O2 depletion)	1-2			X					-
Prena et al 1999 (291)	Grand Banks, Newfoundland, CAN	Low	See #325	120-146			X					See #325
Probert et al 1997 (541)	New Zealand seamounts on Chatham Rise: Graveyard, Spawning Box, NE Area	Low, inf		662-1524							X	Hills and flats examined; substrate not well specified
Queiros et al 2006 (292)	Irish Sea	High	Irish Sea - large tidal ranges that allow accum of mud-sand belts	27-40	X	X						muddy sand (16-75% silt-clay at 7 study areas)
Rosenburg et al 2003 (313)	(a) fjord on W coast Sweden (b) Gulf of Lions, NW Mediterranean	Low, inf	(a) Gullmarsfjord - 73-96 m deep; (b) GOL - 35-88 m deep - low energy mud (see Dufois et al 2007)	73-93	X	X	X					Mud and some sand at site a - for site a, see related studies
Sanchez et al 2000 (320)	Coastal Spain, Mediterreanean Sea	Low, inf	Same study area as Palanques et al (2001) and De Juan et al (2007), low energy inferred from substrate and proximity to Gulf of Lions, where shelf at this depth is low energy	30-40	X							"muddy seabed"
Schwinghamer et al 1998 (325)	Grand Banks, Newfoundland, CAN	Low	no wave induced ripples (authors cited Barrie et al 1984); below depth of storm induced sed trans (cited Amos and Judge 1991)	120-146			X					Moderately to well-sorted medium to fine grained sand
Sheridan and Doerr 2005 (330)	Gulf of Mexico, TX coast, USA	High, inf	High energy area implied (shallow, open coast)	5-20	X	X	X					-
Simboura et al 1998 (599)	Two adjacent gulfs in the Aegean Sea.	High, inf	Most sites 60-70 m, some shallower.	31-70	X	X	X					ca 100% finer sed at S. Evvoikos and sand (70-83%) at Petalioi
Simpson and Watling 2006 (333)	Maine coast, Gulf of Maine, USA	Low, inf	Inferred based on depth and shear stress	84-102	X							-
Smith et al 1985 (334)	Long Island Sound, NY, USA	High, inf	Inferred based on depth	-	X	X	X					-

Citation	Location	Energy	Energy notes	Depth range	Clay-silt	Muddy sand	Sand	Granule-pebble	Cobble	Boulder	Rock outcrop	Substrate notes
Smith et al 2000 (335)	N. coast Crete, Mediterreanean Sea	Low, inf	inferred from sed type and depth	-200	X							80% silt-clay
Smith et al 2003 (336)	Aegean Sea, north coast of Crete	Low, inf	Low energy inferred at deep site (see #335); unknown at shallow site	80-200	X	X	X					mud at 200 m (same site as #335), coarse sand (68%), with some localized mud and maerl fragments at 80-90 m site
Sparks-McConkey and Watling 2001 (338)	Gulf of Maine, Penobscot Bay, ME, USA	Low, inf	Not 100% sure about this one; Paper hints that it's a low energy environment (P. 74, 2nd paragraph) because of presence of clay-silt sediments.	60-60	X							-
Stokesbury and Harris 2006 (352)	Georges Bank, USA	High, inf	Both sites in each exp with similar tidal current velocities	52-70			X	X	X	X		Depth range is means at 4 sites; impact areas in boith exps deeper with more sand than control areas
Stone et al 2005 (355)	Central Gulf of Alaska near Kodiak Island	Both	Bottom currents strong (28 cm/s at neap tide) at site 1, moderate to light (<0.28 m/s) at site 2; depths in transect areas 105-151m site 1, 125-157m site 2	105-157			X					Two sites, one with medium/fine sand (site 1), the other with very fine sand (site 2)
Sullivan et al 2003 (359)	New York Bight, USA	High	Sediment transport model based on wave oscillatory currents predicted bottom disturbance 100% of time at all seasons at 10m, 17% at 50m, and 3% at 100m, with almost all transport >50m storm-driven.	45-88		X	X					Medium-coarse sand at 10 and 50m, fine sand-silt at 100m
Tanner 2003 (360)	Gulf of St. Vincent, Australia	Low, inf	Depths >20m in central gulf, GSV protected from high wave activity by large, offshore island, depositional environment	20-20	X		X					Medium-coarse sand and shell fragments at site 1 and 3, fine silt at site 2
Tillin et al 2006 (368)	North Sea - 4 sites - focus on northern sites here	Both	FG - shear stress 0.08-0.11 N/m2 (low), depth 142-153 m; LF - shear stress 0.30-0.36 (high), depth 74-83 m	74-153	X		X	X				Fladen Ground (FG) - mud; Long Forties (LF) - gravelly sand
Tuck et al 1998 (372)	West coast of Scotland	Low	Sheltered loch; tidal currents of up to 5 knots occur over the shallow (12 m) sandy sill at the narrow (350 m) entrance to the loch, but in the deeper water of the main loch currents are greatly reduced and the seabed is muddy	30-35	X							Approx 95% silt and clay

Citation	Location	Energy	Energy notes	Depth range	Clay-silt	Muddy sand	Sand	Granule-pebble	Cobble	Boulder	Rock outcrop	Substrate notes
Tuck et al 2000 (373)	Sound of Ronay, Outer Hebrides, Scotland	High, inf	These areas provide extreme shelter from wave action, and a wide range of tidal stream strengths through the many narrow channels and rapids (Boyd, 1979)	2-5			X					-
Van Dolah et al 1987 (382)	Georgia, USA	High, inf	Inferred based on depth	20-20			X					Smooth rock (no outcrops) with thin layer of sand, described as "low relief, hard-bottom habitat"
Wassenberg et all 2002 (387)	NW Australia	High, inf	Average depth 78.3 m, most sponges caught <100m, none >156m; high energy inferred based on depth and sediment type plus open exposed nature of coastline	25-358			X	X				coarse sand with 10-30% gravel
Watling et al 2001 (391)	Damariscotta River, ME, USA	High, inf		15-15	X	X						-
Wheeler et al 2005 (393)	Darwin Mounds, small (up to 5 m high, 75 m across) coral-topped mounds about 1000 m deep in N Rockall Trough off UK	Low, inf		900-1060								-

Table 26 – Geological features evaluated by various studies.

Citation	*Surfacne and subsurface sediments*	*Biogenic depressions*	*Biogenic burrows*	*Bedforms*	*Scattered gravel*	*Gravel pavement*	*Piled gravel*	*Shell deposits*	*Geo-chemical*	*Geological impacts description*
Auster et al 1996 (11)		X		X	X	X		X		SI: signif fewer bio dep outside conservation area - assumed related to reduction in spp that create dep.; JB: much of mud veneer removed by fishing, boulders moved; SB: sand ripples smoothed by fishing, shells dispersed
Brown et al 2005b (35)	X	X		X					X	Sediments better sorted in fished area vs closed. No S differnce in grainsize. No diff in mean C content between areas. Sed Chl A was higher in fished area. Sand wave formation was seasonal and therefore differed from fishing effects.
Caddy 1968 (42)	X									Dredge produced a 'bulldozing' effect on substrate at low speeds when bag was not open, but not at higher speeds; lateral skids produced parallel furrows ca 2 cm deep with series of smooth ridges between them caused by rings in chain belly of dredge
Caddy 1973 (43)					X	X				Dredge resuspended sand, burried gravel, overturned gravel fragments, dislodged cobble, plowed boulders; marks left by belly rings in sand/fine gravel, narrow depression made by tow bar, skid marks, thin layer of silt on gravel in vicinity of tows
De Biasi 2004 (88)	X									Trawling re-suspended and re-distributed finer sediments, door tracks less distinct after 48 hr, almost invisible after 1 month, no marks left by net
DeAlteris et al 1999 (92)	X									Door tracks 5-10 cm deep, berm 10-20 cm high. Scarred area 0.9%; sand eroded 100% of time daily, mud eroded <5% of time (mode analysis); 2 month study: mud scars lasted >60 d, sand scars 1-3d.
Drabsch et al 2001 (97)	X		X							Tracks left by otter boards and skids evident within all trawl corridors, removal of topographic features such as mounds
Engel and Kvitek 1998 (101)		X	X				X	X		Signif fewer rocks and biogenic mounds, S less flocculent material, and S more exposed sediment and shell fragments in HT area. Impacts on particular geological subtrates not well defined.
Freese 2001 (110)	X				X					Furrows still prominent after 1 year
Freese et al 1999 (111)	X				X		X			10-27% boulders displaced in 8 tows (mean 19%), tires left furrows 1-8 cm deep in less compact sediment; layer of silt removed in more compact sediment (more cobble); boulder piles mentioned but not evaluated
Gilkinson et al 1998 (120)	X									Trawl doors created berm 5.5 cm high next two furrow 2 cm deep
Gilkinson et al 2003 (121)	X		X					X		Furrows observed in seabed immed after dredging; appeared visually to recover by 1 yr but visible in sonar at 3 yr. Shell dep inc over time, as did polychaete tubes. Burrows and shells from C. siliqua - burrows did not recover due to high F on this spp
Koulouri et al 2005 (211)	X			X						Towed video showed evidence of recent trawling as fresh marks on seabed, uncovered lighter-grey sediments, and flat areas with no sedimentary features
Kutti et al 2005 (214)	X									resuspension of surface sediment
Langton and Robinson 1990 (217)	X									Change from organic silty sand to gravelly sand
Lindholm et al 2004 (225)	X	X	X	X	X			X		Biogenic depressions more abun in immobile sand habitats (>60m) inside closed area, more shell fragments in closed area
MacKenzie 1982 (232)	X									
Mayer et al 1991 (236)	X			X					X	Door tracks several cm deep. Trawl dispersed fine surface sediment, planed surface features, but did not plow bottom.

Citation	Surfacne and subsurface sediments	Biogenic depressions	Biogenic burrows	Bedforms	Scattered gravel	Gravel pavement	Piled gravel	Shell deposits	Geo-chemical	Geological impacts description
										Dredging lowered sed surface 2cm, injected finer sed into lower 5-9cm, increased mean grain size upper 5 cm, disrupted surface diatom mat
Medcof and Caddy 1971 (244)	X									-
Meyer et al 1981 (245)	X									-
Morais et al 2007 (247)	X	X		X	X		X			Trawl doors, groundrope, tickler chains caused marks on seabed. Door marks were 40 cm wide and 20 cm deep. Cleaning and flattening seafloor by nets and chains noted. Even in low-energy environments, persistency of trawl marks noted as "low."
Murawski and Serchuk 1989 (256)	X									Trenches in gravelly areas collapsed quickly, in hard packed sand trenches still visible after a few days
Palanques et al 2001 (277)	X									Footrope removed 2-3 cm fine sediment, silt settled w/in 1 hour, turbidity still 3 times above ambient 4 days later, representing 10% resuspended sediment, rest accumulated on bottom; door tracks still visible 1 yr after trawling, surface seds mixed in 1d
Pilskaln et al 1998 (283)	X									More infaunal worms suspended in water column in more heavily trawled area (W Basin), more abundant during periods of greater trawling activity
Pranovi and Giovanardi 1994 (287)	X									-
Rosenburg et al 2003 (313)	X		X							Gulf of Lions - sig trawl impacts in mud, i.e. lower number of polychaete tubes, greater sediment relief (door tracks), mud clasts ripped up
Sanchez et al 2000 (320)	X									Door tracks remained visible throughout experiment
Schwinghamer et al 1998 (325)	X	X	X					X	X	Door tracks increased relief/roughness, still visible in SS sonar after 2 mos, but not 1 yr later. Trawling susp/disp sed, removed hummocks and organic matter, topography recovered in 1 yr, no effect on sed texture, shells/organisms in linear features
Sheridan and Doerr 2005 (330)	X									No increase of fine sediment in untrawled area
Simpson and Watling 2006 (333)	X		X						X	At inshore site, signif more 3-4 cm d burrows in untrawled area, NS differences for smaller and larger sizes; NS changes in sed porosity on fishing grounds, no net loss of fine sediments, but trawling may alter sed mixing regimes.
Smith et al 1985 (334)	X		X							Door tracks, 5-15 cm in mud, <5 cm in sand, "naturalized" by tidal currents
Smith et al 2000 (335)	X								X	No effect of trawling on organic C surface sediment values
Smith et al 2003 (336)	X	X	X							NS differences in sediment compaction or roughness or in substrate attributes in trawled and untrawled areas (door tracks cancel out smoothing and scraping action of groundrope and net)

Citation	Surfacne and subsurface sediments	Biogenic depressions	Biogenic burrows	Bedforms	Scattered gravel	Gravel pavement	Piled gravel	Shell deposits	Geo-chemical	Geological impacts description
Sparks-McConkey and Watling 2001 (338)									X	Signif decline in porosity, increased food value/chlorophyll production of surface sediments; all geochemical sediment properties recovered within 3.5 months
Stokesbury and Harris 2006 (352)	X				X			X		-
Stone et al 2005 (355)		X	X							Biogenic structures signif less abundant in open area at site 2 (not assssed at site 1)
Sullivan et al 2003 (359)		X		X						Frequency of sand waves, tube mats, and biogenic depressions decreased rel to control plots, vigorous reworking of surface sediments to 2-6 cm
Tuck et al 1998 (372)	X								X	Door tracks, bottom roughness increased during dist period/declined during recovery, no effect on sediment grain size, organic C higher in treatment area
Tuck et al 2000 (373)	X									-
Watling et al 2001 (391)	X								X	Imm loss of fine sediments from top few cm, reduction in food value (S reductions in amino acids and microbial biomass); no recovery of fine seds 6 mos after dredging, but food value completely restored
Dellapenna et al 2006 (406)	X								X	sed props analyzed for physical and geochem properties; susp. Sed settled in hours, turbidity returned to pre-trawl levels in 14 mins; doors, net, and chains excavate to max 1.5 cm (much less in most areas)
Nilsson and Rosenberg 2003 (407)	X		X						X	BHQ values lower/more variable in trawled transects, a severe mechanical disturbance observed in 43% of images increased spatial var of indices in trawled areas
Boat Mirarchi and CR Environmental 2003 (408)	X	X	X	X						Doors created furrows/ridges in seabed (6" in mud, 2-3" in sand), smoothed seafloor, exposed worm tubes, reduced grain size in trawl and control lanes (resuspension by trawl); physical impacts of trawling less visible at shallower/sandy site
Boat Mirarchi and CR Environmental 2005 (409)	X	X	X	X						no signif trawling-induced changes in either physical or biological conditions at the sediment- water interface (analysis of SP images)
Coggan et al 2001 (414)	X			X						-
Simboura et al 1998 (599)	X									Sediments better sorted, higher proportion of fines at S. Evvoikos than Petalioi. Not clear if these differences were related to fishing directly or to degree of enclosure of area.

Table 27 – Biological features evaluated by various studies. Seagrass was not carried forward into the matrices.

Citation	*Sponge*	*Bryozoan*	*Hydroid*	*Anemone*	*Burrowing anemone*	*Soft corals*	*Hard corals*	*Sea pens*	*Tube worms*	*Bivalves*	*Brachiopods*	*Tunicates*	*Macroalgae*	*Sea grass*	*Impacts description*
Asch and Collie 2007 (404)	X	X	X		X				X	X					In shallow water, structurally complex colonial taxa more abundant at UD sites, encrusting taxa at D sites; rel abundance of some taxa at D and UD sites different in deep water ; sponges and bushy bryos recovered inside CAII within 2 yrs of closure
Auster et al 1996 (11)	X	X	X	X					X	X		X			SI: signif lower epifaunal cover outside closed area (sea cuc esp vulnerable); JB: reduced abundance of erect sponges and associated epifauna (Fig 3); SB: removal of epibenthic organisms (ascidians, hydrozoans) that anchor in coarse sand
Ball et al 2000 (17)															Reduced epifaunal/infaunal richness, diversity, and number of species in commercially fished areas compared with control areas, with bigger difference at HF site.
Bergman and VanSantbrink 2000 (21)										X					Percent reductions <0.5-52% for 9 bivalves, 16-26% for a sea urchin, 3-30% for a crustacean, and 2-33% for other species; some reductions significant (see paper); fragile species more vulnerable
Boat Mirarchi and CR Environmental 2003 (408)	X		X	X						X					Fish and inverts (eg Cancer crabs) less numerous imm after trawling, differences not obvious 4-18 hrs later
Boat Mirarchi and CR Environmental 2005 (409)	X		X	X						X					No consistent differences were found between the trawled and control areas, trawling did not appear to alter the overall faunal composition.
Brown et al 2005a (34)	X	X	X	X						X		X			Reduced macrofaunal density, biomass, and richness in chronically fished area, mobile scavengers (eg amphipods) more common in fished area, polychaetes common in closed area (also see prey impacts); no detectable effects of exp trawling experiment
Burridge et al 2003 (38)	X	X	X	X		X				X		X	X		Diff catch biomass shallow vs. deep (> or < dep on taxa). Depletion rate estimates (Fig 4, Tab 2) generally 5-20%. Comparison of vulnerability betw taxa on p 247. Hyp that attachment of soft flexible organisms to large vs small rocks influ catchability.
Collie et al 1997 (69)		X	X						X	X					S effects of fishing AND DEPTH on density, biomass, and diversity, higher in deep U sites; six species abundant at U sites, rare or absent at D sites, and NOT AFFECTED by depth-two (horse mussels, starfish) might provide shelter
Collie et al 2000 (70)	X	X	X	X	X				X	X					Percent cover of all emergent epifauna S higher in deep water, but no S disturbance effect; emergent anemones, sponges, horse mussels, and some tube-worms less frequent at D sites; burrowing anemones much more prevalent at D sites
Collie et al 2005 (71)	X	X	X	X	X				X	X					S higher numercial abundance/biomass of benthic megafauna in LF site, low percent cover of hydroids, bryozoans, and worm tubes at HF site; S increases in abundance, biomass, and epifaunal cover inside CAII after 6 years (see paper for details)
Engel and Kvitek 1998 (101)	X			X				X							Lower densities of large epibenthic taxa in HT area (S for sea pens, starfish, anemones, and sea slugs), higher densities of opportunistic species (infauna and epifauna) in HT area, no differences for crustaceans/mollusks
Eno et al 2001 (102)	X	X				X		X	X			X			

Citation	***Sponge***	***Bryozoan***	***Hydroid***	***Anemone***	***Burrowing anemone***	***Soft corals***	***Hard corals***	***Sea pens***	***Tube worms***	***Bivalves***	***Brachiopods***	***Tunicates***	***Macroalgae***	***Sea grass***	***Impacts description***
Freese 2001 (110)	X		X												No recruitment of new sponges, no repair or re-growth of damaged sponges, but sponges that were knocked over or pieces of sponge lying on bottom were still viable
Freese et al 1999 (111)	X			X				X		X					30% reduction in density of sponges, 50% for anemones, 23% for motile epifauna (not structure-forming); heavy damage to some types of sponges (67% vase sponges), brittle stars (23%), and sea pens (55%)
Gilkinson et al 2005b (123)						X									No sig impacts to soft corals detected, but low power ANOVA and low rate of coral bycatch. Also, suspected corals attached to shells were displaced from dredge path. Spec that there would be greater impact if dredging in larger patches of coral.
Hall et al 1990 (140)															-
Henry et al 2006 (157)	X	X	X			X						X			Short term effects were decreased number of taxa per sample, total biomass, and hydroid biomass, but trends were NS; no cumulative effects and and no long term (3 yrs) effects.
Hermsen et al 2003 (158)									X	X					Signif lower production (P) at HF Canadian site than at LF site, increase in production inside CAII within 6 years to levels similar to LF site; scallops and sea urchins dominated P at recovering site; tube worm dominated P at LF site
Hixon and Tissot 2007 (164)								X							Marked reduction in sea pen density in fished area.
Kaiser et al 2000 (184)			X			X									S habitat effects on # species/indivs, and on spp diversity, but no S fishing effects; in general, as fishing dist increased, more mobile, robust spp, fewer immobile, large, fragile spp
Kenchington et al 2006 (194)				X	X				X	X	X	X			Few detectable imm effects on abundance or biomass of indiv taxa, none on community composition; epifaunal biomass reduced from 90% to 77% after 3 yrs (esp horse mussels); damage to mussels, tube-building polychaete and a brachiopod.
Knight 2005 (203)	X			X						X		X			-
Kutti et al 2005 (214)										X					See below
Langton and Robinson 1990 (217)					X				X	X					Densities of 3 dominant species (see below) declined signif between surveys, apparently due to dredging
Lindholm et al 2004 (225)	X	X	X	X											S higher incidence of rare sponge and shell fragment habitats inside closed area, no signif differences for 6 more common habitat types; sponges more abun in immobile sand habitats (>60m) inside closed area
Link et al 2005 (228)	X	X	X	X	X			X							See below
MacKenzie 1982 (232)					X										Ceriantheopus americanus listed but no statistical test on that spp alone; spp was found more frequently at dredged sites vs. never fished sites
McConnaughey et al 2000 (238)	X	X		X		X				X		X			Sedentary taxa (anemones, soft corals, stalked tunicates, bryozoans, sponges) more abundant inside closed area, diffs signif for sponges/anemones; more patchy dist outside closed area
McConnaughey et al 2005 (239)				X						X		X			On average, 15 of 16 taxa smaller inside closed area but individually, only a whelk and anemones were signif smaller

Citation	Sponge	Bryozoan	Hydroid	Anemone	Burrowing anemone	Soft corals	Hard corals	Sea pens	Tube worms	Bivalves	Brachiopods	Tunicates	Macroalgae	Sea grass	Impacts description
Moran and Stephenson 2000 (248)	X					X		X							Single tow of demersal net reduced benthos (>20 cm high) by 15.5%, 4 tows 50%
Pranovi and Giovanardi 1994 (287)				X						X				X	-
Prena et al 1999 (291)						X									Overall 24% average decrease in epibenthic biomass with S trawling and year effects on total B, smaller organisms, more damage, in trawled areas; B of 5/9 dominant spp S lower in trawled corridors, no effect on molluscs
Smith et al 2003 (336)	X								X				X		Attributes identified on SPI images included a number of biological features (see paper), no analysis of fished and unfished areas
Stokesbury and Harris 2006 (352)	X	X	X	X	X				X	X		X			Changes in density before and after limited fishing in impact areas similar to changes in control areas; fishing affected epibenthic community less than natural disturbance
Stone et al 2005 (355)				X				X		X					Species richness S less in open areas at both sites, site 2 had signif fewer epifauna in open area, S reduced abundance of low-mobility taxa and prey taxa in open areas at both sites; 13/76% fewer anemones sites 1/2 open areas, more sea pens (see Table 1)
Tanner 2003 (360)	X	X								X		X		X	Overall decrease in epifauna (28%) within 1 week of trawling and by another 8% 1 wk to 3 mo after trawling; In 9 of 12 cases, (4 major taxa/3 locations) trawling S reduced abundance by >25%. Taxa=sponges, an erect bivalve, ascidians, and bryozoans.
Tillin et al 2006 (368)	X	X	X	X		X				X		X			Lower trawling intensity = greater prop B of att epifauna/filter feeders, smaller, shorter-lived spp with pelagic larvae; Higher trawl int= greater prop B of infauna, burrowers, and scavengers/predators
Tuck et al 2000 (373)									X						-
Van Dolah et al 1987 (382)	X					X	X								35% fewer barrel sponges (Cliona spp) in high-density transects, 77% fewer in low-density transects, reduced impacts on other sponges, 30% fewer stony corals, 32% sponges still on bottom were damaged; full recovery in density and damaged sponges in 12 mo
Wassenberg et all 2002 (387)	X					X									Trawl impact a function of sponge shape and size. Most sponges <500mm passed under trawl, > 500 mm impacted more (30-60% passed under net). Large branched sponges mostly removed by footrope or crushed; 90% of gorgonians passed under net.

5.0 Estimating susceptibility and recovery for biological and geological features

This section describes the matrix-based approach used to estimate vulnerability (i.e. susceptibility and recovery) of geological and biological habitat features to fishing gear impacts.

5.1 Methods: S-R matrices

As previously described, the SASI approach disaggregates fishing effort by gear type, and classifies habitat into ten types based on two energy levels and five substrate types, with a suite of geological and biological structural features inferred to each habitat type. **With respect to a feature-gear-substrate-energy combination, 'vulnerability' represents the extent to which the effects of fishing gear on a feature are adverse.** 'Vulnerability' is defined as the combination of how susceptible the feature is to a gear effect and how quickly it can recover following the fishing impact. **Specifically, susceptibility is defined as the percentage of total habitat features encountered by fishing gear during a hypothetical single pass fishing event that have their functional value reduced, and recovery is defined as the time in years that would be required for the functional value of that unit of habitat to be restored.** Functional value is intended to indicate the usefulness of that feature in its intact form to a fish species requiring shelter. This relative usefulness as shelter can be extended to the prey of managed species as well, which provides indirect benefits to the managed species. **However, because functional value is difficult to assess directly, and will vary for each managed species using the feature for shelter, feature removal or damage is used as a proxy for reduction in functional value.** Results such as percent reduction of a geological or biological feature are common in the gear impacts literature.

In order to make the susceptibility and recovery information work as a set of model parameters, the susceptibility and recovery of each feature-gear-substrate-energy combination is scored on a 0-3 scale as described in Table 28. The scaling process eliminated any differentiation in units (i.e. percent change for susceptibility vs. time for recovery). The scale is also intended to compare the magnitidue of susceptibility and recovery values, since susceptibility and recovery are closely related. Quantitative susceptibility percentages in Table 28 indicate the proportion of features in the path of the gear likely to be modified to the point that they no longer provide the same functional value. Recovery does not necessarily mean a restoration of the exact same features, but that after recovery the habitat would have the same functional value.

Table 28 – Susceptibility and recovery values

Code	*Quantitative definition of susceptibility*	*Quantitative definition of recovery*
0	0 – 10%	< 1 year
1	>10%-25%	1 – 2 years
2	25 - 50%	2 – 5 years
3	> 50%	> 5 years

Each matrix shown in the following sections includes the features present in that particular substrate and energy environment, gear effects related to that gear type and feature combination, susceptibility and recovery for each feature, and the literature deemed relevant to assigning S and R for a particular feature and gear combination.

Susceptibility and recovery were scored based on information found in the scientific literature, to the extent possible, combined with professional judgment where research results are lacking or inconsistent. To direct PDT members to the appropriate research during the evaluation process, studies are assigned to matrix cells using the literature review database. For this purpose, the set of studies used to inform a particular susceptibility or recovery value is defined fairly narrowly. In some cases, studies from the literature review beyond those listed in a given matrix cell were used as well. For example, otter trawl studies were used to inform some of the scallop dredge scores. Also, for a given scored interaction in the matrix, some studies listed may have informed the score more than other studies. Details regarding the justification for each S or R score, with numbered references, are condensed into separate tables.

In some cases, the fields from the database do not align perfectly with cells in the matrices. This is because the database fields were developed and coded somewhat earlier in the process, while the matrices were still being refined. In particular, mud, sand, and muddy sand were coded during the literature review, but only mud and sand are used to define the model grid and thus only mud and sand matrices are developed. When studies were assigned to matrix cells, those coded as muddy sand went into both the mud and sand matrices, leaving the analyst to determine whether the study was most appropriately applied to one, the other, or both.

In cases where no studies are available to inform a particular S or R value, the analyst relied on the gear and feature descriptions combined with their professional judgment. In some cases, studies that considered another gear type, or were conducted in a different habitat type (either a different substrate, energy regime, or both) are considered.

All feature-substrate-gear-energy combinations were evaluated with the exception of hydraulic dredges, which were scored for sand and granule-pebble substrates only as they are unable to fish in other substrates (Table 29).

Table 29 – Matrices evaluated. Each substrate-type matrix included both energy environments and all associated features.

Gear type	*Mud*	*Sand*	*Granule-pebble*	*Cobble*	*Boulder*
All trawl gears	X	X	x	X	X
Scallop dredge	X	X	X	X	X
Hydraulic dredge	-	X	X	-	-
Longline	X	X	X	X	X
Gillnet	X	X	X	X	X
Trap	X	X	X	X	X

Susceptibility and recovery scoring was discussed at five Plan Development Team (PDT) meetings between January and August 2009. These group discussions ensured that each team member had the same understanding of what was meant by susceptibility and recovery, and understood the assumptions underlying the assessment. During this period, matrices were evaluated in three iterations. Before the March 2009 Science and Statistical Committee (SSC) review, geological features were scored for the otter trawl and scallop dredge matrices by all team members. Before the May PDT meeting, geological and biological features were scored for all mobile gears by all team members. Before the August PDT meeting, geological, biological, and some prey features were scored for all gears, with a subset of team members scoring each matrix. At the August meeting and in subsequent weeks, the PDT divided into small groups of 3-4 members each to evaluate each gear type in detail. Individual members submitted matrices to the group, including justification for each score, and the sub-teams developed consensus scores for each feature. Once consensus was reached for each gear type, the matrices were considered more holistically and scores were compared across gear types to ensure consistency. This final consideration of values continued through March 2010. During this period, the following "rules" for matrix evaluation were developed.

1. Susceptibility was evaluated for the entire swath of seabed affected by the gear during one tow.

In most cases, a feature is small in comparison with the path of the gear. In the case of larger features, (e.g. sand waves), or gears with narrower footprints (e.g. fixed gears), impacts to the portion of the feature in the path of the gear are evaluated.

2. Susceptibility was generally assumed to be similar for both high and low energy areas and therefore a single score was given for both, but recovery was assumed to vary such that separate high and low energy scores could be assigned as appropriate.

Note that in the matrices below, separate high and low energy susceptibility scores are shown to indicate more clearly which features are inferred to which substrate-energy combinations.

3. Susceptibility to and recovery from all trawl gear impacts were considered in one matrix, even though the gears were separated for the purposes of realized area swept and adverse impact modeling.

SASI identifies four trawl gear subtypes (generic, shrimp, squid, raised footrope), but matrices for each type are not completed, for the following reasons. First, literature support for disaggregated shrimp, squid, and raised footrope matrices is limited, as indicated in Table 24. Second, because the contact indices and gear component dimensions vary by gear type, the gears can be distinguished in the model outputs even if susceptibility and recovery scores are the same.

4. The intention of the susceptibility scoring was to consider loss or damage of features in the path of the gear for the portion of the gear that was actually in contact with the seabed, allowing the contact index to account for any reduction in area swept.

However, given that the matrices are based on the results of research that uses actual fishing gears, with varying levels of contact with the seabed, it is difficult to avoid double counting seabed contact in the model, in that the level of gear contact affects the S scores and then may be further accounted for in the area swept models described in section 6.0.

5. Although gear components were modeled separately to estimate area swept, for each gear type, all components were considered together when evaluating susceptibility.

A primary reason for this is that the literature generally does not disaggregate gear effects by component. However, analysts considered the relative contribution of each gear component to area swept when evaluating the matrices.

6. The matrix evaluations consider a hypothetical single pass, with no baseline state of the seabed or features assumed.

Generally, areas within the SASI model domain as well as study sites in the fishing impacts literature have been subject to repeated fishing disturbance for many years. The single pass approach makes the results of some studies more difficult to apply to the scoring of susceptibility and recovery. While there are a number of studies among the 97 evaluated that examine habitat impacts at this level, many do not. It can be argued that such experimental impact studies are simply not practicable at 'relevant' temporal and spatial scales (Tillin et al. 2006, Hinz et al. 2009), but comparative studies also have drawbacks. Comparative studies can be somewhat difficult to evaluate and extrapolate because the scale of fishing disturbance may vary widely between studies, and is often vaguely quantified as high or low (Hinz et al 2009). More generally, a challenge inherent to evaluating the result of the fishing impacts literature is the lack of true control sites and the confounding of natural variations that predispose an area to trawling in comparison with a nearby area with the actual effects of trawling on seabed features (Tillin et al. 2006, Hinz et al. 2009).

7. Recovery rates of features assume the absence of additional fishing pressure.

As a final note regarding the methods used in the matrix-based assessment, it is possible that given the same methods, feature definitions, gear type definitions, and literature to draw from that a different group of experts might score susceptibility and recovery differently. As noted above, an iterative, team-based approach to scoring is used. The matrix evaluations are inherently qualitative, so there is no 'right' answer. The goal is to have internal consistency between team members in their approaches, and to ensure consistency across substrates and gear types in the final values. The scores are being used to estimate the relative impacts of various fishing gears on different types of seafloor features, so in this sense, internal consistency in scoring is more important than the actual scores.

5.2 Results: S-R matrices

The following sections present the S-R matrices by gear type (otter trawl, scallop dredge, hydraulic dredge, longline, gillnet, and trap). To save space, justifications for the scores are presented separately. Following the matrices, there are summary plots of the S and R values comparing scores between gears, substrates, and energies.

5.2.1 Demersal otter trawls

As indicated in the literature review section of the document, there is more research to base assessment of feature vulnerability to otter trawls as compared to other types of gear. Within this, there is more information in the literature to support S scores than R scores. Therefore, for biological features, R scores are heavily informed by life history information. Evaluations for otter trawls also relied on professional judgment gained from individual field research experience. Geological evaluations are more straightforward than biological evaluations, probably because there is less variation within a feature that might influence S and/or R. Many geological recovery scores are estimated to be very low (i.e. rapid), with the exception of features like boulder and cobble piles.

S evaluations require the assumption that disturbance of, damage to, or loss of a feature indicates a change in functional value (i.e. value as shelter). Different types of studies varied in terms of their usefulness. For example, video/photographic studies are found particularly useful for biological susceptibility evaluation. Studies that compared feature abundance before and after fishing in the same exact transect are found to be more useful than studies that compared impact vs. reference transects.

The team discussed that in piled boulders, the boulders themselves might offer some protection to the epifauna living between the boulders. However, this would only hold for boulder piles/reefs, and susceptibility of epifauna in and around smaller boulders would be similar to that in cobble habitats, because the boulders can be moved by the gear. The scores given assume a scattered boulder habitat made up of smaller boulders.

Below, Table 30 shows trawl gear S/R values, grouped by substrate and then by feature. In general, features are inferred to both high and low energy environments for a given substrate, and S and R are scored the same; with exceptions as noted. Table 31 summarizes the justification for the susceptibility scores for trawl gear. Justifications for recovery scores for all gear types are combined into two tables at the conclusion of the matrix results section (Table 39 – geological, Table 40 - biological).

Table 30 – Trawl gear matrices. Susceptibility (S) values are coded as follows: 0: 0-10%; 1: >10-25%; 2: >25-50%; 3: >50%. Recovery (R) values are coded as follows: 0: <1 year; 1: 1-2 years; 2: 2-5 years; 3: >5 years. The literature column indicates those studies identified during the literature review as corresponding to that combination of gear, feature, energy, and substrate. The studies referenced here were intended to be inclusive, so any particular

study may or may not have directly informed the S or R score. Any literature used to estimate scores is referenced in Table 31 (Trawl S), Table 39 (Geo R), and Table 40 (Bio R).

Gear: Trawl					
Substrate: Mud					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Biogenic burrows (G)	filling, crushing	334, 408, 409	97, 101, 313, 333, 336, 407	2	0
Biogenic depressions (G)	filling	236, 408, 409	101, 247, 336	2	0
Sediments, surface/subsurface (G)	re-suspension of fine sediments, compression, geochemical, mixing	88, 92, 211, 236, 330, 334, 406, 408, 409, 599	88, 97, 211, 247, 277, 283, 313, 320, 333, 335, 336, 338, 372, 407, 414	2	0
Amphipods, tube-dwelling (B) – see note	crushing	34, 113, 119, 211, 228, 292, 334, 408, 409, 599, 658	89, 80, 97, 113, 149, 320, 575	1	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	2	2
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	none	101, 164	2 (low energy only)	2 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	408, 409	368	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	21, 34, 368, 408, 409	89, 203, 360, 368	1	3
Substrate: Sand					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Bedforms (G)	smoothing	11, 35, 225, 408, 409	n/a	2 (high energy only)	0 (high energy only)
Biogenic burrows (G)	filling, crushing	225, 334, 355, 408, 409	97, 101, 128, 313, 325, 336, 355	2	0
Biogenic depressions (G)	filling	11, 35, 225, 355, 408, 409	97, 101, 247, 325, 336, 355	2	0
Sediments, surface/subsurface (G)	resuspension, geochemical, mixing and resorting	35, 92, 120, 225, 236, 334, 408, 409, 599, 330	97, 128, 214, 247, 313, 325, 336, 414	2	0
Shell deposits (G)	displacing, burying, crushing	11, 225	101, 325	1	1 (high), 2 (low)
Amphipods, tube-dwelling (B) – see note	crushing	113, 225	34, 97, 113, 119, 141, 194, 228, 292, 334, 408, 409, 599, 658	1	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	228	none	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	11, 34, 38, 157, 238, 368	203, 360, 368	2	1
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	228, 248	101, 247	2 (low energy only)	2 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 34, 38, 69, 70, 71, 157, 184, 225, 228, 285, 368, 408, 409	360	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	38, 69, 70, 71, 158, 194, 285, 355, 368, 408, 409	203, 214, 355, 360	1	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	69, 70, 71, 158, 194, 355, 368, 408, 409	203, 214, 355	1	2

Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 158	11, 336	2	2
Sponges (B)	breaking, crushing, dislodging, displacing	11, 34, 38, 70, 71, 157, 225, 228, 238, 248, 285, 368, 382, 387, 408, 409	336, 203, 360, 101, 247, 368	2	2
Substrate: Granule-pebble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Granule-pebble, pavement (G)	burial, mixing, homogenization	none	n/a	1 (high energy only)	0 (high energy only)
Granule-pebble, scattered, in sand (G)	burial, mixing	11	11, 110, 111, 247	1	0 (high), 2 (low)
Shell deposits (G)	burying, crushing, displacing	11, 225	11, 101	1	1 (high), 2 (low)
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	11, 38, 70, 71, 194, 225, 228, 368	11, 101, 111	2	2
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	70, 71, 194, 228, 404	none	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	11, 157, 194, 368	11	2	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	194	247	2	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	11, 38, 69, 70, 71, 157, 225, 228, 368, 404	11	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 38, 69, 70, 71, 157, 225, 228, 368, 404	11, 111	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	69, 70, 71, 158, 194, 368, 404	11	2	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	69, 70, 71, 158, 194, 368, 404	11	1	2
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 158, 404	11	2	2
Polychaetes, other tube-dwelling (B) – see note	crushing, dislodging	11, 69, 70, 71, 158, 404	11	2	1
Sponges (B)	breaking, dislodging, displacing	11, 38, 70, 71 ,157, 225, 228, 248, 368, 387, 404	11	2	2
Substrate: Cobble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Cobble, pavement (G)	burial, mixing, homogenization	11	n/a	1 (high energy only)	0 (high energy only)
Cobble, piled (G)	smoothing, displacement	none	101	3	3
Cobble, scattered in sand (G)	burial, mixing, displacement	none	11, 110, 111	1	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	11, 70, 71, 194	11, 101, 111	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	11, 157, 194	11	2	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	194	247	2	2
Bryozoans (B)	breaking, crushing, dislodging,	11, 69, 70, 71, 157, 228,	11	1	1

	displacing	404			
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 157, 158, 228, 404	11, 110	1	1
Macroalgae (B)	breaking, dislodging	none		1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 158, 194, 404	111, 214	2	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	11, 69, 70, 71, 158, 194, 404	111, 214	1	2
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	69, 70, 71, 158, 194, 404	none	2	2
Polychaetes, other tube-dwelling (B) – see note	crushing, dislodging	69, 70, 71, 158, 194, 404	none	2	1
Sponges (B)	breaking, dislodging, displacing	11, 70, 71, 157, 158, 228, 404	11, 101, 110, 111	2	2
Substrate: Boulder					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Boulder, piled (G)	displacement	none	101, 111	2	3
Boulder, scattered, in sand (G)	displacement	none	110, 111	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	11, 111	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	none	11	2	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	194	247	2	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	none	11	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	none	11, 110	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	11, 111, 214	2	3
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	2	2
Polychaetes, other tube-dwelling (B) – see note	crushing, dislodging	none	none	2	1
Sponges (B)	breaking, dislodging, displacing	none	11, 110, 111	2	2

Note: Only reference 225 is specific to tube-dwelling amphipods, the rest are derived from entries in database coded as prey/amphipods. Similarly, references for epifaunal bivalves/ scallops and other tube-dwelling polychaetes are based on database entries for epifaunal bivalves/mussels and polychaetes/F. implexa.

Table 31 – Trawl gear susceptibility summary for structural features.

Feature	***Substrates evaluated***	***Score***	***Notes***
Amphipods, tube-dwelling	Mud, sand	1	Tubes are pliable and only extend 2-2.5 cm above bottom, therefore susceptibility to single tows was assumed to be low. “Disruption” of amphipod tube mats on Fippennies Ledge (GOM) after commercial scallop dredging (217).
Anemones, actinarian	Granule-pebble,	2	Anemones are able to retract tentacles, which may offer some protection. 50% reduction after single tows in a low energy area, but anemones remaining on

Feature	***Substrates evaluated***	***Score***	***Notes***
	cobble, boulder		seabed were undamaged (111). *Urticina* sp. on west coast ca 75% less abundant in heavily trawled area than in adjacent lightly trawled area at same depth (101)
Anemones, cerianthid burrowing	Mud, sand, granule-pebble	2	Anemones can retract into semi-rigid tubes. Tubes of largest species (Cerianthus borealis) extend 15 cm above sediment surface and are susceptible to trawls. E.g., the only large organism in study 194 that showed significant decline (> 50%) after trawling (12-14 tows) was *Cerianthus* sp. However, Shepard et al. (1986) surmised that because the tubes of larger cerianthids are deeply buried, shallow grab samples extending only 3-5 cm into the seabed would be unlikely to dislodge these specimens. A similar resistance to fishing gear that skims the sediment surface seems likely. However, this does not mean that the gear does not damage the tube, perhaps making the anemone more vulnerable to predation. It is important to note that tubes of another species (*Cerianthiopsis americanus*) do not extend above the sediment and the tentacle whorl is nearly flush with the sediment surface. William High, in a NMFS Northwest Center report, describes direct observations of trawl groundlines pinching cerianthids between rollers or bobbins or cookies and pulling them out of the bottom. Hence, they are not fully immune due to a retraction response. Andy Shepard also collected cerianthids using the grab sampler on the Johnson-Sea-Link submersible. He was able to collect specimens with a fast "grab", also indicating they are not all that quick.
Ascidians	Sand, granule-pebble, cobble, boulder	2	>25% reductions 1 wk and 3 mo after 2 tows with prawn trawl (chain sweeps) in sand (360)
Bedforms	Sand	2	Smoothing of seafloor (see 97, 247, 325,336), assume that smaller ripples in mud and sand would be fully susceptible, larger sand waves in sand would be less susceptible, no data indicating degree of disturbance from a single tow, probably highly variable, assume 25-50% loss.
Biogenic burrows	Mud, sand	2	Major issue is smoothing of 'surface features' (97, 236, 247, 387, 408), also removal of 'mounds, tubes, and burrows' following trawling (325); no data indicating degree of disturbance from a single tow, assume 25-50% loss.
Biogenic depressions	Mud, sand	2	See above for biogenic burrows.
Boulder, piled	Boulder	2	Assume that displacement of piled boulders would be more likely than displacement of scattered boulders. Loss of deep crevice habitats, potentially greater effect than on piled cobbles, but boulders are more resistant to disturbance because of their size.
Boulder, scattered in sand	Boulder	0	Average 19% displacement of boulders by single tows in a deep, undisturbed environment (111), similar results in Gulf of Maine observational study (11), but no burial, so there is no loss of physical habitat. S scores are based on probability that cobble or boulder would be buried, or partially buried, by gear (higher S for cobble reflects a higher assumed likelihood of burial for smaller sediment sizes). It was assumed that if a cobble or boulder has a depression under it/beside it and it is rolled over or moved, that it is likely to have a new depression in its new location. Thus, its functional value as a habitat is the same. If the depressions under cobble/boulders are biogenic, it was assumed that the biogenic depression under the cobble or boulder is susceptible if the cobble or boulder is susceptible, thus scores of S=1 cobble, S=0 boulder.
Brachiopods	Granule-pebble, cobble, boulder	2	62% reduction in biomass after two years of experimental trawling on Scotian shelf (est 1-4 passes each year, see 194); thus a lower percentage reduction expected after single pass.
Bryozoans	Granule-	1	Bushy bryozoans significantly more abundant at shallow and deep sites

Feature	***Substrates evaluated***	***Score***	***Notes***
	pebble, cobble, boulder		undisturbed by fishing on Georges Bank, emergent growth form makes them vulnerable to fishing gear, but not as much as sponges, which generally are taller (404), one of erect but flexible taxa attached to cobbles that likely passed under trawl and rockhoppers with only limited harm on Scotian shelf (157). S=1 based on best professional judgment.
Cobble, pavement	Cobble	1	Assume that largest impact would be from doors but that overall only 10-25% of feature would be lost (buried) due to size of cobbles
Cobble, piled	Cobble	3	Assume that displacement of piled cobbles would be more likely than displacement of scattered cobbles and would have greater impact because of reduced three-dimensional structure and fewer shelter-providing crevices
Cobble, scattered in sand	Cobble	1	S scores are based on probability that cobble or boulder would be buried, or partially buried, by gear (higher S for cobble reflects a higher assumed likelihood of burial for smaller sediment sizes). It was assumed that if a cobble or boulder has a depression under it/beside it and it is rolled over or moved, that it is likely to have a new depression in its new location. Thus, its functional value as a habitat is the same. If the depressions under cobble/boulders are biogenic, it was assumed that the biogenic depression under the cobble or boulder is susceptible if the cobble or boulder is susceptible, thus scores of S=1 cobble, S=0 boulder.
Corals, sea pens	Mud, sand	2	Significantly lower densities of sea pens (>100% *Ptilosarcus* sp., 80% *Stylatula* sp.) in heavily trawled area than in adjacent lightly trawled with same depth on west coast (101), no experimental before/after impact studies, S=2 based on their size (10 cm for *Pennatula aculeata*) and fact that they don't retract into bottom when disturbed (102)
Granule-pebble, pavement	Granule-pebble	1	Assume pavement broken up mostly by trawl doors and partially buried by sand stirred up by ground cables, sweep, and net, with "loss" of 10-25% of this feature after a single tow.
Granule-pebble, scattered in sand	Granule-pebble	1	Rock-hoppers left 1-8 cm deep furrows in low energy pebble bottom (111) - effects of smaller ground gear (e.g., rollers, chain sweeps) probably less severe; granules and pebbles are small and are susceptible to burial in sand, reducing amount of hard substrate available for growth of emergent epifauna,
Hydroids	Mud, sand, granule-pebble, cobble, boulder	1	Significant decrease in hydroid biomass after trawling (12-14 tows) on Scotian shelf, erect but flexible morphology, low relief, reduces vulnerability to trawls and dredges (see bryozoans) (157); significantly more abundant at deep sites on George Bank undisturbed by trawls and scallop dredges, no difference at shallow sites where densities were lower (404); aggregations of *Corymorpha pendula* "absent" in trawl and scallop dredge paths in coarse sand on Stellwagen Bank (11).
Macroalgae	Granule-pebble, cobble, boulder	1	Flexible body morphology, relatively short height of many species (e.g., red algae in deeper water), assumed to limit removal/structural loss to 10-25% per tow. Although the larger kelps (*Laminaria* spp.) would likely be more susceptible, kelps are relatively rare in their distribution offshore, so the score is intended reflect the susceptibility of smaller algae.
Mollusks, epifaunal bivalve, *Modiolus modiolus*	Mud, sand Granule-pebble, cobble, boulder	1 2	80% reductions in abundance of epifaunal bivalve *Hiatella* sp. Barents Sea after 10 tows (214); >60% reduction in biomass of horse mussels in cobble on Scotian shelf after 2 years of repeated tows (1-4 each year), 8% mussels remaining on bottom were damaged after 1st year (194). *Pinna* sp. reduced >25% 1 wk and 3 mos after 2 tows in mud (360). Horse mussels sensitive to bottom fishing (long-lived, thin-shelled - see 404), partially buried in mud and sand, therefore assumed to be less vulnerable than in gravel substrates.
Mollusks, epifaunal	Sand,	1	Trawls not as efficient as scallop dredges at removing scallops from bottom (S=2

Feature	***Substrates evaluated***	***Score***	***Notes***
bivalve, *Placopecten magellanicus*	granule-pebble, boulder		for scallop dredges)
Polychaetes, *Filograna implexa*	Sand, granule-pebble, cobble, boulder	2	Significantly more at shallow sites disturbed by trawling and dredging on Georges Bank, fewer at deep disturbed sites, tubes heavily affected by bottom fishing because they can be easily crushed and require stable substrate (404), susceptibility based on data for *T. cincinnatus* (see below).
Polychaetes, other tube-dwelling	Granule-pebble, cobble, boulder	2	37% reduction in biomass of *Thelepus cincinnatus* on Scotian shelf after two years of experimental trawling (1-4 tows/yr), 9% on bottom damaged (194)
Sediments, surface/subsurface	Mud, sand	2	Doors create furrows up to 20 cm deep, 40 cm wide, with berms 10-20 cm high in mud (92, 97, 236, 320, 372, 88, 247, 164, 277, 406, 336, 313, 408), shallower furrows in sand (97, 120, 325), but effect is limited to doors. Ground rope and tickler chains also leave marks, mostly in fine sediment (247, 406). Major issue is re-suspension: trawling causes loss of fine surficial sediment (88, 236, 277, 325, 406); also removal of flocculent organic material (325). Little or no evidence that remaining sediments (mud or sand) are re-sorted (35, 325, 372, 408), some evidence that sand is compacted (336), but mud bottom is not "plowed" (236). Assume all fine surficial sediment in path of trawl is subject to re-suspension during a tow, but mud is more susceptible than sand because of its biogenic structure and because it is more easily re-suspended by turbulence. Scores based on professional judgment and comparison with hydraulic dredges which have much greater effects in sand, esp sub-surface sediments. Aside from door tracks, trawls primarily affect top few cm of sediment, reducing functional value of habitat for prey organisms. (Also see scallop dredges).
Shell deposits	Sand, granule-pebble	1	Assume that displacement is more likely than burying or crushing, and that the effects of a single tow are minor (mostly trawl doors) because shells are large and aggregated in a mud or sand matrix.
Sponges	Sand, granule-pebble, cobble, boulder	2	Variations in morphology likely to influence susceptibility; values given in literature are highly variable. In 382, 30-50% reduction in density after one tow (mostly barrel sponge, other spp not signif affected), with 32% damage to sponges remaining on bottom. In 111, 30% reduction in density, heavy damage to some types (67% for vase sponges), very little damage to others (14% "finger" sponges knocked over). In 387, net removed average 14% per tow (all sizes), but removed 40-70% sponges >50 cm - all large branched sponges that did not pass into net were either removed by footrope or crushed under it. In 248, all epifauna >20cm high reduced (average per tow) by 15% - 50% in 4 tows - but sponges are more susceptible. 10% video frames on Jeffreys Bank (GOM) before trawling with >25% cover (max 35%), no frame with >7% 6 yrs later, after area was trawled.

5.2.2 New Bedford-style scallop dredge

In nearly all cases, both S and R scores are assumed to be the same for bottom trawls and scallop dredges.[5] This assumption seems reasonable since the disturbance caused by both gears is similar: aside from the trawl doors, both gears cause a scraping and smoothing of bottom features and a re-suspension of fine sediments. These effects are primarily limited to the sediment surface. While it is acknowledged that scallop gear may skim over the seabed somewhat, the features assessed, particularly the biological features, have a higher relief off the seafloor and thus are expected to be contacted by the gear. Furthermore, the scallop dredge impacts literature does not provide much support for a difference in S/R coding between gear types. In particular, for trawl gear matrix evaluations, the most useful types of studies were those that estimated reductions in features following a single or multiple passes of experimentally fished gear. However, fewer scallop dredge impact studies were designed in this way, and those that did consider single pass impacts did so for geological features only. The studies that considered scallop dredge impacts to biological features were often comparative examinations of unfished areas vs. areas fished by both dredges and trawls. In these instances, it is difficult to make inferences about the impacts of scallop dredges alone.

Table 32 shows scallop dredge gear S/R values, grouped by substrate and then by feature. Scores are the same for high and low energy unless otherwise noted. Table 33 summarizes the justifications for susceptibility scores for scallop dredge gear. Recovery scores for all gear types are combined into two tables at the conclusion of the matrix results section (Table 39 – geological, Table 40 - biological).

Table 32 – Scallop dredge matrices. Susceptibility (S) values are coded as follows: 0: 0-10%; 1: >10-25%; 2: >25-50%; 3: >50%. Recovery (R) values are coded as follows: 0: <1 year; 1: 1-2 years; 2: 2-5 years; 3: >5 years. The literature column indicates those studies identified during the literature review as corresponding to that combination of gear, feature, energy, and substrate. The studies referenced here were intended to be inclusive, so any particular study may or may not have directly informed the S or R score. Any literature used to estimate scores is referenced in Table 33 (Scallop dredge S), Table 39 (Geo R), and Table 40 (Bio R).

Gear: Scallop					
Substrate: Mud					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Biogenic burrows (G)	filling, crushing	none	none	2	0
Biogenic depressions (G)	filling	11	11	2	0
Sediments, surface/subsurface (G)	resuspension, compression, geochem, sorting, mixing	42, 236, 256, 391	none	2	0
Amphipods, tube-dwelling (B) – see note	crushing	228, 359	217	1	0
Anemones, cerianthid	breaking, crushing, dislodging,	228	217	2	2

[5] Despite the close similarities in the matrices, in terms of model outputs, the resulting adverse effects estimated for the two gear types will vary based on differences in gear dimensions, number of tows, and fishing locations.

burrowing (B)	displacing				
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	228	none	2 (low energy only)	2 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 228	11	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	42, 43, 256	203, 217	1	3
Substrate: Sand					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Bedforms (G)	smoothing	11, 225, 236, 359	n/a	2 (high energy only)	0 (high energy only)
Biogenic burrows (G)	filling, crushing	225	none	2	0
Biogenic depressions (G)	filling	11, 225 ,359	11, 359	2	0
Sediments, surface/subsurface (G)	resuspension, compression, geochem, sorting/mixing	42, 119, 225, 236, 256, 352, 359, 391	none	2	0
Shell deposits (G)	displacing, burying, crushing	11, 225, 352	11	1	1 (high), 2 (low)
Amphipods, tube-dwelling (B) – see note	crushing	225, 228, 359	217	1	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	70, 71, 228, 352	217	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	11, 352	203	2	1
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	228	none	2 (low energy only)	2 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 225, 228, 352	11	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	42, 43, 69, 70, 71, 158, 352	203, 217	1	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	42, 43, 69, 70, 71, 158, 352	203, 217	2	2
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 158, 352	11, 217	2	2
Sponges (B)	breaking, crushing, dislodging, displacing	11, 70, 71, 225, 228, 352	203	2	2
Substrate: Granule-pebble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Granule-pebble, pavement (G)	burial, mixing, homogenization	none		1 (high energy only)	0 (high energy only)
Granule-pebble, scattered, in sand (G)	burial, mixing	11, 43, 225, 352	11	1	0 (high), 2 (low)
Shell deposits (G)	burying, crushing, displacing	11, 225, 352	11	1	1 (high), 2 (low)
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	11, 70, 71, 203, 225, 228, 352	none	2	2
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	70, 71, 228, 352, 404	217	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	352	203	2	1
Brachiopods (B)	breaking, crushing, dislodging,	none	none	2	2

	displacing				
Bryozoans (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 225, 228, 352, 404	11	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 225, 228, 352, 404	11	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	43, 69, 70, 71, 158, 352, 404	203, 217	2	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	43, 69, 70, 71, 158, 352, 404	203, 217	2	2
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 158, 352, 404	11, 217	2	2
Polychaetes, other tube-dwelling (B) – see note	crushing, dislodging	11, 69, 70, 71, 158, 352, 404	11, 217	2	1
Sponges (B)	breaking, dislodging, displacing	11, 70, 71, 225, 228, 352, 404	11, 203	2	2
Substrate: Cobble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Cobble, pavement (G)	burial, mixing, homogenization	none	n/a	1 (high energy only)	0 (high energy only)
Cobble, piled (G)	smoothing, displacement	none	none	3	3
Cobble, scattered in sand (G)	burial, mixing, displacement	11, 43, 352	11	1	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	11, 70, 71, 228, 352	none	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	11, 352	11	2	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	2	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 228, 352, 404	11	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 228, 352, 404	11	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	43, 69, 70, 71, 158, 352, 404	217	2	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	43, 69, 70, 71, 158, 352, 404	217	2	2
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 158, 352, 404	11, 217	2	2
Polychaetes, other tube-dwelling (B) – see note	crushing, dislodging	11, 69, 70, 71, 158, 352, 404	11, 217	2	1
Sponges (B)	breaking, dislodging, displacing	11, 70, 71, 228, 352, 404	11	2	2
Substrate: Boulder					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Boulder, piled (G)	displacement	none	none	2	3
Boulder, scattered, in sand (G)	displacement	11, 43, 352	11	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	11, 352	none	2	2

Ascidians (B)	breaking, crushing, dislodging, displacing	11, 352	11	2	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	2	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	11, 352	11	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 352	11	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	43, 352	217	2	3
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	11, 352	11, 217	2	2
Polychaetes, other tube-dwelling (B) – see note	crushing, dislodging	11, 352	11, 217	2	1
Sponges (B)	breaking, dislodging, displacing	11, 352	11, 217	2	2

Note: Only references 217 and 225 are specific to tube-dwelling amphipods, the rest are derived from entries in database coded as prey/amphipods. Similarly, references for epifaunal bivalves/ scallops and other tube-dwelling polychaetes are based on database entries for epifaunal bivalves/mussels and polychaetes/F. implexa.

Table 33 – Scallop dredge susceptibility summary for structural features.

Feature	***Substrates evaluated***	***Score***	***Notes***
Amphipods, tube-dwelling	Mud, sand	1	See trawls
Anemones, actinarian	Granule-pebble, cobble, boulder	2	See trawls
Anemones, cerianthid burrowing	Mud, sand, granule-pebble	2	See trawls
Ascidians	Sand, granule-pebble, cobble, boulder	2	*Molgula arenata* removed from sand in linear patterns by scallop dredges on Stellwagen Bank (11), degree of impact assumed to be same as trawls
Bedforms	Sand	2	Multiple tows reduced frequency of sand waves in treatment areas compared to control areas (359), no information for single tows.
Biogenic burrows	Mud, sand	2	Multiple tows reduced frequency of amphipod tube mats in treatment areas compared to control areas (359), no information for single tows.
Biogenic depressions	Mud, sand	2	Multiple tows reduced frequency of biogenic depressions in treatment areas compared to control areas (359), no information for single tows.
Boulder, piled	Boulder	2	No information, see trawls.
Boulder, scattered in sand	Boulder	0	Single tows plowed boulders (43), but probability of burial is assumed to be low (see trawls).
Brachiopods	Granule-pebble, cobble, boulder	2	See trawls
Bryozoans	Granule-pebble, cobble,	1	See trawls

Feature	Substrates evaluated	Score	Notes
	boulder		
Cobble, pavement	Cobble	1	Single tows dislodged cobbles (43)
Cobble, piled	Cobble	3	
Cobble, scattered in sand	Cobble	1	See trawls
Corals, sea pens	Mud, sand	2	See trawls
Granule-pebble, pavement	Granule-pebble	1	
Granule pebble, scattered in sand	Granule-pebble	1	Single tows overturned and buried gravel fragments (43)
Hydroids	Mud, sand, granule-pebble, cobble, boulder	1	See trawls
Macroalgae	Granule-pebble, cobble, boulder	1	See trawls
Mollusks, epifaunal bivalve, *Modiolus modiolus*	Mud, sand	1	See trawls
	Granule-pebble, cobble, boulder	2	
Mollusks, epifaunal bivalve, *Placopecten magellanicus*	Sand, granule-pebble, cobble	2	Scallop dredge efficiency estimated to be 54% per tow (Gedamke et al. 2005), approximately 30% of scallops slightly buried after passage of 8 m dredge (42). Even if removal rates per tow are high (>50%), shucked shells returned to bottom still provide habitat value, so loss of functional value was assumed to be 25-50%.
Polychaetes, *Filograna implexa*	Sand, granule-pebble, cobble, boulder	2	See trawls
Polychaetes, other tube-dwelling	Granule-pebble, cobble, boulder	2	See trawls
Sediments, surface and subsurface	Mud, sand	2	Single tow lowered mud sediment surface 2 cm, mixed finer sediment to 5-9 cm, increasing mean grain size in upper 5 cm (236). Skids left furrows 2 cm deep in mixed mud/sand bottom, depression from tow bar, marks made by rings in chain belly of dredge (42, 43). Multiple tows in mud/muddy sand caused loss of fine sediments and reduced food value in top few cm (391). In sand, single tows re-suspended sand (43), multiple tows re-worked top 2-6 cm of sediments (359). Effects expected to be especially consequential in mud due to presence of biogenic matrix and because mud is more easily re-suspended by turbulence than sand (see trawls).
Shell deposits	Sand, granule-pebble	1	Individual dredge tows dispersed shell fragments in troughs between sand waves (11), degree of impact assumed to be same as trawls.
Sponges	Sand, granule-	2	Significantly more sponges at shallow sites undisturbed by trawls and

Feature	Substrates evaluated	Score	Notes
	pebble, cobble, boulder		scallop dredges on Georges Bank two years after area was closed, but not at deeper sites (404); for before/after impact experiments, see trawls.

5.2.3 Hydraulic clam dredges

Susceptibility and recovery are only evaluated for hydraulic clam dredges for sand and granule-pebble substrates because this gear cannot be operated in mud or in rocky habitats (NEFSC 2002, Wallace and Hoff 2005). This is because hydraulic dredges harvest clams by injecting pressurized water into sandy sediments to a depth of 8-10 inches, rather than dragging over the sediment surface like bottom trawls and scallop dredges. Water pressures vary from 50 lbs per square inch (psi) in coarse sand to 110 psi in finer sediments (NEFSC 2002). In the absence of much published information on the degree to which benthic habitat features are susceptible to this gear, professional judgment relied on the presumption that these dredges have a more severe immediate impact on surface and sub-surface habitat features than other fishing gears used in the Northeast region.

Table 34 – Hydraulic clam dredge matrices. Susceptibility (S) values are coded as follows: 0: 0-10%; 1: >10-25%; 2: >25-50%; 3: >50%. Recovery (R) values are coded as follows: 0: <1 year; 1: 1-2 years; 2: 2-5 years; 3: >5 years. The literature column indicates those studies idenfied during the literature review as corresponding to that combination of gear, feature, energy, and substrate. The studies referenced here were intended to be inclusive, so any particular study may or may not have directly informed the S or R score. Any literature used to estimate scores is referenced in Table 35 (Hydraulic clam dredge S), Table 39 (Geo R), and Table 40 (Bio R).

Gear: Hydraulic					
Substrate: Sands					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Bedforms (G)	smoothing	none	n/a	3 (high energy only)	0 (high energy only)
Biogenic burrows (G)	filling, crushing	none	121	3	1 (high), 2 (low)
Biogenic depressions (G)	filling	none	none	3	0
Sediments, surface/subsurface (G)	resuspension, compression, geochem, fluidization and resorting	140, 232, 373	121	3	1 (high), 2 (low)
Shell deposits (G)	burying, crushing, displacing	none	121	2	1 (high), 2 (low)
Amphipods, tube-dwelling (B) – see note	crushing	140, 373	122	3	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	3	3
Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	3	1
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	none	none	3 (low energy only)	2 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	3	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	287	none	2	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	287	none	1	2

Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	3	2
Sponges (B)	breaking, crushing, dislodging, displacing	none	none	3	2
Substrate: Granule-pebble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Granule-pebble, pavement (G)	burial, mixing, homogenization	none	none	3 (high energy only)	2 (high energy only)
Granule-pebble, scattered, in sand (G)	burial, mixing	none	None	3	1 (high), 2 (low)
Shell deposits (G)	burying, crushing, displacing	none	none	2	1 (high), 2 (low)
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	3	2
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	3	3
Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	3	1 (high), 2 (low)
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	3	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	none	none	3	1 (high), 2 (low)
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	3	1 (high), 2 (low)
Macroalgae (B)	breaking, dislodging	none	none	3 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	3	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	none	none	1	2
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	3	2
Polychaetes, other tube-dwelling (B)	crushing, dislodging	none	none	3	1 (high), 2 (low)
Sponges (B)	breaking, dislodging, displacing	none	none	3	2

Note: All references for tube-dwelling amphipods are derived from entries in database coded as prey/amphipods. Similarly, references for epifaunal bivalves/ scallops are based on database entries for epifaunal bivalves/mussels.

Table 35 – Hydraulic dredge gear susceptibility summary for structural features.

Feature	***Substrates evaluated***	***Score***	***Notes***
Amphipods, tube-dwelling	Sand	3	Assume pulverizing effect of water pressure would cause 100% destruction of tubes which are soft and attached to bottom, releasing animals into water column where they would be highly susceptible to predation
Anemones, actinarian	Granule-pebble	3	Anemones would be removed from substrate, some might re-attach and survive
Anemones, cerianthid burrowing	Sand, granule-pebble	3	Would expect that most anemones (and tubes) in the path of the dredge would be uprooted due to the depth that pressurized water penetrates into the seabed. Impact could be considerable for uprooted anemones since they are soft bodied and cannot re-bury.
Ascidians	Sand, granule-pebble	3	Tunicates presumed to be highly susceptible to downward effects of water pressure because they are soft-bodied.

Feature	***Substrates evaluated***	***Score***	***Notes***
Bedforms	Sand	3	Assume that due to fluidizing action of the gear, any smaller bedforms would be completely smoothed. Although larger sand waves might only partially damaged, > 50% susceptibility of feature still expected.
Biogenic burrows	Sand	3	Density of burrows reduced by up to 90%, smoothing of seafloor, after 12 overlapping tows (not 100% replicated) (121)
Biogenic depressions	Sand	3	Any depressions in path of gear would be filled in as sand is fluidized and re-settles in dredge path (see surface sediments)
Brachiopods	Granule-pebble	3	Assume that brachiopods attached to gravel in path of dredge would be removed from substrate.
Bryozoans	Granule-pebble	3	See brachiopods.
Corals, sea pens	Sand	3	Assume nearly complete up-rooting of sea pens in dredge path, some of which could re-bury and survive (102)
Granule-pebble, pavement	Granule-pebble	3	Assume that granule-pebble pavement would be affected similarly to scattered granule-pebble.
Granule-pebble, scattered, in sand	Granule-pebble	3	Assume that most granule-pebble in path of dredge would be buried due to re-sorting of sediment (see sub-surface sediment).
Hydroids	Sand, granule-pebble	3	Hydroids are very susceptible to effects of this gear (delicate, soft-bodied)
Macroalgae	Granule-pebble	3	Algae in dredge path would be buried or dislodged from substrate with high mortalities.
Mollusks, epifaunal bivalve, *Modiolus modiolus*	Sand Granule-pebble	2 3	Some mussels dislodged from bottom might re-settle and survive outside dredge paths if they can attach to other mussels or to granule-pebble substrate, but available hard substrate in dredge path would be buried under sand.
Mollusks, epifaunal bivalve, *Placopecten magellanicus*	Sand, granule-pebble	1	Assume most scallops caught in clam dredges are discarded, undamaged, and return to bottom
Polychaetes, *Filograna implexa*	Granule-pebble	3	Assume that *F. implexa* are highly susceptible to breakage/crushing action of water pressure.
Polychaetes, other tube-dwelling	Granule-pebble	3	Assume that most granule-pebble in path of dredge that could be used as substrate would be buried due to re-sorting of sediment (see sub-surface sediment).
Sediments, surface and subsurface	Sand	3	Action of this gear fluidizes sediment to depth of 30 cm in bottom of trench and 15 cm in sides (373), compromising functional value of sedimentary habitat for infauna. In addition, resorting of sediments was observed in dredge path – coarser sediments at bottom (232). Dredges create steep-sided trenches 8-30 cm deep with sediment mounds along edges (140, 244, 245, 256, 287, 373). In path of dredge, assume that nearly all of finer surface sediments will be suspended and re-settle outside dredge path, thus functional value will be compromised substantially.
Shell deposits	Sand	2	Shell deposits in path of dredge would likely be somewhat susceptible to burial in dredge paths and by sand that is re-suspended and settles outside of dredge path, but lighter shell fragments re-settle on top of trench (232), so impact may be <50%.

Feature	Substrates evaluated	Score	Notes
Sponges	Sand, granule-pebble	3	Assume that most granule-pebble in path of dredge that could be used as substrate would be buried due to re-sorting of sediment (see sub-surface sediment).

5.2.4 Fixed gears

Regardless of gear type, groundline movement during setting, soaking, and hauling was assumed to be the primary effect of fixed gears on the seabed. In addition, for trap gear, the possible crushing effect of the trap was considered. Data are sparse regarding the extent to which gears are dragged across the seabed during setting and hauling, or how much they move due to wave action during soaking. This is further discussed in the area swept modeling section (6.0).

5.2.4.1 Demersal longline and sink gillnet

Below, Table 36 shows demersal longline and sink gillnet S/R values, grouped by substrate and then by feature. High and low energy scores for a given feature-gear-substrate combination are the same, except as noted. These gears are considered separately at first but ultimately assigned the same scores, so they are presented together below. No literature specific to the effects of either gear type on seabed features was available.

Table 36 – Demersal longline and sink gillnet matrices. Susceptibility (S) values are coded as follows: 0: 0-10%; 1: >10-25%; 2: >25-50%; 3: >50%. Recovery (R) values are coded as follows: 0: <1 year; 1: 1-2 years; 2: 2-5 years; 3: >5 years. The literature column indicates those studies idenfified during the literature review as corresponding to that combination of gear, feature, energy, and substrate. The studies referenced here were intended to be inclusive, so any particular study may or may not have directly informed the S or R score. Any literature used to estimate scores is referenced in Table 38 (Fixed gear S), Table 39 (Geo R), and Table 40 (Bio R).

Gear: Longline/Gillnet					
Substrate: Mud					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Biogenic burrows (G)	filling, crushing	none	none	1	0
Biogenic depressions (G)	filling	none	none	0	0
Sediments, surface/subsurface (G)	resuspension, compression, geochem, mixing, sorting	none	none	0	0
Amphipods, tube-dwelling (B)	crushing	none	none	1	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	none	none	1 (low energy only)	0 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Substrate: Sand					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Bedforms (G)	smoothing	none	n/a	0 (high energy only)	0 (high energy only)

Biogenic burrows (G)	filling, crushing	none	none	1	0
Biogenic depressions (G)	filling	none	none	1	0
Sediments, surface/subsurface (G)	resuspension, compression, geochem, mixing, sorting	none	none	0	0
Shell deposits (G)	displacing, burying, crushing	none	none	0	0
Amphipods, tube-dwelling (B)	crushing	none	none	1	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	none	none	1 (low energy only)	0 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B)	breaking, crushing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Sponges (B)	breaking, crushing, dislodging, displacing	none	none	0	1
Substrate: Granule-pebble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Granule-pebble, pavement (G)	burial, mixing, homogenization	none	n/a	0 (high energy only)	0 (high energy only)
Granule-pebble, scattered, in sand (G)	burial, mixing	none	none	0	0
Shell deposits (G)	burying, crushing, displacing	none	none	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Mollusks, epifaunal bivalve, P*lacopecten magellanicus* (B)	breaking, crushing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Polychaetes, other tube-dwelling (B)	crushing, dislodging	none	none	1	1
Sponges (B)	breaking, dislodging, displacing	none	none	1	1
Substrate: Cobble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Cobble, pavement (G)	burial, mixing, homogenization	none	n/a	0 (high energy only)	0 (high energy only)
Cobble, piled (G)	smoothing,	none	none	1	3

	displacement				
Cobble, scattered in sand (G)	burial, mixing, displacement	none	none	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B)	breaking, crushing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Polychaetes, other tube-dwelling (B)	crushing, dislodging	none	none	1	1
Sponges (B)	breaking, dislodging, displacing	none	none	1	1
Substrate: Boulder					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Boulder, piled (G)	displacement	none	none	0	3
Boulder, scattered, in sand (G)	displacement	none	none	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Macroalgae (B)	breaking, crushing, dislodging, displacing	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	crushing, dislodging	none	none	1	2
Polychaetes, other tube-dwelling (B)	breaking, dislodging, displacing	none	none	1	1
Sponges (B)	breaking, crushing, dislodging, displacing	none	none	1	1

5.2.4.2 Lobster and deep-sea red crab traps

Below, Table 37 shows trap gear S/R values, grouped by substrate and then by feature. High and low energy scores for a given feature-gear-substrate combination are the same, except as noted. The scores are slightly different from the longline/gillnet scores. In particular, susceptibility of 1 vs. 0 was estimated for biogenic depressions, surface/subsurface sediments, and mussels for trap gears.

Table 37 – Lobster and deep-sea red crab trap matrices. Susceptibility (S) values are coded as follows: 0: 0-10%; 1: >10-25%; 2: >25-50%; 3: >50%. Recovery (R) values are coded as follows: 0: <1 year; 1: 1-2 years; 2: 2-5 years; 3: >5 years. The literature column indicates those studies identified during the literature review as corresponding to that combination of gear, feature, energy, and substrate. The studies referenced here were intended to be inclusive, so any particular study may or may not have directly informed the S or R score. Any literature used to estimate scores is referenced in Table 38 (Fixed gear S), Table 39 (Geo R), and Table 40 (Bio R).

Gear: Trap					
Substrate: Mud					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Biogenic burrows (G)	filling, crushing	none	none	1	0
Biogenic depressions (G)	filling	none	none	1	0
Sediments, surface/subsurface (G)	resuspension, compression, geochem, mixing, sorting	none	none	1	0
Amphipods, tube-dwelling (B)	crushing	none	none	1	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	102	102	1 (low energy only)	0 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Substrate: Sand					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Bedforms (G)	smoothing	none	none	0 (high energy only)	0 (high energy only)
Biogenic burrows (G)	filling, crushing	none	none	1	0
Biogenic depressions (G)	filling	none	none	1	0
Sediments, surface/subsurface (G)	resuspension, compression, geochem, mixing, sorting	none	none	1	0
Shell deposits (G)	crushing	none	none	0	0
Amphipods, tube-dwelling (B)	crushing	none	none	1	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	184	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	none	none	1 (low energy only)	0 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B)	breaking, crushing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Sponge (B)	breaking, crushing, dislodging, displacing	none	none	0	1
Substrate: Granule-pebble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Granule-pebble, pavement (G)	burial, mixing, homogenization	none	n/a	0 (high energy only)	0 (high energy only)
Granule-pebble, scattered, in sand (G)	burial, mixing	none	none	0	0

Shell deposits (G)	burying, crushing, displacing	none	none	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	102	102	1	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	102	102	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	1	0
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B)	breaking, crushing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	102	102	1	2
Polychaetes, other tube-dwelling (B)	crushing, dislodging	102	102	1	1
Sponges (B)	breaking, dislodging, displacing	102	102	1	1
Substrate: Cobble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Cobble, pavement (G)	burial, mixing, homogenization	none	n/a	0 (high energy only)	0 (high energy only)
Cobble, piled (G)	smoothing, displacement	none	none	1	3
Cobble, scattered in sand (G)	burial, mixing, displacement	none	none	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	102	102	1	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	102	102	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	1	0
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B)	breaking, crushing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	102	102	1	2
Polychaetes, other tube-dwelling (B)	crushing, dislodging	102	102	1	1
Sponges (B)	breaking, dislodging, displacing	102	102	1	1

Substrate: Boulder					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Boulder, piled (G)	displacement	none	none	0	3
Boulder, scattered, in sand (G)	displacement	none	none	0	0

Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	102	102	1	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	Add	Add	1	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	102	102	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	1	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	102	102	1	2
Polychaetes, other tube-dwelling (B)	crushing, dislodging	102	102	1	1
Sponges (B)	breaking, dislodging, displacing	102	102	1	1

5.2.4.3 Fixed gear susceptibility summary

Fixed gear susceptibility was generally similar across gear types, and susceptibility values are lower than those determined for trawls and dredges. Little research was available on which to base the fixed gear susceptibility values, but those papers that were used are referenced in the matrices for each gear type. Table 38 summarizes the rationale behind the structural feature susceptibility values for all the fixed gears. Recovery scores for all gear types are combined into two tables at the conclusion of the matrix results section (Table 39 – geological, Table 40 - biological). In some cases, faster recovery was expected to follow a fixed gear impact as compared to a mobile gear impact, because the gear effects are different between fixed and mobile gears. These differences are noted in the recovery summary table.

Table 38 – Fixed gears susceptibility summary for all structural features. When applicable, reasons for differences in values between gear types and/or substrates are summarized.

Feature	*Substrates evaluated*	*Score*	*Susceptibility*
Amphipods, tube-dwelling	Mud, sand	1	The percentage of amphipods impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur.
Anemones, actinarian	Granule-pebble, cobble, boulder	1	The percentage of anemones impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur.
Anemones, cerianthid burrowing	Mud, sand, granule-pebble	1	The percentage of burrowing anemones impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur.
Ascidians	Sand, granule-pebble, cobble, boulder	1	The percentage of tunicates impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur. Study 102 found evidence of tunicate detachment likely from setting and hauling back traps.
Bedforms	Mud, sand	0	Currently there is no evidence that any fixed gears will alter bed forms. Gear will sit atop bedforms.
Biogenic burrows	Mud, sand	1	All three gears can collapse a burrow, especially the anchor for longline and gillnet gears. However, unlikely that the longline, gillnet or trap bottom lines will cause significant damage within 1 meter of the line/net.

Feature	***Substrates evaluated***	***Score***	***Susceptibility***
Biogenic depressions	Mud, sand	0 (mud), 1 (sand)	All three gears can cause damage to biogenic depressions, especially the anchor (gillnet/longlines). However, unlikely that the longline or gillnet will cause significant damage within 1 meter of the line/net.
Boulder, piled	Boulder	0	Fixed gears do not impact this geological feature.
Boulders, scattered in sand	Boulder	0	Fixed gears do not impact this geological feature.
Brachiopods	Granule-pebble, cobble, boulde	1	The percentage of brachiopds impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur.
Bryozoans	Granule-pebble, cobble, boulde	1	The percentage of erect bryozoans impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur. Study 102 found some damage to large individuals of the ross coral, *Pentapora foliacea* likely caused by hauling traps.
Cobble, pavement	Cobble	0	Fixed gears do not impact this geological feature.
Cobble, piled	Cobble	1	Fixed gear could dislodge piled cobbles if dragged across them.
Cobble, scattered in sand	Cobble	0	Fixed gears do not impact this geological feature.
Corals, sea pens	Mud, sand	1	The percentage of sea pens impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur. Study 102 found that sea pens off the coast of Great Britain bent but did not break under the weight of crustacean traps. However, traps used in NE US are much heavier and likely would cause at least some damage.
Granule-pebble, pavement	Granule-pebble	0	Fixed gears do not impact this geological feature.
Granule-pebble, scattered in sand	Granule-pebble	0	Fixed gears do not impact this geological feature.
Hydroids	Mud, sand, granule-pebble, cobble, boulder	1	The percentage of hydroids impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur. Study 184 found lower hydroid biomass in areas that were fished heavily.
Macroalgae	Granule-pebble, cobble, boulde	1	Fixed gear impacts on macroalgae are likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur.
Mollusks, epifaunal bivalve	Mud, sand, granule-pebble, cobble, boulder	0	Long-line and gillnet gears likely do not impact this biological feature. Traps are likely to crush some bivalves that exist on hard substrates such as mussels.
Polychaetes, *Filograna implexa*	Sand, granule-pebble, cobble, boulder	1	Colonial tube worms are very fragile, and consequently are susceptible to damage via contact with anchors, gillnets, bottom lines, and traps. However, it is unlikely that more than 25% of colonial tube worm aggregations would be removed within the 1 m swath of potential impact adjacent to a gillnet, long-line, or trap bottom line.

Feature	Substrates evaluated	Score	Susceptibility
Polychaetes, other tube-dwelling	Granule-pebble, cobble, boulder	1	Colonial tube worms are very fragile, and consequently are susceptible to damage via contact with anchors, gillnets, bottom lines, and traps. However, it is unlikely that more than 25% of colonial tube worm aggregations would be removed within the 1 m swath of potential impact adjacent to a gillnet, long-line, or trap bottom line.
Sediments, surface and subsurface	Mud, sand	0, 1 (traps)	Sediment impacts expected to be limited; some compression due to traps, so score of 1
Shell deposits	Mud, sand, granule-pebble, cobble, boulder	0	Fixed gears do not impact this geological feature.
Sponges	Mud, sand, granule-pebble, cobble, boulder	0	The percentage of sponges impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur. Study 102 found evidence of sponge detachment likely from setting and hauling back traps.

5.2.5 Recovery– all gear types

In general, recovery values are determined to be more dependent on the intrinsic characteristics of the features themselves than on the gear type causing the impact or on the substrate, except in cases where gear impacts are thought to vary substantially between gear types. Thus, for most features, recovery varies slightly between the following three groupings: trawls/scallop dredges, hydraulic dredges, and fixed gears. Recovery values are allowed to vary by high and low energy, however, for biological features, recovery scores are typically the same between energy environments, with the exception of some of the hydraulic dredge scores in granule-pebble. Recovery of lost habitat value provided by structure-forming features or bottom sediments is interpreted to mean the estimated time (in years) that it would take to restore the functional value provided by the feature before it is disturbed. Because disturbance can cause the partial or complete removal of geological features, complete removal of organisms, or damage to organisms that remain in place, recovery times for biological features are evaluated – as much as possible – in terms of how long it would take to replace organisms of the same size and aggregations of organisms (e.g., mussel beds, amphipod tube mats) of the same density and areal coverage, by means of reproduction and growth. Some of the required information is available from experimental studies and comparisons of benthic communities in areas open and closed to commercial fishing, and some is based on life histories (growth, reproductive strategies, longevity) of the affected organisms. In most cases there is not enough information available to make very informed decisions, so recovery scores required a considerable amount of professional judgment. Another complicating problem is that many biological features (e.g., mussels) included a number of species with different recovery potentials, so overall R scores tended towards intermediate values.

Table 39 – Recovery summary for all geological features, by, substrate, gear type, and energy.

Feature	Substrate*	Gear type*	Recovery score high energy	Recovery summary high energy	Recovery score low energy	Recovery summary low energy

Feature	***Substrate****	***Gear type****	***Recovery score high energy***	***Recovery summary high energy***	***Recovery score low energy***	***Recovery summary low energy***
Bedforms	Sand	Trawls, scallop dredges	0	Sand ripples re-formed by tidal currents within hrs/days, sand waves by storms that occur at least once a year	n/a	This feature was assumed not to occur in a low energy environment.
Bedforms	Sand	Hydraulic dredges	0	Dredge tracks still visible after 2 mos (287), no longer visible after 11 wks (373), nearly indistinct after 24 hrs (245), complete recovery of physical features after 40 days (140)	n/a	This feature was assumed not to occur in a low energy environment.
Bedforms	Sand	Fixed gears	0	Bedforms estimated to have very low susceptibility to fixed gears, so recovery is not really required	n/a	This feature was assumed not to occur in a low energy environment.
Biogenic burrows	Mud, sand	Trawls, scallop dredges	0	Assume recovery <1 yr because organisms creating depressions are mobile, will move quickly into trawl/dredge path	0	Same as high energy: depends on number/activity of organisms, no reason to think it will vary by energy level
Biogenic burrows	Sand, granule pebble	Hydraulic dredge	1	Slower re-colonization by organisms (clams?) that live deeper in sediment?	2	No recovery after 3 yrs due to high mortality of organisms (clams) that make burrows (121)
Bedforms	Mud, sand	Fixed gears	0	Burrows estimated to have very low susceptibility to fixed gears, so recovery is not really required	0	Burrows estimated to have very low susceptibility to fixed gears, so recovery is not really required
Biogenic depressions	Mud, sand	All	0	Assume recovery <1 yr because organisms creating depressions are mobile, will move quickly into trawl/dredge path	0	Same as high energy: depends on number/activity of organisms, no reason to think it will vary by energy level
Boulder, piled	Boulder	Trawls, scallop dredges, fixed gears	3	Assume any disturbance would be permanent	3	Assume any disturbance would be permanent

Feature	***Substrate****	***Gear type****	***Recovery score high energy***	***Recovery summary high energy***	***Recovery score low energy***	***Recovery summary low energy***
Boulders, scattered in sand	Boulder	Trawls, scallop dredges, fixed gears	0	If the cobble/boulder is rolled over or buried, the depression underneath it would need to be recreated, but we estimated the time required for this would be under one year (R=0). This is consistent with the recovery times estimated for the burrow and depression features in the mud and sand substrates, except for hydraulic dredge fishing, which doesn't apply to cobble and boulder-dominated areas.	0	If the cobble/boulder is rolled over or buried, the depression underneath it would need to be recreated, but we estimated the time required for this would be under one year (R=0). This is consistent with the recovery times estimated for the burrow and depression features in the mud and sand substrates, except for hydraulic dredge fishing, which doesn't apply to cobble and boulder-dominated areas.
Cobble, pavement	Cobble	Trawls, scallop dredges, fixed gears	0	Assume pavement re-forms quickly as overlying sand is removed by currents, wave action	n/a	This feature was assumed not to occur in a low energy environment.
Cobble, piled	Cobble	Trawls, scallop dredges, fixed gears	3	Assume any disturbance would be permanent	3	Assume any disturbance would be permanent
Cobble, scattered in sand	Cobble	Trawls, scallop dredges, fixed gears	0	Similar to boulder, if cobble is rolled or dragged, it does not change its ability to provide structure, so recovery doesn't really apply and thus was set to zero.	0	Similar to boulder, if cobble is rolled or dragged, it does not change its ability to provide structure, so recovery doesn't really apply and thus was set to zero.
Granule-pebble, pavement	Granule-pebble	Trawls, scallop dredges, fixed gears	0	Assume pavement re-forms quickly as overlying sand is removed by currents, wave action	n/a	This feature was assumed not to occur in a low energy environment.
Granule-pebble, pavement	Granule-pebble	Hydraulic dredges	2	Sediments homogenized, coarser sediments end up deeper in trenches (232); pavement might never reform?	n/a	This feature was assumed not to occur in a low energy environment.
Granule pebble, scattered in sand	Granule-pebble	Trawls, scallop dredges	0	Assume primary action of both gears is displacement, not burial. Assume any buried granules/pebbles would be uncovered quickly by currents, wave action.	2	Storms are less frequent in deeper water; furrows left in pebble bottom by rockhoppers still prominent a year later (111, but 200-300 m deep)

Feature	***Substrate****	***Gear type****	***Recovery score high energy***	***Recovery summary high energy***	***Recovery score low energy***	***Recovery summary low energy***
Granule pebble, scattered in sand	Granule-pebble	Fixed gears	0	Scattered granule-pebble estimated to have very low susceptibility to fixed gears, so recovery is not really required	0	Scattered granule-pebble estimated to have very low susceptibility to fixed gears, so recovery is not really required
Granule pebble, scattered in sand	Granule-pebble	Hydraulic dredges	1	Coarser sediments end up deeper in trenches (232); slower recovery than trawls and scallop dredges since granules-pebbles would be buried deeper by a hydraulic dredge.	2	Storms that would re-expose granules/pebbles are less frequent in deeper water
Sediments, surface and subsurface	Mud	Trawls	0	No data, assume faster recovery in high energy. Although resuspended sediment may be transported away in high energy, it is assumed that the sediment would be replaced by transport from elsewhere.	0	Recovery of bottom roughness in 6 mos (372), all geochemical sediment properties recovered within 3.5 mos (338). Recovery of door tracks takes 1-2 yrs in low energy (372,277), but door impacts less important because such a small proportion of area swept by trawl gear. Resuspension would have limited effects, because resuspended sediment will remain in area.
Sediments, surface and subsurface	Mud	Scallop dredges	0	No recovery of fine sediments 6 mos after dredging (391-multiple tows, recovery not checked after 1 yr)	0	No data, so assume same recovery as trawls
Sediments, surface and subsurface	Mud, Sand	Fixed gears	0	Estimated to have very low susceptibility to fixed gears, so recovery is not really required	0	Estimated to have very low susceptibility to fixed gears, so recovery is not really required
Sediments, surface and subsurface	Sand	Trawls	0	Lost fine sediments replaced very quickly (within hours or days) by bottom currents, or less than a year by turbulence from wave action	0	Door tracks not visible or faintly visible in SS sonar records, recovery of seafloor topography within a year (325), compacted sediments recovered within 5 mos (336)
Sediments, surface and subsurface	Sand	Scallop dredges	0	Same as trawls	0	Recovery of food value of sediments within 6 mos, but no recovery of lost fine sediments (391)

Feature	Substrate*	Gear type*	Recovery score high energy	Recovery summary high energy	Recovery score low energy	Recovery summary low energy
Sediments, surface and subsurface	Sand	Hydraulic dredge	1	Trenches no longer visible a day to three months after dredging (245, 246, 287, 373), also see trawls. Top 20 cm of sand in trenches still fluidized after 11 wks, but not examined after that (373).	2	Trenches no longer visible after 1 yr (121), but replacement of lost fine sediment would take longer in low energy environments. Acoustic reflectance of trenches still different than surrounding seabed after 3 yrs (121)
Shell deposits	Sand, granule-pebble, cobble	Trawls, scallop dredges	1	Shells are much heavier than sand, so if they are dispersed it could take 1-2 yrs for storms to re-aggregate them.	2	Assume it would take 2-5 yrs in low energy because storms would have to be more severe to produce bottom turbulence in deeper water.
Shell deposits	Sand, gr-pebble	Hydraulic dredges	1	Assume shells buried in trench would remain buried, but new ones would "recruit" to sediment surface within 1-2 yrs	2	Over time, empty shells collect in dredge tracks (121). Similar to trawls, s dredges, assume it would take 2-5 yrs in low energy because storms would have to be more severe to produce bottom turbulence in deeper water.
Shell deposits	Sand, granule-pebble, cobble	Fixed gears	0	Gear would not completely remove or crush shells, so deposit would remain largely intact and recovery would not be required	0	Gear would not completely remove or crush shells, so deposit would remain largely intact and recovery would not be required

Table 40 – Recovery summary for all biological features, by, substrate and gear type.

Feature	Substrate	Gear type	Recovery score	Recovery summary (same scoresfor low and high energy, except as noted)
Amphipods, tube-dwelling	Mud, sand	Trawls, scallop dredges	0	*A. abdita* are short-lived, highly seasonal occurrence (several times a year), tube mats re-form within months following benthic recruitment of juveniles (MacKenzie et al 2006)
Amphipods, tube-dwelling	Sand	Hydraulic dredges	0	See above
Amphipods, tube-dwelling	Mud, sand	Fixed gears	0	See above
Anemones, actinarian	Granule-pebble, cobble, boulder	Trawls, scallop dredges	2	Recovery could take >7 yr (see Witman 1998, referenced in 404), colonized cobble in settlement trays on GB within 2.5 yrs (Collie et al 2009)
Anemones, actinarian	Granule-pebble	Hydraulic clam dredge	2	See above
Anemones, actinarian	Granule-pebble, cobble, boulder	Fixed gears	2	See above

Feature	***Substrate***	***Gear type***	***Recovery score***	***Recovery summary (same scoresfor low and high energy, except as noted)***
Anemones, cerianthid burrowing	Mud, sand, granule-pebble	Trawls, scallop dredges	2	Apparently long-lived (>10 yrs?), but If animal is still alive, assume damaged tube can be repaired/replaced fairly quickly; recovery score is a "compromise" between 1-2 yrs for tube repair and 5-10 yrs (?) to replace animal.
Anemones, cerianthid burrowing	Sand, granule-pebble	Hydraulic clam dredge	3	Assume impact is removal of animal, not damage to tube, so recovery time is longer than for other gears (see above)
Anemones, cerianthid burrowing	Mud, sand, granule-pebble	Fixed gears	2	See trawls, scallop dredges
Ascidians	Sand, granule-pebble, cobble, boulder	Trawls, scallop dredges	1	Later colonizers than bryozoans, accounted for 6% of patch space 15 mos after all organisms were removed from rock surface (30m, Cashes Ledge in GOM, Witman 1998). *Molgula arenata* removed in linear patterns by scallop dredges on Stellwagen Bank (sand), widely distributed over bottom a year later (11), but not known whether they had returned to pre-disturbance densities. Assume recovery would be mostly complete within 1-2 years
Ascidians	Sand, granule-pebble	Hydraulic clam dredge	1, except 2 in low energy granule-pebble	See above, except that longer recovery in low energy granule pebble because substrate on which organisms settle (granules, pebbles) highly susceptible also
Ascidians	Sand, granule-pebble, cobble, boulder	Fixed gears	1	See above
Brachiopods	Granule-pebble, cobble, boulder	Trawls, scallop dredges	2	*Terebratulina septentrionalis* is relatively short-lived (1-5 ys), so "lost" individuals would be replaced in 2-5 years.
Brachiopods	Granule-pebble	Hydraulic clam dredge	2	See above
Brachiopods	Granule-pebble, cobble, boulder	Fixed gears	2	See above
Bryozoans	Granule-pebble, cobble, boulder	Trawls, scallop dredges	1	Recovered within 2 yrs after CAII (eastern George Bank) was closed, grow/recolonize rapidly, life spans typically <1 yr (see #404). Two species were first colonizers of rocky substrate on Cashes Ledge, accounting for most of patch space after 15 mos (Witman 1998). At 50m site on Cashes Ledge, bryozoans covered >50% rock substrate within a year and approached 100% by second year (Sebens et al 1988).
Bryozoans	Granule-pebble	Hydraulic clam dredge	1, except 2 in low energy granule-pebble	See above, except that longer recovery in low energy granule pebble because substrate on which organisms settle (granules, pebbles) highly susceptible also
Bryozoans	Granule-pebble, cobble, boulder	Fixed gears	1	See above
Corals, sea pens	Mud, sand	Trawls, scallop dredges, hydraulic clam dredges	2 (high energy only)	Sea pens (Stylatula spp) in mud (180-360m) on west coast are sessile, slow-growing, long-lived (up to 50 yrs) species that are likely to recover slowly from physical disturbance (164), but sea pens are sometimes able to "re-root" if removed from bottom (see below).

Feature	Substrate	Gear type	Recovery score	Recovery summary (same scoresfor low and high energy, except as noted)
		(sand only)		
Corals, sea pens	Mud, sand	Fixed gears	0 (high energy only)	Full recovery from bending, smothering, some from uprooting, from pot fishing (in mud) within days, don't retract when pots drop on them (102); however, little known about lifespan, growth rates
Hydroids	Mud, sand, granule-pebble, cobble, boulder	Trawls, scallop dredges	1	Life histories similar to bryozoans (live 10 days-1 yr), some species are perennial but exhibit seasonal regression, spatial extent of recovery restricted by limited larval dispersal, or absence of pelagic medusa stage (404). On Stellwagen Bank (coarse sand), no recovery of hydroid (*Corymorpha pendula)* a year after removal by trawls and scallop dredges (11)
Hydroids	Sand, granule-pebble	Hydraulic clam dredge	1, except 2 in low energy granule-pebble	See above, except that longer recovery in low energy granule pebble because substrate on which organisms settle (granules, pebbles) highly susceptible also
Hydroids	Mud, sand, granule-pebble, cobble, boulder	Fixed gears	1	See above
Macroalgae	Granule-pebble, cobble, boulder	Trawls, scallop dredges	1	All macroalgae in NE region are perennials, so some re-growth and replacement of lost plants occurs within a year, but assume that full growth and recovery of lost structure would take 1-2 years, maybe longer for large laminarians.
Macroalgae	Granule-pebble	Hydraulic clam dredge	1	See above
Macroalgae	Granule-pebble, cobble, boulder	Fixed gears	1	See above
Mollusks, epifaunal bivalve, *Modiolus modiolus*	Mud, sand, granule-pebble, cobble, boulder	Trawls, scallop dredges	3	*Mytilus edulis* can reach full growth within a year in optimum conditions, but otherwise 2-5 years are needed, *Modiolus* is a long-lived species (some individuals live 25 years or more) and inhabits colder water, presumably with slower growth rate. Recovery of mussel beds – which have greater habitat value – may be longer than for individuals.
Mollusks, epifaunal bivalve , *Modiolus modiolus*	Sand, granule-pebble	Hydraulic clam dredge	3	See above
Mollusks, epifaunal bivalve , *Modiolus modiolus*	Mud, sand, granule-pebble, cobble, boulder	Fixed gears	0	Minimal susceptibility to disturbance, therefore recovery was assumed to be complete within a year.
Mollusks, epifaunal bivalve , *Placopecten magellanicus*	Sand, granule-pebble, cobble, boulder	Trawls, scallop dredges	2	Scallop biomass increased 200x in prime, gravel pavement habitat in closed area on Georges Bank 7 years after area was closed to fishing, much higher than 9-14x increase for all GB closed areas combined (157)
Mollusks, epifaunal bivalve , *Placopecten magellanicus*	Sand, granule-pebble	Hydraulic clam dredge	2	
Mollusks, epifaunal bivalve	Sand, granule-pebble, cobble,	Fixed gears	0	Scallops not susceptible to fixed gears, therefore R=0

Feature	***Substrate***	***Gear type***	***Recovery score***	***Recovery summary (same scoresfor low and high energy, except as noted)***
, Placopecten magellanicus	boulder			
Polychaetes, *Filograna implexa*	Sand, granule-pebble, cobble, boulder	Trawls, scallop dredges	2	*Filograna* colonized cobble in settlement trays on GB within 2.5 yrs (Collie et al 2009), on pebble pavement (eastern GB) full recovery within 5 yrs following closure of area (71)
Polychaetes, *Filograna implexa*	Granule-pebble	Hydraulic clam dredges	2	See above
Polychaetes, *Filograna implexa*	Granule-pebble, cobble, boulder	Fixed gears	2	See above
Polychaetes, other tube-dwelling	Granule-pebble, cobble, boulder	Trawls, scallop dredges	1	Because tubes are less fragile than *Filograna* tubes, assume they are less susceptible to damage from these two gears and therefore recover more quickly.
Polychaetes, other tube-dwelling	Granule-pebble	Hydraulic clam dredges	1, except 2 in low energy granule-pebble	See above, except that longer recovery in low energy granule pebble because substrate on which organisms settle (granules, pebbles) highly susceptible also
Polychaetes, other tube-dwelling	Granule-pebble, cobble, boulder	Fixed gears	1	Slower recovery time based on lower susceptibility to fixed gears
Sponges	Sand, granule-pebble, cobble, boulder	Trawls, scallop dredges	2	With one exception, value is consistent with literature. On eastern GB, recovery in closed area (CAII) within 5 yrs (esp *Polymastia, Isodictya*), colonization of gravel 2.5 yrs after closure with increase in sponge cover after 4.5 yrs (71) . Significantly higher incidence of sponge (*S. ficus*)/shell fragment microhabitats inside S part of CAII after 4.5 yrs (225). No recovery from single tows after a year in Gulf of Alaska (111). Aperiodoc recruitment and perennial life cycles, life spans >5 yrs account for relatively slow recovery times (404). Exception is study 382 (shallow water in Georgia) which reports full recovery of large sponges from damage and return to pre-trawl densities (single tows) within a year.
Sponges	Sand, granule-pebble	Hydraulic clam dredge	2	See above
Sponges	Sand granule-pebble, cobble, boulder	Fixed gears	1	Slower recovery time based on lower susceptibility to fixed gears, higher probability that disturbance would damage or remove parts of sponge rather than remove whole animal.

5.2.6 Summary of vulnerability assessment results

The following series of figures show the average percent reduction in functional value of features and average recovery time in years. The results are summarized by gear type, feature class (geological or biological), substrate, and energy. Longlines and gillnets are grouped together due to equality of S/R scores. In all cases, the S and R scores are converted to percentages and years, respectively, and then the percentages and years for individual features are averaged, with all features weighted equally. Because the SASI model selects percentages and years randomly from the range of possible values according to the S or R score, the figures below are based on random values, as follows:

R=0, years = 1
R=1, years = 1 to 2
R=2, years = 2 to 5
R=3, years = 5 to 10

S=0, % = 0 to 10
S=1, % = 10 to 25
S=2, % = 25 to 50
S=3, % = 50 to 100

The table below each figure summarizes the mean suceptiblity and recovery scores according to substrate, energy, and feature class.

Note that scales vary between gear types depending on the range of values in the data. Slight differences in figures between gear types where average S and R scores are the same reflect the random assignment of years and percentages within each R or S category.

Table 41 – Summary of susceptibility and recovery scores for trawl gear.

Trawl					
		Average S Score		Average R Score	
Substrate	Energy	Geological	Biological	Geological	Biological
Mud	High	2.0	1.3	0.0	1.5
	Low	2.0	1.4	0.0	1.6
Sand	High	1.8	1.5	0.2	1.6
	Low	1.8	1.6	0.5	1.7
Granule-pebble	High	1.0	1.7	0.3	1.7
	Low	1.0	1.7	2.0	1.7
Cobble	High	1.7	1.6	1.0	1.6
	Low	2.0	1.7	1.5	1.7
Boulder	High	1.0	1.7	1.5	1.6
	Low	1.0	1.8	1.5	1.7

Table 42 – Summary of susceptibility and recovery scores for scallop dredge gear.

Scallop Dredge					
		Average S Score		Average R Score	
Substrate	Energy	Geological	Biological	Geological	Biological
Mud	High	2.0	1.3	0.0	1.5
	Low	2.0	1.4	0.0	1.6
Sand	High	1.8	1.6	0.2	1.6
	Low	1.8	1.7	0.5	1.7
Granule-pebble	High	1.0	1.8	0.3	1.7
	Low	1.0	1.8	2.0	1.7
Cobble	High	1.7	1.7	1.0	1.6
	Low	2.0	1.8	1.5	1.7
Boulder	High	1.0	1.7	1.5	1.6
	Low	1.0	1.8	1.5	1.7

Table 43 – Summary of susceptibility and recovery scores for hydraulic dredge gear.

Hydraulic Dredge					
		Average S Score		Average R Score	
Substrate	Energy	Geological	Biological	Geological	Biological
Sand	High	2.8	2.6	0.6	1.8
	Low	2.8	2.7	1.5	1.8
Granule-pebble	High	2.7	2.8	1.3	1.8
	Low	2.5	2.8	2.0	2.2

Table 44 – Summary of susceptibility and recovery scores for longline and gillnet gears.

Longline, Gillnet					
		Average S Score		Average R Score	
Substrate	Energy	Geological	Biological	Geological	Biological
Mud	High	0.3	0.8	0.0	0.8
	Low	0.3	0.8	0.0	0.6
Sand	High	0.4	0.6	0.0	0.9
	Low	0.5	0.7	0.0	0.8
Granule-pebble	High	0.0	0.8	0.0	1.2
	Low	0.0	0.8	0.0	1.2
Cobble	High	0.3	0.8	1.0	1.1
	Low	0.5	0.8	1.5	1.1
Boulder	High	0.0	0.9	1.5	1.2
	Low	0.0	0.9	1.5	1.2

Table 45 – Summary of susceptibility and recovery scores for trap gear.

Trap					
		Average S Score		Average R Score	
Substrate	Energy	Geological	Biological	Geological	Biological
Mud	High	1.0	0.8	0.0	0.8
	Low	1.0	0.8	0.0	0.6
Sand	High	0.6	0.6	0.0	0.9
	Low	0.8	0.7	0.0	0.8
Granule-pebble	High	0.0	0.9	0.0	1.2
	Low	0.0	0.9	0.0	1.2
Cobble	High	0.3	0.9	1.0	1.1
	Low	0.5	0.9	1.5	1.1
Boulder	High	0.0	1.0	1.5	1.2
	Low	0.0	1.0	1.5	1.2

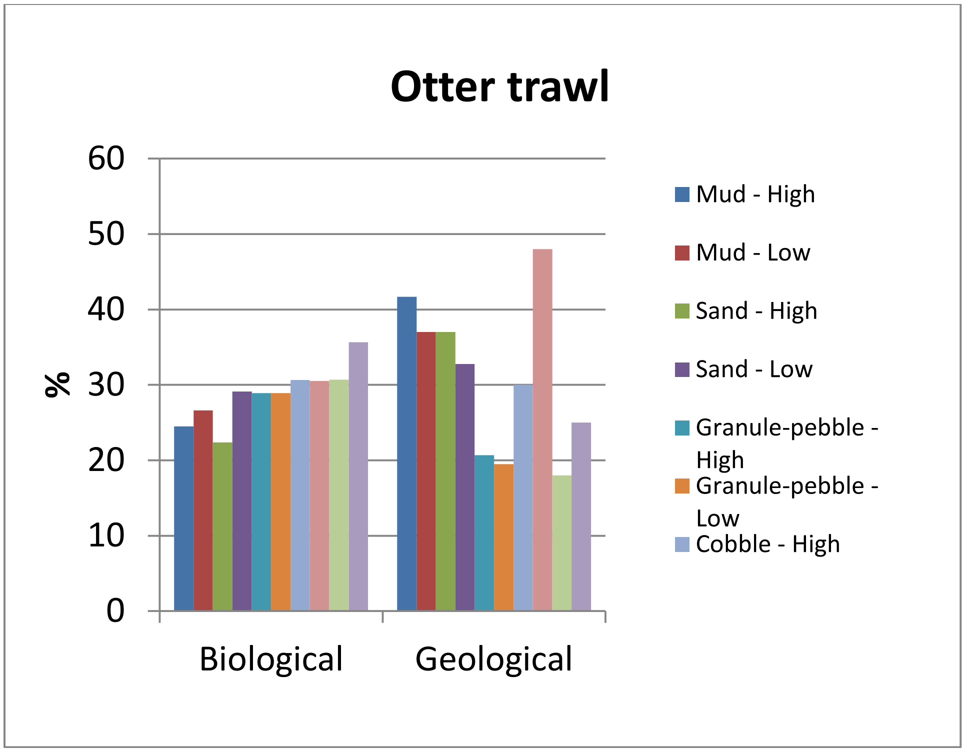


Figure 3 – Susceptibility of geological and biological features to trawl impacts according to substrate and energy.

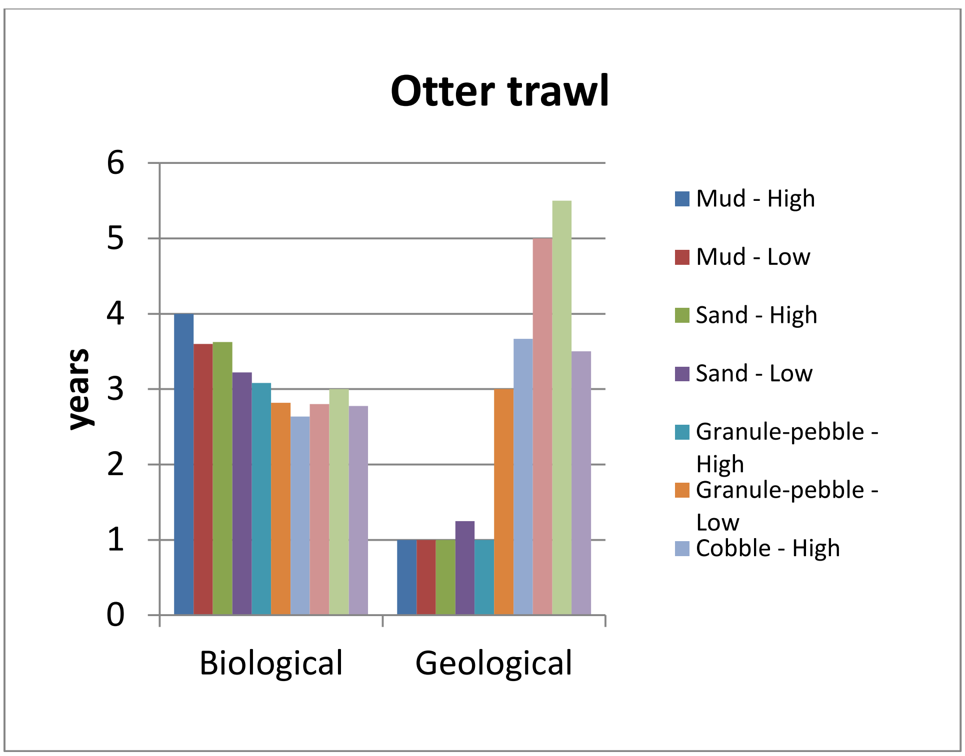


Figure 4 – Recovery of geological and biological features following trawl impacts according to substrate and energy.

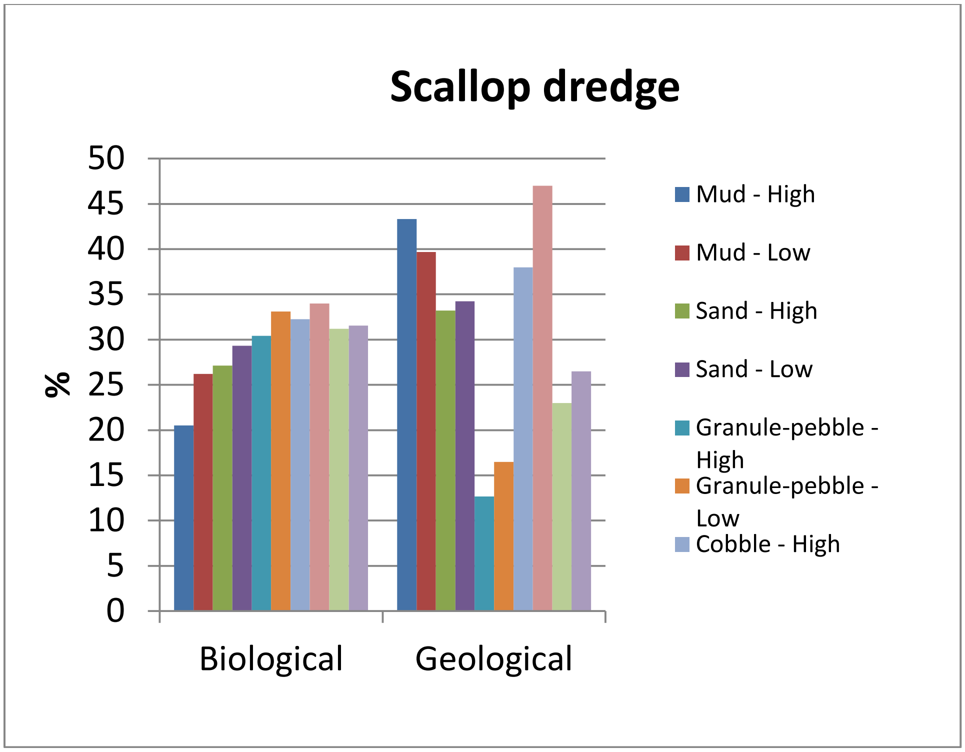


Figure 5 – Susceptibility of geological and biological features to scallop dredge impacts according to substrate and energy.

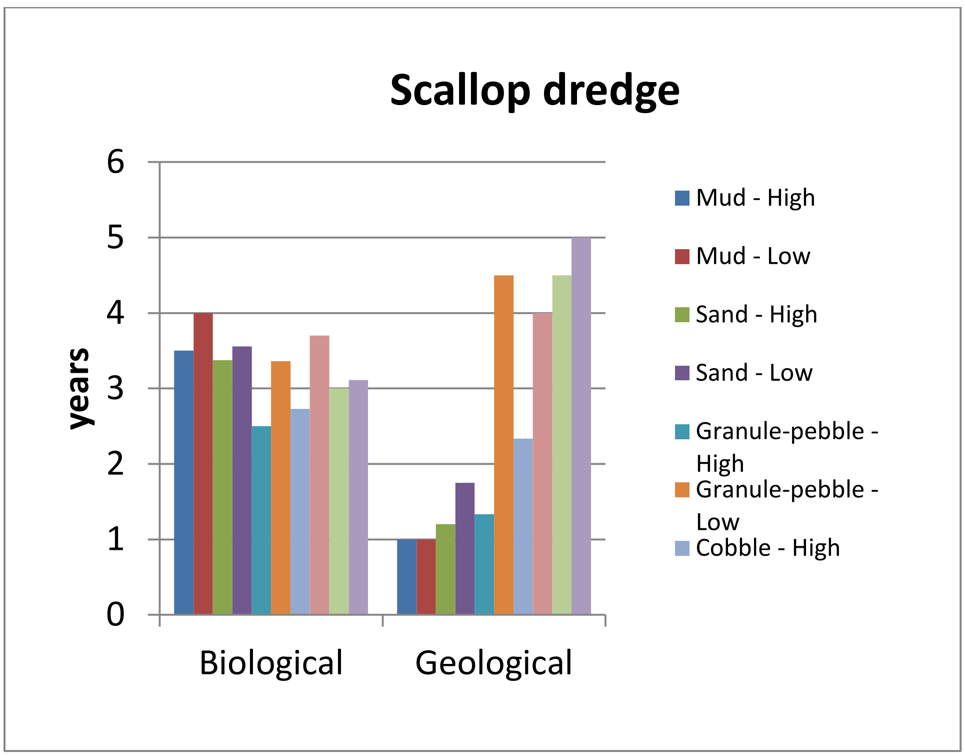


Figure 6 – Recovery of geological and biological features following scallop dredge impacts according to substrate and energy.

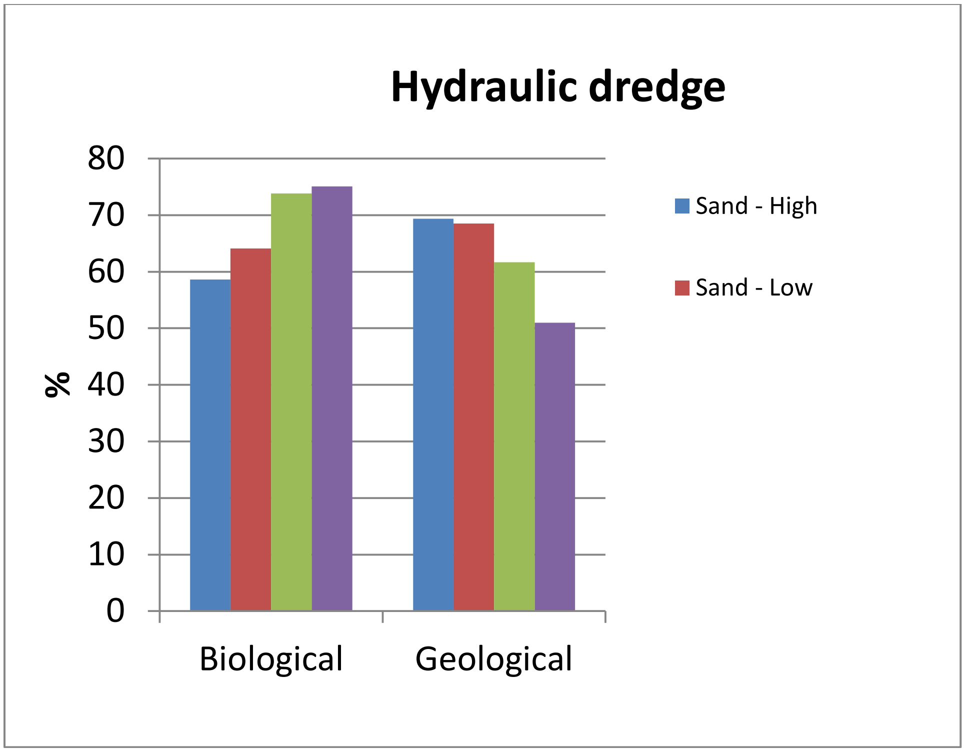


Figure 7 – Susceptibility of geological and biological features to hydraulic dredge impacts according to substrate and energy.

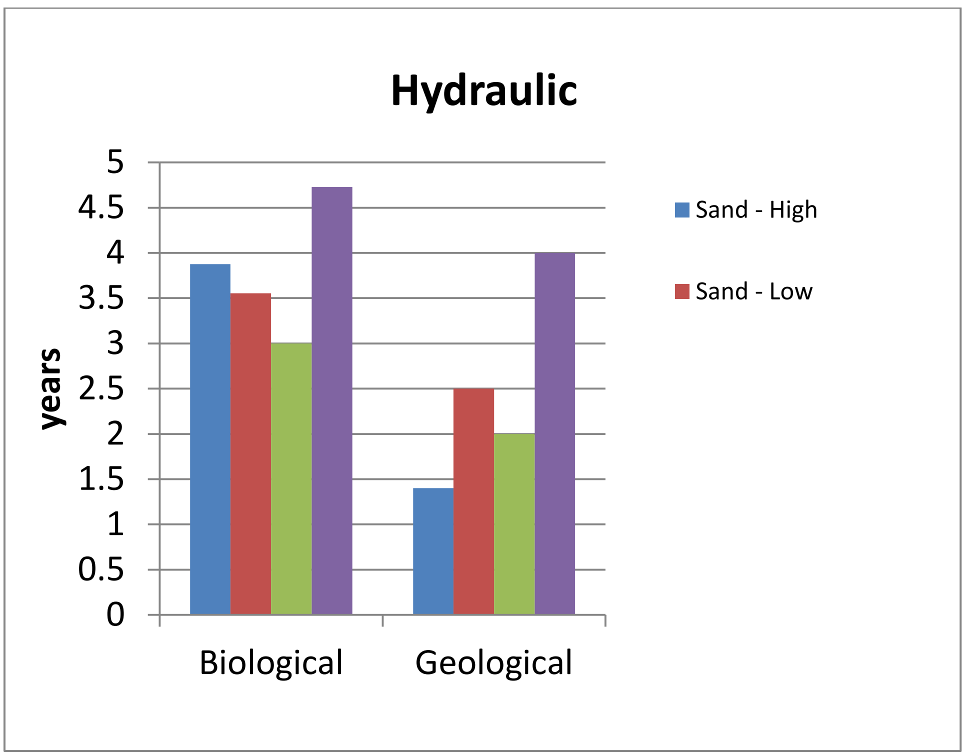


Figure 8 – Recovery of geological and biological features following hydraulic dredge impacts according to substrate and energy.

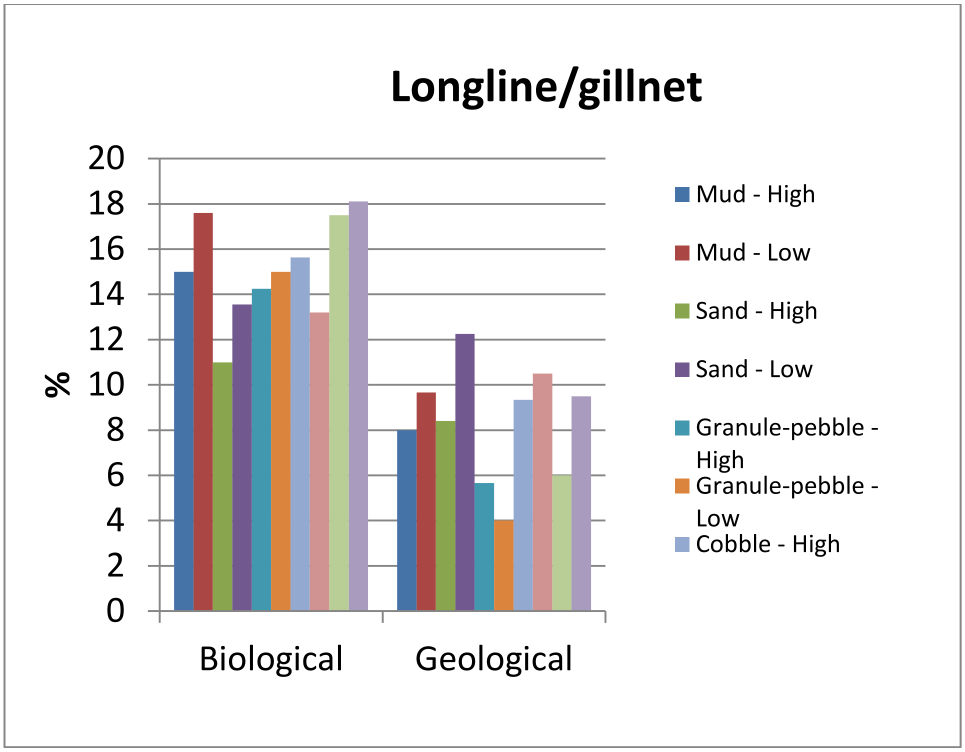


Figure 9 – Susceptibility of geological and biological features to longline and gillnet impacts according to substrate and energy

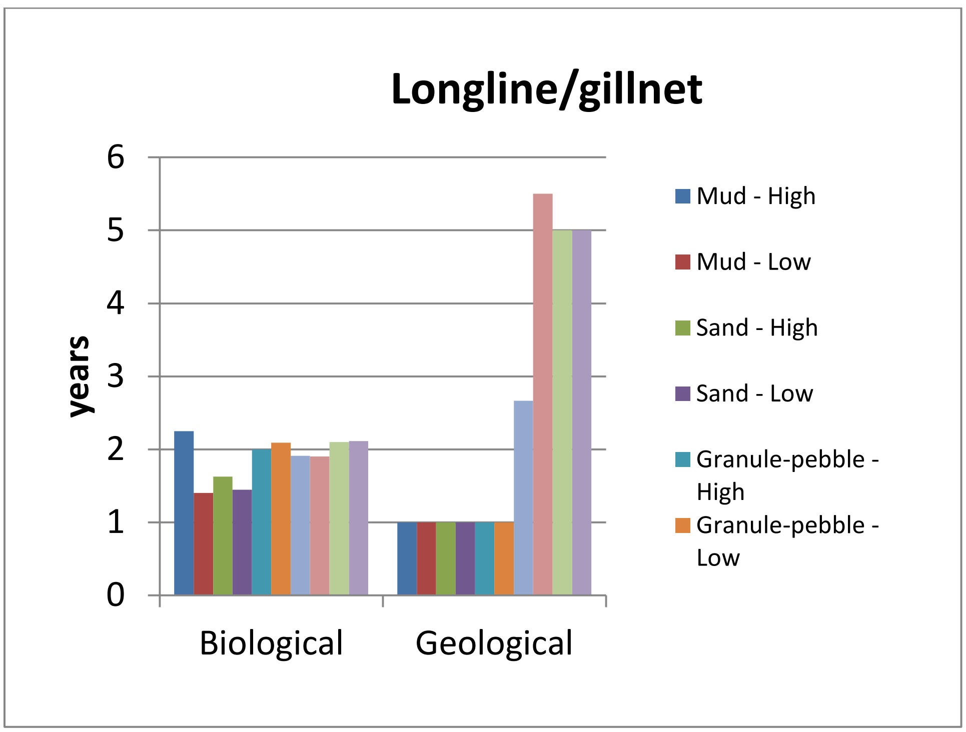


Figure 10 – Recovery of geological and biological features following longline and gillnet impacts according to substrate and energy

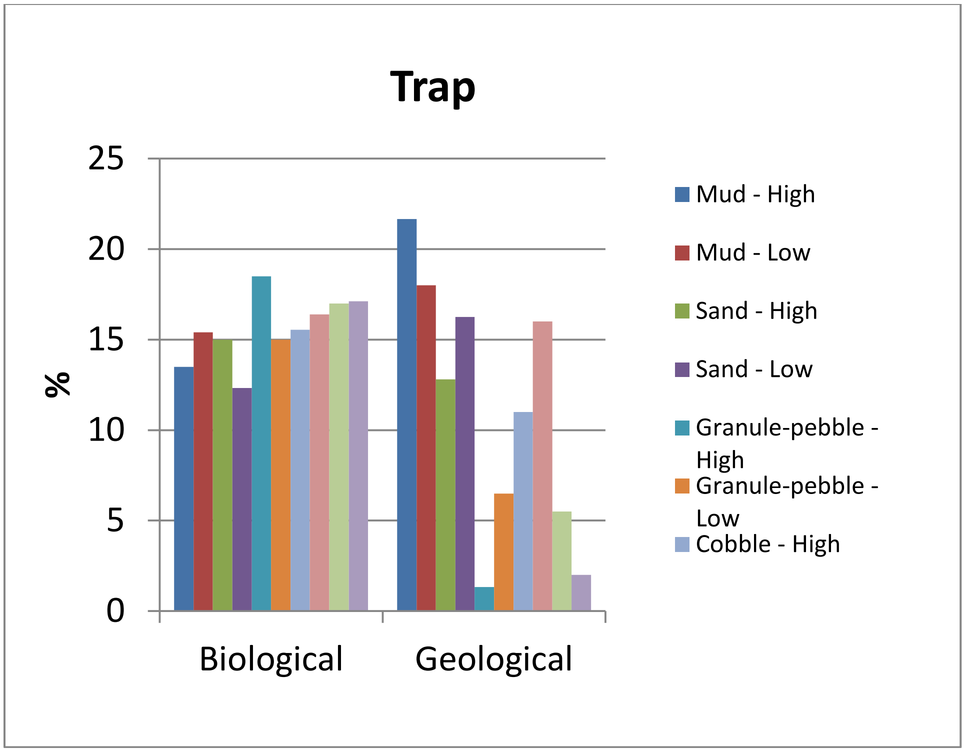


Figure 11 – Susceptibility of geological and biological features to trap impacts according to substrate and energy

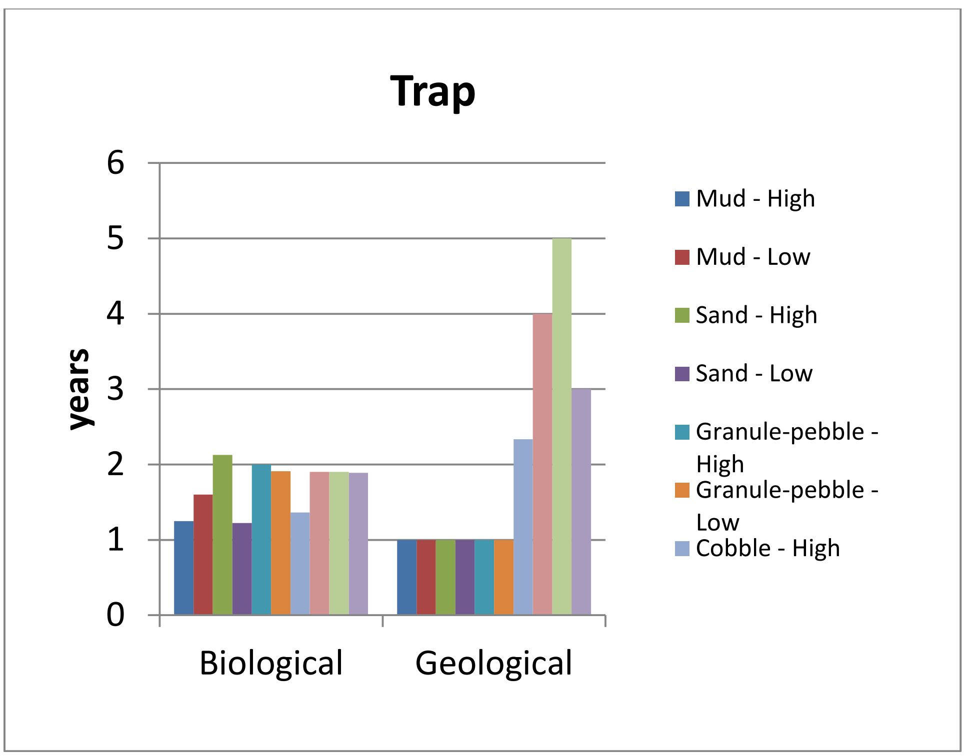


Figure 12 – Recovery of geological and biological features following trap impacts according to substrate and energy

5.3 Discussion

The impacts of fishing on marine ecosystems have been documented by scientists and remain a focus for scientists and fishery managers alike. Fishing can alter marine ecosystems by disturbing the seafloor substrate and removing the features that provide shelter and food for managed species. For instance, bottom-tending gears can remove or damage features such as cobble piles or erect sessile invertebrates that create refugia for juvenile fish. Fishing can also have negative impacts on the prey species that federally managed fish species forage on, such as crustaceans and other benthic invertebrates that are crushed or displaced by fishing gear.

Being able to assess the vulnerability of marine ecosystems to impacts from fishing is of fundamental importance to marine resource managers charged with sustaining the valuable goods and services that ecosystems provide. The SASI model is intended to assess the adverse effects of fishing gear on benthic habitat. Its end product is a spatially-referenced, quantitative measure of the adverse effects of fishing on seabed structural features.

To enable the often tennuous connection between the effects of fishing and the utilization of benthic habitats by commercial fish species, fish habitat is divided into components--geological and biological--which are further subdivided into features. Structural features identified include bedforms, biogenic burrows, sponges, macroalgae, etc. (see sections 2.1 and 2.2 related to geological and biological features, respectively). These features may either provide shelter for managed species directly, or provide shelter for their prey. The geological and biological features are distinguished as being non-living and living, respectively. While both components (geological, biological) are assumed to occur in every habitat type, the presence or absence of particular features is assumed to vary based on substrate type and natural disturbance (energy) regime. Thus, ten habitat types in the vulnerability assessment are distinguished by dominant substrate, level of natural disturbance, and the presence or absence of various features.[6]

The matrix-based vulnerability assessment organizes quantitative estimates of both the magnitude of the impacts that result from the physical interaction of fish habitats and fishing gears (susceptibility), and the duration of recovery following those interactions. Susceptibility (S) is defined as the percentage of total habitat features encountered by fishing gear during a hypothetical single pass fishing event that have their functional value reduced, with values ranging from 0 (0-10% impacted) to 3 (>50% impacted). Because functional value is difficult to assess directly, feature removal is used as a proxy for reduction in functional value. The time required for those features to recover their pre-impact functional value (R) is assigned a value ranging from 0 (<1 year) to 3 (5-10 years). It should be reiterated that the VA is only used to estimate adverse (vs. positive) effects, and that only impacts associated with the seabed (vs. the seabed and the water column) are considered, and that given the minimum one year timestep of

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[6] The substrate and energy classifications used are described in the introduction to section 2.0.

the SASI model, the VA is not intended to capture seasonal variation in relative abundance, susceptibility, or recovery rates of features.

5.3.1 Literature review

Efforts to assess the vulnerability of fish habitats to impacts from fishing remain challenged by (1) a limited amount of information regarding the locations and types of bottom substrates and (2) a lack of clear understanding of specifically how fishing activities affect these substrates. The formality of the VA approach served to highlight these gaps in knowledge. When information is not available on a particular gear type's effects on a specific biological or geological feature, S and R parameter estimates are derived from studies of other gear types or similar features.

In total, the PDT drew from 97 studies of the impacts of fishing gear on habitats, in addition to numerous other sources relevant to the feature descriptions. Only studies with information relevant to Northwest Atlantic fishing gears and substrate features are included, although the list did include studies from other regions of the world. About half of the 97 studies utilized in the assessment are experimental in nature, but only about 25 of these are before/after impact studies directly applicable to the assessment of the susceptibility of habitat features to the effects of single tows or sets. Others are comparative in nature (e.g., evaluations of habitat conditions in areas open and closed to fishing, or where fishing intensity was heavy versus light). While these provided useful information, they are less informative in terms of assigning susceptibility and recovery scores.

Over 70 of the gear-impact studies focused on the effects of demersal trawling on biological and geological substrate features. Most of these considered 'generic' otter trawls, making it difficult to discern the effects of modified otter trawls (e.g., raised footrope or squid trawls) on substrate features. In addition, very few studies provided enough details regarding specific trawl design, configuration, and fishing procedures, which would have been required to assign S and R scores for individual trawl types.[7]

Studies of the remaining gear types are more limited: of the 97 utilized in this assessment, 17 are applicable to scallop dredges, 11 to hydraulic dredges, and 5 to fixed gear. In particular, the literature review emphasized the paucity of existing studies on fixed gear effects on fish habitat. The exceptions to this are Eno et al 2001, Kaiser et al 2000, Fossa et al 2002, Grehan et al 2005, and Mortensen et al 2005, although the latter three focused on deep-sea coral impacts only. A recommendation for future gear effects work would be to study fixed gear impacts on geological and biological seabed structures. This work could be combined with measurements

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[7] However, the SASI model can account for modifications to fishing gear by changing the conditioning factor (the contact index) that estimates the amount of bottom habitat contacted (see section 6.0).

of the area of seabed actually contacted by fixed gears during deployment, which was identified as a related issue during parameterization of the area swept models.

5.3.2 Susceptibility

Feature susceptibilities varied by gear type (see Table 41- Table 45 for a summary). Across all gears, geological and biological features are generally most susceptible to impacts from hydraulic dredges as compared to other gear types (average scores for all features in a particular substrate and energy environment ranged from 2.5-2.8 out of 3). Otter trawl and scallop dredge S scores ranged from 1.0 to 2.0. Scores for these two gears are assumed to be the same across all features, substrates, and energies, with the exception of the bivalve mollusk/scallop feature itself, which was estimated to have a slightly higher susceptibility to scallop dredges. This assumption of similarity between the gears seems reasonable since the disturbance caused by both gears is similar: aside from the trawl doors, both gears cause a scraping and smoothing of bottom features and a re-suspension of fine sediments, and these effects are primarily limited to the sediment surface. Furthermore, the scallop dredge impacts literature (there are only three studies that directly evaluated dredging effects, and they are limited to geological impacts) does not provide compelling support for coding S and R values for the two gear types differently. Fixed gear (traps, longlines, and gillnets) susceptibility scores generally did not differ much if at all between gear types, but are the lower on average than the mobile gear scores, ranging from 0 to 1.

For trawls, scallop dredges, and fixed gears, mud, sand, and cobble features are more susceptible, while granule-pebble and boulder features are less susceptible. Average susceptibility scores for hydraulic dredges are slightly higher in sand than in granule-pebble substrates.

Differences in average biological susceptibility between substrates are fairly subtle. For each gear type, impacts on biological features generally did not differ much among substrates, although there was a slight trend toward higher average S scores in coarser substrates in all gear types. These differences in average scores are due to the different suite of features inferred to areas dominated by gravel substrates.

Higher S scores reflect a higher proportion of features with >25% encountered estimated to have a reduction in functional habitat value. For trawls and scallop dredges, there was a larger proportion of high S scores (S=2 or 3) for geological features, especially in mud and cobble, than for biological features; for hydraulic dredges, however, there was very little difference between feature classes. Susceptibility scores did not vary by energy, though the lack of a difference is likely due to insufficient information on the relative effects of energy regime on impacts, rather than on a true difference in the susceptibility and recovery of features found in high vs. low energy environments. Average susceptibility scores for a substrate did vary slightly by energy regime in some cases, due exclusively to the different features inferred to high vs. low energy environments.

5.3.3 Recovery

Geological feature recovery values are slightly higher (i.e., recovery times are longer) for hydraulic dredges than for the other two mobile gears fished in similar habitats (sand and granule-pebble). Average recovery values are more similar for biological features across the three mobile gear types, although in a few cases estimated recovery times are longer for hydraulic dredge gear. This was due to differences in gear effects associated with hydraulic dredges as compared to scallop dredges or otter trawls. As compared to mobile gears, fixed gears had slightly lower average recovery scores across both geological and biological features.

For each gear type, recovery values are consistently higher on geological components of habitat in coarse grained substrates than in sand and mud substrates, reflecting the increased contribution of features with recovery times of 2-5 and 5-10 years. Energy regime had little impact on recovery scores, with the exception of features recovering much more quickly from mobile gear impacts in granule pebble substrates in high (0.3-1.3) than in low (2.0) energy regimes. Average recovery scores for all biological features found in a habitat type did not differ among substrates or energy regimes for the mobile gears, but are slightly lower in mud and sand than in coarser substrates for fixed gears.

5.3.4 Potential sources of bias in the Vulnerability Assessment

In cases where there isn't clear support for a difference in scores, there was a tendancy to assign the same scores between features, or within features between gear types and/or energies. For example, average recovery values for biological features are more similar across gear types and substrates than are susceptibility values. This may be attributed somewhat to a lack of quantitative information on the recovery rates of benthic habitat features from gear impacts. There was also a tendency to avoid categorizing features as a zero (little to no impact/recovery within a year) or as a three (greater than 50% impact/recovery time greater than five years) unless there was sufficient evidence in support of this ranking, biasing relatively unsupported feature scoring towards median impacts withing our range. This potential bias may wash out true differences in vulnerability between features, homogenizing estimated effects across gears and substrates. Another challenge is that less than one third of the studies examined recovery times of biological and/or geological features following impact, and many of these only considered recovery in the short term. The use of a maximum recovery duration of ~10 years is as much a function of what is not found in the literature as what is.

Another major assumption of the VA is the independence of fishing events. The S and R estimates reflect effects of single, independent gear encounters. This implies that the functional relationship between habitat area impacted and the number of tows is linear and uniform, such that there is no difference in the magnitude of the impact of the first and any subsequent tows. Although the cumulative effects of fishing can be evaluated by adding multiple fishing events together over time, the recovery vector assumes that recovery from an individual event is independent of subsequent fishing events. It likely is not. However, the direction of bias from this depends on whether the first pass is relatively more damaging than subsequent passes, in which case impacts would be overestimated if the same exact feature are impacted multiple times, or if cumulative seabed impact is actually a non-linear concave function.

While the VA is limited by the lack of data available on fishing gear impacts on benthic habitat—especially the effects of, and recovery from, individual tows or sets—it offers a quantitative approach to examine and compare impacts by gear on both the geological and biological features common to substrates in the Northwest Atlantic. Together with the spatial components of the SASI model, the VA transforms gear impacts on benthic habitat into a common currency, i.e. vulnerability-adjusted area swept. It also accounts for both the spatial and temporal components of fishing impacts, which allows for both simulated fishing efforts to assess vulnerability and realized efforts that examine the impacts from past fishing activities. The VA also provides a framework that can be enhanced as future studies that address the above limitations are conducted. Finally, if assessments are developed to estimate vulnerability related to other anthropogenic perturbations in the Northwest Atlantic, they could be used collectively with the gear impact VA to assess the total vulnerability of benthic habitat to multiple human activities, which would be valuable for ongoing and future marine spatial planning efforts in the region.

6.0 Estimating contact-adjusted area swept

In order to (1) quantify fishing effort in like terms and (2) compare the relative effects of different fishing gears, fishing effort inputs to the SASI model are converted to area swept. The area swept by each gear component may be estimated individually. Estimating the contribution of individual gear components separately allows the SASI model to tease out the relative contribution that each component may make toward the area swept by the gear as a whole. Area swept is summed across gear components at the level of the tow, gillnet set, line of hooks, line of traps, etc. Individual tows, sets, etc. are then summed to obtain area swept estimates at the trip level, and all trips for that gear type are summed to generate annual estimates by gear type. These estimates are spatially-specific, and binned at the 100 km^2 grid cell level. The following sections describe the methods used to estimate area swept, including (1) models and assumptions, and (2) data and parameterization.

6.1 Area swept model specification

Simple quantitative models convert fishing effort data to area swept. These models provide an estimate of contact-adjusted area swept, measured in km^2. Regardless of gear type, the area swept models have three requirements:

- total distance towed, or, in the case of fixed gears, total length of the gear;
- width of the individual gear components; and
- contact indices for the various gear components.

The contact index is a key feature of SASI, because it allows the model to 'reward' gears that are modified to reduce seabed contact (e.g. those designed to skim over the seabed, or with raised ground gear). This contact index is a measure of the overall contact width of the various gear components that makes an allowance for the fact that the entire width of the gear may not be in contact with the seabed.

Note that the fishing gears employed in the region and the gears used in impacts studies may be constructed of different materials and rigged or fished in a variety of different ways; the contact indices specified here are oversimplifications. Contact indices are categorically specified by gear type, and may be revised in the future to accommodate additional data and/or new or modified gear types. Currently, contact indices do not vary by substrate, although this level of complexity could be added to the SASI model if and when additional research allows for more explicit treatment of this index.

These models do not explicitly incorporate an estimate of the weight of gear in the water, primarily because estimates of in-use gear component weights are not available. Also, the weight of the gear is accounted for within the SASI model in two ways. First, if the gear component is sufficiently buoyant such that bottom contact is reduced, this will result in a lower contact index value. Second, the quality of the gear-seabed interaction is directly incorporated into the susceptibility estimates, which are based on the results of actual or experimental fishing effects evaluations using real gear configurations/hydrodynamic conditions.

6.1.1 Demersal otter trawl

A demersal trawl has four components that potentially contribute to seabed impact: the otter boards, the ground cables, the sweep, and the net. Because the net follows directly behind the sweep, it is not included in the effective gear width calculation. Thus, the SASI model for a demersal trawl simplifies to

$$A_{trawl}(km^2) = d_t\left[\left(2 \cdot w_o \cdot c_o\right) + \left(2 \cdot w_c \cdot c_c\right) + \left(w_s \cdot c_s\right)\right],$$

where:

- d_t = distance towed in one tow (km)
- w_o = effective width of an otter board (m), which equals otter board length (km)·sin (α_o), where α_o = angle of attack
- c_o = contact index, otter board
- w_c = effective width of a ground cable (km), which equals ground cable length (km)·sin(α_c), where α_c = angle of attack
- c_c = contact index, ground cables
- w_s = effective width of sweep (km)
- c_s = contact index, sweep

The angle of attack (α) of an otter board can be determined at sea by measuring the scratch marks on the shoe of the otter board at the completion of a tow. If this is not possible, an assumed value of α can be utilized ranging between 30° and 50° (Gomez and Jimenez 1994). An intermediate value of 40° is selected for SASI. The angle of attack of a ground cable varies along its length, and cannot be accurately measured at sea. This angle is typically assumed to range between 10° and 20° (Gomez and Jimenez 1994, Baranov 1969). An intermediate value of 15° is selected for SASI. The effective width of a sweep can only be measured at sea using acoustic mensuration sensors. Effective headrope width is generally accepted as being approximately 50% of nominal headrope width; for the sweep, which is shorter, this value drops to between 40-45%. A single model is used for all otter trawl types, including groundfish, shrimp, squid, and raised footrope. Nominal and contact adjusted area swept are represented graphically below (Figure 13). The contact indices assumed for the various trawl types are shown in Table 46.

The demersal otter trawl SASI model assumes the following:

- Seabed contact does not change within a tow
- Otter board angle of attack is constant during a tow
- Ground cables are straight along their entire length
- The effect of towing speed on seabed contact is accommodated by d_t

Figure 13 – Area swept schematic (top down view). The upper portion shows nominal area swept, and the lower portion shows contact adjusted area swept. Contact indices will vary according to Table 46; the figure below is for illustrative purposes only.

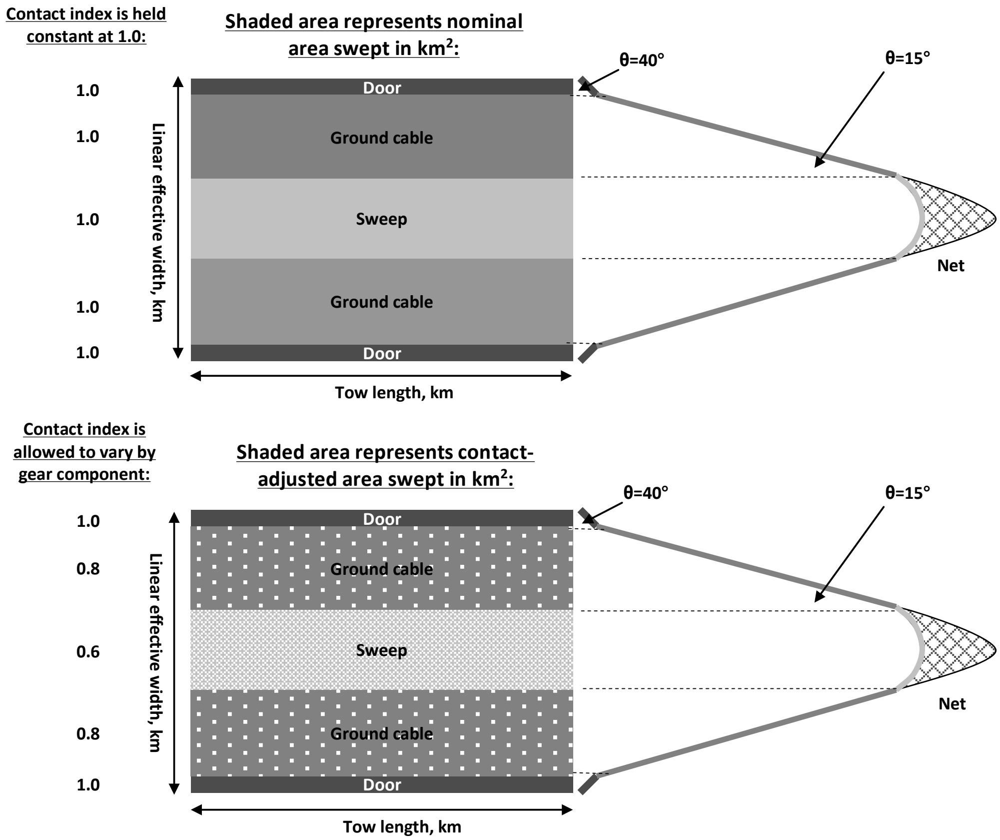


Table 46 - Contact indices for trawl gear components

Gear type	*Component*	*Contact index*
Generic otter trawl	Doors	1.00
Generic otter trawl	Ground cable	0.95
Generic otter trawl	Sweep	0.90
Squid trawl	Doors	1.00
Squid trawl	Ground cable	0.95
Squid trawl	Sweep	0.50
Shrimp trawl	Doors	1.00
Shrimp trawl	Ground cable	0.90
Shrimp trawl	Sweep	0.95
Raised footrope trawl	Doors	1.00
Raised footrope trawl	Ground cable	0.95
Raised footrope trawl	Sweep	0.05

6.1.2 New Bedford-style scallop dredge

A scallop dredge has five key components that potentially contribute to seabed impact. They are: the contact shoes; the dredge bale arm including cutting bar; the bale arm rollers; the chain sweep; and the ring bag and club stick. However, additional dredge components do not add width to the area swept because they follow one behind the other as the gear is towed. Therefore, the dredge model shown below does not consider the potential impact of individual components of a dredge, but groups them together.

Given these simplifying assumptions, the scallop dredge SASI model is

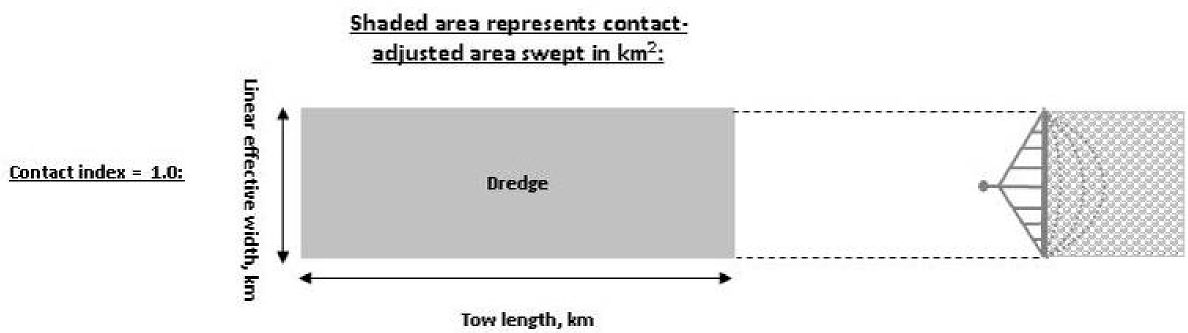
$$A_{scallop}(km^2) = d_t(w \cdot c),$$

where:

d_t = distance towed in one tow (km)
w = effective width of widest dredge component (km)
c = contact index, all dredge components

If two dredges are used simultaneously, the effective width is the sum of the individual dredge widths. A diagrammatic representation of area swept for scallop dredges is provided below (Figure 14). The contact index is set to 1.0, which means that nominal area swept and contact-adjusted area swept are equal.

Figure 14 – Area swept schematic for scallop dredge gear (top down view). Since the contact index is 1.0, nominal area swept and contact-adjusted area swept are equivalent.



Similar to the otter trawl model, the scallop dredge SASI calculation assumes the following:

- Seabed contact does not change within a tow
- The effect of towing speed on seabed contact is accommodated by d_t

6.1.3 Hydraulic clam dredge

Similar to the scallop dredge model, the hydraulic clam dredge model shown below does not consider the potential impact of individual components of a dredge, but groups them together. The area swept model for hydraulic clam dredge is

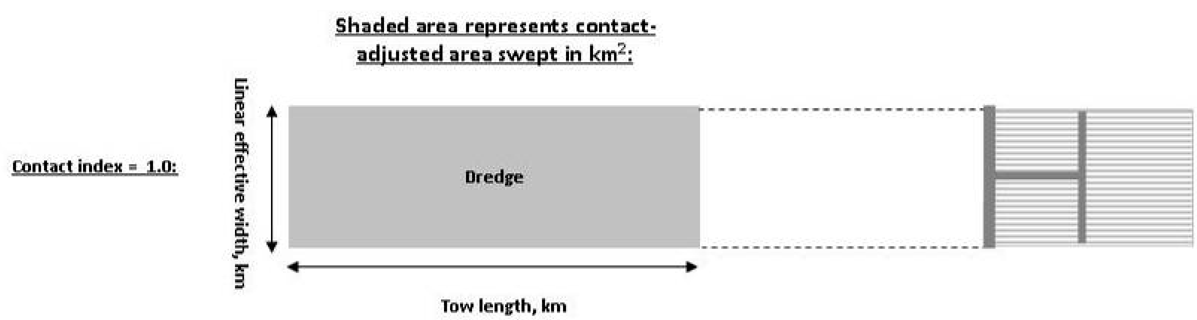
$$A_{hydraulic}(km^2) = d_t(w \cdot c),$$

where:

d_t = distance towed in one tow (km)
w = effective width of widest dredge component (km)
c = contact index, all dredge components

If multiple dredges are used simultaneously, the effective width is the sum of the individual dredge widths. Nominal and contact adjusted area swept are represented graphically below (Figure 15). The contact index is set to 1.0, which means that nominal area swept and contact-adjusted area swept are equal.

Figure 15 – Area swept schematic for hydraulic dredge gear (top down view). Since the contact index is 1.0, nominal area swept and contact-adjusted area swept are equivalent.



The hydraulic dredge area swept calculation assumes the following:

- Seabed contact does not change within a tow
- The effect of towing speed on seabed contact is accommodated by d_t

6.1.4 Demersal longline and sink gillnet

A demersal longline or gillnet has two key components that potentially contribute to seabed impact: the weights and either the mainline (longline) or the footline (gillnets). For longline gear, any impacts of the gangions and hooks are ignored.

The area swept model for a demersal longline or gillnet is

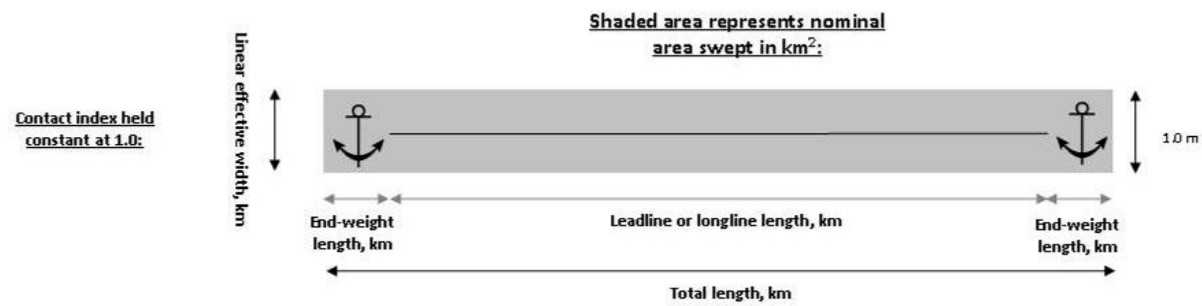
$$A_{longline/gillnet}(km^2) = 2(d_w \cdot l_w \cdot c_w) + (d_l \cdot l_l \cdot c_l),$$

where:

d_w = distance end-weight moves over the seabed (km)
w_w = length of end-weight (km)
c_s = contact index, end-weight
d_l = distance longline or leadline moves over the seabed (km)
l_l = length of longline or leadline (km)
c_l = contact index, longline or leadline

The distance that each gear component moves is a function of movements over the seabed both while the gear is fishing (soaking) and during the setting and hauling processes, although the extent of these movements is unknown. The d_w and d_l parameters are intended to capture both types of movement (i.e. lateral and perpendicular to the long axis of the gear). For both the end weights and the longlines/leadlines, this distance is assumed to be one meter (i.e. d_w and d_l are specified as 0.001 km (1.0 m)), and is assumed to be sufficient to capture any movement both laterally and perpendicular to the mainline. Nominal and contact adjusted area swept are represented graphically below (Figure 16). Seabed contact is assumed to be 1.0 for all gear components.

Figure 16 – Area swept schematic for longline or gillnet gear (top down view). Since the contact index is 1.0, nominal area swept and contact-adjusted area swept are equivalent.



6.1.5 Lobster and deep-sea red crab traps

The area swept model for a line or trawl of n lobster traps, accounting for each individual trap and ground line between traps is

$$A_{trap}(km^2) = \sum_{1}^{n} \left[d_{tn} \cdot l_{tn} \cdot c_{tn} \right] + \sum_{1}^{n-1} \left[d_{gn} \cdot l_{gn} \cdot c_{gn} \right],$$

where:

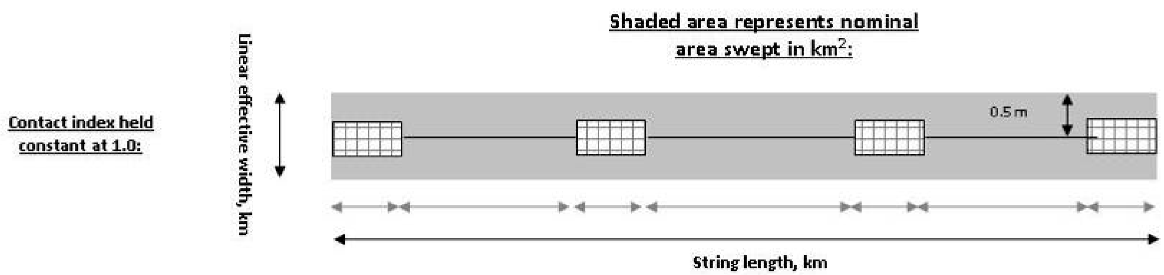
- n = Number of traps
- $n-1$ = Number of groundlines between traps
- d_{tn} = lateral distance nth trap moves over the seabed (km)
- l_{tn} = length of nth trap (km)
- c_{tn} = contact index, nth trap
- d_{gn} = lateral distance the nth ground line moves over the seabed (km)
- l_{gn} = length of nth ground line (km)
- c_{gn} = contact index, nth groundline

Similar to longlines and gillnets, the distance that each gear component moves is a function of movements over the seabed both while the gear is fishing (soaking) and during the setting and hauling processes, although the extent of these movements is unknown. The d_{tn} and d_{gn} parameters are intended to capture both types of movement (i.e. lateral and perpendicular to the long axis of the gear). For both the traps and the groundlines, these distances are assumed to be one meter. If d_{tn} and d_{gn} are specified as 0.001 km (1.0 m), and all traps and segments of groundline are assumed to be the same length, the equation simplifies to

$$A_{trap}(km^2) = (0.001 \cdot n \cdot l_{tn} \cdot c_{tn}) + (0.001 \cdot (n-1) \cdot l_{gn} \cdot c_{gn}).$$

Nominal and contact adjusted area swept are represented graphically below (Figure 17). The seabed contact index is assumed to be 1.0 for lines and traps.

Figure 17 – Area swept schematic for trap gear (top down view). Since the contact index is 1.0, nominal area swept and contact-adjusted area swept are equivalent.



6.2 Data and parameterization

This section describes the data sources used and assumptions made when calculating nominal area swept for each gear type. The contact indices specified in the previous section are then applied to these raw estimates to generate *A*, the contact-adjusted swept area. Note that the information below pertains to the realized effort model runs ($Z_{realized}$) and practicability runs (which use Z_{net}). To facilitate comparison between them, the Z_{∞} runs use the same A values regardless of gear types in all grid cells.

The general requirements for the area swept calculations are: gear width (km), tow length or distance the gear moves over the seabed (km), and number of tows or soaks per year. Ideally, all of the parameters would be specified for every trip in a single data source. However, VTR data are the only synoptic data source for vessel activity, area fished, and catch for commercial fisheries, and this data set does not include information on tow duration or tow speed, or on the dimensions of some gear components. Data from the at sea observer program are then used to specify some parameters. For example, the observer program collects specific information about trawl net configurations and dimensions, as well as towing speeds. In some cases, these parameters are specified annually in order to account for changes over time. It is important to remember that observer data is only a sample, and may not be representative of overall fishery.

6.2.1 Demersal otter trawl

As shown above, the model for otter trawl contact-adjusted area swept for a single tow is

$$A_{trawl}(km^2) = d_t\left[(2 \cdot w_o \cdot c_o) + (2 \cdot w_c \cdot c_c) + (w_s \cdot c_s)\right].$$

The area swept for an individual tow is summed across all tows in a trip, and all trips during a particular year. Thus, to calculate *A* the data required include: gear width for each of the three components (w_o, w_c, w_s), distance towed (d_t), trips per year, and for each trip, tows per trip. For mobile gears including otter trawls, tow length is always a derived value that combines tow speed (km/hour) and tow duration (hours). Effective width of a trawl tow includes the three gear components: otter boards, ground cables and sweep.

Estimating the effective linear width of otter boards

The parameter w_o , the effective width of an otter board (m), is modeled as otter board length (m) times sin (α_o), where α_o = angle of attack (assumed to be 40 ^{o}). Otter board weight data is collected through the observer program, but dimensions are not. Using commercially available data on the size and weight of otter boards for two different door designs (Thyboron Type II and Bison, both distributed by Trawlworks, Inc of Narragansett RI), a linear relationship between otter board weight and otter board length is established (Table 47). The type and brand of otter boards used in the fishery are not reported, and it is not known if this sample is representative of the gear used on observed trips, or in the fishery as a whole.

Table 47 – Linear regression of otter board length on otter board weight

Analysis of variance

	Degrees of freedom	Sum of Squares	Mean square	F	Probability
Model	1	3573531	3573631	303.61	< 0.0001
Error	24	282493	11771		
Corrected total	25	3856124			

R^2: 0.9267 Adj R^2: 0.9237

Parameter estimates

Variable	Degrees of freedom	Parameter estimate	Standard error	t value	Probability
Intercept	1	1223.66251	49.12562	24.91	< 0.0001
Average weight	1	0.83332	0.04783	17.42	< 0.0001

This relationship provides an estimate of otter board length for each observed trip, as follows:

Otter board width (inches) = 1223.7 + (0.8 * otter board weight in pounds)

This relationship is applied to fishing trips by constructing a relationship between reported door weight and a variable or variables common between both observer and VTR datasets. Several relationships are investigated. A significant and relatively strong linear relationship exists between door weight and a combination of gross tonnage and horsepower (Table 48).

Table 48 – Linear regression of otter board weight on vessel gross tonnage and vessel horsepower, observer data 2003-2008

Parameter estimates

Variable	Degrees of freedom	Parameter estimate	Standard error	t value	Probability
Intercept	1	70.84823	7.75592	9.13	< 0.0001
Gross tons	1	1.84431	0.09525	19.36	< 0.0001
Vessel horsepower	1	0.53446	0.02173	24.59	< 0.0001

Thus, door weight for a particular trip is calculated as:

Door weight (tons) = 70.8 + (1.8 * Vessel tonnage) + (0.5 * Vessel horsepower)

Applying this relationship to all VTR-reported trips provides an estimate of door weights. Finally, applying the modeled relationship between otter board weight and otter board length, and correcting for angle of attack, provides an estimate of the effective linear width of otter boards used for each trip.

Estimating the effective linear width of ground cables

The parameter w_c , the effective width of a ground cable (km), equals ground cable length (m) multiplied by $\sin(\alpha_c)$, where α_c = angle of attack (assumed to be 15^o). Ground cable length data are collected directly through the observer program. Relationships between ground cable length and independent variable common between both observer and VTR datasets are investigated. A significant but weak linear relationship exists between ground cable length and vessel length (Table 49).

Table 49 – Linear regression of ground cable length on vessel length

Analysis of variance

	Degrees of freedom	Sum of Squares	Mean square	F	Probability
Model	1	92928	92928	209.32	< 0.0001
Error	2960	1314125	444		
Corrected total	2961	1407054			

R^2: 0.0660 Adj R^2: 0.0657

Parameter estimates

Variable	Degrees of freedom	Parameter estimate	Standard error	t value	Probability
Intercept	1	23.34782	1.72249	13.55	< 0.0001
Length	1	0.37242	0.02574	14.47	< 0.0001

Thus, ground cable length for a particular trip is calculated as:

Ground cable length (km) = 23.3 + (0.4* Vessel length (m)) * 0.001 m/km * 2 cables/trawl

Applying this relationship to all VTR-reported trips using otter trawls provides an estimate of ground cable length, and correcting for angle of attack provides an estimate of the effective linear width of ground cables used for each trip.

Estimating tow length

Tow duration and speed are combined to generate tow lengths in kilometers. Average trawl gear speeds by year are shown below. Based on the similarity between years, the same speed is assumed for all tows in all years.

Table 50 – Trawl gear tow speeds (in knots) by year, based on observer data

YEAR	*Sample size*	*Mean*	*St Dev*
2003	7,185	3.01	0.38
2004	10,875	3.00	0.35
2005	27,129	3.01	0.33
2006	13,577	3.03	0.32
2007	15,143	3.02	0.32
2008	17,359	3.04	0.35
2009	16,582	3.03	0.32

Tow duration is also specified in the observer data.

Table 51 – Trawl gear tow duration (in hours) by year, based on observer data

YEAR	*Sample size*	*Mean*	*St Dev*
2003	7,185	3.55	1.64
2004	10,875	3.13	1.63
2005	27,129	3.34	1.57
2006	13,577	3.44	1.58
2007	15,143	3.27	1.61
2008	17,359	3.29	1.60
2009	16,582	3.16	1.64

Summarizing contact-adjusted area swept parameters

The data used to estimate contact-adjusted area swept (A) parameters are summarized in Table 52 (below).

Table 52 – Assumed trawl parameters

Parameter	*Data source/method*	*Notes*
Door width	Observer – reported in gear tables on a trip-by-trip basis, averaged across all observed trips	
Ground cable width	Observer	
Tow duration	Observer – reported in haul tables on a tow-by-	Specified annually

	tow basis, averaged across all observed trips	
Tow speed	Observer – reported in haul tables on a tow-by-tow basis, and averaged across all observed trips.	Little annual variation (see table below), so single value of 3 km is used
Sweep width	Total sweep length data are reported in the VTR. The effective linear width of the sweep is modeled as the diameter of a circle with a perimeter of two times the sweep length.	
Number of trips per year	VTR	
Number of tows per trip	VTR	

Finally, contact indices are specified separately for the four trawl gear types. This required distinguishing between the different types of trawls, which is done at the trip level by examining the VTR data, as follows:

Table 53 – Distinguishing between trawl gear types

Trawl type	***Thresholds***	***Notes***
Generic otter trawl	All trawl trips not included in other categories	Gear codes 050 (fish), 057 (haddock separator), 052 (scallop), 053 (twin trawl)
Squid trawl	75% of catch, by weight, was either *Illex* squid or *Loligo* squid	Gear code 050 plus catch weight
Shrimp trawl	Any trip with the gear type coded as shrimp gear	Shrimp gear code is 058
Raised footrope trawl	Trip must have occurred during or after 2003, in statistical area with exemptions, during months fishery was open, and have greater than 50% whiting (silver hake) in catch, by weight	

Evaluating bias with respect to at-sea observer data

As previously noted, the observer program does not sample all fisheries and gear types evenly. The distribution of trips in terms of size (horsepower, length) and fishing locations (latitude, longitude) for observer and VTR data are significantly different for trips made with trawl gears Table 54. Assuming that the VTR data are accurate and represent the true fishery, observer data may be biased upwards with respect vessel size. The magnitude and direction of bias resulting from the fishing location differences between the two datasets is unclear, though persistent variations in depth and substrate type across latitudes and longitudes may play a role in the configuration of trawl gears and their dimensions. Year effects cannot be ruled out, as these analyses include the years 1996 – 2008 while observer data is only available from 2003 onward.

Table 54 – Independent group t-test for observer-reported trips made between 2003-2008 with trawl gears, and VTR-reported trips for the same years; paired records discarded from VTR group (Class 1 = VTR, Class 2 = OBS, VHP = vessel horsepower, LEN = length, GTONS = vessel weight, Lat/Lon = Latitude/Longitude)

Variable	*class*	*N*	*Lower CL Mean*	*Mean*	*Upper CL Mean*	*Lower CL Std Dev*	*Std Dev*	*Upper CL Std Dev*	*Std Err*	*Minimum*	*Maximum*
VHP	1	1.64E+05	403.73	404.70	405.67	199.68	200.36	201.05	0.495	25.0	2985.0
VHP	2	4664	489.77	496.39	503.02	226.32	230.91	235.70	3.381	54.0	2775.0
VHP	Diff (1-2)		-97.55	-91.69	-85.84	200.59	201.27	201.95	2.989		
LEN	1	1.64E+05	56.79	56.87	56.94	14.81	14.86	14.91	0.037	18.0	138.0
LEN	2	4664	64.82	65.25	65.68	14.68	14.98	15.29	0.219	32.0	138.0
LEN	Diff (1-2)		-8.81	-8.38	-7.95	14.82	14.87	14.92	0.221		
GTONS	1	1.64E+05	64.08	64.31	64.53	46.69	46.85	47.01	0.116	0.0	476.0
GTONS	2	4664	93.22	94.75	96.27	52.19	53.25	54.36	0.780	3.0	246.0
GTONS	Diff (1-2)		-31.81	-30.44	-29.07	46.88	47.04	47.20	0.699		
Lat	1	1.17E+05	41.06	41.07	41.08	1.65	1.65	1.66	0.005	35.0	44.6
Lat	2	4658	41.09	41.13	41.17	1.35	1.38	1.41	0.020	35.2	43.9
Lat	Diff (1-2)		-0.11	-0.07	-0.02	1.64	1.64	1.65	0.025		
Lon	1	1.17E+05	71.52	71.53	71.54	1.80	1.81	1.81	0.005	65.6	77.3
Lon	2	4658	70.43	70.49	70.55	2.10	2.14	2.19	0.031	66.5	76.5
Lon	Diff (1-2)		0.99	1.04	1.10	1.81	1.82	1.83	0.027		

T-Tests

Variable	*Method*	*Variances*	*DF*	*t Value*	*Pr > |t|*
VHP	**Pooled**	Equal	1.70E+05	-30.68	<.0001
LEN	**Satterthwaite**	Unequal	4927	-37.68	<.0001
GTONS	**Pooled**	Equal	1.70E+05	-43.58	<.0001
Lat	**Pooled**	Equal	1.20E+05	-2.69	0.0071
Lon	**Pooled**	Equal	1.20E+05	38.32	<.0001

Equality of Variances

Variable	*Method*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
VHP	**Folded F**	4663	1.64E+05	1.33	<.0001
LEN	**Folded F**	4663	1.64E+05	1.02	0.4485
GTONS	**Folded F**	4663	1.64E+05	1.29	<.0001
Lat	**Folded F**	1.17E+05	4657	1.43	<.0001
Lon	**Folded F**	4657	1.17E+05	1.41	<.0001

6.2.2 New Bedford-style scallop dredge

The model for New Bedford-style scallop dredge contact-adjusted area swept for a single tow is:

$$A_{scallop}(km^2) = d_t(w \cdot c)$$

Parameter estimates

Similar to trawls, scallop tow distance is estimated by multiplying tow speed by tow duration reported in the observer data, as shown in the following tables.

Table 55 – Scallop dredge tow speeds (knots) by year, based on observer data

YEAR	*Sample size*	*Mean*	*St Dev*
2003	5,270	4.43	0.46
2004	8,306	4.46	0.39
2005	6,139	4.56	0.41
2006	6,009	4.60	0.45
2007	7,557	4.60	0.43
2008	11,349	4.70	0.33
2009	23,726	4.63	0.37

Table 56 – Scallop dredge tow duration (hours) by year, based on observer data

YEAR	*Sample size*	*Mean*	*St Dev*
2003	5,270	1.05	0.29
2004	8,306	1.11	0.31
2005	6,139	1.03	0.34
2006	6,009	1.02	0.34
2007	7,557	1.01	0.30
2008	11,349	0.96	0.21
2009	23,726	1.05	0.38

Table 57 – Assumed scallop dredge parameters

Parameter	*Data source/method*	*Notes*
Tow speed	Speeds from observed tows were averaged by year	Scallop dredge trips were assumed to tow at 4.4 knots for all years prior to 2004, 4.5 knots for trips taken in 2004, 4.6 knots for trips taken from 2005 to 2007, and 4.7 knots for trips taken in 2008.
Tow duration	Durations from observed tows were averaged by year	
Number of trips per year	VTR	
Number of tows per trip	VTR	
Number of dredges used	VTR	
Width of dredges	VTR	

6.2.3 Hydraulic clam dredge

The model for hydraulic clam dredge contact-adjusted area swept for a single tow is:

$$A_{hydraulic}(km^2) = d_t(w \cdot c)$$

6.2.4 Demersal longline

The model for demersal longline contact-adjusted area swept for a single longline is:

$$A_{longline/gillnet}(km^2) = 2(d_w \cdot l_w \cdot c_w) + (d_l \cdot l_l \cdot c_l)$$

6.2.5 Sink gillnet

The model for sink gillnet contact-adjusted area swept for a single gillnet is:

$$A_{longline/gillnet}(km^2) = 2(d_w \cdot l_w \cdot c_w) + (d_l \cdot l_l \cdot c_l)$$

6.2.6 Traps

The model for trap gear contact-adjusted area swept for a string of traps is:

$$A_{trap}(km^2) = (0.001 \cdot n \cdot l_{tn} \cdot c_{tn}) + (0.001 \cdot (n-1) \cdot l_{gn} \cdot c_{gn})$$

7.0 Defining habitats spatially

The spatial domain of the SASI model is US Federal waters (between 3-200 nm offshore) from Cape Hatteras to the US-Canada border. Within this region, habitats are defined based on dominant substrates and natural disturbance regime, with the latter categorized as high or low bottom energy based on water flow and water depth. Spatial substrate data are used to generate the model grid and energy is inferred from an oceanography model (flow) and a coastal relief model (depth).

7.1 Substrate data and unstructured grid

A geological substrate-based grid is selected for the SASI model for both theoretical and practical reasons. Theoretically, substrate type influences the distribution of managed species, structure-forming epifauna, and prey species by providing spatially discrete resources such as media for burrowing organisms, attachment points for vertical epifauna, etc. Practically, substrate provides a common link between empirical spatial seabed habitat data and the literature covering the effects of fishing on habitat, as most studies reference substrate as either a classification for habitat or a description of the habitats within the study areas. Further, and critically, substrate data is available at varying resolutions for the entire model domain.

Within the model domain, the collection methods, sampling resolution, and ranges of sampled substrates vary a widely over both temporal and spatial scales. To accommodate variation in sampling methods, the dominant substrate in each sample is used to represent the substrate class occurring at that particular X,Y location. Dominant substrate type is defined as the substrate type composing the largest fraction of each sample. Dominance is determined by volume, area, or frequency of occurrence, depending on the sampling methodology.

To accommodate varying spatial resolutions of substrate samples, the X,Y locations of the substrate data are tessellated to create a Voronoi diagram. In a Voronoi diagram, each polygon is convex, and defined by the perpendicular bisectors of lines drawn between geological data points such that each polygon bounds the region closer to that data point relative to all others (Thiessen and Alter 1911, Gold 1991, Okabe et al. 1992, Legendre and Legendre 1998). In other words, the midpoint of each line segment making up a Voronoi polygon is equidistant between the two closest substrate sampling locations. Voronoi diagrams have been used in terrestrial and aquatic ecological studies and are particularly useful for creating a surface from spatially clustered point data. (Isaaks and Srivastava 1989, Fortin and Dale 2005). Harris and Stokesbury (2005) used Voronoi polygons to map substrate and macroinvertebrate distributions on Georges Bank and in the Mid-Atlantic.

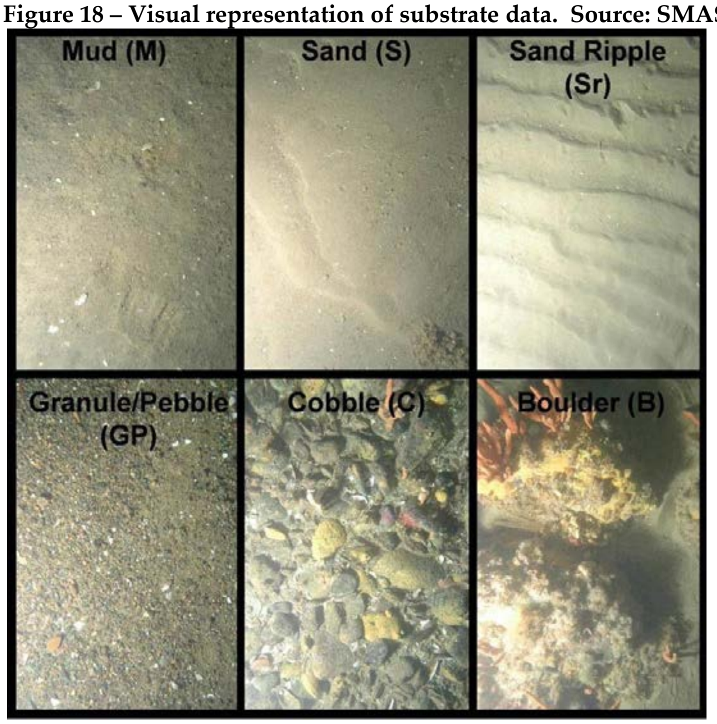
The advantage of this type of base grid is that the resulting unsmoothed surface consists of cells that maintain the spatial characteristics of their source data. For example, the sampling information associated with each data point remains accessible and where geological sampling is spare, the polygons are large. This is in contrast to mathematical interpolations (e.g. Inverse distance weighting, kriging), which result in a standardized grid despite the spatial resolution of the source data.

The geological data are organized into five classes according to particle size: mud, sand/sand ripple, granule-pebble, cobble, and boulder (Table 58, Figure 18, Wentworth 1922). Substrate data are assembled from two primary sources: the SMAST video survey (Stokesbury 2002, Stokesbury et al. 2004); and the usSEABED extracted and parsed datasets from the U.S. Geological Survey (Reid et al 2005). Only substrate data with positive location and time metadata are used. Not all data sources provide information based on sampling capable of detecting all five dominate substrate classes; for example, much of the substrate data compiled in the usSEABED database are collected using grab and coring samplers that are typically not capable of representatively sampling grain sizes larger than granule-pebble (i.e. cobbles and boulders). These sampling limitations are coded into the geological datasets R_sub value, which is a ratio of detectable substrate types to total types (5). For example, the SMAST optical survey technique R-sub = 5/5 because it detects all 5 substrate classes, while the usSEABED R_sub = 0.6 datasets 3/5 because cobbles and boulders are not detected.

Table 58 – Substrate classes by particle size range

Substrate	***Particle size range***	***Corresponding Wentworth class***
Mud	< 0.0039-0.0625 mm	Clay (< 0.0039 mm) and silt (0.0039 – 0.0625mm)
Sand	0.0625 – 2 mm	Sand (0.0625 – 2 mm)
Granule-pebble	2-64 mm	Gravel (2-4 mm) and pebble (4-64 mm)
Cobble	64 – 256 mm	Cobble (64 – 256 mm)
Boulder	> 256 mm	Boulder (> 256 mm)

Figure 18 – Visual representation of substrate data. Source: SMAST video survey.



SMAST video survey

The SMAST video survey uses a multi-stage quadrat-based sampling design and a dual-view video quadrat. Survey stations are arranged as grids based on random starting points. The resolution (distance between stations) is originally calculated to obtain estimates of the dominant macrobenthic species density (sea scallops m^{-2}) with a precision of 5 to 15% for the normal and negative binomial distributions respectively (Stokesbury 2002). At each station, four replicate video-quadrats are sampled haphazardly with a steel pyramid lander equipped with underwater cameras and lighting (for details, see Stokesbury 2002, Stokesbury et al. 2004).

The SMAST database presently includes 190,369 quadrat samples from 24,784 stations covering 65,675 km^2 of USA continental shelf including Jefferys, Cashes, Platts, and Fippenese Ledges, and Stellwagen, Jeffreys, and Georges Banks from the Northern Edge to the Great South Channel, and the Mid-Atlantic Bight from off Block Island to Norfolk Canyon. The SMAST survey uses three live-feed S-VHS underwater video cameras, two in plan-view and one in parallel-view. The two plan-view cameras sample 3.235 m^2 and 0.8 m^2 quadrats, respectively, with the small camera view nested within the large camera view. The parallel-view camera (side camera) provides a cross-quadrat view of both large and small camera sample areas and is used to validate the quadrat observations.

Each quadrat is characterized as containing silt, sand, sand ripple, granule-pebble, cobble, and/or boulder substrates based on particle diameters from the Wentworth scale (Wentworth 1922). Substrates are visually identified in real time during survey cruises using texture, color, relief and structure as observed in the three camera views. Later, all video footage is reviewed in the laboratory where analysts digitized and catalogued a still frame from the large and small camera footage at each quadrat and verified substrate identification.

There are strengths and limitations to the dataset for mapping purposes. Strengths include:

- Formal sampling design with replication.
- Multiview optic sample of sand to boulder substrates
- High spatial sampling frequency
- Annual sampling of Georges Bank and the Mid-Atlantic since 1999

Limitations include:

- Database includes only surficial geology and does not include particles finer than silt.
- Surveys do not include depths greater than 150m.

usSEABED database

The usSEABED database contains a compilation of published and unpublished sediment texture and other geologic data about the seafloor from numerous projects (Reid et al 2005). The USGS DS 118 Atlantic Coast data extend from the U.S./Canada border (northern Maine) to Key West Florida, including some Great Lakes, other lakes, and some rivers, beaches, and estuaries. The database is built using more than 150 data sources containing more than 200,000 data points distributed across the five output data files. The USGS is preparing an update to DS 118 (pers. comm. M. Arsenault USGS) and any new data for the NE region will be included in the SASI model if possible.

Extracted (numeric, lab-based) and parsed (word-based) data are used in the current analysis. Extracted data (_EXT) are from strictly performed, lab-based, numeric analyses. Most data in this file are listed as reported by the source data report; only minor unit changes are performed or assumptions made about the thickness of the sediment analyzed based on the sampler type. Typical data themes include textural classes and statistics (TXR: gravel, sand, silt, clay, mud, and various statistics), phi grain-size classes (GRZ), chemical composition (CMP), acoustic measurements (ACU), color (COL), and geotechnical parameters (GTC). The _EXT file is based on rigorous lab-determined values and forms the most reliable data sets. Limitations, however, exist due to the uncertainty of the sample tested. For example, are the analyses performed on whole samples or only on the matrix, possibly with larger particles ignored? Parsed data (_PRS) are numeric data obtained from verbal logs from core descriptions, shipboard notes, and (or) photographic descriptions are held in the parsed data set. The input data are maintained using the terms employed by the original researchers and are coded using phonetically sensible terms for easier processing by dbSEABED.

Reid et al (2005) provide the following caveats for use of the usSEABED database.

- As many reports are decades old, users of usSEABED should use their own criteria to determine the appropriateness of data from each source report for their particular purpose and scale of interest.
- In cases where no original metadata are available, metadata are created based on existing available information accompanying the data. Of particular importance, site locations are as given in the original sources, with uncertainties due to navigational techniques and datums ignored in the usSEABED compilation.
- As a caution in using the usSEABED database in depicting seabed sedimentary character or creating seafloor geologic maps, users should aware that all seafloor regions are by their nature dynamic environments and subject to a variety of physical processes such as erosion, winnowing, reworking, and sedimentation or accretion that vary on different spatial and temporal scales. In addition, as with any such database, usSEABED is comprised of samples collected and described and analyzed by many different organizations and individuals over a span of many years, providing inherent uncertainties between data points.
- Plotting the data can also introduce uncertainties that are largely unknown at this time.
- There are uncertainties in data quality associated with both the extracted data (numeric/ analytical analyses) and parsed data (word-based descriptions).
- On occasion grain-size analyses are done solely on the sand fraction, excluding coarse fractions such as shell fragments and gravel, while word descriptions of sediment samples can emphasize or de-emphasize the proportion of fine or coarse sediment fraction, or disregard other important textural or biological components.

There are strengths and limitations to the dataset for mapping purposes.

Strengths:

- As a compilation, the usSEABED database covers the model domain.
- The extracted data are based on physical examination of substrates.

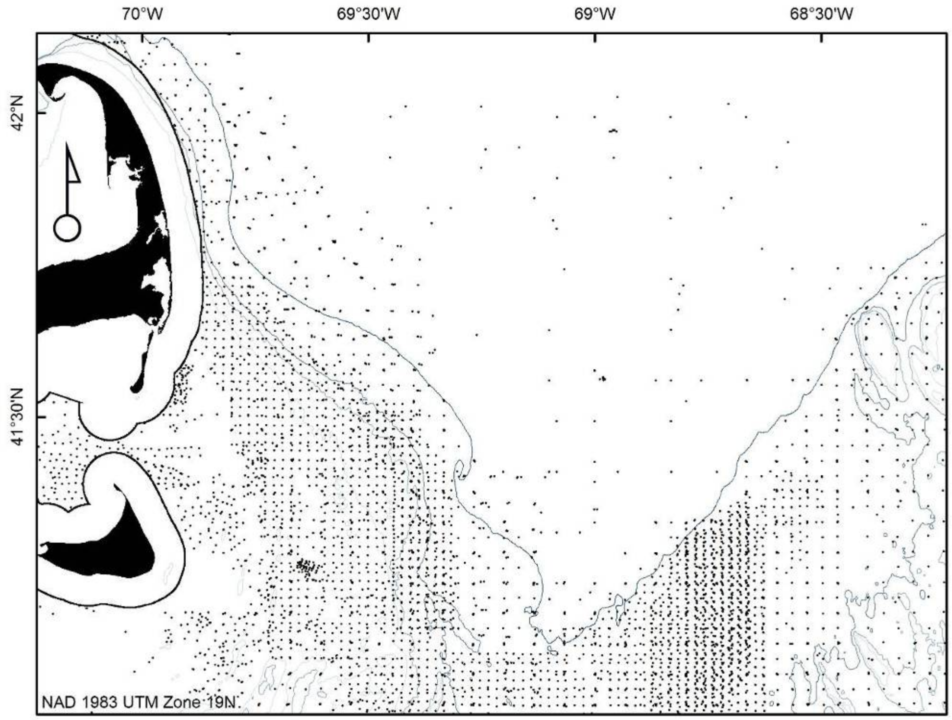
Limitations:

- The sampling design, device, and analytical methods used are temporally and spatially variable.
- Few individual studies used a formal experimental design.
- Most sampling devices used are not capable of sampling cobbles and boulders. Many devices used have sampling selectivity characteristics, which may over or under represent small or large particles.

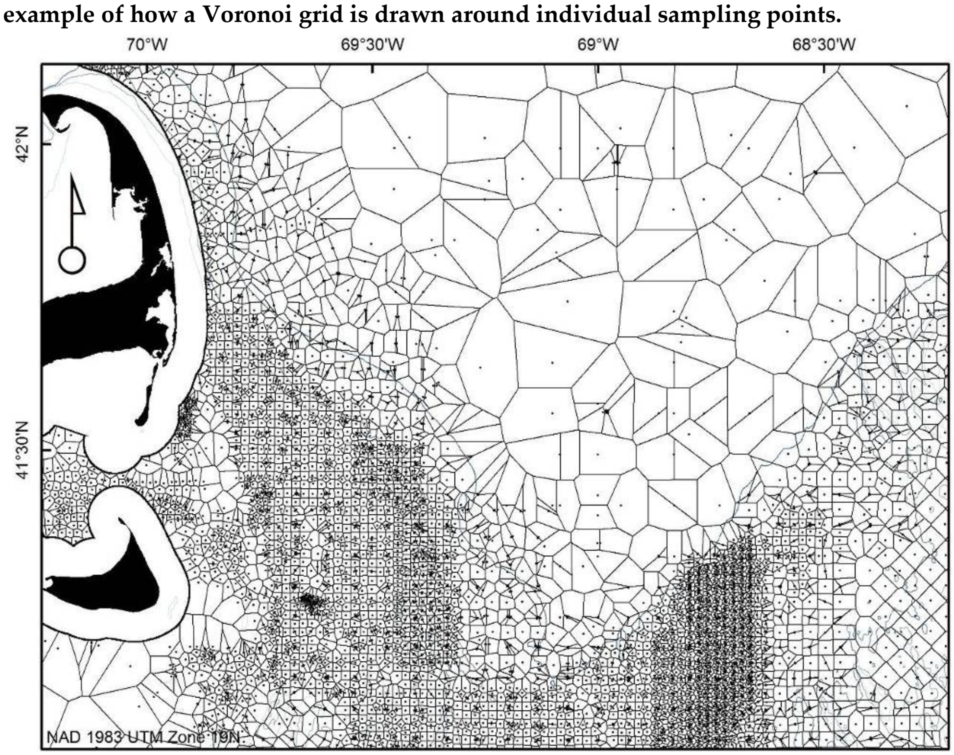
Developing the base grid

The dominant substrate in each sample is the substrate type composing the largest fraction as determined by volume, or frequency of occurrence depending on the sampling methodology. The usSEABED extracted data come from volumetric samplers so the dominant substrate is the type constituting most of the sample. The SMAST video survey samples report the frequency of substrate type occurrences at four locations along a station drift, so the dominant substrate is the most frequently occurring largest type. The dominant substrate type fields for these two data sources are merged, and the X, Y locations of the samples are tessellated to create the Voronoi diagram which serves as the base grid for the SASI model. Each polygon is given the dominant substrate attribute of its base X, Y sample point. The Voronoi tessellation process is depicted on Map 1 and Map 2. All geological data points and their sources are shown on Map 3 and Map 4, respectively. Resulting substrate coding is shown on Map 5. Substrate coding for subregions of the model domain are shown in Map 6-Map 8.

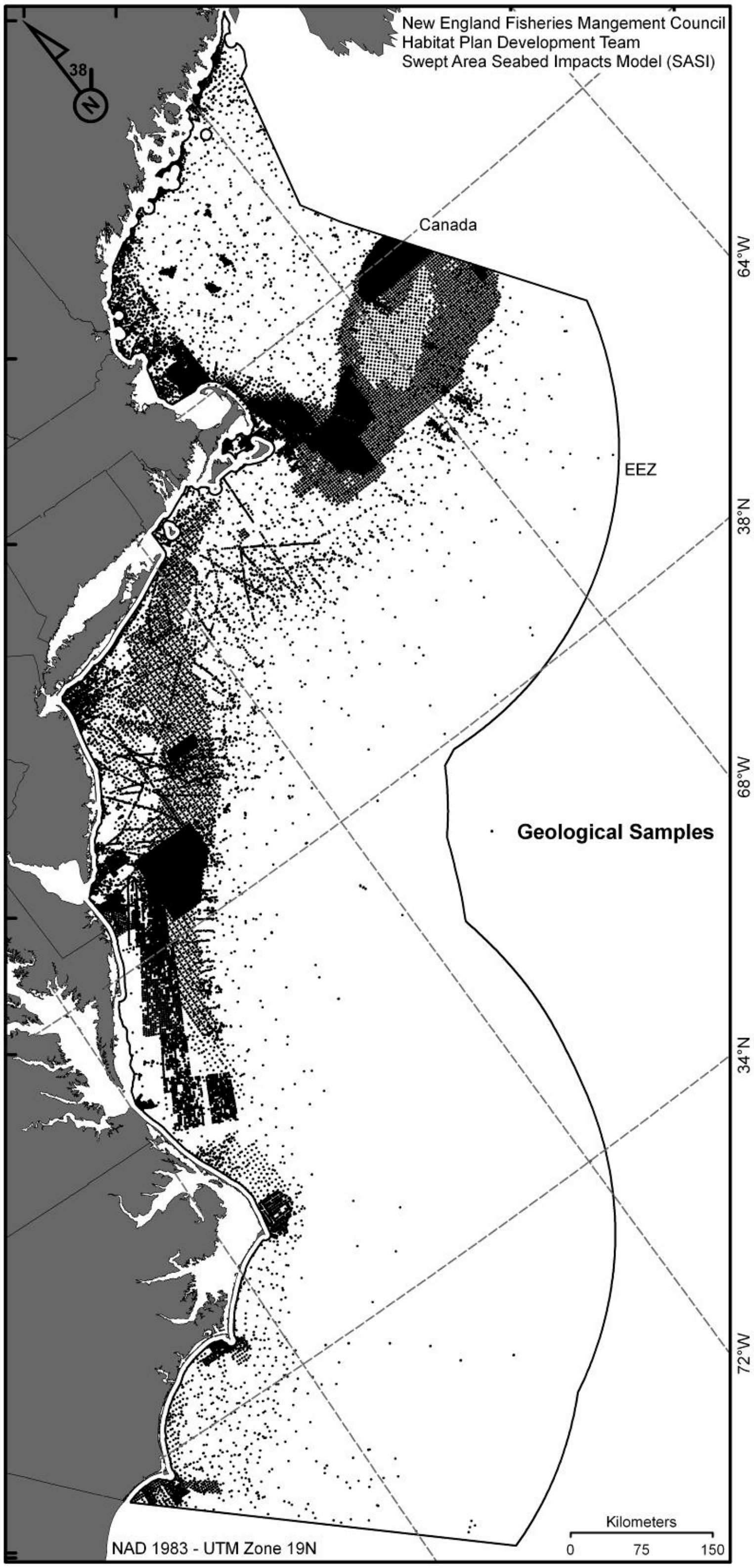
Map 1 – Construction of a Voronoi diagram, part one. This zoomed-in view of the model domain shows the individual substrate data sampling points.



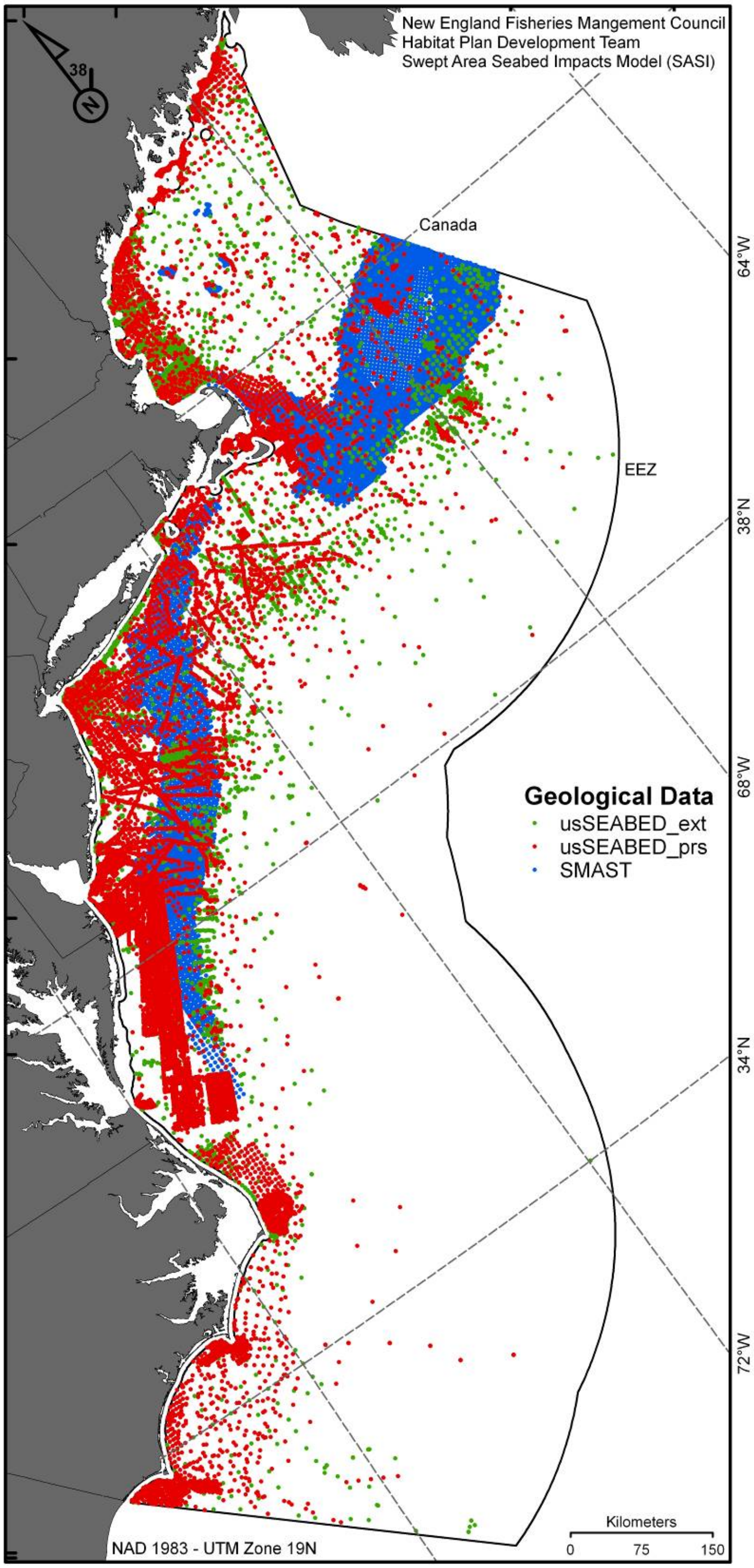
Map 2 – Construction of a Voronoi diagram, part two. This zoomed-in view of the model domain gives an example of how a Voronoi grid is drawn around individual sampling points.



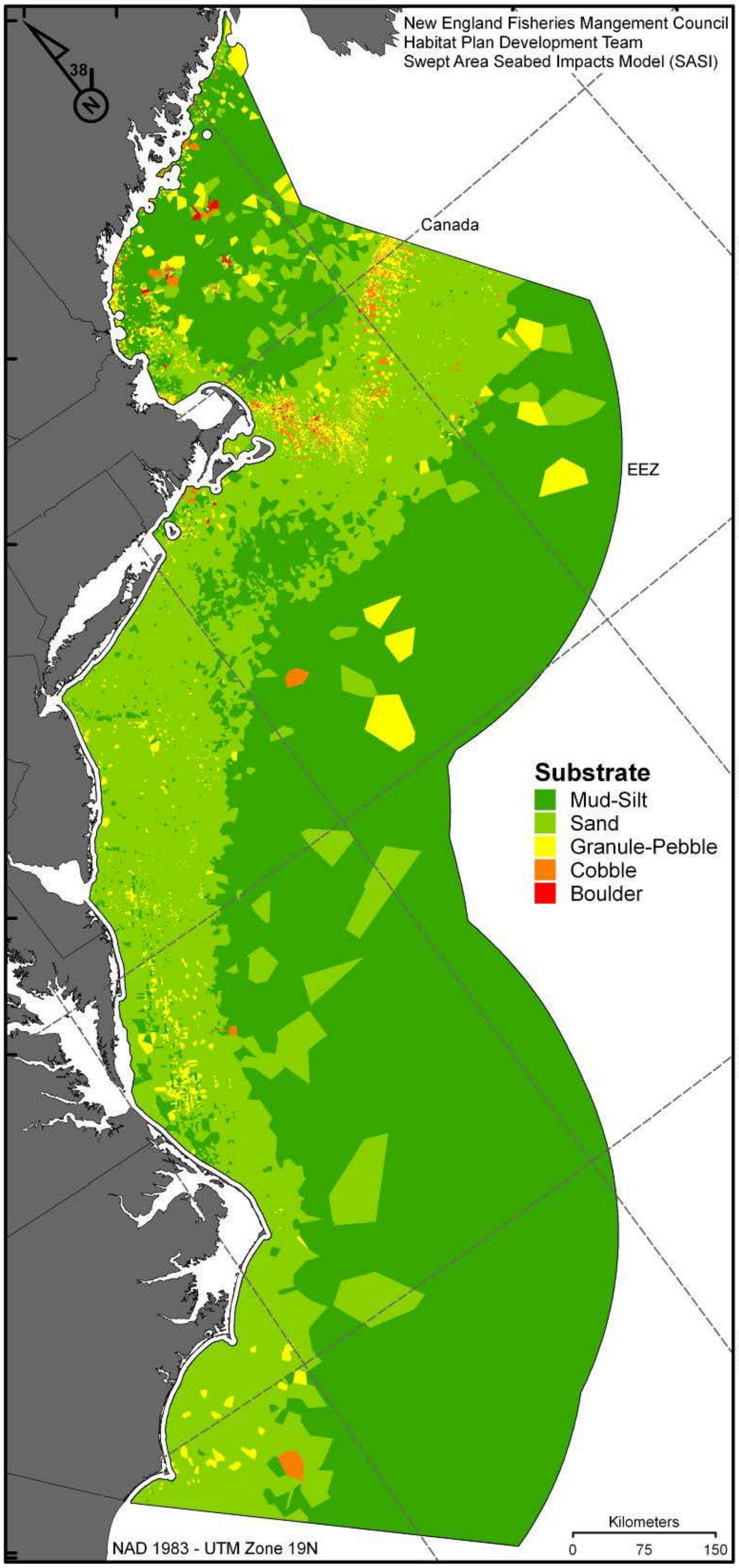
Map 3 – Geological sample locations.



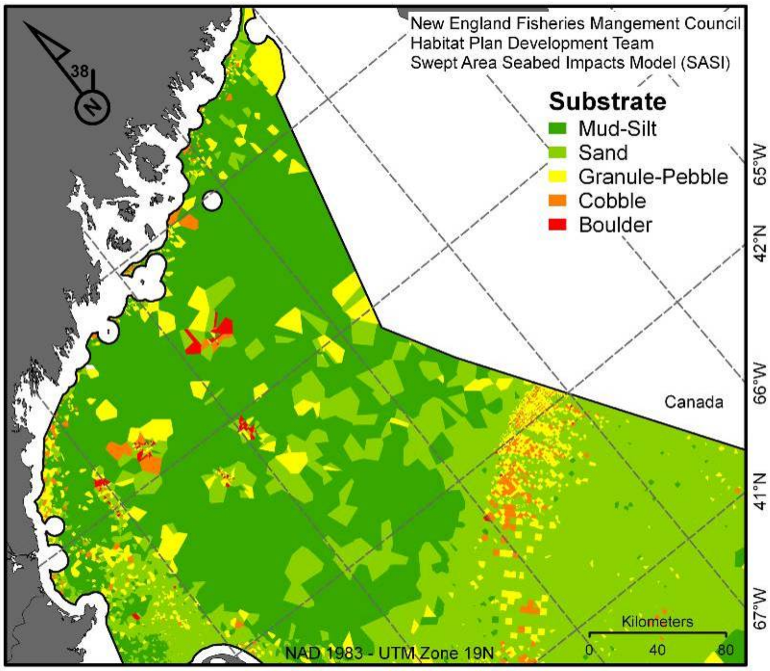
Map 4 – Geological samples by source.



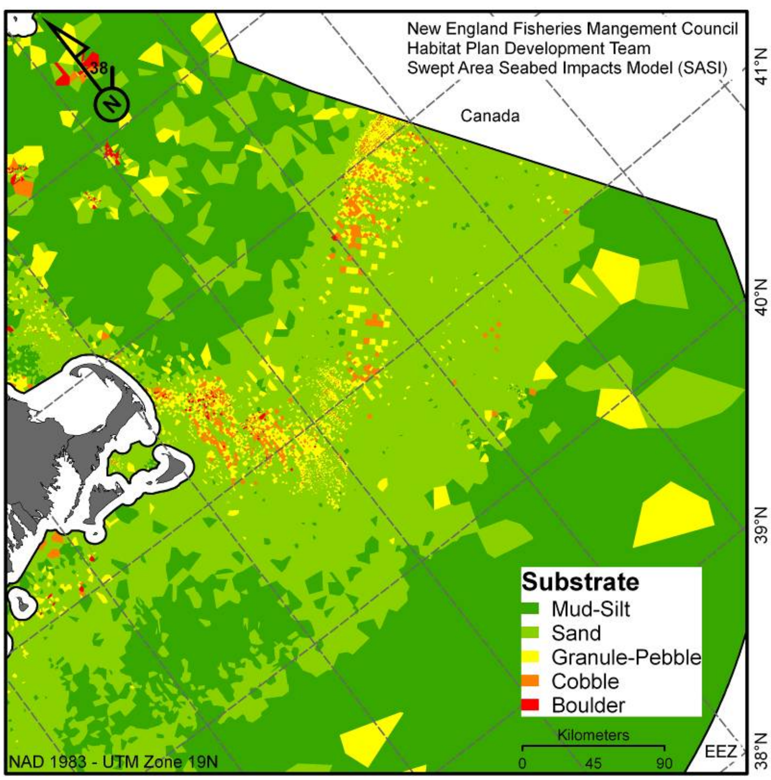
Map 5 - Dominant substrate coding for the entire model domain.



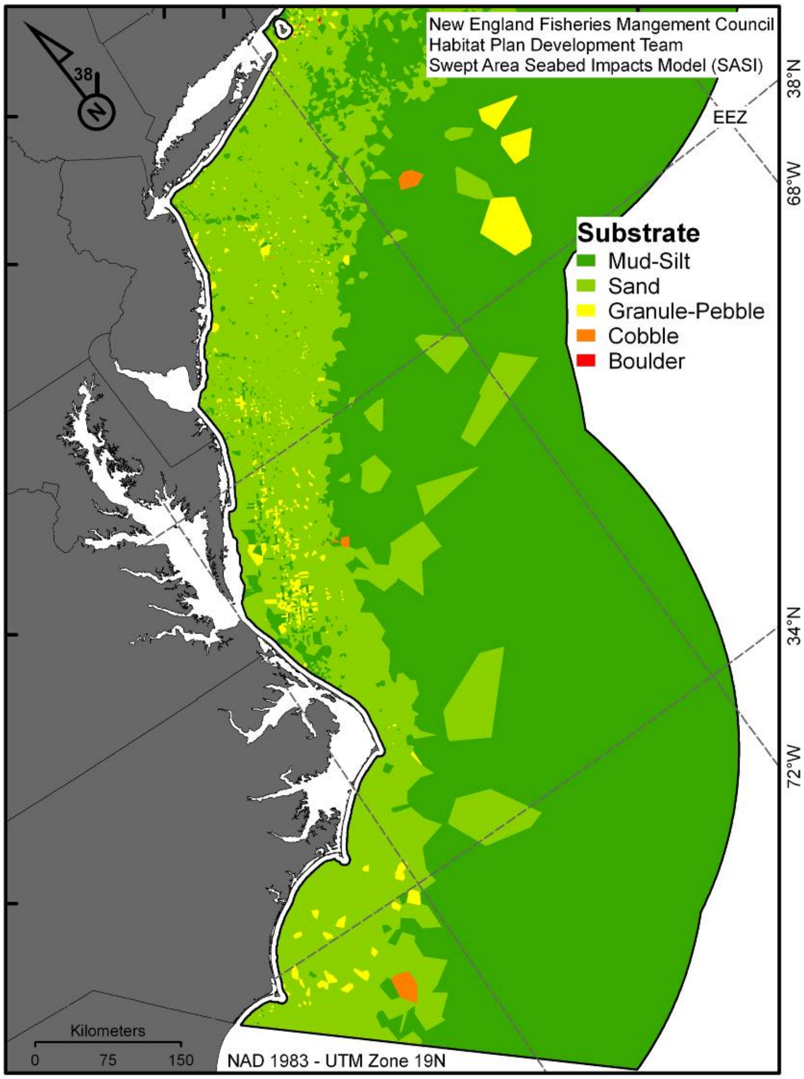
Map 6 –Dominant substrate coding for Gulf of Maine.



Map 7 – Dominant substrate coding for Georges Bank.



Map 8 – Dominant substrate coding for the Mid-Atlantic Bight.



7.2 Classifying natural disturbance using depth and shear stress

As water flow increases over the seabed, the shear stress increases and the hydrodynamic forces acting on the bottom will eventually dislodge and start to move substrate particles. The relationship between velocity and critical levels are substrate particles start to move is depicted by the Hjulstrøm Curve and the relationship between shear stress and particle movement with a the Shield's Curve. This threshold for substrate particle movement is termed critical shear stress. To allow for the use of separate habitat recovery parameters based on shear stress, each cell in the base grid is classified as either high or low energy based on model-derived maximum shear stress. Where shear stress modeling is unavailable, depth is used as shown below (Table 59). Depth is used as a proxy for wave-driven annual flow events. A depth of 60 m is selected as the boundary for high-energy levels based on the average depth where annual storm-event wave height conditions occur (Butman 1986).

Table 59 – Shear stress model components

Condition	*Data source*	*Parameterization*	
		High energy	*Low energy*
Shear stress	The max shear stress magnitude on the bottom in $N{\cdot}m^{-2}$ derived from the M2 and S2 tidal components only	High = shear stress ≥ 0.194 $N{\cdot}m^{-2}$ (critical shear stress sufficient to initiate motion in coarse sand)	Low = shear stress < 0.194 $N{\cdot}m^{-2}$
Depth	Coastal Relief Model depth data	High = depths ≤ 60m	Low = depths > 60m

Digital soundings data are queried from the National Geophysical Data Center of NOAA using the online National Ocean Service data portal (http://www.ngdc.noaa.gov/mgg/gdas/ims/hyd_cri.html). There are 4,000,000 records in the model domain and depth is estimated using the average value of the digital soundings data in each map cell.

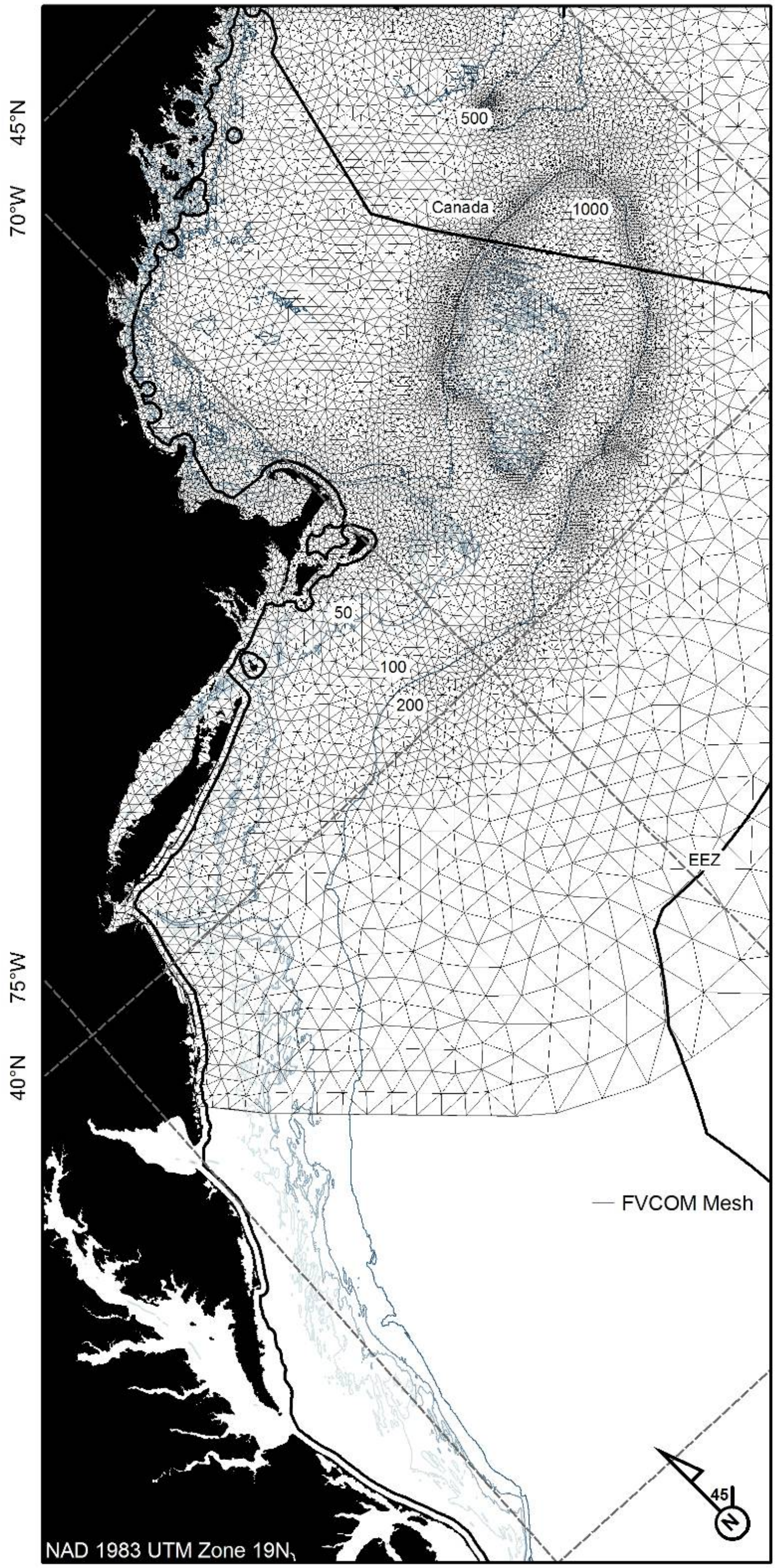
Shear stress is calculated using the Gulf of Maine module of the Finite Volume Coastal Ocean Model (FVCOM-GoM) (Chen et al., 2003, 2006, Cowles, 2008). The bottom stress in the model is calculated where the drag coefficient is depth-based and critical shear stress is $\log_{10}$ (shear). Maximum shear stress magnitudes are derived from the M_2 and S_2 tidal components; these would thus represent the mean spring tides and would not include the effects of perigee/apogee.

FVCOM is an open source Fortran90 software package for the simulation of ocean processes in coastal regions run by the Marine Ecosystem Dynamics Modeling Group at the University of Massachusetts Dartmouth, Department of Fisheries Oceanography (http://fvcom.smast.umassd.edu/FVCOM/index.html). The kernel of the code computes a solution of the hydrostatic primitive equations on unstructured grids using a finite-volume flux formulation (for details see Chen et al. 2003, 2006, Cowles, 2008). The FVCOM-Gulf of Maine (GoM) domain includes the entire Gulf of Maine, the Scotian Shelf to 45.2° N, and the New England Shelf to the northern edge of the Mid-Atlantic at 39.1° N. The model mesh contains 30,000 elements in the horizontal and 30 layers in the vertical. Resolution ranges from approximately 3km on Georges Bank to 15km near the open boundary. The model is advanced at a time step of 120s. A high performance computer cluster (32 processors) is used to run FVCOM-GoM, requiring about 8 hours of wall clock time for each month of simulated time. Boundary forcing in the FVCOM-GoM system includes prescription of the five major tidal constituents at the open boundary, freshwater input from major rivers in the Gulf of Maine, and wind stress and heat flux derived from a high resolution configuration of the MM5 meteorological model. At the open boundary, hydrography is set using monthly climatology fields derived from survey data using optimal interpolation techniques. Assimilation of daily mean satellite-derived sea surface temperature (SST) into the model SST is included to improve the model temperature state. The model has been validated using long-term observations of tidal and subtidal currents and as well as hydrography (Cowles et al. 2008).

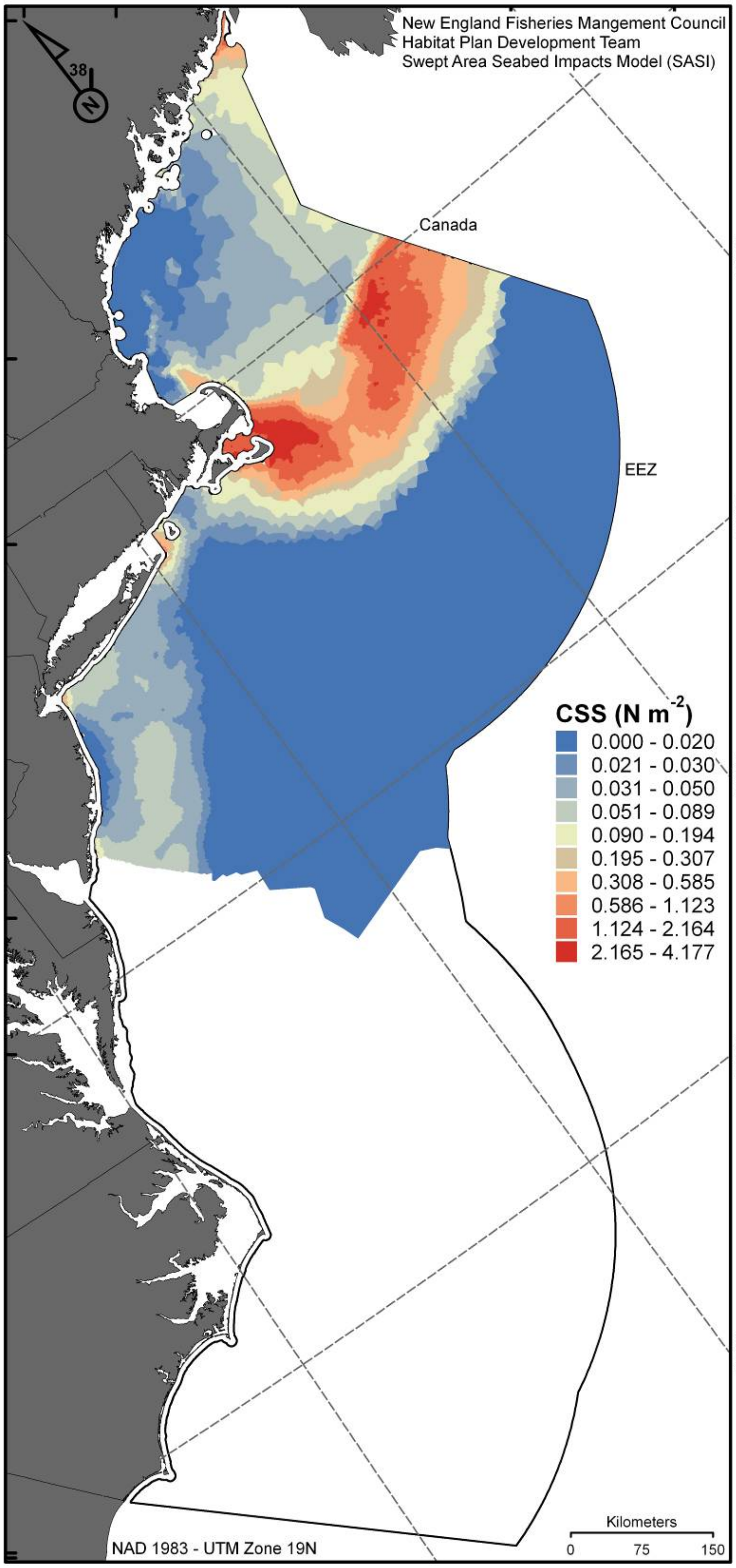
The circulation in the Gulf of Maine, Georges Bank and the New England Shelf regions is simulated from 1995-present. Hourly model hydrographic and velocity data fields are computed at each cell in the domain. Shear stress is computed from the model velocity fields using the "law of the wall" with a depth-based estimate of bottom roughness (Bradshaw and Huang 1995).

High or low energy values are inferred from the shear stress surface to the SASI model grid based on spatial overlap (Map 10). Where more than one shear stress estimate occurred per SASI model grid, the mean of the values is used. Outside the FVCOM model domain energy values are based on the 60 m depth criteria (Map 11). This is reasonable given regions outside the domain include the deep water GOM and the southern Mid-Atlantic where tidal flows are relatively low or are diminished by depth. Combining these two sources of information, Map 12 shows the basis for coding each Voronoi grid cell as high or low energy.

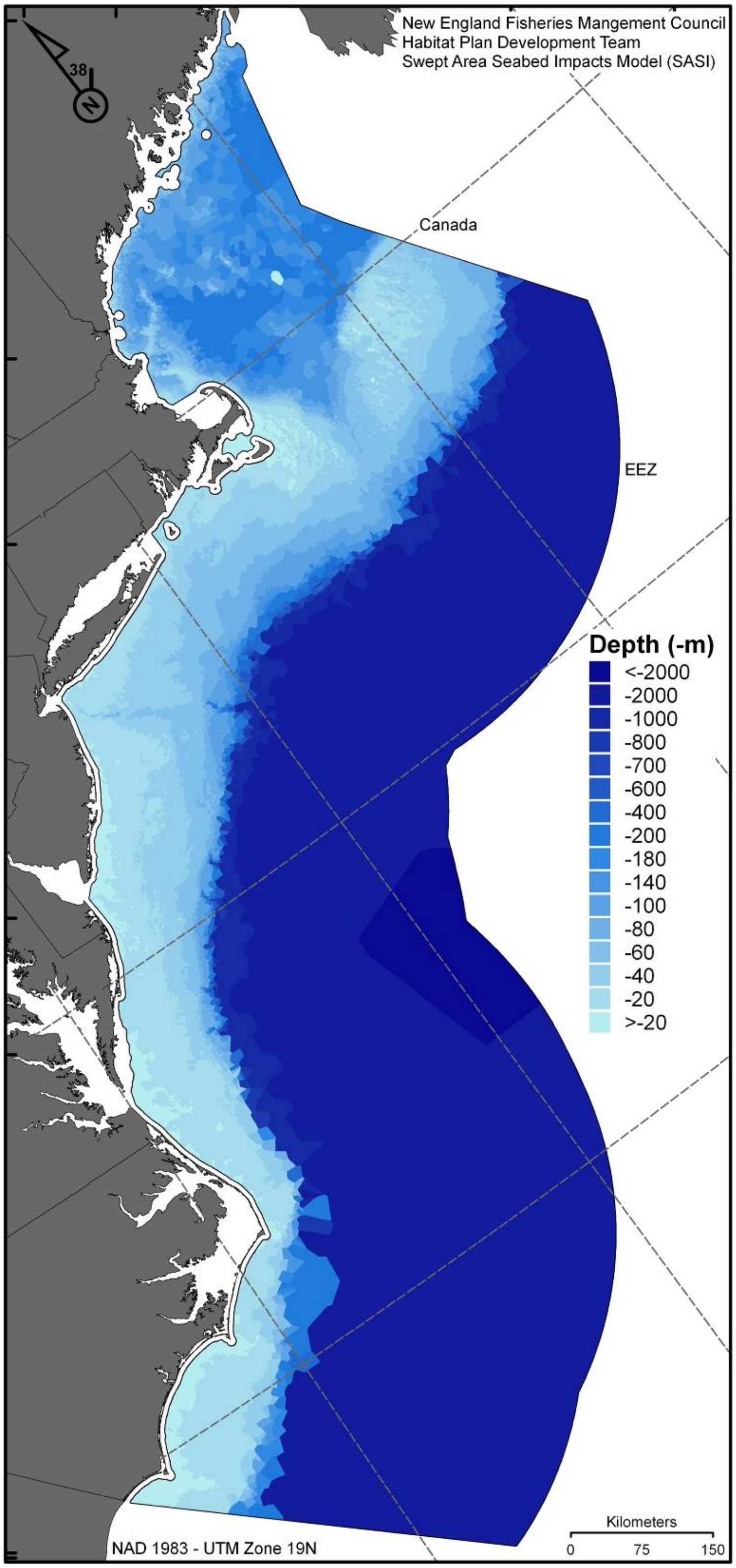
Map 9 - FVCOM domain and nodes.



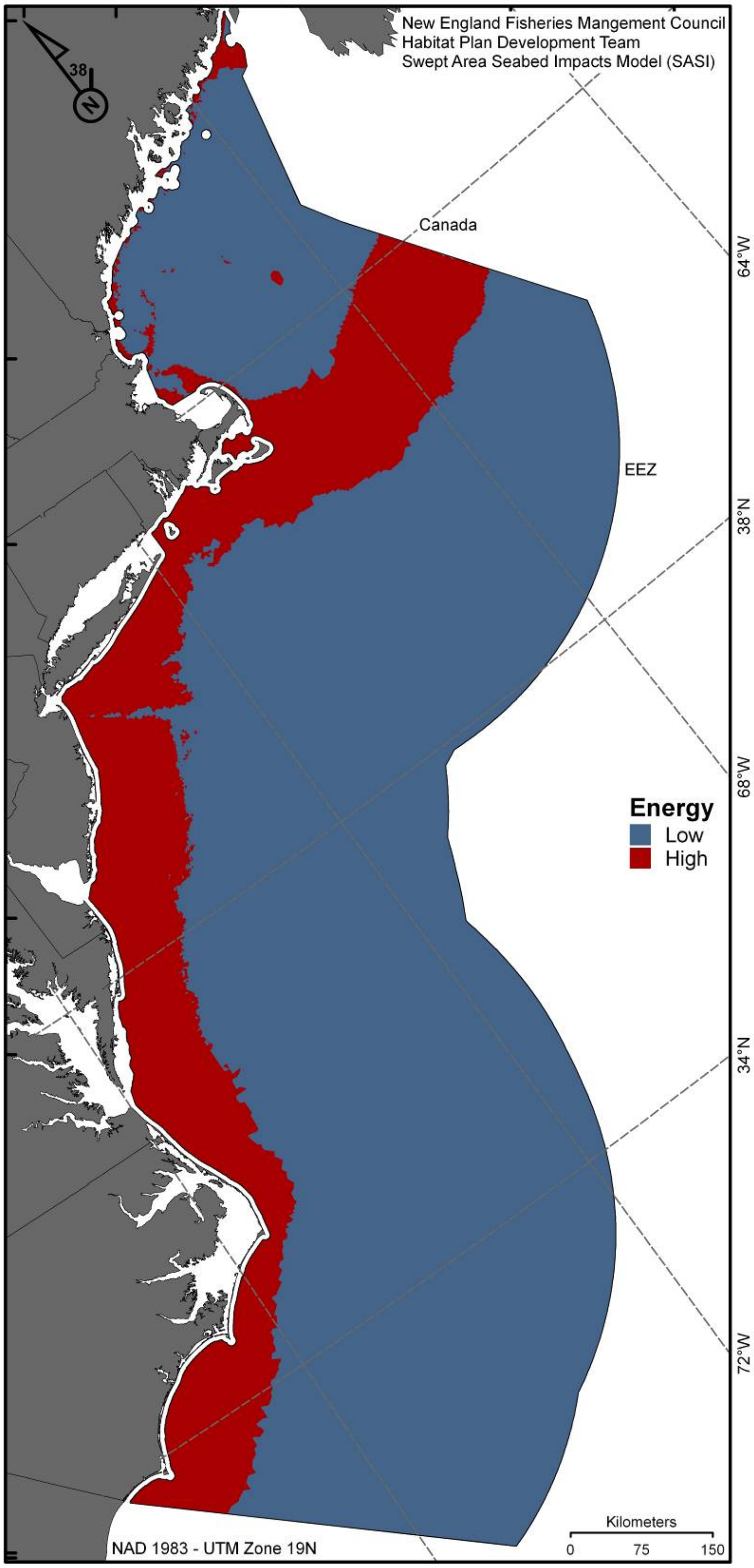
Map 10 – Base grid cell coding of energy resulting from critical shear stress model.



Map 11 – Bathymetry map based on the National Ocean Service data portal



Map 12– Base grid cell coding of energy resulting from depth and energy combined. Coastline is rotated 38°.



8.0 Spatially estimating adverse effects from fishing on fish habitats: the SASI model

This section describes how the two components of the SASI model, vulnerability and contact-adjusted area swept, are integrated with the spatial grids to produce the adverse effect estimate, *Z*, which is measured in km^2.

8.1 Equations

One unit of fishing effort will generate an impact on benthic habitat that is equal to the area swept by that unit of effort, *A*, scaled by the assessed vulnerability of the underlying habitat type to that type of fishing gear.

In the Vulnerability Assessment, the vulnerability of each habitat type to fishing is decomposed into a combination susceptibility and recovery. The susceptibility parameters are used to initially modify area swept, and the recovery parameters are used to determine the rate of decay of the adverse effect estimate in the years following impact. Incorporating this recovery vector requires a discrete difference equation. Let the basic equation be:

$$Z_{t+1} = Z_t\left[1 + \left(X_t - Y_t\right)\right], \qquad (1)$$

where Z_t is adverse effect going into that year, X_t is the positive effect of one time unit (year) of habitat recovery, and Y_t is the adverse effect of one time unit of fishing activity (i.e., *A* modified by the susceptibility parameters). If adverse effect in a given year (Y_t combined with Z_t) is greater than recovery, X_t, Z_{t+1} will be negative.

The positive effect term X_t is the proportion of Z_t that recovers within a given time step, and is estimated using a linear decay model as

$$X_t = \frac{\left\lfloor \lambda(\mathrm{A}\omega)_{t_0} \right\rfloor \Delta t}{Z_t} \quad . \qquad (2)$$

The parameter λ represents the decay rate and is calculated as $1/\tau$ where τ is the total number of time steps (years) over which the adverse effects of fishing will decay, t_0 is the initial time unit when the effect entered the model, and Δt is the contemporary time step, such that $\Delta t = t - t_0$ where *t* is the year for which the calculation is being made.

A, the contact-adjusted area swept by one unit of fishing effort, can be represented as

$$A = (w\chi)d\ , \qquad (3)$$

where, *w* is the linear effective width of the fishing gear and χ is a constant representing the degree of bottom contact a particular fishing gear component may have. The variable *d* is the distance traveled in one unit of fishing effort.

The adverse effect term *Y* is the proportion of *Z* that is introduced into the model at time *t*,

$$Y_t = \frac{(A\omega)_t}{Z_t} \quad . \qquad (4)$$

Indexing this dynamic model across all units of fishing effort (*j*) by nine fishing gear types (*i*) and a matrix of habitat types determined by combinations of five substrates (*k*), two energy environments (*l*) and *y* individual habitat features (*m*) leaves us with

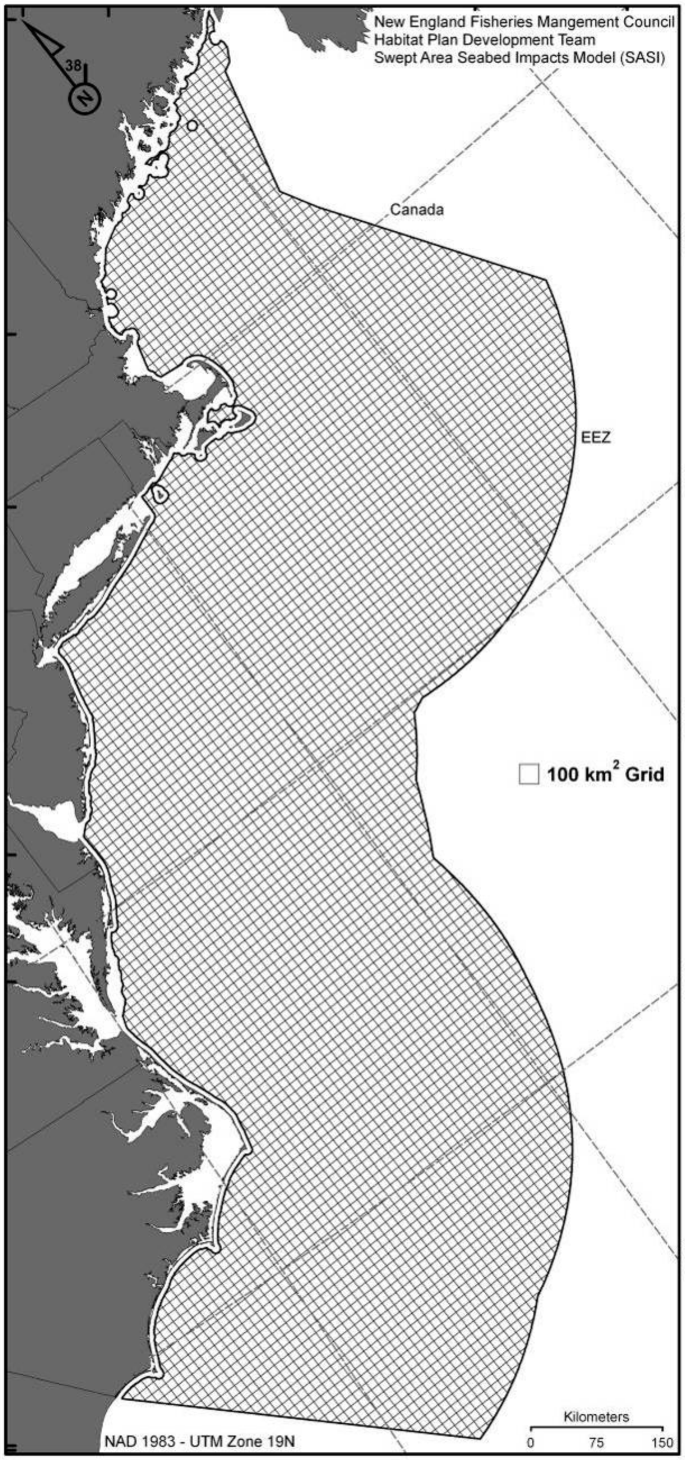
$$Z_{t+1} = Z_t + \left[\sum_{i=1}^{9} \sum_{j=1}^{n} \sum_{k=1}^{5} \sum_{l=1}^{2} \sum_{m=1}^{y} \left[\left(\lambda \left(A_{i,j} \omega_{k,l} \right)_{t_0} \Delta t \right) - \left(A_{i,j} \omega_{k,l} \right)_t \right] \right] . \qquad (5)$$

8.2 Methods

This section describes how the vulnerability parameters (S and R) are combined with area swept data to produce spatially-specific estimates of adverse effect. One issue that needed to be resolved in the model is that the spatial resolutions of substrate and fishing effort data are not the same. Many of the cells in the unstructured substrate grid are extremely small--much smaller than the resolution of trip report data. Therefore, a structured grid is created to overlay the unstructured grid (Map 13). A higher resolution map showing the overlay between the structured and unstructured grids is also shown (Map 14).

If a unit of fishing effort occurs within a 100 km^2 grid cell, it is modified according to the S and R values associated with that grid cell, in proportion to the area covered by each dominant substrate/energy combination (i.e. habitat type). Table 60 shows the ten habitat types identified in the Vulnerability Assessment, broken down into their geological and biological components. As an example, the lower part of the figure above shows the proportions of four sample 100 km^2 grid cell that are coded as sand, granule-pebble, cobble, and boulder dominated. Note that all of the grid cells shown are high energy, and do not contain any mud substrate, such that only four habitat types are represented in the highlighted cells.

Map 13 - Structured SASI grid



Map 14 – Structured and unstructured grid overlay.

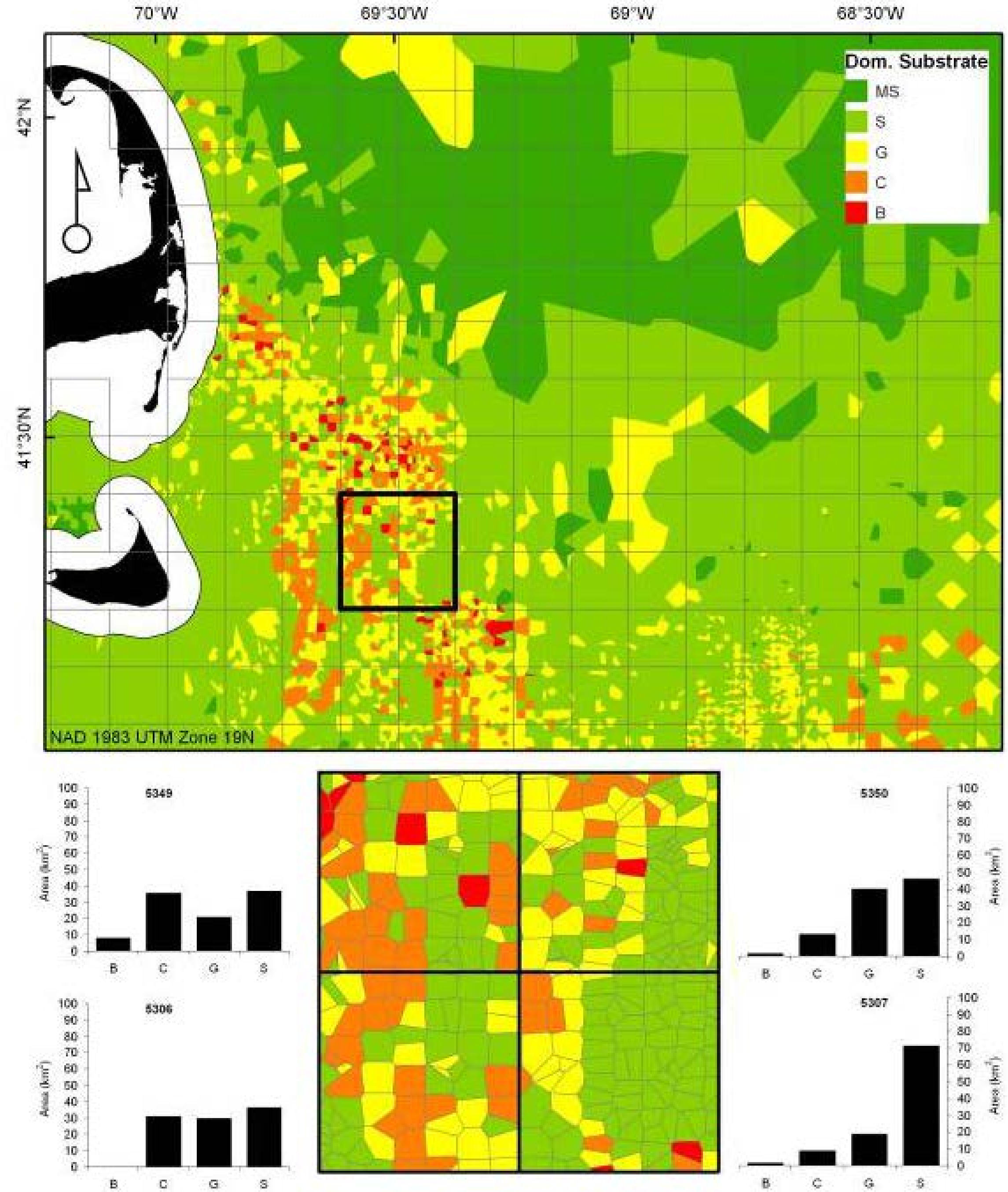


Table 60 – Ten habitat types identified in the Vulnerability Assessment.

	High Energy		Low energy	
	Geological features (modify 50% of A)	***Biological features (modify 50% of A)***	***Geological features (modify 50% of A)***	***Biological features (modify 50% of A)***
Mud	Biogenic burrows, biogenic depressions, sediments	Cerianthid burrowing anemones, hydroids, mussels, tube-dwelling amphipods	Biogenic burrows, biogenic depressions, sediments	Cerianthid burrowing anemones, sea pens, hydroids, mussels, tube-dwelling amphipods
Sand	Biogenic burrows, biogenic depressions, sediments, bedforms, shell deposits	Cerianthid burrowing anemones, tube-dwelling amphipods, ascidians, hydroids, *Filograna implexa*, sponges, mussels, scallops	Biogenic burrows, biogenic depressions, sediments, shell deposits	Cerianthid burrowing anemones, sea pens, tube-dwelling amphipods, ascidians, hydroids, *Filograna implexa*, sponges, mussels, scallops
Granule-pebble	Scattered granule-pebble, granule-pebble pavement, shell deposits	Actinarian anemones, cerianthid burrowing anemones, ascidians, brachiopods, bryozoans, hydroids, macroalgae, *Filograna implexa*, other tube-dwelling polychaetes, sponges, mussels, scallops	Scattered granule-pebble, shell deposits	Actinarian anemones, cerianthid burrowing anemones, ascidians, brachiopods, bryozoans, hydroids, *Filograna implexa*, other tube-dwelling polychaetes, sponges, mussels, scallops
Cobble	Scattered cobble, piled cobble, cobble pavement	Actinarian anemones, ascidians, brachiopods, bryozoans, hydroids, macroalgae, *Filograna implexa*, other tube-dwelling polychaetes, sponges, mussels	Scattered cobble, piled cobble	Actinarian anemones, ascidians, brachiopods, bryozoans, hydroids, *Filograna implexa*, other tube-dwelling polychaetes, sponges, mussels
Boulder	Scattered boulder, piled boulder	Actinarian anemones, ascidians, brachiopods, bryozoans, hydroids, macroalgae, *Filograna implexa*, other tube-dwelling polychaetes, sponges, scallops, mussels	Scattered boulder, piled boulder	Actinarian anemones, ascidians, brachiopods, bryozoans, hydroids, *Filograna implexa*, other tube-dwelling polychaetes, sponges, scallops, mussels

When applying S and R values to area swept estimates in the model, SASI draws from the appropriate distribution of gear-appropriate percent reduction (S) and recovery time (R) sciresm as indicated by the 0-3 scores from Table 30, Table 32, Table 34, Table 36, and Table 37. **Within a habitat type, the geological and biological components are weighted equally** (i.e. they contribute equally to modifying area swept). **Within each habitat type, individual features contribute equally as well**. These equal weighting assumptions are made in the absence of empirical data on either the distribution of features within substrates or the relative importance of the features to managed species.

As an example, if an entire 100 km^2 grid cell is coded as low energy mud, with susceptibility scores for three geological features of 1, 2, and 3, respectively, and susceptibility scores for three biological features of 1, 2, and 3, respectively, 1/6 of the area swept for that cell is modified by each feature's score. As area swept enters the model in year 1, for the proportion modified by S scores of 1, anywhere from 10-25% of the effort would go forward in the model, corresponding to the S definitions. For scores of 2, anywhere from 25-50% would go forward, for scores of 3, some amount >50% would go forward. No particular underlying distribution of percentages is assumed; in other words, as implemented, the SASI model has an equal probability of using 51% and 96% when applying an S score of 3 to the fraction of area swept expected to encounter features with a score of S=3.

Similarly, for the recovery scores, if R=0, that fraction of the area swept would be removed from the model in the following year. For R=1, this would take either 1 or 2 years, for R=2, 2-5 years, or for R=3, 5-10 years. The terminal year selected for R=3 is expected to have a significant effect on how much area swept accumulates under a given model run. A value of 10 years is selected according to the potential recovery times for the various features incorporated in the SASI model, acknowledging that it may be an underestimate for some features.

Assumptions are also made that limit certain gear types to certain substrates when the model is implemented spatially (Table 61). In particular, matrices for hydraulic dredges in mud, cobble, and boulder (both for high and low energy) are not evaluated because hydraulic dredges are assumed unable to fish in these substrate types and therefore matrices are not evaluated. In the case of shrimp, squid, and raised footrope trawls, trawl matrices for cobble and boulder are developed, but S/R values from these matrices are not applied to these gear types.

Table 61 – Rules for applying matrix results to a particular substrate/energy combination. Asterisk (*) indicates that if that substrate/gear type interaction occurs in 100 km^2 grid cell the model, that type of substrate would be ignored and effort would be modified according to S/R scores for the 'fishable' gear/substrate interactions, in proportion to the percent coverage of those substrates.

Gear type	***If cell is coded as mud, matrix results applied:***	***If cell is coded as sand, matrix results applied:***	***If cell is coded as g/p, matrix results applied***	***If cell is coded as cobble, matrix results applied***	***If cell is coded as boulder, matrix results applied***
Generic otter trawl	All trawls, mud	All trawls, sand	All trawls, g/p	All trawls, cobble	All trawls, boulder
Shrimp trawl	All trawls, mud	All trawls, sand	All trawls, g/p	-*	-*
Squid trawl	All trawls, mud	All trawls, sand	All trawls, g/p	-*	-*
Raised footrope trawl	All trawls, mud	All trawls, sand	All trawls, g/p	-*	-*
Scallop dredge	Scallop, mud	Scallop, sand	Scallop, g/p	Scallop, cobble	Scallop, boulder
Hydraulic dredge	-*	Hydraulic, sand	Hydraulic, g/p	-*	-*
Longline	Longline, mud	Longline, sand	Longline, g/p	Longline,	Longline,

Gear type	If cell is coded as mud, matrix results applied:	If cell is coded as sand, matrix results applied:	If cell is coded as g/p, matrix results applied	If cell is coded as cobble, matrix results applied	If cell is coded as boulder, matrix results applied
				cobble	boulder
Gillnet	Gillnet, mud	Gillnet, sand	Gillnet, g/p	Gillnet, cobble	Gillnet, boulder
Trap	Trap, mud	Trap, sand	Trap, g/p	Trap, cobble	Trap, boulder

These assumptions are necessary because of uncertainties associated with the substrate and fishing effort distributions, which might cause unrealistic spatial overlaps between area swept for a particular gear type and certain substrates. In cases where a fraction of the seabed within a cell is coded as an unfishable substrate for a gear type, that fraction of the cell is ignored when applying S and R scores, and only the scores associated with the fishable substrates are used.

For example, take a case where a 100 km^2 cell is all high energy, with 50% of the area sand-dominated, 40% granule-pebble-dominated, and 10% cobble-dominated, and 1000 km^2 of fishing effort area swept associated with squid trawl gear is applied to the cell. If the gear were assumed to be able to fish on cobble-dominated bottom, 500 km^2 would be modified according to the S and R scores in the generic otter trawl high energy sand matrix, 400 km^2 would be modified according to the S and R scores in the generic otter trawl high energy granule-pebble matrix, and 100 km^2 would be modified according to the S and R scores in the generic otter trawl high energy cobble matrix. Because the gear cannot fish on cobble, 555.6 km^2 would be modified according to the sand matrix, and 444.4 km^2 would be modified according to the granule-pebble matrix.

In cases where an entire 100 km^2 cell contains an unfishable dominant substrate type, any area swept that would have been applied to that cell is zeroed out and does not carry forward in the model. In practice, because the areas dominated by cobble and boulder are so small, and are surrounded by sand, granule-pebble, and/or mud, this scenario only applies to hydraulic dredge gear area swept in 100 km^2 cells coded entirely as mud.

8.3 Outputs

The vulnerability and area swept data layers are combined with the substrate/energy grids to generate impact surfaces at the 100km^2 cell level. The resulting Z (adverse effect) estimates are measured in square kilometers, and represent the nominal area swept in a cell conditioned by the susceptibility and recovery parameters assigned to the habitat features inferred to the substrates known to exist in that cell. Three classes of outputs are generated: simulated (Z_∞/$Z_{infinity}$), realized ($Z_{realized}$), and instantaneous (Z_{net}). Z_∞ and $Z_{realized}$ outputs are discussed below; Znet outputs are discussed in section 10.0.

8.3.1 Simulation runs

Simulated model outputs (Z_{∞}/$Z_{infinity}$) are based on running the SASI model with a hypothetical, uniformly distributed amount of area swept applied to each 100 km^2.grid cell for each gear type. The model results and maps are intended to show how the SASI model combines the susceptibility and recovery parameters for a particular gear type with the underlying substrate and energy distributions. **This is intended to indicate the underlying vulnerability of a given location to a given gear type.** Because the amount of area swept is the same across gears, the locations that are more or less vulnerable to adverse effects from fishing can be compared.

The model is run continuously, with area swept added in annual time steps, and the simulated outputs for the terminal year are mapped/analyzed, once the model has reached its asymptotic equilibrium (i.e., once Z is stable). Because the maximum recovery time that may be assigned to a habitat feature is 10 years, this equilibrium is reached in year 11. This asymptotically stable equilibrium is referred to as Z_{∞}. Not all grid cells in the model domain are included in these model runs. For each gear type, the domain is truncated based on a maximum depth, estimated based on depths reported in the fishery observer data. Also, these simulation runs are only conducted for the six major gear types, corresponding with the six sets of vulnerability assessment matrices. Results for individual types of trawls (i.e. shrimp, squid, raised footrope) and the two permit categories of scallop dredge (i.e. limited access, general category) are decomposed in the realized runs (see next section).

According to the assumptions made in section 2.0 about which features occur in which substrate/energy-dominated environments, fishing gears can then be expected to encounter different features at different rates. Some features will be encountered more frequently because the substrate/energy environment in which they occur is more common, and/or the feature occurs in multiple substrate/energy environments. Features that are more frequently encountered will have a greater influence on the resulting area swept values from the model.

Table 62 and Table 63 show the implicit interactions of gears and features from the SASI model under a uniform area swept assumption. The total km^2 of high and low energy seabed potentially fished by each gear type given the fishing depth assumptions is shown on the last line of each subsection. Geological and biological features are shown separately because their S and R scores are applied to fishing effort in equal proportion. Within a particular substrate/energy and within the biological or geological habitat component, an equal distribution of each individual biological or geological feature is assumed. Therefore, the different percentages for each feature relate to the underlying distribution of dominant-substrates, and also to the presence of some features in multiple dominant substrates. The distributions in the tables relate also to the assumed depth-based footprint of a particular gear type.

Table 62– Distribution of geological features in high and low energy environment within the areas assumed to be fishable by particular gears. Hydraulic dredge gears are additionally assumed not to be able to fish in mud, cobble, or boulder substrates.

Distribution of geological features in low energy		Trawl	Scallop	Hydraulic	Longline	Gillnet	Trap
	Bedforms	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Biogenic burrows	24.9%	24.0%	17.6%	24.6%	24.3%	24.9%
	Biogenic depressions	24.9%	24.0%	17.6%	24.6%	24.3%	24.9%
	Boulder, piled	0.4%	0.2%	0.0%	0.5%	0.5%	0.4%
	Boulder, scattered, in sand	0.4%	0.2%	0.0%	0.5%	0.5%	0.4%
	Cobble, pavement	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Cobble, piled	1.0%	1.1%	0.0%	1.1%	1.2%	1.0%
	Cobble, scattered in sand	1.0%	1.1%	0.0%	1.1%	1.2%	1.0%
	Granule-pebble, pavement	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Granule-pebble, scattered, in sand	4.7%	4.5%	5.9%	4.8%	4.9%	4.7%
	Sediments, subsurface	0.0%	0.0%	17.6%	0.0%	0.0%	0.0%
	Sediments, unfeatured surface	24.9%	24.0%	17.6%	24.6%	24.3%	24.9%
	Shell deposits	17.9%	20.8%	23.6%	18.4%	18.8%	17.9%
	Total area, low energy (km^2)	*105,111*	*22,684*	*35,225*	*93,029*	*80,835*	*106,734*

Distribution of geological features in high energy		Trawl	Scallop	Hydraulic	Longline	Gillnet	Trap
	Bedforms	15.1%	15.1%	15.9%	15.1%	15.1%	15.1%
	Biogenic burrows	19.3%	19.4%	15.9%	19.3%	19.3%	19.3%
	Biogenic depressions	19.3%	19.4%	15.9%	19.3%	19.3%	19.3%
	Boulder, piled	0.6%	0.6%	0.0%	0.6%	0.6%	0.6%
	Boulder, scattered, in sand	0.6%	0.6%	0.0%	0.6%	0.6%	0.6%
	Cobble, pavement	2.1%	2.0%	0.0%	2.1%	2.1%	2.1%
	Cobble, piled	2.1%	2.0%	0.0%	2.1%	2.1%	2.1%
	Cobble, scattered in sand	2.1%	2.0%	0.0%	2.1%	2.1%	2.1%
	Granule-pebble, pavement	6.5%	6.5%	6.9%	6.6%	6.5%	6.5%
	Granule-pebble, scattered, in sand	6.5%	6.5%	6.9%	6.6%	6.5%	6.5%
	Sediments, subsurface	0.0%	0.0%	15.9%	0.0%	0.0%	0.0%
	Sediments, unfeatured surface	4.3%	4.3%	0.0%	4.3%	4.3%	4.3%
	Shell deposits	21.6%	21.6%	22.7%	21.6%	21.6%	21.6%
	Total area, high energy (km^2)	*125,324*	*119,982*	*116,382*	*125,261*	*125,204*	*125,324*

Table 63 – Distribution of biological features in high and low energy environment within the areas assumed to be fishable by particular gears, according to the maximum depth thresholds. Hydraulic dredge gears are additionally assumed not to be able to fish in mud, cobble, or boulder substrates.

Distribution of biological features in low energy		Trawl	Scallop	Hydraulic	Longline	Gillnet	Trap
	Amphipods, tube-dwelling	10.3%	9.7%	7.9%	10.0%	9.8%	9.8%
	Anemones, actinarian	2.5%	2.3%	2.7%	2.6%	2.7%	2.4%
	Anemones, cerianthid burrowing	12.2%	11.5%	10.5%	12.0%	11.8%	11.7%
	Ascidians	8.0%	8.9%	10.5%	8.1%	8.3%	7.6%
	Brachiopods	2.5%	2.3%	2.7%	2.6%	2.7%	2.4%
	Bryozoans	2.5%	2.3%	2.7%	2.6%	2.7%	2.4%
	Corals, sea pens	10.3%	9.7%	7.9%	10.0%	9.8%	9.8%
	Hydroids	12.8%	12.0%	10.5%	12.6%	12.5%	12.2%
	Macroalgae	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Modiolus modiolus	12.8%	12.0%	10.5%	12.6%	12.5%	12.2%
	Placopecten magellanicus	7.8%	8.9%	10.5%	7.9%	8.1%	7.5%
	Polychaetes, *Filograna implexa*	8.0%	8.9%	10.5%	8.1%	8.3%	7.6%
	Polychaetes, other tube-dwelling	2.5%	2.3%	2.7%	2.6%	2.7%	2.4%
	Sponges	8.0%	8.9%	10.5%	8.1%	8.3%	12.2%
	Total area, low energy (km^2)	*105,111*	*22,684*	*35,225*	*93,029*	*80,835*	*106,734*

Distribution of biological features in high energy		Trawl	Scallop	Hydraulic	Longline	Gillnet	Trap
	Amphipods, tube-dwelling	7.3%	7.4%	7.1%	7.3%	7.3%	7.3%
	Anemones, actinarian	3.5%	3.5%	3.0%	3.5%	3.5%	3.5%
	Anemones, cerianthid burrowing	9.8%	9.8%	10.1%	9.8%	9.8%	9.8%
	Ascidians	9.2%	9.2%	10.1%	9.2%	9.2%	9.2%
	Brachiopods	3.5%	3.5%	3.0%	3.5%	3.5%	3.5%
	Bryozoans	3.5%	3.5%	3.0%	3.5%	3.5%	3.5%
	Corals, sea pens	7.3%	7.4%	7.1%	7.3%	7.3%	7.3%
	Hydroids	10.8%	10.8%	10.1%	10.8%	10.8%	10.8%
	Macroalgae	3.5%	3.5%	3.0%	3.5%	3.5%	3.5%
	Modiolus modiolus	10.8%	10.8%	10.1%	10.8%	10.8%	10.8%
	Placopecten magellanicus	9.0%	9.0%	10.1%	9.0%	9.0%	9.0%
	Polychaetes, *Filograna implexa*	9.2%	9.2%	10.1%	9.2%	9.2%	9.2%
	Polychaetes, other tube-dwelling	3.5%	3.5%	3.0%	3.5%	3.5%	3.5%
	Sponges	9.2%	9.2%	10.1%	9.2%	9.2%	9.2%
	Total area, high energy (km^2)	*125,324*	*119,982*	*116,382*	*125,261*	*125,204*	*125,324*

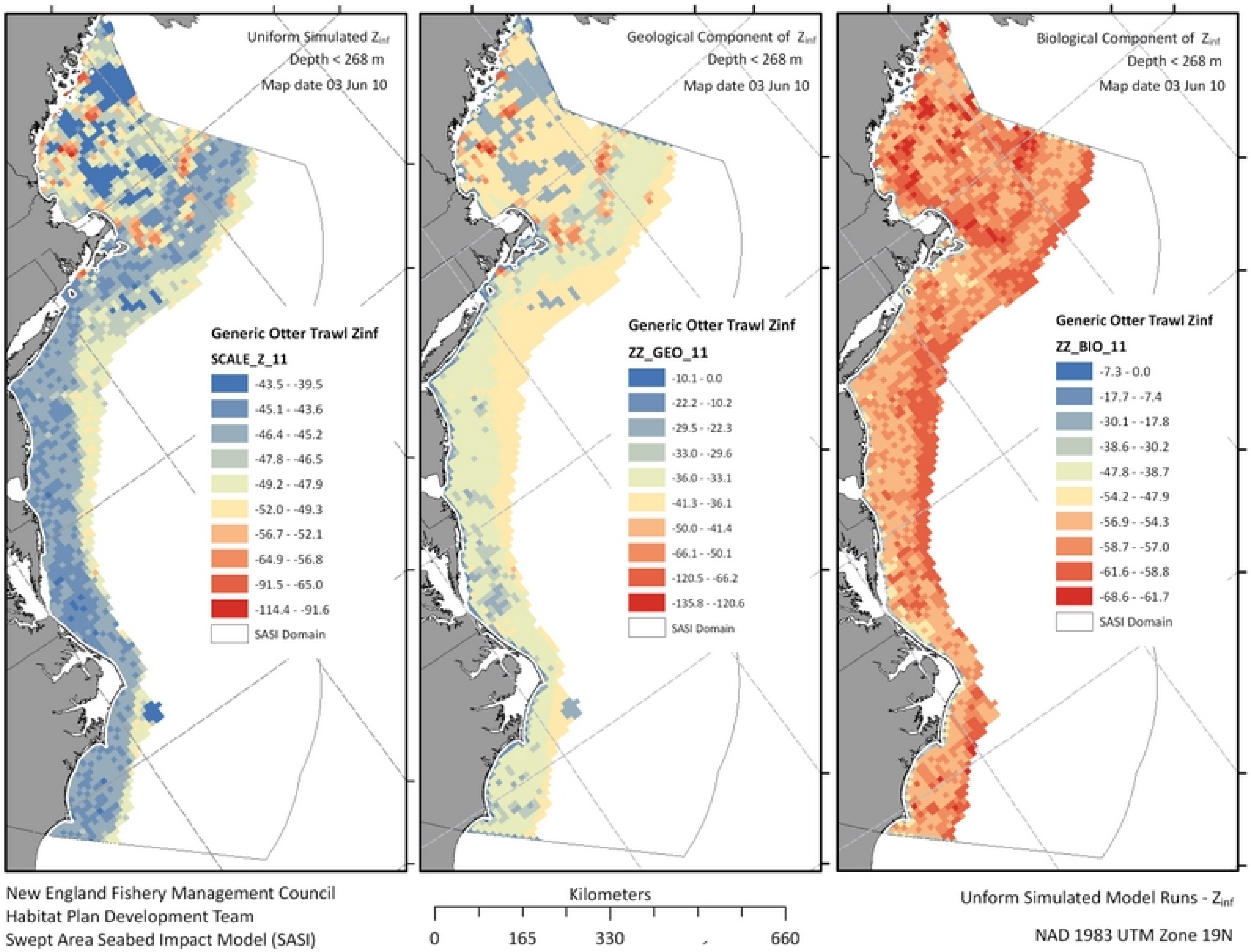
Table 64 (below) is similar to the ones above, but shows the proportions of the fishable area for each gear type dominated by each substrate class.

Table 64 – Distribution of dominant substrates, by energy environment, within the areas assumed to be fishable by particular gears, according to maximum depth thresholds. Hydraulic dredge gears are additionally assumed not to be able to fish in mud, cobble, or boulder substrates.

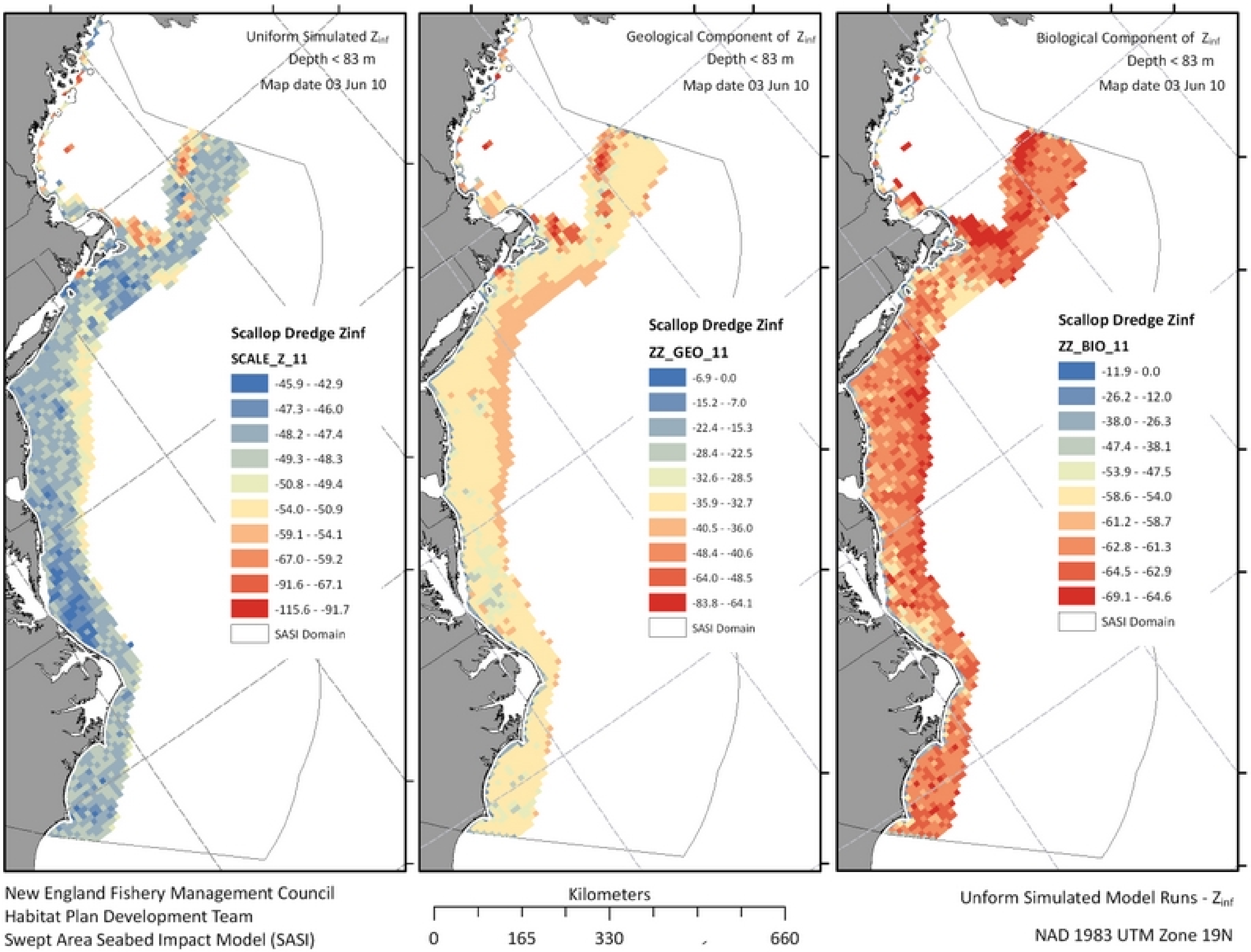
		Trawl	Scallop	Hydraulic	Longline	Gillnet	Trap
Distribution of substrates in low energy	Mud	37.5%	25.8%	0.0%	35.7%	33.9%	37.6%
	Sand	42.9%	54.8%	74.8%	43.8%	44.8%	42.9%
	Granule- pebble	15.1%	15.1%	25.2%	15.7%	15.9%	15.1%
	Cobble	3.2%	3.7%	0.0%	3.4%	3.8%	3.1%
	Boulder	1.4%	0.7%	0.0%	1.5%	1.6%	1.3%
	Total area, low energy (km^2)	*105,111*	*22,684*	*35,225*	*93,029*	*80,835*	*106,734*
		Trawl	**Scallop**	**Hydraulic**	**Longline**	**Gillnet**	**Trap**
Distribution of substrates in high energy	Mud	15.0%	15.1%	0.0%	14.9%	14.9%	15.0%
	Sand	52.9%	53.0%	69.9%	52.9%	52.9%	52.9%
	Granule- pebble	22.9%	22.9%	30.1%	23.0%	23.0%	22.9%
	Cobble	7.2%	7.0%	0.0%	7.2%	7.2%	7.2%
	Boulder	2.1%	2.1%	0.0%	2.1%	2.1%	2.1%
	Total area, high energy (km^2)	*125,324*	*119,982*	*116,382*	*125,261*	*125,204*	*125,324*

Simulated outputs for each of the six major gear types are shown in the maps below. These are presented as combined Z_∞ (left panel), geological contribution to Z_∞ (center panel), and biological contribution to Z_∞ (right panel),. Note that the scales (color ramps) vary between panels and between gear types.

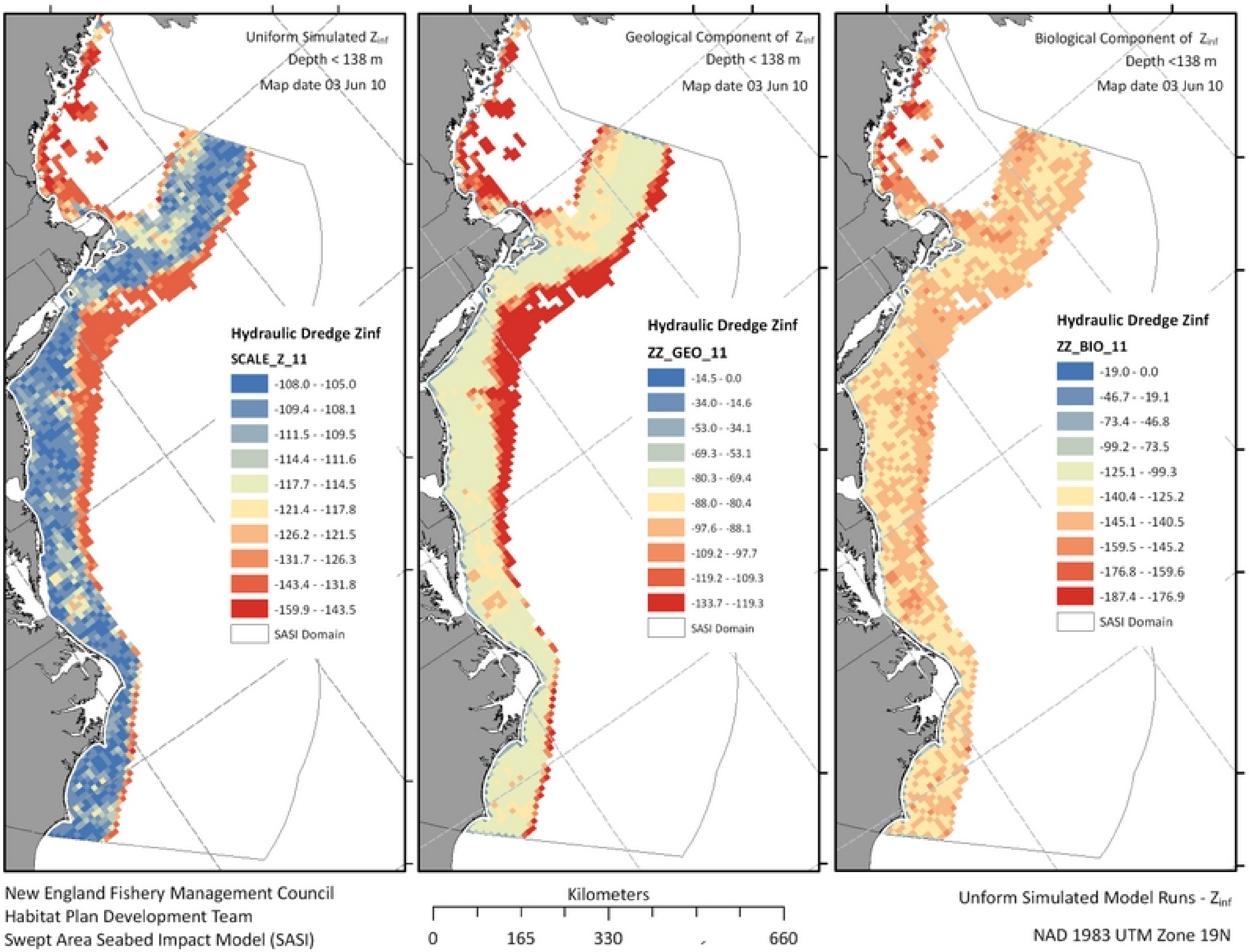
Map 15 – Simulation outputs (Z_∞) for trawl gear.



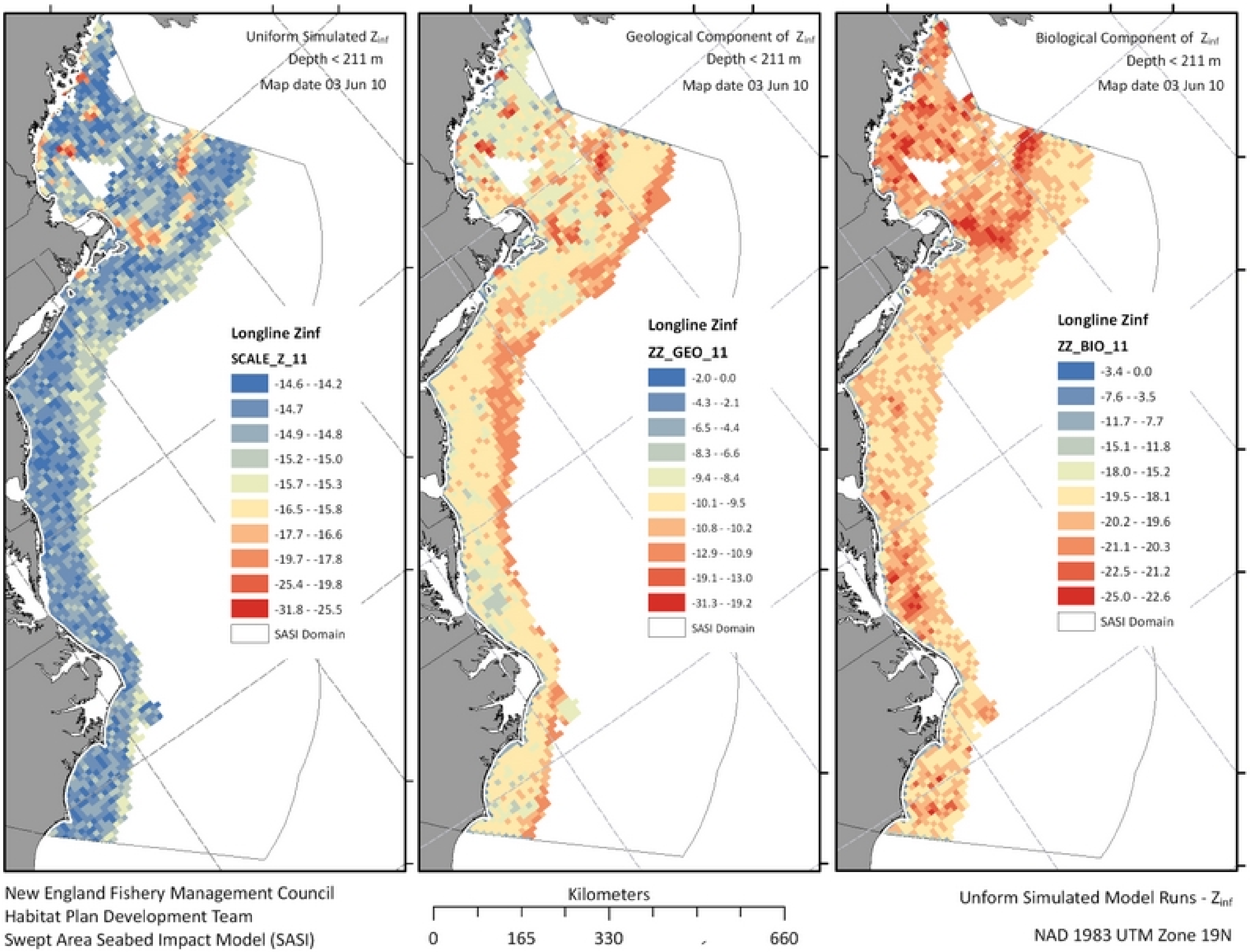
Map 16 – Simulation outputs (Z_∞) for scallop dredge gear.



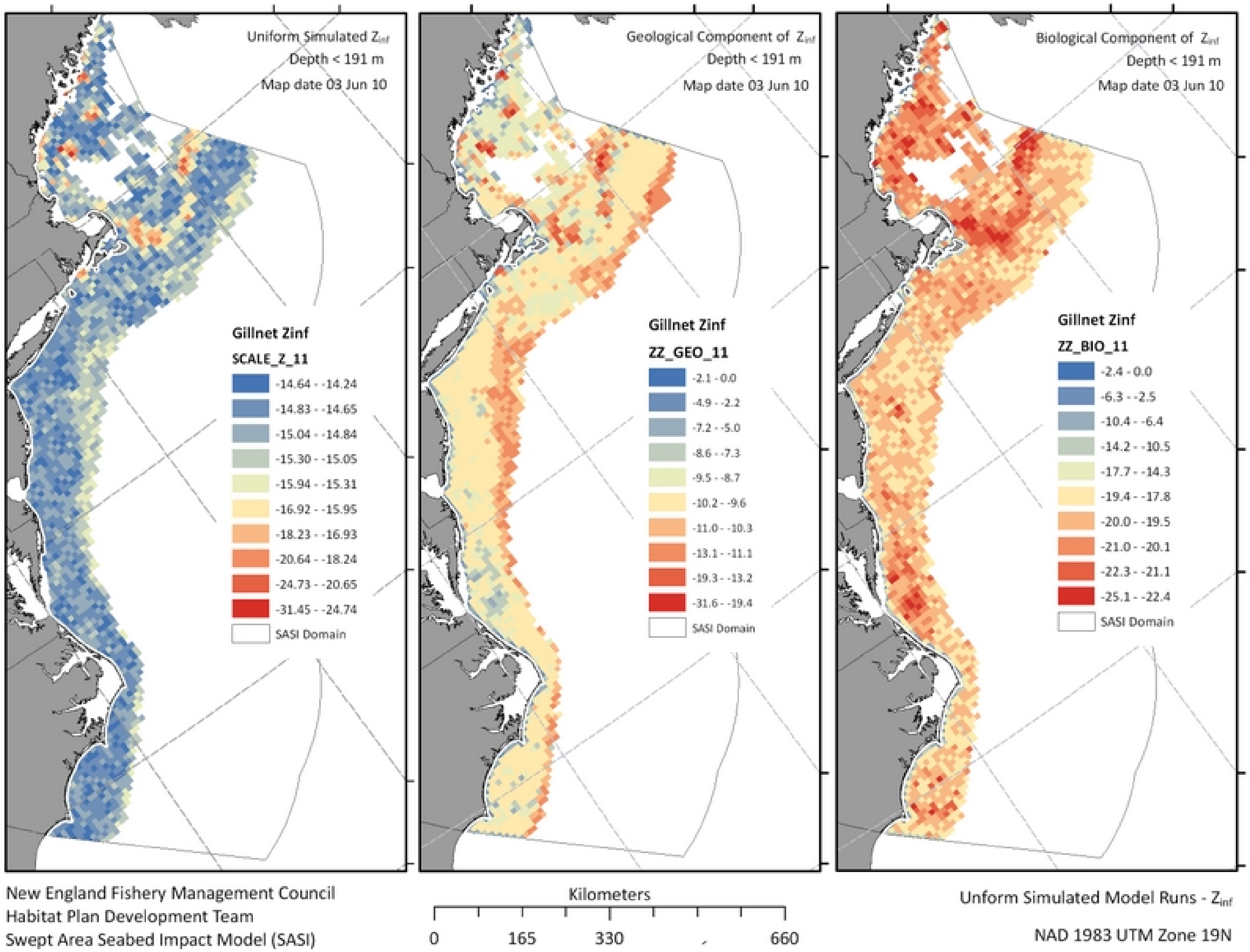
Map 17 – Simulation outputs (Z_∞) for hydraulic dredge gear.



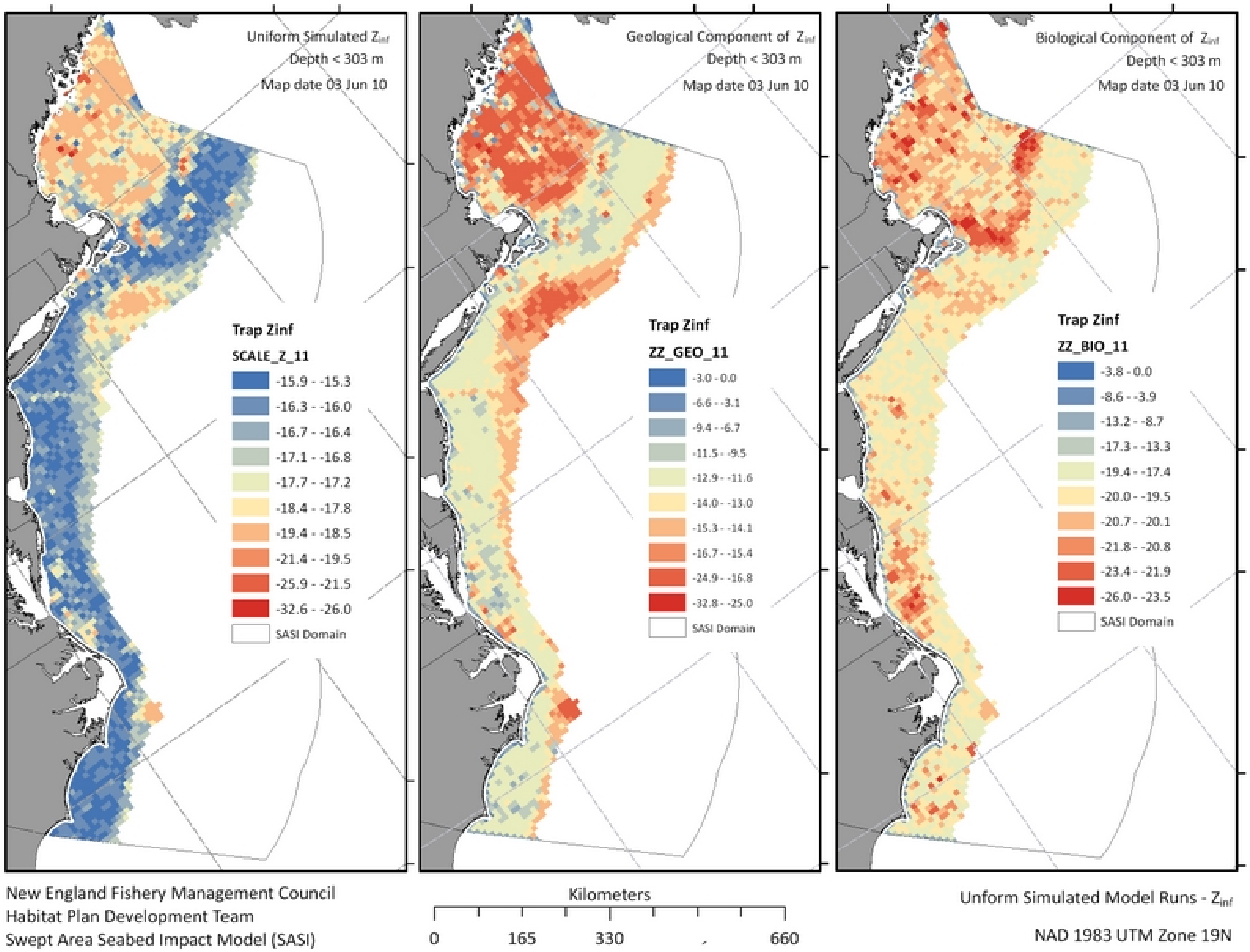
Map 18 – Simulation outputs (Z_∞) for longline gear.



Map 19 – Simulation outputs (Z_∞) for gillnet gear.



Map 20– Simulation outputs (Z∞) for trap gear.



8.3.2 Realized effort runs

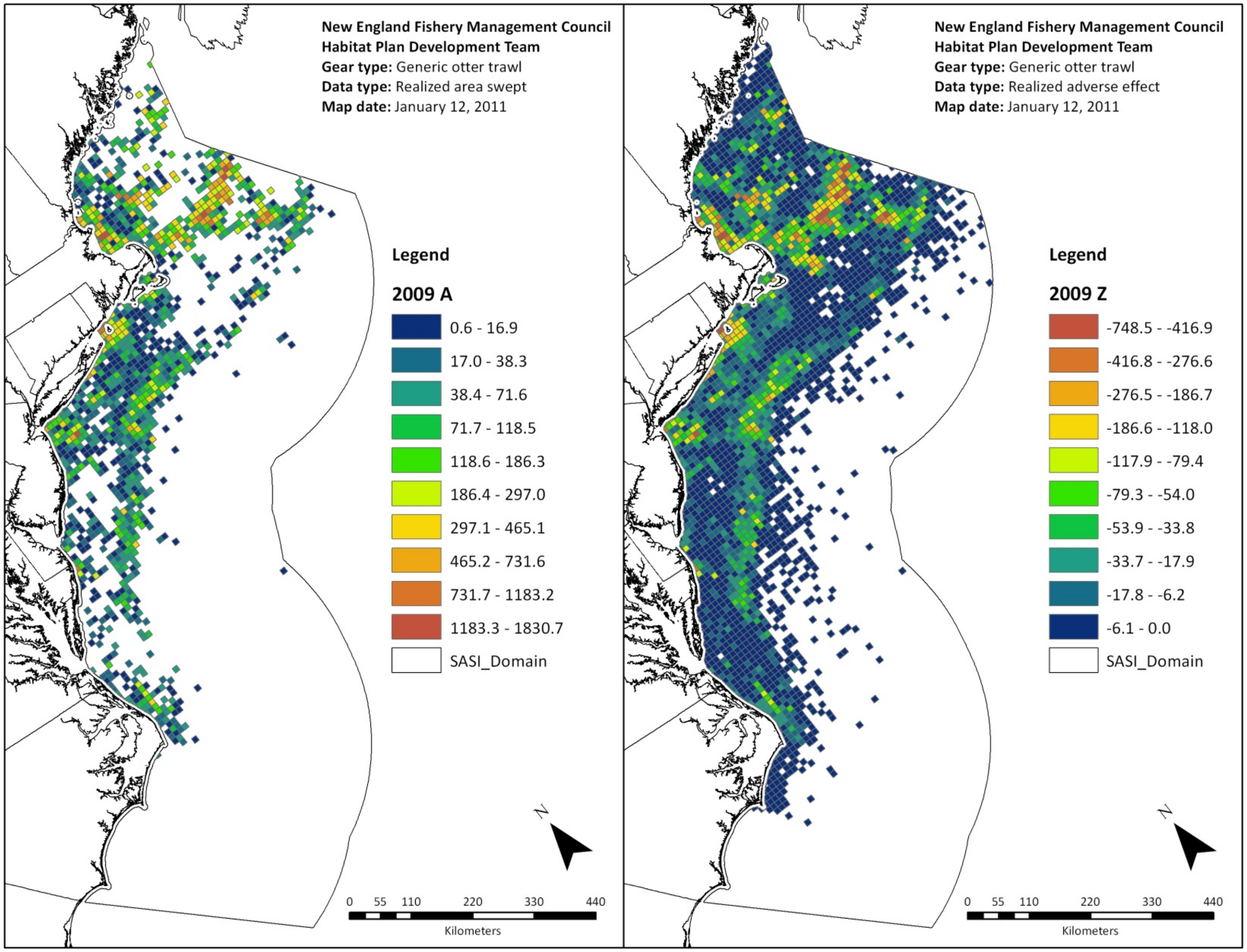
Realized model outputs use empirical estimates of contact-adjusted area swept (A) based on VTR data from 1996-2008, generated as described in section 6.0. They are intended to represent the actual impact of fishing on the seabed. The magnitude of the resulting adverse effect (Z) estimates can be compared between years and between gear types. Four trawl types and two scallop dredge types are decomposed for this analysis. The analysis is run on a calendar year basis, despite different fishing years for the various gear types/FMPs (e.g. May 1 – April 30 for Multispecies FMP, March 1 – February 28/29 for the Scallop FMP).

As with the simulation runs, the model runs continuously, with area swept added in annual time steps. However, realized outputs are mapped on an annual basis to show change over time. Unlike the simulation model, to ensure that the annual $Z_{realized}$ values in the first ten years after 1996 incorporate decaying adverse effect from each of the ten previous years, as applicable, a starting $Z_{realized}$ condition is required. In order to approximate these starting conditions, 1996 area swept data are used for each year from 1985 onward. The exception to this is the hydraulic dredge gear type, where year 2000 area swept data are used (data for this gear are only available from 2000 onward).

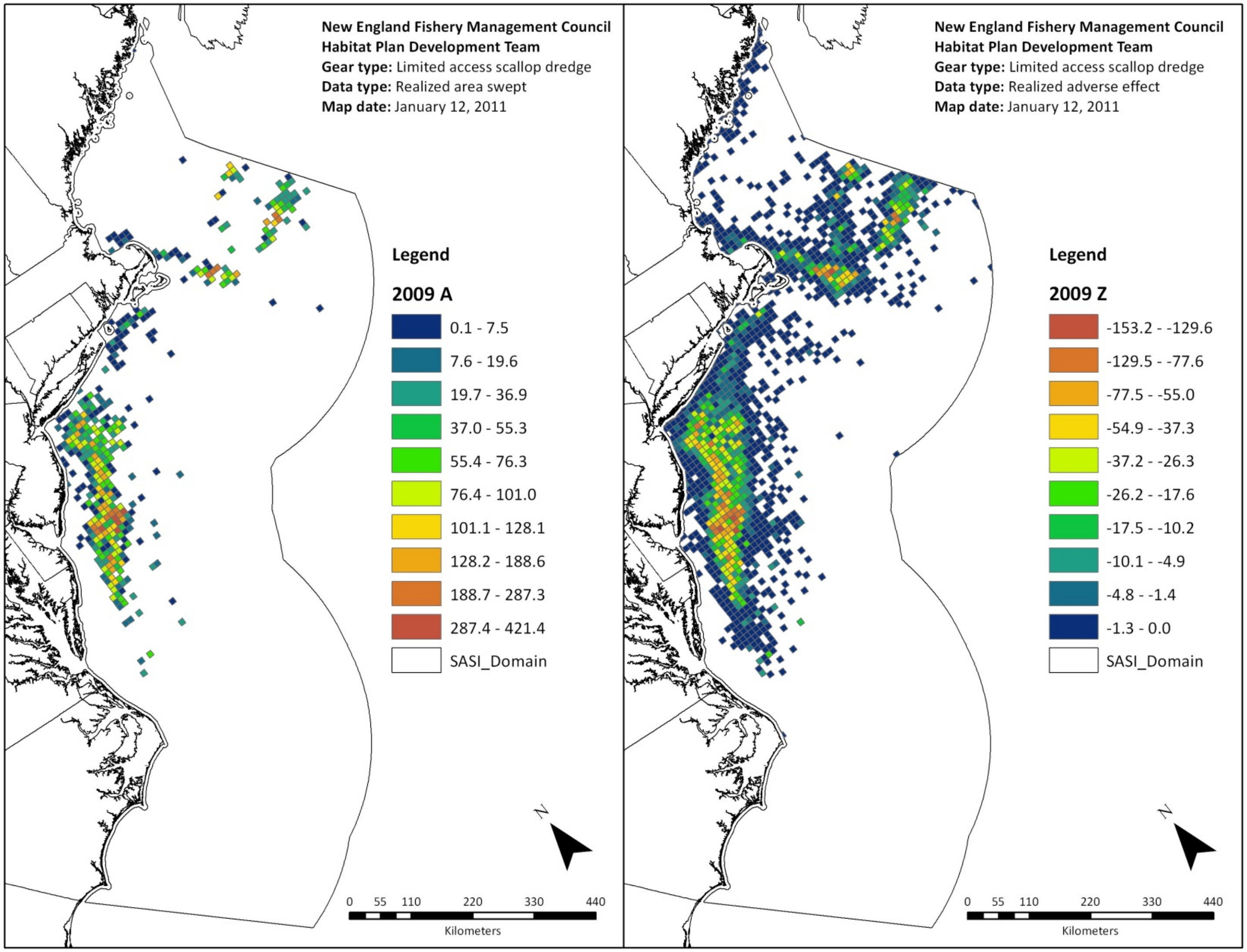
For the two gear types that account for the majority of fishing effort (generic otter trawl and limited access sea scallop), it appears likely that using 1996 data to represent the previous 10 years' adverse effect leads to underestimates of the magnitude of the starting adverse effect condition. For groundfish species, as well as for sea scallops, 1996 landings are much lower than the annual average for the previous ten years. However, this is not universally true: for some of the species that accounted for less fishing effort, including skates (harvested with generic otter trawl gear), as well as for squids, 1996 landings are higher than the previous ten years' averages. It is important to bear in mind that area swept does not have a direct relationship with landings, however: it depends partly on catch rate and partly on the magnitude of catches.

The following sample maps show realized area swept and adverse effect for selected gear types during selected years. Note that larger positive values of A indicate more fishing effort, but that because of the way the model equations are written, the more negative Z values indicate a greater magnitude of area swept.

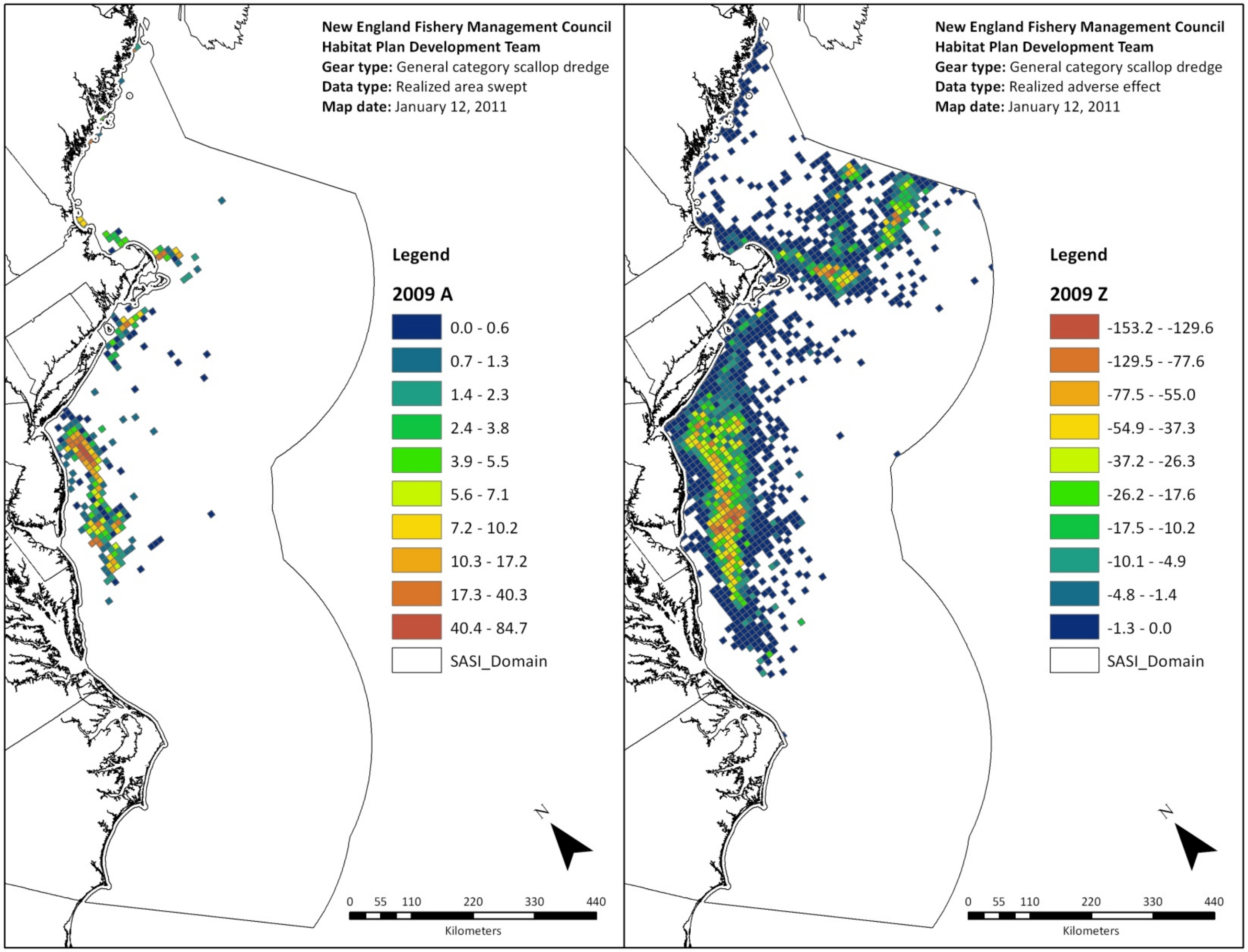
Map 21 – Generic otter trawl realized area swept and adverse effect for calendar year 2009.



Map 22 – Limited access scallop dredge realized adverse effect and area swept for calendar year 2009.



Map 23 – General category scallop dredge realized adverse effect and area swept for calendar year 2009.



8.4 Model assumptions and limitations

Any model is necessarily a simplification of reality, and should be interpreted with a full understanding of the underlying data sources and assumptions. In the absence of perfect information about fishing effort, substrate and feature distributions, and the nature of the interaction between fishing gears and seabed features, numerous simplifying assumptions are made during development of SASI. It is important to bear these assumptions in mind when using SASI for management applications.

The primary assumption of SASI is that area swept, when adjusted for gear contact with the seabed, is a proxy for seabed impact. Further, seabed impact as modified to account for the vulnerability of habitat features encountered is taken as a suitable proxy for the adverse effect of fishing on fish habitat.

This assumption relates closely to a limitation of the model, namely that **the analysis is unable to provide information about the relationship between habitat or seafloor features and fish production**. Seabed structural features, both geological and biological, are assumed to be components of the essential habitat required by various managed species. However, little information about the relationship between particular habitat features and fish or fishery productivity is available. In other words, the relative importance of these features to fish is not well known, nor is the relative abundance of structural features in the environment. Investigations of these critical relationships is suggested as a research priority.

Another assumption is that fishing does not have significant impacts on the water column. This assumption limited the scope of the SASI model. While EFH includes "both the waters and substrate necessary for spawning, breeding, feeding and growth to maturity", this analysis focuses exclusively on habitat features capable of providing shelter.

Certain assumptions relate to the area swept models. One is that, **within a tow, fishing gear impact is constant.** In particular, there is constant and unchanged impact along the entire length of a gear component and the impact of each gear component on fish habitat is cumulative. In the case of a demersal trawl, additional assumptions include, otter board angle of attack is constant, ground cables are straight along their entire length, and otter board and net spread are constant.

Other assumptions relate to the spatial data and parameter estimates. For example, we assumed **that habitats are homogeneous within unstructured grid cells, and between unstructured cells with the same substrate and energy.** This is despite the knowledge that the attributes of habitat mediating the distribution of individual fish within a habitat "type" are extremely patchy. In other words, there are fine-scale ecological interactions of species with their habitats that are not addressed in SASI. In addition, this implies a lack of regional and/or depth-based differences in the feature distributions associated with SASI habitat types, which is an obvious oversimplification of reality. Another assumption, which relates to the lack of information on the relationship between habitat features and fish production, **is that each of the geological and biological features should contribute equally to the modification of area swept and that, between them, the geological and biological components should contribute equally**.

Other assumptions relate to the way fishing effort is combined in the model. Foremost among these is the assumption that **fishing area swept is additive**. As the model runs over time, units of fishing area swept are continually added in annual time steps. This area swept decays based on the appropriate feature recovery values for that substrate and energy type.

This approach ignores two possibilities. One is that the first pass of a fishing gear in an area may have the greatest impact. A "first pass" hypothesis has been proposed but has not been verified empirically and is not universally accepted. Second, and conversely, that adverse effects from fishing may be greater once fishing effort levels reach a certain magnitude and the seabed state is altered such that later passes of the gear have a more deleterious effect—that fishing impacts have a non-linear concave effect on the functional value of habitats. Importantly, a conceptual model of fishing impacts on habitat developed by Auster (1998) illustrates a linear decline in physical attributes, consistent with SASI model assumptions, but also discusses the issues of threshold and feedback effects. He hypothesized that an alternative to the "first pass" scenario is one that approaches a linear, arithmetic decline based on increased rate of impacts with feedback loops to an earlier state due to recovery/recruitment and the physical processes that reset the clock to some earlier state. This alternative view is adopted here.

Certain limitations are the result of data availability. **A major limitation is that the spatial resolution of fishing effort data is generally poor.** For example, the primary type of fishing effort data used, vessel trip reports, have limited spatial information associated with them. The best case scenario is a trip report where the latitude/longitude coordinate given accurately corresponds to the average fishing location for the trip. Even in this instance, the locations of all tows are inferred to this single point. Using the 100 km^2 structured grid allows the SASI model to bridge between low resolution effort data and the more finely resolved unstructured substrate grid. However, in some cases, fishing effort can only reliably be inferred to statistical areas, which are much larger than the unstructured grid cells to which vulnerability estimates are inferred. If appropriate for a specific data set, larger (or smaller) structured grid cells could be used with the same unstructured substrate/energy grid. Spatial scale issues are further discussed in section 8.5.

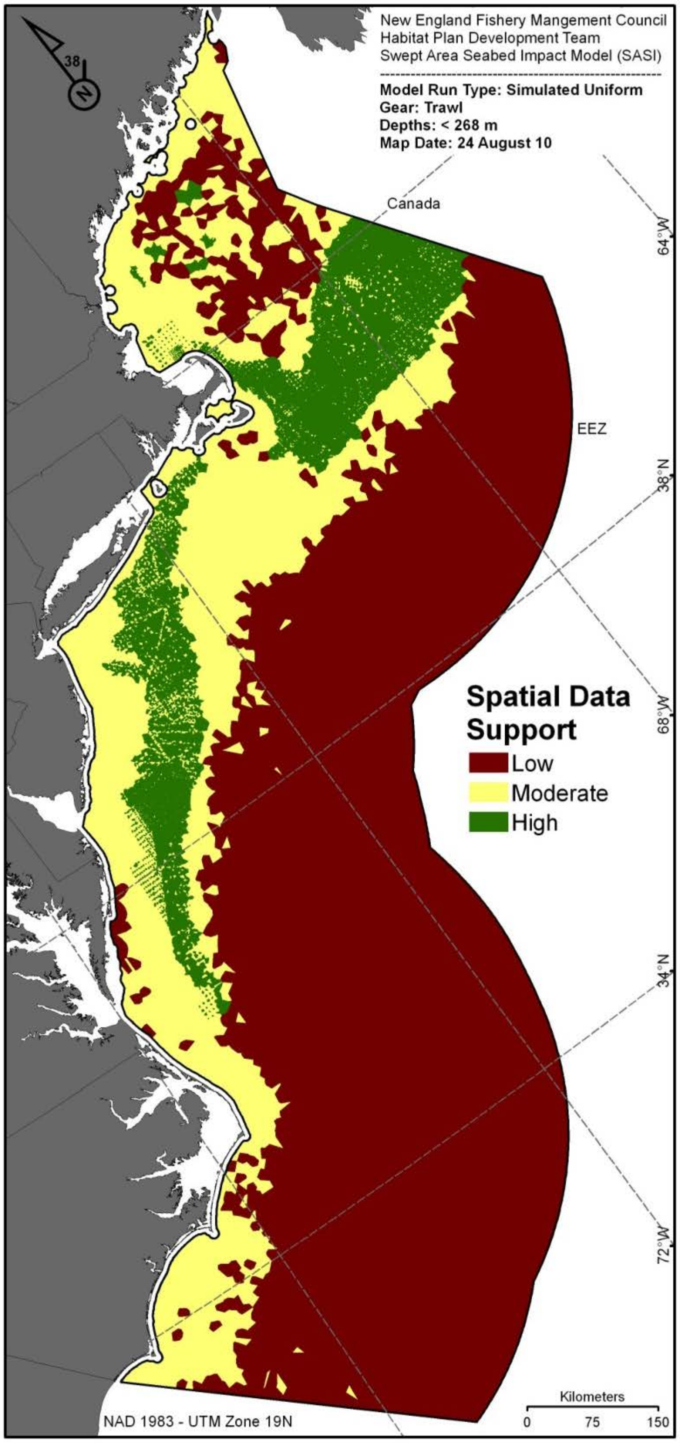
In addition, **the ability of the model to produce differential estimates of adverse effect between similar gear types is limited by the lack of information about gear configurations.** In particular, both the susceptibility values and the contact indices average between trawl tows that in reality represent a variety of sweep configurations. The configurations could range from large rockhoppers to small rollers, and it is likely that sweep configuration influences seabed impact. However, because data on sweep types are not available for all trips, and because the influence of different sweep types on susceptibility is not clearly demonstrated in the literature, the model does distinguish impacts between different types of sweeps, except to the extent that contact indices for shrimp, raised footrope, and squid trawls are specified individually. The influence of this limitation is mitigated by the fact that the sweep comprises only about 30% of the total effective linear width for most otter trawl gears. Going beyond trawl gear, there is substantial uncertainty associated with the various fixed gear model specifications, in terms of estimating both the contact patch and the movement of the gear across the seabed. Because mobile gear area swept and seabed impact dwarfs that for fixed gear, this has not been the subject of much research.

Another model limitation relates to the availability of substrate data. Fortunately, a strength of SASI is that the unstructured grid can be modified as data becomes available. **However, in the near term, information on substrate classes larger than granule-pebble is unavailable in deeper waters outside the domain of the SMAST video survey.** For example, spatial distributions of hard substrates in the canyon areas along the edge of the continental shelf are not well known, so these locations are not well resolved in the model grid. As a result, their vulnerability may not be accurately estimated. Higher resolution spatial data incorporating all five dominant substrates may exist for some deep-water areas, but they are not geographically comprehensive and would require substantial work to put in a useful format (P. Auster, pers. comm.). It might also be possible to infer presence of outcropped rocks and rafted boulders based on bathymetric data. In large part, these locations are currently coded as mud. If features in rock outcrops had higher vulnerability than features in mud, the SASI model will underestimate overall vulnerability. Map 24 is a visual representation of spatial data support.

In translating VA-derived S and R estimates into SASI, a uniform distribution of habitat features within their assigned dominate substrates is assumed. In the SASI model, individual feature S and R scores are used to modify small portions of area swept, and then the effects are summed across features, substrates, and energy regimes to generate impact estimates at the 100 km^2 grid cell level. Therefore, minimizing estimation error requires both the presence and relative abundance of features in the cell to be as reflective of actual distributions as possible. Unfortunately there is no comprehensive empirical data available to inform relative abundance estimates. An even weighting of features' scores is assumed. (An alternative approach might be to weight the relative abundance of features equal to the relative importance of those features to commercially targeted fish as habitat, but this is also, obviously, unknown.) Due to this equal weighting approach, the contribution of rare features to adverse effects are almost certainly overestimated. In addition, for those substrates that contained fewer features in a given feature class, the individual contribution of each feature is greater, and the subsequent potential for any individual feature to bias the result is higher. For example, the geological feature category for boulder substrates includes only two features - scattered boulders or piled boulders. In contrast, there are ten biological features inferred to boulder substrates, such that each feature's score has relatively less weight.

All features are assumed to have equal probabilities of encounter by fishing gears. Logically, however, some features are likely to be avoided during fishing operations, such as cobble and boulder piles that tend to snag nets. Thus, assuming that all features are equally at risk likely results in overestimating the vulnerability of these avoided features. Assigning the same biological feature scores across substrates and energies implies that the biological features consist of the same species in each substrate and energy level, even though they are, in reality, different. Research on the distribution of both biological and geological features and how the species composition and vulnerability of biological features differ as a function of these factors could be used to enhance future assessments. Since the distribution of features within a substrate and energy regime likely varies both on local and regional (as well as temporal/seasonal) scales, readers should be careful to avoid over interpreting the findings.

Map 24 - Spatial data support. High = full range of substrates detectable, high sampling frequency; Moderate = only mud- granule pebble detectable or low sampling frequency; Low = only mud- granule pebble detectable and low sampling frequency.



8.5 Spatial and temporal scale

It is critical to understand the spatial scale of the model and how this affects its application to fishery management decision making. Ecological studies should clearly define the components of sampling and analysis scales (Dungan et al., 2002). The scale of sampling includes three levels; the *grain* is the elementary sampling unit (most basic measurement scale), the *lag* is the distance or time between samples, and *extent* is the sampling domain (Dungan et al. 2002). Most importantly, no spatial or temporal structure can be detected that is smaller than the sampling grain or larger than the extent (Legendre and Legendre, 1998).

For example, the spatial sampling unit of the SMAST video survey is a 3.24 m^2 video quadrat but in this analysis quadrats are pooled by station so the spatial grain is 100 m^2, the total area in which quadrat sampling occurred at each station. The spatial lag, the average distance between stations, is 1 km, and the total spatial extent of the surveys is 70,000 km^2 (Table 65). Similarly, the temporal grain, the video recording time at each quadrat, is 0.25 – 0.5 minutes. The temporal lag, the time interval between stations, is 0.5 – 1 hours / 5 – 10 days, and the total temporal extent is 11 years (1999 - 2009). This is the only data source used in the SASI analysis which employed one sampling design throughout its temporal extent (11yrs). The usSEABED data were compiled from more than 50 different geological surveys so the temporal and spatial scales of sampling vary widely depending on the methods employed. Most samples (~80%) were collected with benthic grabs, so the sampling grain likely ranges from 0.1 to 0.5 m^2.

Table 65 – SASI inputs and output spatial scales

		Spatial Scale		
Input	**Data Source**	**Grain**	**Lag**	**Extent**
Geology	Video Survey	100 m^2	1 km	70,000 km^2
Geology	usSEABED	0.1 - 0.5 m^2	3.1 km	598,089 km^2
Geology	Combined	0.1 - 100 m^2	1.96 km	598,089 km^2
Energy	NOS Depth	1-10 m^2	0.35 km	598,089 km^2
Energy	FVCOM CSS	-	5.9 km	30,8976 km^2
Fishing	VTR, VMS	5 - 11,000 km^2	2 - 100 km	598,089 km^2
SASI output		**100 km^2**	**10 km**	**598,089 km^2**

Table 66 – SASI inputs and output temporal scales

		Temporal Scale		
Input	**Data Source**	**Grain**	**Lag**	**Extent**
Geology	Video Survey	seconds-minutes	hours -days	11 years
Geology	usSEABED	instant	hours - years	>50 years
Geology	Combined	-	hours - years	>50 years
Energy	NOS Depth	seconds-minutes	days	129 years
Energy	FVCOM CSS	seconds	minutes	10 years
Fishing	VTR, VMS	minutes - days	minutes - months	10 years

	Temporal Scale		
SASI output	**I year**	**1 year**	**25 years**

8.6 Sensitivity analyses

Given model formulation, it is not possible to construct confidence intervals or estimates of uncertainty around the adverse effects estimates generated by SASI. To evaluate the robustness of model outputs to certain assumptions/inputs, the SASI simulation model is tested for changes in the distribution of adverse effects when three model parameters are changed:

(1) the duration of recovery;
(2) the gear/substrate sensitivity and recovery values; and
(3) the contribution of geological and biological features to the total adverse effect

The methods and results for each sensitivity test are described in the following sections.

8.6.1 Model Sensitivity Test 1: Duration of Recovery

To test model sensitivity to the recovery time steps parameterized in the model, two potential sources of error are considered; specifically that the recovery durations parameterized in the model are either too short (test 1.1) or too long (test 1.2). Sensitivity is tested by changing parameters as follows:

Table 67 – Recovery sensitivity test 1.1 (extended recovery duration)

R	*Definition*	*Model Parameter*	*Sensitivity Definition*	*Sensitivity Parameter*
0	1 year	1	1 year	1
1	1-2 years	1 + round(ranuni(0))	2-3 years	2 + round(ranuni(0))
2	2-5 years	2 + round(3*(ranuni(0)))	3-20 years	3 + round(17*(ranuni(0)))
3	5-10 years	5 + round(5*(ranuni(0)))	20-50 years	20 + round(30*(ranuni(0)))

The left frame (below) shows the spatial distribution of adverse effect (Z_∞) binned by standard deviations from the mean value domain-wide for this sensitivity test. The highlighted areas represent roughly the top 3% of the distribution, or approximately 80-100 cells out of roughly 2,550 cells in the domain. The right frame (below) shows the spatial distribution of adverse effects under the base case scenario, as SASI is currently parameterized. Extending the duration of recovery time steps does not fundamentally alter the spatial distribution of modeled adverse effects. Areas accumulating adverse effects within the bin covered by Z_∞ values ranging between 1.5 and 2.5 standard deviations from the mean tended to expand around central core clusters with the longer time steps, and a few isolated grid cells are elevated, particularly in the Gulf of Maine. While trawl gear is the only model output shown here, this conclusion holds across gear types.

Map 25 – Recovery sensitivity test 1.1 (extended recovery duration)

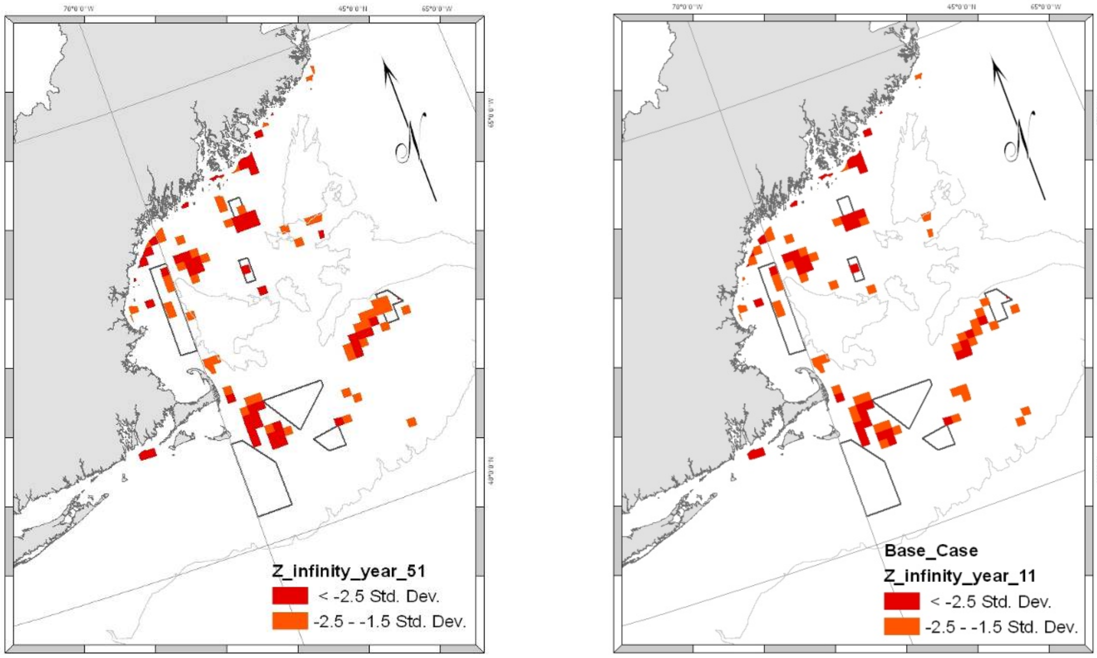


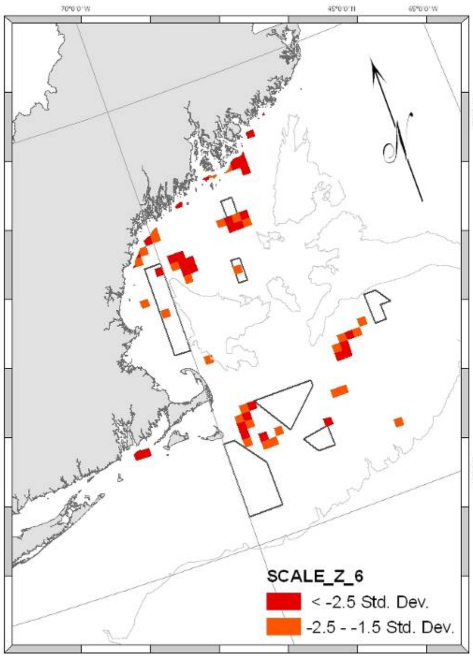
Table 68 – Recovery sensitivity test 1.2 (compressed recovery duration)

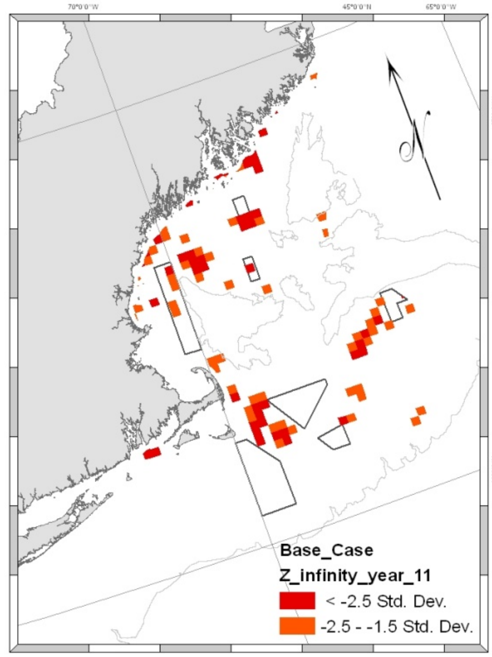
R	*Definition*	*Model Parameter*	*Sensitivity Test Definition*	*Sensitivity Test Parameter*
0	1 year	1	1 year	1
1	1-2 years	1 + round(ranuni(0))	1 year	1
2	2-5 years	2 + round(3*(ranuni(0)))	1-2 years	1 + round(1*(ranuni(0)))
3	5-10 years	5 + round(5*(ranuni(0)))	2-5 years	2 + round(3*(ranuni(0)))

The left frame (below) shows the spatial distribution of adverse effect (Z_∞) binned by standard deviations from the mean value domain-wide for this sensitivity test. The highlighted areas represent roughly the top 3% of the distribution, or approximately 80-100 cells out of roughly 2,550 cells in the domain. The right frame (below) shows the spatial distribution of adverse effects under the base case scenario, as SASI is currently parameterized.

Compressing the recovery durations does not fundamentally alter the spatial distribution of modeled adverse effects. Areas accumulating adverse effects within the bin covered by Z_∞ values ranging between 1.5 and 2.5 standard deviations from the mean tended to contract around central core clusters with the shorter time steps, and a few isolated grid cells dropped out of this bin, particularly on Georges Bank. While trawl gear is the only model output shown here, this conclusion holds across gear types.

Map 26 – Recovery sensitivity test 1.2 (compressed recovery duration)





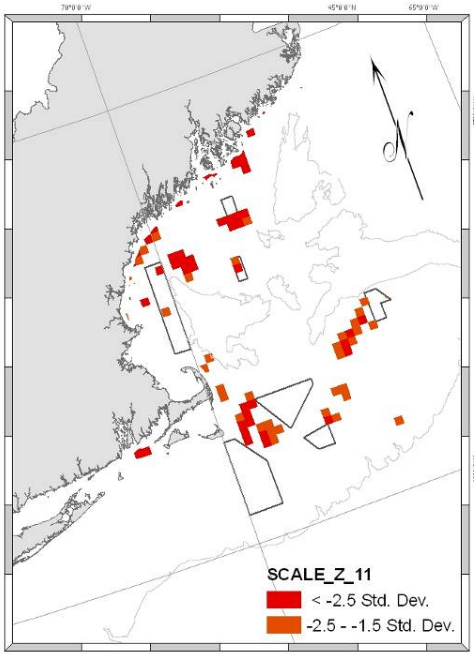
8.6.2 Model Sensitivity Test 2: Susceptibility and Recovery Scoring

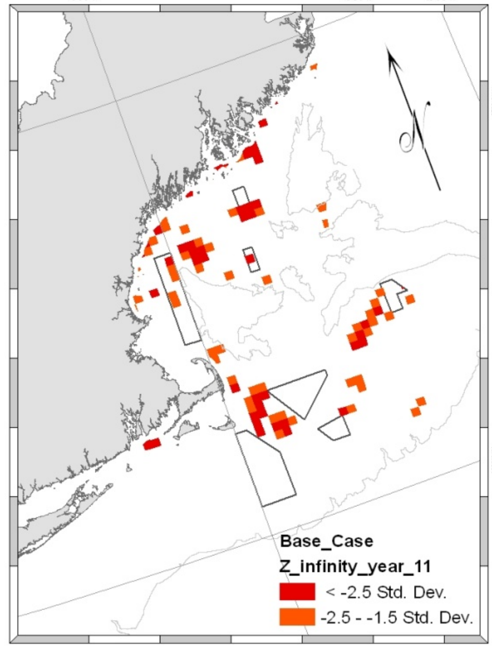
The PDT notes that the most difficult interpretations of the published gear effects literature came when estimating susceptibility and recovery scores at the outer extremes of the zero, one, two and three scale. To test model sensitivity to these parameters, the team conducted model runs after converting all one (1) scores for both sensitivity and recovery to scores of zero (0) (test 2.1), and again after converting all scores of two (2) to scores of three (3) (test 2.2).

The left frame in Map 27 shows the spatial distribution of adverse effect (Z_∞) binned by standard deviations from the mean value domain-wide for the sensitivity test which set all (1) scores to (0). The highlighted areas represent roughly the top 3% of the distribution, or approximately 80-100 cells out of roughly 2,550 cells in the domain. The right frame (below) shows the spatial distribution of adverse effects under the base case scenario, as SASI is currently parameterized.

Shifting the parameter value for all features coded 1 to a code of 0 reduces slightly the number of cells that fall into the bins greater than 1.5 standard deviations from the mean adverse effect value. The fundamental distribution and clustering of areas likely to accumulate adverse effects is relatively unchanged. While trawl gear is the only model output shown here, this conclusion holds across gear types.

Map 27 – Susceptibilty and recovery sensitivity test 2.1 (under-utilization of lowest scoring category)





The top left frame in Map 28 shows the spatial distribution of adverse effect (Z_∞) for trawl gear, binned by standard deviations from the mean value domain-wide, for the sensitivity test which converted all (2) scores to (3). The highlighted areas represent roughly the top 3% of the distribution, or approximately 80-100 cells out of roughly 2,550 cells in the domain. The top right frame in Map 28 shows the spatial distribution of adverse effects under the base case scenario, as SASI is currently parameterized.

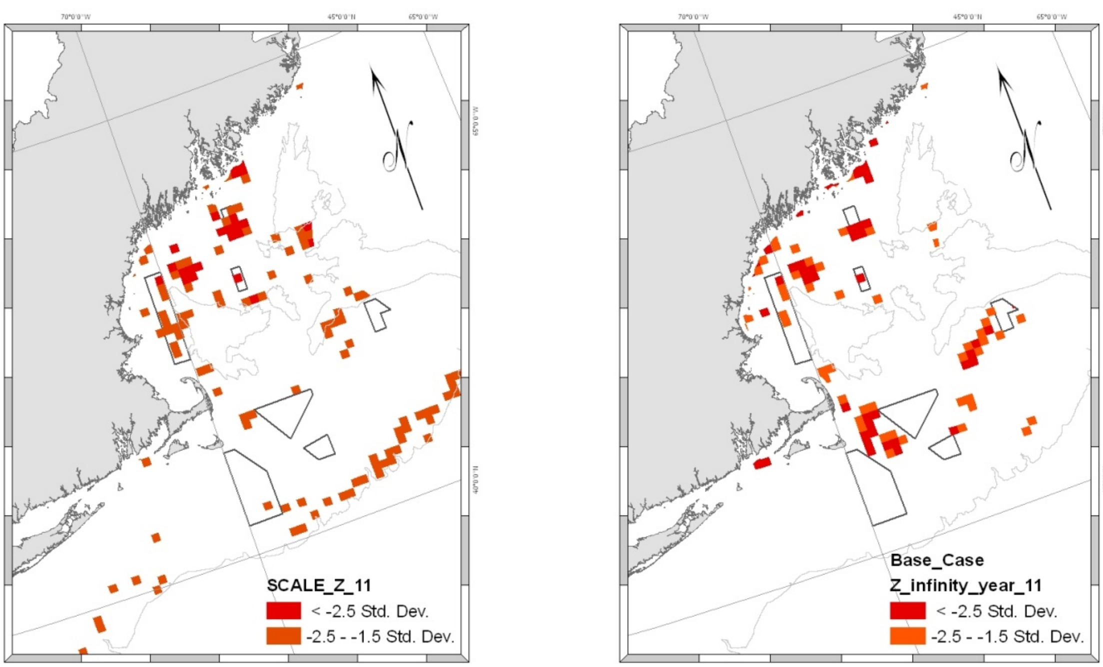
Shifting the parameter value for all features coded 2 to a code of 3 has a significant impact on the distribution of estimated adverse effects for trawl and scallop dredge gears (trawl gear shown in figure), shifting high adverse effect areas from the northern flank of Georges Bank to the edge of the continental shelf and a deepwater area just north of Georges Bank. Adverse effect accumulation in the Gulf of Maine remains similar to the base case.

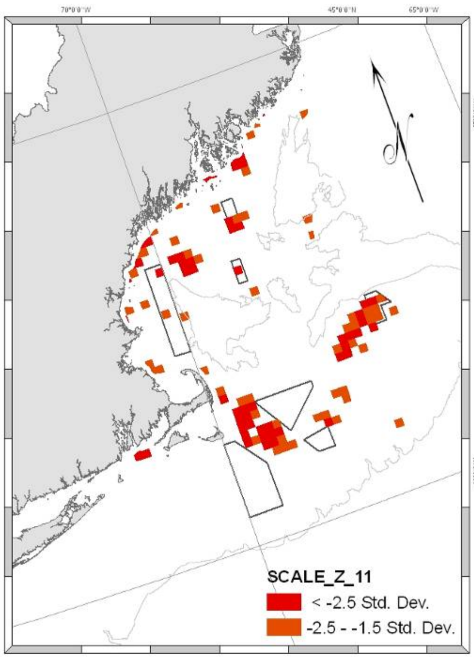
For these two gears, there are 116 individual class/feature/energy/substrate combinations evaluated in the model. Of these, only 14 are evaluated with a score of 3 for either susceptibility or recovery, while 85 are evaluated with a score of two or higher, resulting in a six-fold increase in the maximum values assigned in the matrix. The change in distribution of adverse effects that results from this six-fold increase in maximum-value scores is dominated by biological habitat components.

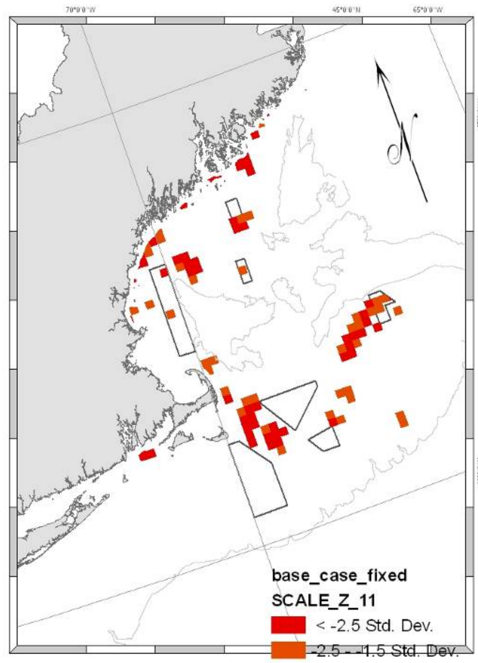
This sensitivity model run changes values for 71 features in total. Fifteen (15) of these are geological habitat features with high recovery rates—their mean recovery score is less than 1 (0.4). Fifty six (56) biological habitat components have their scores increased, and the mean recovery score for these features is 1.9. The features are roughly evenly distributed amongst the five dominant substrate categories, but low energy features see the greatest change in susceptibility and recovery values. All of this implies that the primary driver in the change in the distribution of areas estimated to have high adverse effects under the sensitivity model test is the relatively long recovery duration for biological features in low energy habitats.

Unlike other sensitivity model tests performed by the PDT, the SASI model is much more sensitive to extreme S and R values for trawl and scallop dredge gears than hydraulic dredge and static gears. For hydraulic clam dredge gears, this is due to the fact that very few features are evaluated with a sensitivity score of two (most features for this gear type are evaluated with either a three or zero). Twenty seven (27) features do have their recovery score increased from a two to a three under this test, but this serves only to compound the adverse effects in areas already estimated to have high values. For static gears, the lack of sensitivity to this assumption results because the static gears have zero features coded with a two or higher for susceptibility and only 26 of 102 features similarly coded for recovery. Similar to the hydraulic clam dredge case, the net effect of this is to compound the degree of adverse effect in locations already estimated to be high. The spatial distribution of high adverse effect accumulation areas therefore changes imperceptibly for these gears. The bottom left frame on Map 28shows the sensitivity model output for gillnet and longline gear, while the bottom right frame on Map 28 shows the base case model output for these gears.

Map 28 – Susceptibilty and recovery sensitivity test 2.2 (under-utilization of highest scoring category), trawl gear, top panels, gillnet and longline gear, bottom panels.





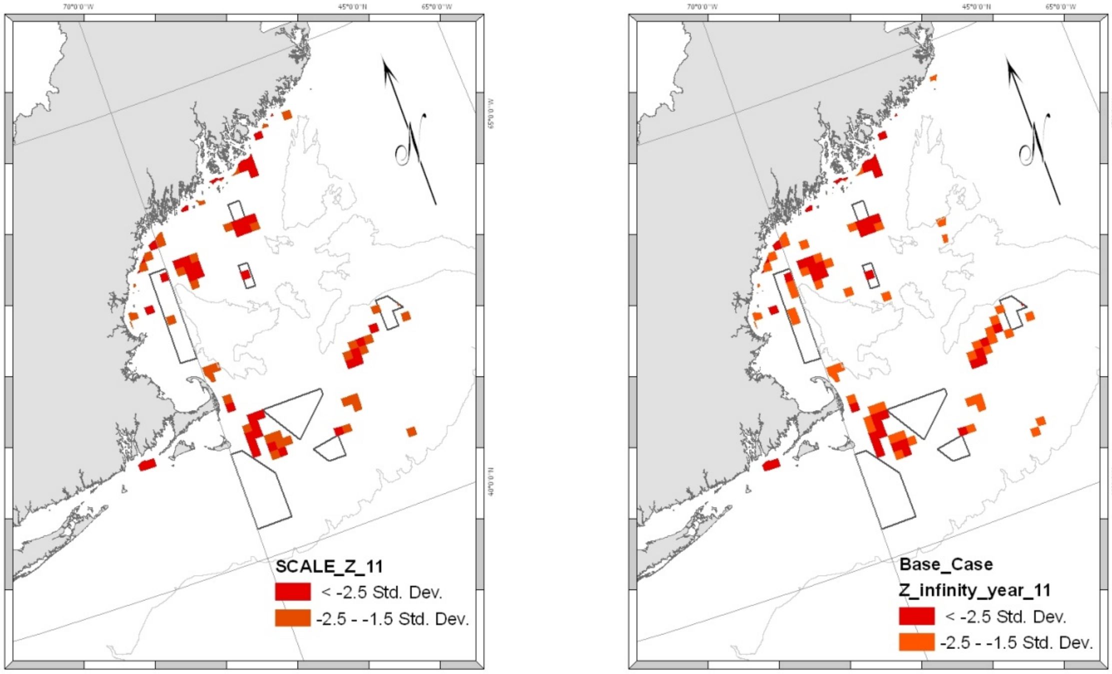


8.6.3 Model Sensitivity Test 3: Geological and Biological Feature Weighting

Absent empirical data on the relative abundance of the various features assigned sensitivity and recovery scores in the vulnerability assessment, the PDT assumed that features specific to these two components of structural habitat would be weighted equally, and therefore contribute equally to the resulting estimated adverse effect. The PDT tested the sensitivity of the model to this equal-weighting assumption by re-weighting in favor of geological habitat features and biological habitat features. Specifically, the sensitivity models altered the weighting from 50/50 (equal weighting) to 90/10 (highly skewed). Test 3.1 skewed the weighting in favor of geological habitat features, and test 3.2 skewed the weighting in favor of biological habitat features.

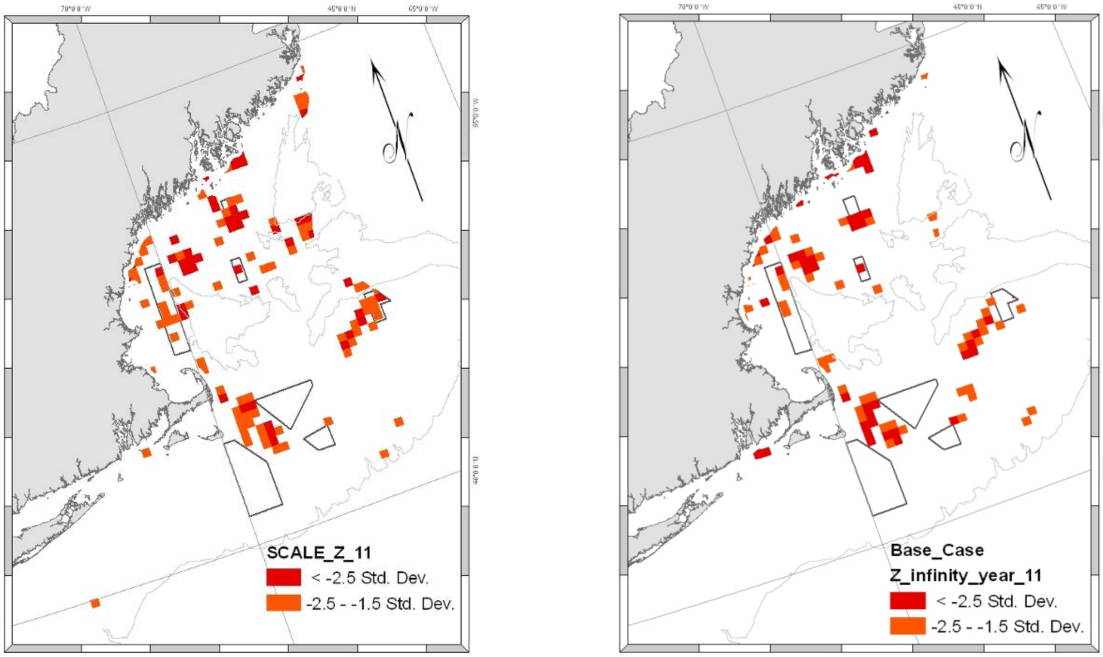
The left frame of Map 29 shows the spatial distribution of adverse effect (Z_∞) binned by standard deviations from the mean value domain-wide for this sensitivity test. The highlighted areas represent roughly the top 3% of the distribution, or approximately 80-100 cells out of roughly 2,550 cells in the domain. The right frame of Map 29 shows the spatial distribution of adverse effects under the base case scenario, as SASI is currently parameterized. Skewing the feature weighting in favor of geological habitat components reduces slightly the number of cells that fall into the bins greater than 1.5 standard deviations from the mean adverse effect value. Isolated cells in the Gulf of Maine also fall out of these bins in the distribution. The fundamental distribution and clustering of areas likely to accumulate adverse effects is relatively unchanged. While trawl gear is the only model output shown here, this conclusion holds across gear types.

Map 29 – Feature weighting sensitivity test 3.1 results (trawl gear shown)



The left frame of Map 30 shows the spatial distribution of adverse effect (Z_∞) binned by standard deviations from the mean value domain-wide for this sensitivity test. The highlighted areas represent roughly the top 3% of the distribution, or approximately 80-100 cells out of roughly 2,550 cells in the domain. The right frame of Map 30 shows the spatial distribution of adverse effects under the base case scenario, as SASI is currently parameterized.

Map 30 – Feature weighting sensitivity test 3.2 results (trawl gear shown)



Skewing the feature weighting in favor of biological habitat components increases the number of cells that fall into the bin between 1.5 and 2.5 standard deviations from the mean adverse effect value. Spatially, many of these additional cells expand smaller clusters of high adverse effect areas in the Gulf of Maine that are not necessarily highlighted in other model runs or in the base case. This implies that, conditioned on all other assumptions in the SASI model, if biological components of structural habitat are on the order of nine times more susceptible to the adverse effects from fishing on habitat, adverse effects in a few areas in the Gulf of Maine may be underrepresented in the base case model. In particular, the center of the Western Gulf of Maine closed area and the offshore portions of the Gulf are highlighted. The PDT notes that substrate sampling in the deepwater portions of the Gulf of Maine is significantly less dense than in other areas of the domain, and that a few isolated samples of granule/pebble are likely influencing the results in these areas. The area in the center of the Western Gulf of Maine, however, is well sampled. The PDT notes that this is most likely area where the model may underestimate adverse effects if indeed the sensitivity assumption of biology-skewed feature weighting is more correct than the SASI assumption of equal weighting. While trawl gear is the only model output shown here, this conclusion holds across gear types.

8.6.4 Conclusions

The SASI model appears to be robust to all three classes of model assumption with one exception. When SASI is run with a re-coded matrix where all scores of 2 are coded as 3, areas of high adverse effects for trawl and scallop dredge gears shift somewhat from Georges Bank to the outer continental shelf. The Gulf of Maine is relatively unaffected, as are hydraulic clam dredge and static gears. Extended recovery durations for biological features in low energy areas may explain the shift. Because this sensitivity model re-codes nearly half of the features evaluated for trawl and scallop dredge gears, it is unsurprising that some change in the spatial distribution of high adverse effects results. <u>Overall, the model appears highly robust to the primary assumptions underlying the vulnerability assessment, matrix values and the relative contribution of geological and biological habitat components to the estimated adverse effects from fishing gears on structure-forming habitat.</u>

9.0 Spatial analyses

9.1 Objectives

The objectives of the SASI Spatial Analysis are to (1) explore the spatial structure of the asymptotic area swept (Z_∞), (2) define clusters of high and low Z_∞ for each gear type, (3) determine the levels of Z_∞ in present and candidate management areas relative to the model domain, and (4) identify the areas of equal size with Z_∞ values similar to or higher than the tested areas. Objectives 1 and 2 are addressed using Local Indicators of Spatial Association (LISA) statistics, while objectives 3 and 4 are addressed using an Equal Area Permutation (EAP) approach.

9.2 Z_∞ spatial structure and clusters (LISA)

The Local Indicators of Spatial Association (LISA) statistics developed by Anselin (1995) are designed to test individual sites for membership in clusters. These tools differ from commonly used global statistics such as Moran's *I*, Geary's *c*, and Matheron's variogram, which are designed to describe the general autocorrelation characteristics of a pattern. Cressie's (1993) "pocket plot" can identify outliers, but does not provide a formal test of significance. Variograms can dissect patterns into their directional components, but are not designed for single spatial foci as are local statistics.

9.2.1 Methods

LISA statistics including Moran Scatterplots and Local Moran's *I* are used to explore the spatial structure of Z_∞ and to determine if each SASI grid cell is a member of a high or low Z_∞ accumulation cluster. The LISA analysis for each SASI grid cell (1) indicates the extent of significant spatial clustering of similar values around that cell, and (2) the sum of LISAs for all cells is proportional to a global indictor of spatial association (Anselin 1995).

For exploratory spatial data analysis, Global Moran's *I* is used to determine the general level of spatial autocorrelation in the data. *I* is an index of linear association between a set of spatial observations x_i x_j, and a weighted average w_{ij} of their neighbors (Moran 1950):

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j} x_i x_j}{\sum_{i=1}^{n} x_i^2} , \qquad (1)$$

where $x_i = z_{\infty i} - \overline{Z_\infty}$, $z_{\infty i}$ is the asymptotic area swept accumulated in cell i, and $\bar{X}$ is the overall mean asymptotic area swept accumulated in the entire model domain. The neighborhood weights, $w_{i,j}$, are determined using Queen Contiguity, also known as the 8-neighbor rule (Fortin and Dale 2005). Moran's $I > 0$ indicates that the Z_∞ values in the model domain are positively autocorrelated, while $I < 0$ indicates negative autocorrelation. When $I = 0$ the values are spatially random.

The spatial association of each cell with its neighbors is estimated with the Local Moran's I_i (Anselin 1995):

$$I_i = \frac{x_i}{Q_i^2} \sum_{j=1, j \neq i}^{n} w_{i,j} x_i \ , \qquad (2)$$

where

$$Q_i^2 = \frac{\sum_{j=1, j \neq i}^{n} w_{i,j}}{n-1} - \overline{X}^2 . \qquad (3)$$

When $I_i > 0$ there is positive local autocorrelation, i.e., the cell is in a neighborhood of cells with similar characteristics, but which deviate (positively or negatively) from the overall mean cell characteristics $\overline{X}^2 (= \overline{Z_\infty})$. Negative autocorrelation ($I_i < 0$) occurs when the cell is in a neighborhood with dissimilar z_∞ characteristics. When $I_i = 0$, the cell is in a neighborhood with random characteristics, or when the cell and its neighbors have characteristics equal to the overall mean (Boots 2002).

A Moran scatterplot is a bivariate plot of w_i as a function of x_i, and the slope of a line fit to the scatterplot gives global Moran's I (Anselin 1996). The four quadrants of the scatterplot indicate an observation's value relative to its neighbors with cluster significance defined by the p-values associated with each cell's I_i. Cells with higher than average values ($x_i > 0$) with neighboring high values ($w_i > 0$) are in the High-High quadrant, and together with those in the Low-Low ($x_i < 0$, $w_i < 0$) quadrant indicate positive local spatial autocorrelation. The High-Low and Low-High quadrants indicate negative local spatial autocorrelation. Because the objective of this spatial analysis is to identify clusters of high Z_∞, the High-High (H-H) and High-Low (H-L) clusters are mapped.

Local spatial statistics are particularly susceptible to Type I errors when the data are globally autocorrelated because multiple comparisons are being made among many values, some of which are clearly not independent (Ord and Getis 2001, Boots 2002). Ord and Getis (2001) state "if tests are applied without regard to global autocorrelation structure, Type I errors may abound. That is, locations are identified as hot spots simply because they lie in areas of generally high (or low) values." Applying typical multiple comparison corrections (e.g. Sidak or Bonferonni) to the 2,600 cells compared in the SASI model domain results in extreme criteria for significance (i.e., $p < 1 \times 10\text{-}6$). However, not all samples in the data set are correlated to all others so these corrections are far too conservative (Boots 2002). When global autocorrelation is evident ($I \neq 0$) Ord and Getis (2001) suggest using the significance tests in "informal search procedures rather than formal bases for inference". Therefore, a range of p-values ($p \leq 0.1$, 0.05, and 0.01) are examined as the criteria for systematically defining clusters of Z_∞. Global autocorrelation in Z_∞ values influences these tests.

9.2.2 Results

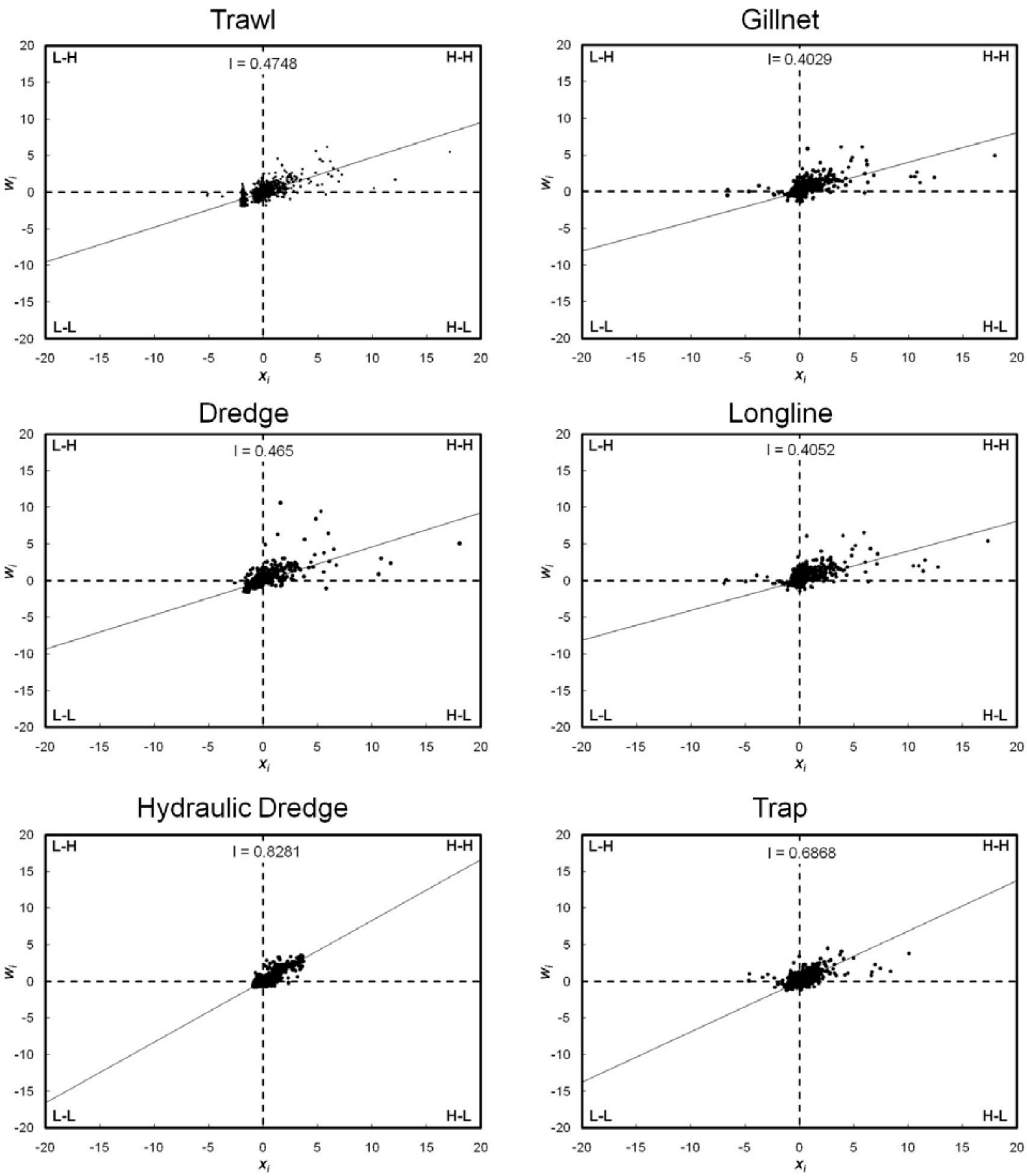
Asymptotic area swept (Z_∞) for all gear types demonstrated strong global spatial autocorrelation ($I > 0$, $p \leq 0.0001$, Table 1).

Table 69 - Global Morans *I* statistic and p-value for each gear type.

Gear	***Global Morans* I**	**p**
Trawl	0.4748	≤0.0001
Dredge	0.4650	≤0.0001
H. Dredge	0.8281	≤0.0001
Gillnet	0.4029	≤0.0001
Longline	0.4052	≤0.0001
Trap	0.6868	≤0.0001

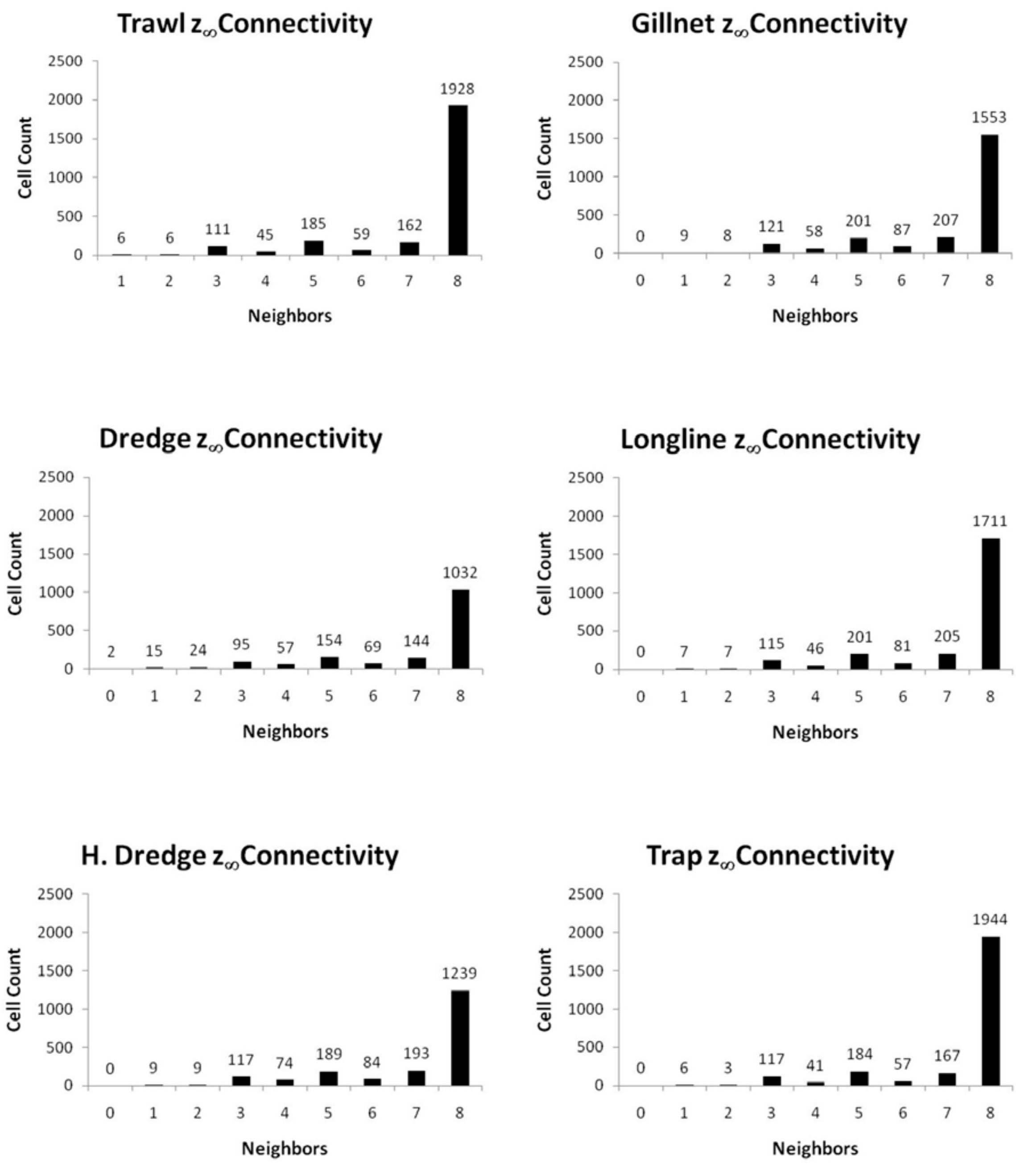
The Moran scatterplots show the degree of global spatial autocorrelation for each gear type and identify the quadrant location of every cell and neighborhood in the domain (Figure 19).

Figure 19 – Moran scatterplots for each gear type.



The different gear-specific depth limits used in SASI result in different connectivity between cells in the model (i.e. more or less edge). Reduced connectively (fewer neighbors) impacts cluster identification. The distribution of connections is similar between gear types and in all cases more than 60% of cells had 8 neighbors and 90% had at least 4 neighbors indicating that cluster identification is consistent between gear types (Figure 20).

Figure 20 – Connectivity histograms show the number of cells by number of neighbors for each gear type



The LISA analysis delimited clusters of high and low Z_∞ for all gear types at the $p \le 0.1$, 0.05 and 0.01 levels. Using $p \le 0.1$ criteria results in clusters which are nearly identical to $p \le 0.05$ (11 additional cells, see Map 31) so only $p \le 0.05$ and 0.01 results are presented in Map 32 and Map 33. Regardless of gear type, most of the cells in the model did not form significant clusters (Map 32). Where clustering occurrs, between 85 and 99% of cells are in Low-Low or High-High clusters consistent with strong spatial autocorrelation. Outliers (High-Low and Low-High) are rare. There are seven clusters identified for both trawls and scallop dredges which are larger than 300 km². These clusters correspond to named features (Table 70 and Table 71).

Table 70 – The name, mean z∞, sum z∞, and the area of each p ≤ 0.01 cluster greater than 300 km² identified for Trawl gear.

Trawl *p* ≤ 0.01

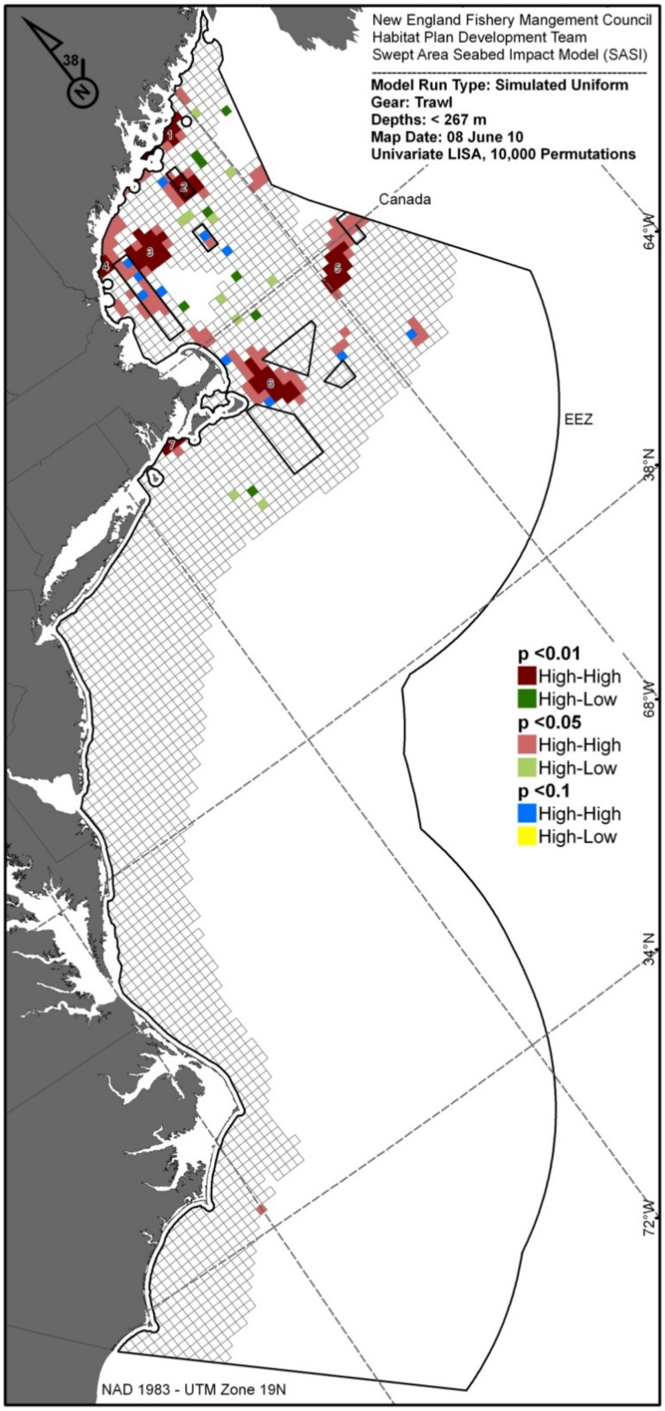
Number	Name	Mean z∞	Sum z∞	km²
1	South of Mt Desert Island Cluster	67.828	474.797	470
2	Jeffrey's Bank Cluster	60.898	487.185	800
3	Platts Bank Cluster	57.369	917.911	1600
4	Cape Neddick Cluster	51.416	154.247	283
5	Georges Shoal Cluster	57.404	746.251	1300
6	Great South Channel Cluster	55.580	833.696	1500
7	Brown's Ledge Cluster	55.785	223.138	273

Table 71 – The name, mean z∞, sum z∞, and the area of each p ≤ 0.01 cluster greater than 300 km² identified for Dredge gear.

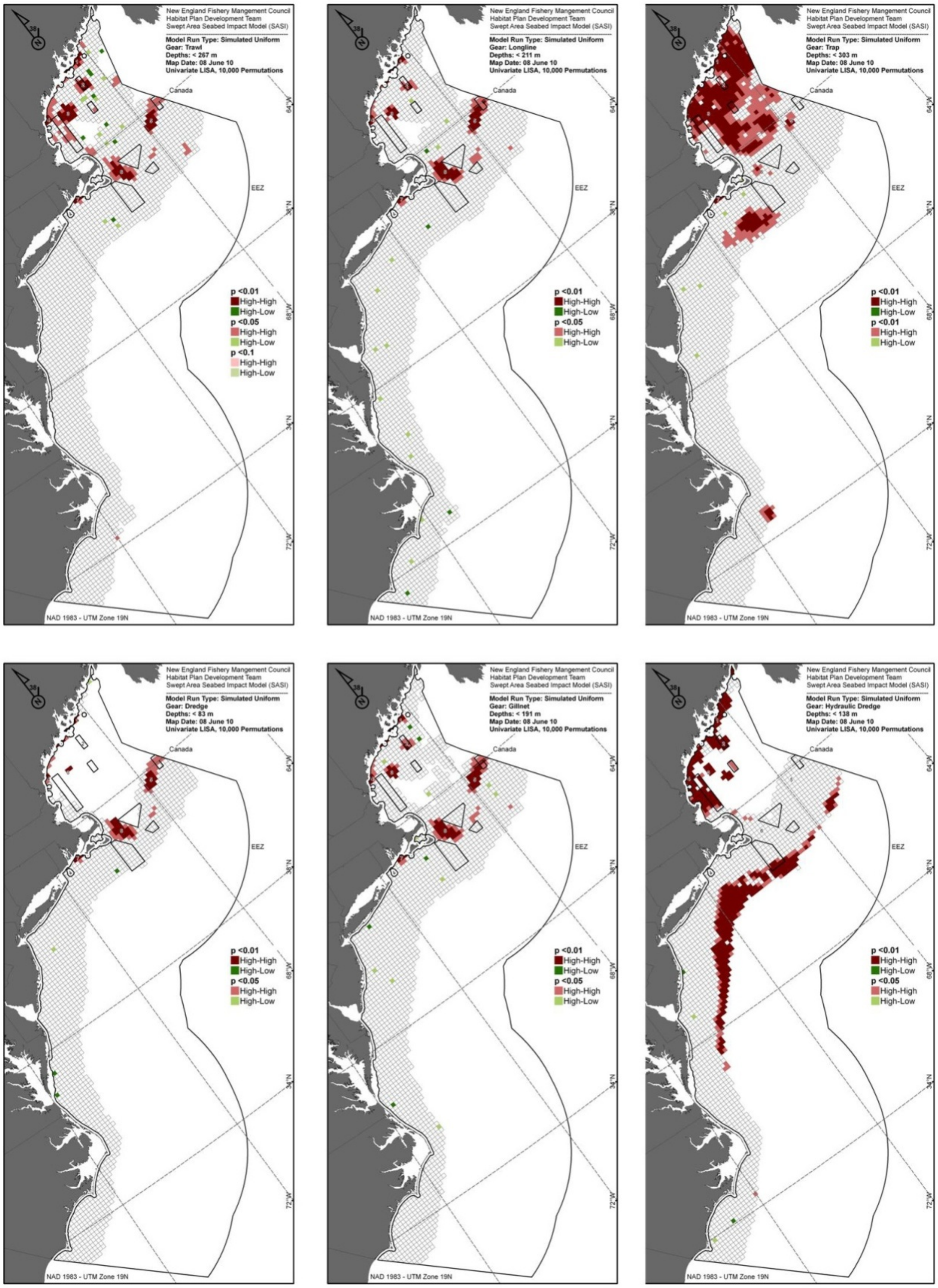
Dredge *p* ≤ 0.01

Cluster	Name	Mean z∞	Sum z∞	km²
1	South of Mt Desert Island Cluster	77.805	311.222	182
2	Jeffrey's Bank Cluster	-	-	-
3	Platts Bank Cluster	68.593	137.186	200
4	Cape Neddick Cluster	58.058	58.058	87
5	Georges Shoal Cluster	59.805	717.656	1200
6	Great South Channel Cluster	58.432	934.908	1600
7	Brown's Ledge Cluster	58.155	232.621	273

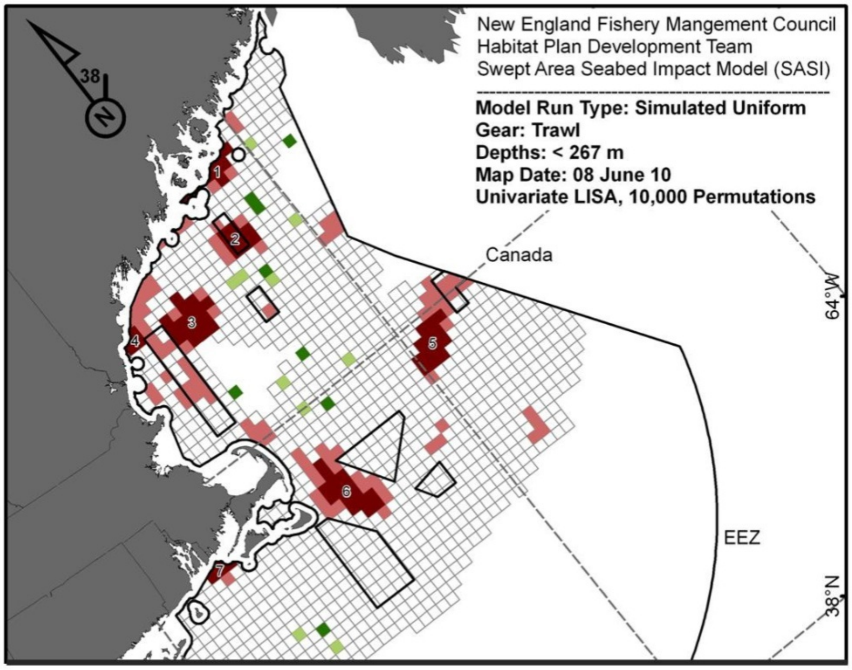
Map 31 – Maps of Z∞ H-H and H-L clusters defined by *p* ≤ 0.1, 0.05 and 0.01 levels for otter trawl gear.

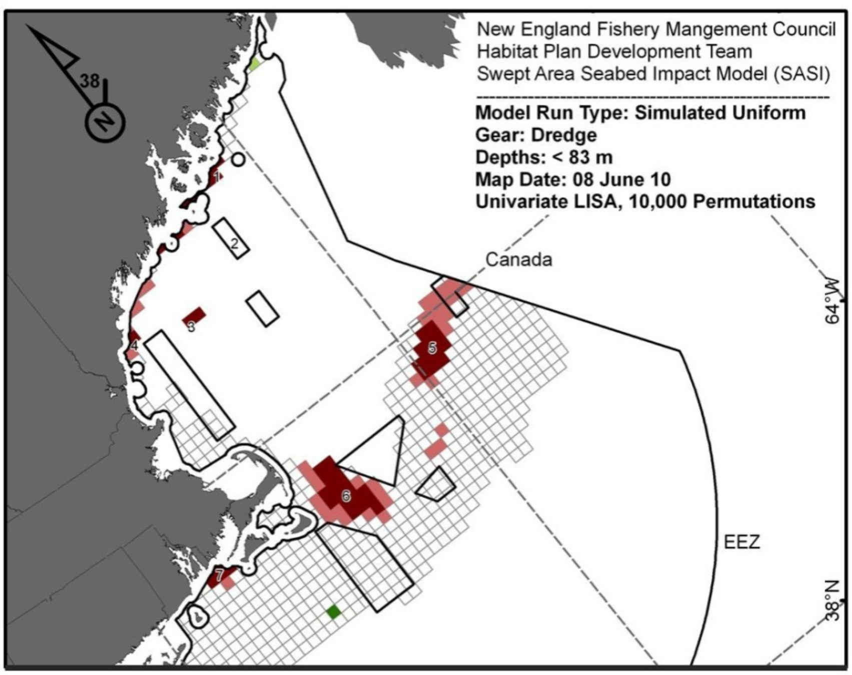


Map 32 – Maps of z_∞ HH and HL clusters defined by $p \leq 0.05$ and 0.01 levels for each gear type.



Map 33 – Maps of z_∞ HH and HL clusters defined by $p \leq 0.05$ and 0.01 levels for each trawl and scallop dredge gears.





9.3 Z∞ in present and proposed management areas (EAP)

Equal Area Permutation (EAP) tests are used to determine the levels of Z∞ in present and proposed management areas relative to the model domain.

9.3.1 Methods

The area-weighted mean Z∞ ($\overline{z_w^\infty}$) for each tested area is compared to a permutation distribution of $\overline{z_w^\infty}$ calculated using 9,999 randomly placed areas equal in size to the test area. The percentile of the tested area's $\overline{z_w^\infty}$ value and number of areas with $\overline{z_w^\infty}$ greater than or equal to the tested area are identified. These permutation-based areas are mapped along with the 100 highest $\overline{z_w^\infty}$ value areas (99th percentile of the permutations distribution) to indicate alternative management area locations.

The shapes and orientations of the tested areas vary depending on their locations and original management objectives. Circles are used to construct consistent permutation distributions for the EAP tests because they are isotropic and their areas can calculated simply using radii (Area = 2π x radius^2).

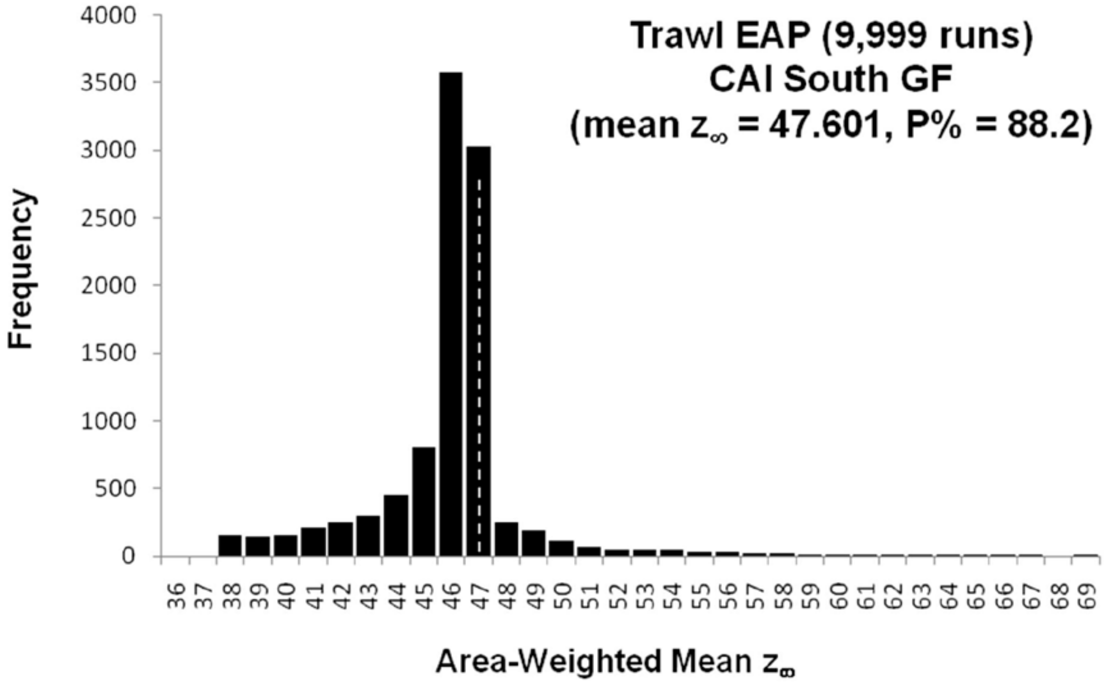
9.3.2 Results

The EAP results for trawl gear are summarized in Table 72. On the following pages, results from the CAI S GF EFH area are illustrated in a histogram (Figure 21) and on a map (Map 34). The histogram indicates the position of the area in its respective EAP distribution, and the map shows the locations of the permutation areas with $\overline{z_w^\infty}$ ≥ than the tested areas, and also the 99th percentile of the $\overline{z_w^\infty}$ permutation values (i.e. the locations of the highest 100 $\overline{z_w^\infty}$ permutation values). Histograms and maps for the other areas listed in Table 72 are not shown.

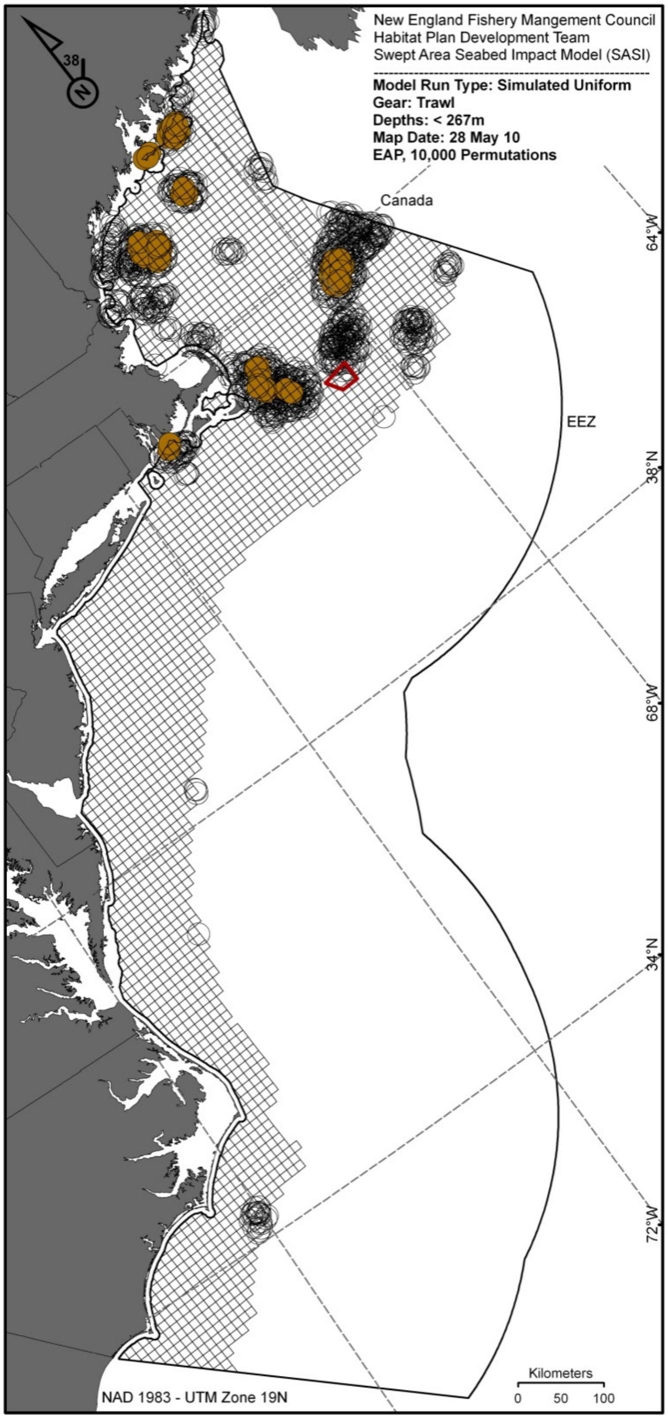
Table 72 – Trawl EAP results with tested areas, their size, $\overline{z_w^\infty}$ permutation percentile (P%) and number of permutation areas with $\overline{z_w^\infty}$ ≥ than the tested area.

		Tested area result			Permutation results		
	Closed Area	**km^2**	**AWM z∞**	**Sum z∞**	**P%**	**Areas with ≥ Mean z∞**	**99th %**
Groundfish (Amendment 13) EFH Closed Areas	Cashes L. EFH GF	443	51.437	588.06	96.00%	400	57.661
	Jeffreys B. EFH GF	499	57.667	510.13	99.10%	90	57.101
	WGOM EFH GF	2272	50.114	1777.55	95.10%	490	52.63
	CAII EFH GF	641	49.425	844.79	92.20%	780	56.567
	CAI N. EFH GF	1937	45.186	1287.93	12.80%	8721	53.15
	CAI S. EFH GF	584	46.085	609.67	50.30%	4970	57.101
	NLCA EFH GF	3387	46.787	2205.24	56.80%	4320	51.884
Multispecies mortality closures	Cashes L. Closed Area	1373	48.505	1186.07	83.00%	1700	54.314
	WGOM Closed Area	3030	49.874	2362.75	94.70%	530	52.037
	Closed Area II	6862	46.338	4354.63	41.10%	5891	50.912
	Closed Area I	3939	45.891	2556.1	34.20%	6581	51.589
	Nantucket Lightship	6248	46.466	4002.39	46.30%	5371	51.015

Figure 21 – Trawl EAP histogram for CAI South EFH Groundfish Closed Area indicating the position of the tested area in the EAP distribution (dashed line), the $\overline{z_w^\infty}$ (mean z∞) and permutation percentile (P%).



Map 34 – Trawl EAP map for CAI South EFH Groundfish Closed Area. Open circles are permutation areas with $\overline{z_w^\infty}$ ≥ than the tested area, and orange circles show the locations of the highest 100 $\overline{z_w^\infty}$ permutation values.



10.0 Practicability analysis

The objectives of the SASI Practicability/Opportunity Cost Analysis are to (1) understand and quantify the trade-offs inherent in the use of durable fishing gear restriction (closed) areas; and (2) define measurable thresholds for achieving the requirements to minimize adverse effects on habitat from fishing to the extent practicable, as specified in the Omnibus Amendment 2 Goals and Objectives.

10.1 Introduction

In a 2002 report entitled "Effects of Trawling and Dredging on Seafloor Habitat" (NRC 2002) the National Research Council outlined three primary tools available to fishery managers for minimizing the adverse effects from fishing on fish habitat as area closures, gear modifications and effort reductions. Large-scale, year-round area closures have been used by New England fishery managers for over fifteen years. Since 2004, these areas have also been used as a tool to minimize the adverse effects from fishing on habitat (NEFMC 2003a, 2003b). It is well recognized that both temporary and year-round fishing area closures result in effort displacement if they are not accompanied by commensurate catch or effort controls (Rijnsdorp et al. 2001, Dinmore et al. 2003). However, few studies have addressed the trade-off between habitat recovery in areas closed to fishing and the additional adverse effects of fishing in open areas. In the most pertinent and thorough such analysis, Hiddink et. al. (2006) looked specifically at the effects of area closure and effort control tools on the biomass, production, and species richness of benthic communities in the North Sea and concluded:

> *"If the areas closed to fishing have low levels of production because of high natural disturbance, and/or recover quickly after disturbance, then closure tends to have a negative effect, because trawling effort may redistribute to more productive habitats with longer recovery times. If the closed areas have high production in the absence of disturbance, and effort is displaced to areas where production is low, then closure is more beneficial."*

This section proposes a method for assessing the trade-off between recovery in areas closed to fishing and additional adverse effects resulting from fishing in the open areas. It also proposes a novel method for addressing the opposite: the potential change in aggreagate adverse effects from opening currently closed areas.

10.2 Methods

we simply construct a ratio estimator using the adverse effects from fishing (Z) and the profits derived from fishing (X). We call this the environmental impact coefficient, or *E.*

$$E = \frac{Z}{X} \quad . \qquad (1)$$

Here *E* represents the domain-wide ratio of adverse effect to fishing vessel profits. Because of the granularity of the SASI model, however, it can be scaled down to the individual gear type (*i*) and parcel (p) level. Further, because Z is a time-dependant variable, a true estimate of the adverse effect of fishing requires summing all of the adverse effects from each individual fishing event across all years in which they are felt. This lifecycle estimate of adverse effect, its net stock (Z^{net}), is defined as

$$z^{net}{}_{ip} = \sum_{t=1}^{n} z_{ip} \ , \qquad (2)$$

where t is the duration, in years, of the adverse effect for each unit of fishing activity. The length of the adverse effect lifecycle for a given fishing event is directly related to the recovery times of the structural habitat features inferred to the substrate(s) found within the parcel being fished. Incorporating Z_{net} into equation (1) and indexing across gear types and parcels gives us

$$e_{ip} = \left(\frac{z^{net}}{x} \right)_{ip} \ , \qquad (3)$$

where x_{ip} is the profit ($) derived as a result of fishing by gear type i at parcel p. Profit (x) is calculated as the product of all revenues r and variable trip-level costs c across gear types i and parcels p as

$$x_{ip} = (r - c)_{ip} \ . \qquad (4)$$

Note that crew remuneration is not included in c, nor is the price of leasing either DAS or ACE in fisheries where such leases are available. Profit is not discounted over the duration of the adverse effect, as the monetary benefits of fishing are instantaneous.

Data

Z^{net} is parameterized using VTR data for actual fishing trips made by vessels fishing with any of the ten gear types used in the SASI model during the 1996-2009 timeframe. Table 1 shows the mean Z^{net} and trip length by gear type and year.

The x variable is composed of r, trip-level revenue, and c, trip-level costs. Trip-level revenues are generated using a combination of dealer reported-landings and, when dealer-level data are not available or incomplete, self-reported VTR data. Observer data are used to estimate two trip-level cost models, and these models are applied to the VTR in-domain point data used in the SASI model. The time frame for observer data collection is 2003-2009, whereas the time series for the SASI model is 1996-2009. This inconsistency is likely to induce bias, as trip-level costs (particularly fuel costs) may not be representative at the earlier years. VTR trips with no valid location data are deleted. All values are converted to 2007 dollars using the Bureau of Labor Statistics producer price index for unprocessed and packaged fish, series WPU0223.

Trip costs are sensitive to trip duration, and therefore separate cost models are estimated for trips less than 24 hours and for trips equal to or greater than 24 hours. Trip cost, the dependant variable, are the sum of the following costs: ice, food, fuel, intra-trip vessel or gear damage, miscellaneous supplies, water, oil and bait. Several model specifications and combinations of explanatory variables are explored. The final model specifications are presented in Table 2 and Table 3. Gillnet and longline are categorical variables representing the presence of that gear used on a trip; crew is a continuous variable representing the number of crew plus captain; ln_dur is the natural log of the total trip duration measured in hours; vhp2 is the vessel horsepower squared. Table 3 presents the annual sum of trip revenues, trip costs and profits by gear type.

Hydraulic clam dredge gear is, unfortunately, excluded from this analysis due to difficulties in computing trip-level revenue and insufficient observer data for generating a meaningful trip cost model.

Table 73 – Trip cost model with natural log of trip cost as dependant variable for trips less than 24 hours, Adj R^2 = 0.525 (OLS). Gillnet and longline are categorical variables representing the presence of that gear used on a trip; crew size is a continuous variable representing the number of crew plus captain; LN(duration) is the natural log of the total trip duration measured in hours.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	2.90496	0.06213	46.75	<.0001
Gillnet	-0.57755	0.02764	-20.9	<.0001
Longline	0.24488	0.06531	3.75	0.0002
Crew size	0.32479	0.01631	19.92	<.0001
LN(duration)	0.86415	0.02679	32.26	<.0001

Table 74 – Trip cost model with natural log of trip cost as dependant variable for trips greater than or equal to 24 hours, Adj R^2 = 0.807 (OLS). Gillnet is a categorical variable representing the presence of that gear used on a trip; crew size is a continuous variable representing the number of crew plus captain; LN(duration) is the natural log of the total trip duration measured in hours; $horsepower^2$ is the vessel horsepower squared.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1.8691	0.09207	20.3	<.0001
Horsepower2	1.81E-07	3.35E-08	5.41	<.0001
Gillnet	-0.76861	0.04381	-17.54	<.0001
Crew size	0.14529	0.01171	12.41	<.0001
LN(duration)	1.2594	0.02187	57.58	<.0001

Table 75 – Mean Z_{net} and trip length (days) by year and gear type. Short (< 24h) and long (≥ 24 hr) trips were combined to produce these averages.

	Generic otter trawl		Shrimp trawl		Squid trawl		Raised trawl	
Year	**Z_{net}**	**Trip length**	**Z_{net}**	**Trip length**	**Z_{net}**	**Trip length**	**Z_{net}**	**Trip length**
1996	-5.54	1.9	-1.34	0.55	-4.85	2.36	.	.
1997	-5	1.71	-1.41	0.6	-3.74	2.12	.	.
1998	-4.79	1.64	-1.35	0.55	-4.92	2.5	.	.
1999	-4.81	1.68	-1.3	0.57	-3.33	2.09	.	.
2000	-4.14	1.55	-1.32	0.51	-2.59	1.39	.	.
2001	-3.85	1.64	-1.16	0.5	-3.37	1.85	.	.
2002	-3.16	1.46	-1.25	0.61	-3.34	1.84	.	.
2003	-3.32	1.51	-1.09	0.47	-4.73	2.51	-1.03	0.96
2004	-3.18	1.45	-1.11	0.48	-3.84	2.07	-1.04	0.61
2005	-3.08	1.41	-1.07	0.49	-4.88	2.71	-0.78	0.56
2006	-3.13	1.43	-1.01	0.46	-4.11	2.18	-0.75	0.81
2007	-3.27	1.43	-1.12	0.5	-3.61	2.05	-0.76	0.54
2008	-3.09	1.36	-1.16	0.5	-3.79	2.02	-0.7	0.44
2009	-3.44	1.28	-1.13	0.45	-4.58	2.39	-0.87	0.46

	Limited access scallop dr		General category scallop dr		Longline		Gillnet	
Year	**Z_{net}**	**Trip length**	**Z_{net}**	**Trip length**	**Z_{net}**	**Trip length**	**Z_{net}**	**Trip length**
1996	-3.83	7.06	-0.1	0.44	-0.04	0.73	0	0.79
1997	-3.08	6.36	-0.12	0.45	-0.03	0.75	0	0.64
1998	-3.28	6.02	-0.13	0.46	-0.03	0.76	0	0.63
1999	-2.92	5.73	-0.13	0.46	-0.28	0.63	0	0.72
2000	-2.73	5.92	-0.17	0.53	-0.02	0.69	0	0.72
2001	-2.82	6.09	-0.18	0.55	-0.05	0.68	0	0.73
2002	-2.59	7.08	-0.18	0.54	-0.03	0.86	0	0.67
2003	-2.4	6.61	-0.16	0.56	-0.02	0.82	0	0.64
2004	-2.15	5.84	-0.15	0.59	-0.02	0.72	0	0.61
2005	-1.3	3.27	-0.16	0.61	-0.03	0.74	0	0.61
2006	-1.15	2.6	-0.19	0.67	-0.03	0.71	0	0.58
2007	-1.44	2.78	-0.18	0.67	-0.03	0.72	0	0.51
2008	-1.72	2.95	-0.17	0.64	-0.04	0.8	0	0.53
2009	-2.35	3.53	-0.16	0.59	-0.03	0.86	0	0.48

	Pots and traps	
Year	**Z_{net}**	**Trip length**
1996	-0.01	0.58
1997	-0.01	0.58
1998	-0.01	0.57
1999	-0.01	0.58
2000	-0.01	0.54
2001	-0.01	0.54
2002	-0.01	0.53
2003	-0.01	0.55
2004	-0.01	0.54
2005	-0.01	0.52
2006	-0.01	0.53
2007	-0.01	0.53
2008	-0.01	0.55
2009	-0.01	0.56

Table 76 – Average value, cost, and profit for all trips, and average trip duration (days) by year and gear type.

	Generic otter trawl				Shrimp trawl				Squid trawl			
Year	Trip value	Trip cost	Profit	Trip duration	Trip value	Trip cost	Profit	Trip duration	Trip value	Trip cost	Profit	Trip duration
1996	7,434	1,787	5,648	1.9	2,032	357	1,675	0.55	11,696	2,199	9,497	2.36
1997	6,951	1,569	5,381	1.71	1,687	387	1,300	0.6	9,048	1,874	7,174	2.12
1998	6,559	1,479	5,080	1.64	1,598	346	1,252	0.55	12,414	2,495	9,919	2.5
1999	6,757	1,533	5,225	1.68	1,246	347	899	0.57	8,815	2,026	6,789	2.09
2000	6,667	1,395	5,272	1.55	1,664	315	1,349	0.51	6,157	1,232	4,925	1.39
2001	7,104	1,485	5,619	1.64	943	309	634	0.5	7,726	1,704	6,021	1.85
2002	6,559	1,317	5,242	1.46	1,318	404	914	0.61	8,139	1,674	6,466	1.84
2003	6,935	1,365	5,570	1.51	1,296	289	1,006	0.47	12,132	2,394	9,738	2.51
2004	7,252	1,311	5,941	1.45	1,299	290	1,009	0.48	11,742	1,923	9,819	2.07
2005	6,297	1,266	5,031	1.41	1,153	291	862	0.49	17,315	2,722	14,594	2.71
2006	6,665	1,288	5,376	1.43	1,420	283	1,137	0.46	11,469	2,115	9,354	2.18
2007	6,358	1,306	5,053	1.43	1,447	322	1,125	0.5	10,069	2,084	7,985	2.05
2008	6,639	1,231	5,408	1.36	1,302	316	986	0.5	9,474	1,966	7,507	2.02
2009	6,388	1,155	5,234	1.28	1,231	290	940	0.45	14,255	2,310	11,946	2.39

	Raised footrope trawl				Limited Access scallop dredge				General Category scallop dredge			
Year	Trip value	Trip cost	Profit	Trip duration	Trip value	Trip cost	Profit	Trip duration	Trip value	Trip cost	Profit	Trip duration
1996	.	.	.	.	44,695	10,804	33,891	7.06	972	294	678	0.44
1997	.	.	.	.	38,452	9,399	29,053	6.36	1,074	281	793	0.45
1998	.	.	.	.	29,936	8,666	21,270	6.02	976	288	688	0.46
1999	.	.	.	.	47,359	8,265	39,095	5.73	1,231	294	936	0.46
2000	.	.	.	.	57,423	8,725	48,698	5.92	1,643	454	1,189	0.53
2001	.	.	.	.	56,322	8,989	47,333	6.09	1,712	438	1,274	0.55
2002	.	.	.	.	62,417	10,546	51,872	7.08	1,753	392	1,361	0.54
2003	3,139	791	2,349	0.96	61,867	9,617	52,250	6.61	1,884	390	1,494	0.56
2004	2,253	383	1,870	0.61	67,458	8,153	59,305	5.84	2,337	441	1,897	0.59
2005	2,112	454	1,658	0.56	42,911	4,129	38,782	3.27	3,008	479	2,529	0.61
2006	2,932	661	2,270	0.81	24,753	3,043	21,710	2.6	2,343	493	1,850	0.67
2007	2,123	381	1,742	0.54	26,566	3,338	23,228	2.78	2,343	497	1,846	0.67
2008	1,979	343	1,636	0.44	32,499	3,729	28,770	2.95	2,444	471	1,973	0.64
2009	2,072	358	1,714	0.46	41,260	4,695	36,565	3.53	2,636	458	2,178	0.59

	Longline				Gillnet				Pots and traps			
Year	**Trip value**	**Trip cost**	**Profit**	**Trip duration**	**Trip value**	**Trip cost**	**Profit**	**Trip duration**	**Trip value**	**Trip cost**	**Profit**	**Trip duration**
1996	2,725	592	2,133	0.73	2,792	320	2,473	0.79	2,342	432	1,911	0.58
1997	2,641	640	2,001	0.75	2,609	263	2,346	0.64	2,086	418	1,668	0.58
1998	2,711	645	2,065	0.76	2,670	253	2,417	0.63	1,865	409	1,456	0.57
1999	2,737	463	2,274	0.63	3,293	282	3,010	0.72	2,232	416	1,816	0.58
2000	2,452	517	1,935	0.69	3,068	265	2,803	0.72	2,189	372	1,817	0.54
2001	2,719	484	2,235	0.68	2,937	265	2,672	0.73	1,948	376	1,572	0.54
2002	3,057	625	2,432	0.86	3,015	244	2,771	0.67	2,008	372	1,636	0.53
2003	2,885	621	2,265	0.82	2,813	239	2,575	0.64	2,112	390	1,722	0.55
2004	4,061	584	3,477	0.72	2,558	228	2,331	0.61	1,982	381	1,601	0.54
2005	3,884	564	3,320	0.74	2,791	221	2,570	0.61	2,086	371	1,715	0.52
2006	2,985	546	2,440	0.71	2,545	216	2,328	0.58	1,971	362	1,608	0.53
2007	3,057	627	2,430	0.72	2,408	196	2,213	0.51	1,813	366	1,447	0.53
2008	2,787	654	2,133	0.8	2,343	201	2,142	0.53	1,834	381	1,453	0.55
2009	3,006	684	2,322	0.86	1,963	185	1,779	0.48	1,812	395	1,417	0.56

10.3 Results

To summarize the relationship between costs and benefits for each gear type, *e* is calculated as the unweighted mean value across all years and all parcels (grid cells, Table 5). This estimate includes only parcels with three or more trips per year and with three or more years of data. The reported standard deviation applies to *e* at the parcel level across time—relatively lower standard deviations (such as the raised footrope, squid and shrimp trawls) indicate fisheries with similar *e* coefficients within the same parcel across time, and higher standard deviations (such as gillnets and longlines) represent higher inter-annual variability.

In Table 5, the *e* coefficient may accurately be interpreted as the quality-adjusted area swept, in square kilometers, that results from the generation of $1,000 of gross profit at the individual trip level. The number of grid cells meeting the requirement of three or more trips in a year and three or more years in the dataset are noted.

The rank order and magnitude of the adverse effect generated per dollar provide a useful approach to understanding the impacts of various fishing gears on structural habitat. Here we can see that fixed gears are much more efficient, in terms of adverse effect, at generating fishing profits than mobile gears. Even within those classes there is variation—trawls generate an order of magnitude greater adverse effect per unit of fishing profit than scallop dredges; gillnets and pots and traps similarly generate less adverse effect per unit profit than longlines.

Table 77 – Unweighted mean *e* across all included grid cells and years, by gear type

Gear	*# grid cells*	*Mean e*	*Stddev e*
Generic otter trawl	1271	5.00	8.30
Shrimp trawl	96	8.10	11.73
Squid trawl	195	2.82	3.69
Raised footrope trawl	5	1.48	1.71
Limited Access scallop dredge	446	0.64	1.05
General Category scallop dredge	215	0.68	1.09
Demersal longline	110	0.11	0.26
Sink gillnet	688	0.03	0.08
Trap gear	601	0.04	0.07

Impacts analysis methods for closure removal options

It must be noted from the beginning that attempts to assess changes in the spatial distribution of fishing due to area-based regulatory change is extremely difficult. In the Northeast region we have used two models with relative success—the Closed Area model (CAM) for assessing impacts in the groundfish fishery and the SAMS model in the scallop fishery. Unfortunately, the large size and high level of granularity found in the SASI model does not present an easy path for the integration of those two models, though we believe that with some work the SAMS model would be an ideal basis for predicting changes in adverse effect that may result from changes in spatial management.

Site choice models, which predict where fishing vessels will re-distribute their fishing effort after closures or openings based on expected profits, are commonly used for these types of analyses. Unfortunately, they have only been successfully utilized to predict effort redistribution across much lower levels of granularity—on the order of 10 to 50 sites, rather than the 200-1,000 sites with active fishing in the SASI model. They are also extremely complicated models that take years to develop. A fully parameterized and operational site choice model covering all areas and gear types assessed within the SASI framework would certainly be valuable at this phase of analysis, but such a model is unavailable.

To allow the Council and public adequate consideration of the potential impacts of changes in spatial management regulations, we utilize the basic mechanics of SASI to demonstrate whether the proposed spatial regulation will result in GREATER or LESSER adverse effects, holding other inputs constant.

The problems basic questions to be addressed in modeling these effects are:
(1) How much different will adverse effects be in the areas potentially being opened?
(2) How much different will catch rates be?
(3) How much effort will flow into these areas?

We have little empirical data (SAPs and rotational management areas) upon which to base cost (adverse effects) and benefit (profits) estimates on. As a first approximation, we base our estimates on the potential profits and adverse effects from parcels that are proximate to and potentially representative of the profits and adverse effects likely to be observed within the opened area if fishing were allowed. These estimates are then propagated to the newly fishable areas. Eleven separate regions are selected as sub-sets of existing habitat and year-round management closures: Closed Area 1 east, north and west; Closed Area 2 south, central and north; Nantucket Lightship east and west; Cashes; Jeffries; and the Western Gulf of Maine. The figures below show which cells are used in our fished and unfished scheme. Note that individual grid cells may be coded as both fished and unfished, and unfished cells overlay the fished. Therefore, not all unfished cells are visible in these figures.

To answer question (1) above, we compare Z_{inf} estimates from the fishable areas with estimates from their matched unfished areas. Table 78 provides the difference between similar fished and unfished areas in percentage terms. These percentages are then used to scale up or down the Z^{net} estimates for the unfished areas found inside current closures.

For question (2), we begin with the assumption that catch rates and therefore profits for all fisheries will be higher than they are in the proximate similar areas, though we are unsure of how much higher they may be. To model this, we apply a factor ranging from 1 to 1.5 times observed proximate profits and iterate the model stochastically. For scallop dredge gears, where catch rates inside area closures are known to be significantly higher than 1.5 times proximate outside areas, we apply a factor that ranges from 1 to 4 times observed proximate profits.

Because we have no economic or behavioral model upon which to base the *amount* of effort likely to flow into a newly opened area, we use a similar stochastic estimation method. Effort flowing into newly opened areas is likely to be similar in distribution to the observed effort in proximate currently opened areas, and linearly related in magnitude. We therefore use observed profits in these areas as a basis for estimating profits derived from newly opened areas. To do this, we apply a range of between 1 and 5 times the observed proximate open-area profits to the newly opened areas. All profits flowing into these newly open areas are subtracted uniformly from the observed profits over the entire domain; profits are then held constant, and changes in resulting Z^{net} are reported.

Data from all years 1996-2009 are averaged to construct the profit and Z^{net} estimates for each parcel. Each of the eleven potential open areas is assess individually. Due to computing power limitations at the NEFSC, only 15 iterations of the stochastic model are performed.

Figure 22 – Closed Area 1 fished and unfished parcels

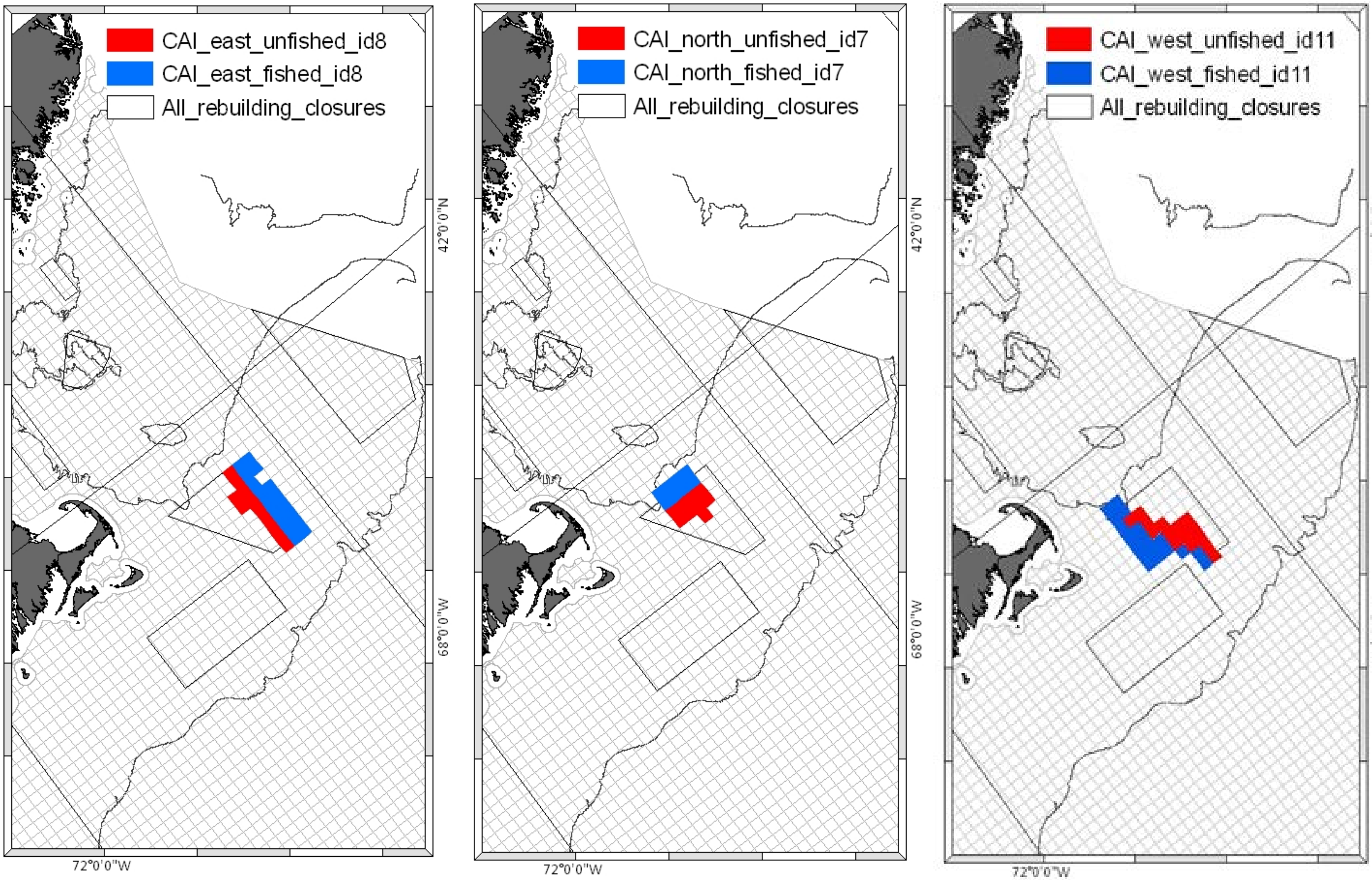


Figure 23 – Closed Area 2 fished and unfished parcels

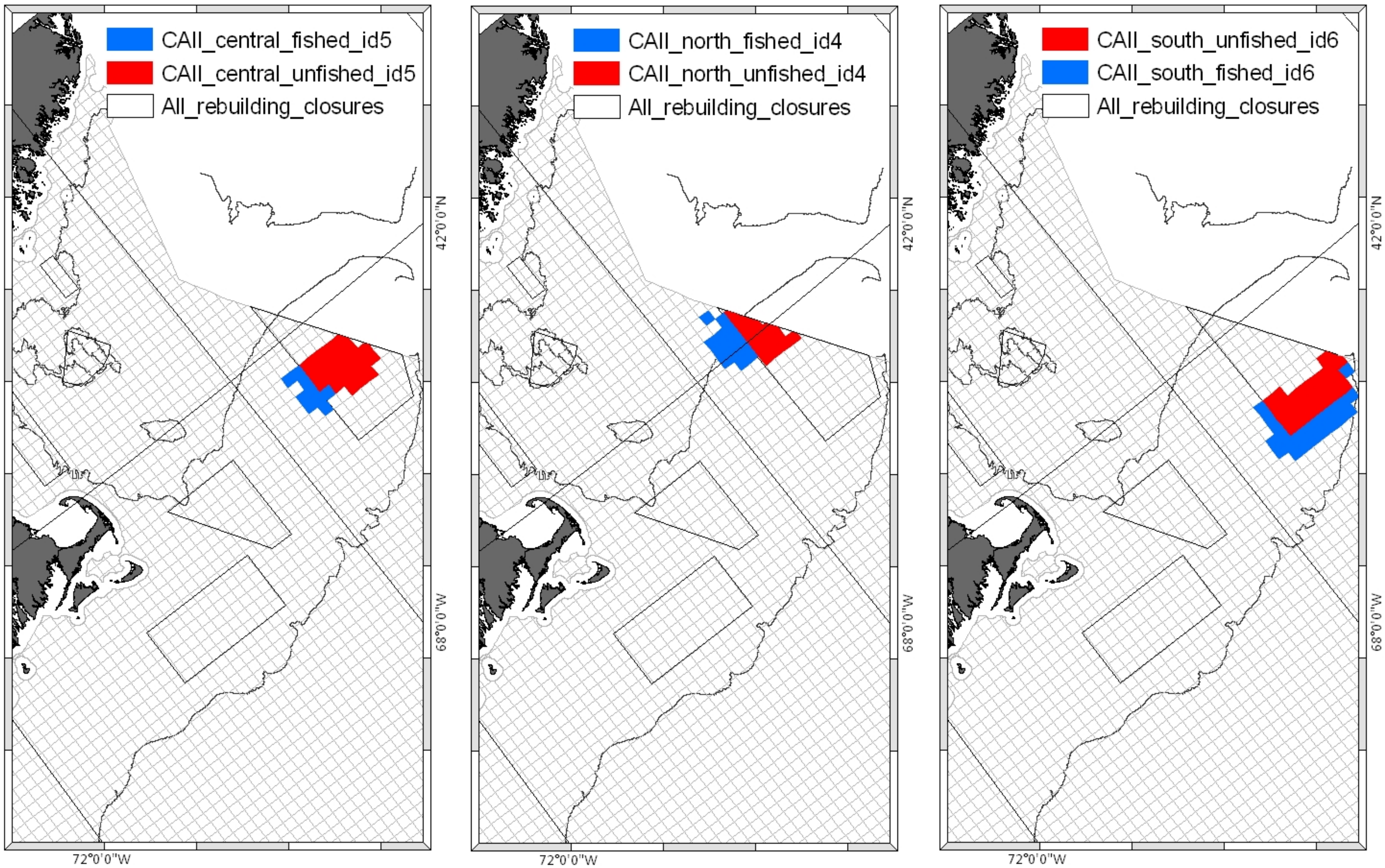
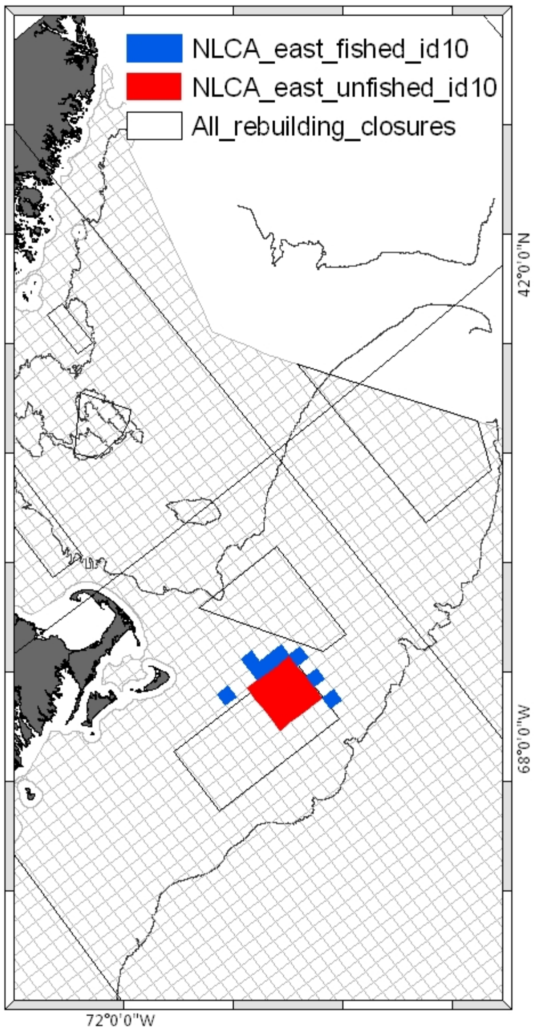


Figure 24 – Nantucket Lightship Closed Area fished and unfished parcels



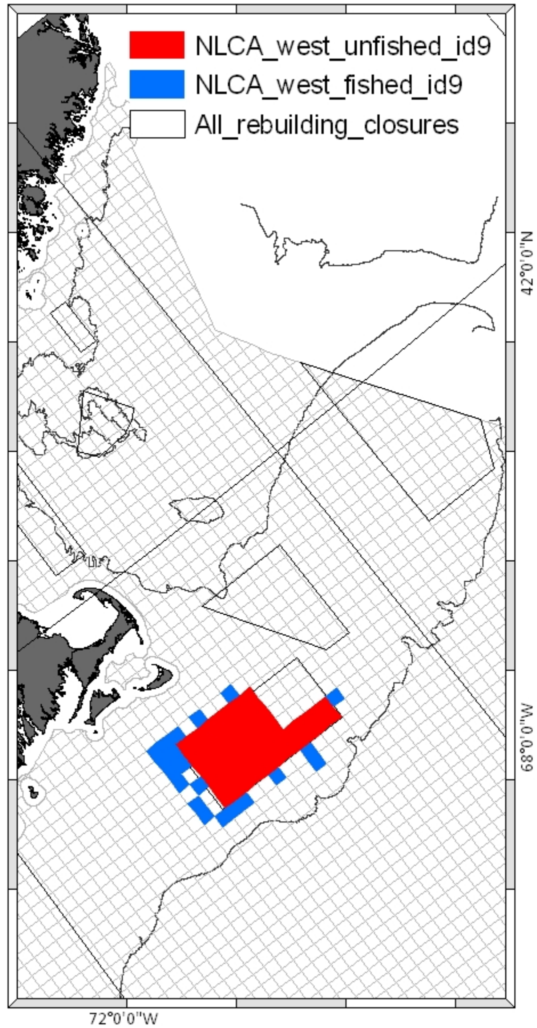


Figure 25 – Western Gulf of Maine Closed Area, Cashes Closed Area and Jeffries Bank Closed Area

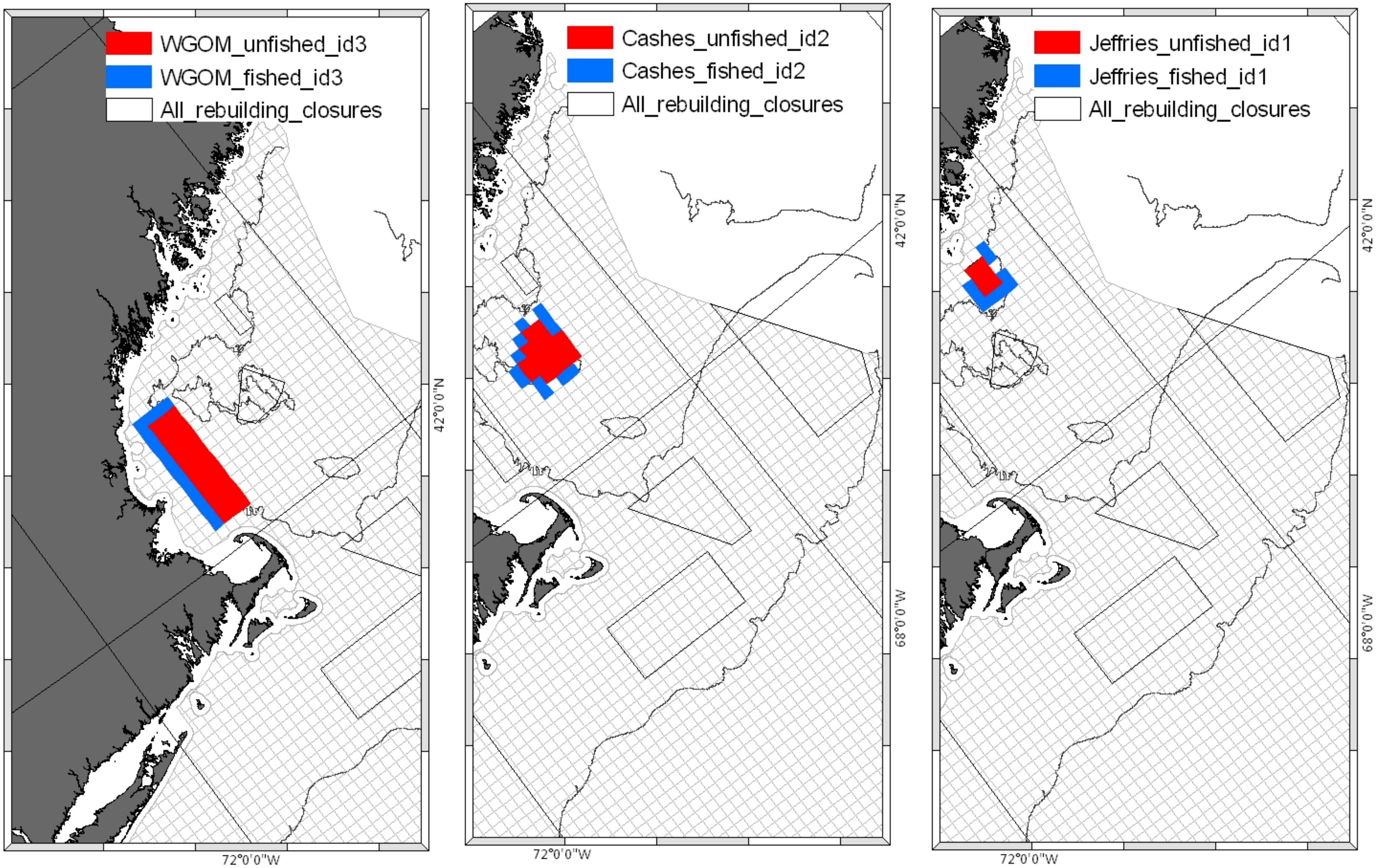


Table 78 – Z_inf, percent difference between fished and unfished parcels, by gear type

Average pct_z_inf_difference										
Row Labels	**GC Scal Dr**	**Gillnet**	**Hydaulic Dr**	**LA Scal Dr**	**Longline**	**Otter trawl**	**Pot/Trap**	**Raised trawl**	**Shrimp trawl**	**Squid trawl**
Cashes	-1.62%	-1.01%	0.93%	-1.62%	-0.83%	-3.56%	0.25%	-3.56%	-3.56%	-3.56%
Closed Area 1 East	-2.94%	-3.76%	-2.25%	-2.94%	-4.68%	0.16%	-2.99%	0.16%	0.16%	0.16%
Closed Area 1 North	3.17%	0.96%	9.68%	3.17%	1.15%	4.83%	2.82%	4.83%	4.83%	4.83%
Closed Area 1 West	4.48%	3.84%	1.63%	4.48%	3.97%	5.35%	3.28%	5.35%	5.35%	5.35%
Closed Area 2 Central	-0.87%	0.59%	1.38%	-0.87%	-0.02%	-0.67%	-0.60%	-0.67%	-0.67%	-0.67%
Closed Area 2 North	3.77%	1.56%	7.28%	3.77%	1.44%	4.65%	3.75%	4.65%	4.65%	4.65%
Closed Area 2 South	1.96%	1.12%	7.22%	1.96%	1.53%	2.05%	1.28%	2.05%	2.05%	2.05%
Jeffries	2.85%	5.05%	-6.81%	2.85%	4.98%	3.25%	7.29%	3.25%	3.25%	3.25%
NLCA East	4.21%	3.47%	1.87%	4.21%	3.93%	11.80%	3.18%	11.80%	11.80%	11.80%
NLCA West	-3.26%	0.11%	0.03%	-3.26%	-0.17%	-2.01%	5.14%	-2.01%	-2.01%	-2.01%
WGOM	-3.97%	-1.39%	-2.59%	-3.97%	-1.27%	-2.30%	0.11%	-2.30%	-2.30%	-2.30%

Summary results for closure removal options
This model estimates the potential change in adverse effects from fishing on fish habitat after a regulatory fishing area opening. The point of the analysis is to demonstrate whether or not aggregate adverse effects would increase or decrease after an area opening, given existing profit-to-adverse effect relationships in the vicinity of the potential opening and reasonable assumptions about how those relationships would translate onto newly opened fishing grounds.

We find that for nearly all area and gear type combinations, opening existing closed areas to fishing is predicted to decrease aggregate adverse effects. For mobile bottom tending gears, which comprise nearly 99% of all adverse effects in our region, allowing fishing in almost any portion of the area closures on Georges Bank is estimated to substantially decrease total adverse effects from fishing. Closures in the Gulf of Maine appear to also decrease aggregate adverse effects, but the magnitude of these reductions is substantially smaller.

The parameters used to estimate both catch rate and total effort increases for potential fishing inside closed areas may easily be adjusted either up or down based on feedback from the Committee and public, and additional time may allow for calibration of these parameters based on empirical data from special access programs, etc. So long as there is agreement that, if areas are opened, catch rates and effort levels for most fisheries are likely to be higher inside these areas than outside, the direction of change in aggregate adverse effect for these various opening scenarios will not change. Summary results presented below rely on two sets of assumptions for a HIGH and LOW estimate:

High:

- Catch rates increase btwn 0 and 50%
- Effort inside is multiple of btwn 1 and 5 of the proximate outside effort

Low:

- Catch rates increase btwn 0 and 25%
- Effort inside is multiple of btwn 1 and 2 of the proximate outside effort

Table 79 – Percent change in total Z_net after independent opening of each closure

Unfished area	Total Z_net = 158,882	*High estimate* Change in total after single-area opening	% *change*	*Low estimate* Change in total after single-area opening	% *change*
Cashes		**(5,183)**	***-8.8%***	**(420)**	***-2.2%***
Closed Area 1 East		**(5,510)**	***-4.1%***	**(1,315)**	***-1.6%***
Closed Area 1 North		**(3,000)**	***-2.3%***	**(245)**	***-1.5%***
Closed Area 1 West		**(6,248)**	***-7.0%***	**(1,303)**	***-2.3%***
Closed Area 2 Central		**(7,734)**	***-2.2%***	**(907)**	***-0.7%***
Closed Area 2 North		**(4,247)**	***-11.3%***	**319**	***-3.7%***
Closed Area 2 South		**(6,530)**	***-1.6%***	**(2,091)**	***-0.8%***
Jeffries		**(278)**	***-0.5%***	**129**	***0.1%***
NLCA East		**(4,265)**	***-5.6%***	**(1,030)**	***-2.2%***
NLCA West		**(3,902)**	***-5.4%***	**1,311**	***-1.6%***
WGOM		**(1,446)**	***-6.6%***	**599**	***-0.2%***

Impacts analysis methods for additional closure options

Similar to the methods used for estimating the potential impacts of regulatory openings of fishing areas, we use Z^{net} and e to estimate the potential changes in adverse effects resulting from closing additional areas to fishing.

To more accurately reflect current fishing practices we use parcel level mean profit and Z^{net} data from 2007 – 2009 only. For each closure scenario, we simply sum the amount of profit and Z^{net} that is found inside the proposed closure area, redistribute the 'missing' profits proportional to the observed spatial distribution of fishing effort, assign the corresponding Z^{net} estimate to the profits now generated outside the proposed area closure, and calculate the change in aggregate Z^{net}. Unlike the area opening analysis, no assumptions are made here regarding catch rates and profits for the redistributed fishing effort post-closure. Redistributed fishing effort will almost always result in lower profits and proportionally higher Z^{net}, and for this reason the estimates provided in this analysis are highly likely to overstate reductions in aggregate Z^{net}.

Data for only the George's Bank and Gulf of Maine regions are used to better reflect where displaced effort will likely fish. We focused our efforts for these analyses on the two most affected gear types – generic otter trawl and limited access scallop dredge.

Summary results for additional closure options

Area closure options for Cluster's 5 and 6 appear to potentially affect between $5-7.5 million of profits for these two gear types, representing less than 5% of their total aggregate profits from the Georges Bank and Gulf of Maine regions (see "profit at risk" in the tables below). However, the redistribution of these profits is estimated to have relatively minimal effects on aggregate Z^{net}. As with all adverse effects options, the largest net gains are to be had by regulating the otter trawl gear type, with Z^{net} reductions on the order of 1,000 km^2 for Cluster's 5 and 6. Closure of Cluster 5 is estimated to slightly increase adverse effects for the limited entry scallop dredge fishery. Cluster 7 is estimated to have the smallest impact, both on industry profits and adverse effects minimization.

Table 80 – Closure option for Cluster 5 (Georges Shoal), change in Z^{net} (2007-2009 VTR, profits in 1,000 dollars)

	pre_closure_ profit	profit_at_ risk	pre_closure_ z_net	closure_ z_net	*% reduction z_net*
Otter trawl	$ 57,076	$ 2,921	37,816	36,946	*2.3%*
LA Scal dr	$ 105,998	$ 4,483	6,526	6,592	*-1.0%*

Table 81 – Closure option for Cluster 6 (Great South Channel), change in Z^{net} (2007-2009 VTR, profits in 1,000 dollars)

	pre_closure_ profit	profit_at_ risk	pre_closure_ z_net	closure_ z_net	*% reduction z_net*
Otter trawl	$ 57,076	$ 1,996	37,816	36,695	*3.0%*
LA Scal dr	$ 105,998	$ 3,048	6,526	6,071	*7.0%*

Table 82 – Closure option for Cluster 7 (Brown's Ledge), change in Z^{net} (2007-2009 VTR, profits in 1,000 dollars)

	pre_closure_ profit	profit_at_ risk	pre_closure_ z_net	closure_ z_net	*% reduction z_net*
Otter trawl	$ 57,076	$ 310	37,816	37,862	*-0.1%*
LA Scal dr	$ 105,998	$ -	6,526	6,526	*0.0%*

11.0 Application of SASI results to fishery management decision making

The SASI model is intended to provide an objective and data-driven framework for evaluating fishery management decisions designed to minimize, to the extent practicable, the adverse effects of fishing on fish habitat.

The Council is required to minimize the adverse effects of fishing on EFH to the extent practicable. The MSA defines adverse effects as

"…any impact that reduces quality and/or quantity of EFH. Adverse effects may include direct or indirect physical, chemical, or biological alterations of the waters or substrate and loss of, or injury to, benthic organisms, prey species and their habitat, and other ecosystem components, if such modifications reduce the quality and/or quantity of EFH. Adverse effects to EFH may result from actions occurring within EFH or outside of EFH and may include site-specific or habitat-wide impacts, including individual, cumulative, or synergistic consequences of actions."

According to the EFH final rule, the threshold to determine whether effects are adverse is if the impact is "more than minimal and not temporary in nature". Specifically:

"Temporary impacts are those that are limited in duration and that allow the particular environment to recover without measurable impact. Minimal impacts are those that may result in relatively small changes in the affected environment and insignificant changes in ecological functions (EFH Final Rule)."

In order to minimize adverse effects, Councils must evaluate the potential adverse effects of current and proposed fishery management measures on EFH, considering.

"…the effects of each fishing activity on each type of habitat found within EFH. FMPs must describe each fishing activity, review and discuss all available relevant information (such as information regarding the intensity, extent, and frequency of any adverse effect on EFH; the type of habitat within EFH that may be affected adversely; and the habitat functions that may be disturbed), and provide conclusions regarding whether and how each fishing activity adversely affects EFH. The evaluation should also consider the cumulative effects of multiple fishing activities on EFH (EFH Final Rule)."

The EFH final rule outlines the types of management measures that might be proposed (see also NRC 2002):

- "Fishing equipment restrictions. These options may include, but are not limited to: seasonal and areal restrictions on the use of specified equipment, equipment modifications to allow escapement of particular species or particular life stages (e.g., juveniles), prohibitions on the use of explosives and chemicals, prohibitions on anchoring or setting equipment in sensitive areas, and prohibitions on fishing activities that cause significant damage to EFH.

- Time/area closures. These actions may include, but are not limited to: closing areas to all fishing or specific equipment types during spawning, migration, foraging, and nursery activities and designating zones for use as marine protected areas to limit adverse effects of fishing practices on certain vulnerable or rare areas/species/ life stages, such as those areas designated as habitat areas of particular concern.
- Harvest limits. These actions may include, but are not limited to, limits on the take of species that provide structural habitat for other species assemblages or communities and limits on the take of prey species."

Measures adopted to date by NEFMC are consistent with this guidance, and include:

- gear restrictions, including the inshore Gulf of Maine roller gear restriction;
- establishment of habitat closed areas in the multispecies and scallop FMPs;
- establishment of groundfish mortality closed areas (with associated gear restrictions), which are assumed to provide incidental benefits to EFH; and
- reductions in area swept over time (via reductions in effort and/or increased use of rotational management that provides for the same or greater harvest with less area swept).

Note that the Vulnerability Assessment estimates the susceptibility of habitats (at the feature level) to fishing gears, and the duration of the recovery period following impact. Impacts to both geological and biological structure-forming seabed features are considered. Thus, the Vulnerability Assessment, independent of the SASI model, can aid the Council in identifying habitat/gear combinations that are more susceptible and/or recover more slowly.

By combining vulnerability information with either realized or simulated fishing area swept, spatial overlap between vulnerable habitats and gear types may be assessed. Although SASI outputs are on a gear-by-gear basis, they can be evaluated synergistically for all bottom tending gear types if desired because seabed impact is expressed in like terms (i.e. km^2 area swept) for all gears.

Two fishing effort surfaces are modeled using SASI – simulated fishing effort, in which area swept for each gear type is applied evenly across grid cells, and realized fishing effort, which represents the past distribution and magnitude of area swept for the gear types across the model domain. For analyzing the impacts of management alternatives, a projected fishing effort surface could be applied to the model, allowing for comparisons between a no action alternative and any alternatives included for analysis. Such an effort surface could be thought of as a hybrid of the realized and simulated effort surfaces.

Evenly distributed simulated area swept model runs are useful for identifying areas within the domain that are likely to be vulnerable to adverse effects from particular gear types. Vulnerable areas are those in which the adverse effects of fishing gear area swept are likely to accumulate over time, due to a combination of higher susceptibility of present features to gears, slower recovery of the functional value of those features.

SASI results for different gear types can be compared in order to evaluate the benefits and costs of restricting fishing in particular areas for one or more gear types. Because SASI is based on an annual time step, model outputs are not useful for considering seasonal closures. Status quo habitat closed areas can be evaluated by considering whether adverse effects accumulate in those areas to a greater degree than across the portions of the model domain as a whole.

Additional information including the realized distribution of adverse effects, the magnitude of catches/revenues, bycatch considerations, presence of spawing areas, etc., may be incorporated to assess the practicability of existing or proposed management alternatives.

Another way in which SASI can be used is to model the difference in contact-adjusted (*A*) and vulnerability-adjusted (*Z*) area swept given a change in the assumptions about gear contact with the seabed. For example, if a new type of otter trawl with reduced bottom contact is developed, the model can estimate the resulting difference in Z by specifying a new contact index appropriate trawl component. Similarly, analyzing a roller gear restriction is possible by making the assumption that such a restriction would result in vessels no longer being able to fish in a particular substrate-dominated habitat (such as boulder-dominated), and calculating the resulting Z estimate after excluding that habitat from the model.

12.0 Research needs and future work

Development of the model has highlighted gaps in our knowledge of fishing impacts on habitat. The model might be updated in a variety of ways given additional research/data, including:

- Regionalize implementation to account for different feature distributions
- Incorporate observer data more fully, and incorporate vessel monitoring system data to estimate area swept data layers
- Continue to update substrate data, and perhaps add multibeam data
- Adjust geological and biological component weightings, or feature weightings within each component, to reflect importance of features to managed species
- Adjust contact indices, and/or make them substrate-specific
- Better specify fixed gear area swept models given data on the movement of fixed gear along the seabed
- Change the assumption that the impacts of subsequent tows are additive
- Shorten the minimum time interval to less than one year to allow for estimation of seasonal effects (this might require seasonal estimation of vulnerability parameters as well)

13.0 References

13.1 Acronyms used

EFH	Essential Fish Habitat
GIS	Geographic Information System
NEFMC	New England Fishery Management Council
MAFMC	Mid-Atlantic Fishery Management Council
PDT	Plan Development Team
R	Recovery
S	Susceptibility
SASI	Swept Area Seabed Impact (model)
VA	Vulnerability Assessment

13.2 Glossary

A	Refers to the area swept by a piece of fishing gear, adjusted for contact of gear with the seabed (contact index). *A* is added to the SASI model in annual time steps.
Adverse effect	An impact to EFH that is 'more than minimal and not temporary in nature'
Biological feature	Any living seabed structure assumed to be used for shelter by managed species of fish or their prey
Contact index	The proportion of a gear component that is assumed to touch the seabed during fishing
Essential Fish Habitat	Those waters and substrate necessary to fish for spawing, breeding, feeding, and growth to maturity
Geological feature	Any non-living seabed structure assumed to be used for shelter by managed species of fish or their prey
Prey feature	One of six benthic invertebrate taxa commonly consumed by managed species in the Northeast Region
Realized	Refers to an area swept data layer that is intended to realistically represent actual fishing effort, where gear dimensions, fishing locations, and number of trips/tows/sets are based on observer, trip report, or other data sources. Realized area swept is aggregated on an annual basis.
Recovery, R	Recovery is defined as the time in years that would be required for the functional value of that habitat feature to be restored.
SASI model	The combination of vulnerability assessment and geo-referenced fishing effort and habitat data used to estimate the magnitude and location of the adverse effects of fishing on habitat
Simulated	Refers to an area swept data layer that is intended to allow for spatial visualization the underlying seabed vulnerability, independent of the magnitude of area swept. Simulated area swept might be uniformly distributed, or non-uniformly distributed.
Substrate classes	Mud, sand, granule-pebble, cobble, and boulder, as defined by the Wentworth particle grade scale

Susceptibility, S	Susceptibility is defined as the percentage of total habitat features encountered by fishing gear during a hypothetical single pass fishing event that have their functional value reduced.
Structured grid	A regular grid of consisting of 100 km^2 cells to which area swept estimates are inferred.
Unstructured grid	An irregular grid based on the distribution of substrate data points. High or low energy and a suite of features are inferred to each unstructured grid cell
Vulnerability	The combination of a feature's susceptibility to fishing gear impact and its ability to recover from fishing gear impact
Wentworth	A size-based sediment classification scheme
Voronoi tessellation	A mathematical procedure used to develop the unstructured substrate grid based on point data
Z	A measure of the adverse effect of fishing effort on seabed habitat features, measured in km^2 units. Z is area swept (A) that has been adjusted for susceptibility (S) and recovery (R). Z is considered a "stock" effect that accumulates over time based on the amount of adverse effect entering the fishery in any particular time step (Y), and the amount of adverse effect deemed to have recovered in that time step (X), such that Z = X – Y.
Z	The adverse effect of fishing effort on seabed habitat features, measured in km^2 units. Z is area swept (A) that has been adjusted for susceptibility (S) and recovery (R). Z is considered a "stock" effect that accumulates over time based on the amount of adverse effect entering the fishery in any particular time step (Y), and the amount of adverse effect deemed to have recovered in that time step (X), such that Z = X – Y
Z_{∞}	The asymptotically stable equilibrium level of Z. Z_{∞} is reached when a constant annual level of fishing area swept is applied to the all grid cells in the model for a length of time just slightly greater than the greatest terminal year of recovery estimated for all features in the Vulnerability Assessment.
Z_{net}	An instantaneous estimate of all the adverse effect that occurs as a result of a single fishing event. Z_{net} sums the annual Z value from the year the fishing event occurred until Z decays to 0 (i.e. until recovery is complete).

$Z_{realized}$	The actual distribution of Z by gear type based on past area swept estimates. Annual $Z_{realized}$ estimates for each 100 km^2 grid cell include the current year Z summed across all area swept in the cell, adjusted for feature susceptibility, plus *Z* accumulated from fishing events in past years that has not yet decayed.

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Table 83 - References from literature review by number.

# Cite	# Cite	# Cite
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17 Ball et al 2000	146 Hall-Spencer et al 2002	313 Rosenburg et al 2003
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35 Brown et al 2005b	164 Hixon and Tissot 2007	333 Simpson and Watling 2006
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OMNIBUS ESSENTIAL FISH HABITAT AMENDMENT 2
DRAFT ENVIRONMENTAL IMPACT STATEMENT

Appendix E – Synopsis of Closed Area Technical Team analysis of juvenile groundfish habitats and groundfish spawning areas

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Note – this appendix is adapted from a memorandum provided to the New England Fishery Maangement Council's Scientific and Statistical Committee on May 10, 2013.

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Analytical approach

Between January and April 2013, the Closed Area Technical Team developed an analysis of data to assist in identifying areas that more restrictive measures could reduce impacts on juvenile groundfish habitat and groundfish spawning. Instead of focusing on physical characteristics of the environment that might be damaged by fishing and could be suitable habitat for groundfish, the CATT took an approach that focuses on aggregations of small juvenile groundfish and large fully-mature groundfish.

The CATT made a few key decisions about how to focus the analysis to meet the objectives. First, the CATT decided that the primary data source it would use to analyze juvenile and mature groundfish distribution would be from the various fishery-independent surveys, conducted by NMFS and coastal states. Figure 6 shows the geographic distribution of the surveys used for this analysis. Certain other surveys, such as RSA surveys or the Canadian survey were not readily available. The NMFS, MA DMF, and ME/NH surveys were the most useful for identifying hotspots or clusters of large catches. The IBS (Industry Based Survey) cod survey was also suitable, but the spatial domain of the survey was limited. The IBS goosefish and yellowtail flounder surveys were potentially suitable and were included in the analysis, but the sampling density was low and the analysis yielded few hotspots.

One important issue with survey data that was recognized by the CATT and addressed was the apparent overdispersion and high amount of zero catch observations in the survey catch per tow data. As such, it was unlikely that the data would be suitable for parametric analysis embedded in the Getis-Ords G* (henceforth simply called G*) statistic, particularly when interpreting the p-value to distinguish clusters of significantly high catches. Although the G* statistics is valid using data that is not normally distributed, Zhang et al (2008) published a proof that the G* statistics are not accurate for overdispersed data. It is furthermore common practice to either use non-parametric tests or transform survey data before analysis. A Box-Cox procedure was applied in R and Systat to potentially identify a transformation yielding distributions that were approximately normal. None were satisfactory, including a log (or any other) transformation of N+1.

The CATT explored the issue by running several trials with untransformed and transformed data, but in the end followed the advice of Dr. Brian Kinlan to adjust the data in a two-step (Hurdle model like approach) procedure to down weight catches on tows that occur in strata having higher numbers of zero catch tows. The catch per tow was multiplied by the proportion of non-zero catches in a stratum during each year and survey, before applying a log transformation. This procedure yielded normally distributed data, adjusted for the proportion of zero tows in a stratum (i.e. catches in strata having higher proportions of no-catch tows were down weighted relative to strata where the catches were more consistently non-zero).

Size ranges that approximate age 0/1 were chosen by the CATT for the juvenile groundfish hotspot analysis. A size threshold was selected that included all of age 0 fish and about 90% of age 1 fish from regenerated age length keys for 2002-2012 for the spring and fall NMFS trawl surveys (Table 5). Size ranges derived from the spring survey were applied to measured groundfish for all spring and summer surveys. Size ranges derived from the fall survey were applied to measured groundfish for all fall and winter surveys The CATTs rationale for choosing these size thresholds was to key in on the smallest juvenile groundfish caught by the lined survey trawls, which are more likely to be associated with bottom habitat that could be adversely affected by fishing. The thresholds were always smaller than the L20 for that species maturity ogive, which had been re-estimated for 2002-2012 (Table 4).

In general, the L80 on the re-estimated maturity ogives were generally within 5 cm of the L50 and if used as a threshold for spawners would have favored identification of hotspots of small spawners. Instead, the CATT chose to focus the analysis on larger spawners which were thought to be more likely to have mature spawning behavior, higher fecundity, and better egg viability. Large spawners were identified using a threshold that larger fish made up about 20% of the total biomass in the 2002-2012 NMFS trawl surveys. Since growth at this size is typically slower than at younger ages, a single threshold was applied in all seasons for each species (see Table 8).

These transformed data were used to perform the G* hotspot analyses, following the steps outlined in Table 9. For each survey, species, and size range (juveniles and large spawners) a spatial autocorrelation analysis was performed to identify distances that had significant positive correlations. When they existed (see examples in Figure 20 to Figure 28), the first statistically significant peak was used to set the G* Zone of Indifference, defining the neighborhood that was considered for identifying clusters. At other times, there was no first peak in autocorrelation and the maximum peak was used instead. Generally, if there was no statistically significant spatial autocorrelation, the G* procedure also failed to identify any clusters or hotspots. The zone of indifference setting for each G* analysis performed is listed in Table 10.

Two important choices or assumptions were made in the hotspot analysis. One of these choices is the neighborhood of tows considered to be a potential hotspot. There are a variety of choices ranging from a fixed distance, inverse distance weighting, to a zone of indifference (with inverse distance weighting). The choice made by the CATT after considerable sensitivity analysis was a zone of indifference determined by a local maximum ("first peak") spatial autocorrelation. Unlike a fixed distance application, the zone of indifference was valid for all tows because no tows had no neighboring tows, a key violation of a fixed distance model which frequently gave warnings using the survey data. Only significant ($p<=0.05$) hotspots with above average catches were selected for further use as a hotspot (see Figure 10; Map 1). No standard p-value is available to determine significance, although p-values less than 0.05 were examined as a sensitivity analysis. For redfish, the hotspots tended to contract to a more centralized location in the Western Gulf of Maine with lower p-values.

Since the ultimate purpose of this analysis is to identify areas where a reduction in fishing would reduce impacts on juvenile groundfish habitat and groundfish spawning, for a variety of large mesh groundfish species, the CATT needed a way to summarize the hotspots across species and in shapes that were amenable to combinations into area options. The hotspots for all surveys were summarized in 100 km2 grids, compatible with SASI model outputs.

Juvenile groundfish hotspots for each stock were given an importance weight (Table 1), a simple arithmetic sum of four factors: Stock vulnerability, sub-population characteristics, residency characteristics, and substrate affinity. Stock vulnerability was chosen as a measure of how close the stock biomass is to the target biomass, i.e. B_{msy}/B. Stocks at the target had a value of 1, while overfished stocks had a value of 2 or more. Sub-population characteristics, residency characteristics, and substrate affinity were assigned a score from 1 to 3 based on published information and EFH source documents. More details are provided in a difference SSC document. Vulnerability or characteristics that were unknown (UNK) or could not be assigned were given a mean score as a proxy value in the final weighting sum.

Hotspots, i.e. clusters of significantly above average catches, of large mature groundfish were given similar importance weights using the same factors as applied for juvenile groundfish, but without the substrate affinity classification (Table 2), because the CATT decided that other factors (water temperature, moon phase, etc.) were more important to spawning of many groundfish species than was substrate affinity. Stocks were excluded from the seasonal hotspot summary gridding during seasons when the stock was not spawning (Table 2).

These weighted hotspot results were then summed by season over all species to guide the CATT to design potential juvenile groundfish area management options. The characteristics of these areas as well as those proposed by the Habitat PDT and Oversight Committee were analyzed for the number of juvenile and large spawner groundfish hotspots, Z-infinity scores from the SASI model, species diversity, potential displacement of net fishery revenue, etc. Hotspot grids and potential areas were compared (Figure 11 to Figure 13) with presence of observed developing, ripe, and running ripe groundfish to verify their location with respect to observations of spawning condition fish. Similarly the CATT intends to compare egg distribution from the ECOMON project with the results of the hotspot analysis as verification and to refine the timing of potential spawning closures.

Table 1. Selection of and weighting factors applied to juvenile groundfish hotspot data to sum hotspots across species and develop area management options. The final weighting sum was applied to the gridded hotspots for each species shaded in red. Grey shaded rows designate species that are not managed by catch shares.

Stock (Red cells indicate selected stocks for Option 3)	Juvenile size threshold Age 0 and 1 length (90th percentile, cm)	Length at 20% female maturity (cm) (re-estimated by CATT)	Vulnerability of species (Bmsy/B)[1]	Sub-populations[2]	Residency[3]	Substrate[4]	Final Weighting Sum
GB Cod	24 (Sp), 34 (Fa)	36	14.11	2	1	3	20.11
GOM Cod	24 (Sp), 34 (Fa)	36	5.53	3	1	3	12.53
GB Yellowtail Flounder	13 (Sp), 15 (Fa)	25	9.39	1	2	1	13.39
CC/GOM Yellowtail Flounder	13 (Sp), 15 (Fa)	25	4.21	1	2	1	8.21
SNE/MA Yellowtail Flounder	13 (Sp), 15 (Fa)	25	0.77	1	2	1	4.77
GOM Winter Flounder	18 (Sp), 28 (Fa)	27	UNK	UNK	2	1	10.04
GB Winter Flounder	18 (Sp), 28 (Fa)	27	1.22	3	2	1	7.22
SNE/MA Winter Flounder	18 (Sp), 28 (Fa)	27	6.17	3	2	1	12.17
White Hake	34 (Sp), 39 (Fa)	25	1.21	UNK	2	1	6.04
GOM Haddock	24 (Sp), 34 (Fa)	28	1.71	1	1	3	6.71
GB Haddock	24 (Sp), 34 (Fa)	28	0.75	1	1	3	5.75
Witch Flounder	20 (Sp), 19 (Fa)	28	2.45	3	2	1	8.45
American Plaice	12 (Sp), 18 (Fa)	24	1.70	UNK	1	1	5.54
Pollock	23 (Sp), 32 (Fa)	39	0.46	2	2	2	6.46
Acadian Redfish	14 (Sp), 13 (Fa)	19	0.76	1	2	3	6.76
Atlantic Halibut	see winter flounder	NA	28.82	UNK	2	2	34.66
Ocean Pout	29	29[6]	12.05	UNK	1	2	16.88
Northern (GOM-GB) Windowpane Flounder	see yellowtail flounder	18	3.48	UNK	2	1	8.31
Southern (SNE-MA) Windowpane Flounder	see yellowtail flounder	18	0.69	UNK	2	1	5.52
Atlantic Wolffish	47	47[7]	3.48	UNK	UNK	2	8.99
Sum							208.52
Mean			**5.21**	**1.83**	**1.68**	**1.70**	**10.43**

[1]Either SSBmsy/SSB or Bmsy/B used depending on what is reported in the assessment

[2]Derived from Table 81 in Framework 48 or from NEFSC biological data. 1=no subpopulations, 2=some evidence, 3=known subpopulations

[3]Based on information in literature. 1=less resident, more migratory; 2=more resident, less migratory

[4]Based on information in literature. 1=almost exclusively in mud or sand substrates, 2=occur in a variety of substrates including gravels, 3=strong affinity for coarse or hard substrates

[5]Sums include a mean value for unknowns

[6] From O'Brien et al. (1993)

[7] From Templeman (1986)

Table 2. Selection of and weighting factors applied to large spawner groundfish hotspot data to sum hotspots across species and develop area management options. The final weighting sum was applied by season to the gridded hotspots for each species shaded in red. Grey shaded rows designate species that are not managed by catch shares.

Stock	Large spawner threshold (20% of total biomass)	Length at 80% female maturity (cm) (re-estimated by CATT)	Vulnerability of species (Bmsy/B)[1]	Sub-populations[2]	Residency[3]	Final weighting Sum[4]	Spring multiplier	Summer multiplier	Fall multiplier	Winter multiplier
GB Cod	75	52	14.11	2	1	17.1	1	1	0	1
GOM Cod	75	52	5.53	3	1	9.5	1	1	0	1
GB Yellowtail Flounder	40	30	9.39	1	2	12.4	1	0	0	0
CC/GOM Yellowtail Flounder	40	30	4.21	1	2	7.2	1	0	0	0
SNE/MA Yellowtail Flounder	40	30	0.77	1	2	3.8	1	0	0	0
GOM Winter Flounder	45	31	UNK	UNK	2	9.0	1	0	0	1
GB Winter Flounder	45	31	1.22	3	2	6.2	1	0	0	1
SNE/MA Winter Flounder	45	31	6.17	3	2	11.2	1	0	0	1
White Hake	75	45	1.21	UNK	2	5.0	1	0	0	0
GOM Haddock	50	40	1.71	1	1	3.7	1	0	0	0
GB Haddock	50	40	0.75	1	1	2.7	1	0	0	0
Witch Flounder	45		2.45	3	2	7.5	1	1	1	0
American Plaice	40	32	1.70	UNK	1	4.5	1	0	0	0
Pollock	75	52	0.46	2	2	4.5	0	0	0	1
Acadian Redfish	30	25	0.76	1	2	3.8	1	1	0	0
Atlantic Halibut	45	NA	28.82	UNK	2	32.7	1	1	1	1
Ocean Pout	60	NA	12.05	UNK	1	14.9	0	1	1	1
Northern (GOM-GB) Windowpane Flounder	30	24	3.48	UNK	2	7.3	1	1	1	1
Southern (SNE-MA) Windowpane Flounder	30	24	0.69	UNK	2	4.5	1	1	1	1
Atlantic Wolffish	45	NA	3.48	UNK	UNK	7.0	1	0	0	0
Sum						174.5	18	8	5	10
Mean			**5.21**	**1.83**	**1.68**	**8.73**				

[1]Either SSBmsy/SSB or Bmsy/B used depending on what is reported in the assessment

2Derived from Table 81 in Framework 48 or from NEFSC biological data. 1=no subpopulations, 2=some evidence, 3=known subpopulations

3Based on information in literature. 1=less resident, more migratory; 2=more resident, less migratory

4Sums include a mean value for unknowns

The CATT also examined the suitability of sea sampling data and tagging data for this purpose as well. Sea sampling data were not suitable for this purpose because large areas are undersampled due to regulatory effects of area closures, regional catch limits, or other factors. To analyze catch distributions, the sea sampling data would further more have to be standardized with respect to vessel, gear, and possibly other factors. If not properly adjusted, clusters or hotspots using these data may have biases that identify areas where a single large vessel with large gear frequently fishes, rather than a localized high abundance or biomass of fish. Sea sampling data would also have very limited utility for analyzing distributions of groundfish due to selectivity.

Tagging data is potentially useful from two perspectives. Often, ripe and running ripe fish are identified by external examination (Figure 5). When the tag return data are adjusted for fishing effort to account for varying opportunities to catch tagged fish, the information could be useful to determine retention rates in existing or potential future closed areas. Fish that are retained for longer periods would tend to benefit more from closures than more transient fish. Unfortunately, the existing tag data tends to be relatively inaccessible (behind a Unix firewall in a foreign SQL data base), are not effort adjusted, and most tagging is done on only a few species. So the CATT felt that the tagging data had limited utility for identification of persistent spawning aggregations.

Other information was also examined or analyzed. Literature about regional groundfish spawning was examined, compiled, and taken into consideration (see Table 3and Figure 1 to Figure 5 below). Most papers were fairly general or focused on specific areas. A few, for example Ames 2004 and Deese 2005, provide broad-scale evaluation of spawning distributions, observed by fishermen. Working with Sam Truesdell at Universtiy of Maine Orono, the CATT also conducted a juvenile habitat association analysis for Gulf of Maine cod and Georges Bank cod and yellowtail flounder, applying a general additive model approach. Information from these sources was considered during the analysis and interpretation of the hotspot analysis results, but are not being reviewed in depth by the SSC.

With assistance from Owen Liu of EDF, the CATT also examined four case studies around the world where spatial management was employed in temperate fisheries that are managed with quotas. Conclusions about those studies may help influence the overall design of juvenile groundfish habitat and spawning areas.

Lastly, working with Sam Truesdell of University of Maine, Orono, the CATT developed an exploratory analysis of habitat association for three stocks: Gulf of Maine cod, Georges Bank cod, and Georges Bank yellowtail flounder. The results of this analysis were promising and for the Gulf of Maine largely corroborated the CATT's hotspot analysis for juvenile cod. A full report of this analysis is presented in a different SSC document. The results were not quantitatively used to design and propose juvenile groundfish area management options, but provided support for the options that were developed, particularly for a coastal juvenile groundfish habitat area option.

Based on the above analyses, the CATT proposed two area management options to conserve juvenile groundfish habitat. One option (Figure 14) includes all areas in the Gulf of Maine in depths less than 90 m and within 15 nm of the coastline. A second option (Figure 15) is a network of areas that include most of the weighted hotspots from the above analysis. These area management options would be applied year round to protect vulnerable juvenile groundfish habitat, even though some groundfish species utilize the habitat on a seasonal basis.

The CATT also proposed three area management options to reduce impacts on large spawning groundfish. These management options would limit fishing activity for gears capable of catching groundfish to reduce impacts on spawning behavior and activity of large mature groundfish.

One spawning area option (Figure 16) is a network of areas that encompass the majority of the weighted hotspots. These areas would close seasonally. Areas in the Western Gulf of Maine would close following a similar seasonal progression as the existing rolling closures they would replace. A second spawning area option (Figure 17 to Figure 19) is a modification of the existing rolling closures for sector vessels, which would include all of the existing Western Gulf of Maine area and run from March to June (instead of April to June). A third option would retain a spring closure for the existing Western Gulf of Maine area and all of Closed Area II.

Table 3. Summary of groundfish spawning and habitat associations.

	Identified Spawning Locations	Spawning Notes	Habitat Area Location/Characteristics	Habitat Notes
Cod	Gulf of Maine: Ames Study Areas (Ames 2004). Ipswich Bay (specific spawning aggregation at Whaleback feature)(Siceloff and Howell 2012). Cape Cod Bay, western Maine coast, Jeffries Ledge and Northern Mass. Bay (Deese 2005 and Dean et al. 2012), inshore aggregations in Area 133 in the western GOM (Morin 2000) Georges Bank: concentrated in the Northeast area (mostly gravel and complex relief levels)(Berlinsky 2009).	Spring spawning in northern GOM (Berlinsky 2009). Fall spawning in inshore areas from Cape Cod to Nantucket Shoal (Deese 2005). Winter spawning in southern GOM and Coxes Ledge (Deese 2005). Spawning occurs year-round but with peaks in the summer and from Nov – Feb (Tallack 2008). Spring and winter spawning in western GOM (Berlinsky 2009 and Morin 2000). Peak Georges Bank spawning activity occurs in February-March (Lough 2010)	Juveniles (age 0-1) prefer gravel substrates with lower bathymetric relief (Gregory et al. 1997) Older and larger cod would move to coarse substrates with higher bathymetric relief, such as humps and ridges (Gregory et al. 1997). Ipswich Bay, Mass. Bay and Cape Cod Bay (Howe et al 2002). Spread across Georges Bank in early summer, constant concentration in NE Georges Bank (Lough 2010).	Age 0 cod prefer shallower depths (<90') and move to deeper waters both in autumn and as they grow older (Howe et al. 2002) Young juveniles would hide in cobble to avoid predators, and would partially remain after the threat was removed (Gotceitas and Brown, 1993).
Haddock	Georges Bank: Concentrated in Eastern and Northeastern areas (Overholtz 1987).	Peak spawning in Georges Bank from late March-early April (Overholtz 1987) Ideal temperatures from 4-7°C at depths from 28-110' (Overholtz 1987)	Spread throughout Georges Bank	As pelagic juveniles grow, they move deeper in the water column (Lough and Potter 1994).
Yellowtail Flounder			Eastern Georges Bank, specifically within Closed Area II. (Pereira et al 2012)	Occupied area in Georges Bank doubled from ~4000 to ~8000 km² when abundance increased (Pereira et al 2012)

Winter Flounder	Plymouth Bay (minor activity in Plymouth Estuary) (DeCelles and Cadrin 2010)	Peak spawning in March-May in the Plymouth Bay (DeCelles and Cadrin 2010)		

Additional figures

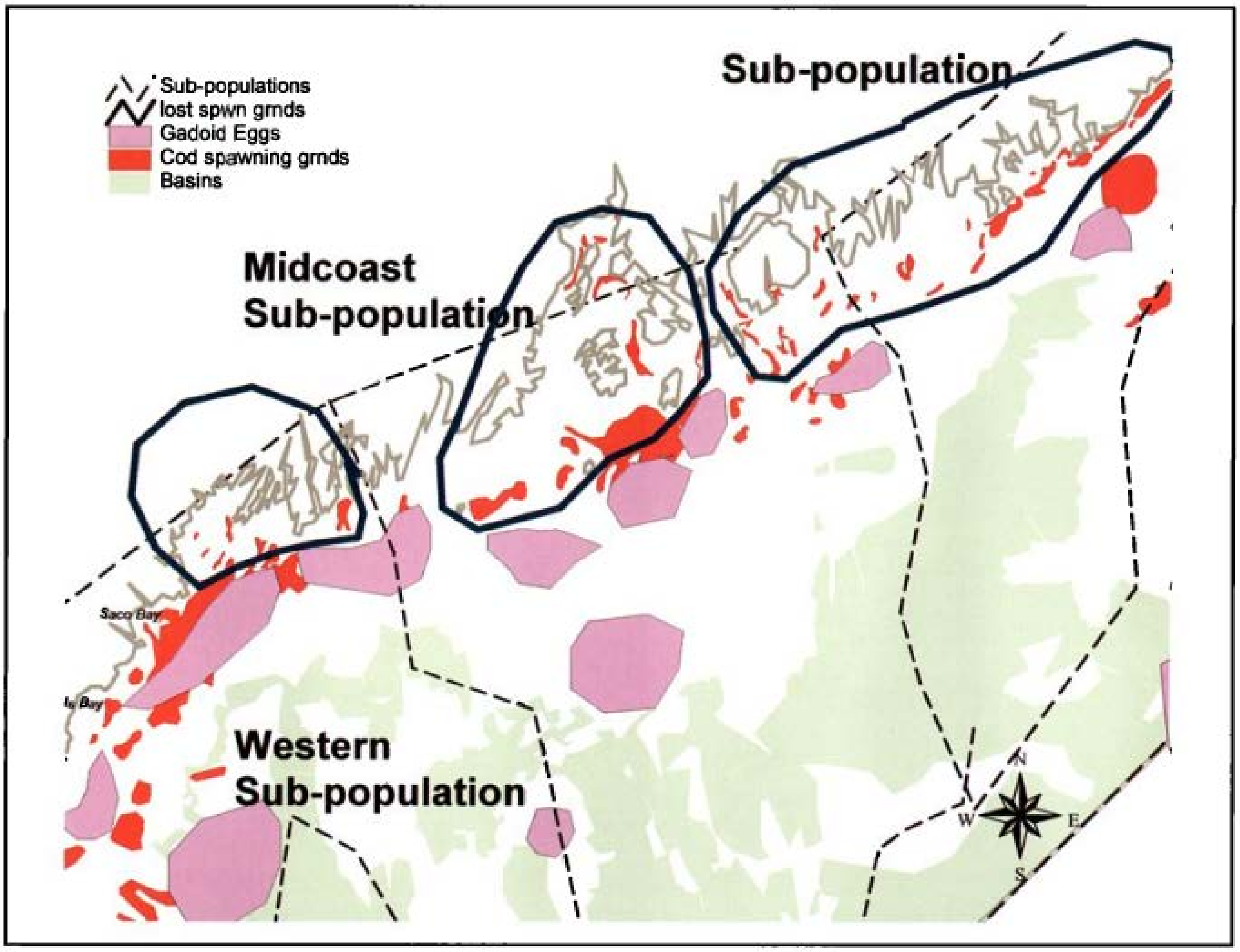


Figure 1. Map of indicated cod spawning areas. Circled areas indicate former spawning grounds that are no longer active. Ames, 2004.

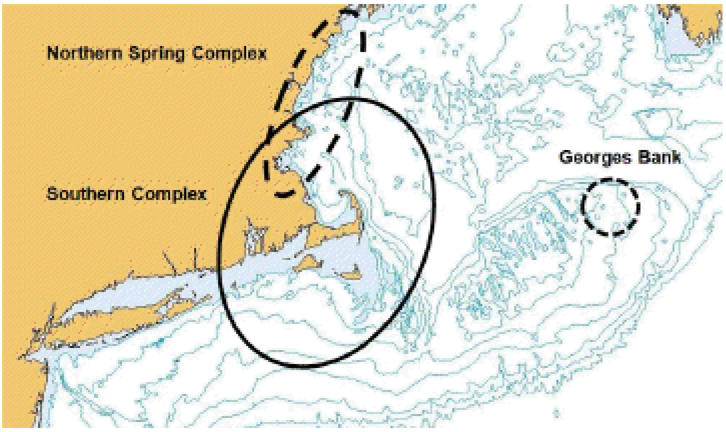


Figure 2. Proposed cod spawning complexes. Berlinsky, 2005.

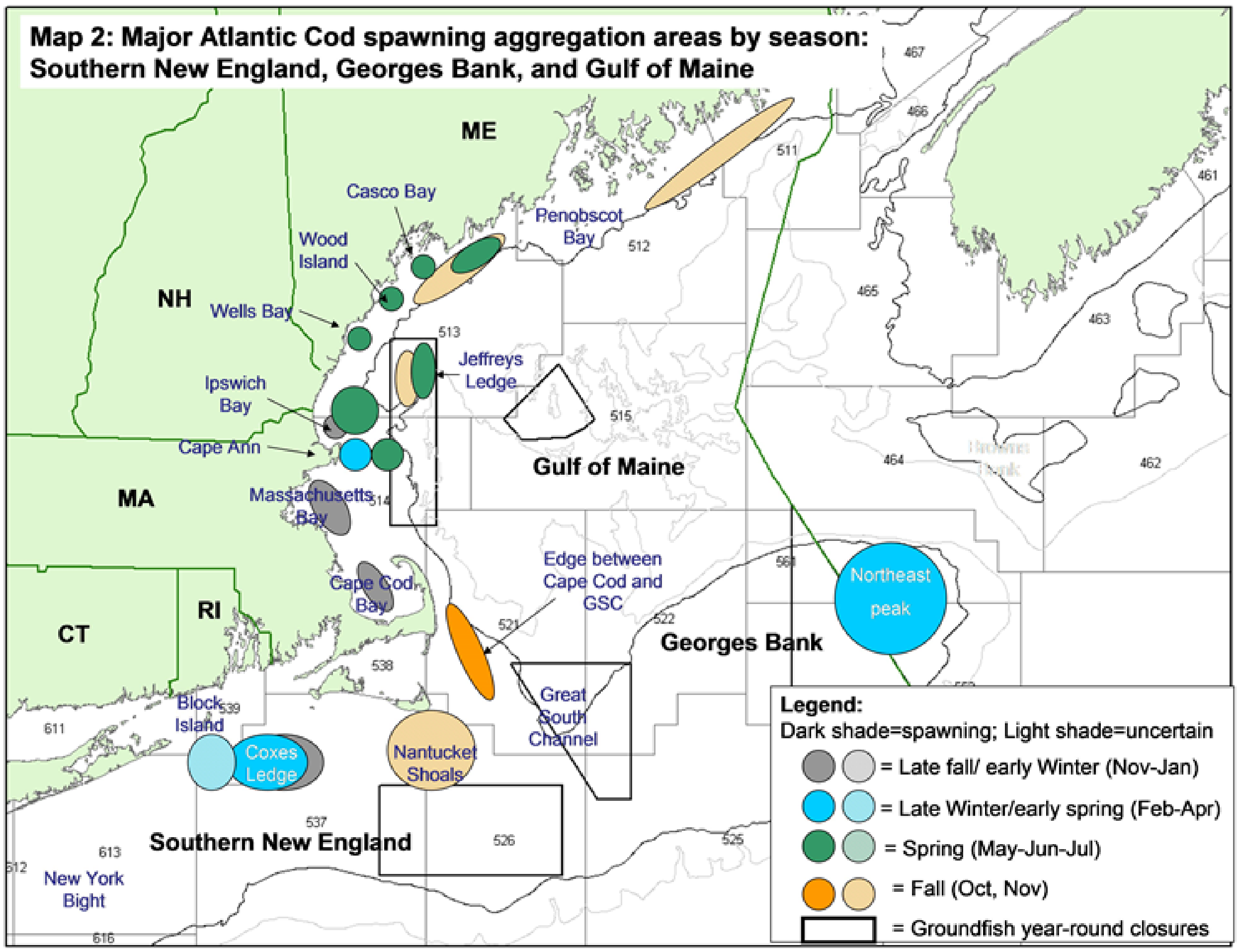


Figure 3. Summary of cod spawning areas. Deese, 2005.

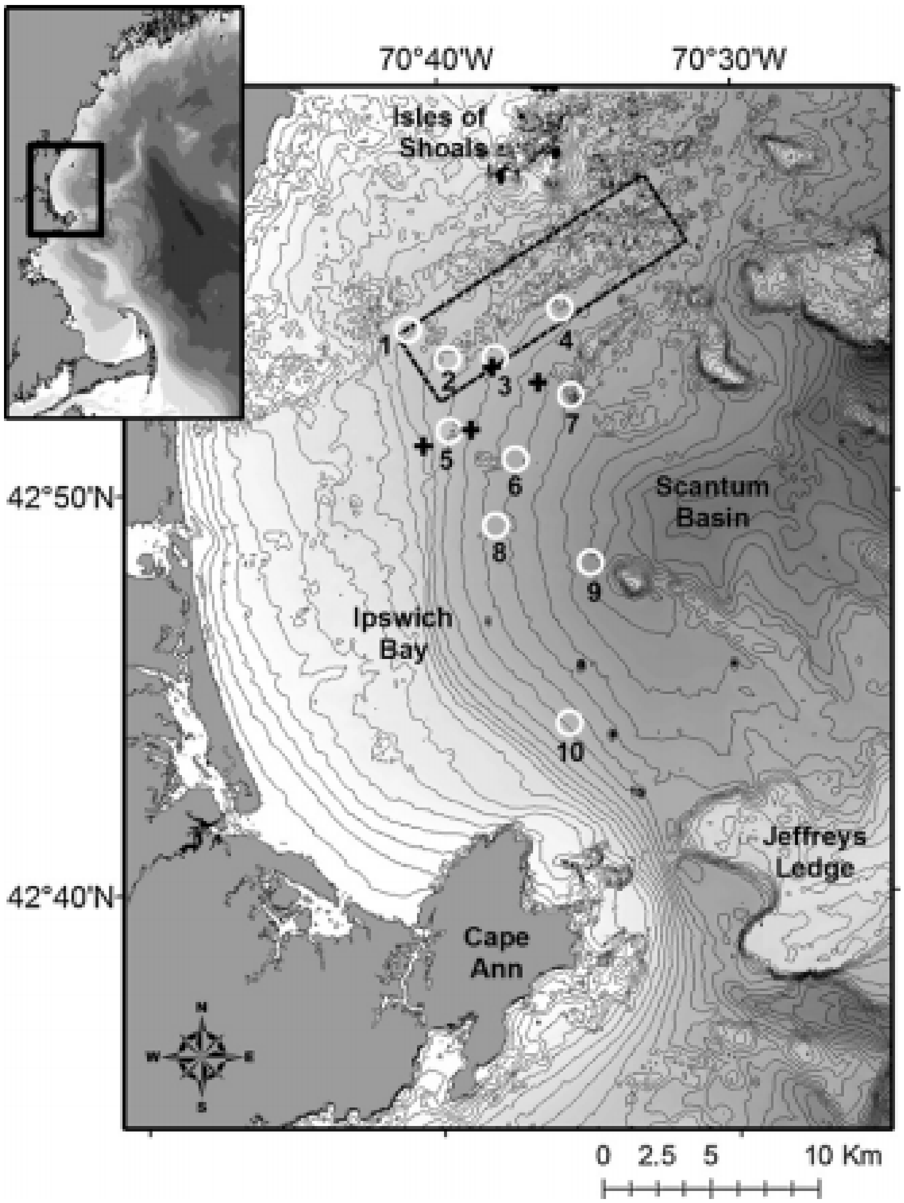


Figure 4. Bathymetric map of Ipswich Bay. Black dotted rectangle highlights the elevated bathymetric feature "Whaleback". Siceloff and Howell, 2012.

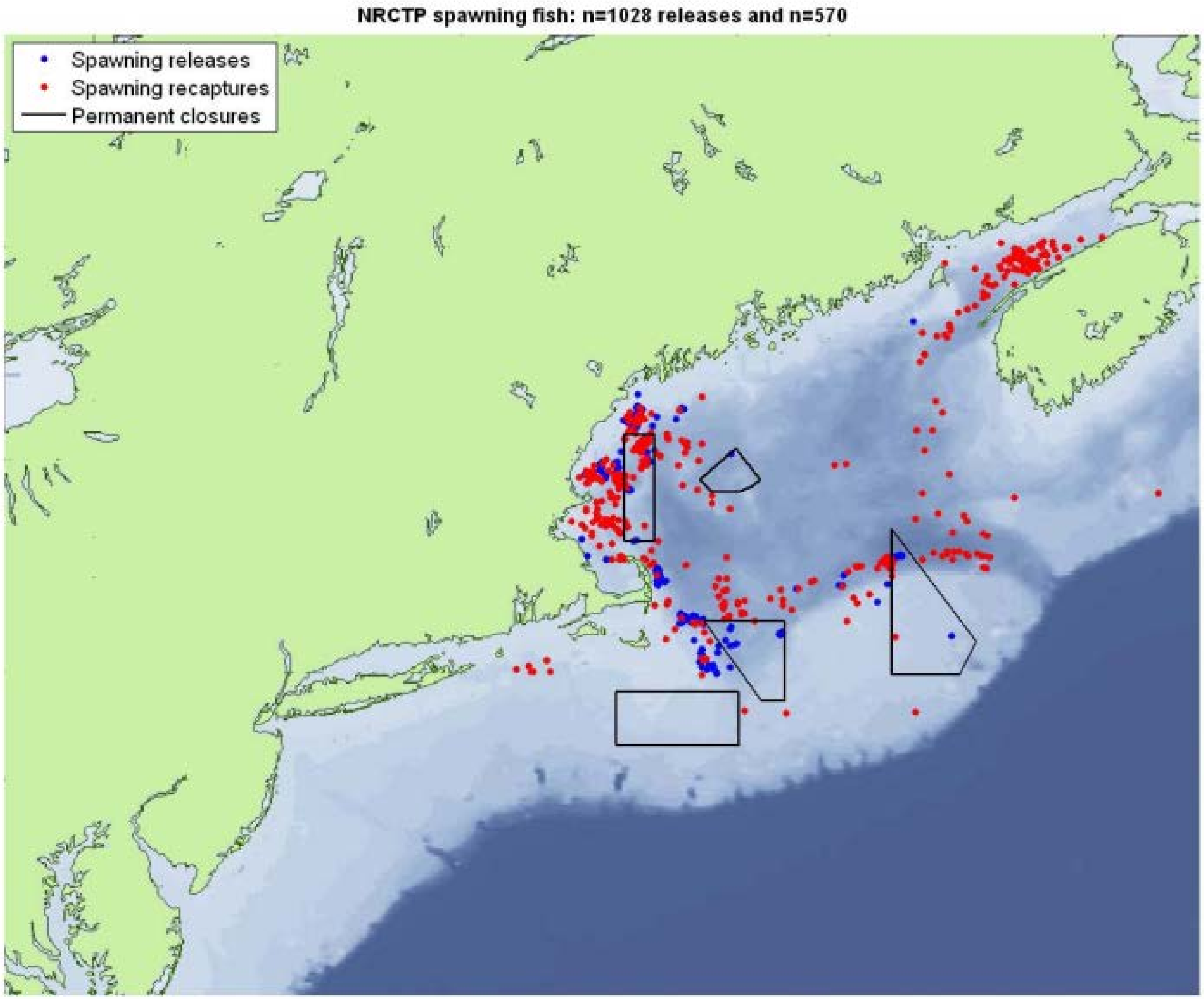


Figure 5. The distribution of tagged cod releases and recaptures in spawning condition, relative to closed areas and across all years. Tallack, 2008.

Juveniles and adults were distinguished based on lengths-at-maturity for each species, which was defined according to the length at which 50% of the fish in a population mature sexually. For most species, these sizes vary by sex and stock units. They also vary over time, according to changes in growth rate, sometimes considerably. Lengths used to distinguish juveniles and adults for most species were based on data reported by O'Brien et al. (1993). Lengths at maturity for the skate species were based on information included in EFH source documents. These lengths are listed in Table 4. In most cases, O'Brien et al. based 50% lengths at maturity on females; if there was more than one size available because of analyses that were performed at different time periods or for different stocks, they were averaged.

$$r(l) = \{ \exp(a + bl) / [1+\exp(a + bl)] \}$$

Table 4. Lengths-at-maturity used to distinguish juveniles and adults in EFH designations. Juveniles are less than the specified length; adults are equal to or larger.

Species	***Length (cm) at 50% Maturity O'Brien et al. (1993) and EFH Skate Source Document***	***Length (cm) at maturity (rounded to nearest 5 cm for analysis of juvenile and spawning distributions)*** ***Calculated from parameters in latest assessment, generally GARM III*** ***Red values are average L20/L50 and L80/L50 ratios of other species***			***Approximate length (rounded up to 5 cm increment) at greater than 80% Maturity from 2002-2012 spring and fall trawl survey data***
		L20	***L50***	***L80***	
American Plaice	27	23.6 (25)	27.6	31.6 (30)	30
Atlantic Cod	35	35.4-36.8 (35)	43-44.5	49.2-53.6 (50)	50
Atlantic Herring	25	(20)	NA	(25)	25
Barndoor Skate	102	(85)	NA	(115)	115*
Clearnose Skate	61	(50)	NA	(70)	
Deep-sea Red Crab	8		NA		
Goosefish	43	(35)	NA	(45)	45
Haddock	32	28.2-28.3 (30)	33-34.7	37.8-41.1 (40)	40
Little Skate	50	(45)		(55)	
Ocean Pout	29				
Offshore Hake	30	(25)		(35)	
Pollock	39	38.8 (40)	45.4	51.9 (50)	45
Red Hake	26	(20)		(35)	35
Redfish	22	19.2 (20)	22.0	24.8 (25)	25
Rosette Skate	46	(40)		(55)	
Sea Scallop	10				
Silver Hake	23	(20)		(30)	30
Smooth Skate	56	(50)		(65)	
Thorny Skate	84	(70)		(95)	

Species	***Length (cm) at 50% Maturity O'Brien et al. (1993) and EFH Skate Source Document***	***Length (cm) at maturity (rounded to nearest 5 cm for analysis of juvenile and spawning distributions) Calculated from parameters in latest assessment, generally GARM III Red values are average L20/L50 and L80/L50 ratios of other species***			***Approximate length (rounded up to 5 cm increment) at greater than 80% Maturity from 2002-2012 spring and fall trawl survey data***
		L20	***L50***	***L80***	
White Hake	35	25.0 (25)	35.1	45.2 (45)	60
Windowpane	22	17.5-18.2 (20)	20.5-21.3	23.5-24.4 (25)	
Winter Flounder	27	26.7 (25)	29-29.1	31.1 (30)	30
Winter Skate	85	(70)		(95)	
Witch Flounder	30	28.1 (30)	32.9	31.1 (40)	40
Yellowtail Flounder	27	24.6-25.8 (25)	27.4-28.2	30.2-30.7 (30)	30

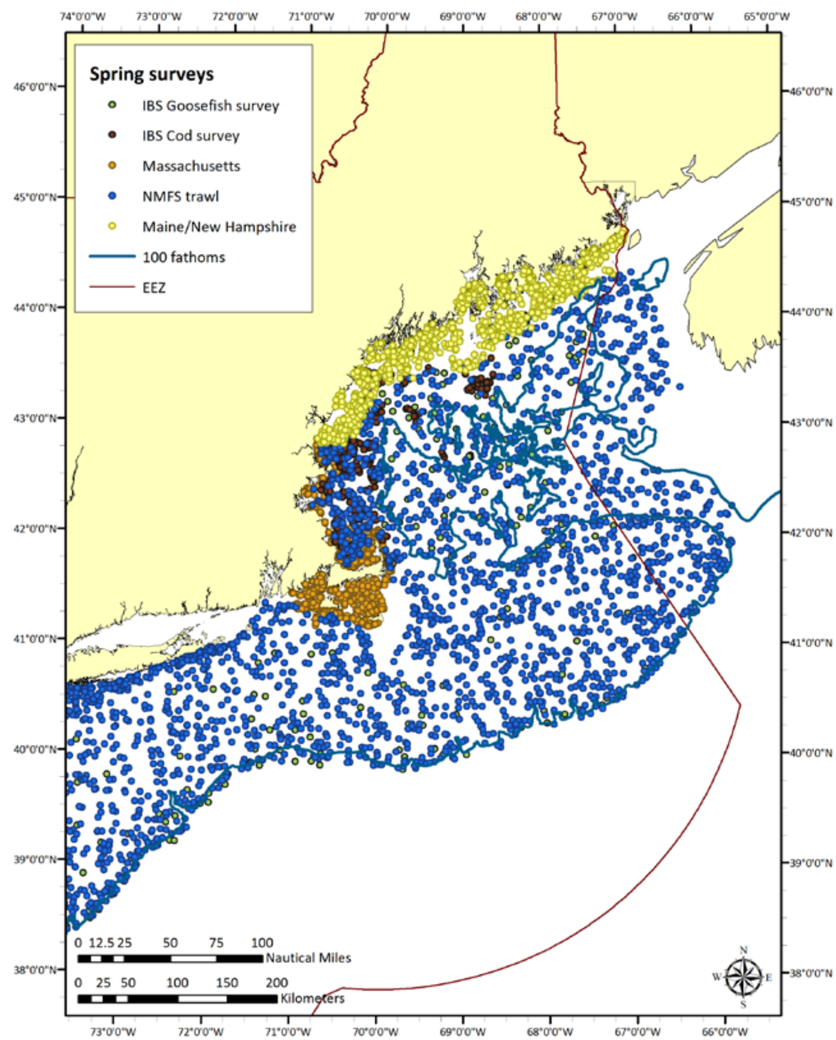
Wolffish – 47 cm (Templeman 1986)

Table 5. Cumulative proportion of abundance at age by species, survey, and stock area. First line of data represents an approximate L20 for each species. Second line of data represents a size that approximates the 90th percentile of age 1 fish (some species use age 2) for the predominate stock area for each species.

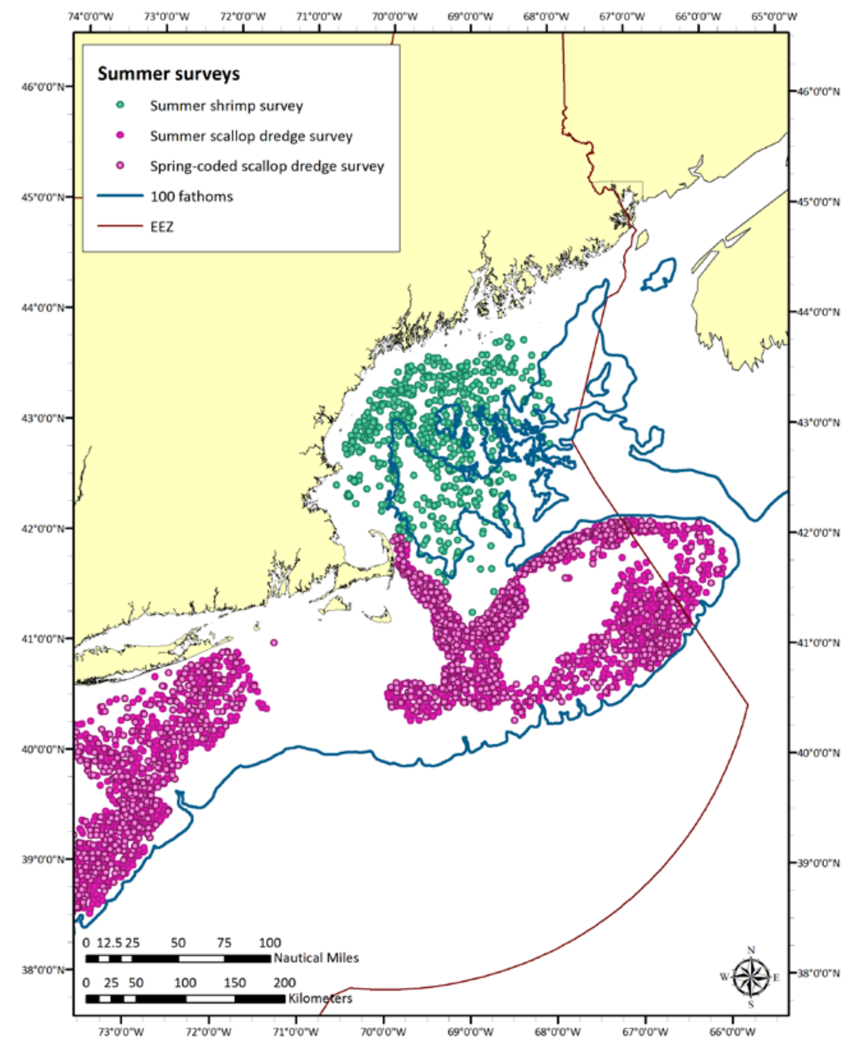
	Spring 2002-2012		Region															
	Fall 2002-2011		Age															
			Mid-Atlantic				**Georges Bank**				**Gulf of Maine**				**Scotian Shelf**			
Species	Survey	Length (cm)	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**
American plaice	Spring	25						100.0%	99.4%	63.4%		100.0%	99.5%	86.3%		100.0%	98.6%	85.1%
		12						91.5%	4.3%	0.0%		84.2%	2.6%	0.0%		90.5%	0.0%	0.0%
	Fall	25					100.0%	100.0%	86.9%	37.7%	100.0%	100.0%	98.1%	65.7%	100.0%	100.0%	97.1%	57.1%
		18					100.0%	89.6%	16.4%	1.0%	100.0%	98.2%	35.4%	1.7%	100.0%	98.0%	16.2%	0.0%
Atlantic cod	Spring	35	100.0%	100.0%	15.0%	0.0%	100.0%	99.7%	29.5%	0.8%	100.0%	100.0%	75.9%	12.1%	100.0%	100.0%	45.8%	2.2%
		24	100.0%	41.4%	0.0%	0.0%	100.0%	65.2%	0.7%	0.0%	100.0%	90.6%	14.7%	0.0%	100.0%	95.3%	1.0%	0.0%
	Fall	35	100.0%		0.0%	0.0%	100.0%	66.4%	2.0%	0.0%	100.0%	94.0%	29.2%	2.7%	100.0%	84.9%	13.3%	2.7%
		34	100.0%		0.0%	0.0%	100.0%	58.6%	1.4%	0.0%	100.0%	91.3%	25.3%	1.5%	100.0%	80.2%	10.7%	0.0%
Atlantic herring	Spring	20		100.0%	99.5%	65.5%		100.0%	99.8%	73.1%	100.0%	100.0%	99.8%	75.8%		100.0%	100.0%	70.6%
		9		100.0%	0.3%	0.0%		91.7%	0.2%	0.0%	100.0%	94.1%	1.1%	0.0%		90.0%	7.1%	0.0%
	Fall	20		100.0%	84.2%	66.7%		100.0%	81.8%	12.0%		100.0%	84.1%	11.8%		100.0%	90.6%	10.2%
		16		100.0%	0.0%	0.0%		95.8%	3.2%	0.0%		96.9%	8.1%	0.0%		100.0%	10.4%	0.0%
Goosefish	Spring	35			100.0%	100.0%			100.0%	100.0%		100.0%	100.0%	100.0%			100.0%	
		28			100.0%	84.2%			100.0%	92.3%		100.0%	100.0%	93.0%			100.0%	
	Fall	35	100.0%	100.0%	100.0%	76.9%	100.0%	100.0%	100.0%	54.5%	100.0%	100.0%	100.0%	70.0%	100.0%	100.0%	100.0%	
		26	100.0%	100.0%	90.9%	0.0%	100.0%	100.0%	95.2%	0.0%	100.0%	100.0%	77.8%	0.0%	100.0%	100.0%	100.0%	
Haddock	Spring	30		100.0%	0.0%			99.9%	48.0%	7.5%		100.0%	35.9%	3.5%		100.0%	56.9%	11.7%
		24		67.4%	0.0%			88.6%	7.8%	0.0%		93.3%	1.4%	0.0%		95.0%	6.4%	3.3%
	Fall	30	100.0%	0.0%			100.0%	68.5%	10.5%	0.2%	100.0%	77.4%	4.9%	0.4%	100.0%	83.9%	8.1%	0.0%
		34	100.0%	100.0%			100.0%	93.5%	29.3%	7.8%	100.0%	97.4%	27.6%	3.3%	100.0%	99.1%	45.1%	9.4%
Ocean pout (all years)	Spring	29		100.0%	11.1%	3.8%		100.0%	18.8%	0.0%				75.0%				66.7%
	Fall																	
Pollock	Spring	40		100.0%	100.0%	100.0%		100.0%	100.0%	58.8%		100.0%	100.0%	88.0%		100.0%	100.0%	100.0%
		23		100.0%	70.0%	0.0%		78.9%	40.4%	0.0%		95.7%	21.5%	0.0%		95.5%	18.2%	0.0%
	Fall	40	100.0%	100.0%			100.0%	100.0%	87.1%	15.7%	100.0%	100.0%	91.8%	35.5%	100.0%	100.0%	89.6%	16.7%
		32	100.0%	100.0%			100.0%	89.5%	19.4%	0.0%	100.0%	96.7%	40.1%	1.8%	100.0%	93.3%	22.9%	0.0%
Red hake	Spring	20		91.7%	0.0%	0.0%		83.3%	0.0%	0.0%		95.0%	10.0%	0.0%		100.0%	20.0%	0.0%
		20		91.7%	0.0%	0.0%		83.3%	0.0%	0.0%		95.0%	10.0%	0.0%		100.0%	20.0%	0.0%
	Fall	20	100.0%	11.1%	0.0%	0.0%		6.7%	0.0%	0.0%	100.0%	35.2%	0.0%	0.0%	100.0%	12.5%	0.0%	
		28	100.0%	88.9%	30.0%	25.0%		93.3%	14.8%	4.0%	100.0%	92.6%	37.0%	2.2%	100.0%	87.5%	0.0%	
Redfish (all years)	Spring	20		100.0%		100.0%	0.0%		100.0%	100.0%		100.0%	100.0%	100.0%			100.0%	100.0%
		14		100.0%		33.3%	0.0%		100.0%	17.6%		100.0%	90.9%	72.7%			100.0%	50.0%
(2002-2011)	Fall	20						100.0%	100.0%	100.0%		100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
		13						100.0%	92.6%	31.1%		100.0%	93.9%	29.5%		100.0%	100.0%	30.7%
Silver hake	Spring	20		94.6%	16.8%	0.0%		96.8%	31.8%	0.0%		98.6%	40.0%	0.1%		97.7%	44.0%	0.0%
		19		90.5%	12.7%	0.0%		93.2%	27.2%	0.0%		95.8%	32.6%	0.0%		93.1%	40.7%	0.0%
	Fall	20	98.7%	22.0%	0.0%	0.0%	100.0%	19.0%	0.0%	0.0%	100.0%	26.7%	0.0%	0.0%	100.0%	15.8%	0.0%	0.0%
		26	100.0%	87.1%	30.6%	0.0%	100.0%	91.0%	31.2%	5.1%	100.0%	91.4%	28.6%	3.3%	100.0%	86.7%	30.7%	3.0%
White hake	Spring	25			0.0%	0.0%		4.3%	0.0%	0.0%		26.3%	7.2%	0.0%			13.2%	0.0%
		34			25.0%	0.0%		78.3%	7.9%	0.0%		90.9%	55.8%	10.8%			83.8%	25.0%
	Fall	25		50.0%	0.0%	0.0%	77.4%	1.5%	0.0%	0.0%	46.3%	23.5%	0.0%	0.0%	100.0%	49.1%	0.0%	0.0%
		39		100.0%	25.0%	0.0%	100.0%	82.1%	32.1%	0.0%	100.0%	94.0%	27.0%	0.0%	100.0%	100.0%	43.1%	0.0%
Winter flounder	Spring	25		100.0%	44.5%	4.5%		100.0%	60.3%	10.3%		100.0%	97.8%	57.2%		100.0%	100.0%	79.3%
		18		92.6%	4.7%	0.0%		94.3%	6.6%	0.0%		97.5%	40.0%	4.7%		90.0%	44.1%	3.0%
	Fall	25		88.9%	19.2%	0.0%	100.0%	75.6%	8.6%	0.1%	100.0%	100.0%	77.0%	19.0%		100.0%	96.1%	45.2%
		28		99.2%	48.0%	4.2%	100.0%	91.8%	25.3%	1.2%	100.0%	100.0%	93.2%	50.4%		100.0%	98.7%	86.3%
Witch flounder	Spring	30			100.0%	100.0%		100.0%	100.0%	100.0%		100.0%	100.0%	100.0%		100.0%	100.0%	100.0%
		20			100.0%	84.0%		100.0%	91.7%	18.2%		100.0%	74.3%	14.7%		100.0%	33.3%	8.6%
	Fall	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	84.6%	100.0%	100.0%	100.0%	88.0%	100.0%	100.0%	100.0%	66.7%
		19	100.0%	100.0%	53.3%	11.3%	100.0%	100.0%	0.0%	0.0%	100.0%	88.9%	7.3%	1.4%	100.0%	100.0%	11.1%	0.0%
Yellowtail flounder	Spring	25		100.0%	23.6%	0.0%		100.0%	19.6%	0.0%		100.0%	62.0%	5.7%			30.0%	5.3%
		13		96.1%	0.0%	0.0%		92.5%	0.0%	0.0%		67.2%	0.0%	0.0%			0.0%	0.0%
	Fall	25	100.0%	95.9%	1.5%	0.0%	100.0%	80.8%	0.7%	0.0%	100.0%	91.1%	11.3%	0.3%	100.0%	25.0%	11.1%	0.0%
		15	73.7%	0.0%	0.0%	0.0%	93.2%	0.2%	0.0%	0.0%	100.0%	1.3%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%

Figure 6. Domain of surveys used in the hotspot analysis by season.

Spring

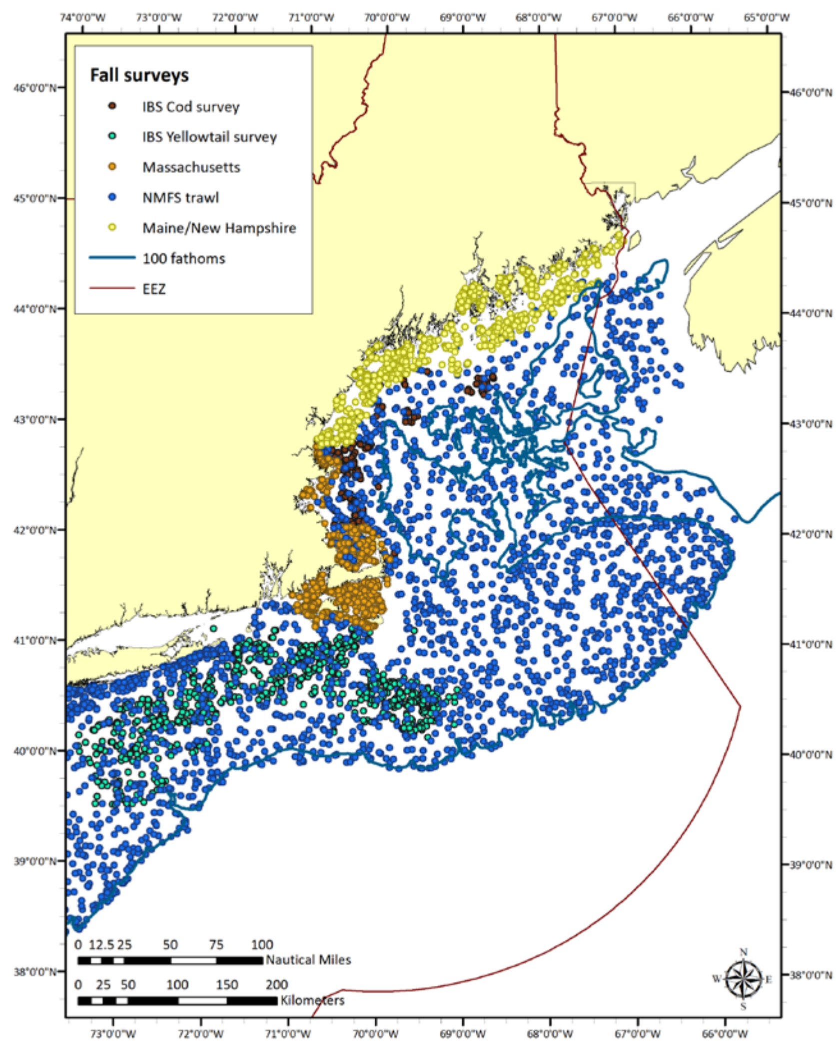


Summer



Fall

Winter


Fall surveys
IBS Cod survey
IBS Yellowtail survey
Massachusetts
NMFS trawl
Maine/New Hampshire
100 fathoms
EEZ
0 12.5 25 50 75 100 Nautical Miles
0 25 50 100 150 200 Kilometers

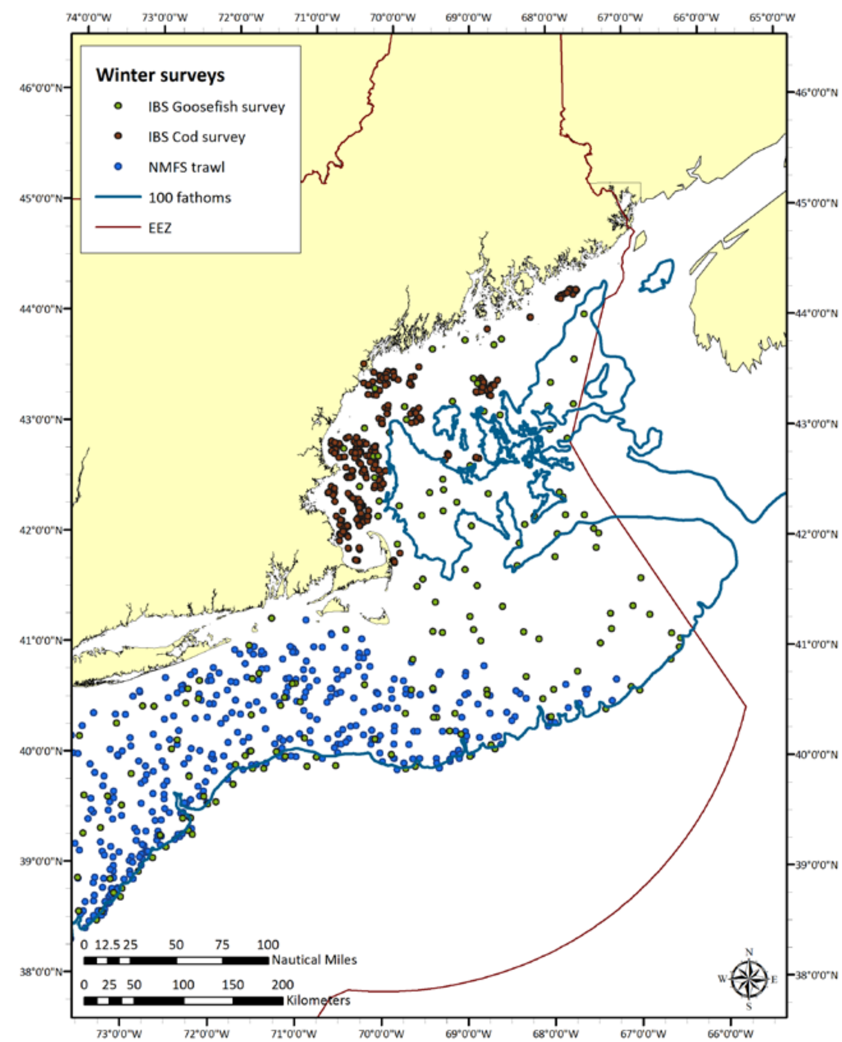

Winter surveys
IBS Goosefish survey
IBS Cod survey
NMFS trawl
100 fathoms
EEZ
0 12.5 25 50 75 100 Nautical Miles
0 25 50 100 150 200 Kilometers

Figure 7. Frequency distribution plots of 2002-2012 NMFS spring trawl catches of cod <= 25 cm. Top – untransformed kg/tow; Middle – Catches adjusted for the proportion of zero tows in strata; Bottom – Log transformed adjusted catches.

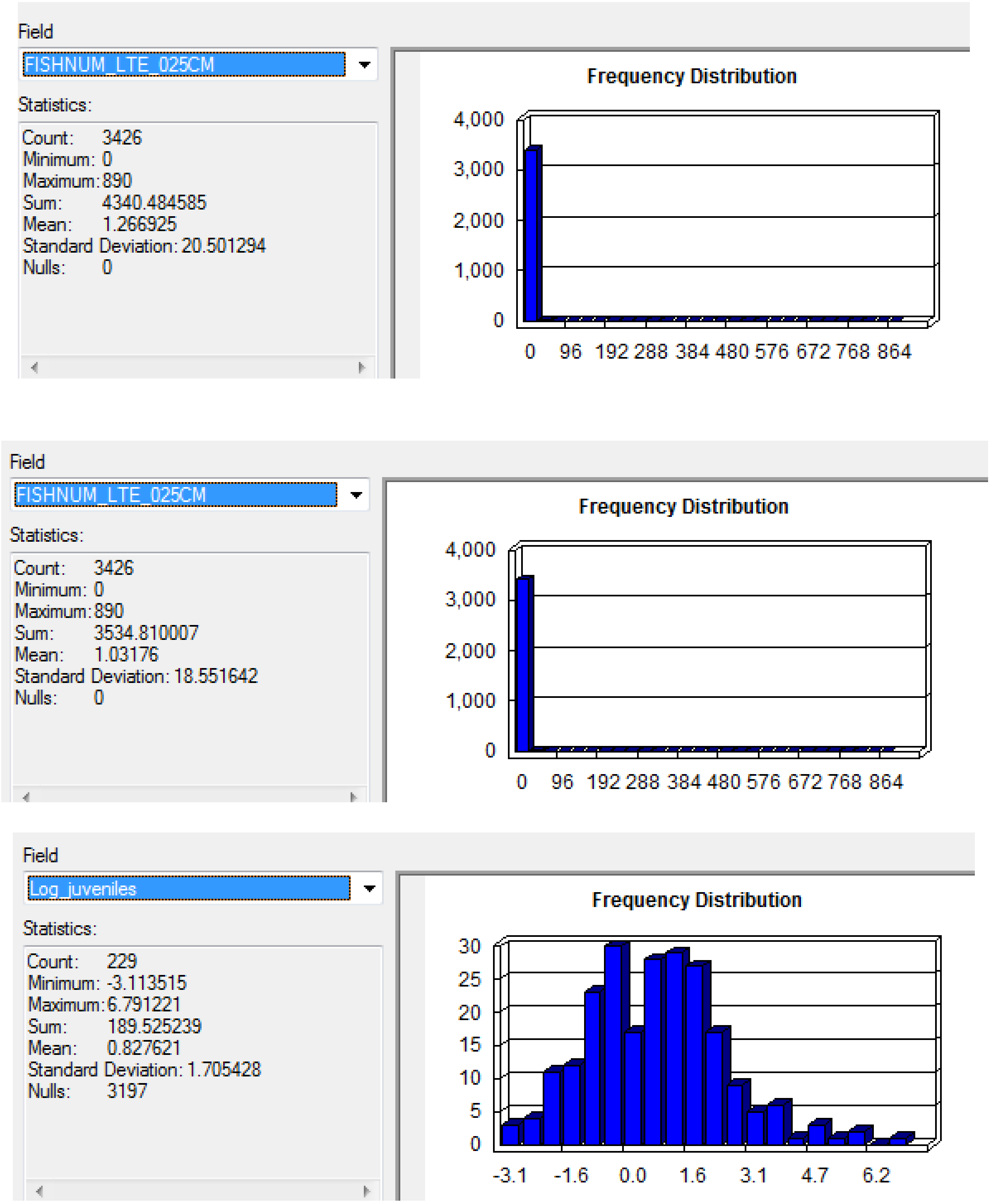


Table 6. Cumulative number of cod caught by survey over time by size range, compared to 20 percent of total abundance.

COMNAME	ATLANTIC COD							
REGION	(Multiple Items)							
Row Labels	20Pct total num	Num <= 5 cm	Num <= 10 cm	Num <= 15 cm	Num <= 20 cm	Num <= 25 cm	Num <= 30 cm	Num <= 35 cm
IBS Cod Spawning	**713**	**0**	**1**	**46**	**200**	**309**	**610**	**1,340**
WINTER	**353**	**0**	**1**	**31**	**99**	**128**	**270**	**737**
2002-2012	353	0	1	31	99	128	270	737
SPRING	**360**	**0**	**0**	**15**	**101**	**181**	**340**	**603**
2002-2012	360	0	0	15	101	181	340	603
NMFS trawl	**19,013**	**1,824**	**4,110**	**6,547**	**9,888**	**14,750**	**22,563**	**32,232**
WINTER	**602**	**2**	**21**	**98**	**247**	**419**	**514**	**599**
1963-1971	314	1	20	32	61	118	159	210
1972-1981	92	0	0	0	1	14	22	26
1992-2001	153	1	1	6	34	94	132	162
2002-2012	44	0	0	60	152	194	200	201
SPRING	**9,157**	**1,692**	**1,815**	**2,339**	**3,983**	**6,797**	**10,455**	**14,481**
1963-1971	359	62	71	83	104	132	169	259
1972-1981	2,301	443	524	612	901	1,326	1,837	2,507
1982-1991	1,614	78	90	179	396	737	1,113	1,608
1992-2001	607	109	115	141	232	323	427	563
2002-2012	4,276	999	1,015	1,324	2,350	4,280	6,908	9,544
SUMMER	**1,486**	**39**	**339**	**440**	**603**	**910**	**1,355**	**1,849**
1963-1971	474	9	18	37	87	118	192	287
1972-1981	847	16	232	282	355	583	905	1,236
1982-1991	23	0	1	1	2	6	14	23
1992-2001	142	14	88	120	159	203	244	302
FALL	**7,767**	**91**	**1,936**	**3,670**	**5,055**	**6,623**	**10,240**	**15,304**
1963-1971	660	7	131	190	254	354	523	804
1972-1981	2,140	40	215	356	592	1,045	1,796	2,877
1982-1991	1,111	18	180	299	426	675	1,199	1,847
1992-2001	674	8	57	158	188	272	494	810
2002-2012	3,182	18	1,352	2,667	3,593	4,277	6,228	8,966
MADMF trawl	**38,071**	**136,436**	**162,095**	**166,907**	**172,556**	**178,159**	**181,176**	**183,722**
SPRING	**32,859**	**116,635**	**140,697**	**143,081**	**148,325**	**153,380**	**155,937**	**158,110**
1972-1981	3,072	4,436	8,954	9,685	11,532	12,971	13,542	14,042
1982-1991	1,382	1,383	1,921	2,440	3,155	4,127	4,824	5,319
1992-2001	3,374	9,900	12,231	12,645	13,756	14,940	15,365	15,831
2002-2012	25,032	100,916	117,592	118,312	119,882	121,342	122,206	122,919
FALL	**5,212**	**19,801**	**21,398**	**23,826**	**24,231**	**24,779**	**25,239**	**25,612**
1972-1981	1,874	7,580	7,716	8,444	8,544	8,789	9,006	9,202
1982-1991	1,845	8,230	8,731	8,892	8,981	9,102	9,159	9,201
1992-2001	563	1,124	1,535	2,668	2,709	2,746	2,766	2,787
2002-2012	929	2,867	3,416	3,822	3,996	4,142	4,308	4,423
Grand Total	57,796	138,260	166,206	173,500	182,644	193,218	204,348	217,294

Table 7. Cumulative weight of cod caught by survey over time by size range, compared to 20 percent of total weight.

COMNAME	ATLANTIC COD								
REGION	(Multiple Items)								
Row Labels	**20 pct total weight**	**Wgt >= 50 cm**	**Wgt >= 55 cm**	**Wgt >= 60 cm**	**Wgt >= 65 cm**	**Wgt >= 70 cm**	**Wgt >= 75 cm**	**Wgt >= 80 cm**	**Wgt >= 85 cm**	**Wgt >= 90 cm**
IBS Cod Spawning	**747**	**2,408**	**2,110**	**1,855**	**1,624**	**1,347**	**1,064**	**798**	**593**	**430**
WINTER	**219**	**315**	**184**	**117**	**94**	**50**	**28**	**7**	**7**	**0**
2002-2012	219	315	184	117	94	50	28	7	7	0
SPRING	**528**	**2,093**	**1,926**	**1,738**	**1,530**	**1,296**	**1,036**	**791**	**587**	**430**
2002-2012	528	2,093	1,926	1,738	1,530	1,296	1,036	791	587	430
NMFS trawl	**30,250**	**126,234**	**116,874**	**105,602**	**91,915**	**78,010**	**64,149**	**52,264**	**40,675**	**31,445**
WINTER	**1,654**	**7,744**	**7,421**	**6,875**	**6,273**	**5,663**	**5,002**	**4,400**	**3,594**	**2,866**
1963-1971	1,071	5,112	4,959	4,720	4,403	4,013	3,596	3,173	2,661	2,128
1972-1981	306	1,452	1,397	1,246	1,127	1,070	1,010	923	777	632
1992-2001	269	1,159	1,046	891	724	570	395	305	156	105
2002-2012	8	21	18	18	18	9	2	0	0	0
SPRING	**14,558**	**59,891**	**55,579**	**50,284**	**43,393**	**36,609**	**29,872**	**24,347**	**18,652**	**14,302**
1963-1971	1,141	5,430	5,229	4,938	4,517	4,148	3,620	3,126	2,501	1,990
1972-1981	4,480	18,878	17,665	16,273	14,448	12,238	10,391	8,984	7,183	5,748
1982-1991	3,639	16,391	15,546	14,307	12,278	10,593	8,661	6,889	5,323	4,055
1992-2001	1,387	6,317	5,887	5,359	4,720	4,063	3,341	2,706	1,977	1,462
2002-2012	3,911	12,875	11,253	9,408	7,430	5,567	3,860	2,642	1,668	1,047
SUMMER	**2,879**	**12,728**	**11,567**	**10,206**	**8,948**	**7,525**	**6,234**	**4,992**	**3,984**	**3,132**
1963-1971	1,207	5,566	5,241	4,789	4,186	3,500	2,851	2,317	1,769	1,329
1972-1981	1,455	6,301	5,544	4,735	4,162	3,498	2,915	2,279	1,897	1,557
1982-1991	42	172	147	132	104	83	72	68	51	26
1992-2001	174	689	635	550	496	444	395	328	267	220
FALL	**11,158**	**45,872**	**42,307**	**38,236**	**33,302**	**28,213**	**23,040**	**18,526**	**14,445**	**11,145**
1963-1971	1,684	7,793	7,458	6,993	6,330	5,665	4,982	4,275	3,540	2,821
1972-1981	4,366	19,429	18,092	16,496	14,560	12,593	10,480	8,678	7,073	5,590
1982-1991	1,679	6,914	6,397	5,710	4,879	3,990	3,277	2,553	1,888	1,493
1992-2001	1,063	4,411	3,899	3,322	2,717	2,131	1,512	1,019	702	431
2002-2012	2,365	7,325	6,461	5,716	4,816	3,834	2,789	2,001	1,242	810
MADMF trawl	**2,206**	**5,354**	**4,219**	**3,313**	**2,459**	**1,767**	**1,129**	**736**	**546**	**409**
SPRING	**2,038**	**5,097**	**4,015**	**3,140**	**2,330**	**1,681**	**1,090**	**715**	**533**	**404**
1972-1981	407	836	627	445	297	208	149	110	87	71
1982-1991	414	742	533	369	264	180	148	122	101	60
1992-2001	320	633	475	347	225	155	105	60	35	20
2002-2012	896	2,886	2,381	1,980	1,544	1,138	688	423	310	252
FALL	**168**	**257**	**204**	**173**	**130**	**86**	**39**	**22**	**13**	**5**
1972-1981	61	53	44	37	27	25	16	13	13	5
1982-1991	16	11	9	7	4	3	0	0	0	0
1992-2001	13	12	4	2	0	0	0	0	0	0
2002-2012	78	182	147	126	98	57	23	9	0	0
Grand Total	**33,202**	**133,997**	**123,202**	**110,770**	**95,998**	**81,124**	**66,342**	**53,798**	**41,814**	**32,284**

Table 8. Cumulative biomass above 5 cm size ranges by species, survey, and decade, compared to 20% of total weight per tow (kg) and the size at estimated 80% maturity for females.

Approximate 20% of biomass (upper), L80 for maturity (lower)	Species	Row Labels	Sum of 20 pct total wgt	WGT >= 25cm	Wgt >= 30cm	Wgt >= 35cm	Wgt >= 40 cm	Wgt >= 45cm	Wgt >= 50cm	Wgt >= 55 cm	Wgt >= 60cm	Wgt >= 65cm	Wgt >= 70cm	Wgt >= 75cm	Wgt >= 80cm	Wgt >= 85cm	Wgt >= 90cm	Wgt >= 95cm	Wgt >= 100cm
75 cm	ATLANTIC COD	**All**	**30,250**	**150,605**	**149,271**	**146,284**	**141,220**	**134,113**	**126,234**	**116,874**	**105,602**	**91,915**	**78,010**	**64,149**	**52,264**	**40,675**	**31,445**	**23,602**	**17,149**
L80 = 50 cm	ATLANTIC COD	**WINTER**	**1,654**	**8,247**	**8,226**	**8,202**	**8,141**	**7,983**	**7,744**	**7,421**	**6,875**	**6,273**	**5,663**	**5,002**	**4,400**	**3,594**	**2,866**	**1,978**	**1,353**
	ATLANTIC COD	1963-1971	1,071	5,348	5,339	5,325	5,291	5,222	5,112	4,959	4,720	4,403	4,013	3,596	3,173	2,661	2,128	1,461	1,016
	ATLANTIC COD	1972-1981	306	1,530	1,528	1,527	1,517	1,488	1,452	1,397	1,246	1,127	1,070	1,010	923	777	632	460	312
	ATLANTIC COD	1992-2001	269	1,339	1,330	1,321	1,305	1,247	1,159	1,046	891	724	570	395	305	156	105	57	25
	ATLANTIC COD	2002-2012	8	30	29	29	28	26	21	18	18	18	9	2	0	0	0	0	0
	ATLANTIC COD	**SPRING**	**14,558**	**72,457**	**71,801**	**70,561**	**68,244**	**64,198**	**59,891**	**55,579**	**50,284**	**43,393**	**36,609**	**29,872**	**24,347**	**18,652**	**14,302**	**10,866**	**7,891**
	ATLANTIC COD	1963-1971	1,141	5,701	5,696	5,672	5,614	5,551	5,430	5,229	4,938	4,517	4,148	3,620	3,126	2,501	1,990	1,516	1,130
	ATLANTIC COD	1972-1981	4,480	22,342	22,248	22,062	21,645	20,446	18,878	17,665	16,273	14,448	12,238	10,391	8,984	7,183	5,748	4,489	3,320
	ATLANTIC COD	1982-1991	3,639	18,153	18,082	17,935	17,643	17,118	16,391	15,546	14,307	12,278	10,593	8,661	6,889	5,323	4,055	3,222	2,343
	ATLANTIC COD	1992-2001	1,387	6,923	6,906	6,864	6,778	6,591	6,317	5,887	5,359	4,720	4,063	3,341	2,706	1,977	1,462	1,007	675
	ATLANTIC COD	2002-2012	3,911	19,338	18,869	18,028	16,564	14,492	12,875	11,253	9,408	7,430	5,567	3,860	2,642	1,668	1,047	632	423
	ATLANTIC COD	**SUMMER**	**2,879**	**14,357**	**14,282**	**14,124**	**13,863**	**13,478**	**12,728**	**11,567**	**10,206**	**8,948**	**7,525**	**6,234**	**4,992**	**3,984**	**3,132**	**2,334**	**1,736**
	ATLANTIC COD	1963-1971	1,207	6,032	6,020	5,991	5,927	5,799	5,566	5,241	4,789	4,186	3,500	2,851	2,317	1,769	1,329	974	726
	ATLANTIC COD	1972-1981	1,455	7,252	7,197	7,088	6,936	6,745	6,301	5,544	4,735	4,162	3,498	2,915	2,279	1,897	1,557	1,169	874
	ATLANTIC COD	1982-1991	42	209	207	205	203	195	172	147	132	104	83	72	68	51	26	26	26
	ATLANTIC COD	1992-2001	174	864	858	840	796	739	689	635	550	496	444	395	328	267	220	166	111
	ATLANTIC COD	**FALL**	**11,158**	**55,545**	**54,962**	**53,397**	**50,972**	**48,454**	**45,872**	**42,307**	**38,236**	**33,302**	**28,213**	**23,040**	**18,526**	**14,445**	**11,145**	**8,424**	**6,170**
	ATLANTIC COD	1963-1971	1,684	8,407	8,379	8,292	8,177	8,005	7,793	7,458	6,993	6,330	5,665	4,982	4,275	3,540	2,821	2,220	1,622
	ATLANTIC COD	1972-1981	4,366	21,777	21,653	21,317	20,808	20,197	19,429	18,092	16,496	14,560	12,593	10,480	8,678	7,073	5,590	4,351	3,324
	ATLANTIC COD	1982-1991	1,679	8,367	8,280	8,078	7,697	7,259	6,914	6,397	5,710	4,879	3,990	3,277	2,553	1,888	1,493	1,046	724
	ATLANTIC COD	1992-2001	1,063	5,306	5,269	5,173	4,995	4,742	4,411	3,899	3,322	2,717	2,131	1,512	1,019	702	431	293	156
	ATLANTIC COD	2002-2012	2,365	11,688	11,380	10,536	9,295	8,252	7,325	6,461	5,716	4,816	3,834	2,789	2,001	1,242	810	514	344
40 cm	AMERICAN PLAICE	**WINTER**	**62**	**310**	**300**	**261**	**202**	**130**	**76**	**47**	**22**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
L80 = 30 cm	AMERICAN PLAICE	1972-1981	17	85	83	75	63	41	32	27	16	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	1992-2001	44	219	212	182	136	88	44	21	6	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	2002-2012	1	6	5	5	4	1	0	0	0	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	**SPRING**	**2,492**	**11,176**	**9,366**	**6,995**	**4,939**	**3,250**	**1,793**	**763**	**289**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	AMERICAN PLAICE	1963-1971	233	1,113	972	756	543	359	194	109	68	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	1972-1981	1,076	4,968	4,453	3,662	2,815	1,951	1,089	482	167	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	1982-1991	453	2,007	1,647	1,216	861	601	366	137	45	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	1992-2001	338	1,498	1,173	757	457	234	105	33	8	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	2002-2012	392	1,589	1,122	603	264	106	38	2	0	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	**SUMMER**	**924**	**4,013**	**3,153**	**2,062**	**1,264**	**793**	**424**	**171**	**62**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	AMERICAN PLAICE	1963-1971	81	385	331	244	172	104	65	36	20	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	1972-1981	434	1,875	1,556	1,196	835	544	296	125	38	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	1982-1991	81	350	216	73	20	11	6	0	0	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	1992-2001	328	1,402	1,049	549	237	134	57	11	4	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	**FALL**	**2,690**	**12,037**	**10,086**	**7,423**	**5,086**	**3,152**	**1,750**	**768**	**244**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	AMERICAN PLAICE	1963-1971	171	812	706	540	368	224	138	79	39	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	1972-1981	1,248	5,780	5,148	4,197	3,186	2,113	1,221	535	169	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	1982-1991	412	1,777	1,418	982	673	422	234	103	28	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	1992-2001	504	2,217	1,785	1,119	578	265	109	33	8	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	2002-2012	355	1,452	1,030	586	281	128	48	18	0	0	0	0	0	0	0	0	0
	AMERICAN PLAICE	**All**	**6,168**	**27,535**	**22,904**	**16,741**	**11,491**	**7,327**	**4,042**	**1,750**	**617**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	ATLANTIC HERRING	**WINTER**	**304**	**765**	**85**	**4**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
L80 = 25 cm	ATLANTIC HERRING	1963-1971	8	23	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	1972-1981	9	22	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	1992-2001	260	670	77	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	2002-2012	27	49	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	**SPRING**	**2,253**	**4,363**	**255**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	ATLANTIC HERRING	1963-1971	10	23	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	1972-1981	239	649	83	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	1982-1991	321	1,063	104	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	1992-2001	778	1,738	46	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	2002-2012	906	890	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	**SUMMER**	**1,782**	**5,508**	**927**	**69**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	ATLANTIC HERRING	1963-1971	229	1,088	615	68	1	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	1972-1981	64	220	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	1982-1991	484	1,224	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	1992-2001	1,006	2,976	164	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	**FALL**	**4,896**	**12,628**	**1,070**	**6**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	ATLANTIC HERRING	1963-1971	71	318	99	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	1972-1981	32	148	57	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	1982-1991	651	2,285	513	4	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	1992-2001	1,713	5,766	368	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	2002-2012	2,429	4,112	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ATLANTIC HERRING	**All**	**9,235**	**23,264**	**2,337**	**83**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Approximate 20% of biomass (upper), L80 for maturity (lower)	Species	Row Labels	Sum of 20 pct total wgt	WGT >= 25cm	Wgt >= 30cm	Wgt >= 35cm	Wgt >= 40 cm	Wgt >= 45cm	Wgt >= 50cm	Wgt >= 55 cm	Wgt >= 60cm	Wgt >= 65cm	Wgt >= 70cm	Wgt >= 75cm	Wgt >= 80cm	Wgt >= 85cm	Wgt >= 90cm	Wgt >= 95cm	Wgt >= 100cm
50 cm	**HADDOCK**	**All**	**51,238**	**243,899**	**226,195**	**201,572**	**172,426**	**140,490**	**103,964**	**68,131**	**41,692**	**23,073**	**11,224**	**4,337**	**1,219**	**0**	**0**	**0**	**0**
L80 = 40 cm	**HADDOCK**	**WINTER**	**3,338**	**15,592**	**14,832**	**12,926**	**10,452**	**8,468**	**6,770**	**5,048**	**3,350**	**1,972**	**898**	**340**	**66**	**0**	**0**	**0**	**0**
	HADDOCK	1963-1971	2,933	14,261	13,566	11,708	9,309	7,389	5,820	4,306	2,744	1,578	682	265	49	0	0	0	0
	HADDOCK	1972-1981	141	707	707	706	703	686	620	471	394	292	168	58	0	0	0	0	0
	HADDOCK	1992-2001	228	491	432	400	333	291	230	183	136	56	27	11	11	0	0	0	0
	HADDOCK	2002-2012	35	133	127	112	108	102	99	88	76	46	21	6	6	0	0	0	0
	HADDOCK	**SPRING**	**16,040**	**75,439**	**69,873**	**65,941**	**59,644**	**50,826**	**38,933**	**25,459**	**16,166**	**9,113**	**4,571**	**1,736**	**510**	**0**	**0**	**0**	**0**
	HADDOCK	1963-1971	1,416	7,060	7,043	7,001	6,831	6,388	5,732	4,366	2,789	1,492	574	170	27	0	0	0	0
	HADDOCK	1972-1981	4,819	23,073	22,141	21,302	18,842	15,899	12,933	9,283	6,487	3,895	2,040	796	258	0	0	0	0
	HADDOCK	1982-1991	1,803	8,905	8,755	8,478	7,793	6,900	5,682	4,175	2,996	1,951	1,150	551	189	0	0	0	0
	HADDOCK	1992-2001	1,535	7,494	7,330	7,103	6,404	5,589	4,553	3,179	2,049	995	479	121	25	0	0	0	0
	HADDOCK	2002-2012	6,467	28,907	24,604	22,058	19,774	16,050	10,034	4,455	1,844	780	326	99	11	0	0	0	0
	HADDOCK	**SUMMER**	**6,262**	**30,338**	**27,797**	**24,468**	**20,319**	**14,428**	**10,562**	**7,379**	**4,708**	**2,538**	**1,262**	**478**	**124**	**0**	**0**	**0**	**0**
	HADDOCK	1963-1971	4,349	20,828	18,542	15,937	12,591	9,914	7,824	5,390	3,277	1,657	770	209	39	0	0	0	0
	HADDOCK	1972-1981	1,877	9,338	9,085	8,364	7,570	4,367	2,601	1,872	1,356	844	475	255	85	0	0	0	0
	HADDOCK	1982-1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	HADDOCK	1992-2001	36	172	171	166	158	147	137	117	76	37	18	14	0	0	0	0	0
	HADDOCK	**FALL**	**25,598**	**122,530**	**113,693**	**98,237**	**82,011**	**66,768**	**47,700**	**30,245**	**17,469**	**9,451**	**4,493**	**1,783**	**519**	**0**	**0**	**0**	**0**
	HADDOCK	1963-1971	3,186	15,626	15,119	14,014	12,557	10,651	8,649	6,386	4,247	2,411	1,158	401	70	0	0	0	0
	HADDOCK	1972-1981	6,409	31,571	31,068	27,606	23,347	19,954	15,446	11,065	7,138	4,220	2,278	1,086	343	0	0	0	0
	HADDOCK	1982-1991	1,664	8,112	7,873	6,994	6,116	5,337	4,397	3,164	1,966	1,114	562	214	88	0	0	0	0
	HADDOCK	1992-2001	2,978	14,762	14,573	13,737	12,317	10,554	7,506	4,677	2,542	1,235	401	68	18	0	0	0	0
	HADDOCK	2002-2012	11,361	52,459	45,060	35,885	27,674	20,272	11,703	4,953	1,576	470	94	12	0	0	0	0	0
100 cm	**BARNDOOR SKATE**	**WINTER**	**659**	**3,294**	**3,292**	**3,275**	**3,254**	**3,211**	**3,153**	**3,074**	**2,991**	**2,848**	**2,684**	**2,535**	**2,331**	**2,175**	**1,995**	**1,777**	**1,601**
L80 = 115 cm	**BARNDOOR SKATE**	1963-1971	207	1,033	1,032	1,032	1,032	1,026	1,018	1,001	981	946	895	853	781	720	648	586	559
	BARNDOOR SKATE	1972-1981	6	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29
	BARNDOOR SKATE	1992-2001	150	750	749	743	736	722	706	682	657	602	566	523	485	458	432	379	331
	BARNDOOR SKATE	2002-2012	297	1,483	1,483	1,472	1,457	1,435	1,400	1,362	1,324	1,271	1,196	1,131	1,037	969	886	783	682
	BARNDOOR SKATE	**SPRING**	**495**	**2,471**	**2,469**	**2,463**	**2,452**	**2,433**	**2,401**	**2,341**	**2,272**	**2,171**	**2,040**	**1,873**	**1,765**	**1,645**	**1,520**	**1,420**	**1,330**
	BARNDOOR SKATE	1963-1971	46	228	228	228	228	227	226	219	211	193	180	163	163	156	153	143	143
	BARNDOOR SKATE	1972-1981	9	47	47	47	47	47	47	45	43	36	34	34	34	34	21	21	21
	BARNDOOR SKATE	1982-1991	0	2	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0
	BARNDOOR SKATE	1992-2001	52	258	258	257	256	254	253	247	240	228	221	211	196	196	192	176	164
	BARNDOOR SKATE	2002-2012	387	1,936	1,934	1,929	1,920	1,904	1,874	1,831	1,778	1,714	1,606	1,465	1,373	1,260	1,154	1,080	1,001
	BARNDOOR SKATE	**SUMMER**	**89**	**443**	**443**	**443**	**443**	**441**	**439**	**433**	**416**	**392**	**361**	**330**	**301**	**265**	**257**	**218**	**183**
	BARNDOOR SKATE	1963-1971	89	443	443	443	443	441	439	433	416	392	361	330	301	265	257	218	183
	BARNDOOR SKATE	1972-1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	BARNDOOR SKATE	1982-1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	BARNDOOR SKATE	1992-2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	BARNDOOR SKATE	**FALL**	**688**	**3,438**	**3,435**	**3,431**	**3,421**	**3,401**	**3,351**	**3,279**	**3,175**	**3,047**	**2,919**	**2,734**	**2,556**	**2,410**	**2,242**	**2,059**	**1,893**
	BARNDOOR SKATE	1963-1971	151	756	756	756	756	753	744	731	707	658	614	554	498	446	409	378	334
	BARNDOOR SKATE	1972-1981	7	34	34	34	34	34	33	30	25	23	23	19	16	16	16	16	16
	BARNDOOR SKATE	1982-1991	5	26	26	26	26	26	26	24	23	21	18	14	14	14	10	5	0
	BARNDOOR SKATE	1992-2001	82	410	410	410	409	407	402	397	389	381	374	350	328	303	288	269	263
	BARNDOOR SKATE	2002-2012	442	2,210	2,208	2,204	2,196	2,181	2,146	2,097	2,031	1,964	1,890	1,797	1,700	1,632	1,518	1,390	1,279
	BARNDOOR SKATE	**All**	**1,930**	**9,646**	**9,639**	**9,612**	**9,570**	**9,486**	**9,344**	**9,127**	**8,854**	**8,457**	**8,005**	**7,472**	**6,953**	**6,496**	**6,014**	**5,474**	**5,008**
75 cm	**GOOSEFISH**	**WINTER**	**1,048**	**5,221**	**5,175**	**5,070**	**4,902**	**4,569**	**4,093**	**3,474**	**2,916**	**2,491**	**2,014**	**1,615**	**1,288**	**1,019**	**759**	**0**	**0**
L80 = 45 cm	**GOOSEFISH**	1963-1971	414	2,067	2,064	2,059	2,054	2,036	2,005	1,959	1,882	1,722	1,481	1,256	1,030	848	628	0	0
	GOOSEFISH	1972-1981	36	179	178	178	177	175	173	171	154	142	123	112	91	75	75	0	0
	GOOSEFISH	1992-2001	329	1,629	1,599	1,543	1,444	1,245	944	621	440	331	244	151	113	67	56	0	0
	GOOSEFISH	2002-2012	270	1,346	1,334	1,289	1,226	1,112	971	723	441	296	167	96	54	29	0	0	0
	GOOSEFISH	**SPRING**	**1,828**	**9,086**	**9,024**	**8,920**	**8,749**	**8,487**	**8,074**	**7,556**	**6,979**	**6,317**	**5,548**	**4,716**	**3,957**	**3,177**	**2,449**	**0**	**0**
	GOOSEFISH	1963-1971	113	563	562	560	557	551	536	511	488	463	389	329	266	159	129	0	0
	GOOSEFISH	1972-1981	1,017	5,073	5,050	5,017	4,957	4,863	4,692	4,449	4,187	3,907	3,540	3,083	2,638	2,132	1,615	0	0
	GOOSEFISH	1982-1991	308	1,537	1,528	1,517	1,500	1,471	1,429	1,364	1,272	1,156	1,011	861	759	694	589	0	0
	GOOSEFISH	1992-2001	171	833	815	780	732	669	585	506	445	345	286	224	137	96	63	0	0
	GOOSEFISH	2002-2012	218	1,080	1,068	1,045	1,003	932	831	726	588	446	322	218	157	95	53	0	0
	GOOSEFISH	**SUMMER**	**646**	**3,209**	**3,182**	**3,140**	**3,077**	**3,007**	**2,923**	**2,807**	**2,720**	**2,563**	**2,291**	**2,041**	**1,778**	**1,461**	**1,097**	**0**	**0**
	GOOSEFISH	1963-1971	218	1,090	1,090	1,086	1,081	1,069	1,051	1,017	984	921	799	688	576	449	281	0	0
	GOOSEFISH	1972-1981	334	1,669	1,667	1,664	1,662	1,644	1,631	1,595	1,565	1,492	1,368	1,272	1,121	940	765	0	0
	GOOSEFISH	1982-1991	9	44	39	33	27	23	16	9	9	5	5	0	0	0	0	0	0
	GOOSEFISH	1992-2001	84	406	386	357	307	271	225	185	162	144	119	81	81	72	51	0	0
	GOOSEFISH	**FALL**	**2,515**	**12,508**	**12,425**	**12,304**	**12,131**	**11,852**	**11,447**	**10,816**	**10,154**	**9,227**	**8,234**	**7,074**	**6,002**	**4,823**	**3,740**	**0**	**0**
	GOOSEFISH	1963-1971	514	2,568	2,563	2,561	2,550	2,535	2,502	2,444	2,330	2,152	1,927	1,606	1,297	1,056	828	0	0
	GOOSEFISH	1972-1981	1,204	6,011	6,001	5,978	5,947	5,882	5,800	5,612	5,407	5,073	4,626	4,133	3,590	2,964	2,375	0	0
	GOOSEFISH	1982-1991	322	1,599	1,587	1,572	1,547	1,517	1,447	1,335	1,227	1,076	940	804	702	541	427	0	0
	GOOSEFISH	1992-2001	242	1,178	1,137	1,083	1,017	925	833	716	626	513	430	322	260	171	82	0	0
	GOOSEFISH	2002-2012	234	1,152	1,136	1,111	1,070	994	866	709	564	412	310	209	154	91	28	0	0
	GOOSEFISH	**All**	**6,036**	**30,023**	**29,807**	**29,433**	**28,858**	**27,915**	**26,536**	**24,652**	**22,769**	**20,598**	**18,086**	**15,445**	**13,025**	**10,479**	**8,045**	**0**	**0**

Approximate 20% of biomass (upper), L80 for maturity (lower)	Species	Row Labels	Sum of 20 pct total wgt	WGT >= 25cm	Wgt >= 30cm	Wgt >= 35cm	Wgt >= 40 cm	Wgt >= 45cm	Wgt >= 50cm	Wgt >= 55 cm	Wgt >= 60cm	Wgt >= 65cm	Wgt >= 70cm	Wgt >= 75cm	Wgt >= 80cm	Wgt >= 85cm	Wgt >= 90cm	Wgt >= 95cm	Wgt >= 100cm
50 cm	**LITTLE SKATE**	**WINTER**	**4,589**	**22,768**	**22,311**	**21,183**	**19,260**	**13,916**	**2,149**	**124**	**34**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
L80 = 55 cm	LITTLE SKATE	1963-1971	457	2,285	2,281	2,257	2,170	1,624	277	32	6	0	0	0	0	0	0	0	0
	LITTLE SKATE	1972-1981	144	707	688	637	574	482	221	83	25	0	0	0	0	0	0	0	0
	LITTLE SKATE	1992-2001	2,721	13,488	13,186	12,366	11,071	7,779	1,152	8	3	0	0	0	0	0	0	0	0
	LITTLE SKATE	2002-2012	1,266	6,288	6,156	5,923	5,444	4,031	498	1	0	0	0	0	0	0	0	0	0
	LITTLE SKATE	**SPRING**	**4,842**	**23,884**	**23,220**	**22,036**	**20,462**	**16,028**	**3,493**	**178**	**7**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	LITTLE SKATE	1963-1971	297	1,476	1,459	1,424	1,360	1,104	239	18	0	0	0	0	0	0	0	0	0
	LITTLE SKATE	1972-1981	1,399	6,915	6,758	6,428	5,958	4,685	1,034	74	3	0	0	0	0	0	0	0	0
	LITTLE SKATE	1982-1991	1,088	5,359	5,205	4,978	4,665	3,583	795	36	4	0	0	0	0	0	0	0	0
	LITTLE SKATE	1992-2001	872	4,277	4,112	3,858	3,554	2,752	604	22	0	0	0	0	0	0	0	0	0
	LITTLE SKATE	2002-2012	1,187	5,857	5,686	5,349	4,925	3,905	820	28	0	0	0	0	0	0	0	0	0
	LITTLE SKATE	**SUMMER**	**506**	**2,519**	**2,505**	**2,478**	**2,405**	**2,005**	**487**	**53**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	LITTLE SKATE	1963-1971	191	951	949	942	918	720	132	30	5	0	0	0	0	0	0	0	0
	LITTLE SKATE	1972-1981	271	1,348	1,338	1,320	1,279	1,101	231	4	0	0	0	0	0	0	0	0	0
	LITTLE SKATE	1982-1991	0	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0
	LITTLE SKATE	1992-2001	44	218	217	214	206	182	123	19	0	0	0	0	0	0	0	0	0
	LITTLE SKATE	**FALL**	**4,375**	**21,686**	**21,347**	**20,638**	**19,327**	**15,447**	**3,816**	**213**	**27**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	LITTLE SKATE	1963-1971	342	1,708	1,696	1,666	1,603	1,298	285	41	3	0	0	0	0	0	0	0	0
	LITTLE SKATE	1972-1981	1,383	6,853	6,764	6,598	6,256	5,192	1,308	80	16	0	0	0	0	0	0	0	0
	LITTLE SKATE	1982-1991	859	4,242	4,137	3,927	3,547	2,701	727	27	0	0	0	0	0	0	0	0	0
	LITTLE SKATE	1992-2001	940	4,668	4,604	4,477	4,255	3,403	829	39	7	0	0	0	0	0	0	0	0
	LITTLE SKATE	2002-2012	851	4,215	4,145	3,970	3,666	2,853	666	27	0	0	0	0	0	0	0	0	0
	LITTLE SKATE	**All**	**14,312**	**70,856**	**69,383**	**66,335**	**61,454**	**47,397**	**9,944**	**568**	**73**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
60 cm	**OCEAN POUT**	**WINTER**	**1,476**	**7,370**	**7,359**	**7,310**	**7,176**	**6,915**	**6,414**	**5,599**	**4,314**	**2,888**	**1,919**	**1,135**	**584**	**213**	**81**	**0**	**0**
NA	OCEAN POUT	1963-1971	540	2,700	2,699	2,696	2,689	2,672	2,615	2,459	2,124	1,622	1,219	813	454	177	63	0	0
	OCEAN POUT	1972-1981	41	203	203	202	200	199	191	168	154	125	83	46	24	8	4	0	0
	OCEAN POUT	1992-2001	848	4,235	4,225	4,181	4,056	3,823	3,416	2,805	1,909	1,076	575	257	99	29	14	0	0
	OCEAN POUT	2002-2012	46	232	232	232	231	221	192	166	126	65	41	20	6	0	0	0	0
	OCEAN POUT	**SPRING**	**2,483**	**12,390**	**12,343**	**12,201**	**11,861**	**11,029**	**9,865**	**8,242**	**6,549**	**4,631**	**3,047**	**1,720**	**904**	**381**	**137**	**0**	**0**
	OCEAN POUT	1963-1971	146	728	728	725	718	684	607	549	467	370	283	159	94	41	24	0	0
	OCEAN POUT	1972-1981	710	3,541	3,527	3,484	3,363	2,974	2,517	2,010	1,575	1,128	743	455	281	125	43	0	0
	OCEAN POUT	1982-1991	1,111	5,546	5,529	5,473	5,343	5,078	4,685	3,986	3,196	2,271	1,468	829	410	175	67	0	0
	OCEAN POUT	1992-2001	353	1,764	1,759	1,742	1,706	1,621	1,471	1,209	914	598	392	201	89	33	3	0	0
	OCEAN POUT	2002-2012	163	810	801	776	732	671	585	489	397	264	162	76	31	6	0	0	0
	OCEAN POUT	**SUMMER**	**277**	**1,384**	**1,375**	**1,345**	**1,277**	**1,170**	**1,042**	**918**	**787**	**629**	**453**	**273**	**146**	**55**	**26**	**0**	**0**
	OCEAN POUT	1963-1971	95	473	472	471	466	459	452	439	407	340	236	128	62	28	12	0	0
	OCEAN POUT	1972-1981	127	631	625	608	578	531	456	396	329	269	203	143	84	28	13	0	0
	OCEAN POUT	1982-1991	15	73	72	70	62	46	32	22	13	10	8	2	0	0	0	0	0
	OCEAN POUT	1992-2001	42	207	205	197	171	134	101	62	38	10	6	0	0	0	0	0	0
	OCEAN POUT	**FALL**	**446**	**2,216**	**2,188**	**2,088**	**1,908**	**1,663**	**1,358**	**1,027**	**729**	**481**	**293**	**183**	**114**	**59**	**28**	**0**	**0**
	OCEAN POUT	1963-1971	54	271	269	264	251	231	205	166	137	104	60	38	25	11	11	0	0
	OCEAN POUT	1972-1981	151	752	744	725	686	620	526	404	291	185	137	97	63	40	13	0	0
	OCEAN POUT	1982-1991	85	422	416	395	364	315	243	182	119	77	49	23	13	4	4	0	0
	OCEAN POUT	1992-2001	111	552	546	523	465	395	312	233	158	102	45	25	13	4	0	0	0
	OCEAN POUT	2002-2012	45	219	212	182	142	102	72	42	25	14	1	0	0	0	0	0	0
	OCEAN POUT	**All**	**4,682**	**23,360**	**23,265**	**22,943**	**22,221**	**20,777**	**18,679**	**15,786**	**12,378**	**8,629**	**5,712**	**3,311**	**1,748**	**707**	**273**	**0**	**0**
75 cm	**POLLOCK**	**WINTER**	**621**	**3,094**	**3,071**	**3,039**	**2,934**	**2,838**	**2,712**	**2,576**	**2,384**	**2,143**	**1,800**	**1,466**	**1,051**	**607**	**311**	**139**	**0**
L80 = 50 cm	POLLOCK	1963-1971	505	2,518	2,495	2,463	2,359	2,266	2,142	2,013	1,845	1,630	1,351	1,094	761	416	195	89	0
	POLLOCK	1972-1981	106	529	529	528	528	525	523	517	498	473	413	340	273	174	105	40	0
	POLLOCK	1992-2001	10	48	48	48	47	47	47	45	41	39	36	32	17	17	10	10	0
	POLLOCK	2002-2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	POLLOCK	**SPRING**	**5,183**	**25,770**	**25,582**	**25,096**	**24,484**	**23,329**	**22,026**	**20,190**	**17,838**	**15,673**	**13,483**	**11,170**	**8,798**	**6,597**	**4,321**	**2,219**	**0**
	POLLOCK	1963-1971	459	2,286	2,280	2,270	2,257	2,233	2,194	2,158	2,077	1,996	1,964	1,859	1,608	1,166	632	244	0
	POLLOCK	1972-1981	1,753	8,743	8,651	8,337	8,009	7,547	7,201	6,720	6,088	5,590	5,054	4,547	3,889	3,065	1,997	1,040	0
	POLLOCK	1982-1991	1,630	8,125	8,093	8,038	7,951	7,600	6,981	6,114	5,196	4,457	3,650	2,950	2,385	1,964	1,481	851	0
	POLLOCK	1992-2001	513	2,533	2,500	2,448	2,305	2,036	1,818	1,589	1,351	1,079	864	643	377	170	100	44	0
	POLLOCK	2002-2012	828	4,084	4,058	4,003	3,961	3,914	3,833	3,609	3,126	2,551	1,951	1,171	540	232	110	40	0
	POLLOCK	**SUMMER**	**812**	**3,975**	**3,913**	**3,881**	**3,805**	**3,705**	**3,616**	**3,459**	**3,285**	**3,089**	**2,738**	**2,273**	**1,797**	**1,298**	**820**	**458**	**0**
	POLLOCK	1963-1971	349	1,747	1,746	1,735	1,694	1,614	1,538	1,427	1,343	1,244	1,093	847	575	304	132	48	0
	POLLOCK	1972-1981	429	2,076	2,025	2,012	1,982	1,964	1,950	1,909	1,827	1,745	1,578	1,395	1,204	976	677	399	0
	POLLOCK	1982-1991	1	5	4	4	3	2	2	2	0	0	0	0	0	0	0	0	0
	POLLOCK	1992-2001	33	147	138	131	126	125	125	121	115	100	67	32	19	19	11	11	0
	POLLOCK	**FALL**	**4,206**	**20,989**	**20,736**	**20,392**	**19,826**	**18,807**	**17,416**	**15,918**	**14,777**	**13,520**	**11,736**	**9,743**	**7,499**	**5,375**	**3,642**	**2,017**	**0**
	POLLOCK	1963-1971	681	3,404	3,400	3,378	3,319	3,158	2,965	2,864	2,780	2,646	2,318	1,837	1,256	794	504	285	0
	POLLOCK	1972-1981	1,975	9,874	9,845	9,803	9,614	9,158	8,848	8,506	8,104	7,553	6,771	5,849	4,797	3,631	2,526	1,376	0
	POLLOCK	1982-1991	489	2,434	2,393	2,342	2,260	2,169	1,975	1,706	1,528	1,414	1,274	1,105	884	673	446	266	0
	POLLOCK	1992-2001	321	1,582	1,501	1,373	1,246	1,120	924	749	578	462	323	199	143	88	54	31	0
	POLLOCK	2002-2012	741	3,694	3,597	3,497	3,387	3,202	2,703	2,092	1,786	1,446	1,050	754	419	188	112	59	0
	POLLOCK	**All**	**10,822**	**53,828**	**53,302**	**52,408**	**51,049**	**48,678**	**45,770**	**42,143**	**38,284**	**34,426**	**29,757**	**24,652**	**19,145**	**13,877**	**9,095**	**4,834**	**0**

Approximate 20% of biomass (upper), L80 for maturity (lower)	Species	Row Labels	Sum of 20 pct total wgt	WGT >= 25cm	Wgt >= 30cm	Wgt >= 35cm	Wgt >= 40 cm	Wgt >= 45cm	Wgt >= 50cm	Wgt >= 55 cm	Wgt >= 60cm	Wgt >= 65cm	Wgt >= 70cm	Wgt >= 75cm	Wgt >= 80cm	Wgt >= 85cm	Wgt >= 90cm	Wgt >= 95cm	Wgt >= 100cm
35 cm	RED HAKE	WINTER	818	3,968	2,731	1,249	497	199	83	30	0	0	0	0	0	0	0	0	0
L80 = 35 cm	RED HAKE	1963-1971	317	1,570	1,470	892	395	178	77	29	0	0	0	0	0	0	0	0	0
	RED HAKE	1972-1981	2	11	11	7	4	2	2	2	0	0	0	0	0	0	0	0	0
	RED HAKE	1992-2001	419	2,046	1,185	336	96	19	4	0	0	0	0	0	0	0	0	0	0
	RED HAKE	2002-2012	80	341	67	15	2	0	0	0	0	0	0	0	0	0	0	0	0
	RED HAKE	SPRING	2,156	10,414	8,692	5,260	2,749	1,180	438	128	0	0	0	0	0	0	0	0	0
	RED HAKE	1963-1971	80	393	367	257	139	69	32	10	0	0	0	0	0	0	0	0	0
	RED HAKE	1972-1981	718	3,501	3,185	2,149	1,224	562	237	78	0	0	0	0	0	0	0	0	0
	RED HAKE	1982-1991	427	2,066	1,871	1,298	737	337	117	33	0	0	0	0	0	0	0	0	0
	RED HAKE	1992-2001	427	2,064	1,662	912	435	156	40	4	0	0	0	0	0	0	0	0	0
	RED HAKE	2002-2012	504	2,390	1,607	644	214	56	13	3	0	0	0	0	0	0	0	0	0
	RED HAKE	SUMMER	825	4,045	3,797	2,714	1,508	667	249	88	0	0	0	0	0	0	0	0	0
	RED HAKE	1963-1971	191	928	858	562	282	135	56	21	0	0	0	0	0	0	0	0	0
	RED HAKE	1972-1981	383	1,887	1,817	1,357	790	355	143	54	0	0	0	0	0	0	0	0	0
	RED HAKE	1982-1991	30	147	143	109	59	33	9	1	0	0	0	0	0	0	0	0	0
	RED HAKE	1992-2001	221	1,083	980	686	376	144	41	12	0	0	0	0	0	0	0	0	0
	RED HAKE	FALL	3,613	17,177	14,333	9,416	4,954	2,143	744	223	0	0	0	0	0	0	0	0	0
	RED HAKE	1963-1971	257	1,246	1,113	786	403	200	75	15	0	0	0	0	0	0	0	0	0
	RED HAKE	1972-1981	1,087	5,270	4,767	3,458	1,895	844	322	107	0	0	0	0	0	0	0	0	0
	RED HAKE	1982-1991	762	3,681	3,152	2,259	1,314	633	225	68	0	0	0	0	0	0	0	0	0
	RED HAKE	1992-2001	838	3,878	3,129	1,919	979	376	99	24	0	0	0	0	0	0	0	0	0
	RED HAKE	2002-2012	670	3,102	2,172	994	363	90	22	10	0	0	0	0	0	0	0	0	0
	RED HAKE	All	7,413	35,603	29,554	18,639	9,708	4,190	1,514	469	0	0	0	0	0	0	0	0	0
30 cm	ACADIAN REDFISH	WINTER	745	3,127	1,895	705	35	3	0	0	0	0	0	0	0	0	0	0	0
L80 = 25 cm	ACADIAN REDFISH	1963-1971	745	3,127	1,895	705	35	3	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1972-1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1992-2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	2002-2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	SPRING	9,999	40,176	23,508	8,686	1,887	307	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1963-1971	1,010	4,384	3,038	1,333	190	13	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1972-1981	2,415	11,202	8,598	4,513	1,259	269	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1982-1991	646	3,049	2,471	1,219	292	20	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1992-2001	2,212	6,703	3,099	687	94	2	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	2002-2012	3,716	14,838	6,303	934	52	4	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	SUMMER	2,449	10,299	6,804	2,913	463	28	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1963-1971	1,859	8,020	5,280	2,060	274	23	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1972-1981	401	1,787	1,298	779	170	5	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1982-1991	12	29	13	5	0	0	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1992-2001	178	464	212	69	18	0	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	FALL	14,447	57,004	33,362	12,479	2,454	95	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1963-1971	2,272	9,463	6,746	2,739	349	19	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1972-1981	2,895	13,232	10,478	5,990	1,477	46	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1982-1991	865	3,812	2,990	1,545	382	12	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	1992-2001	2,188	6,929	2,720	727	167	8	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	2002-2012	6,227	23,569	10,428	1,478	80	10	0	0	0	0	0	0	0	0	0	0	0
	ACADIAN REDFISH	All	27,641	110,606	65,569	24,782	4,839	433	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	WINTER	6	31	30	29	24	0	0	0	0	0	0	0	0	0	0	0	0
L80 = 55 cm	ROSETTE SKATE	1963-1971	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1972-1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1992-2001	2	12	12	12	11	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	2002-2012	4	18	18	17	13	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	SPRING	1	3	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1963-1971	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1972-1981	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1982-1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1992-2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	2002-2012	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	SUMMER	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1963-1971	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1972-1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1982-1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1992-2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	FALL	4	19	18	17	10	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1963-1971	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1972-1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1982-1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	1992-2001	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	2002-2012	3	16	15	14	7	0	0	0	0	0	0	0	0	0	0	0	0
	ROSETTE SKATE	All	11	54	53	50	37	0	0	0	0	0	0	0	0	0	0	0	0

Approximate 20% of biomass (upper), L80 for maturity (lower)	Species	Row Labels	Sum of 20 pct total wgt	WGT >= 25cm	Wgt >= 30cm	Wgt >= 35cm	Wgt >= 40 cm	Wgt >= 45cm	Wgt >= 50cm	Wgt >= 55 cm	Wgt >= 60cm	Wgt >= 65cm	Wgt >= 70cm	Wgt >= 75cm	Wgt >= 80cm	Wgt >= 85cm	Wgt >= 90cm	Wgt >= 95cm	Wgt >= 100cm
30 cm	SILVER HAKE	**WINTER**	**530**	**1,815**	**675**	**312**	**134**	**78**	**44**	**13**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
L80 = 30 cm	SILVER HAKE	1963-1971	208	775	443	241	108	64	40	11	0	0	0	0	0	0	0	0	0
	SILVER HAKE	1972-1981	4	19	15	9	7	6	3	2	0	0	0	0	0	0	0	0	0
	SILVER HAKE	1992-2001	280	919	185	51	17	6	1	0	0	0	0	0	0	0	0	0	0
	SILVER HAKE	2002-2012	39	102	33	11	3	2	0	0	0	0	0	0	0	0	0	0	0
	SILVER HAKE	**SPRING**	**3,994**	**12,959**	**6,550**	**2,564**	**1,024**	**508**	**284**	**152**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	SILVER HAKE	1963-1971	70	298	189	102	49	26	8	2	0	0	0	0	0	0	0	0	0
	SILVER HAKE	1972-1981	1,714	6,911	4,682	1,876	727	381	219	115	0	0	0	0	0	0	0	0	0
	SILVER HAKE	1982-1991	484	1,678	789	289	118	52	30	18	0	0	0	0	0	0	0	0	0
	SILVER HAKE	1992-2001	1,045	2,517	486	183	90	33	20	13	0	0	0	0	0	0	0	0	0
	SILVER HAKE	2002-2012	681	1,555	404	114	40	16	6	4	0	0	0	0	0	0	0	0	0
	SILVER HAKE	**SUMMER**	**1,639**	**5,840**	**3,990**	**1,837**	**853**	**467**	**277**	**125**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	SILVER HAKE	1963-1971	571	2,651	1,873	821	354	184	114	50	0	0	0	0	0	0	0	0	0
	SILVER HAKE	1972-1981	438	1,927	1,579	807	414	242	135	64	0	0	0	0	0	0	0	0	0
	SILVER HAKE	1982-1991	94	206	108	42	9	7	4	0	0	0	0	0	0	0	0	0	0
	SILVER HAKE	1992-2001	535	1,056	430	167	75	34	24	11	0	0	0	0	0	0	0	0	0
	SILVER HAKE	**FALL**	**6,532**	**23,582**	**13,035**	**5,751**	**2,586**	**1,322**	**727**	**364**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	SILVER HAKE	1963-1971	569	2,436	1,754	911	528	339	198	94	0	0	0	0	0	0	0	0	0
	SILVER HAKE	1972-1981	1,417	6,111	4,801	2,432	1,091	630	401	222	0	0	0	0	0	0	0	0	0
	SILVER HAKE	1982-1991	1,525	6,284	3,577	1,470	577	189	55	26	0	0	0	0	0	0	0	0	0
	SILVER HAKE	1992-2001	1,530	4,656	1,738	554	243	112	46	14	0	0	0	0	0	0	0	0	0
	SILVER HAKE	2002-2012	1,491	4,093	1,167	384	148	53	27	8	0	0	0	0	0	0	0	0	0
	SILVER HAKE	**All**	**12,695**	**44,196**	**24,250**	**10,463**	**4,597**	**2,376**	**1,332**	**654**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
55 cm	SMOOTH SKATE	**WINTER**	**33**	**165**	**162**	**154**	**142**	**128**	**109**	**67**	**18**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
L80 = 65 cm	SMOOTH SKATE	1963-1971	16	78	76	72	66	60	52	29	7	0	0	0	0	0	0	0	0
	SMOOTH SKATE	1972-1981	10	52	50	47	43	39	34	24	5	0	0	0	0	0	0	0	0
	SMOOTH SKATE	1992-2001	7	35	35	34	33	29	23	14	5	0	0	0	0	0	0	0	0
	SMOOTH SKATE	2002-2012	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
	SMOOTH SKATE	**SPRING**	**226**	**1,115**	**1,095**	**1,057**	**995**	**900**	**712**	**382**	**109**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	SMOOTH SKATE	1963-1971	23	116	115	113	108	103	91	54	18	0	0	0	0	0	0	0	0
	SMOOTH SKATE	1972-1981	77	382	376	365	344	309	250	141	46	0	0	0	0	0	0	0	0
	SMOOTH SKATE	1982-1991	35	172	169	165	159	149	127	74	27	0	0	0	0	0	0	0	0
	SMOOTH SKATE	1992-2001	25	124	122	116	112	102	75	36	4	0	0	0	0	0	0	0	0
	SMOOTH SKATE	2002-2012	66	322	313	298	272	236	168	76	15	0	0	0	0	0	0	0	0
	SMOOTH SKATE	**SUMMER**	**26**	**129**	**127**	**124**	**118**	**107**	**90**	**55**	**17**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	SMOOTH SKATE	1963-1971	12	58	58	57	56	51	42	26	10	0	0	0	0	0	0	0	0
	SMOOTH SKATE	1972-1981	5	27	27	26	25	21	18	10	3	0	0	0	0	0	0	0	0
	SMOOTH SKATE	1982-1991	2	12	11	11	9	9	8	4	0	0	0	0	0	0	0	0	0
	SMOOTH SKATE	1992-2001	7	32	31	30	28	26	22	15	3	0	0	0	0	0	0	0	0
	SMOOTH SKATE	**FALL**	**247**	**1,219**	**1,199**	**1,166**	**1,118**	**1,041**	**892**	**511**	**152**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	SMOOTH SKATE	1963-1971	39	191	188	182	173	162	141	82	22	0	0	0	0	0	0	0	0
	SMOOTH SKATE	1972-1981	58	291	289	285	278	261	223	124	43	0	0	0	0	0	0	0	0
	SMOOTH SKATE	1982-1991	39	195	192	189	182	173	154	97	34	0	0	0	0	0	0	0	0
	SMOOTH SKATE	1992-2001	55	272	266	257	246	223	187	104	28	0	0	0	0	0	0	0	0
	SMOOTH SKATE	2002-2012	56	271	264	253	240	222	188	105	25	0	0	0	0	0	0	0	0
	SMOOTH SKATE	**All**	**532**	**2,628**	**2,583**	**2,502**	**2,373**	**2,176**	**1,804**	**1,015**	**296**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
85 cm	THORNY SKATE	**WINTER**	**592**	**2,945**	**2,927**	**2,893**	**2,852**	**2,795**	**2,723**	**2,614**	**2,482**	**2,320**	**2,130**	**1,920**	**1,640**	**1,205**	**854**	**468**	**189**
L80 = 95 cm	THORNY SKATE	1963-1971	486	2,422	2,410	2,389	2,368	2,334	2,291	2,218	2,123	2,005	1,864	1,685	1,467	1,130	829	450	189
	THORNY SKATE	1972-1981	83	413	409	404	395	382	362	339	313	280	243	215	158	69	25	18	0
	THORNY SKATE	1992-2001	22	109	107	98	87	76	69	56	46	35	23	20	16	6	0	0	0
	THORNY SKATE	2002-2012	0	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0
	THORNY SKATE	**SPRING**	**2,268**	**11,258**	**11,162**	**11,035**	**10,829**	**10,557**	**10,115**	**9,495**	**8,737**	**7,931**	**7,090**	**6,159**	**5,186**	**4,047**	**2,771**	**1,691**	**869**
	THORNY SKATE	1963-1971	474	2,354	2,338	2,324	2,295	2,250	2,166	2,094	1,979	1,871	1,710	1,556	1,371	1,094	779	494	290
	THORNY SKATE	1972-1981	1,059	5,262	5,223	5,162	5,068	4,944	4,757	4,448	4,088	3,683	3,288	2,801	2,353	1,914	1,280	833	450
	THORNY SKATE	1982-1991	495	2,459	2,435	2,406	2,355	2,297	2,207	2,057	1,881	1,660	1,460	1,256	1,013	721	508	279	96
	THORNY SKATE	1992-2001	134	663	654	643	625	599	556	510	446	397	353	309	254	168	103	41	22
	THORNY SKATE	2002-2012	105	520	512	501	486	468	429	385	344	320	279	237	195	149	102	43	10
	THORNY SKATE	**SUMMER**	**952**	**4,741**	**4,719**	**4,687**	**4,642**	**4,576**	**4,483**	**4,330**	**4,095**	**3,821**	**3,498**	**3,089**	**2,636**	**2,053**	**1,528**	**847**	**321**
	THORNY SKATE	1963-1971	527	2,627	2,617	2,607	2,587	2,554	2,504	2,437	2,329	2,199	2,050	1,862	1,627	1,324	1,086	660	275
	THORNY SKATE	1972-1981	315	1,570	1,566	1,553	1,539	1,515	1,493	1,440	1,354	1,255	1,119	934	772	562	339	152	45
	THORNY SKATE	1982-1991	35	174	171	169	168	165	160	157	150	146	134	116	91	64	31	9	0
	THORNY SKATE	1992-2001	75	369	364	359	349	342	325	296	262	221	195	177	147	104	72	26	0
	THORNY SKATE	**FALL**	**3,659**	**18,194**	**18,090**	**17,923**	**17,687**	**17,342**	**16,831**	**16,030**	**14,937**	**13,700**	**12,420**	**10,676**	**9,031**	**6,884**	**4,928**	**2,952**	**1,212**
	THORNY SKATE	1963-1971	1,141	5,679	5,651	5,609	5,559	5,484	5,392	5,245	5,032	4,760	4,461	4,037	3,575	2,969	2,339	1,565	691
	THORNY SKATE	1972-1981	1,627	8,103	8,067	8,005	7,913	7,769	7,553	7,162	6,642	6,008	5,388	4,509	3,696	2,675	1,790	947	347
	THORNY SKATE	1982-1991	489	2,427	2,408	2,379	2,329	2,268	2,172	2,049	1,866	1,695	1,482	1,244	1,023	745	535	326	160
	THORNY SKATE	1992-2001	284	1,408	1,396	1,377	1,351	1,303	1,230	1,139	1,014	897	786	618	513	349	184	96	10
	THORNY SKATE	2002-2012	118	576	567	554	536	517	484	434	383	339	303	269	224	146	80	19	3
	THORNY SKATE	**All**	**7,471**	**37,138**	**36,898**	**36,538**	**36,010**	**35,271**	**34,152**	**32,469**	**30,252**	**27,771**	**25,138**	**21,845**	**18,493**	**14,188**	**10,081**	**5,958**	**2,590**

Approximate 20% of biomass (upper), L80 for maturity (lower)	Species	Row Labels	Sum of 20 pct total wgt	WGT >= 25cm	Wgt >= 30cm	Wgt >= 35cm	Wgt >= 40 cm	Wgt >= 45cm	Wgt >= 50cm	Wgt >= 55 cm	Wgt >= 60cm	Wgt >= 65cm	Wgt >= 70cm	Wgt >= 75cm	Wgt >= 80cm	Wgt >= 85cm	Wgt >= 90cm	Wgt >= 95cm	Wgt >= 100cm
75 cm	**WHITE HAKE**	**WINTER**	**302**	**1,502**	**1,483**	**1,427**	**1,349**	**1,248**	**1,134**	**1,051**	**955**	**813**	**639**	**515**	**445**	**397**	**352**	**313**	**295**
L80 = 45 cm	WHITE HAKE	1963-1971	258	1,286	1,270	1,247	1,194	1,107	1,024	952	878	755	609	491	421	378	339	300	282
	WHITE HAKE	1972-1981	18	90	90	79	71	69	54	49	40	31	16	13	13	13	13	13	13
	WHITE HAKE	1992-2001	19	93	90	74	61	53	43	38	28	21	14	11	11	6	0	0	0
	WHITE HAKE	2002-2012	7	33	33	27	23	20	14	11	8	5	0	0	0	0	0	0	0
	WHITE HAKE	**SPRING**	**3,694**	**18,429**	**18,187**	**17,524**	**16,803**	**15,598**	**14,114**	**12,786**	**11,344**	**9,412**	**7,425**	**5,441**	**3,983**	**2,905**	**2,405**	**1,950**	**1,581**
	WHITE HAKE	1963-1971	170	849	839	816	769	690	614	561	506	432	364	321	273	240	212	171	138
	WHITE HAKE	1972-1981	1,691	8,445	8,358	8,125	7,843	7,410	6,813	6,296	5,769	5,008	4,198	3,157	2,331	1,610	1,320	1,118	961
	WHITE HAKE	1982-1991	795	3,967	3,900	3,712	3,538	3,270	2,966	2,698	2,346	1,919	1,413	981	695	572	494	422	356
	WHITE HAKE	1992-2001	450	2,246	2,211	2,115	2,014	1,802	1,523	1,289	1,088	786	523	339	210	148	121	84	44
	WHITE HAKE	2002-2012	587	2,923	2,879	2,756	2,639	2,425	2,198	1,942	1,636	1,267	927	643	475	334	259	155	82
	WHITE HAKE	**SUMMER**	**1,171**	**5,840**	**5,741**	**5,426**	**4,997**	**4,494**	**3,956**	**3,489**	**3,087**	**2,507**	**1,885**	**1,381**	**1,013**	**719**	**587**	**504**	**437**
	WHITE HAKE	1963-1971	355	1,776	1,770	1,745	1,700	1,614	1,515	1,417	1,300	1,088	822	566	426	333	272	236	204
	WHITE HAKE	1972-1981	414	2,070	2,062	1,998	1,861	1,722	1,561	1,416	1,290	1,089	884	715	537	369	316	268	233
	WHITE HAKE	1982-1991	135	672	652	562	436	343	247	174	124	73	32	20	9	0	0	0	0
	WHITE HAKE	1992-2001	266	1,322	1,257	1,121	1,000	815	633	482	374	258	147	80	40	16	0	0	0
	WHITE HAKE	**FALL**	**5,519**	**27,377**	**26,873**	**26,313**	**24,673**	**22,062**	**19,488**	**17,049**	**14,531**	**11,918**	**9,129**	**6,826**	**5,143**	**3,764**	**2,940**	**2,370**	**1,933**
	WHITE HAKE	1963-1971	779	3,885	3,826	3,725	3,542	3,217	2,909	2,616	2,284	1,899	1,509	1,136	897	716	651	528	490
	WHITE HAKE	1972-1981	2,231	11,109	10,951	10,783	10,258	9,366	8,471	7,547	6,702	5,769	4,647	3,640	2,803	2,033	1,654	1,371	1,151
	WHITE HAKE	1982-1991	1,080	5,307	5,164	5,020	4,548	3,881	3,308	2,822	2,313	1,840	1,354	960	628	402	243	182	142
	WHITE HAKE	1992-2001	801	3,968	3,891	3,798	3,537	3,120	2,646	2,188	1,705	1,237	788	533	412	329	231	168	73
	WHITE HAKE	2002-2012	628	3,108	3,042	2,988	2,787	2,478	2,154	1,876	1,527	1,173	830	558	404	284	162	120	76
	WHITE HAKE	**All**	**10,687**	**53,149**	**52,284**	**50,691**	**47,823**	**43,402**	**38,693**	**34,375**	**29,917**	**24,650**	**19,078**	**14,164**	**10,583**	**7,784**	**6,285**	**5,138**	**4,247**
30 cm	**WINDOWPANE**	**WINTER**	**1,033**	**4,331**	**1,304**	**119**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
L80 = 25 cm	WINDOWPANE	1963-1971	28	134	77	13	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	1972-1981	15	66	44	13	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	1992-2001	869	3,573	978	79	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	2002-2012	121	557	205	14	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	**SPRING**	**834**	**3,681**	**1,863**	**426**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	WINDOWPANE	1963-1971	20	91	51	8	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	1972-1981	439	1,948	948	186	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	1982-1991	238	1,074	638	211	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	1992-2001	75	306	124	15	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	2002-2012	62	262	102	6	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	**SUMMER**	**101**	**484**	**327**	**76**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	WINDOWPANE	1963-1971	19	94	67	7	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	1972-1981	81	387	260	69	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	1982-1991	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	1992-2001	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	**FALL**	**1,097**	**4,636**	**2,200**	**420**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	WINDOWPANE	1963-1971	54	230	109	19	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	1972-1981	370	1,668	955	200	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	1982-1991	251	1,055	607	157	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	1992-2001	263	1,077	374	35	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	2002-2012	159	607	155	10	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINDOWPANE	**All**	**3,066**	**13,132**	**5,695**	**1,041**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
45 cm	**WINTER FLOUNDER**	**WINTER**	**271**	**1,340**	**1,287**	**1,140**	**910**	**620**	**316**	**126**	**15**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
L80 = 30 cm	WINTER FLOUNDER	1963-1971	157	782	767	718	600	415	192	78	12	3	0	0	0	0	0	0	0
	WINTER FLOUNDER	1972-1981	43	214	209	188	165	132	87	40	3	0	0	0	0	0	0	0	0
	WINTER FLOUNDER	1992-2001	57	278	250	183	115	55	27	9	0	0	0	0	0	0	0	0	0
	WINTER FLOUNDER	2002-2012	14	67	61	50	31	17	10	0	0	0	0	0	0	0	0	0	0
	WINTER FLOUNDER	**SPRING**	**2,113**	**9,986**	**8,765**	**6,791**	**4,642**	**2,690**	**1,090**	**344**	**94**	**11**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	WINTER FLOUNDER	1963-1971	149	739	722	686	551	382	202	52	14	0	0	0	0	0	0	0	0
	WINTER FLOUNDER	1972-1981	650	3,164	2,906	2,392	1,698	1,003	431	169	53	3	0	0	0	0	0	0	0
	WINTER FLOUNDER	1982-1991	551	2,606	2,312	1,788	1,193	626	220	65	21	7	0	0	0	0	0	0	0
	WINTER FLOUNDER	1992-2001	279	1,323	1,161	834	535	271	96	23	0	0	0	0	0	0	0	0	0
	WINTER FLOUNDER	2002-2012	484	2,154	1,663	1,092	665	408	141	34	5	0	0	0	0	0	0	0	0
	WINTER FLOUNDER	**SUMMER**	**799**	**3,690**	**3,069**	**2,101**	**1,314**	**693**	**349**	**154**	**38**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	WINTER FLOUNDER	1963-1971	159	794	776	709	564	305	140	62	18	3	0	0	0	0	0	0	0
	WINTER FLOUNDER	1972-1981	529	2,437	1,978	1,274	709	382	208	92	20	0	0	0	0	0	0	0	0
	WINTER FLOUNDER	1982-1991	6	25	16	8	2	0	0	0	0	0	0	0	0	0	0	0	0
	WINTER FLOUNDER	1992-2001	105	434	300	110	39	6	0	0	0	0	0	0	0	0	0	0	0
	WINTER FLOUNDER	**FALL**	**3,111**	**14,859**	**12,977**	**9,244**	**5,730**	**3,254**	**1,584**	**584**	**153**	**35**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	WINTER FLOUNDER	1963-1971	234	1,165	1,136	1,064	895	611	348	169	66	23	0	0	0	0	0	0	0
	WINTER FLOUNDER	1972-1981	762	3,719	3,392	2,690	1,858	1,095	575	225	52	12	0	0	0	0	0	0	0
	WINTER FLOUNDER	1982-1991	396	1,857	1,579	1,097	664	332	128	34	14	0	0	0	0	0	0	0	0
	WINTER FLOUNDER	1992-2001	812	3,868	3,282	1,969	997	475	205	59	8	0	0	0	0	0	0	0	0
	WINTER FLOUNDER	2002-2012	906	4,250	3,587	2,424	1,315	741	328	97	13	0	0	0	0	0	0	0	0
	WINTER FLOUNDER	**All**	**6,294**	**29,876**	**26,098**	**19,277**	**12,596**	**7,257**	**3,339**	**1,208**	**301**	**53**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Approximate 20% of biomass (upper), L80 for maturity (lower)	Species	Row Labels	Sum of 20 pct total wgt	WGT >= 25cm	Wgt >= 30cm	Wgt >= 35cm	Wgt >= 40 cm	Wgt >= 45cm	Wgt >= 50cm	Wgt >= 55 cm	Wgt >= 60cm	Wgt >= 65cm	Wgt >= 70cm	Wgt >= 75cm	Wgt >= 80cm	Wgt >= 85cm	Wgt >= 90cm	Wgt >= 95cm	Wgt >= 100cm
85 cm	WINTER SKATE	**WINTER**	**4,668**	**23,318**	**23,259**	**22,960**	**22,031**	**20,363**	**18,249**	**16,314**	**14,709**	**13,096**	**11,643**	**9,629**	**7,502**	**5,206**	**3,107**	**1,294**	**0**
L80 = 95 cm	WINTER SKATE	1963-1971	383	1,913	1,913	1,910	1,891	1,815	1,599	1,377	1,251	1,145	1,070	925	752	543	313	153	0
	WINTER SKATE	1972-1981	262	1,312	1,311	1,307	1,296	1,273	1,243	1,179	1,122	1,007	903	704	418	244	112	44	0
	WINTER SKATE	1992-2001	2,655	13,268	13,234	12,982	12,226	10,878	9,282	7,891	6,776	5,746	4,860	3,816	2,991	2,132	1,446	827	0
	WINTER SKATE	2002-2012	1,368	6,824	6,802	6,760	6,618	6,397	6,126	5,867	5,560	5,198	4,811	4,185	3,341	2,286	1,236	270	0
	WINTER SKATE	**SPRING**	**9,956**	**49,756**	**49,672**	**49,296**	**48,195**	**46,627**	**44,769**	**42,691**	**40,306**	**37,361**	**34,054**	**29,903**	**24,996**	**18,536**	**12,538**	**7,691**	**0**
	WINTER SKATE	1963-1971	390	1,949	1,948	1,945	1,928	1,891	1,809	1,685	1,480	1,239	1,005	727	544	390	232	143	0
	WINTER SKATE	1972-1981	1,357	6,783	6,776	6,753	6,686	6,593	6,480	6,283	6,024	5,661	5,132	4,454	3,557	2,387	1,305	736	0
	WINTER SKATE	1982-1991	5,405	27,006	26,950	26,715	26,134	25,429	24,699	23,936	23,122	22,029	20,807	19,070	16,886	13,331	9,715	6,253	0
	WINTER SKATE	1992-2001	1,238	6,187	6,180	6,132	5,921	5,490	4,899	4,333	3,764	3,172	2,612	2,105	1,572	1,004	631	373	0
	WINTER SKATE	2002-2012	1,567	7,832	7,819	7,751	7,527	7,225	6,882	6,454	5,916	5,260	4,497	3,547	2,437	1,424	655	185	0
	WINTER SKATE	**SUMMER**	**1,968**	**9,839**	**9,836**	**9,821**	**9,780**	**9,693**	**9,524**	**9,339**	**9,120**	**8,869**	**8,522**	**7,951**	**6,903**	**5,141**	**3,275**	**1,814**	**0**
	WINTER SKATE	1963-1971	318	1,589	1,588	1,586	1,580	1,551	1,459	1,342	1,217	1,102	964	784	589	394	233	114	0
	WINTER SKATE	1972-1981	1,633	8,163	8,162	8,152	8,124	8,071	7,997	7,933	7,844	7,716	7,514	7,128	6,285	4,735	3,035	1,699	0
	WINTER SKATE	1982-1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WINTER SKATE	1992-2001	17	86	86	83	75	71	68	64	60	51	44	39	29	12	6	0	0
	WINTER SKATE	**FALL**	**13,916**	**69,553**	**69,461**	**69,078**	**68,009**	**66,538**	**64,471**	**61,888**	**58,517**	**54,479**	**49,958**	**44,159**	**36,580**	**26,821**	**17,513**	**10,275**	**0**
	WINTER SKATE	1963-1971	431	2,151	2,146	2,126	2,096	2,020	1,852	1,678	1,453	1,234	1,028	810	589	412	347	233	0
	WINTER SKATE	1972-1981	2,861	14,300	14,276	14,209	14,065	13,848	13,580	13,290	12,953	12,471	11,813	10,649	8,916	6,472	4,068	2,342	0
	WINTER SKATE	1982-1991	4,979	24,882	24,842	24,731	24,468	24,113	23,667	23,194	22,527	21,721	20,782	19,427	17,664	14,260	9,876	6,158	0
	WINTER SKATE	1992-2001	2,415	12,069	12,059	12,010	11,823	11,453	10,773	9,770	8,573	7,222	5,984	4,843	3,587	2,396	1,543	910	0
	WINTER SKATE	2002-2012	3,231	16,151	16,138	16,002	15,557	15,105	14,600	13,956	13,010	11,831	10,352	8,429	5,823	3,280	1,678	632	0
	WINTER SKATE	**All**	**30,508**	**152,466**	**152,229**	**151,154**	**148,015**	**143,222**	**137,014**	**130,231**	**122,652**	**113,805**	**104,177**	**91,643**	**75,982**	**55,703**	**36,432**	**21,074**	**0**
45 cm	WITCH FLOUNDER	**WINTER**	**217**	**1,079**	**1,018**	**951**	**788**	**545**	**336**	**181**	**41**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
L80 = 40 cm	WITCH FLOUNDER	1963-1971	118	586	582	564	526	441	319	178	40	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	1972-1981	2	9	9	9	9	7	3	0	0	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	1992-2001	54	271	269	255	185	71	11	3	2	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	2002-2012	43	213	158	123	69	26	3	0	0	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	**SPRING**	**997**	**4,916**	**4,748**	**4,332**	**3,715**	**3,006**	**2,039**	**926**	**186**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	WITCH FLOUNDER	1963-1971	140	697	692	674	636	528	324	147	38	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	1972-1981	508	2,511	2,457	2,328	2,118	1,854	1,320	589	103	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	1982-1991	153	757	735	684	602	482	348	172	42	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	1992-2001	70	334	297	220	123	68	33	15	3	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	2002-2012	126	618	568	426	235	75	15	2	0	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	**SUMMER**	**278**	**1,356**	**1,314**	**1,224**	**1,092**	**925**	**690**	**366**	**94**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	WITCH FLOUNDER	1963-1971	129	642	635	616	554	456	324	182	44	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	1972-1981	107	530	522	505	472	423	334	169	42	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	1982-1991	11	48	43	31	20	15	10	4	2	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	1992-2001	31	135	114	72	46	30	22	11	6	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	**FALL**	**980**	**4,842**	**4,663**	**4,294**	**3,750**	**3,055**	**2,176**	**1,093**	**267**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	WITCH FLOUNDER	1963-1971	286	1,427	1,413	1,368	1,263	1,041	719	334	90	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	1972-1981	405	2,012	1,969	1,895	1,784	1,579	1,183	604	123	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	1982-1991	106	526	507	466	402	314	225	140	53	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	1992-2001	97	460	390	271	153	74	38	14	1	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	2002-2012	86	418	384	293	148	47	10	0	0	0	0	0	0	0	0	0	0
	WITCH FLOUNDER	**All**	**2,472**	**12,193**	**11,744**	**10,800**	**9,345**	**7,530**	**5,241**	**2,566**	**589**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
40 cm	YELLOWTAIL FLOUNDER	**WINTER**	**1,267**	**6,287**	**5,679**	**3,978**	**1,812**	**394**	**49**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
L80 = 30 cm	YELLOWTAIL FLOUNDER	1963-1971	213	1,028	958	767	406	116	18	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	1972-1981	61	303	283	234	112	38	10	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	1992-2001	918	4,582	4,117	2,767	1,230	230	20	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	2002-2012	75	374	321	210	65	11	0	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	**SPRING**	**3,196**	**15,625**	**14,140**	**8,588**	**3,313**	**766**	**133**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	YELLOWTAIL FLOUNDER	1963-1971	221	1,062	921	655	314	113	27	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	1972-1981	530	2,584	2,284	1,671	835	262	64	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	1982-1991	258	1,240	1,056	680	343	113	22	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	1992-2001	309	1,524	1,377	832	325	80	13	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	2002-2012	1,878	9,214	8,502	4,749	1,496	199	7	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	**SUMMER**	**520**	**2,529**	**2,253**	**1,549**	**673**	**166**	**31**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	YELLOWTAIL FLOUNDER	1963-1971	305	1,504	1,360	1,009	428	102	19	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	1972-1981	200	952	833	523	241	63	12	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	1982-1991	2	7	6	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	1992-2001	13	66	54	16	3	1	0	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	**FALL**	**3,581**	**17,198**	**15,714**	**9,999**	**4,108**	**918**	**126**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	YELLOWTAIL FLOUNDER	1963-1971	463	2,175	1,999	1,306	567	146	22	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	1972-1981	791	3,760	3,436	2,424	1,148	369	70	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	1982-1991	182	841	673	375	158	35	7	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	1992-2001	557	2,716	2,504	1,672	751	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	2002-2012	1,588	7,706	7,103	4,222	1,483	159	4	0	0	0	0	0	0	0	0	0	0
	YELLOWTAIL FLOUNDER	**All**	**8,564**	**41,640**	**37,786**	**24,113**	**9,905**	**2,244**	**339**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table 9. Summary of cluster analysis procedures applied to survey catch of juveniles (number) and large spawners (weight).

Procedures run individually on age 0/1 juveniles[1] and large spawners[2]	Process	Sample size or effect	
Hurdle model approach adjustment	Adjust cumulative catch at size, multiplying by the proportion of	All tows included	
Log transform	Transform non-zero catches to a normalized distribution	Zero catches are ignored (reduced number of tows analyzed)	
Select tows for analysis	Select by survey, season, and decade	Reduces number of tows; analysis occurs in desired time period and season; surveys analyzed separately due to catchability differences. Remaining tows may be insufficient number to analyze spatial autocorrelation or hotspots.	
Spatial autocorrelation (Moran's I)	Determine range of highest spatial autocorrelation to set Zone of Indifference parameter for hotspot analysis	Analyzes untransformed tows, including zero catch tows. Procedure may not detect a significant positive spatial autocorrelation. If peak is weak or undetected by analysis, a reasonable alternative was applied for hot spot analysis.	
Hot spot analysis (Getis-Ord's G*) and selection	Identifies hotspots, filtered for significant ($p<0.05$) hotspots above the mean.	Procedure may not identify any significant hotspots at $p<0.05$ level.	
Grid hotspots	Number of significant hotspots for a species within a 100 km^2 SASI grid is summed.	All surveys in a season are included, since the hotspot data are standardized relative to each survey's mean.	
Weight layers by importance factor	Number of hotspots in a grid is multiplied by importance factor	Final grid for a season includes all surveys where significant hotspots	

[1] For aged species, upper size threshold that approximated 90th percentile of age 1 fish. Threshold set at the approximate L20 for maturity for unaged species.
[2] Lower size threshold set where fish at or larger than the threshold comprised 20% of estimated biomass in the spring (applied to spring and summer) and fall (applied to fall and winter) NMFS trawl surveys.

Procedures run individually on age 0/1 juveniles[1] and large spawners[2]	Process	Sample size or effect	
	and summed over species.	were identified by the analysis, weighted by the relative importance of the effect that spatial management will have on regulated groundfish.	

Table 10. Summary of peak spatial autocorrelation results and alternative trial peaks in parantheses. NA = analysis not attempted due to infrequent catch or data not yet available. NP = No significant peak autocorrelation detected. NSHS = No significant hotspots of above average catches detected or produced by the hotspot analysis. IC = insufficient catch to conduct either a spatial autocorrelation or hotspot analysis.

	Survey: NMFS spring		Survey: MADMF spring		Survey: ME/NH spring	
Species	Juvenile	Spawner	Juvenile	Spawner	Juvenile	Spawner
Cod	8510 (11510)	11510	10528 (15528)	10525 (17528)	4620 (10620)	30620
Haddock	8010 (10010)	8010 (20010)	16528	10528	4620 (6620)	13620 (NSHS)
Yellowtail flounder	11510	11510 (16510)	9528 (14528)	8528 (17528)	IC	IC
American plaice	14510	10510	8528 (17528)	11528	15620	17620
Atlantic wolffish	IC (2 + tows)	NP (20010)	NA	NA	NA	NA
Ocean pout	21510 (12 + tows)	10510	15528 (22528)	13528	5620	17620 NSHS
Pollock	13510	10510	NP (21 + tows)	IC	3620 (7620)	IC
Red Hake	11510 (14510)	NP (14510)	8528	8528	9620	5620
Redfish	9510	10510	IC	11528 (NSHS)	3620 (9620)	4620 (17620) NSHS
Silver hake	10510	32510	20639	10528	6620	11620
White hake	NP (20010)	8510 (21510)	NP (7528)	IC	8620	NP (10620)
Winter flounder	11510	8510 (15510)	7528	8528	3620 (14620)	NP 912620) NSHS
Witch flounder	13510	8510	NP (8528)	IC	7620	NP (3620) NSHS
Windowpane flounder	10510 (23510)	8510	8528 NSHS	8528	4320 NSHS	NP NSHS
Alewife	NA	NA	NA	NA	7620	3620 (20620)
Atlantic herring	NA	NA	NA	NA	4620 (7620)	5620 (23620)
Atlantic halibut	NA	NA	NA	NA	12620	NP NSHS
Goosefish	NA	NA	NA	NA	NA	NA
Barndoor skate	NA	NA	NA	NA	NA	NA

	Survey: IBS Cod spring		Survey: IBS Goosefish spring		Survey: NMFS dredge summer	
Species	Juvenile	Spawner	Juvenile	Spawner	Juvenile	Spawner
Cod	4534 (13534)	NP (28534)	IC	36226	10338 IC	IC
Haddock	11534	7534	NP (48226) NSHS	34226	7338 (16338)	9338 (13338)
Yellowtail flounder	IC	13534 NSHS	IC	34226	5338	5338
American plaice	6534 (9534)	8534	NA	NA	NA	NA
Atlantic wolffish	IC	IC	NA	NA	NA	NA
Ocean pout	IC	IC	NA	NA	NA	NA
Pollock	5334	5334 IC	NA	NA	NA	NA
Red Hake	IC	IC	NA	NA	NP (19338)	IC
Redfish	26534 (5534)	2634 (5534)	NA	NA	NA	NA
Silver hake	IC	IC	NA	NA	NA	NA
White hake	6534 (14534)	6534 (14534)	NA	NA	NA	NA
Winter flounder	5534	5534	NA	NA	16338	17338
Witch flounder	6534 NSHS	6534 NSHS	NA	NA	NA	NA
Windowpane flounder	IC	IC	NA	NA	NA	NA
Alewife	NA	NA	NA	NA	NA	NA
Atlantic herring	NA	NA	NA	NA	NA	NA
Atlantic halibut	NA	NA	NA	NA	NA	NA
Goosefish	NA	NA	35226	NP	NP (19764)	5338 (23338)
Barndoor skate	NA	NA	NA	NA	NP (15338)	11338 (15338)

	Survey: NMFS shrimp summer		Survey: NMFS fall		Survey: MADMF fall	
Species	Juvenile	Spawner	Juvenile	Spawner	Juvenile	Spawner
Cod	8528 (16528)	7528 (13528)	8624 (18624)	8624 (17624)	7365 (9365)	NP (5365) NSHS
Haddock	8528	20528 (26528)	13624	13624	6365 (strong SAC)	22365
Yellowtail flounder	NA	NA	9624	14264	NP (31365) NSHS	4365 (22365) NSHS
American plaice	12528 (18528)	9528 (15528)	9624	10624	4365	6365 (strong peak)
Atlantic wolffish	IC	IC	IC	NP	IC	IC
Ocean pout	IC	10528 NSHS	24624	9624 (23624)	22365 NSHS	18365 NSHS
Pollock	20528 NSHS	18528 (27528) NSHS	11624 (15624)	8624 (27624)	12365	IC
Red Hake	8528	14528	33624	8624 (33624)	8365	7365 (13365)
Redfish	8528	12528	17624	9624 (17624)	12365 IC	5365
Silver hake	8528 (28528)	9528 (15528)	14624	13624	10365	14365
White hake	12528 (18528)	10528	18624	9624 (18624)	4365	IC
Winter flounder	19528	NC	25624	8624	9365	10365 (22365)
Witch flounder	NP (18528)	8528 (13528)	8964 (22624)	8624 (11624)	17365 IC	10365 NSHS
Windowpane flounder	13528	IC	8964 (22624)	33624	5365 (9365) (strong 2nd peak)	6365 (10365) (strong 2nd peak)
Alewife	NA	NA	NA	NA	NA	NA
Atlantic herring	NP	NP	12624	16624	11365	5365 NSHS
Atlantic halibut	NA	NA	NA	NA	NA	NA
Goosefish	11528	28528 NSHS	13624	9624 (12624) NSHS	11365 (13365) NSHS	5365 NSHS
Barndoor skate	NA	NA	NA	NA	NA	NA

	Survey: ME/NH fall		Survey: IBS Cod fall		Survey: IBS YTF fall	
Species	Juvenile	Spawner	Juvenile	Spawner	Juvenile	Spawner
Cod	5988 (7988)	4988 (21998)	7313	9313	IC	IC
Haddock	29998	NP IC	7313	20913	IC	IC
Yellowtail flounder	8988 NSHS	NP IC	IC	5313	24642 NSHS	16642
American plaice	24988	3988	5313	NP (25313)	NA	NA
Atlantic wolffish	NA	NA	IC	IC	NA	NA
Ocean pout	4998	IC	NA	NA	NA	NA
Pollock	NP (18998)	IC	NP (11313) NSHS	12313	NA	NA
Red Hake	16998 (strong peak)	10998 (strong peak)	IC	IC	NA	NA
Redfish	5998 (17998)	NP 6998	12313	NP (8313)	NA	NA
Silver hake	13998	9988	IC	IC	NA	NA
White hake	17998	6998 IC	10313	IC	NA	NA
Winter flounder	17998	NP IC	5313 (17313)	7313	IC	IC
Witch flounder	4998 (14998)	8998 (17998) NSHS	NP	5313 (9313)	NA	NA
Windowpane flounder	8988	3988 IC	IC	7313	NA	NA
Alewife	16988	7988 (17988)	NA	NA	NA	NA
Atlantic herring	5998	3988	NA	NA	NA	NA
Atlantic halibut	12998 IC	3998 IC	NA	NA	NA	NA
Goosefish	11998 NSHS	IC	5313 (9313)	NP (23313)	NP IC	IC
Barndoor skate	NA	NA	NA	NA	NA	NA

	Survey: NMFS winter		Survey: IBS Cod winter		Survey: IBS GSF winter	
Species	Juvenile	Spawner	Juvenile	Spawner	Juvenile	Spawner
Cod	15806	27806	9728 (12728)	NP (7728)	NP (31083) NSHS	NP
Haddock	17806	NP (23806)	17728 (31728)	10728	NP	49083
Yellowtail flounder	21806	12806 (28806)	IC	NP (3728)	IC	NP
American plaice	IC	24806	8728	6728	59083 NSHS	35083 NSHS
Atlantic wolffish	NA	NA	IC	IC	NA	NA
Ocean pout	14806 (16806)	14806	IC	IC	NA	NA
Pollock	IC	IC	IC	NP (15728)	NA	NA
Red Hake	20806 (27806)	12806	NA	NA	NA	NA
Redfish	NA	NA	NA	NA	NA	NA
Silver hake	19806	12806 (31806)	NA	NA	NA	NA
White hake	NA	NA	11728	NP IC		
Winter flounder	12806 (16806)	21806	5728 (20728)	NP (24728) NSHS	35083	NP NSHS
Witch flounder	19806	12806 (14806)	7728 (12728)	8728	IC	36083 (40083)
Windowpane flounder	15806 (17806)	14806 (37806)	IC	6728	NA	NA
Alewife	NA	NA	NA	NA	NA	NA
Atlantic herring	NA	NA	NA	NA	NA	NA
Atlantic halibut	NA	NA	NA	NA	NA	NA
Goosefish	12806 (25806)	32806	6728 (21728)	NP	35083 (44083)	34083
Barndoor skate	NA	NA	NA	NA	40083 NSHS	NP NSHS

Table 11. Summary of significant hotspots of above average catches identified by survey and species for age 0/1 juvenile (upper) and for large spawners (lower), 2002-2012.

Survey	Years	Tows	Mean to ne	StdDev	90th pctle	95th pctle	Alewife	Am Plaice	Atlantic Herring	Atlantic halibut	Atlantic Wolffish	Barndoor skate	Cod	Goosefish	Haddock	Ocean pout	Pollock	Red hake	Redfish	Silver hake	White hake	Winter flounder	Witch flounder	Windowpane flounder	Yellowtail flounder	Total survey
NMFS spring	2002-2012	3,426	4,012.0	3,630.0	7,509.5	9,014.9		85	0				35		31	0	0	122	25	167	70	53	7	3	11	609
NMFS shrimp		677	3,088.9	2,328.5	6,527.5	8,258.9		114					1	48	4			23	161	87	112		56			606
NMFS scallop	2002-2011	4,634	1,538.7	1,454.9	3,337.7	4,269.8						81	18	250	61			0				14			7	431
NMFS fall	2002-2011	3,413	4,004.0	2,634.0	7,624.0	8,979.0		91	1				33	30	80	0	1	286	69	254	77	132	19	4	5	1082
NMFS winter	2002-2007	659	6,212.4	5,272.9	11,805.6	13,468.3		0					2	3	1	1		18		59		8	3	4	0	99
MADMF spring	2002-2012	936	832.9	655.3	1,798.9	2,184.9		44					80		8	0	3	19	0	41	4	150		0	17	366
MADMF fall	2002-2011	714	1,096.8	835.9	2,364.8	2,807.9		24	1				5	0	4	0	0	58	0	88	2	131		2		315
MENH spring		1,194	1,078.7	1,156.7	2,619.4	3,298.2	187	269	51	19			85		36	9	16	70	116	317	71	264	57	149	0	1716
MENH fall		812	1,271.7	1,436.0	2,987.9	3,859.1	192	233	92	11			29	0	15	4	4	186	329	275	209	187	46	134	0	1946
IBS cod spring		449	1,513.1	1,643.0	3,533.9	4,638.3		77					54		25				18		10	16	0			200
IBS cod fall		175	2,202.4	2,559.9	4,312.8	6,101.3		12					21	7	8		0		2		8	28	0			86
IBS cod winter		274	2,064.9	3,114.4	3,728.0	5,131.3							2	10	10						14	65	1			102
IBS goosefish spring		229	15,551.0	13,125.6	30,226.1	34,028.5								13	0											13
IBS goosefish winter		198	16,992.9	9,778.9	31,082.6	34,286.3							2		0											2
IBS YTF fall		709	3,382.5	14,471.1	5,642.0	7,373.3																			0	0
					Total species hotspots =		379	949	145	30	0	81	367	361	283	14	24	782	720	1288	577	1048	189	296	40	7573

Survey	Years	Tows	Mean to ne	StdDev	90th pctle	95th pctle	Alewife	Am Plaice	Atlantic Herring	Atlantic halibut	Atlantic Wolffish	Barndoor skate	Cod	Goosefish	Haddock	Ocean pout	Pollock	Red hake	Redfish	Silver hake	White hake	Winter flounder	Witch flounder	Windowpane flounder	Yellowtail flounder	Total survey
NMFS spring	2002-2012	3,426	4,012.0	3,630.0	7,509.5	9,014.9		43	67				22		145	14	6	92	19	174	7	5	4	35	30	663
NMFS shrimp		677	3,088.9	2,328.5	6,527.5	8,258.9		23	66				1	0	16	0	0	139	71		0	4				320
NMFS scallop	2002-2011	4,634	1,538.7	1,454.9	3,337.7	4,269.8						1	1		3							24			17	46
NMFS fall	2002-2011	3,413	4,004.0	2,634.0	7,624.0	8,979.0		14					16	0	91	1	13	259	51	141	13		4	51	39	693
NMFS winter	2002-2007	659	6,212.4	5,272.9	11,805.6	13,468.3							0	3	1	14		2		31			0	20	3	74
MADMF spring	2002-2012	936	832.9	655.3	1,798.9	2,184.9	127	3					0		1	30		9		24		5		29	29	257
MADMF fall	2002-2011	714	1,096.8	835.9	2,364.8	2,807.9		1	0				0	0	0	0		24		30			0	2		57
MENH spring		1,194	1,078.7	1,156.7	2,619.4	3,298.2		73	74	0	0		0		0			15	0	38		0	0		0	200
MENH fall		812	1,271.7	1,436.0	2,987.9	3,859.1	19	2	23	0			2					57	39	54	0		0	0		196
IBS cod spring		449	1,513.1	1,643.0	3,533.9	4,638.3		14					7		28		1		6			0	0	1	0	57
IBS cod fall		175	2,202.4	2,559.9	4,312.8	6,101.3		0					8	0	6		0		1				3	2	4	24
IBS cod winter		274	2,064.9	3,114.4	3,728.0	5,131.3		2					6	0	13		4						0	0	3	28
IBS goosefish spring		229	15,551.0	13,125.6	30,226.1	34,028.5							1	1	5											7
IBS goosefish winter		198	16,992.9	9,778.9	31,082.6	34,286.3		5				0	0	2	3								4	0	0	14
IBS YTF fall		709	3,382.5	14,471.1	5,642.0	7,373.3																			65	65
					Total species hotspots =		146	180	230	0	0	1	64	6	312	59	24	597	187	492	20	38	15	140	190	2701

Figure 8. Data processing flowchart for spatial autocorrelation and hotspot analyses for juvenile (upper) and large spawner (lower) life stages. The example analyzes witch flounder juvenile and large spawner distribution in the 2009 IBS winter goosefish survey.

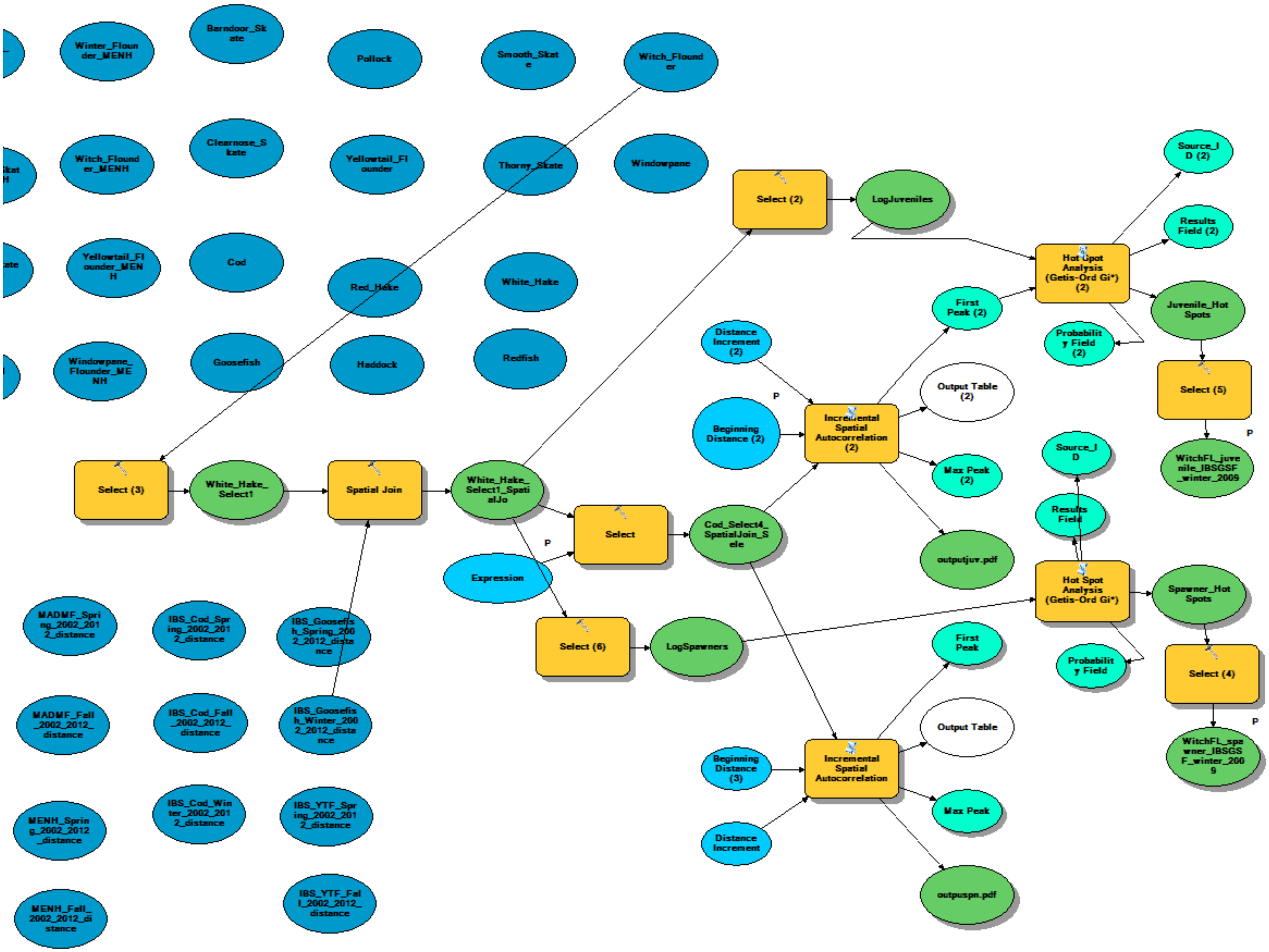
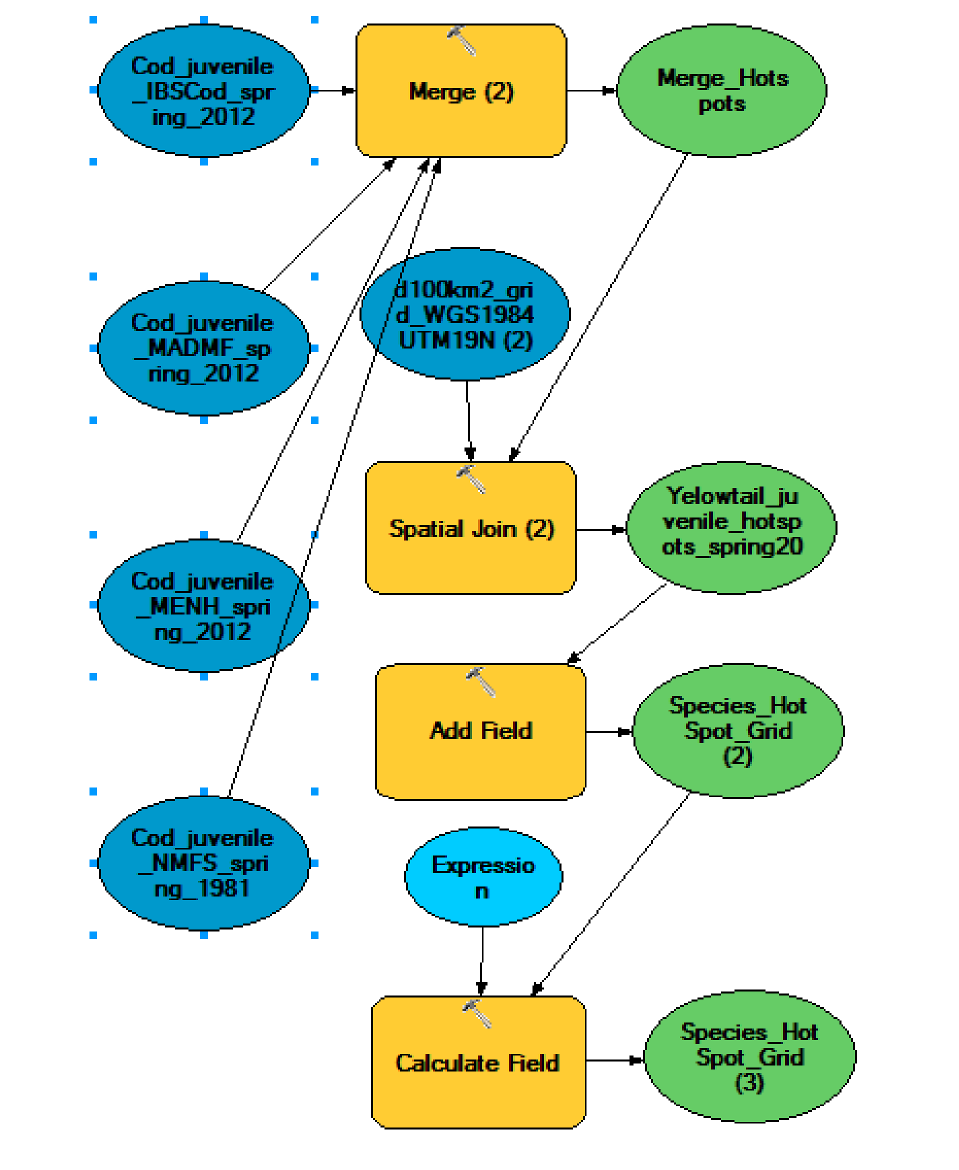


Figure 9. Workflow for merging and gridding weighted number of hotspots for a season.

Synopsis of juvenile groundfish habitat and spawning analysis

Merge survey layers and grid for a species



Apply grid weights and merge for a season

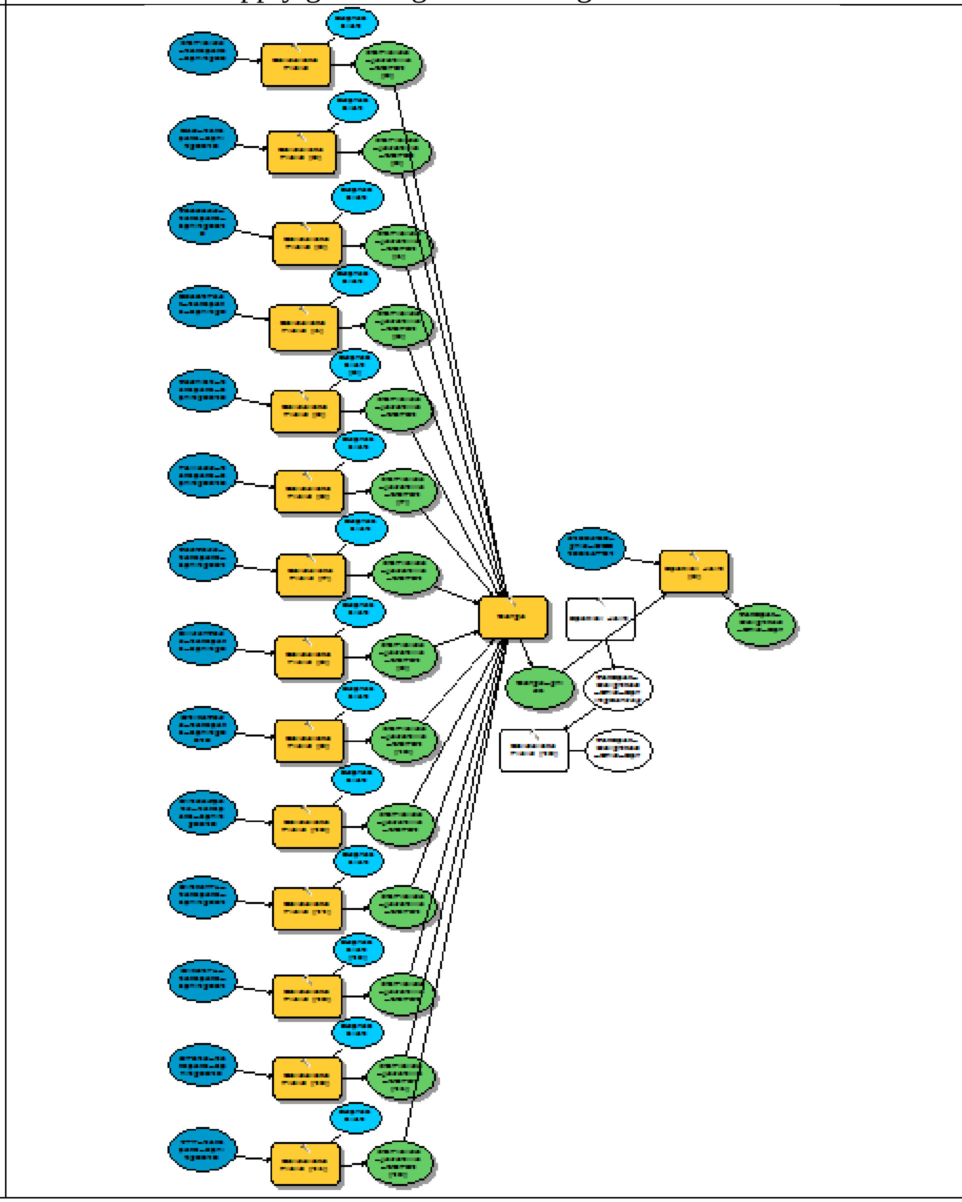
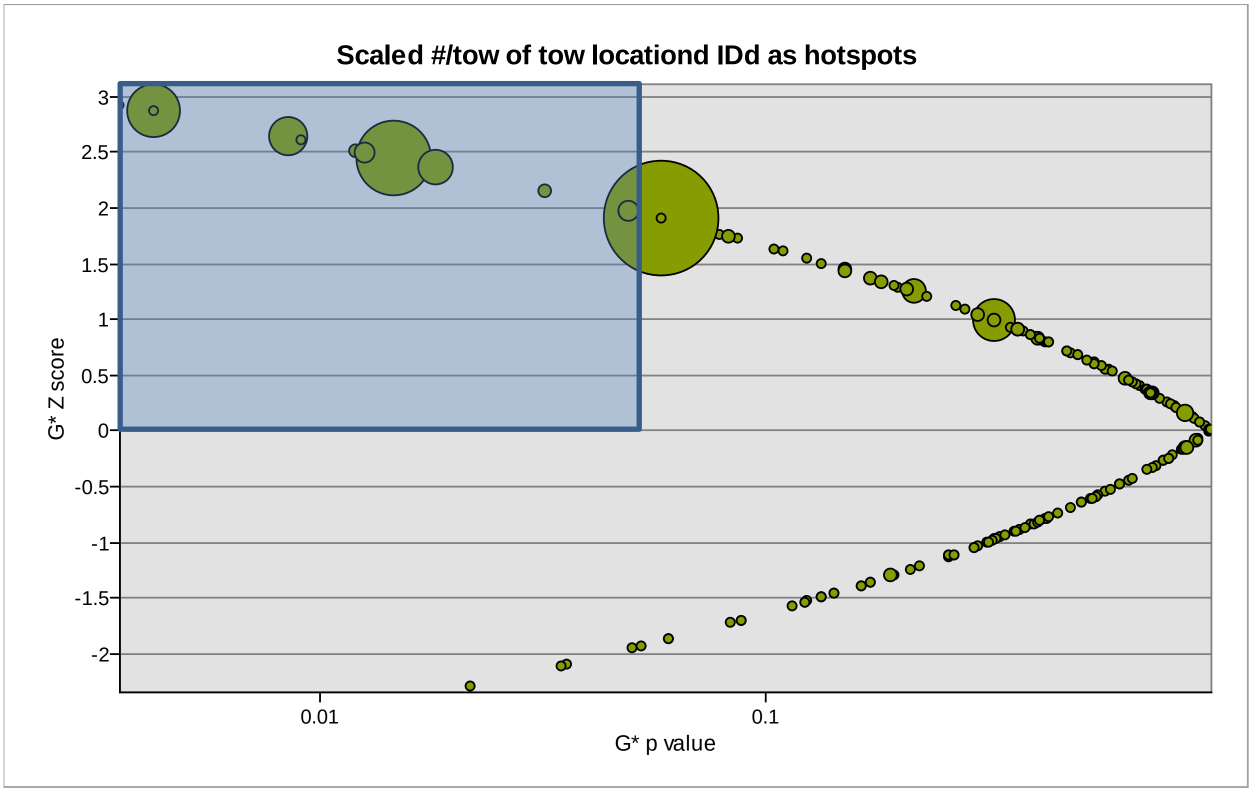


Figure 10. Juvenile cod (<= 25 cm) per tow in 2002-2012 NMFS spring trawl surveys vs. Getis-Ords G* hotspot statistics for 229 hotspots derived from 3426 tow locations. All tows are non-zero and the diameter is scaled to untransformed catch per tow. Low p values represent significant clusters. Positive Z scores are above the mean of non-zero tows. Tows that fall within the light blue box represent high catch rates derived from significant (p<=0.05) clusters.



Map 1. Location of above average significant hotspots (blue circles) compared to all clusters (shaded circles) overlaying scaled <= 25 cm cod/tow (pink squares), NMFS spring trawl survey 2002-2012.

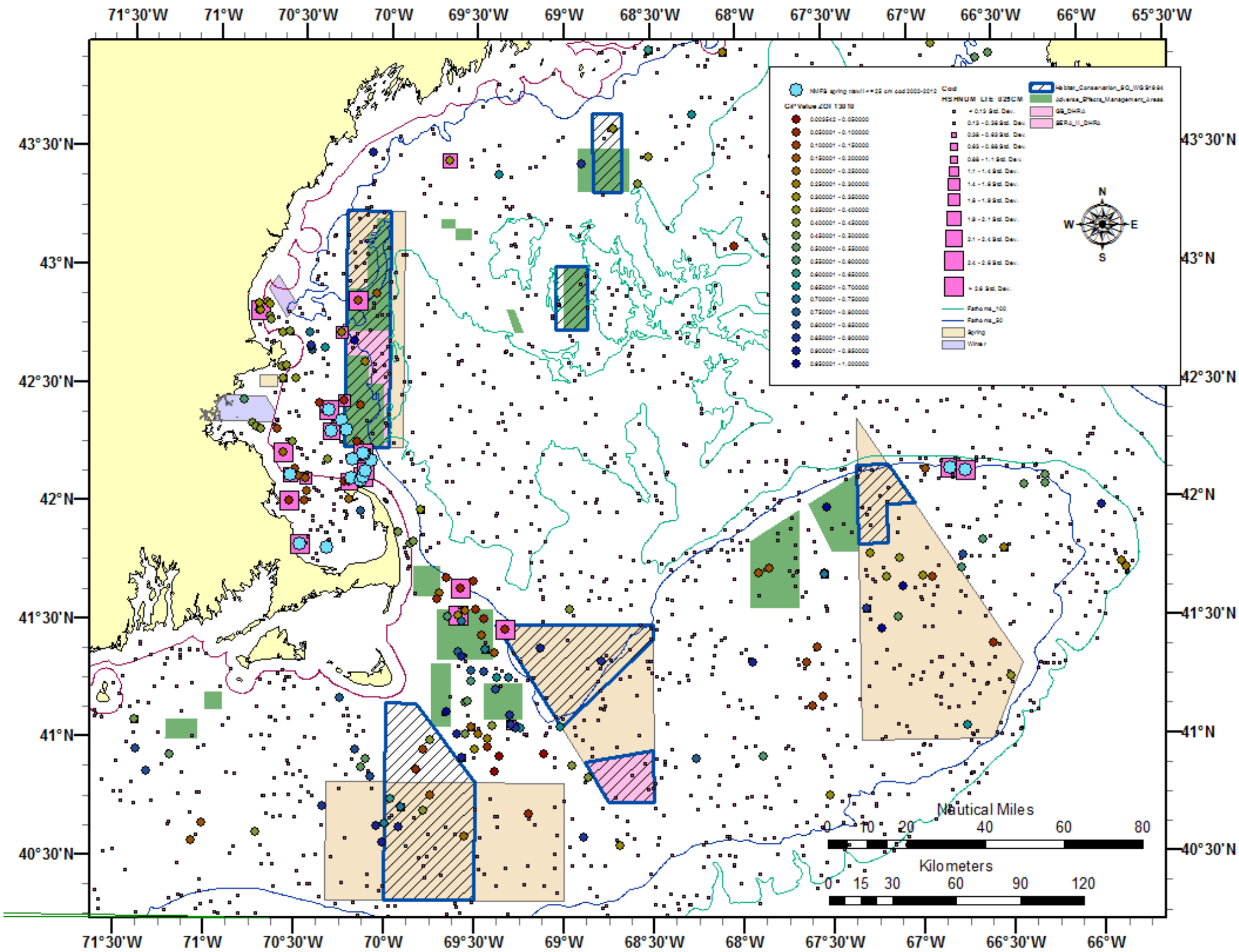


Figure 11. Presence (red)/absence (red) of cod in spawning condition observed during the 2002-2012 NMFS spring trawl surveys.

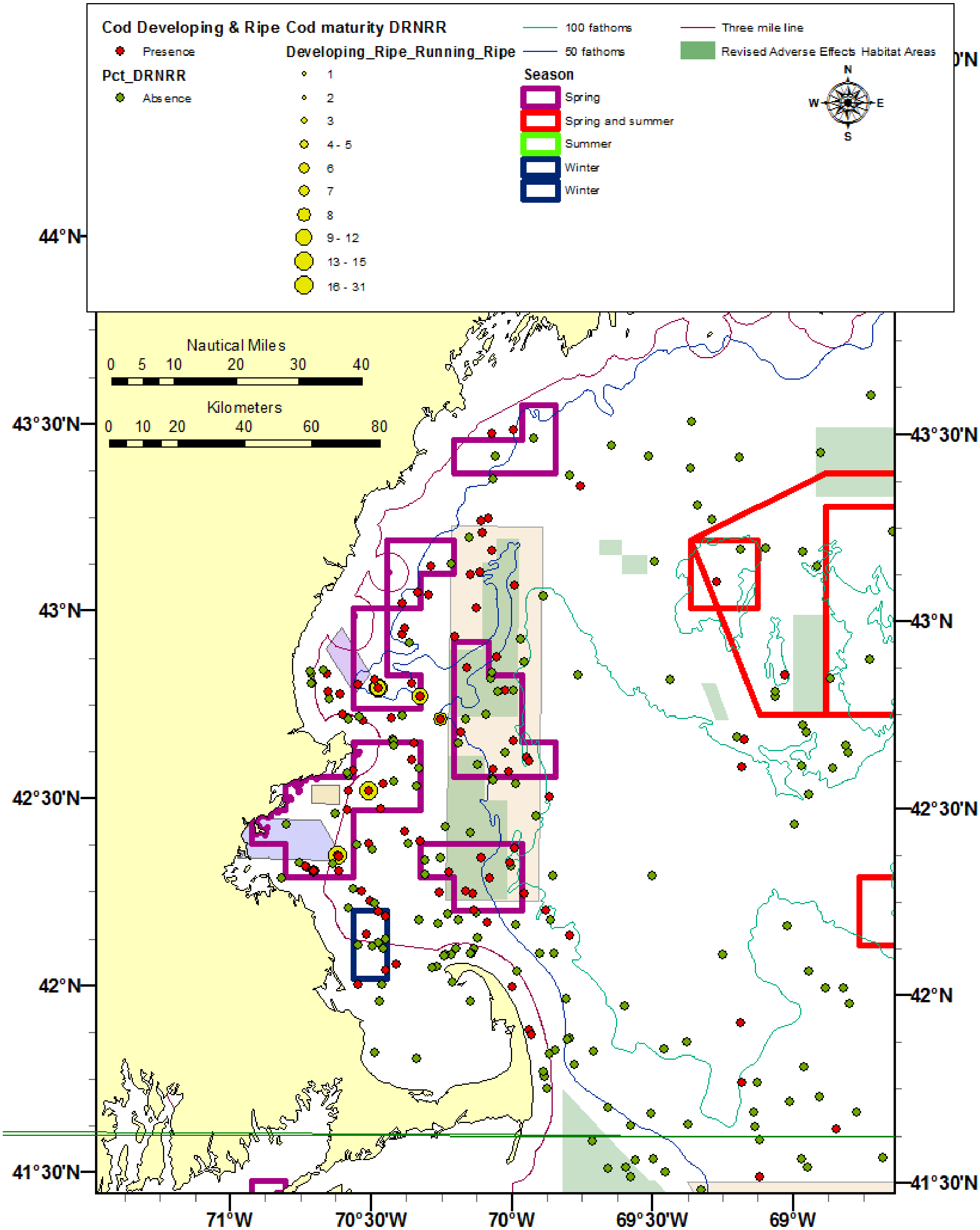


Figure 12. Presence (red)/absence (red) of haddock in spawning condition observed during the 2002-2012 NMFS spring trawl surveys.

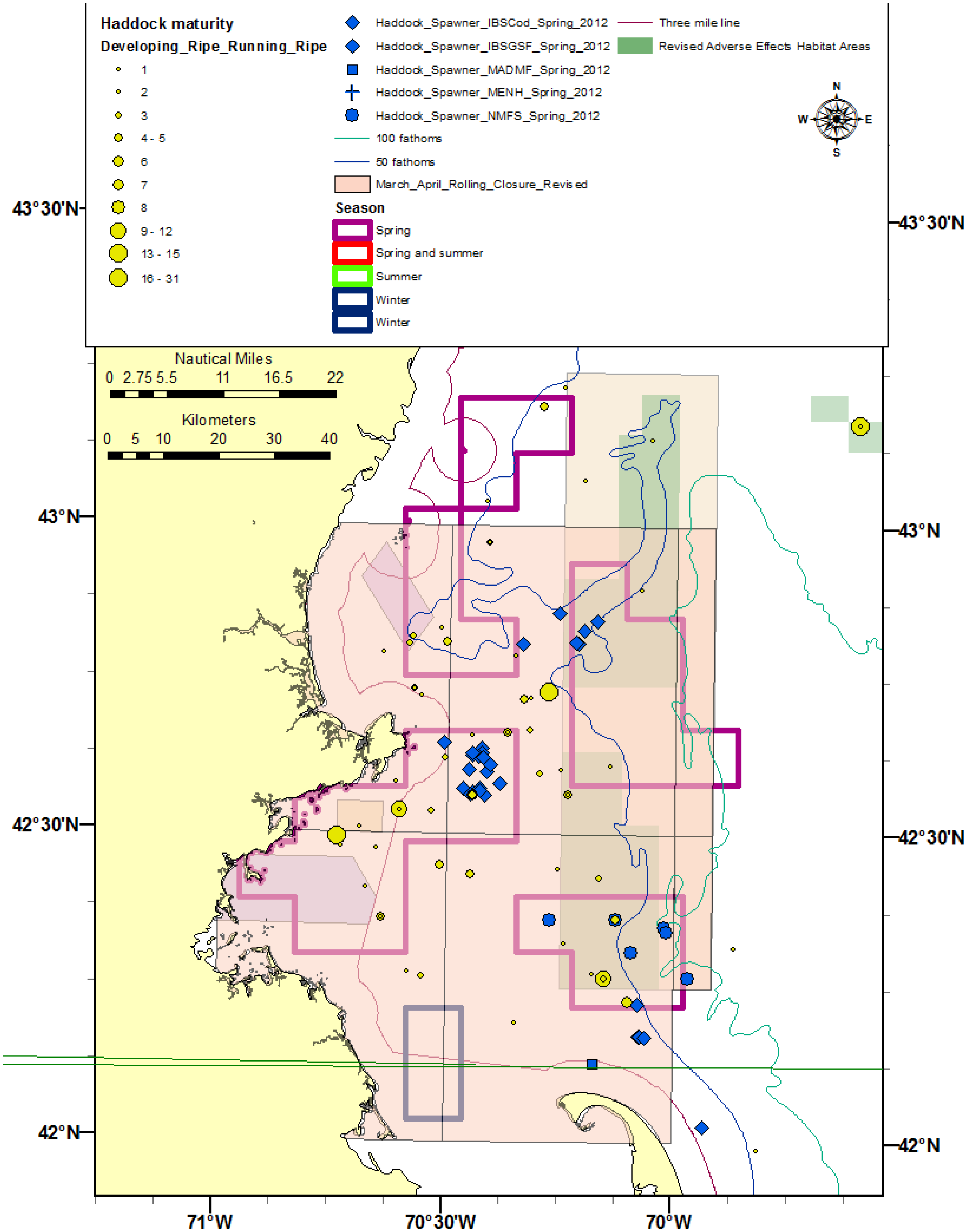


Figure 13. Presence (red)/absence (red) of haddock in spawning condition observed during the 2002-2012 NMFS spring trawl surveys.

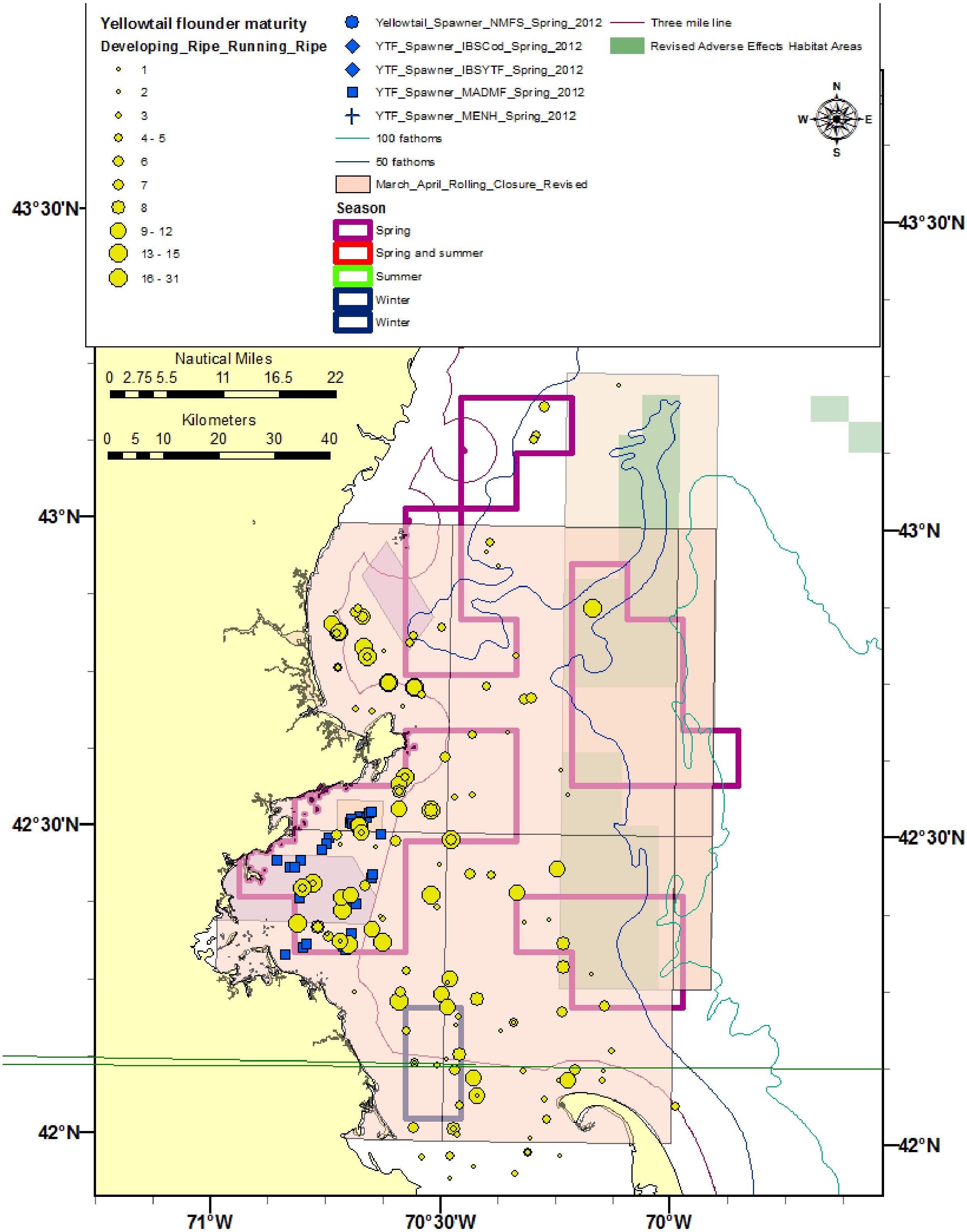


Figure 14. Coastal juvenile groundfish habitat management area option, compared to a summary grid of weighted hotspots (darker shade denotes a higher weighted hotspot value; outlined and unshaded blocks represent areas with hotspots given zero weight).

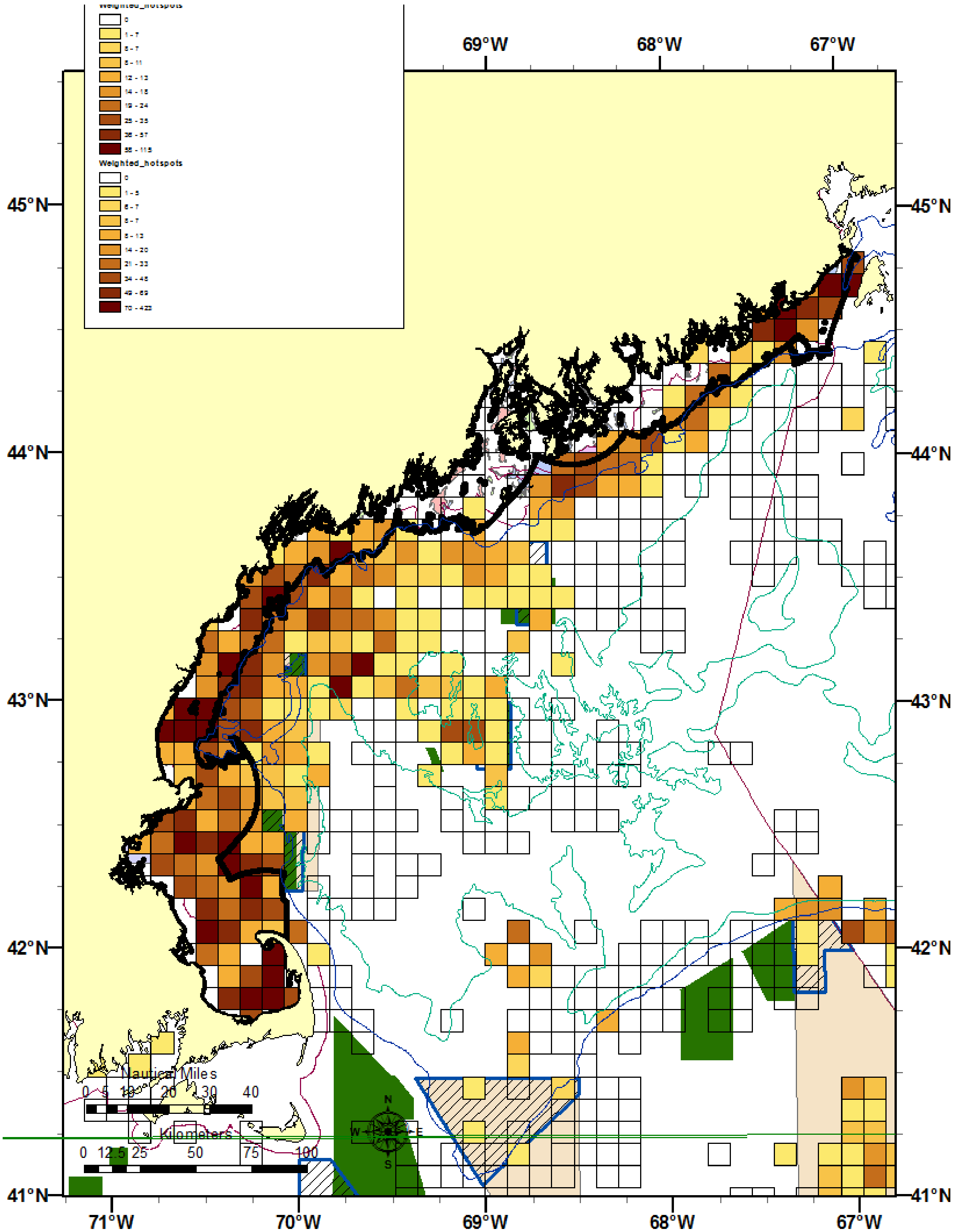


Figure 15. Juvenile groundfish habitat management area option, compared to a summary grid of weighted hotspots (darker shade denotes a higher weighted hotspot value; outlined and unshaded blocks represent areas with hotspots given zero weight).

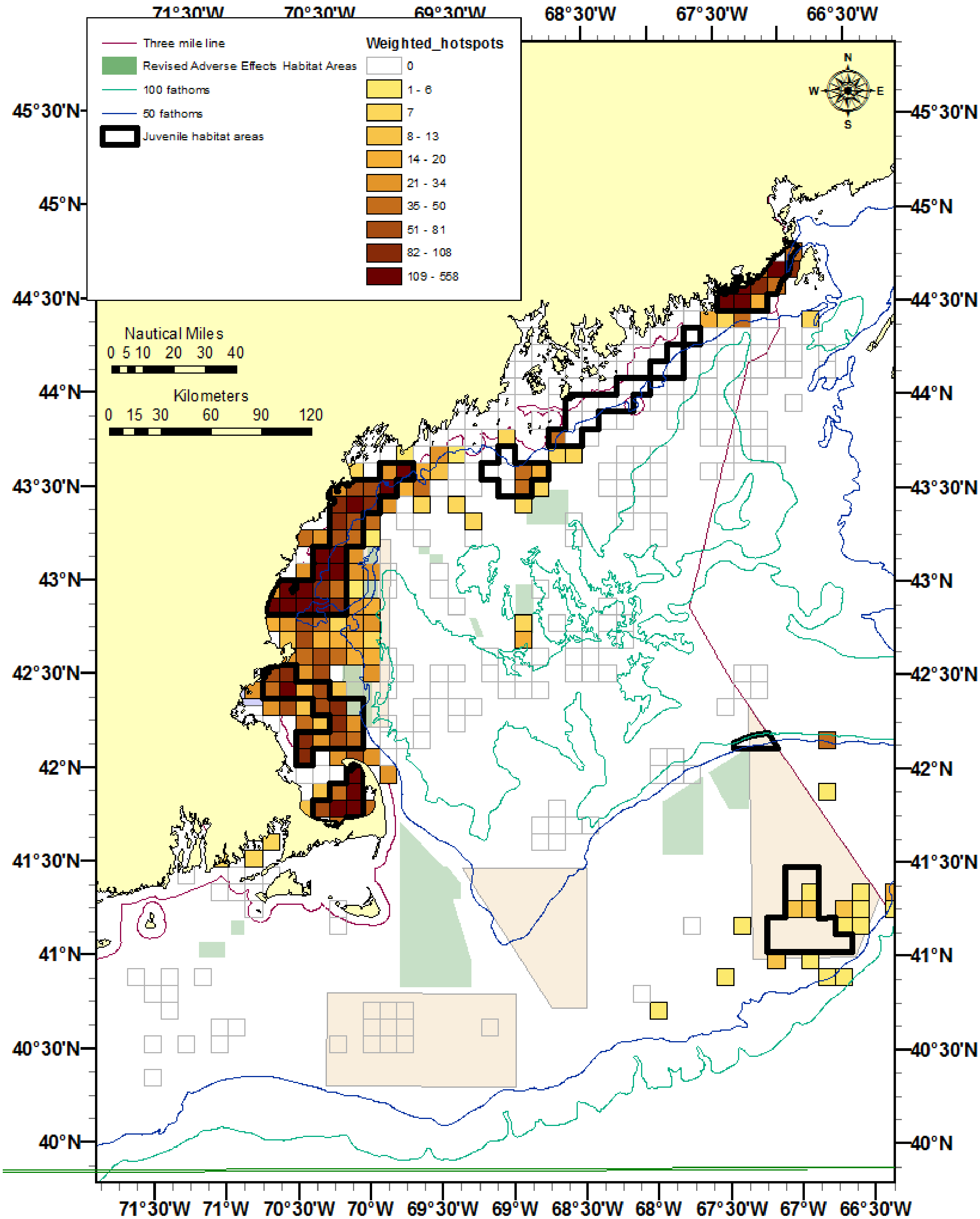


Figure 16. Seasonal groundfish spawning areas derived from hotspot analysis.

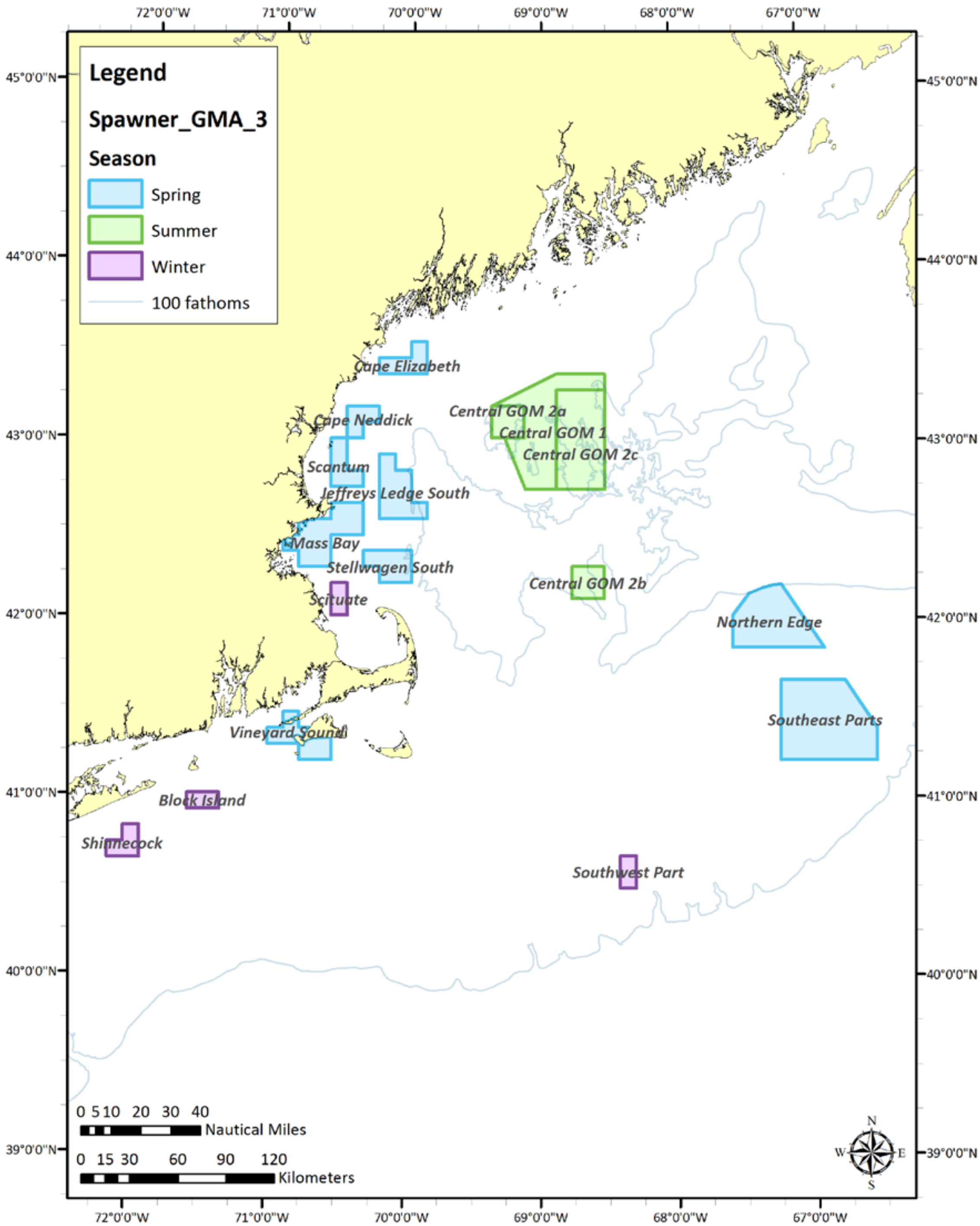


Figure 17. Proposed March-April modified rolling closure option (black outline) compared to existing April sector rolling closure (shaded).

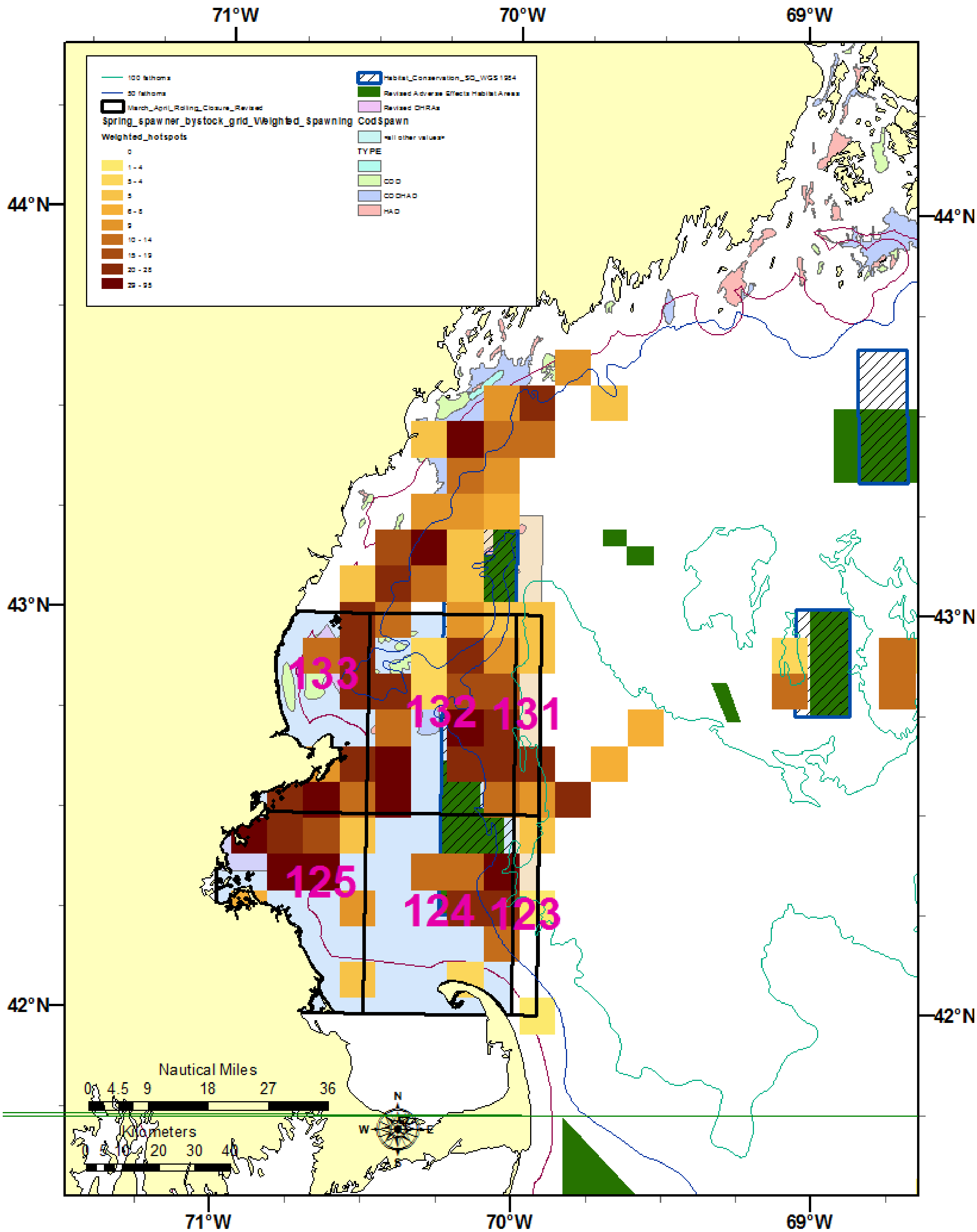


Figure 18. Proposed May modified rolling closure option (black outline) compared to existing May sector rolling closure (shaded).

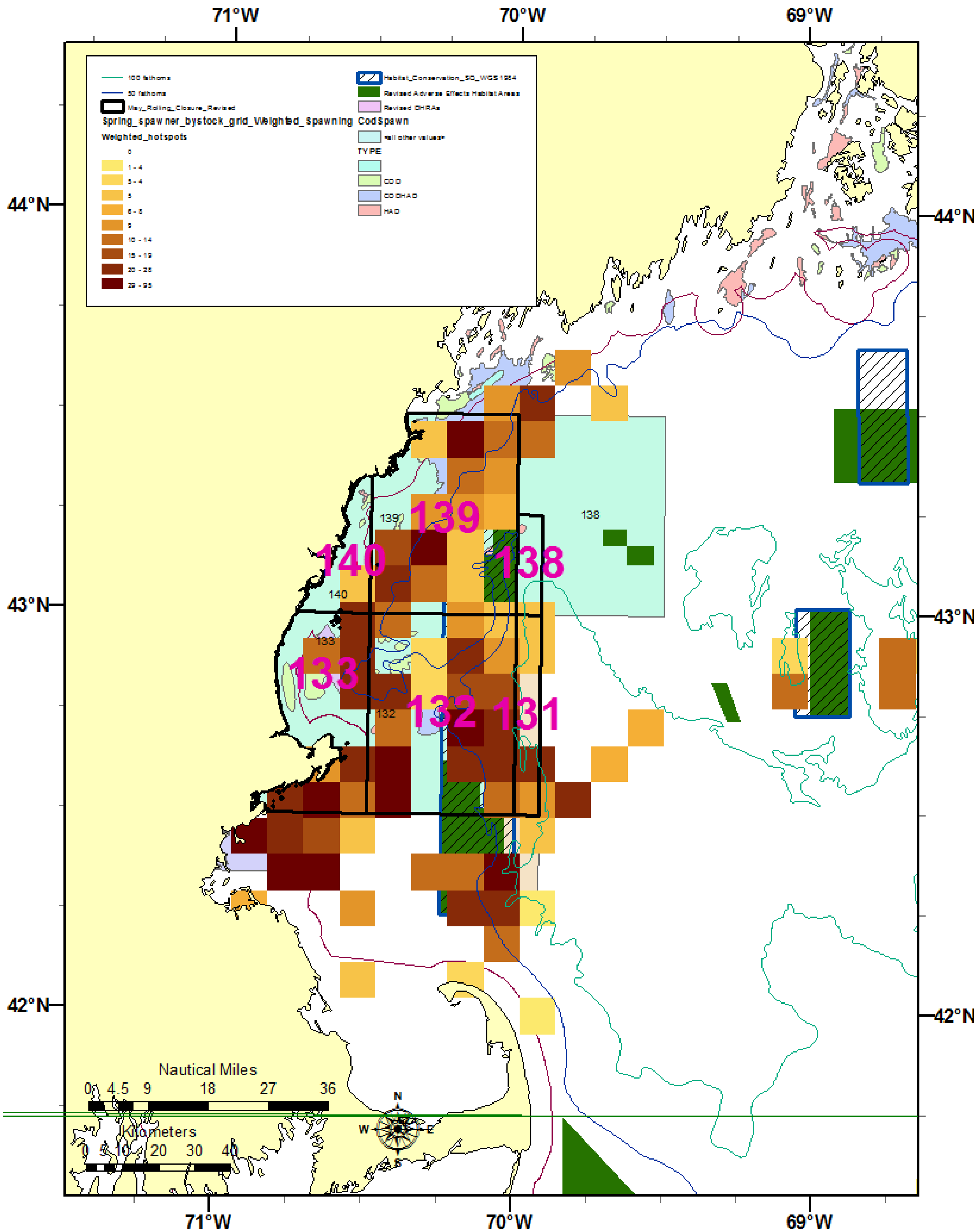
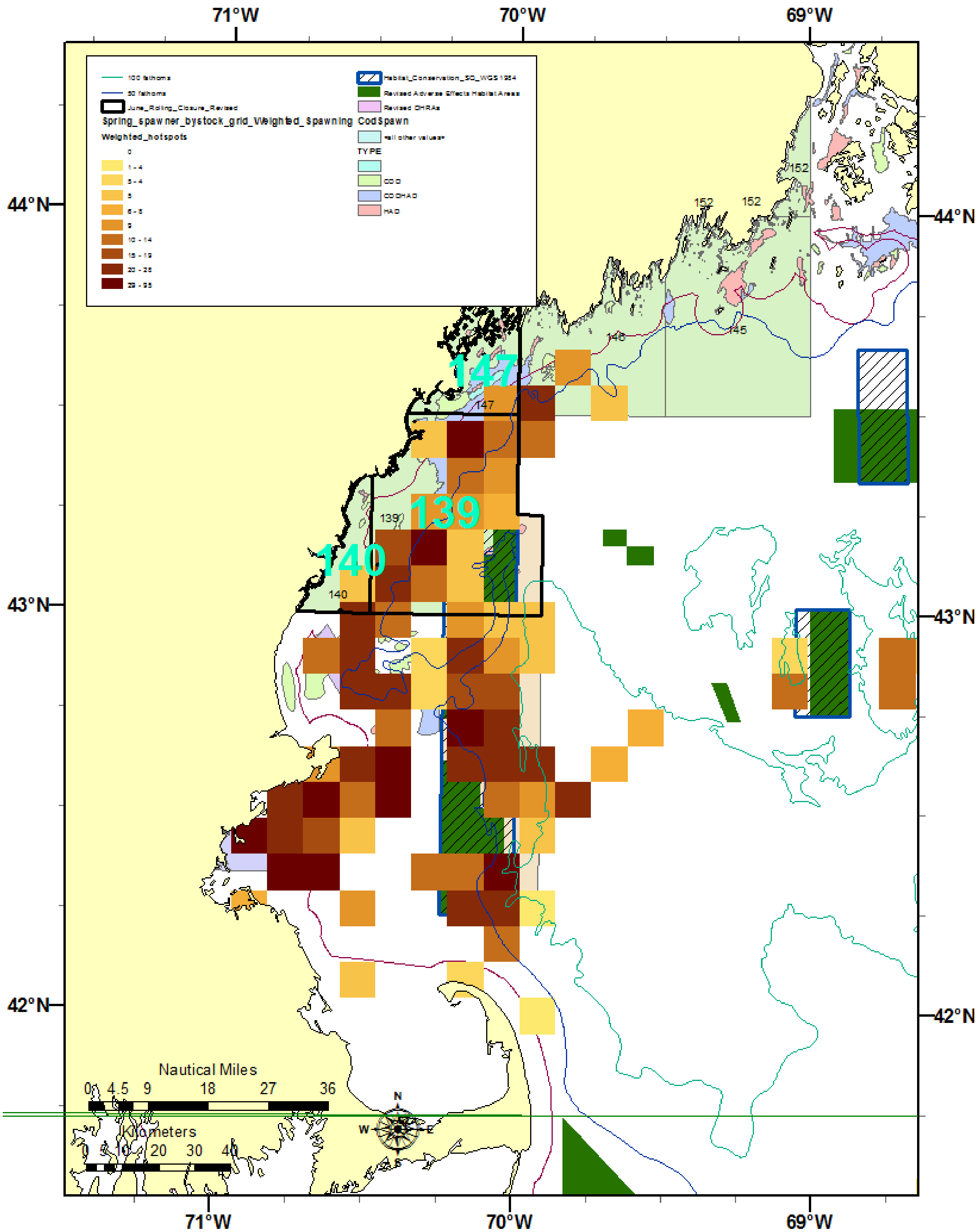


Figure 19. Proposed June modified rolling closure option (black outline) compared to existing June sector rolling closure (shaded).



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Getis-Ord Gi* statistic in ArcGIS

The Hot Spot Analysis tool calculates the Getis-Ord Gi* statistic (pronounced G-i-star) for each feature in a dataset. The resultant z-scores and p-values tell you where features with either high or low values cluster spatially. This tool works by looking at each feature within the context of neighboring features. A feature with a high value is interesting but may not be a statistically significant hot spot. To be a statistically significant hot spot, a feature will have a high value and be surrounded by other features with high values as well. The local sum for a feature and its neighbors is compared proportionally to the sum of all features; when the local sum is very different from the expected local sum, and that difference is too large to be the result of random chance, a statistically significant z-score results.

Calculations

The Getis-Ord local statistic is given as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j} \right)^2 \right]}{n-1}}} \quad (1)$$

where x_j is the attribute value for feature j, $w_{i,j}$ is the spatial weight between feature i and j, n is equal to the total number of features and:

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (2)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \quad (3)$$

The G_i^* statistic is a z-score so no further calculations are required.

Interpretation

The Gi* statistic returned for each feature in the dataset is a z-score. For statistically significant positive z-scores, the larger the z-score is, the more intense the clustering of high values (hot spot). For statistically significant negative z-scores, the smaller the z-score is, the more intense the clustering of low values (cold spot). For more information about determining statistical significance, see What is a z-score? What is a p-value?

Output

This tool creates a new **Output Feature Class** with a z-score and p-value for each feature in the **Input Feature Class.** If there is a selection set applied to the Input Feature Class, only selected features will be analyzed, and only selected features will appear in the Output Feature Class. This tool also returns the z-score and p-value field names as derived output values for potential use in custom models and scripts.

When this tool runs in ArcMap, the **Output Feature Class** is automatically added to the table of contents with default rendering applied to the z-score field. The hot to cold rendering applied is defined by a layer file in <ArcGIS>/ArcToolbox/Templates/Layers. You can reapply the default rendering, if needed, by importing the template layer symbology.

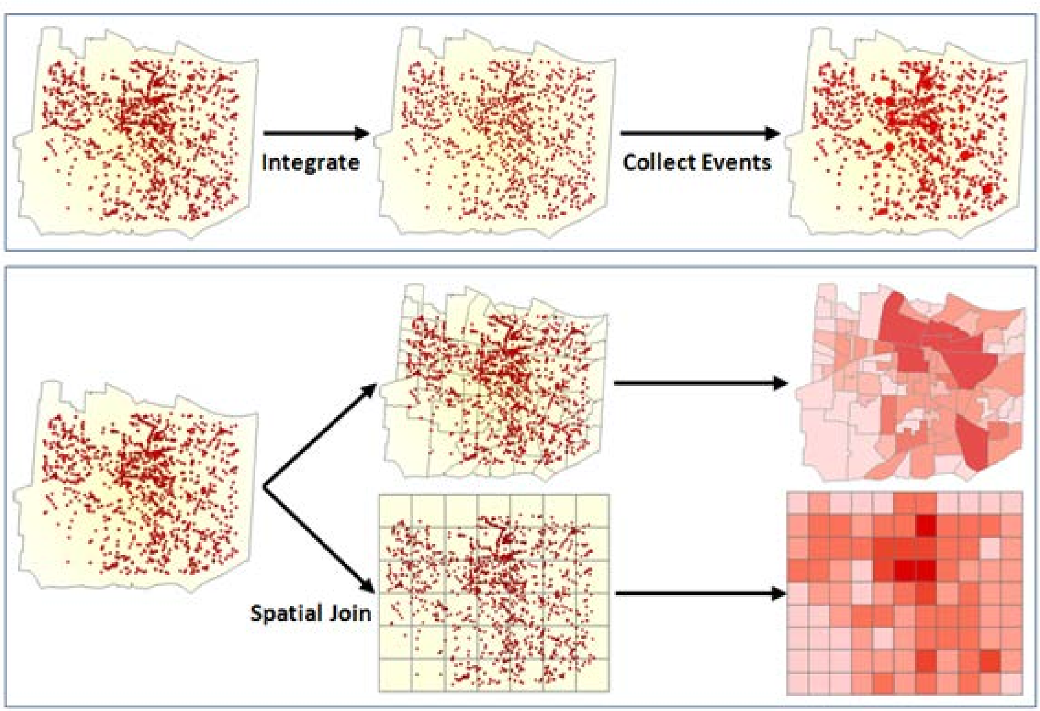
Hot spot analysis considerations

There are three things to consider when undertaking any hot spot analysis:

1. What is the Analysis Field (**Input Field**)? The hot spot analysis tool assesses whether high or low values (the number of crimes, accident severity, or dollars spent on sporting goods, for example) cluster spatially. The field containing those values is your Analysis Field. For point incident data, however, you may be more interested in assessing incident intensity than in analyzing the spatial clustering of any particular value associated with the incidents. In that case, you will need to aggregate your incident data prior to analysis. There are several ways to do this:
   - If you have polygon features for your study area, you can use the Spatial Join tool to count the number of events in each polygon. The resultant field containing the number of events in each polygon becomes the **Input Field** for analysis.
   - Use the Create Fishnet tool to construct a polygon grid over your point features. Then use the Spatial Join tool to count the number of events falling within each grid polygon. Remove any grid polygons that fall outside your study area. Also, in cases where many of the grid polygons within the study area contain zeros for the number of events, increase the polygon grid size, if appropriate, or remove those zero-count grid polygons prior to analysis.
   - Alternatively, if you have a number of coincident points or points within a short distance of one another, you can use Integrate with the Collect Events tool to (1) snap features within a specified distance of each other together, then (2) create a new feature class containing a point at each unique location with an associated count attribute to indicate the number of events/snapped points. Use the resultant ICOUNT field as your **Input Field** for analysis.

     Note:

     If you are concerned that your coincident points may be redundant records, the Find Identical tool can help you to locate and remove duplicates.



2. Which **Conceptualization of Spatial Relationships** is appropriate? What **Distance Band or Threshold Distance** value is best?

   The recommended (and default) **Conceptualization of Spatial Relationships** for the Hot Spot Analysis (Getis-Ord Gi*) tool is **Fixed Distance Band**. Space-Time Window, Zone of Indifference, Contiguity, K Nearest Neighbor, and Delaunay Triangulation may also work well. For a discussion of best practices and strategies for determining an analysis distance value, see Selecting a Conceptualization of Spatial Relationships and Selecting a Fixed Distance. For more information about space-time hot spot analysis, see Space-Time Analysis.

3. What is the question?

   This may seem obvious, but how you construct the **Input Field** for analysis determines the types of questions you can ask. Are you most interested in determining where you have lots of incidents, or where high/low values for a particular attribute cluster spatially? If so, run Hot Spot Analysis on the raw values or raw incident counts. This type of analysis is particularly helpful for resource allocation types of problems. Alternatively (or in addition), you may be interested in locating areas with unexpectedly high values in relation to some other variable. If you are analyzing foreclosures, for example, you probably expect more foreclosures in locations with more homes (said another way, at some level, you expect the number of foreclosures to be a function of the number of houses). If you divide the number of foreclosures by the number of homes, then run the Hot Spot Analysis tool on this ratio, you are no longer asking Where are there lots of foreclosures?; instead, you are asking Where are there unexpectedly high numbers of foreclosures, given the number of homes? By creating a rate or ratio prior to analysis, you can control for certain expected relationships (for example, the number of crimes is a function of population; the number of foreclosures is a function of housing stock) and identify unexpected hot/cold spots.

Best practice guidelines

- Does the **Input Feature Class** contain at least 30 features? Results aren't reliable with less than 30 features.
- Is the **Conceptualization of Spatial Relationships** you selected appropriate? For this tool, the **Fixed Distance Band** method is recommended. For space-time hot spot analysis, see Selecting a Conceptualization of Spatial Relationships.
- Is the **Distance Band or Threshold Distance** appropriate? See Selecting a Fixed Distance.
  - All features should have at least one neighbor.
  - No feature should have all other features as neighbors.
  - Especially if the values for the **Input Field** are skewed, you want features to have about eight neighbors each.

Potential applications

Applications can be found in crime analysis, epidemiology, voting pattern analysis, economic geography, retail analysis, traffic incident analysis, and demographics. Some examples include the following:

- Where is the disease outbreak concentrated?
- Where are kitchen fires a larger than expected proportion of all residential fires?
- Where should the evacuation sites be located?
- Where/When do peak intensities occur?
- Which locations and at during what time periods should we allocate more of our resources?

Additional resources

Mitchell, Andy. *The ESRI Guide to GIS Analysis,* Volume 2. ESRI Press, 2005.

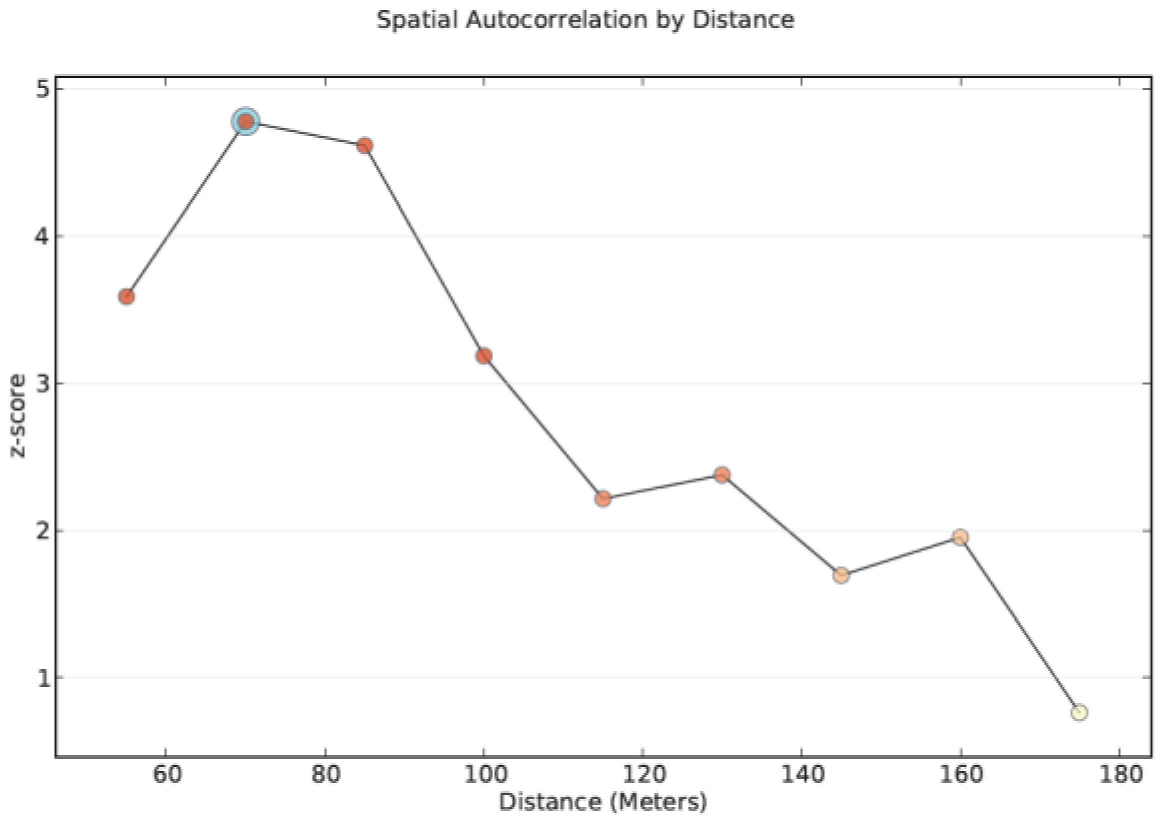
Getis, A. and J.K. Ord. 1992. "The Analysis of Spatial Association by Use of Distance Statistics" in *Geographical Analysis* 24(3).
Ord, J.K. and A. Getis. 1995. "Local Spatial Autocorrelation Statistics: Distributional Issues and an Application" in *Geographical Analysis* 27(4).

How Incremental Spatial Autocorrelation works in ArcGIS

Desktop » Geoprocessing » Tool reference » Spatial Statistics toolbox » Analyzing Patterns toolset

With much of the spatial data analysis you do, the scale of your analysis will be important. The default **Conceptualization of Spatial Relationships** for the Hot Spot Analysis tool, for example, isFIXED_DISTANCE_BAND and requires you to specify a distance value. For many density tools you will be asked to provide a **Radius**. The distance you select should relate to the scale of the question you are trying to answer or to the scale of remediation you are considering. Suppose, for example, you want to understand childhood obesity. What is your scale of analysis? Is it at the individual household or neighborhood level? If so, the distance you use to define your scale of analysis will be small, encompassing the homes within a block or two of each other. Alternatively, what will be the scale of remediation? Perhaps your question involves where to increase after-school fitness programs as a way to potentially reduce childhood obesity. In that case, your distance will likely be reflective of school zones. Sometimes it’s fairly easy to determine an appropriate scale of analysis; if you are analyzing commuting patterns and know that the average journey to work is 12 miles, for example, then 12 miles would be an appropriate distance to use for your analysis. Other times it is more difficult to justify any particular analysis distance. This is when the Incremental Spatial Autocorrelation tool is most helpful.

Whenever you see spatial clustering in the landscape, you are seeing evidence of underlying spatial processes at work. Knowing something about the spatial scale at which those underlying processes operate can help you select an appropriate analysis distance. The Incremental Spatial Autocorrelation tool runs the Spatial Autocorrelation (Global Moran’s I) tool for a series of increasing distances, measuring the intensity of spatial clustering for each distance. The intensity of clustering is determined by the z-score returned. Typically, as the distance increases, so does the z-score, indicating intensification of clustering. At some particular distance, however, the z-score generally peaks. Sometimes you will see multiple peaks.



Peaks reflect distances where the spatial processes promoting clustering are most pronounced. The color of each point on the graph corresponds to the statistical significance of the z-score values.

Significance Level (p-value)		Critical Value (z-score)
0.01		< -2.58
0.05		-2.58 - -1.96
0.10		-1.96 - -1.65
---		-1.65 - 1.65
0.10		1.65 - 1.96
0.05		1.96 - 2.58
0.01		> 2.58

One strategy for identifying an appropriate scale of analysis is to select the distance associated with the statistically significant peak that best reflects the scale of your question. Often this is the first statistically significant peak.

How do I select the Beginning Distance and Distance Increment values?

All distance measurements are based on feature centroids and the default **Beginning Distance** is the smallest distance that will ensure every feature has at least one neighboring feature. This is generally a good choice, unless your dataset includes spatial outliers. Determine whether or not you have spatial outliers, then select all but the outlier features and run Incremental Spatial Autocorrelation on just the selected features. If you find a peak distance for the selection set, use that distance to create a spatial weights matrix file based on all of your features (even the outliers). When you run theGenerate_Spatial_Weights_Matrix tool to create the spatial weights matrix file, set the **Number of**

Neighbors parameter to some value so that all features will have at least that many neighboring features.

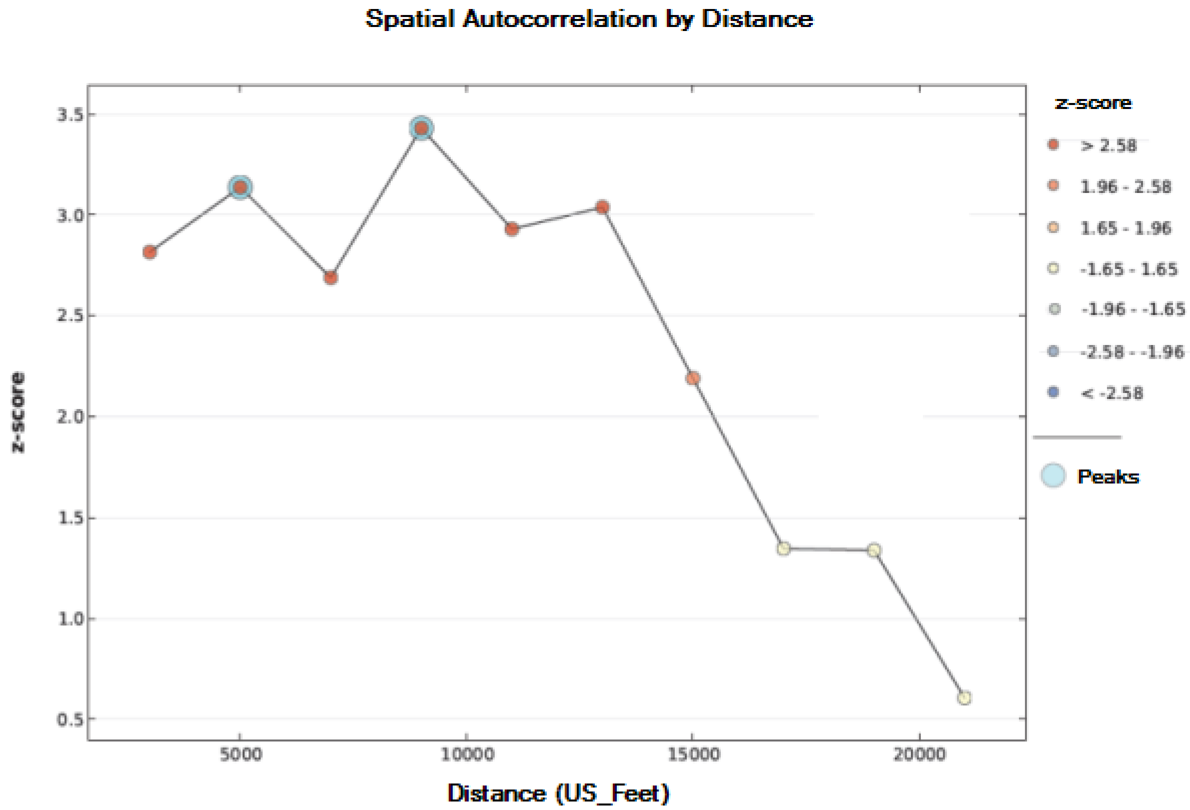
The default **Increment Distance** is the average distance to each feature's nearest neighboring feature. If you've determined an appropriate starting distance using the strategies above and still don't see a peak distance, you may want to experiment with smaller or larger increment distances.

What if the graph never peaks?

In some cases, you will use the Incremental Spatial Autocorrelation tool and get a graph with a z-score that just continues to rise with increasing distances; there is no peak. This most often happens in cases where data has been aggregated and the scale of the processes impacting your **Input Field** variable are smaller than the aggregation scheme. You can try making your Distance Increment smaller to see if this captures more subtle peaks. Sometimes, however, you won't get a peak because there are multiple spatial processes, each operating at a different distance, in your study area. This is often the case with large point datasets that are noisy (no clear spatial pattern to the point data values you're analyzing). In this case, you will need to justify your scale of analysis using some other criteria.

Interpreting results

When you run the Incremental Spatial Autocorrelation tool in the foreground, the z-score results for each distance are written to the ***Progress*** window. This output is also available from the Results window. If you right-click on the Messages entry in the Results window and select **View**, the tool results are displayed in a **Message** dialog box. When you specify a path for the optional **Output Table** parameter, a table is created that includes fields for **Distance**, **MoransI**, **ExpectedI**, **Variance**, **z_score**, and **p_value**. By examining the z-score values in the ***Progress*** window, **Message** dialog box, or **Output Table**, you can determine if there are any peak distances. More typically, however, you would identify peak distances by looking at the graphic in the optional **Output Report** file. The report has three pages. An example of the first page of the report is shown below. Notice that this graph has three peak z-scores associated with distances of 5000, 9000, and 13000 feet. A halo will be drawn to highlight both the first peak distance and the maximum peak distance, but all peaks represent distances where the spatial processes promoting clustering are most pronounced. You can select the peak that best reflects the scale of your analytical question. In some cases, there will only be one halo because the first and the maximum peaks are found at the same distance. If none of the z-score peaks are statistically significant, then none of the peaks will have the light blue halo. Notice that the color of the plotted z-score corresponds to the legend showing the critical values for statistical significance.



On page two of the report, the distances and z-score values are presented in table format. The last page of the report documents the parameter settings used when the tool was run. To get a report file, provide a path for the **Output Report** parameter.

Figure 20. Example of 'good' spatial autocorrelation result: Large spawner silver hake from MADMF fall survey, 2002-2011.

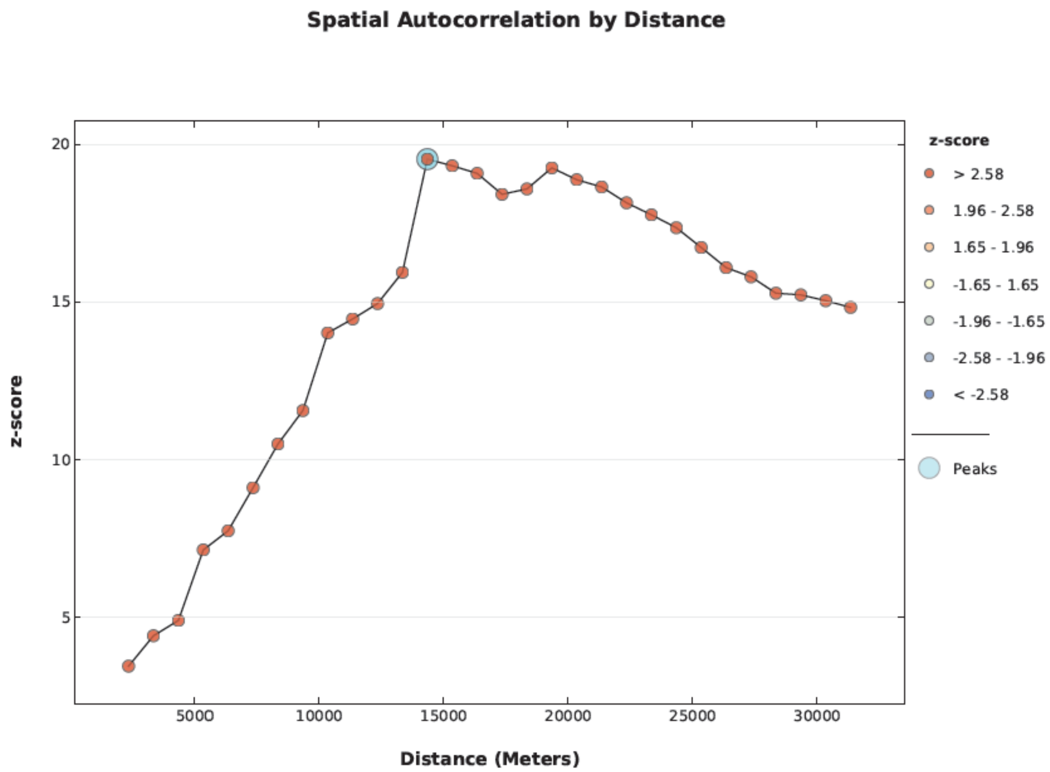


Figure 21. Example of 'satisfactory' spatial autocorrelation result, with secondary peak autocorrelation: Juvenile American plaice from IBS cod fall survey, 2002-2011.

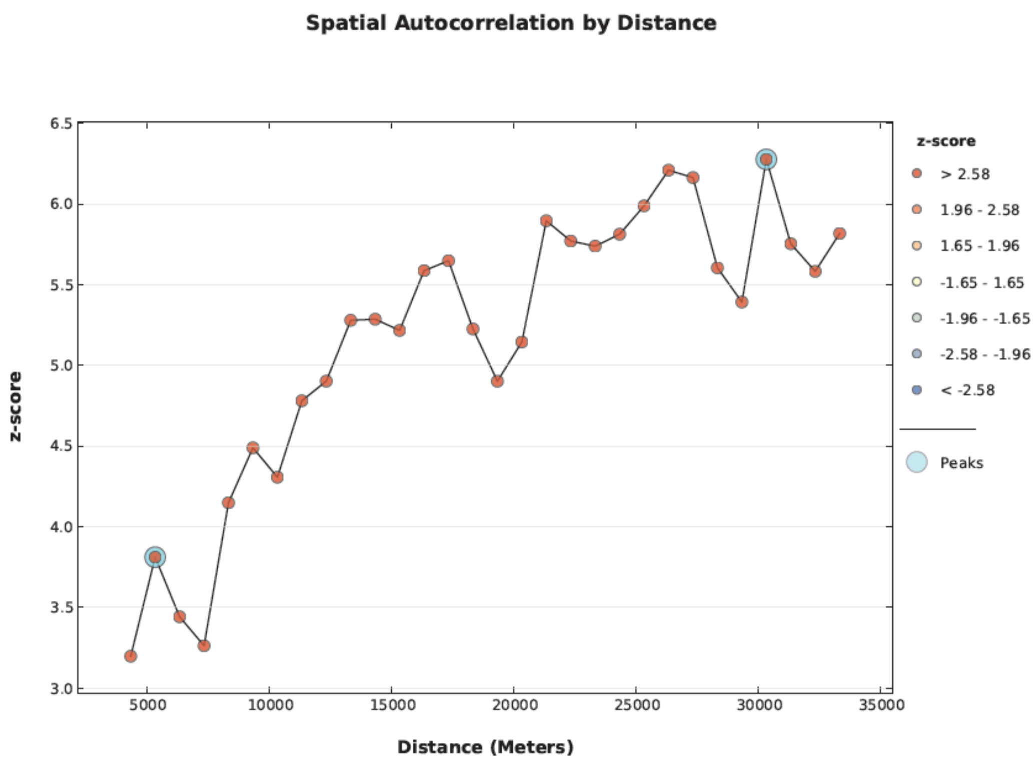


Figure 22. Example of unsatisfactory spatial autocorrelation result, with no significant peak in autocorrelation: Large spawner American plaice from IBS cod fall survey, 2002-2011. In this case, hotspot analysis was re-run with a zone of indifference parameter of 25313 m, corresponding of a secondary non-significant spatial autocorrelation peak, but there were no significant hotspots identified nonetheless.

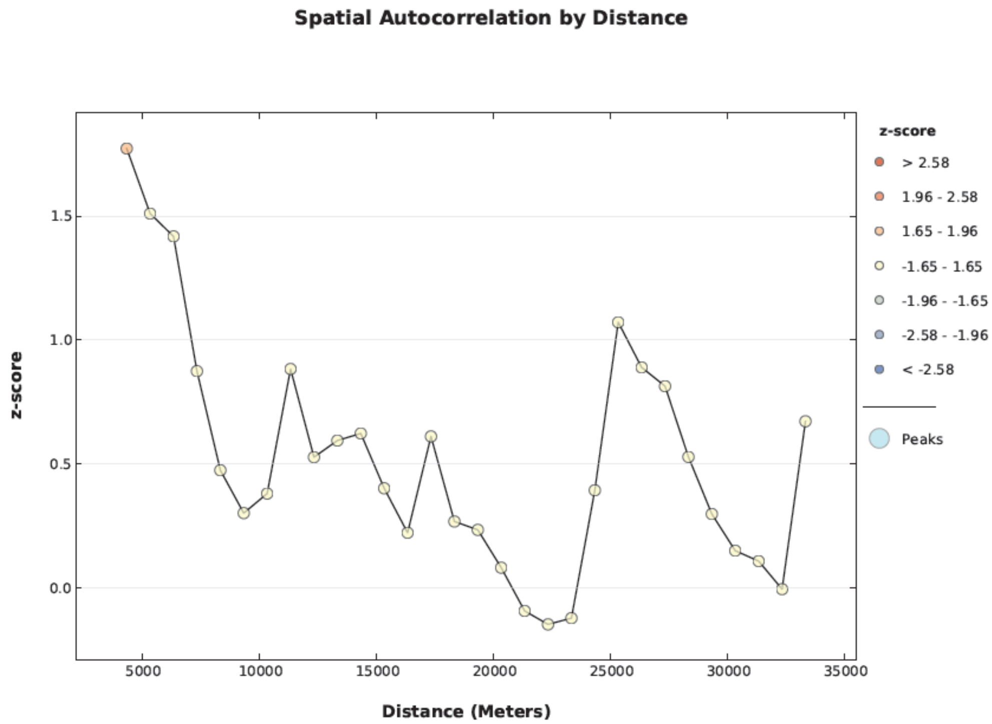


Figure 23. Example of unsatisfactory spatial autocorrelation resulting from insufficient non-zero catches: Large spawner pollock from IBS cod fall survey, 2002-2011. No significant hotspots were identified and no further analysis was attempted.

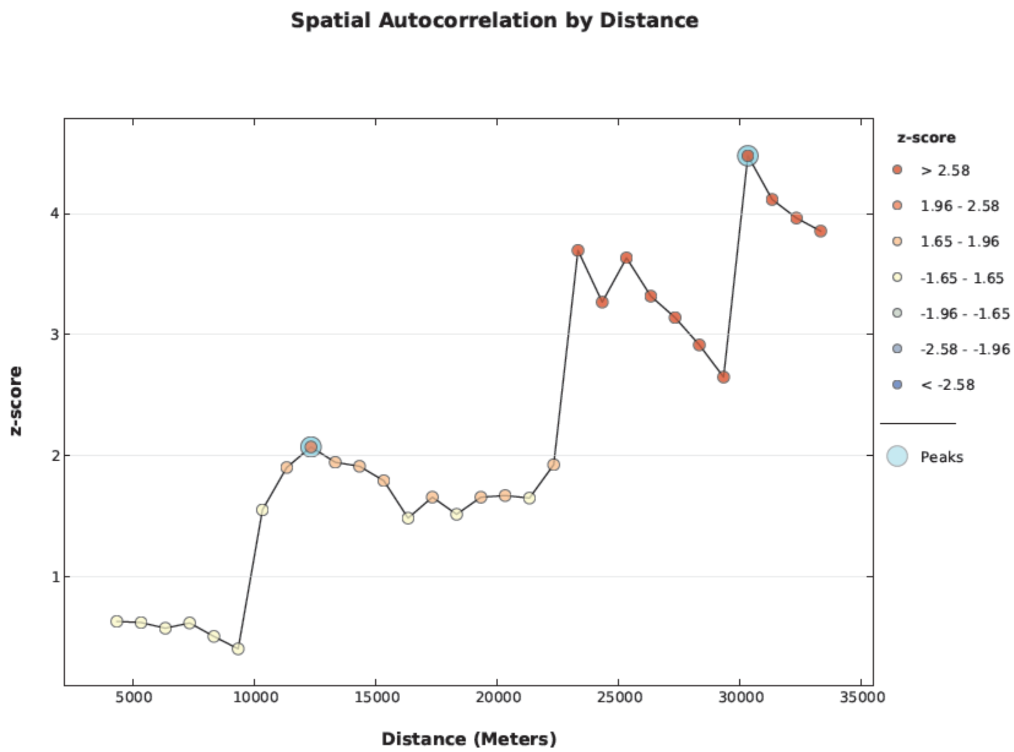


Figure 24. Example of 'good' spatial autocorrelation result, but first autocorrelation peak is probably not meaningful: Juvenile winter flounder from IBS cod fall survey, 2002-2011. The maximum peak of 17,313 m was used as the Zone of Indifference parameter in the hotspot analysis in lieu of the first peak.

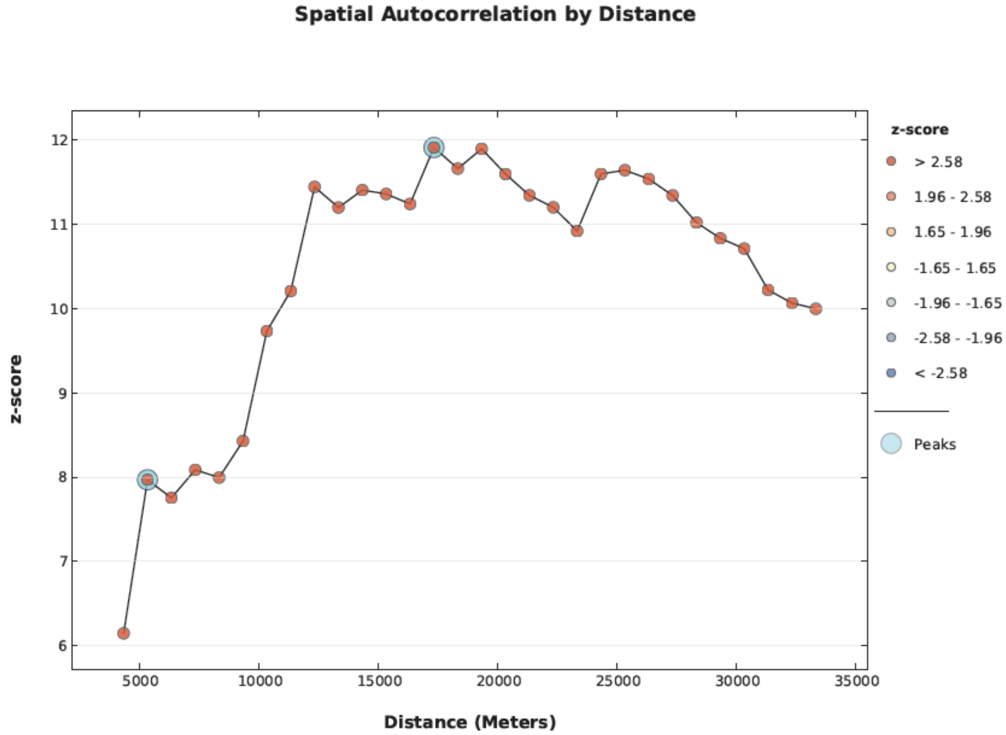


Figure 25. Example of unsatisfactory spatial autocorrelation: Juvenile witch flounder from IBS cod fall survey, 2002-2011. No significant hotspots were identified and no further analysis was attempted.

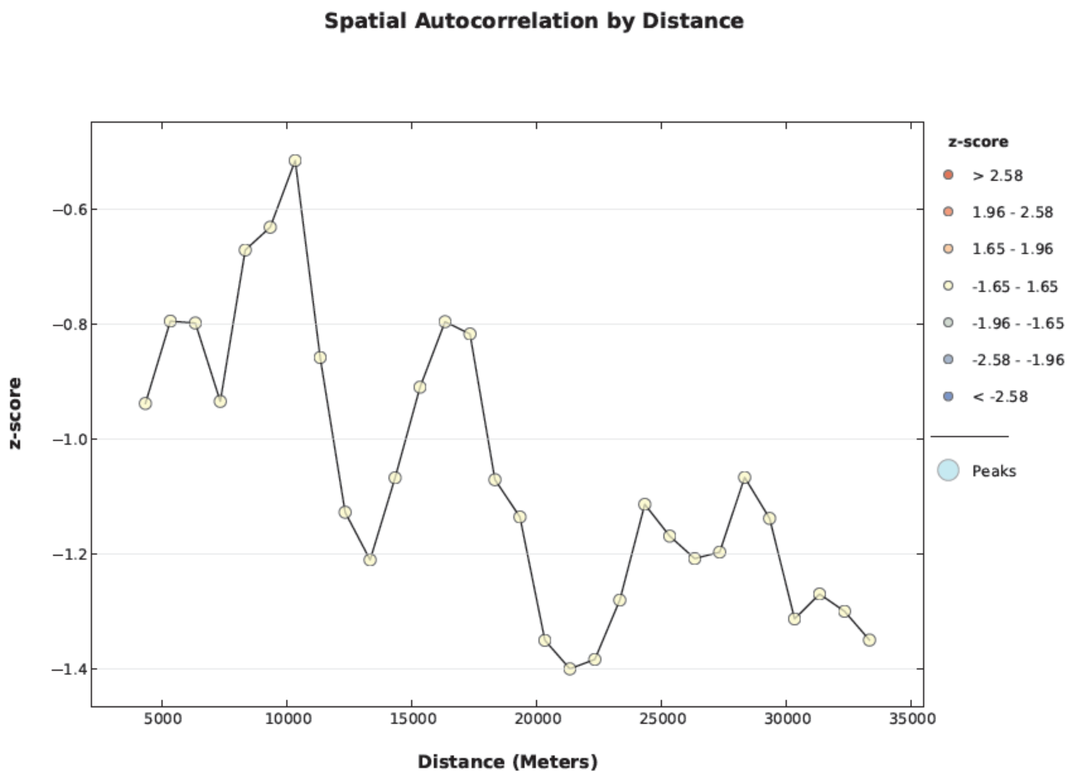


Figure 26. Example of 'good' spatial autocorrelation result, with no meaningful first autocorrelation: Large spawner yellowtail flounder from NMFS winter survey, 2002-2007. The maximum peak was applied as a Zone of Indifference parameter in the hotspot analysis.

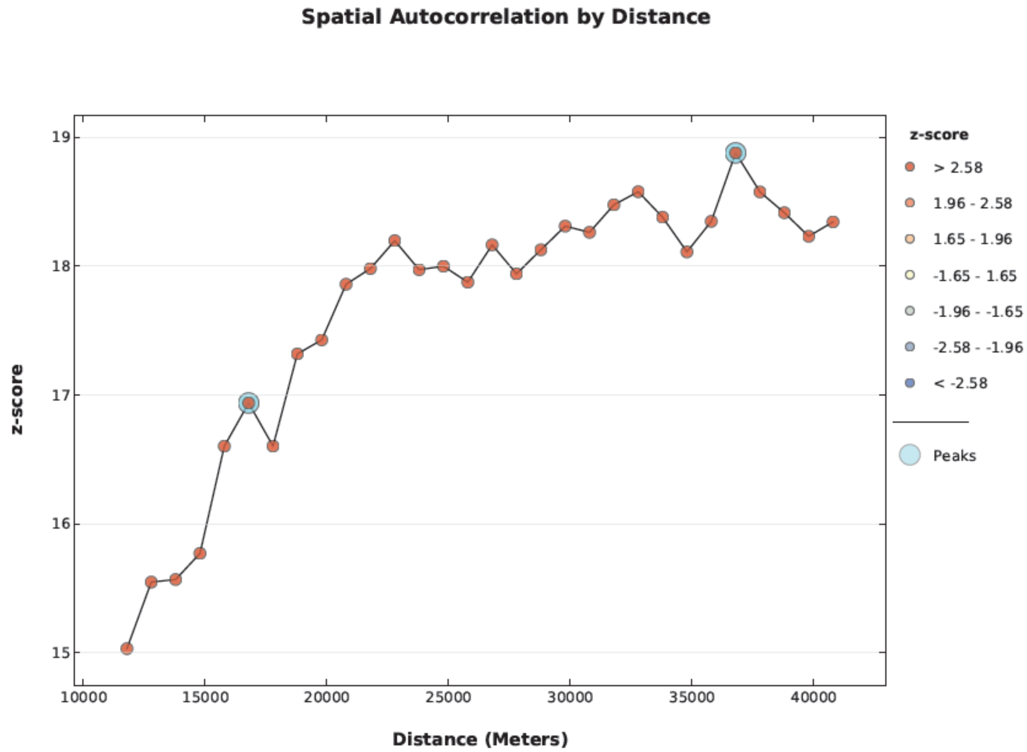


Figure 27. Example of 'poor' spatial autocorrelation result. Data are sparse and tend the spatial autocorrelation has a 'choppy' appearance: Juvenile cod from NMFS winter survey, 2002-2007. Usually, this pattern is associated with a hotspot analysis that has no significant positive hotspots.

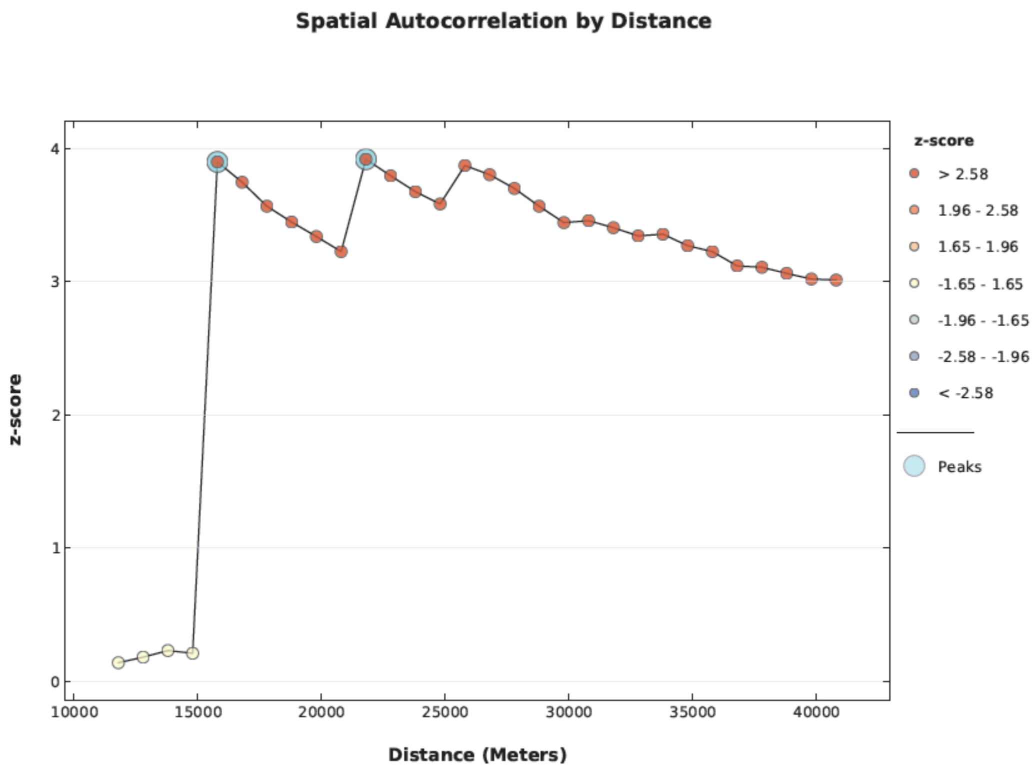
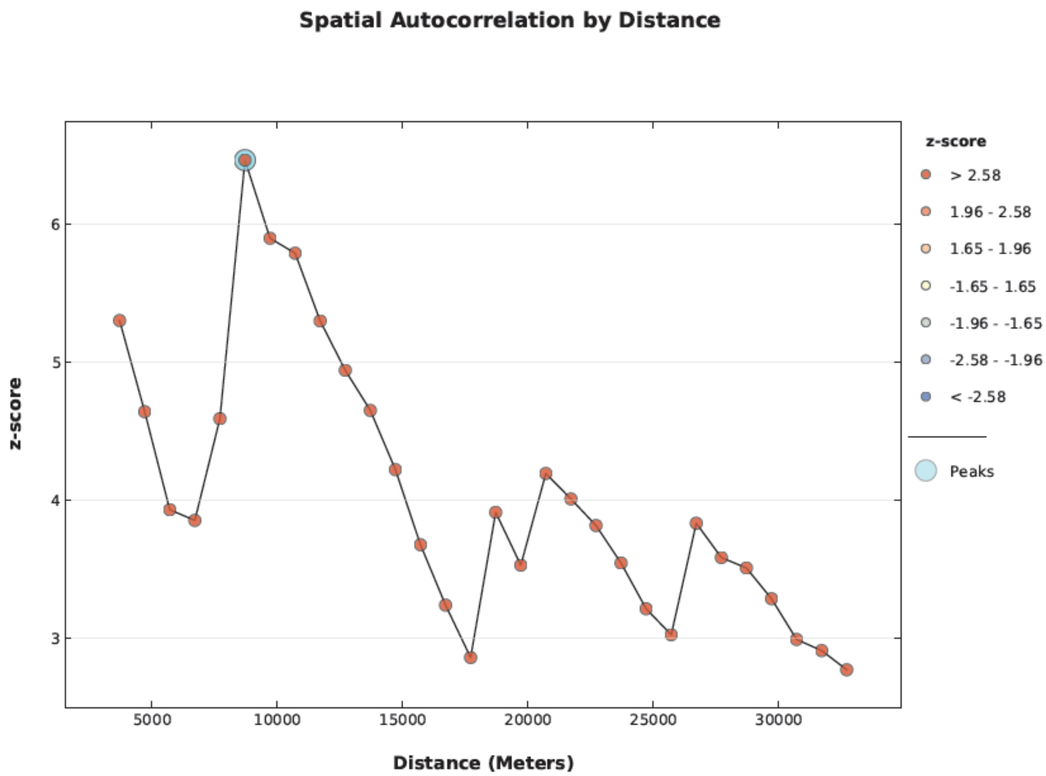


Figure 28. Example of 'strong' spatial autocorrelation result: Large spawner witch flounder from the NMFS winter survey, 2002-2007.



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OMNIBUS ESSENTIAL FISH HABITAT AMENDMENT 2
DRAFT ENVIRONMENTAL IMPACT STATEMENT

Appendix F: Modeling juvenile Atlantic cod and yellowtail flounder abundance on Georges Bank and in the Gulf of Maine using 2-stage generalized additive models

Modeling Juvenile Atlantic cod and yellowtail flounder abundance on Georges Bank and in the Gulf of Maine using 2-stage generalized additive models

A final report to the Closed Area Technical Team of the New England Fisheries Management Council
April 12, 2013

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Sections

1. EXECUTIVE SUMMARY

1.1 Value of the models to management

Management strategies, especially for species or communities in changing ecosystems, should be grounded in ecology; in other words regulations should be designed considering ecological explanations. Statistical models that estimate the combined effects of such explanations (i.e. that use ecological variables) are thus a natural fit to serve as a foundation for management. However, because of the complexity and nonlinear nature of natural environments, especially flexible models are often necessary to explain the relationships observed within these systems. Generalized additive models are in many cases well suited for use in these situations because they are highly adaptable and unbounded by the linear assumptions of traditional statistical models, and we use this class of model here to explain relationships between juvenile groundfish and their habitat. The outputs from the additive models include the linear or nonlinear relationships between each of the explanatory variables and the model response, the residuals for sampled locations, and the predicted values at those locations.

The generalized additive models are able to identify important habitat characteristics that can be used by managers, but they are constrained to the available variables and the statistical assumptions of the models. These models together with empirical methods like the spatial cluster analyses that were conducted separately by members of the New England Fisheries Management Council provide a useful parallel examination of juvenile groundfish habitat; the value of this parallel process lies in that the approaches are different. The cluster analyses are completely observational and thus represent a thoroughly empirical technique for identifying critical habitat, and although they cannot explain ecological associations or processes (useful in the backing of management decisions) like the generalized additive models they provide an excellent check on the soundness of the additive models. The analysis of groundfish critical habitat benefits greatly from the combination of these two approaches.

1.2 Short summary of findings

The final generalized additive models were decided upon using a backwards selection algorithm (section 3) beginning with a full model including physical and environmental variables such as depth, bottom characteristics, temperature, and zenith angle. Once a final model was developed it was evaluated using model diagnostics, the critical habitat variables were identified, and predictions were produced.

The habitat variables that (qualitatively) proved most important in determining the distribution of the juvenile groundfish stocks we examined were depth and bottom temperature and both had generally negative effects on abundance (i.e. expected abundance decreased with increasing depth or temperature). Season, sediment, and the shape of the seabed were also important, but the particular effects were not as consistent across the stocks (and in the case of sediment could not be compared across all three). Zenith angle was also an important variable for standardizing catch in some cases; it can remove variation in fish catchability that is related to circadian rhythms.

Juvenile cod on Georges Bank were predicted to occur mostly off Cape Cod, in the Great South Channel, and along the northern edge of Georges. In the Gulf of Maine the region of highest expected juvenile cod catch was in Massachusetts Bay, and elsewhere the model predicted the highest abundances along the Maine coast. High predictions for Georges Bank yellowtail were scattered, though they were more common on the southeast part of Georges and in the Nantucket Lightship area.

2. MODELING RATIONALE

Two-stage generalized additive models were used to describe the relationship between the explanatory variables and the counts of juvenile groundfish.

2.1 Generalized additive models

We used generalized additive models because of their flexibility which is often a critical attribute when describing ecological phenomena. This class of model is an extension of generalized linear models in that they can accept the various error distributions from within the exponential family and the explanatory variables are related to the predicted value through a "link function." The difference is that the additive models are capable of including nonlinear effects, so no assumption of linearity is required when relating the model terms to the response. Within the modeling process the relationships between the continuous variables and the response are described by nonlinear smooth functions, so each of these relationships can change across values of the continuous independent variables.

2.2 Two-stage models

An oft-encountered difficulty in modeling fisheries data is the presence of an excessive number of zeros. If the ratio of zeros to non-zeros is too large then the response cannot be modeled effectively using a common error distribution. Various strategies exist for dealing with this problem but the one we used was a two-stage model. Two models were developed: one estimating the simple presence or absence of a species and another modeling the data conditional on presence. Predictions can be made by multiplying the expected values of the two models together.

For the presence-absence model we used a binomial error distribution and for the conditional presence model we logged the response and used a Gaussian error distribution with an identity link function, meaning that we assumed the residuals to be distributed normally and used no transformation between the scale of the model fitting and the scale of the response.

3. MODEL SELECTION ALGORITHM

Final candidate models were found using a backwards-selecting algorithm that employs a combination of likelihood ratio tests and model significance p-values to choose reasonable models.

3.1 Details of the model selection algorithm

Each iteration of the model selection algorithm has four steps. They are:

(1) Begin with a full model with *n* terms.

(2) Remove each model term one-at-a-time, creating *n* new models with *n*-1 terms each.

(3) Use a likelihood ratio test to determine which of the sub-models provides the least new information (i.e. which likelihood ratio test of sub-model against the full model is the least significant; this identifies which term adds the least to the model's explanatory power).

(4) Remove that term and use the rest as an updated "full" model.

This algorithm is repeated until two conditions are met:

(1) All model terms are significant based on the specified p-value significance threshold for significant model terms; and

(2) Removing any of the remaining terms produces a significant model difference based on the specified p-value significance threshold for the likelihood ratio tests.

3.2 Rationale for p-value thresholds

P-value significance thresholds for both the model term significance and the likelihood ratio tests were set at p=0.25. With respect to the model term significance, this generous threshold ensures that even marginally significant variables are retained in the final model. Should any of these variables be considered unimportant or unusable for management they are easily discarded and the model can be updated. Similarly, the relatively high threshold p-value for the likelihood ratio tests encourages the algorithm to stop when only marginally significant differences are found because it is easier for two models to be significantly different when the p-value is set relatively high.

We selected "generous" p-value thresholds because we did not want the selection algorithm to remove variables that were important even in a very small way; this selection is better left as a qualitative analysis by experts in juvenile groundfish ecology.

3.3 Interaction terms

Interaction terms were not included in the saturated model that fed into the backwards selection algorithm. Already there were many single terms in the model relative to the amount of data, especially for the presence models on Georges Bank (only 176 data points). Since each categorical variable removes at least two degrees of freedom and each continuous variable in these models typically used between 1 and 7 degrees of freedom, including interaction terms at the start often led to candidate models that were not possible to run.

We did, however, manually include interaction terms after the algorithm was complete. We chose each set of significant terms in the final model and added them to the saturated model singly and evaluated their significance. We used a less generous significance threshold of 0.05 for interaction terms because they are more difficult to explain and thus to justify for inclusion in management measures. None of these terms had p-values lower than 0.05 and so none were included in the final models. We did not use likelihood ratio tests for interaction term models.

3.4 Likelihood ratio as opposed to AIC

The algorithm used likelihood ratio tests as opposed to AIC (Akaike Information Criterion). The difference is that AIC includes a penalty for the number of parameters estimated in the model. In this case we were not particularly interested in the most parsimonious model, which is why we set our model term significance and likelihood ratio test p-value thresholds high at 0.25. Since these models will be used or adapted by managers who have an expert understanding of the biology of the species we felt the best approach was to err on the side of a more inclusive model that could be reduced further if need be. AIC encourages parsimony and so would risk removing important terms.

4. VARIABLES

The response variables for the binomial additive models were the presence/absence of juvenile cod or yellowtail flounder and for the count models the response was the logged tow abundance. Juvenile cod were defined as those less than or equal to 35cm in fall and 25cm in spring, while juvenile yellowtail were defined as less than or equal to 15cm year-round.

The candidate variables to explain variability in the catch of juvenile cod and yellowtail were:

(1) Bottom temperature: collected from survey tows;

(2) Average tow depth: collected from survey tows;

(3) Seabed Form: A combination of slope and “Land Position Index” from TNC that indicates the type of bottom e.g. “depression” or “high slope;”

(4) Dominant sediment type: from Harris and Stokesbury (2010) with categories such as mud and sand [available on Georges Bank only];

(5) Sediment coarseness: indicates the grain size of the sediment (Harris and Stokesbury 2010) [available on Georges Bank only];

(6) Shear stress: benthic boundary layer shear stress from Harris et al. 2012 [available on Georges Bank only];

(7) Substrate: categorical variable indicating substrate type from TNC

(8) Season: spring or fall;

(9) Purpose code: indicates what survey the data come from (spatial and seasonal survey coverage may be found in appendix 2); and

(10) Zenith angle: can help account for diel behavioral changes in catchability (courtesy L. Jacobson and J. Tang; http://nefsc.noaa.gov/publications/crd/crd1114/index.html).

The substrate variable (7) overlaps with substrate oriented variables on Georges Bank from Harris and Stokesbury (2010; 4-5) and so was not used for the Georges Bank data since the resolution was coarser. However, this finer scale sediment data along with shear stress (6) were not available outside Georges Bank, so the coarse sediment data were used to model Gulf of Maine cod. Additional information on the variables can be found in tables 1-4 of appendix 1.

5. MODELING RESULTS AND INTERPRETATION

The data, models, predictions and diagnostics for all three stocks are summarized below.

5.1 Georges Bank cod

5.1.1 Data

The general saturated model for Georges Bank cod was:

$$\hat{J} = SEA + PC + SBF + SD + s(SC) + s(STR) + s(T) + s(Z) + s(D)$$

Where SEA is season, PC is purpose code (survey type), SBF is seabed form, SD is dominant sediment type, SC is sediment coarseness, STR is shear stress, T is temperature, Z is zenith angle at tow-time, and D is depth. $\hat{J}$, the expected value of the response, was zero or one for the presence-absence model and the logged measured juvenile abundance for the conditional presence model.

Before the modeling stage began, all these data were investigated to examine their relationship with juvenile abundance and check for outliers. Figures including histograms for the variables and plots of each against total juvenile abundance and abundance conditioned on presence may be found in appendix 3. The available data, including the proportion of positive tows are in Fig. 1. The resolution of the grid in Fig. 1, as in all the similar figures including residual plots is 0.09 x 0.09 min., or approximately 10 km^2 (referenced in the north-south direction).

Cooperative research surveys for goosefish and cod (purpose codes 4 and 5) were excluded for this analysis because these surveys had little overlap with the regions of interest on Georges Bank; the goosefish survey was excluded because there was only one positive tow in the overlapping area, and the cod survey excluded because there were only 3 tows overall in the region (Table 1).

5.1.2 Correlations among continuous variables

No variables were removed from the cod data set based on their correlation. The one potential candidate was to remove either sediment coarseness or shear stress. While the relationship was clear and positive there was still considerable variability within the overall correlation (Fig. 2). Both terms were left in the model. Both shear stress and coarseness remained in the final model and since coarseness was only marginally significant it may be reasonable to remove this term from the final model.

5.1.3 Model results

5.1.3.1 Presence-absence model

Following model selection, the significant terms for the presence-absence model were purpose code, season, sediment coarseness, shear stress, zenith, temperature and average depth. Shear stress and zenith angle were marginally significant, but the rest had p-values less than 0.01 (Table 3). There were 901 data points used and the model explained 31.8% of the deviance.

Spring had a negative effect on the probability of presence and the Massachusetts Department of Marine Fisheries survey (purpose code 11) had a positive effect relative to the NFMS bottom trawl survey (purpose code 10). The model output smooth plots for the continuous variables are given in figure 13. They show sediment coarseness to have a positive linear effect; shear stress to have a negative effect between values of 1 and 3; bottom temperature to have a highly negative almost linear effect; zenith angle to have a slightly positive linear effect; and depth to have a positive effect between approximately 5 to 35 meters and then a strong negative effect between depths of about 35 to 80 meters. A general summary of the effects are given in tables 2 and 3 and the smooth plots for continuous variables are given in Fig. 3.

Model diagnostics (Fig. 4) showed the presence-absence model to be somewhat reasonable (for an ecological data set). The residuals and quantiles showed a slightly skewed distribution that lacks small positive values and has too many small negative values. The high number of small negatives probably comes from observed values of zero and very small predictions. While the observed data are actual discrete counts, since the model expected values are not they are unlikely to predict a response of exactly zero. But since they predict close to zero, when the residuals are calculated (observed minus predicted) the result is an overrepresentation of residuals that are negative but close to zero.

5.1.3.2 Conditional presence model

The conditional presence model proved to explain much less variance at only 6.11%. The only significant effect in the model was shear stress and it was marginal at $p = 0.03$ (Table 3). The effect was negative and linear, so expected abundance decreased with increasing shear stress, but the residuals show much scatter around the trend line (Fig. 5). Season and purpose code were forced into the model as standardizing variables though neither were statistically significant. Spring had a negative effect relative to fall and the Massachusetts Department of Marine Fisheries survey (purpose code 11) had a positive effect relative to the NFMS bottom trawl survey (purpose code 10). There were many fewer observations available for the conditional model, with only 176 locations. A summary of the effects is given in tables 2 and 3.

The conditional presence model had mixed diagnostics (Fig. 6). There was some skew in the residuals and some increasing variance in the residuals versus linear predictors but these patterns were not overly concerning. On the other hand the plot of the response versus fits (each observation plotted against its fitted value) indicates that the model does not fit particularly well.

5.1.3.3 Residuals

Spatial plots of residuals and standardized residuals (residual divided by the mean) are provided for the final output, i.e. the product of the presence-absence and conditional presence models, for each scenario. These types of residual plots are an important diagnostic for ecological data sets with a spatial component. They show the range of the departure from the expected values; but, more importantly, they indicate whether there are spatial patterns in the residuals. Spatial patterns in the residuals indicate that there are likely to be other important variables that are not defined in the model.

The Georges Bank cod residuals are generally positive on the western part, especially around Cape Cod, and negative across the rest of Georges Bank (Figs. 7 and 8). This indicates that there are other sources of variability within the models that are not taken into account and that cause this spatial pattern in the residuals.

5.1.4 Predictions

The overall predictions (Fig. 9) for Georges Bank cod show the highest expected abundance off Cape Cod and east of Nantucket throughout the Great South Channel. There are also higher predicted values along the northern edge of Georges Bank. Throughout the rest of the area the predictions are mostly mixed, but typically predict an expected survey catch of less than one fish per tow.

The spring and fall predictions (Figs. 10 and 11) also show concentrations around Cape Cod and in the Great South Channel. They differ, however, in that on Georges Bank itself in the spring the model predicts relatively more cod in the center of the bank area while in the fall they are confined to the outskirts.

5.2 Gulf of Maine cod

5.2.1 Data

The general saturated model for Gulf of Maine cod was:

$$\hat{J} = SEA + PC + SBF + SED + s(T) + s(Z) + s(D)$$

Where SEA is season, PC is purpose code (survey type), SBF is seabed form, SED is sediment type, T is temperature, Z is zenith angle at tow-time, and D is depth. $\hat{J}$, the expected value of the response, was zero or one for the presence-absence model and the logged measured juvenile abundance for the count model.

Before the modeling stage began, all these data were investigated to examine their relationship with juvenile abundance and check for outliers. Figures including histograms for the variables and plots of each against total juvenile abundance and abundance conditioned on presence may be found in appendix 4.

Only the cooperative research goosefish survey (purpose code 4) was excluded for this analysis; it was eliminated because there were zero positive tows, again due to lack of overlap with the region of interest. The other data sets had reasonable numbers of positive records (Table 4). The spatial distribution of the data we used, including where juvenile cod were actually caught, is given in Fig. 12.

5.2.2 Correlations among continuous variables

While some trends are evident in the relationships among continuous variables for the Gulf of Maine cod data, there is too much variability to warrant any exclusion among the one relationship that is approximately linear on average, zenith angle and depth (Fig. 13). All continuous variables were retained for the saturated model.

5.2.3 Model results

5.2.3.1 Presence absence model

The variables that best explain the presence of juvenile cod were sediment type, seabed form, temperature and depth; all these p-values were less than 0.01 (Table 3). The model explained 20.7% of the deviance and was based on 4030 data points. Out of the sediment types, mud had a very negative effect and the smallest sand category as well as the largest sand category also had negative effects though they was weaker. The "high flat" seabed form category had a strong positive effect, as did the high slope. Relative to the Maine-New Hampshire inshore trawl survey (purpose code 1), the industry-based cod cooperative survey (purpose code 5) had a positive effect, the NMFS bottom trawl survey (purpose code 10) had a negative effect, and the Massachusetts Department of Marine Fisheries survey (purpose code 11) had a positive effect. Only this final survey was statistically different from the Maine-New Hampshire survey. Season insignificant, but spring had a negative effect relative to fall. Temperature and depth both had highly significant, negative effects on abundance (Table 3; Fig. 14). The temperature effect shows a sharp decline at values less than about five, followed by a more gradual decline between 5 and 11 degrees, then a steeper decline again at temperatures higher than 11 (though there is relatively less data at these higher temperatures). On average, abundance is highest at depths between approximately 0 and 80 meters, then declines rapidly after that. The partial residuals (the residuals with respect to a single term after the intercept and the effects of the other model terms have been removed; Wood 2006), however, show two modes: one being this decline and another (much smaller) an increase in abundance with depth (Fig. 14). These residuals were mapped but there was no obvious spatial pattern that would explain the second mode.

Similarly to the Georges Bank cod residuals, the Gulf of Maine presence-absence residuals show a break in the distribution at small positive values (Fig. 15). Otherwise the residuals are fairly normal. The response against the fits show more misclassifications than with the Georges Bank cod model; especially there were more fitted values close to 1 (expected presence) where in fact juveniles were absent in the observed data set.

5.2.3.2 Conditional presence model

The conditional presence model explained only 11.3% of the deviance, and was based on 1277 data points. Most important to describing the abundance of cod in this model were sediment type, temperature, depth and season. Mud had a negative effect on measured juvenile abundance, while large and medium sand sizes had a positive, marginally significant effect (Tables 2 and 3). Spring had a highly significant, positive effect and the effect of large-sized sand was also positive. Relative to the Maine-New Hampshire inshore trawl survey (purpose code 1), the industry-based cod cooperative survey (purpose code 5), the NMFS bottom trawl survey (purpose code 10), and the Massachusetts Department of Marine Fisheries survey (purpose code 11) each had negative effects. Temperature and depth again both had significant effects (Table 3). Abundance increased slightly with temperature from 0 to 10 degrees, then showed a marked decline, though there were only very few data points above 10 degrees. The depth effect was slightly negative and linear, and zenith remained in the model but the effect direction was not clear (Fig. 16).

Residuals for the conditional presence model are not entirely symmetrical about zero but do not indicate a concerning departure from normality (Fig. 17). The residuals against the linear predictor do not show terribly increasing variance, but again the response versus fitted values leaves much to be desired as the trend is barely discernible.

5.2.3.3 Residuals

The residuals and standardized residuals show underpredictions in Massachusetts Bay and in eastern Maine and generally slight overpredictions across the rest of the sample area (Figs. 18 and 19).

5.2.4 Predictions

The 2-stage model predicts most juvenile cod in the Gulf of Maine to be found close to the coast and on Stellwagen Bank (Fig. 20). There is also a cluster of positive predictions in the eastern Gulf of Maine at the edge of the sampling area. Unlike for the Georges Bank juvenile cod, the spring and fall predictions in the Gulf of Maine do not appear to differ measurably (Figs. 21 and 22).

5.3 Georges Bank Yellowtail Flounder

5.3.1 Data

The general saturated model for Georges Bank yellowtail was:

$$\hat{J} = SEA + PC + SBF + SD + s(SC) + s(STR) + s(T) + s(Z) + s(D)$$

Where SEA is season, PC is purpose code (survey type), SBF is seabed form, SD is dominant sediment type, SC is sediment coarseness, STR is shear stress, T is temperature, Z is zenith angle at tow-time, and D is depth. $\hat{J}$, the expected value of the response, was zero or one for the presence-absence model and the logged measured juvenile abundance for the conditional presence model.

Before the modeling stage began, all these data were investigated to examine their relationship with juvenile abundance and check for outliers. Figures including histograms for the variables and plots of each against total juvenile abundance and abundance conditioned on presence may be found in appendix 5.

All surveys except the NMFS bottom trawl and Massachusetts Marine Fisheries trawl (purpose codes 10 and 11) were excluded for this analysis. The most positive records (77) came from the NMFS survey, so despite the low ratio of tows in which yellowtail were actually caught it was included (Table 5). The Massachusetts Marine fisheries survey had a small sample size at 75, but 20% of those tows caught juvenile yellowtail. The spatial distribution of the data we used, including where juvenile yellowtail flounder were actually caught, is given in Fig. 23.

5.3.2 Correlations among continuous variables

These data were almost identical to those used in the Georges Bank cod analysis, and so the same description follows as found in section 5.1.2. No variables were removed from the cod data set based on their correlation. The one potential candidate was to remove either sediment coarseness or shear stress. While the relationship was clear and positive there was still considerable variability within the overall correlation (Fig. 24). Both terms were left in the model.

5.3.3 Model results

5.3.3.1 Presence-absence model

The presence-absence model explained 23.3% of the variance and was based on 915 sample locations. Spring had a positive and significant effect as did zenith angle (Tables 2 and 3; Fig. 25). The Massachusetts Department of Marine Fisheries survey (purpose code 11) had a positive effect relative to the NMFS bottom trawl survey (purpose code 10). Seabed form, sediment coarseness and depth all remained in the model although their significance was only marginal, though a small positive effect was noted for "high flat" areas relative to depressions. Sediment coarseness increased slightly across values less than about 2.2 and decreased slightly at values larger than about 2.5 but these effects were small. Estimated abundance increased slightly with depth until about 85 meters, after which it declined. Zenith angle had a highly significant, positive, almost linear effect indicating that more yellowtail are caught at night. Season also had a highly significant, posiotive effect.

The model produced close to no residuals between zero and one using these data, indicating that it is not doing a sufficient job capturing the variability in the response. Large observations are underpredicted leading to the cluster of positive residuals greater than one. Many zero catches were slightly overpredicted which results in the skewed count between zero and negative one (Fig. 26). Extreme outliers are evident in the plot of residuals against the linear predictor and there are almost no locations that predict presence at a probability greater than 0.5. The poor model diagnostics question both the model predictions and the effects of the significant variables.

5.3.3.2 Conditional presence model

The conditional presence model explained 52.9% of the variance using 90 tow locations where juveniles were caught. The unfixed terms remaining in the model were sediment coarseness, temperature, and depth (Table 3). The standardizing variable season had a negative though non-significant effect for spring relative to fall, and the Massachusetts Division of Marine Fisheries survey (purpose code 11) had a negative effect relative to the NFMS bottom trawl survey (purpose code 10). The temperature effect was marginally significant and positive between 4 and 7 degrees where most of the data lay, and then declined at higher values. The depth effect was significant (Table 3) and negative linear and sediment coarseness was also significant but inconclusive in direction (Fig. 27).

The diagnostics for this model were much better (Fig. 28). The residuals appear normally distributed and no patterns are evident in the plot of residuals against the linear predictor. The fitted values look to be highly correlated with the response. However, due to the small number of data points it is possible (and perhaps likely) that this model is overspecified and the diagnostics are misleading. Care should be taken that the overall predictions are closely examined to be sure they are realistic.

5.3.3.3 Residuals

No spatial patterns are particularly evident in the residuals for yellowtail on Georges Bank (Figs. 29 and 30). There seems to be some underprediction just off the northern tip of Cape Cod (more evident in the standardized residuals; Fig. 30), but other than that no clustering is evident.

5.3.4 Predictions

The overall model predictions for Georges Bank yellowtail are somewhat scattered at this scale of spatial grouping (Fig. 31). The clusters, though they are not very tight, look to be in the Nantucket Lightship area and on the eastern part of Georges Bank. There are scattered high predictions in the Great South Channel and elsewhere on Georges Bank. Some clusters of positive tows on eastern Georges Bank and in the Nantucket Lightship area are visible in spring (Fig. 32), but the patterns look somewhat more random in fall (Fig. 33).

6. EXPLANATION OF APPENDICES

Appendix 1 is an extension of section 4 and contains additional information about the candidate variables and their sources. The tables were prepared by M. Bachman.

Appendix 2 shows the spatial and seasonal distribution of the fisheries surveys that were used in the modeling. These figures were prepared by M. Bachman.

Appendices 3-5 contain preliminary analyses for each of the stocks. Included are (1) Histograms for those candidate variables that are continuous; (2) barplots for those that are discrete; (3) scatterplots with loess smooths for each continuous variable against the logged juvenile counts for all tows and also for only the tows in which juveniles of the species were present; and (4) boxplots of logged juvenile counts conditioned on each category of the discrete variables also for both all tows and only the tows where juveniles of the species were present.

Appendix 6 contains the generalized additive model output from R (package mgcv).

7. ACKNOWLEDGEMENTS

The author would like to thank Larry Jacobson and Jiashen Tang for providing the code we used to calculate zenith angle, Jui-Han Chang for playing the primary role in developing the model selection algorithm and both Jui-Han and Stefan Zhand for their comments on the analyses. Members of the Closed Area Technical Team's comments on 3/7/2013 were extremely helpful, and comments on drafts of this report by Andy Applegate and Michelle Bachman of the New England Fisheries Management Council were much appreciated. Michelle Bachman prepared the tables in appendix 1 and the figures in appendix 2.

SOURCES CITED

Harris, BP and KDE Stokesbury. 2010. The spatial structure of local surficial sediment characteristics on Georges Bank, USA. Continental Shelf Research 30: 1840-1853.

Harris, BP, GW Cowles and KDE Stokesbury. 2012. Surficial sediment stability on Georges Bank, in the Great South Channel and on eastern Nantucket Shoals. Continental Shelf Research 49: 65-72.

Wood, SN. 2006. Generalized additive models an introduction with R. Taylor & Francis : New York, 391 pp.

Table 1: Tow counts for all survey types in the Georges Bank cod data set.

Data Type	Purpose Code			
	4	5	10	11
Conditional Presence	1	2	144	48
All data	56	3	983	72
Ratio	0.018	0.67	0.15	0.67

Table 2: Summary of parameter effects for all models. +/++ = positive/very positive effect; -/-- = negative/very negative; ~ = complicated spline relationship; 0 = significant term but spline relationship questionable. Purpose code is not included because it is too inconsistent across the various data sets; since different data sets were used for each analysis the effects are not meaningful as a comparison.

Variable	(Relative to)	GB Cod		GOM Cod		GB Yellowtail	
		P/A	P	P/A	P	P/A	P
DEPTH		— —		— —	—	0	— —
TEMPERATURE		— —		— —	~		~
ZENITH		+			0	+ +	
Sed Coarseness		+ +		NA		0	~
Shear Stress		—	—	NA			
Season – Spring	Fall	— —			+ +	+ +	
SB Form – High Flat	Depression			+ +		+	
SB Form – High Slope	Depression			+ +			
SB Form – Low Slope	Depression						
SB Form – Mid Flat	Depression						
SB Form – Side Slope	Depression						
Dominant Sed – Sand	Silt/Mud			NA			
Dominant Sed – Pebble	Silt/Mud			NA			
Dominant Sed – Cobble	Silt/Mud			NA			
Dominant Sed – Boulder	Silt/Mud			NA			
Sediment – SandXL	Gravel	NA		—			NA
Sediment – SandLarge	Gravel	NA			+		NA
Sediment – SandMed	Gravel	NA					NA
Sediment – SandSmall	Gravel	NA		—			NA
Sediment – Silt/Mud	Gravel	NA		— —	—		NA

Table 3: P-values for the effects included in the final models. Purpose code is not divided into separate categories because the categories vary by data set, so the minimum p value relative to the reference level is reported.

Variable	(Relative to)	GB Cod		GOM Cod		GB Yellowtail	
		P/A	P	P/A	P	P/A	P
DEPTH		<0.001		<0.001	<0.001	0.043	0.006
TEMPERATURE		<0.001		<0.001	<0.001		0.032
ZENITH		0.0034			0.098	<0.001	
Sed Coarseness		<0.001		NA	NA	0.063	0.001
Shear Stress		0.098	0.027	NA	NA		
Season – Spring	Fall	<0.001	0.380	0.113	<0.001	<0.001	0.242
SB Form – High Flat	Depression			<0.001		0.018	
SB Form – High Slope	Depression			0.022		0.919	
SB Form – Low Slope	Depression			0.764		1	
SB Form – Mid Flat	Depression			0.132		0.109	
SB Form – Side Slope	Depression			0.870		1	
Dominant Sed – Sand	Silt/Mud			NA	NA		
Dominant Sed – Pebble	Silt/Mud			NA	NA		
Dominant Sed – Cobble	Silt/Mud			NA	NA		
Dominant Sed – Boulder	Silt/Mud			NA	NA		
Sediment – SandXL	Gravel	NA	NA	0.090	0.392	NA	NA
Sediment – SandLarge	Gravel	NA	NA	0.143	0.023	NA	NA
Sediment – SandMed	Gravel	NA	NA	0.955	0.061	NA	NA
Sediment – SandSmall	Gravel	NA	NA	0.010	0.469	NA	NA
Sediment – Silt/Mud	Gravel	NA	NA	<0.001	0.009	NA	NA
Purpose Code	NA	<0.001	0.304	<0.001	<0.001	<0.001	<0.001

Table 4: Tow counts for all survey types in the Gulf of Maine cod data set.

Data Type	Purpose Code				
	1	4	5	10	11
Conditional Presence	616	0	39	219	462
All data	2005	117	115	1461	763
Ratio	0.31	0	0.34	0.15	0.61

Table 5: Tow counts for all survey types in the Georges Bank yellowtail flounder data set.

Data Type	Purpose Code						
	4	5	6	10	11	40	60
Conditional Presence	0	0	0	77	15	0	7
All data	58	15	149	997	75	7	2018
Ratio	0	0	0	0.08	0.20	0	0.003

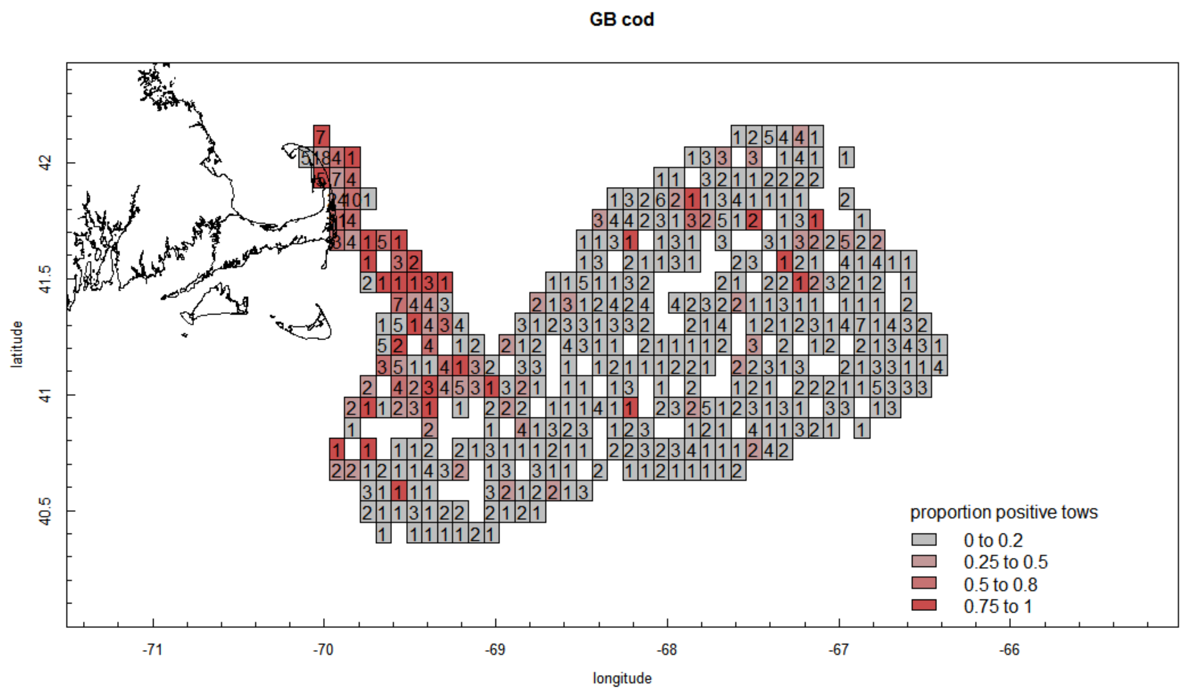


Figure 1: Number of tows per grid square and the proportion of those tows where juvenile cod were caught. The resolution of the grid, as in all the similar figures including the residual plots is 0.09 x 0.09 min., or approximately 10 km^2 (referenced in the north-south direction).

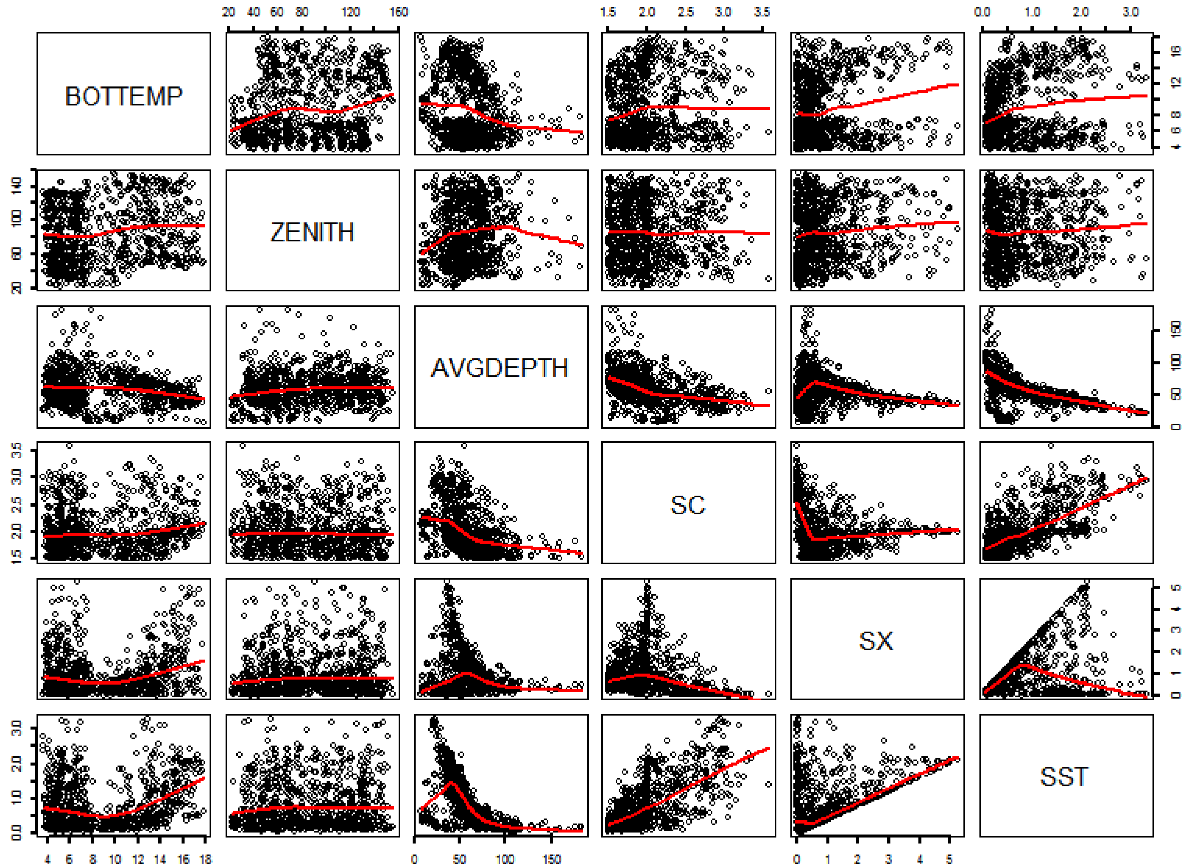


Figure 2: Correlations among continuous variables for the Georges Bank cod dataset.

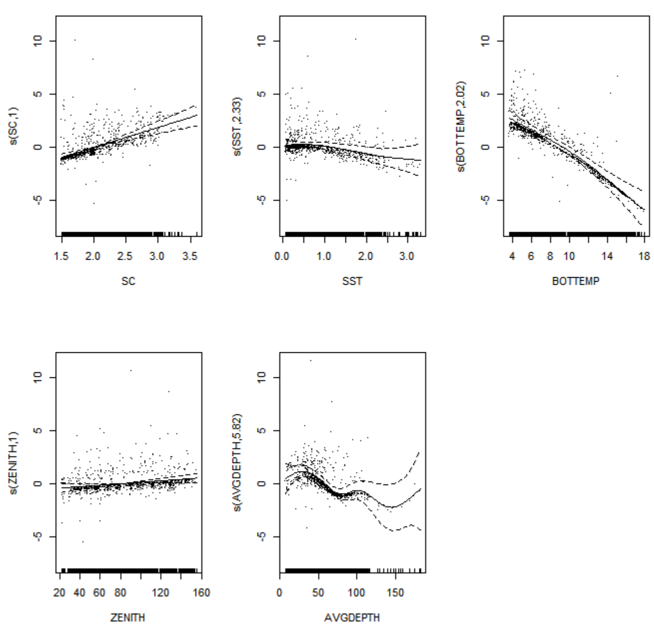


Figure 3: GAM smooth plots for the Georges Bank cod presence-absence model

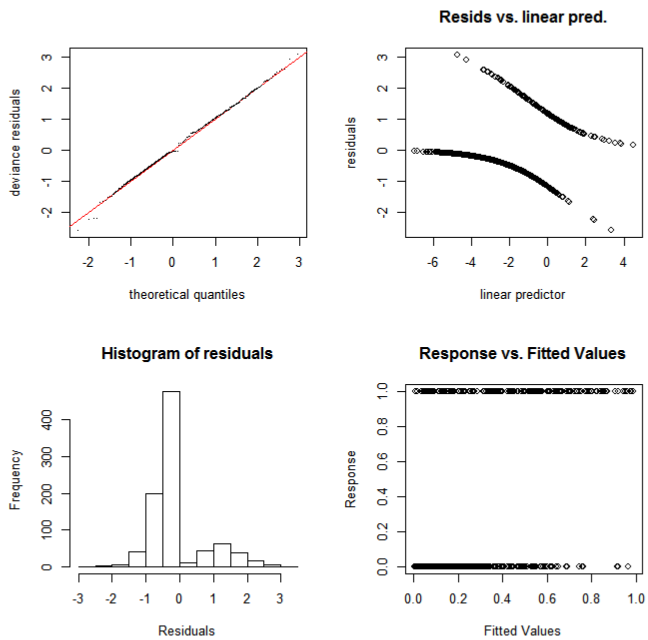


Figure 4: Diagnostic plots of presence absence model for Georges Bank cod

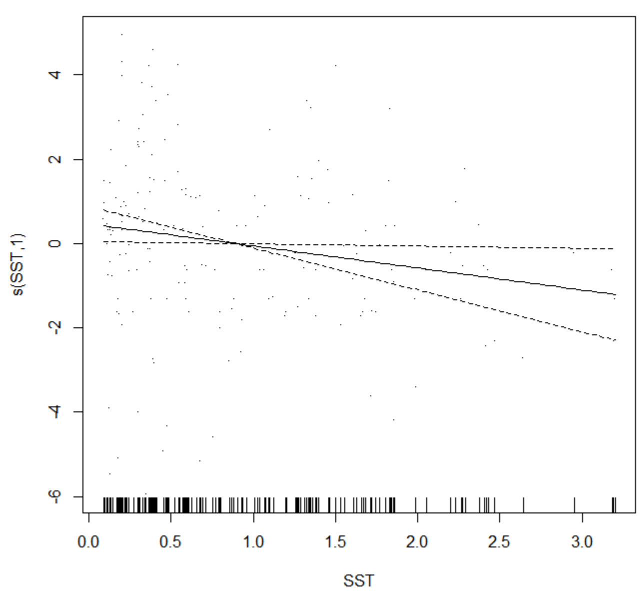


FIGURE 5: GAM smooth plot for the Georges Bank cod conditional presence model

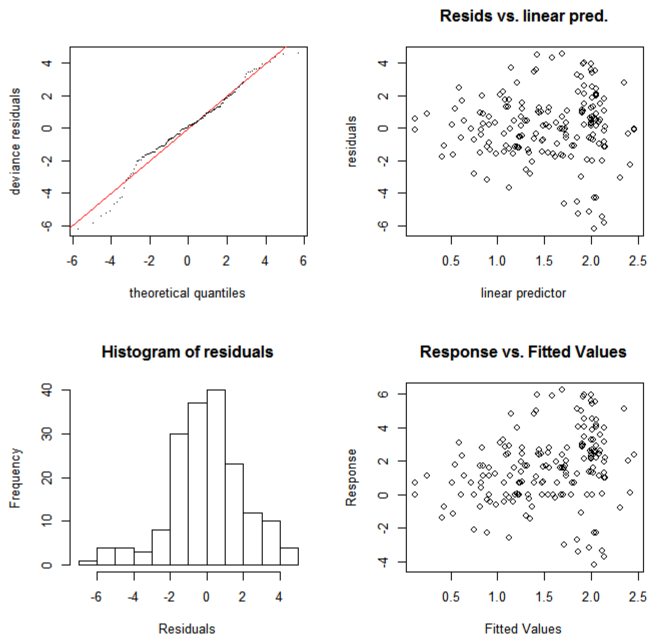


Figure 6: Diagnostic plots of conditional presence model for Georges Bank cod

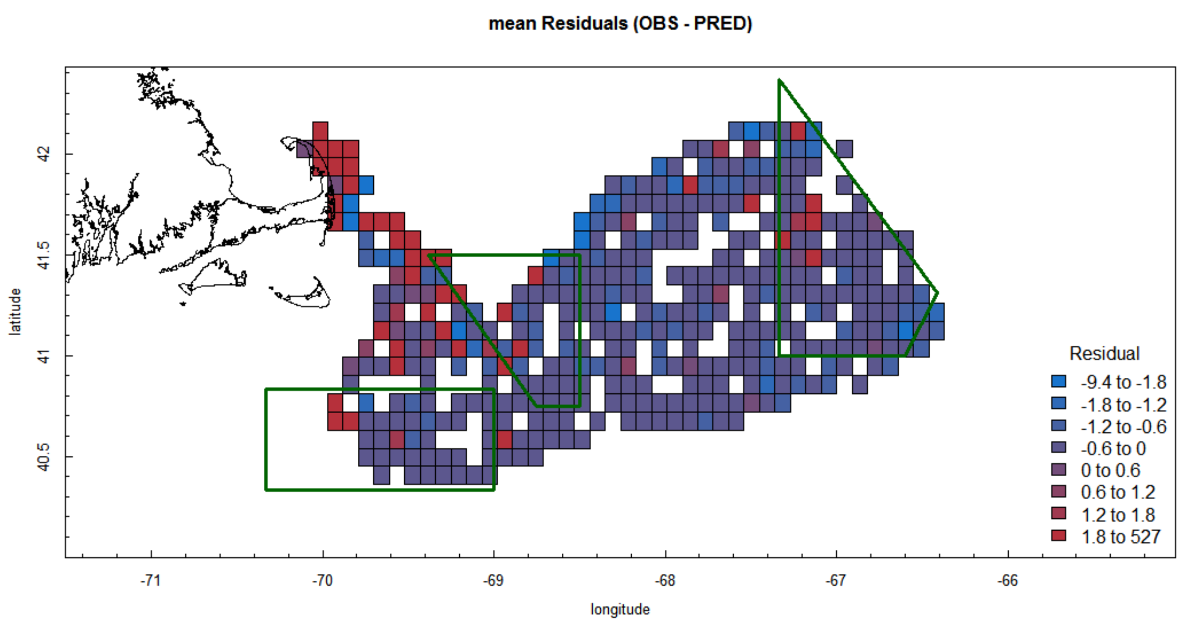


Figure 7: Mean residuals per square bin for Georges Bank cod

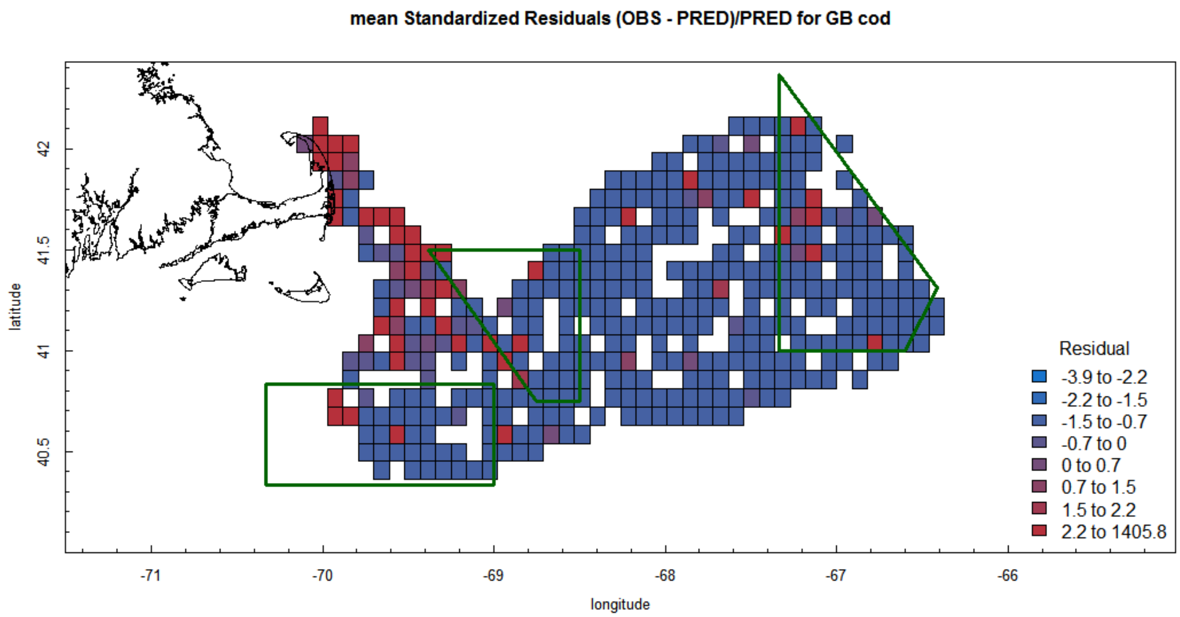


Figure 8: Mean residuals standardized by predictions per square bin for Georges Bank cod.

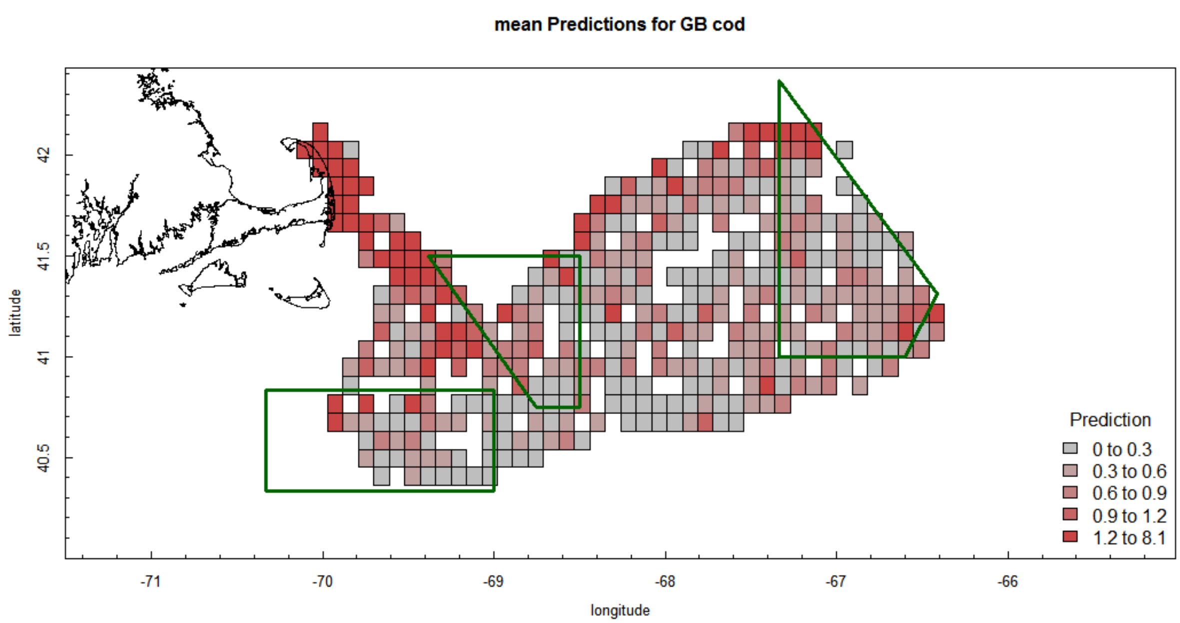


Figure 9: Mean overall predictions for Georges Bank cod.

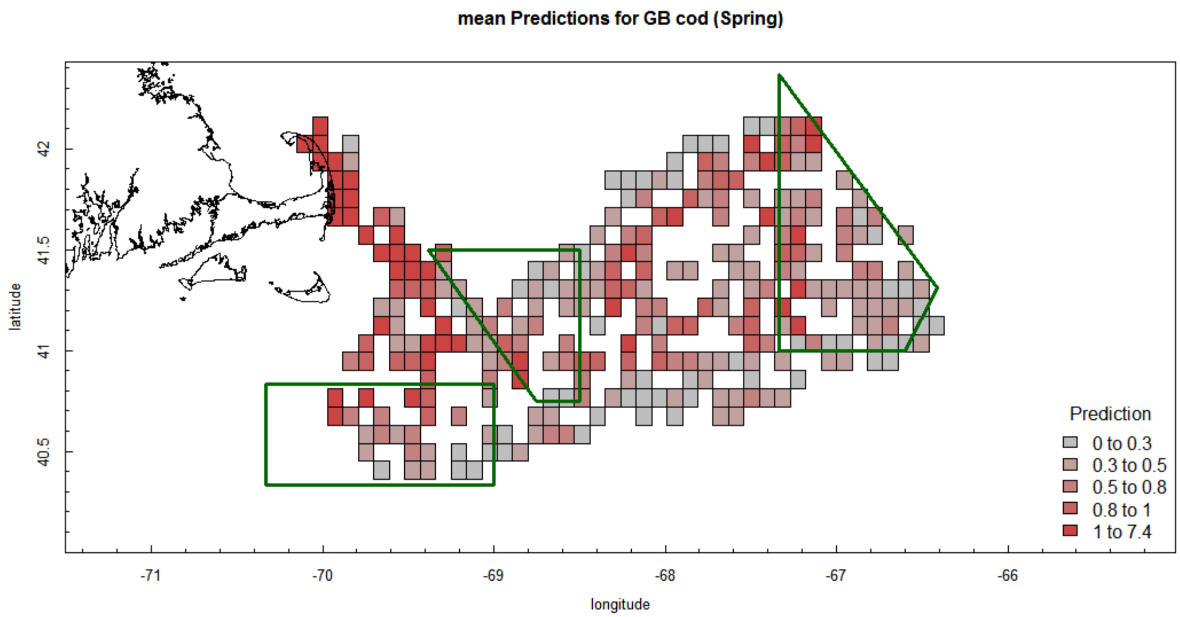


Figure 10: Mean predictions for Georges Bank cod in spring.

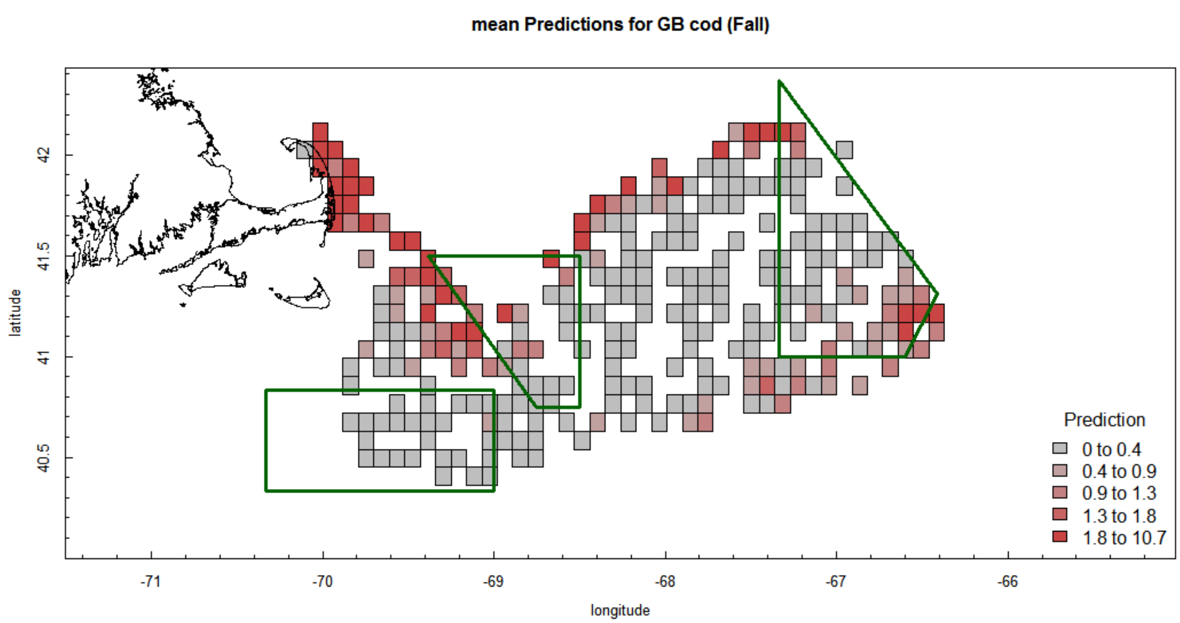


Figure 11: Mean predictions for Georges Bank cod in fall.

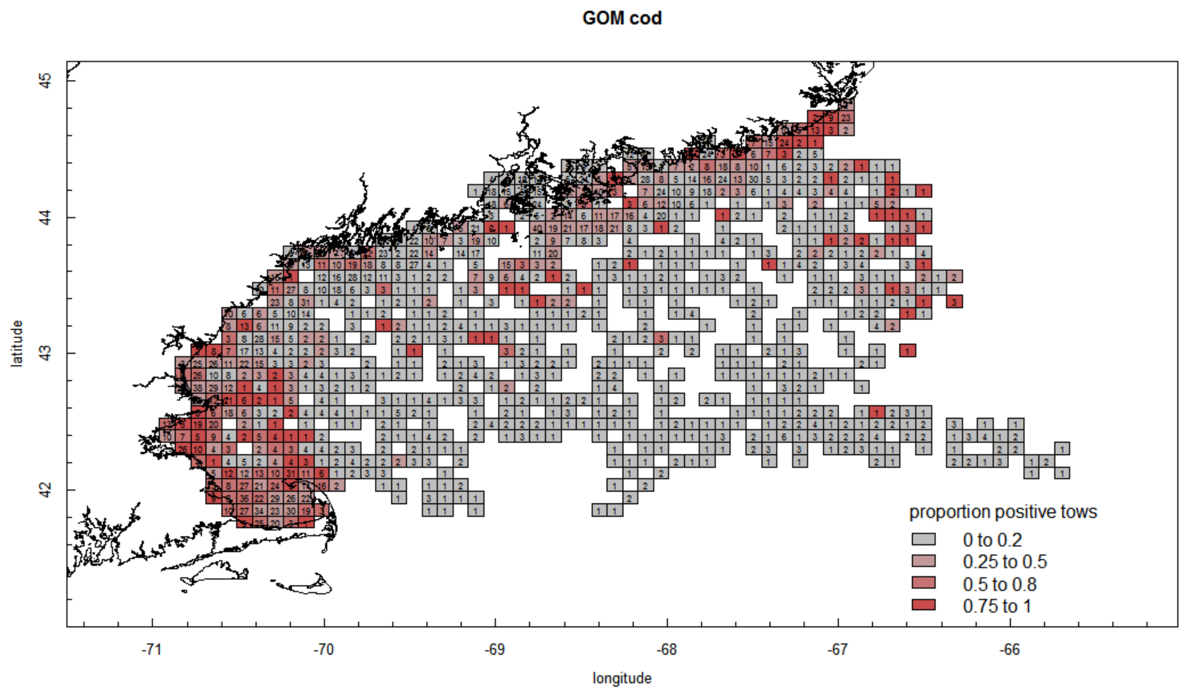


Figure 12: Number of tows per grid square and the proportion of those tows where juvenile cod were caught.

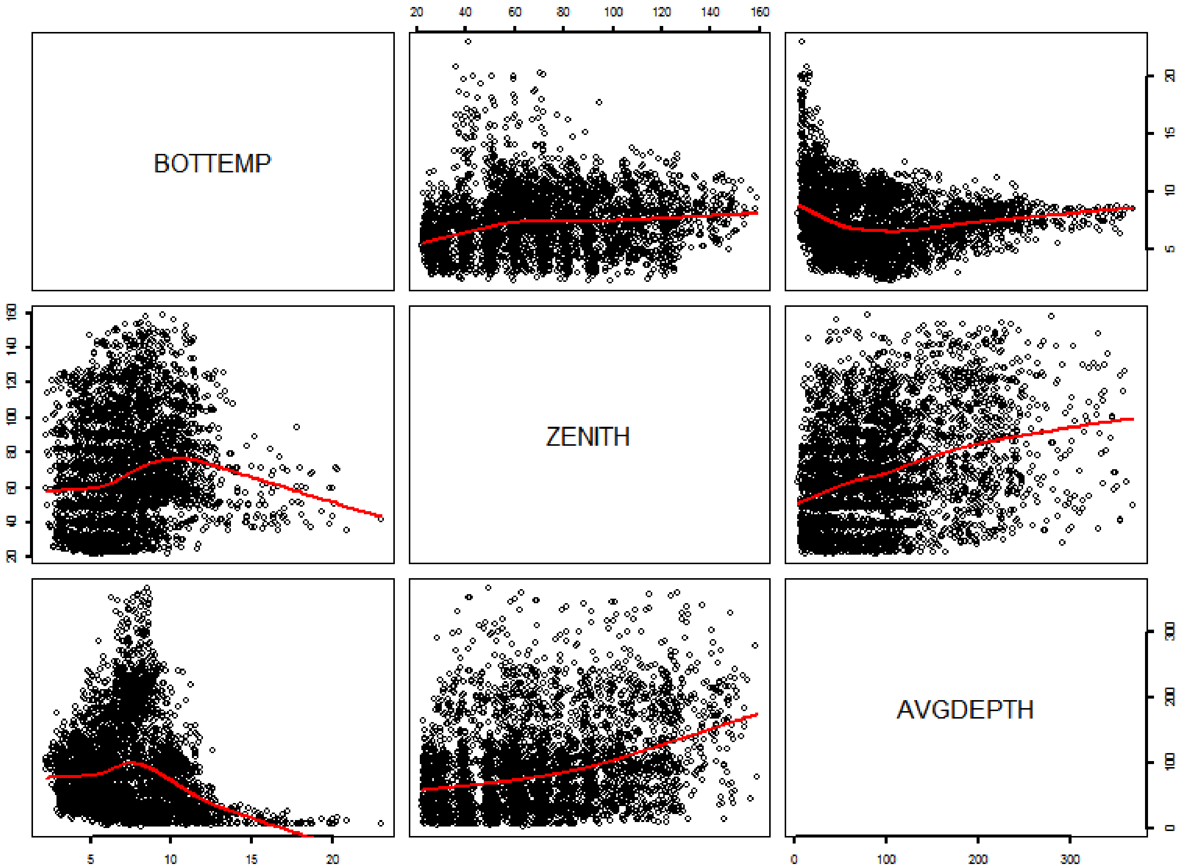


Figure 13: Correlations among continuous variables for the Gulf of Maine cod dataset.

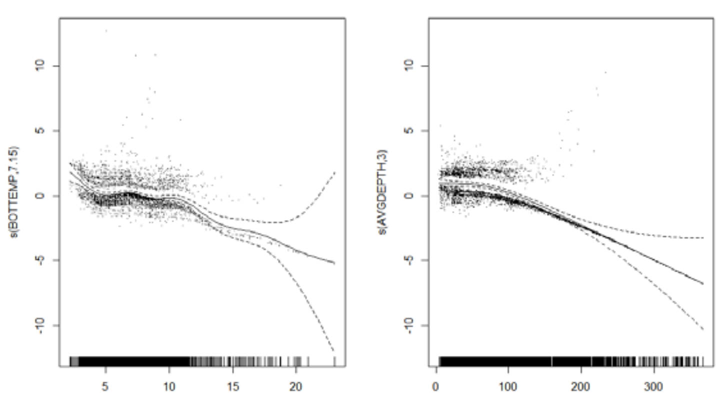


Figure 14: GAM smooth plots for the Gulf of Maine cod presence-absence model

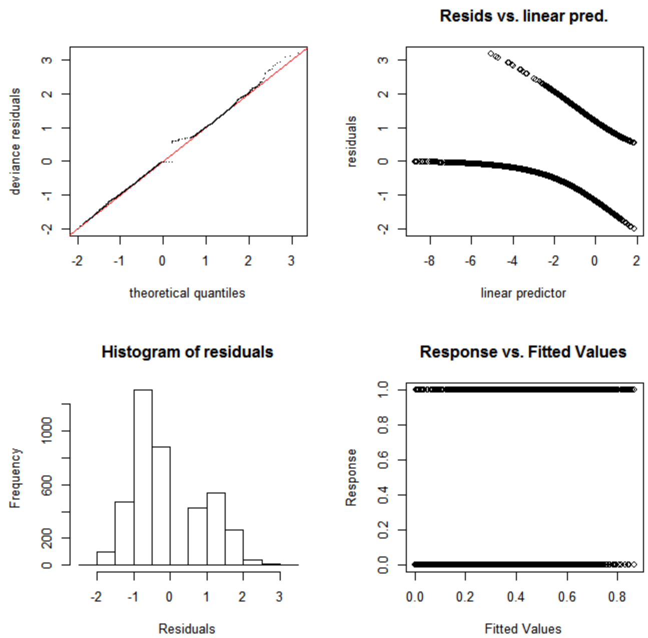


Figure 15: Diagnostic plots of presence absence model for Gulf of Maine cod.

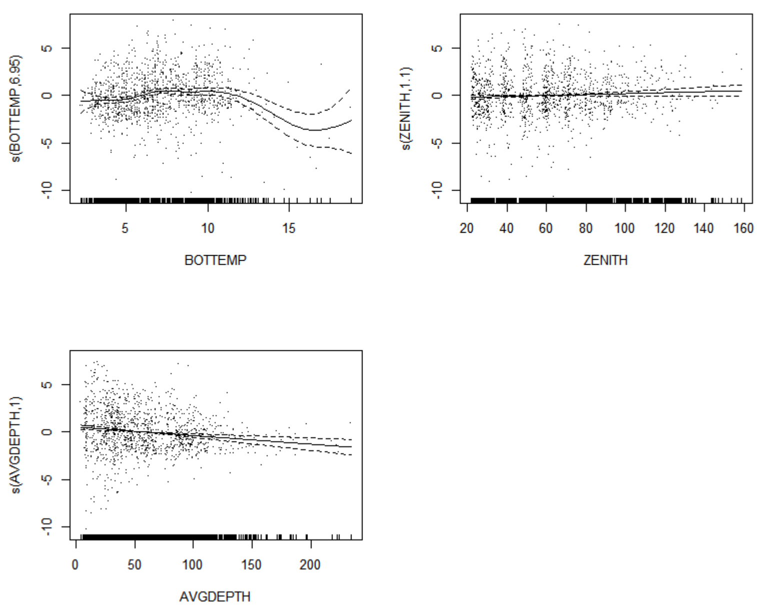


Figure 16: GAM smooth plots for the Gulf of Maine cod conditional presence model.

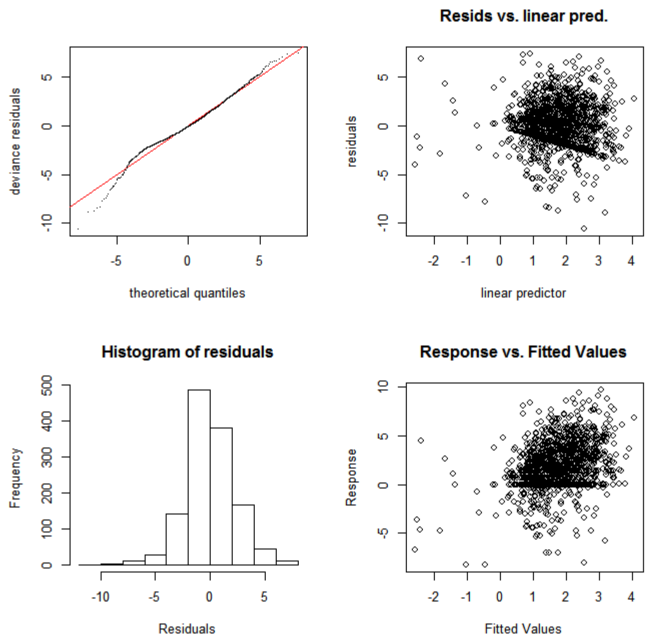


Figure 17: Diagnostic plots of conditional presence model for Gulf of Maine cod.

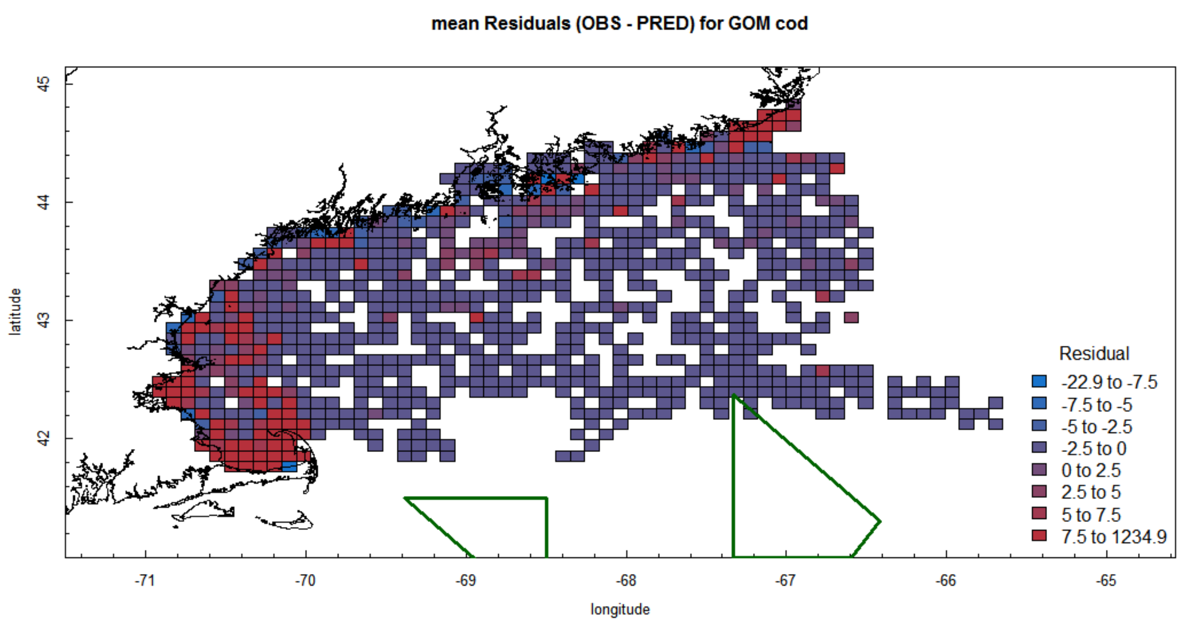


Figure 18: Mean residuals per square bin for Gulf of Maine cod.

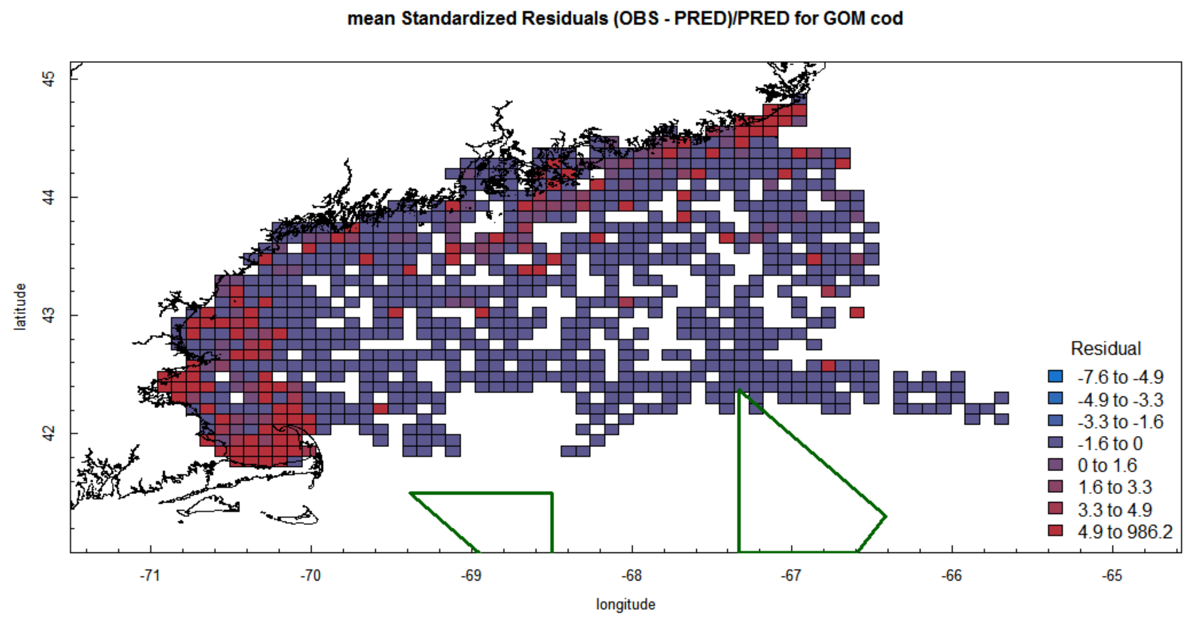


Figure 19: Mean residuals standardized by predictions per square bin for Gulf of Maine cod

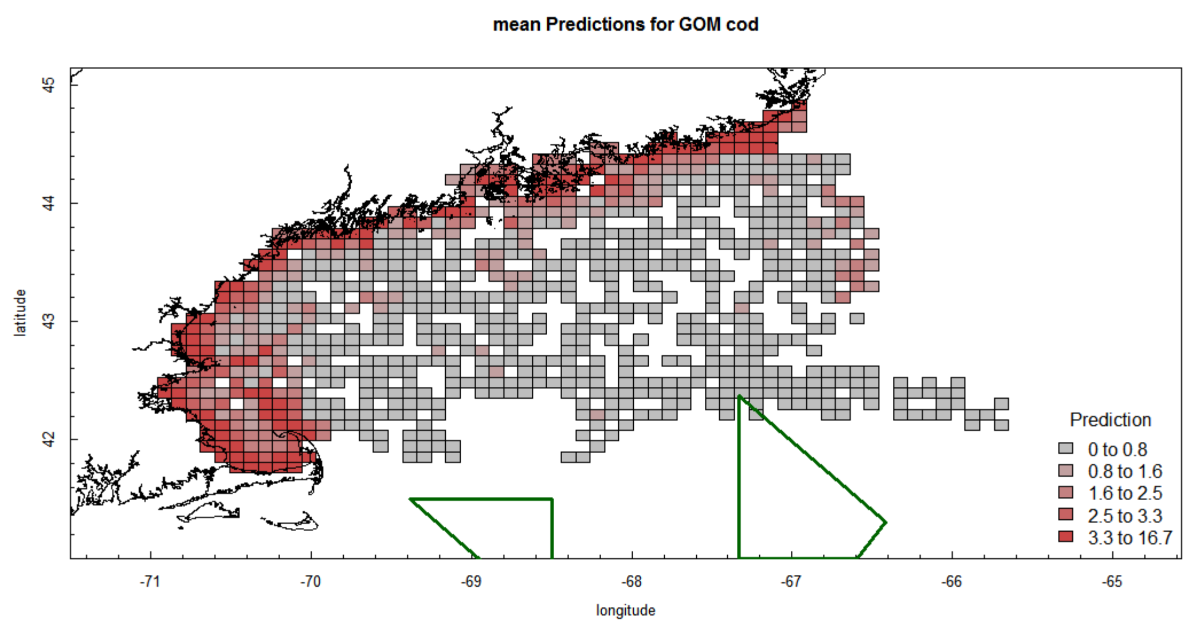


Figure 20: Mean overall predictions for Gulf of Maine cod

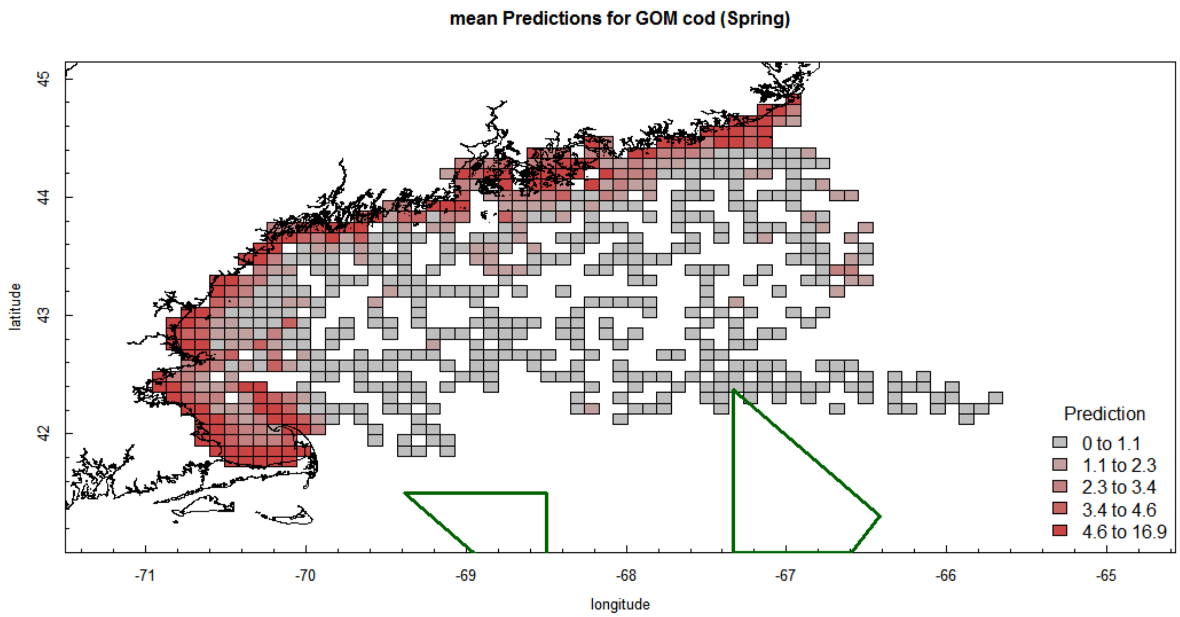


Figure 21: Mean predictions for Gulf of Maine cod in spring

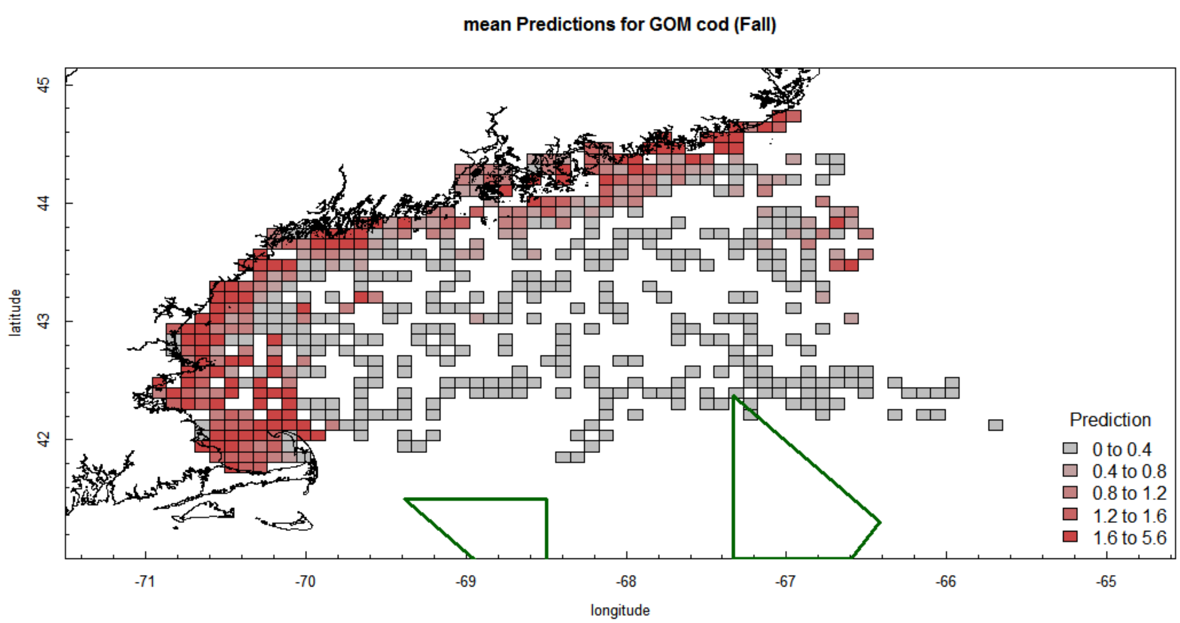


Figure 22: Mean predictions for Gulf of Maine cod in fall.

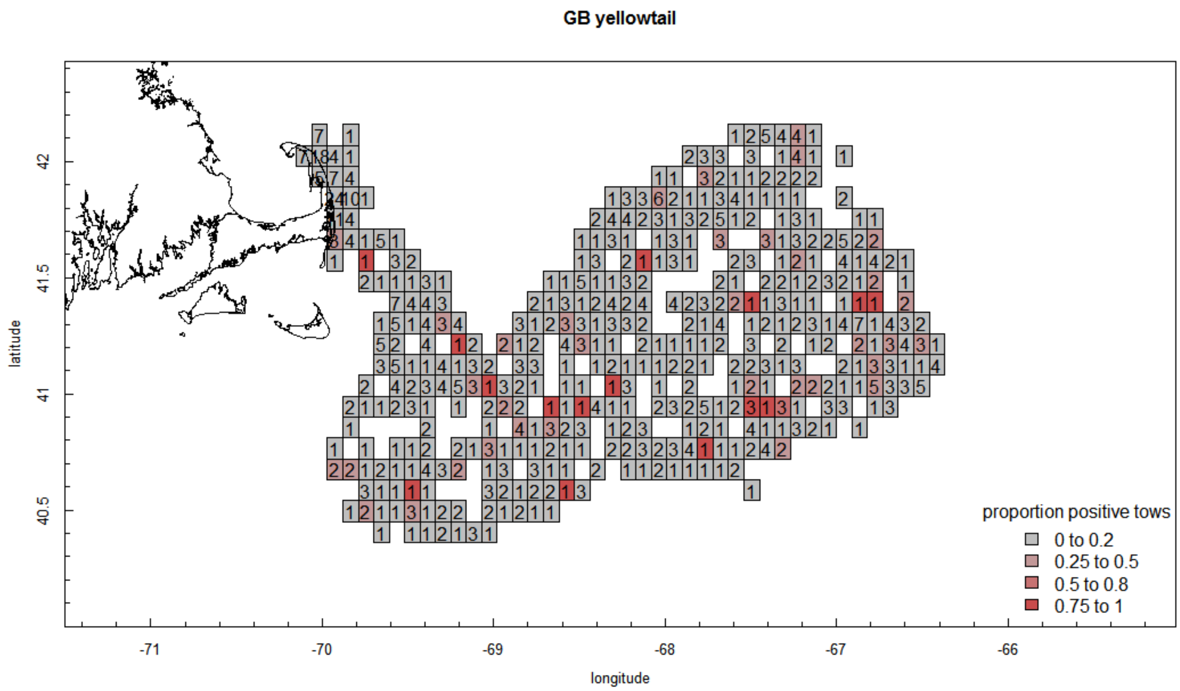


Figure 23: Number of tows per grid square and the proportion of those tows where juvenile yellowtail were caught.

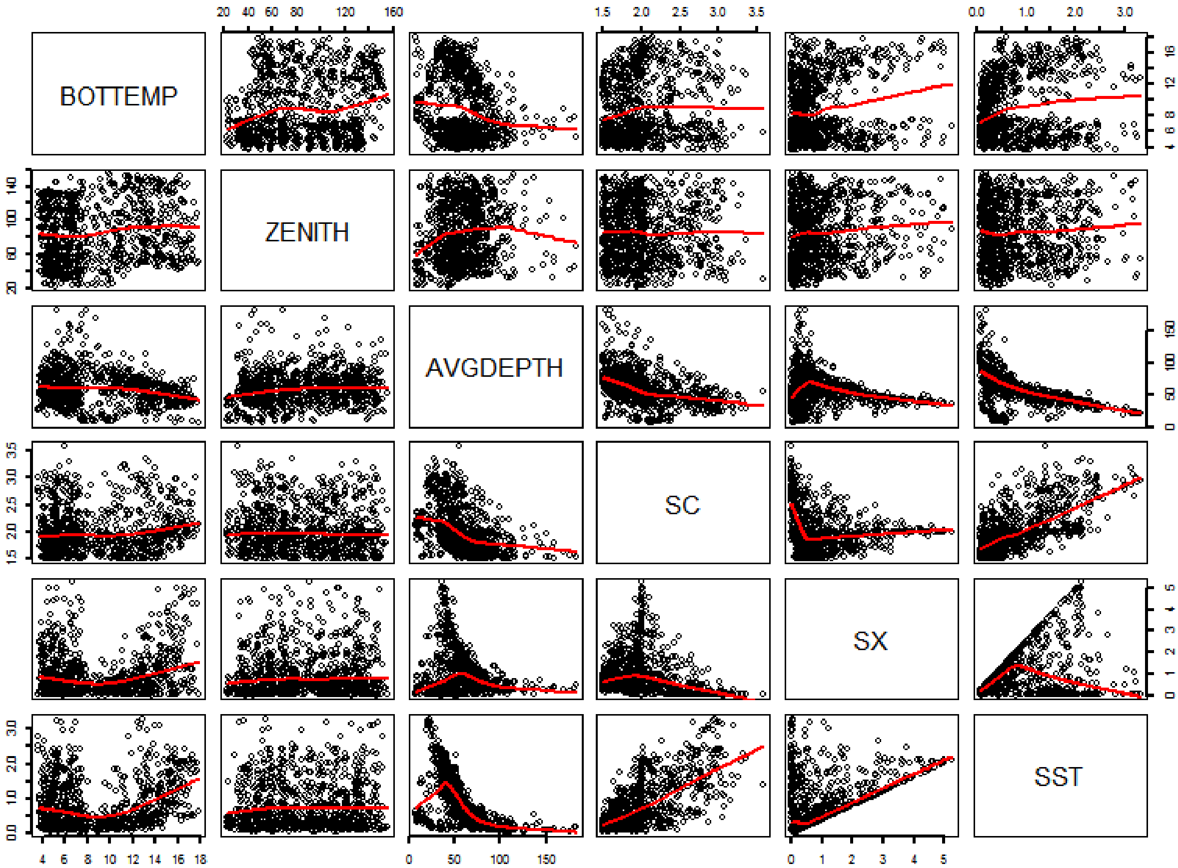


Figure 24: Correlations among continuous variables for the Georges Bank yellowtail flounder dataset.

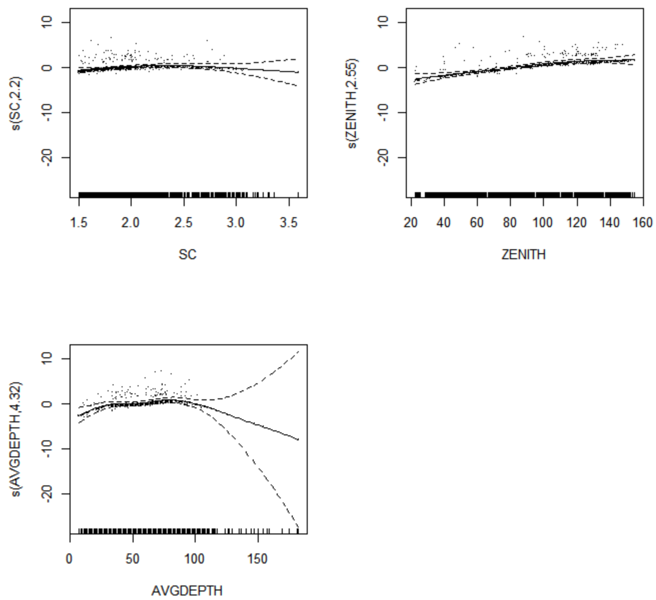


Figure 25: GAM smooth plots for the Georges Bank yellowtail flounder presence-absence model.

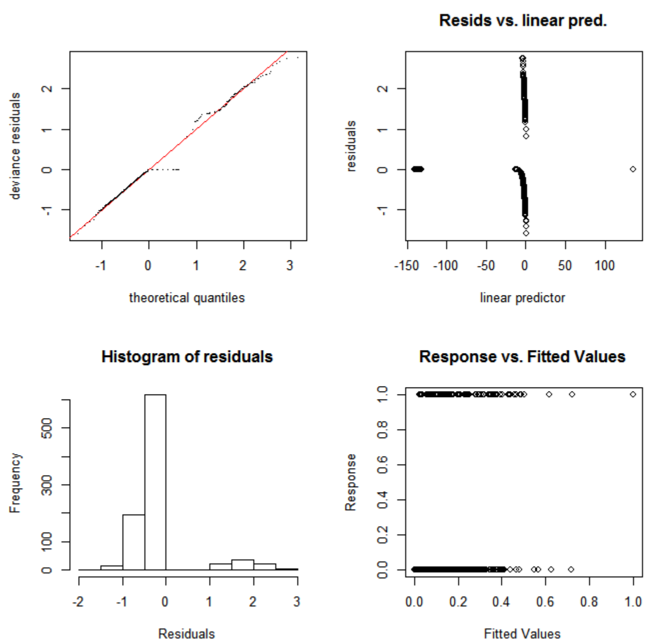


Figure 26: Diagnostic plots of presence absence model for Georges Bank yellowtail flounder.

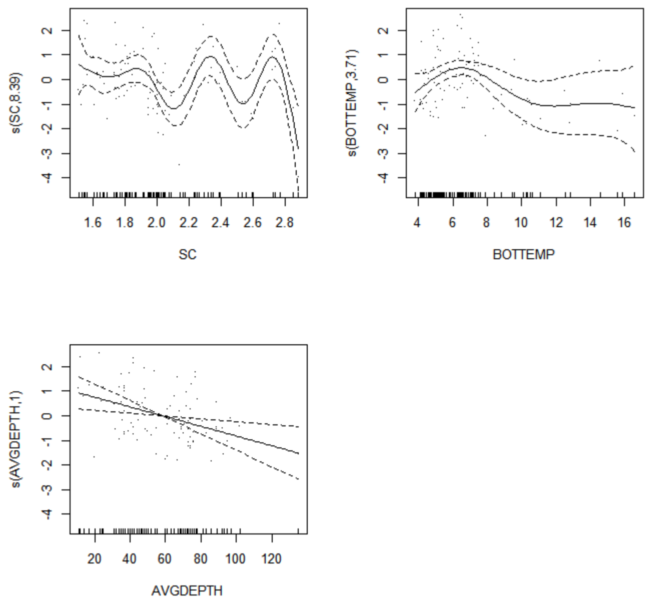


Figure 27: GAM smooth plots for the Georges Bank yellowtail flounder conditional presence model

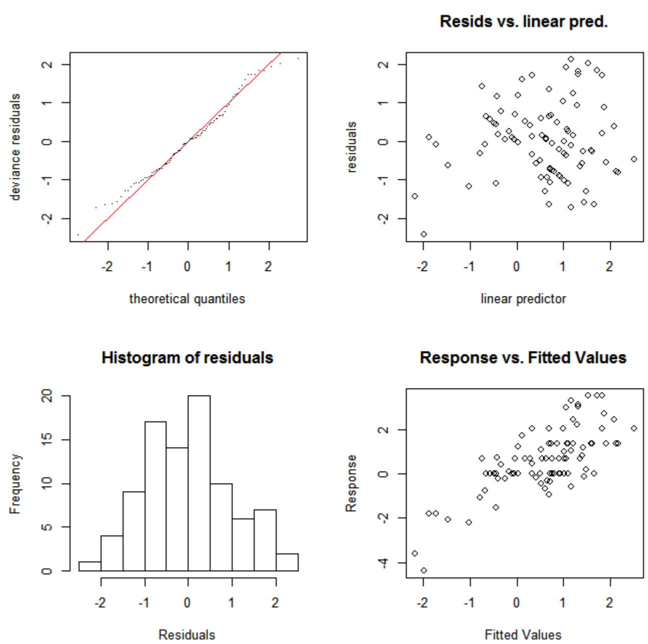


Figure 28: Diagnostic plots of conditional presence model for Georges Bank yellowtail flounder

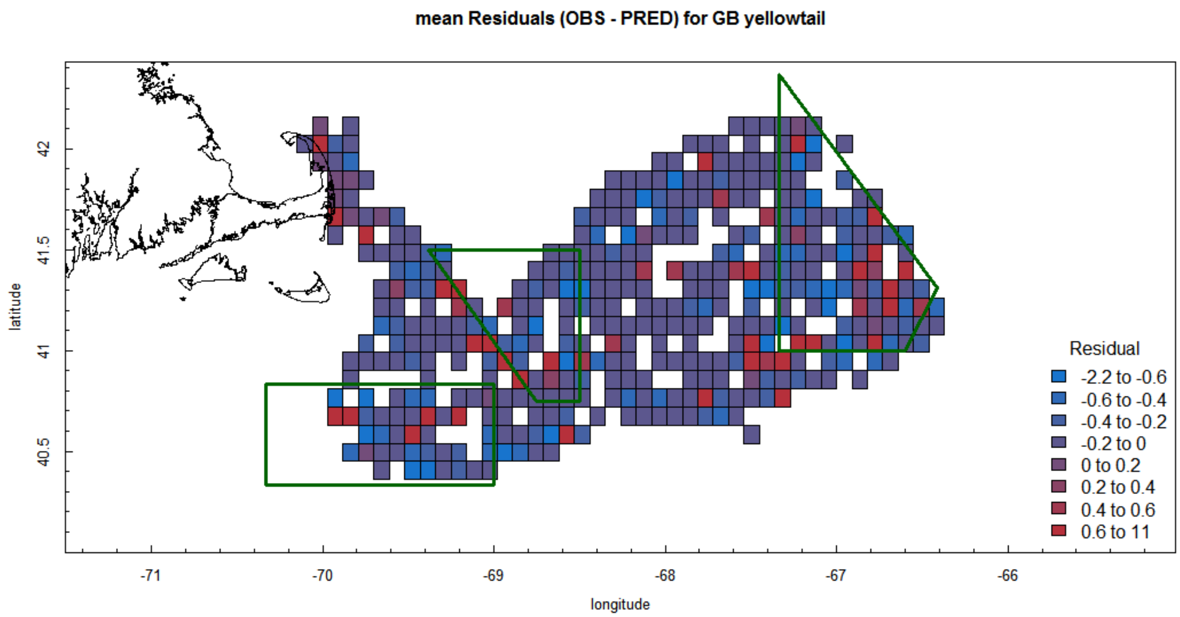


Figure 29: Mean residuals per square bin for Georges Bank yellowtail flounder.

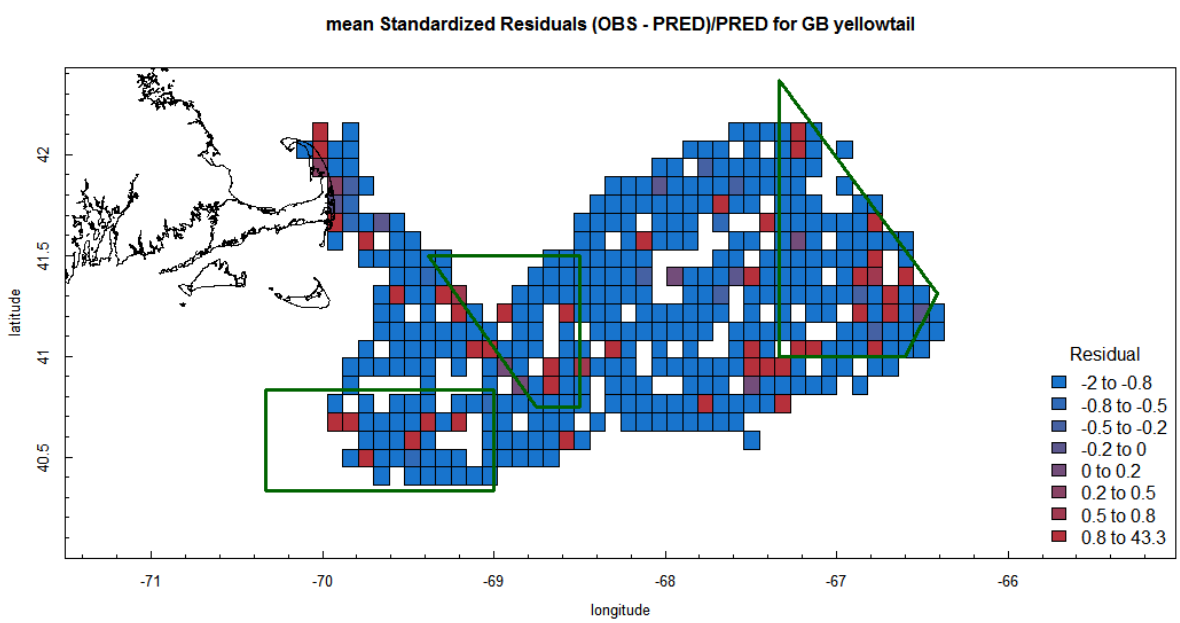


Figure 30: Mean residuals standardized by predictions per square bin for Georges Bank yellowtail flounder.

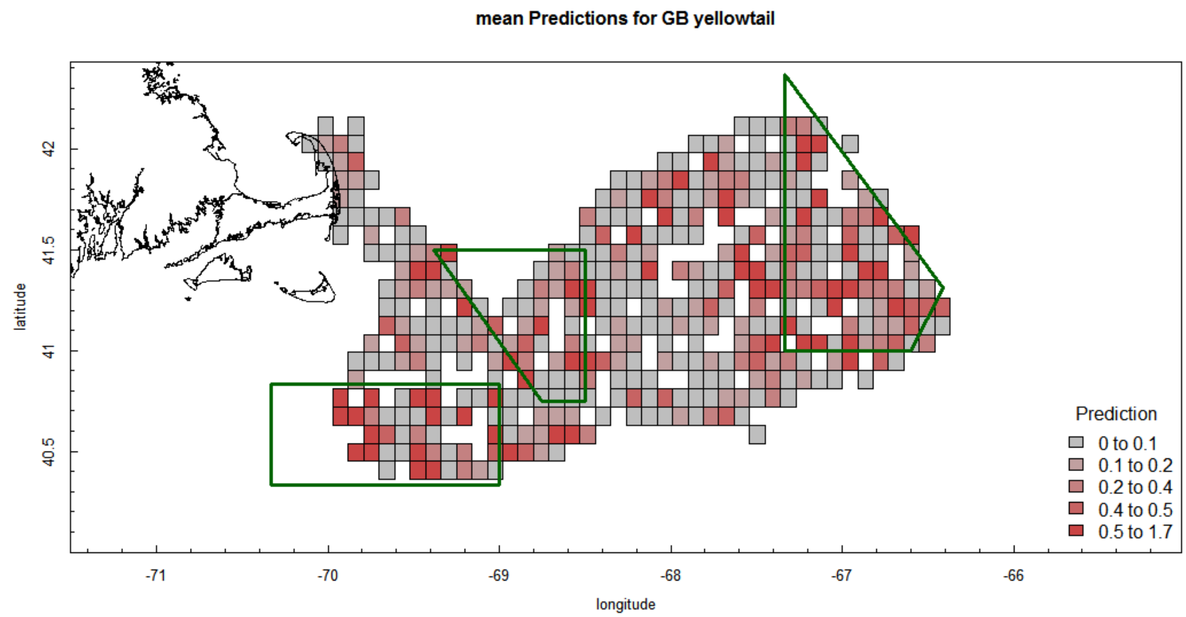


Figure 31: Mean overall predictions for Georges Bank yellowtail flounder.

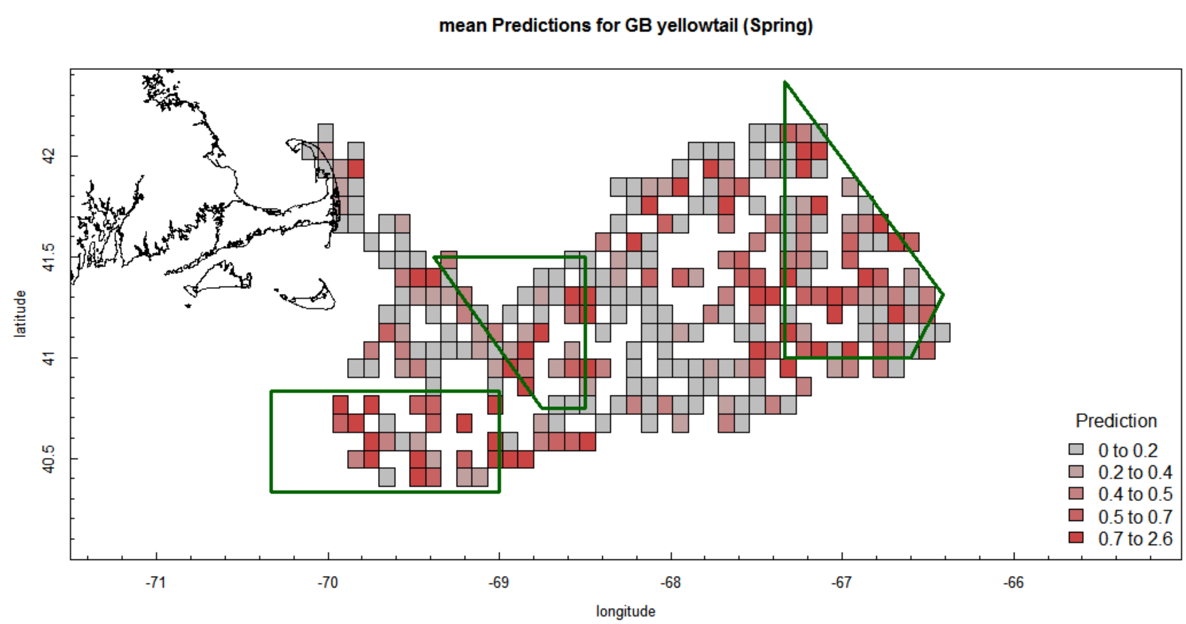


Figure 32: Mean predictions for Georges Bank yellowtail flounder in spring.

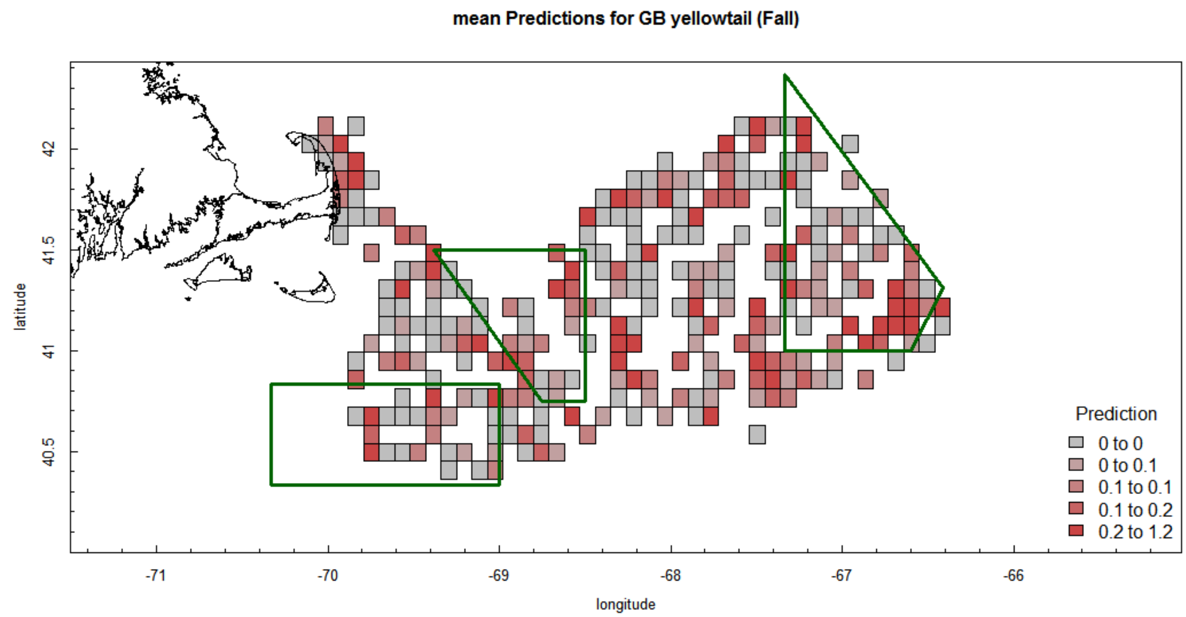


Figure 33: Mean predictions for Georges Bank yellowtail flounder in fall.

APPENDIX 1: Additional information on the candidate variables

Table 1 – Length thresholds analyzed for small fish. The thresholds were selected using age/length keys based on fall and spring NMFS trawl survey data to capture most of the age 0 and 1 juveniles. All lengths were rounded to the nearest 5 cm.

Species	Survey season	Juvenile max length
Atlantic cod	Spring	25
	Fall	35
Yellowtail flounder	Spring	15
	Fall	15

Table 2 - Survey purpose codes

Purpose code	Description	Notes
1	Maine New Hampshire trawl survey	Separate data file
4	Cooperative research survey – goosefish	Data from 2004 and 2009
5	Cooperative research survey – IBS cod	Data from 2003-2007
6	Cooperative research survey – IBS yellowtail	Data from 2003-2005, SNE-MAB
9	Cooperative research survey – paired trawl	
10	NMFS NEFSC bottom trawl survey	Spring, summer, fall, winter (winter through 2009, all other years 2002-2012)
11	MA DMF bottom trawl survey	Fall and spring, off MA coast
40	NMFS NEFSC shrimp survey	GOM, summer survey
60	NMFS NEFSC sea scallop survey	GB and MAB, summer survey

Table 3 – Habitat data in first data sets distributed

Data type	Data source	Coverage	Variable type	Notes
Depth	Fish survey data 2002-2012.	Same as catch data - each station has a depth	Continuous integer	Should probably use coastal relief model depth if we need a surface to predict to – working on joining this data set. Because depth is not expected to vary between years, CRM or survey depth should be fairly consistent.
Bottom temperature	Fish survey data 2002-2012.	Same as catch data - each station has a bottom temp	Continuous integer	Hard to come up with a single average bottom temperature layer by season – varies by year. Best info will be the temperature at the time of the tow.
Substrate	usSEABED, as processed forTNC ecoregional assessment	Entire coast to about 2500 m	Categorical- interpolated polygons of average grain size. 5 bins – 1 mud, 3 subdivisions of sand, 1 gravel. Polygons spatially joined to midpoint of tows.	Have other data sources for substrate as well but this one is the easiest to work with/most spatially comprehensive. Will provide additional data for yellowtail and cod for GB only.

Data type	Data source	Coverage	Variable type	Notes
Substrate	State of Maine	Inshore Maine coast – just beyond 3 nm boundary.	Categorical - interpolated polygons based on multibeam backscatter – sand, rock, gravel, mud. Polygons spatially joined to midpoint of tows.	Can be used as an alternative for MENH catch data. Does not cover entire footprint of MENH survey so there will be some tows without a substrate attribute if using these data
Seabed form	Derived from TNC depth and position index	Entire coast to about 2500 m	Publically available as a raster, 83 m resolution. Categorical variable – 9 combos of low/mid/high position combined with flat/moderate/steep slope.	Would need to join spatially to survey data set – having issues extracting raster to points. Trying to include these data and will send an updated data set.

Table 4 - Sediment and sediment stability data from Harris and Stokesbury 2010 and Harris et al 2012

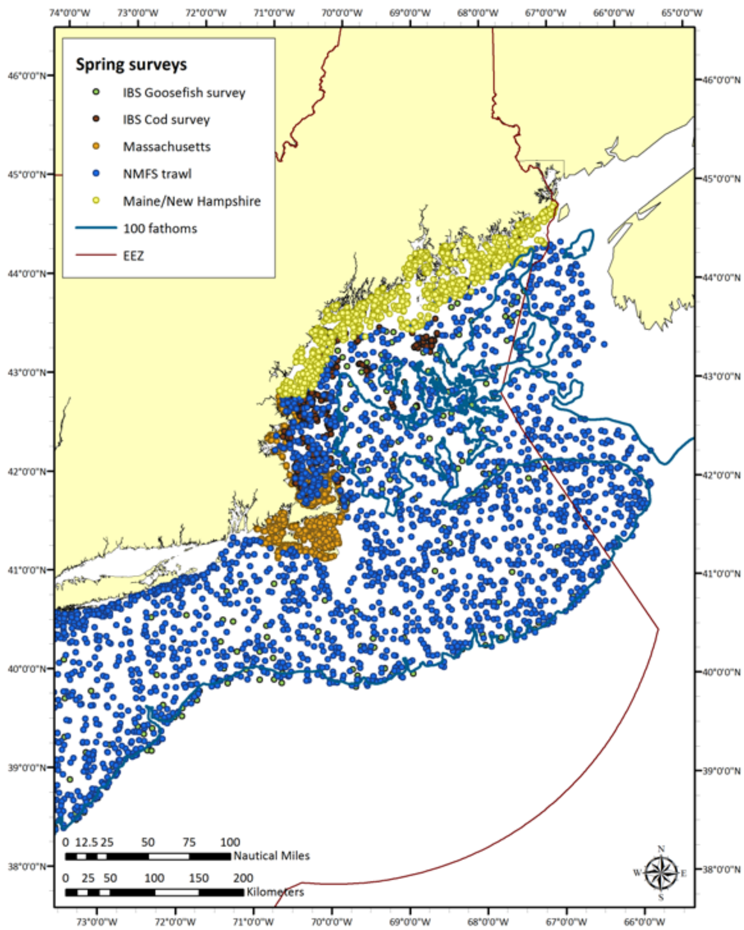
Field	Description
Long	Sediment Map Grid Longitude
Lat	Sediment Map Grid Latitude
Sm	Maximum Size Sediment Type Values: 1 = Silt/Mud, 2 = Sand, 3 = Granule/Pebble, 4 = Cobble, 5= Boulder Details on page 1842 - 1843 of Harris and Stokesbury 2010
Sd	Dominant Sediment Type (Most commonly occurring type in four replicate samples per station). Values: 1 = Silt/Mud, 2 = Sand, 3 = Granule/Pebble, 4 = Cobble, 5= Boulder Details on page 1842 - 1843 of Harris and Stokesbury 2010
Sc	Sediment Coarseness Values ≤ 2 = Smooth, >2 but <4 = Intermediate, ≥ 4 = Coarse Details on page 1842 - 1843 of Harris and Stokesbury 2010
Sx	Sediment Stability Index Values ≥ 1 = unstable. Values < 1 = Stable Details in section 2.3 of Harris et al 2012
Sst	Benthic boundary shear stress (N m^{-2}, annual mean max M_2+S_2 tidal = bi-weekly) Details in section 2.1 of Harris et al 2012

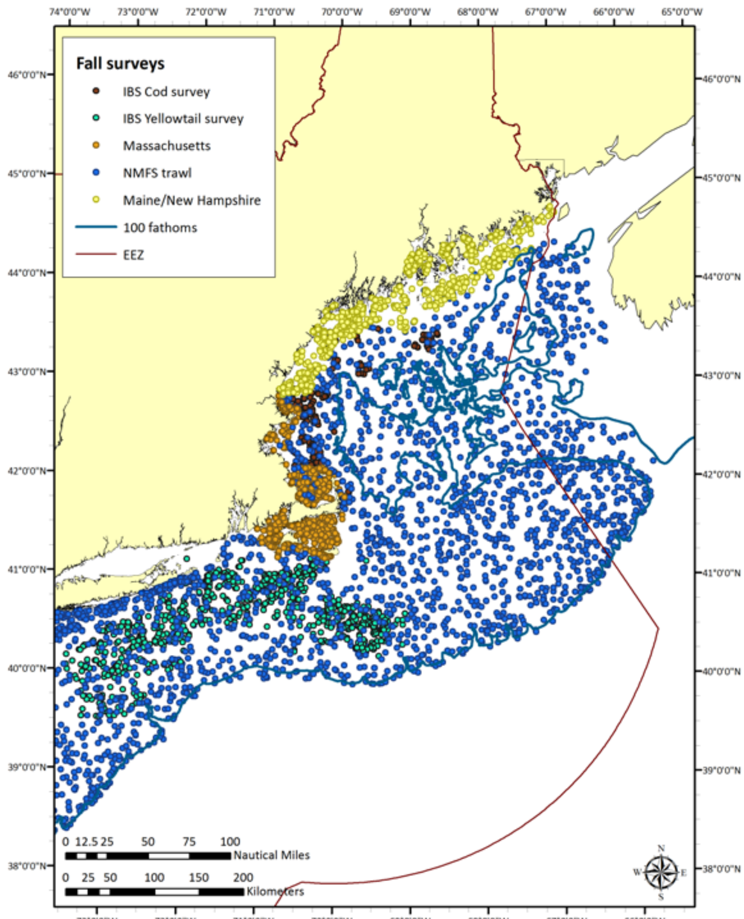
Table 5 - Seabed forms data

SLOPE	C_SLOPE	LPI	C_LPI	SEABEDFORM	SB_form
0 - 0.015%	1	Low Land Position	1	Depression	1
0 - 0.015%	1	Low Land Position	2	Depression	1
0 - 0.015%	1	Mid Land Position	3	Mid Flat	2
0 - 0.015%	1	Mid Land Position	4	Mid Flat	2
0 - 0.015%	1	High Land Position	5	High Flat	3
0 - 0.015%	1	High Land Position	6	High Flat	3
0.015 - 0.05%	2	Low Land Position	1	Depression	1
0.015 - 0.05%	2	Low Land Position	2	Depression	1
0.015 - 0.05%	2	Mid Land Position	3	Mid Flat	2

SLOPE	C_SLOPE	LPI	C_LPI	SEABEDFORM	SB_form
0.015 - 0.05%	2	Mid Land Position	4	Mid Flat	2
0.015 - 0.05%	2	High Land Position	5	High Flat	3
0.015 - 0.05%	2	High Land Position	6	High Flat	3
0.05 - 0.8	3	Low Land Position	1	Low Slope	4
0.05 - 0.8	3	Low Land Position	2	Low Slope	4
0.05 - 0.8	3	Mid Land Position	3	Side Slope	6
0.05 - 0.8	3	Mid Land Position	4	Side Slope	6
0.05 - 0.8	3	High Land Position	5	High Slope	5
0.05 - 0.8	3	High Land Position	6	High Slope	5
0.8 -8%	4	Low Land Position	1	Low Slope	4
0.8 -8%	4	Low Land Position	2	Low Slope	4
0.8 -8%	4	Mid Land Position	3	Side Slope	6
0.8 -8%	4	Mid Land Position	4	Side Slope	6
0.8 -8%	4	High Land Position	5	High Slope	5
0.8 -8%	4	High Land Position	6	High Slope	5
>8%	5	Low Land Position	1	Steep	7
>8%	5	Low Land Position	2	Steep	7
>8%	5	Mid Land Position	3	Steep	7
>8%	5	Mid Land Position	4	Steep	7
>8%	5	High Land Position	5	Steep	7
>8%	5	High Land Position	6	Steep	7

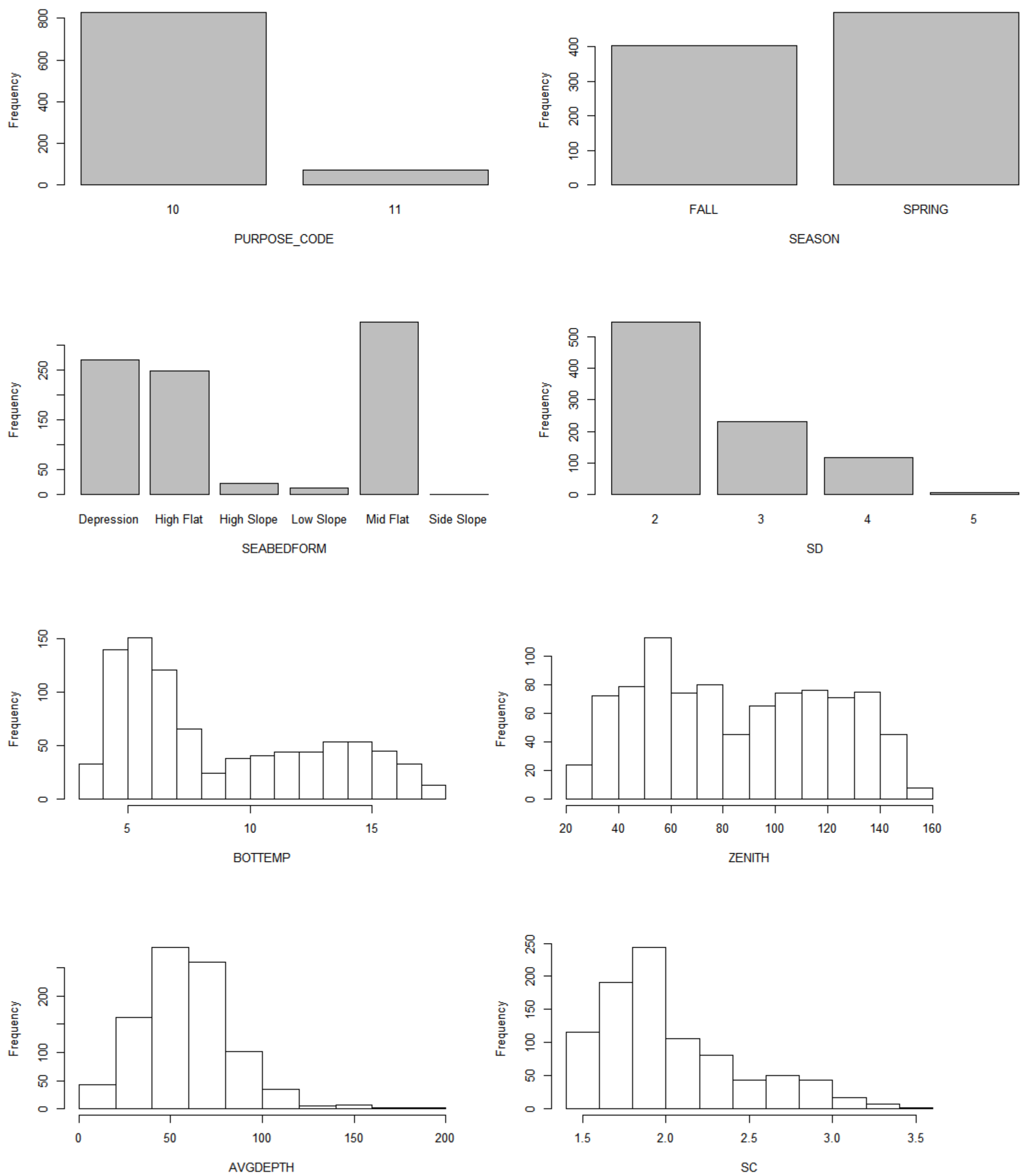
APPENDIX 2: Spatial and seasonal distribution of the fisheries surveys that were used in the modeling

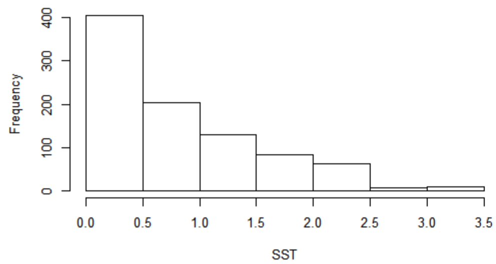


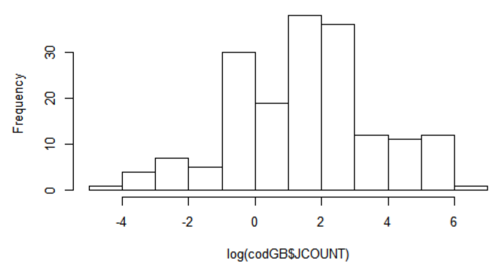


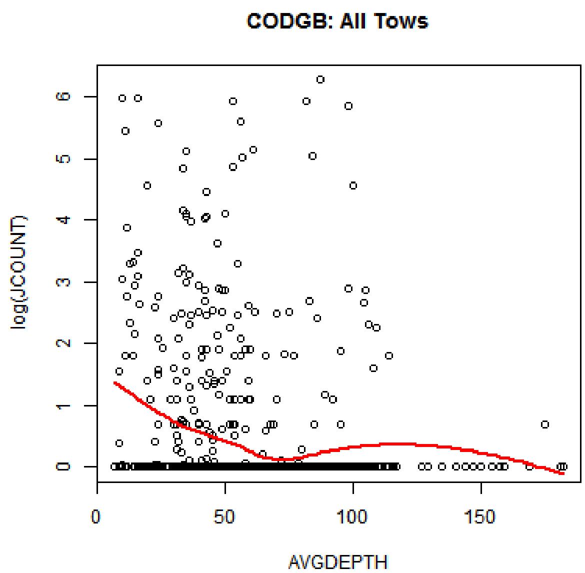
Fall surveys
IBS Cod survey
IBS Yellowtail survey
Massachusetts
NMFS trawl
Maine/New Hampshire
100 fathoms
EEZ
0 12.5 25 50 75 100
Nautical Miles
0 25 50 100 150 200
Kilometers
74°0'0"W
73°0'0"W
72°0'0"W
71°0'0"W
70°0'0"W
69°0'0"W
68°0'0"W
67°0'0"W
66°0'0"W
65°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
41°0'0"N
40°0'0"N
39°0'0"N
38°0'0"N
N
S
E
W

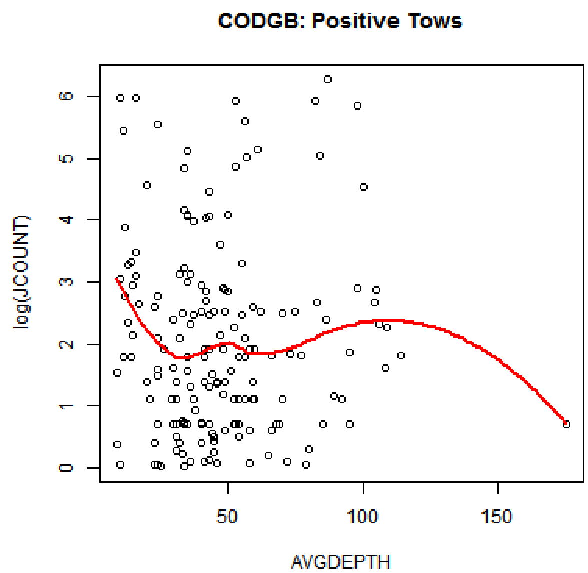
APPENDIX 3: Premodeling Georges Bank cod analysis

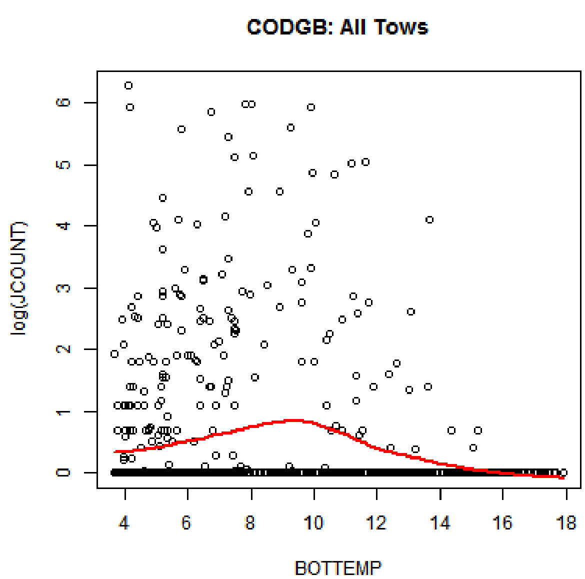


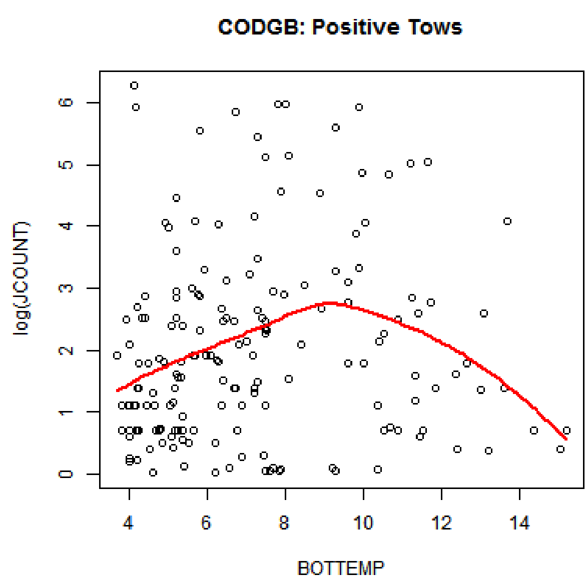

Frequency
SST

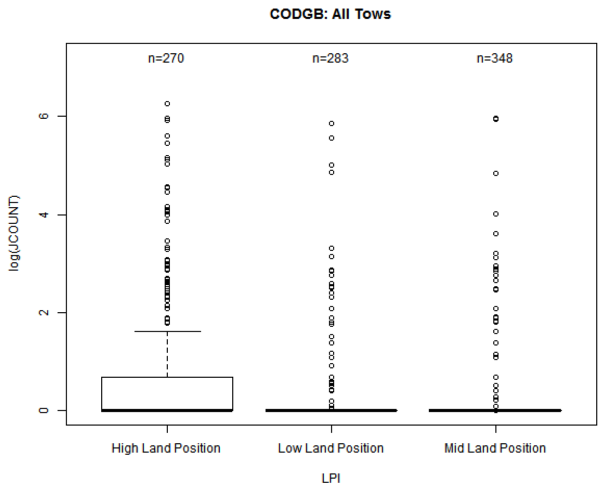

Frequency
log(codGB$JCOUNT)

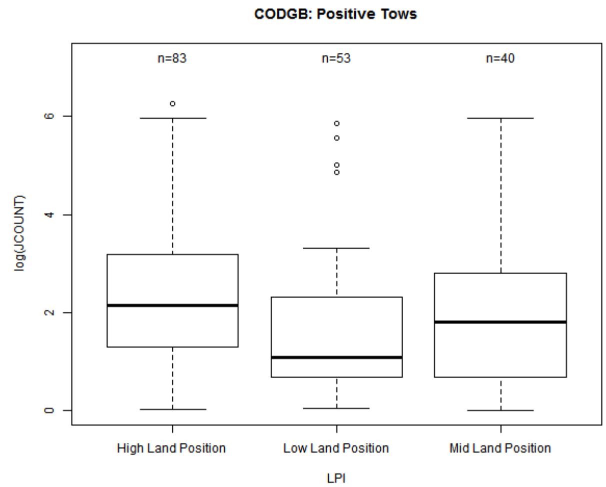

CODGB: All Tows
log(JCOUNT)
AVGDEPTH

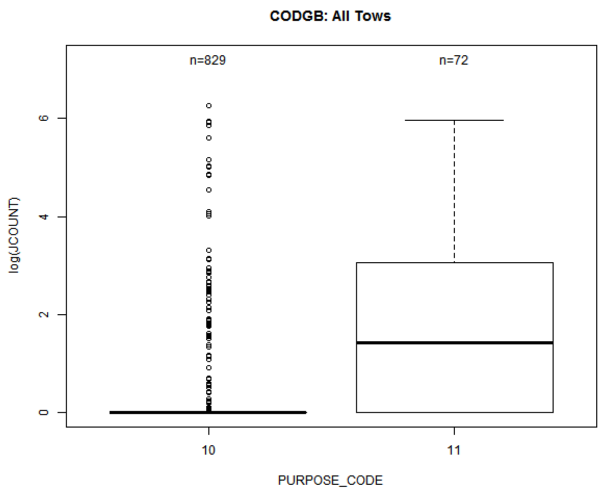

CODGB: Positive Tows
log(JCOUNT)
AVGDEPTH

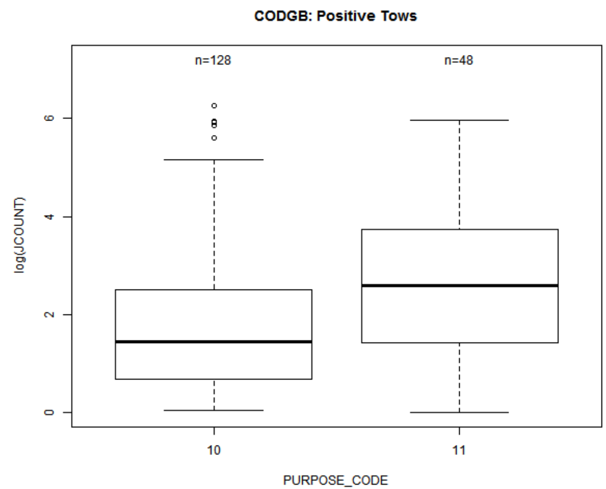

CODGB: All Tows
log(JCOUNT)
BOTTEMP

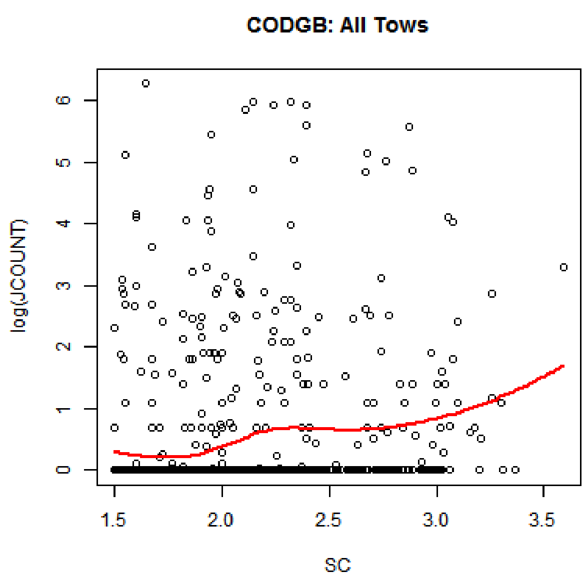

CODGB: Positive Tows
log(JCOUNT)
BOTTEMP

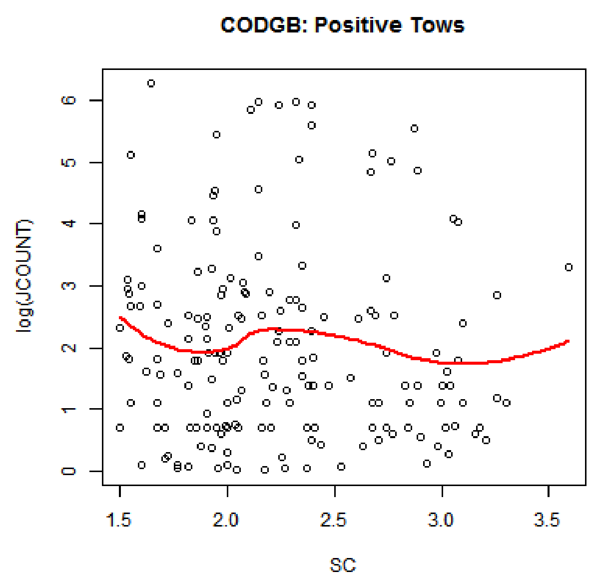

CODGB: All Tows
n=270
n=283
n=348
log(JCOUNT)
0
2
4
6
High Land Position
Low Land Position
Mid Land Position
LPI

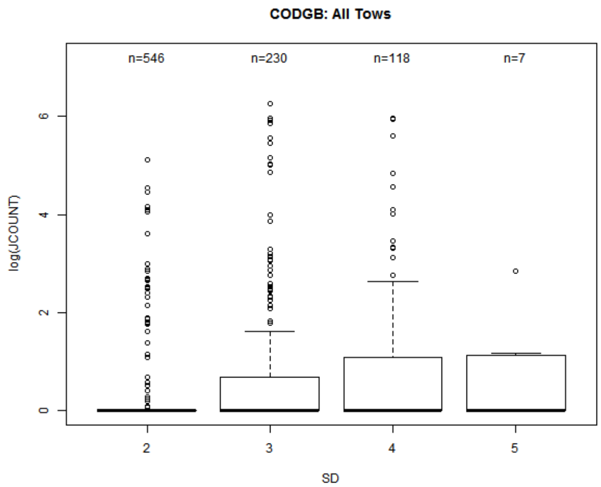

CODGB: Positive Tows
n=83
n=53
n=40
log(JCOUNT)
0
2
4
6
High Land Position
Low Land Position
Mid Land Position
LPI

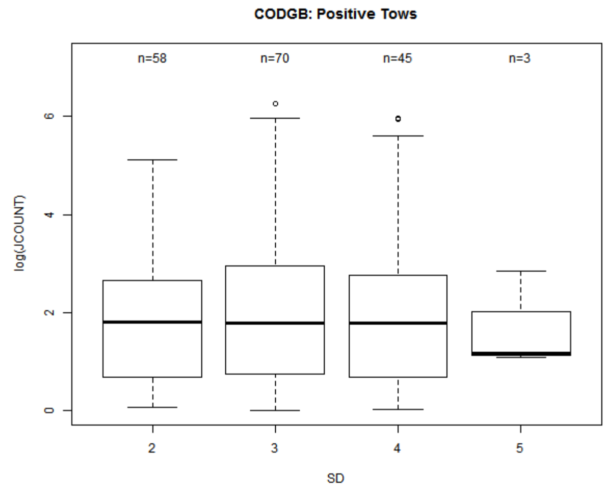

CODGB: All Tows
n=829
n=72
log(JCOUNT)
0
2
4
6
10
11
PURPOSE_CODE

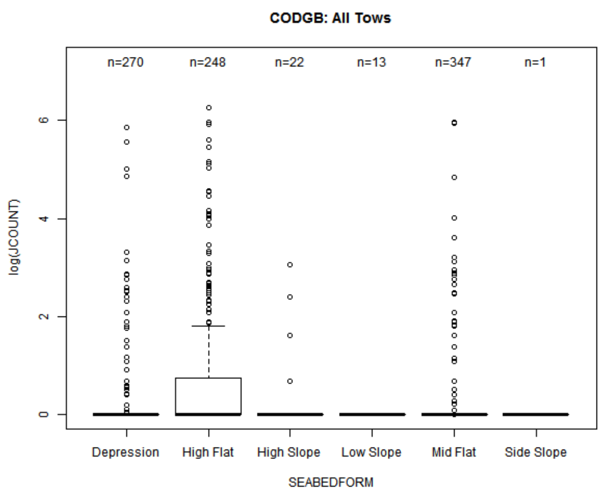

CODGB: Positive Tows
n=128
n=48
log(JCOUNT)
0
2
4
6
10
11
PURPOSE_CODE

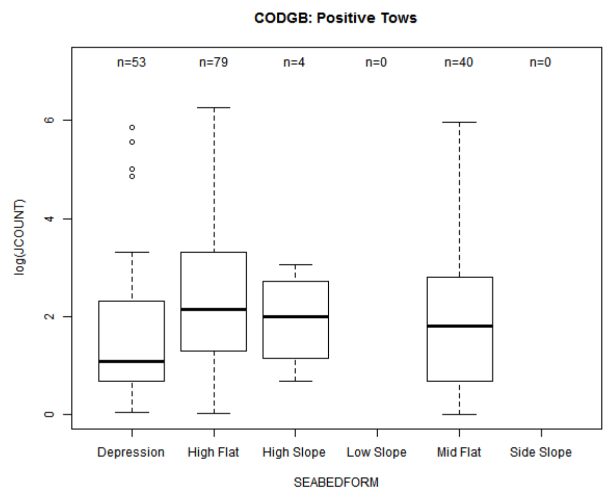

CODGB: All Tows
log(JCOUNT)
0
1
2
3
4
5
6
1.5
2.0
2.5
3.0
3.5
SC

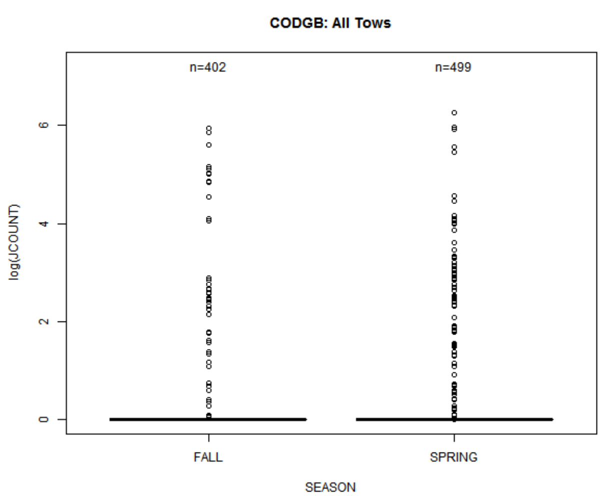

CODGB: Positive Tows
log(JCOUNT)
0
1
2
3
4
5
6
1.5
2.0
2.5
3.0
3.5
SC

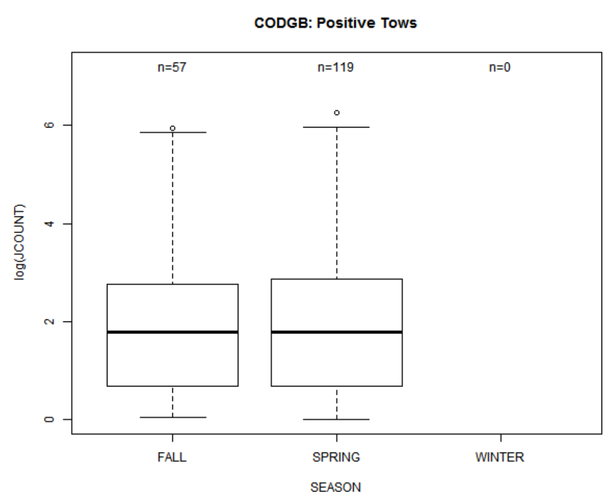

CODGB: All Tows
n=546
n=230
n=118
n=7
log(JCOUNT)
SD

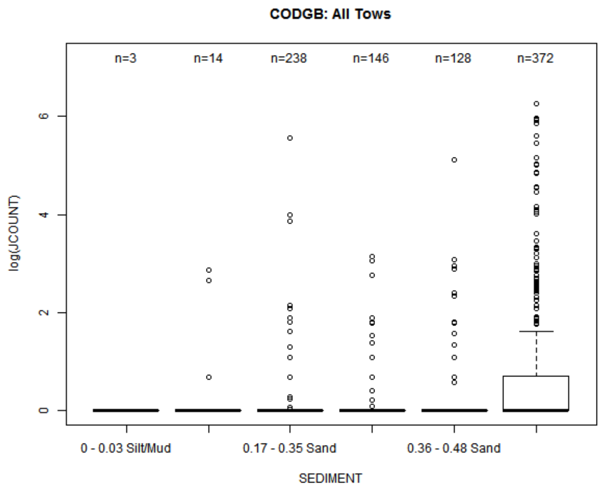

CODGB: Positive Tows
n=58
n=70
n=45
n=3
log(JCOUNT)
SD

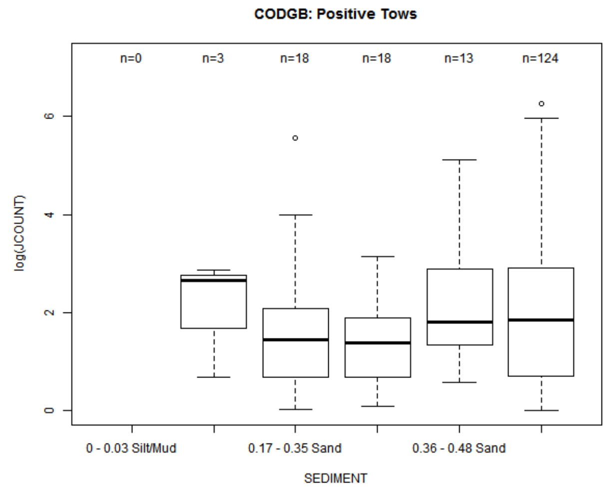

CODGB: All Tows
n=270
n=248
n=22
n=13
n=347
n=1
log(JCOUNT)
Depression
High Flat
High Slope
Low Slope
Mid Flat
Side Slope
SEABEDFORM

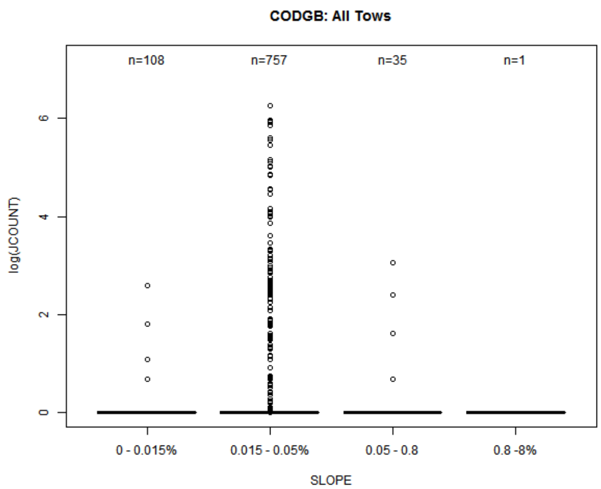

CODGB: Positive Tows
n=53
n=79
n=4
n=0
n=40
n=0
log(JCOUNT)
Depression
High Flat
High Slope
Low Slope
Mid Flat
Side Slope
SEABEDFORM

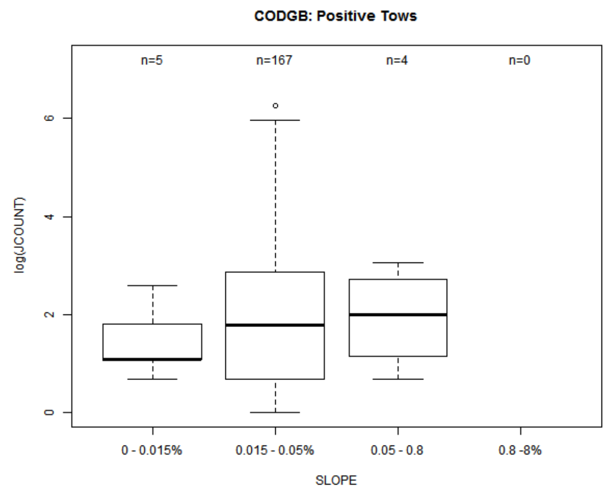

CODGB: All Tows
n=402
n=499
log(JCOUNT)
FALL
SPRING
SEASON

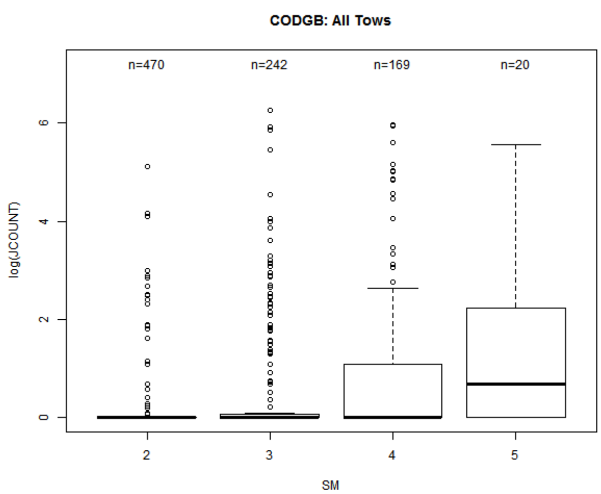

CODGB: Positive Tows
n=57
n=119
n=0
log(JCOUNT)
FALL
SPRING
WINTER
SEASON

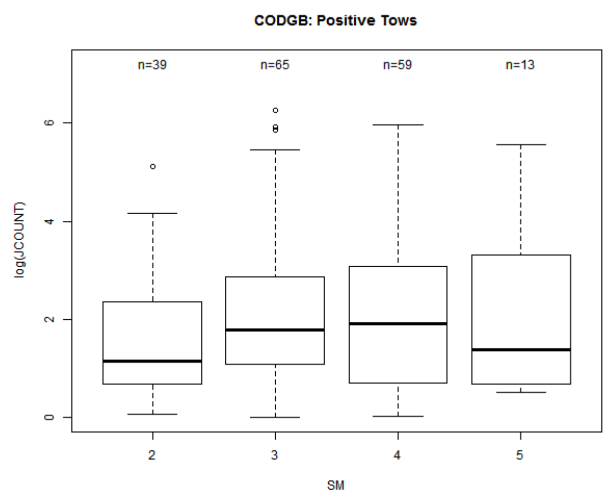

CODGB: All Tows
n=3
n=14
n=238
n=146
n=128
n=372
log(JCOUNT)
0 - 0.03 Silt/Mud
0.17 - 0.35 Sand
0.36 - 0.48 Sand
SEDIMENT

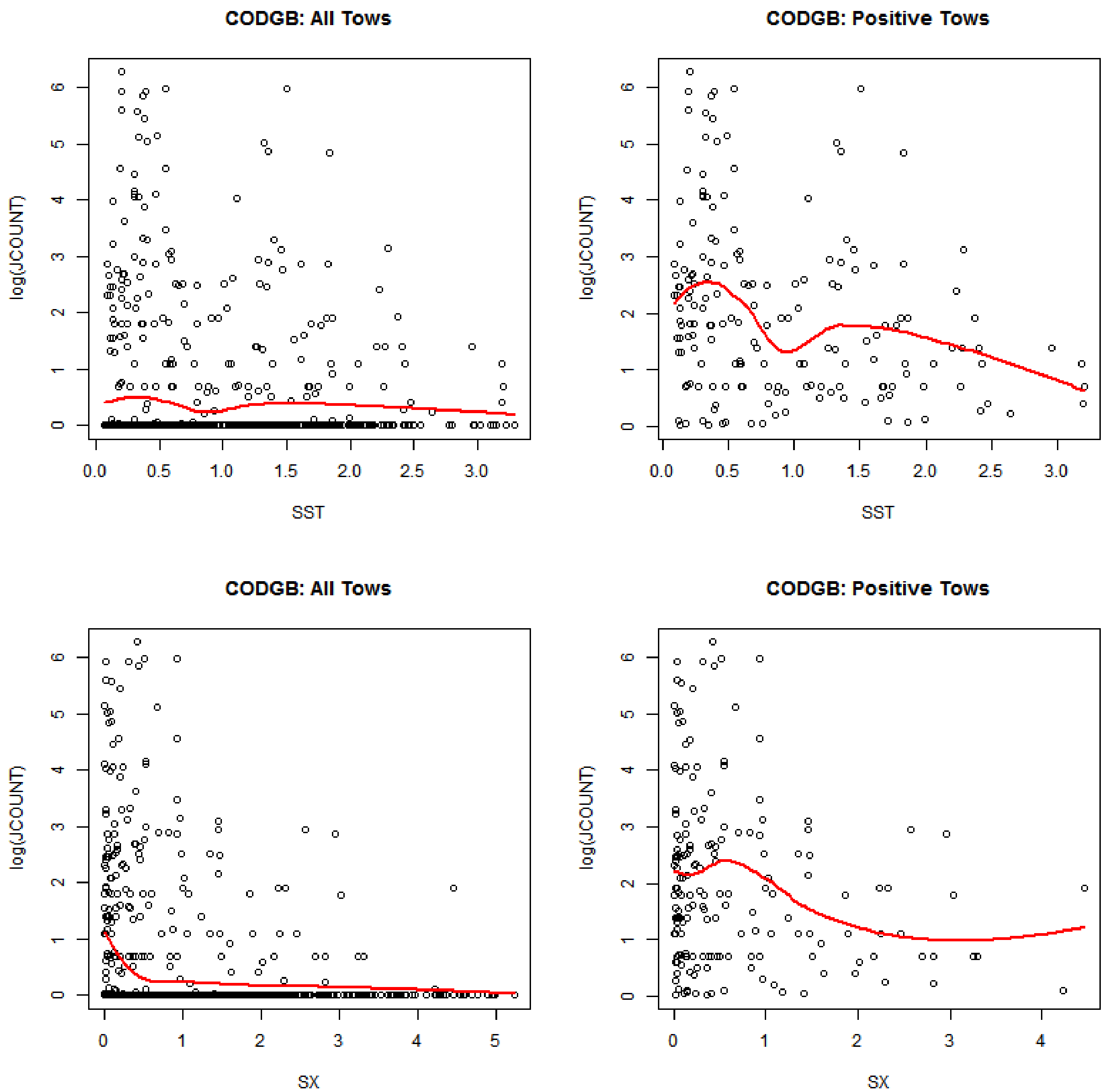

CODGB: Positive Tows
n=0
n=3
n=18
n=18
n=13
n=124
log(JCOUNT)
0 - 0.03 Silt/Mud
0.17 - 0.35 Sand
0.36 - 0.48 Sand
SEDIMENT

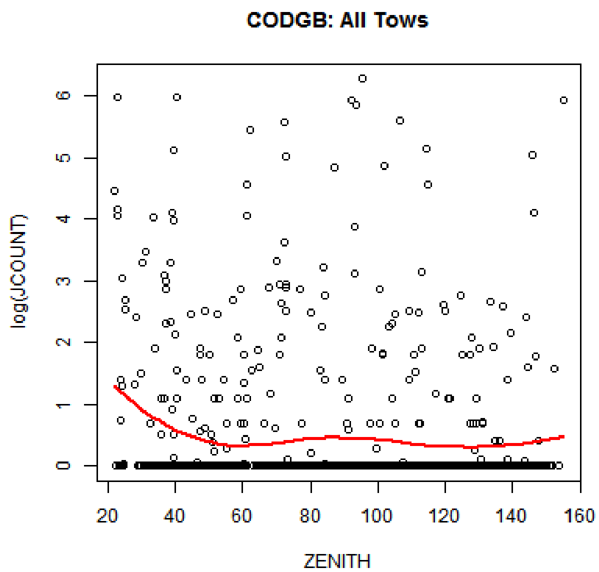

CODGB: All Tows
n=108
n=757
n=35
n=1
log(JCOUNT)
0 - 0.015%
0.015 - 0.05%
0.05 - 0.8
0.8 -8%
SLOPE


CODGB: Positive Tows
n=5
n=167
n=4
n=0
log(JCOUNT)
0 - 0.015%
0.015 - 0.05%
0.05 - 0.8
0.8 -8%
SLOPE

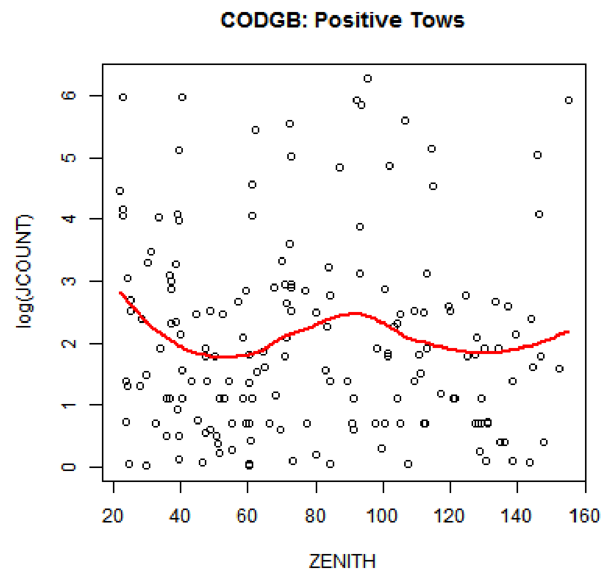

CODGB: All Tows
n=470
n=242
n=169
n=20
log(JCOUNT)
SM


CODGB: Positive Tows
n=39
n=65
n=59
n=13
log(JCOUNT)
SM


CODGB: All Tows
CODGB: Positive Tows
CODGB: All Tows
CODGB: Positive Tows
log(JCOUNT)
SST
SX
0
1
2
3
4
5
6
0.0
0.5
1.0
1.5
2.0
2.5
3.0

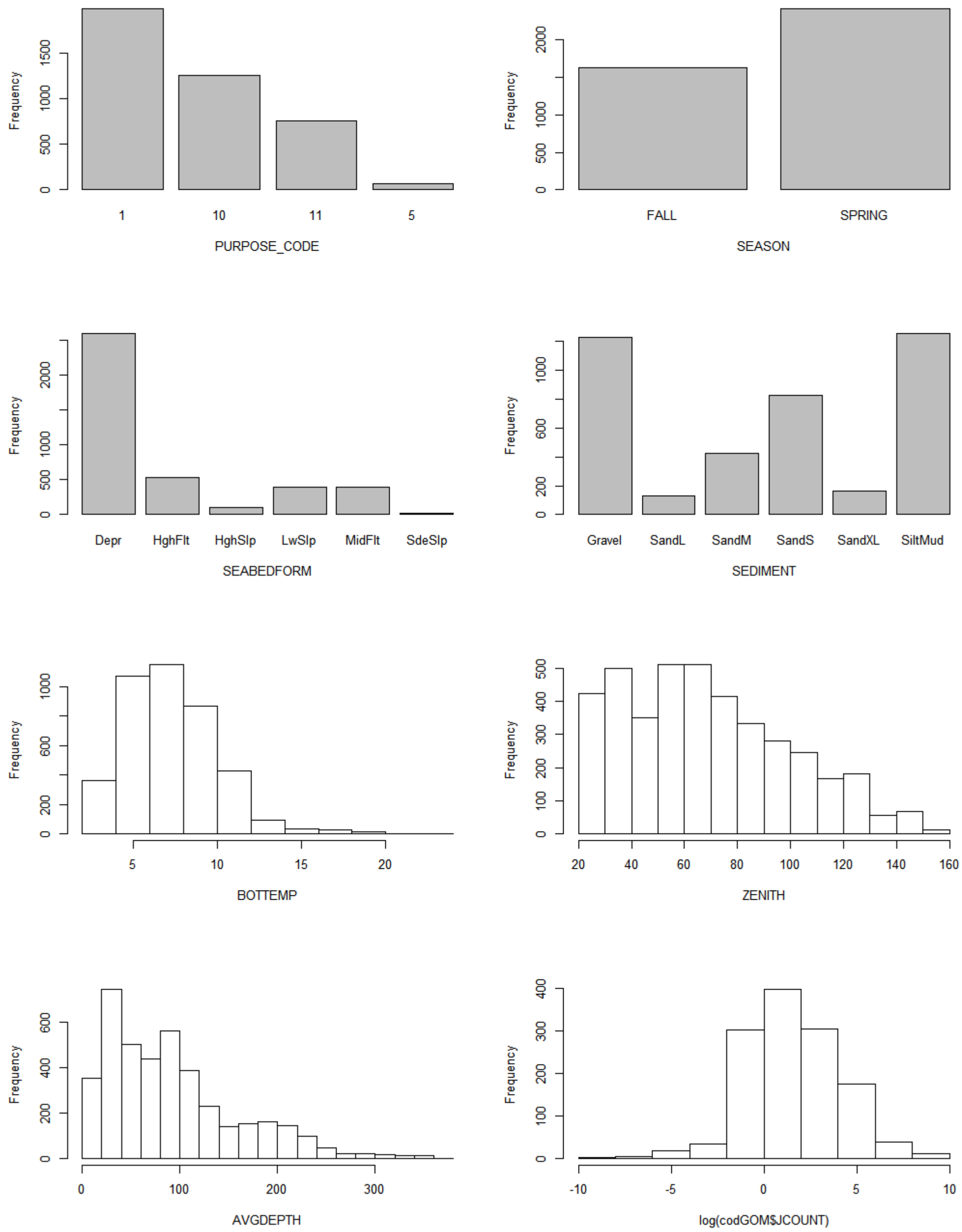


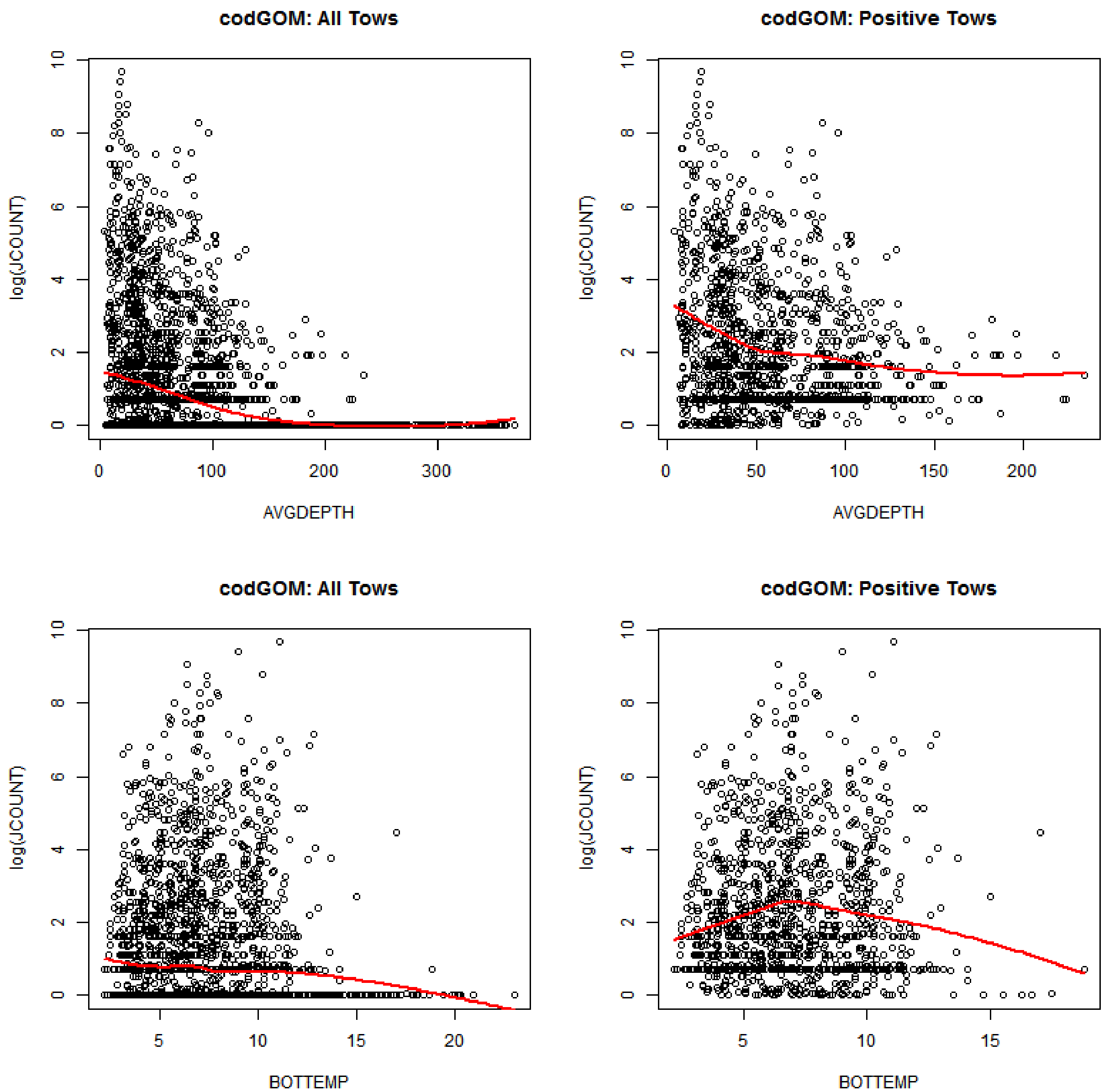
CODGB: All Tows
log(JCOUNT)
ZENITH
0
1
2
3
4
5
6
20
40
60
80
100
120
140
160

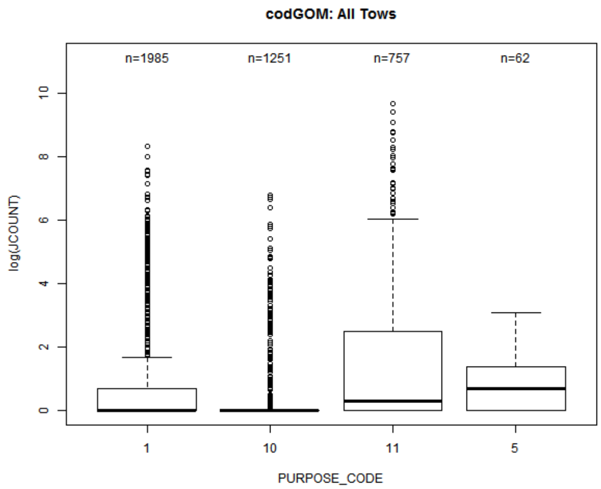


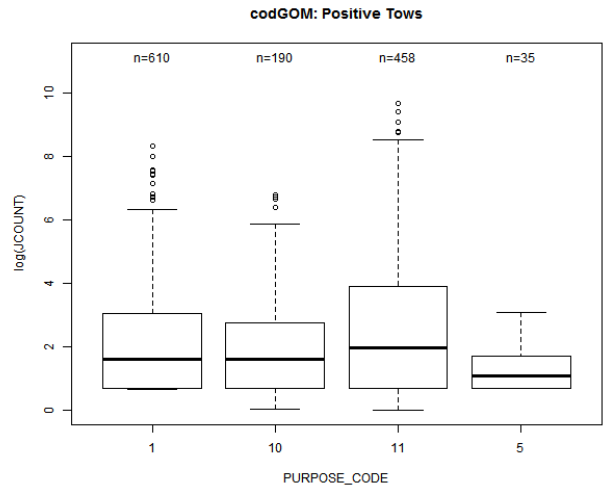
CODGB: Positive Tows
log(JCOUNT)
ZENITH
0
1
2
3
4
5
6
20
40
60
80
100
120
140
160

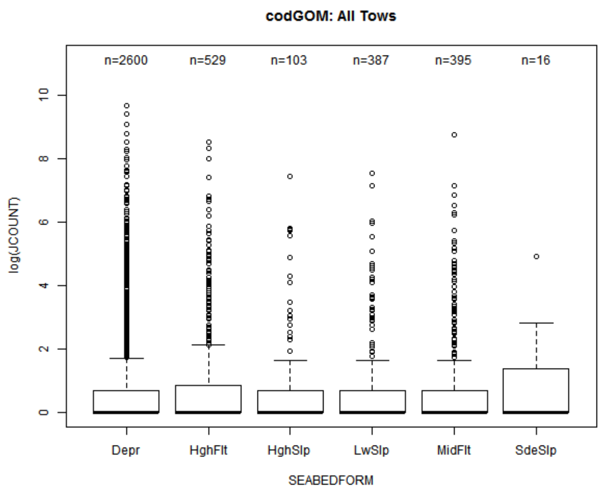
APPENDIX 4: Premodeling Gulf of Maine cod analysis

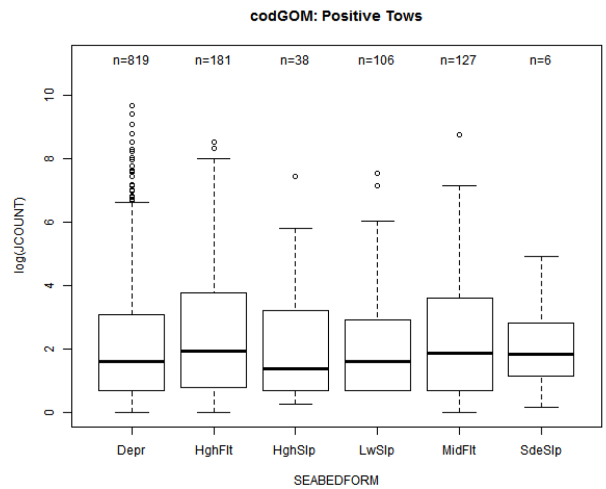


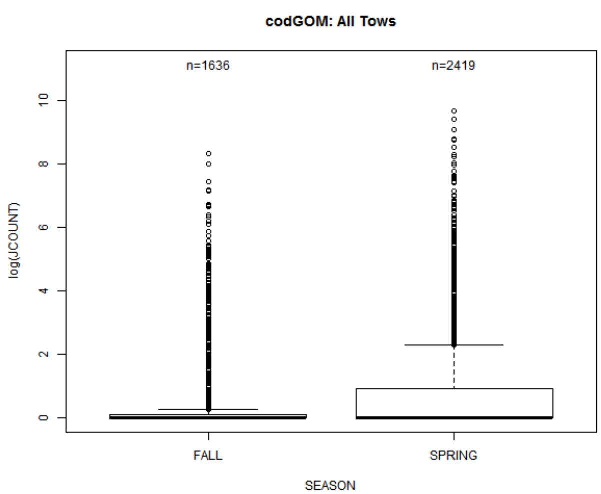

codGOM: All Tows
codGOM: Positive Tows
log(JCOUNT)
AVGDEPTH
0
2
4
6
8
10
0
100
200
300
0
50
100
150
200
codGOM: All Tows
codGOM: Positive Tows
log(JCOUNT)
BOTTEMP
5
10
15
20

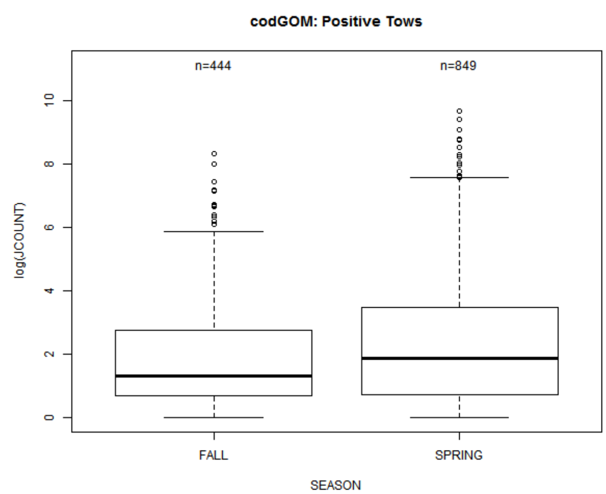

codGOM: All Tows
n=1985
n=1251
n=757
n=62
log(JCOUNT)
0
2
4
6
8
10
1
10
11
5
PURPOSE_CODE

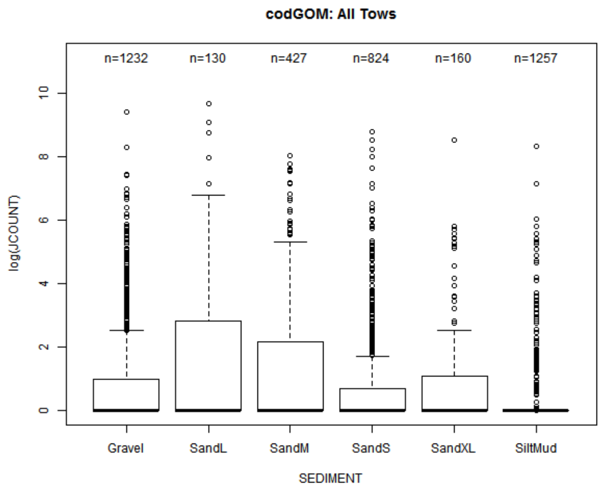

codGOM: Positive Tows
n=610
n=190
n=458
n=35
log(JCOUNT)
0
2
4
6
8
10
1
10
11
5
PURPOSE_CODE

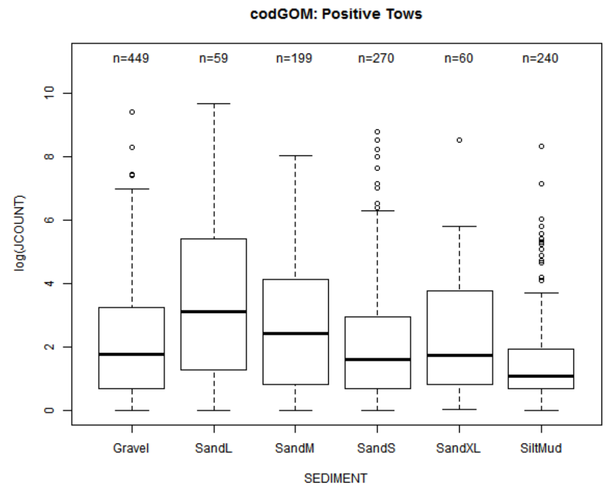

codGOM: All Tows
n=2600
n=529
n=103
n=387
n=395
n=16
log(JCOUNT)
0
2
4
6
8
10
Depr
HghFlt
HghSlp
LwSlp
MidFlt
SdeSlp
SEABEDFORM

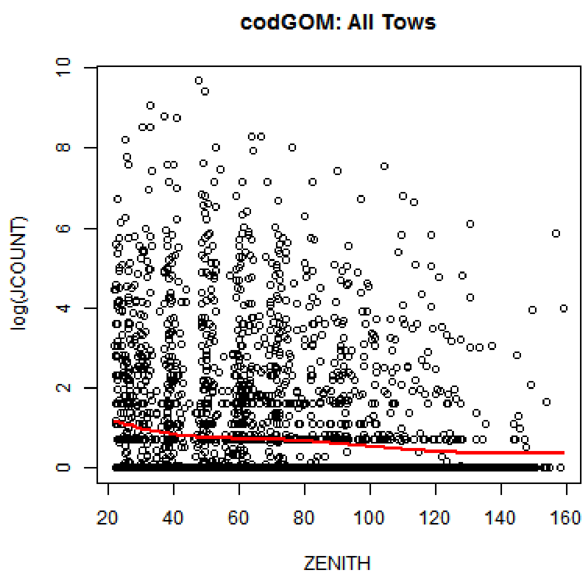

codGOM: Positive Tows
n=819
n=181
n=38
n=106
n=127
n=6
log(JCOUNT)
0
2
4
6
8
10
Depr
HghFlt
HghSlp
LwSlp
MidFlt
SdeSlp
SEABEDFORM

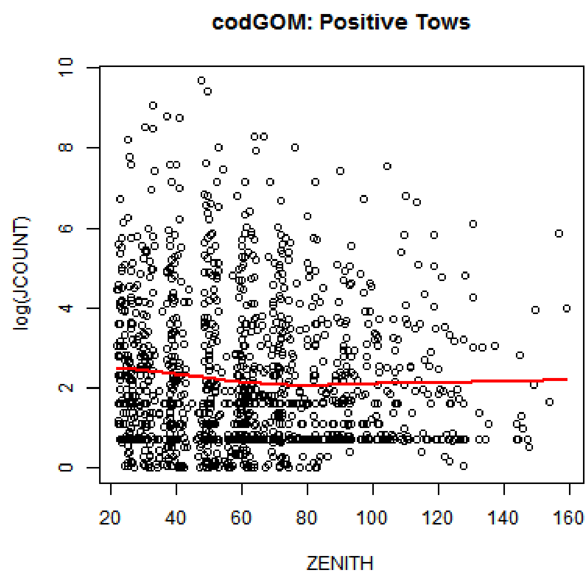

codGOM: All Tows
n=1636
n=2419
log(JCOUNT)
0
2
4
6
8
10
FALL
SPRING
SEASON


codGOM: Positive Tows
n=444
n=849
log(JCOUNT)
0
2
4
6
8
10
FALL
SPRING
SEASON

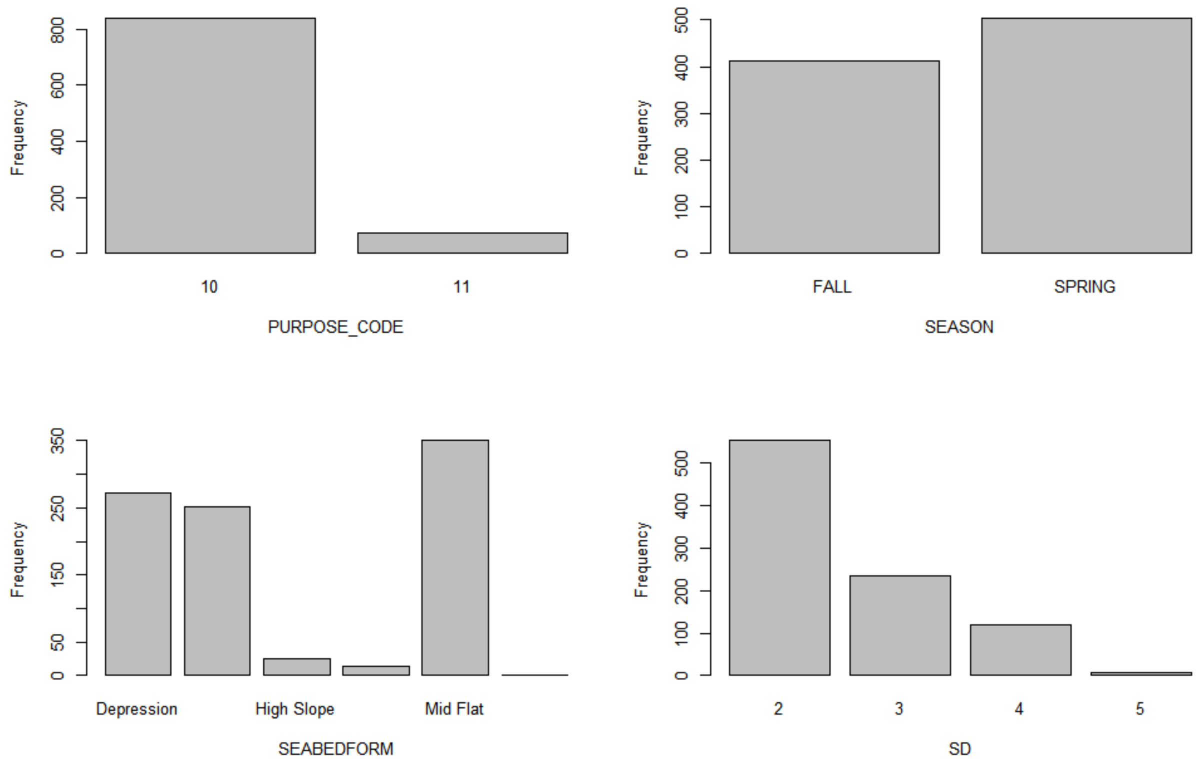

codGOM: All Tows
n=1232
n=130
n=427
n=824
n=160
n=1257
log(JCOUNT)
Gravel
SandL
SandM
SandS
SandXL
SiltMud
SEDIMENT

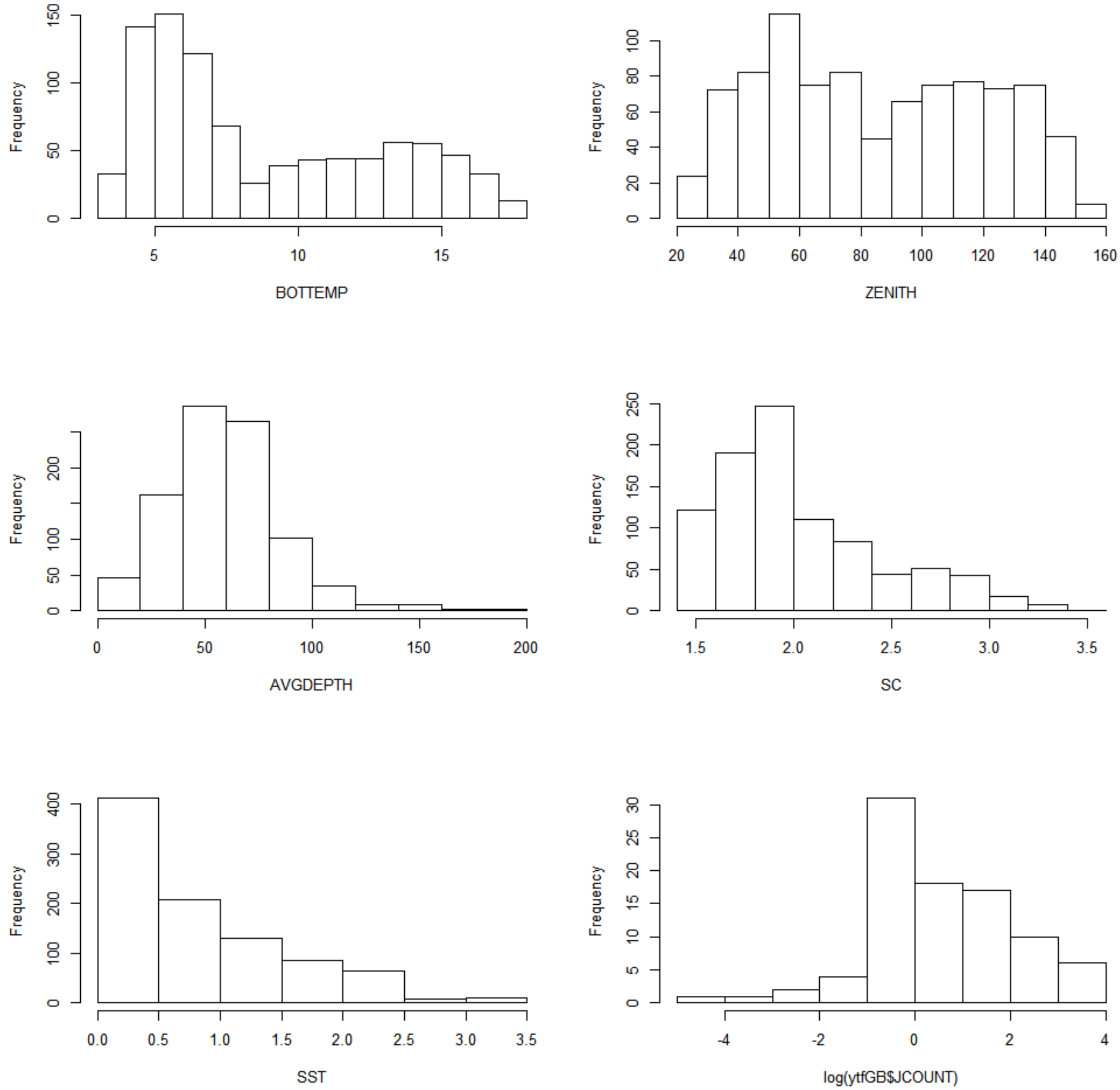

codGOM: Positive Tows
n=449
n=59
n=199
n=270
n=60
n=240
log(JCOUNT)
Gravel
SandL
SandM
SandS
SandXL
SiltMud
SEDIMENT


codGOM: All Tows
log(JCOUNT)
ZENITH

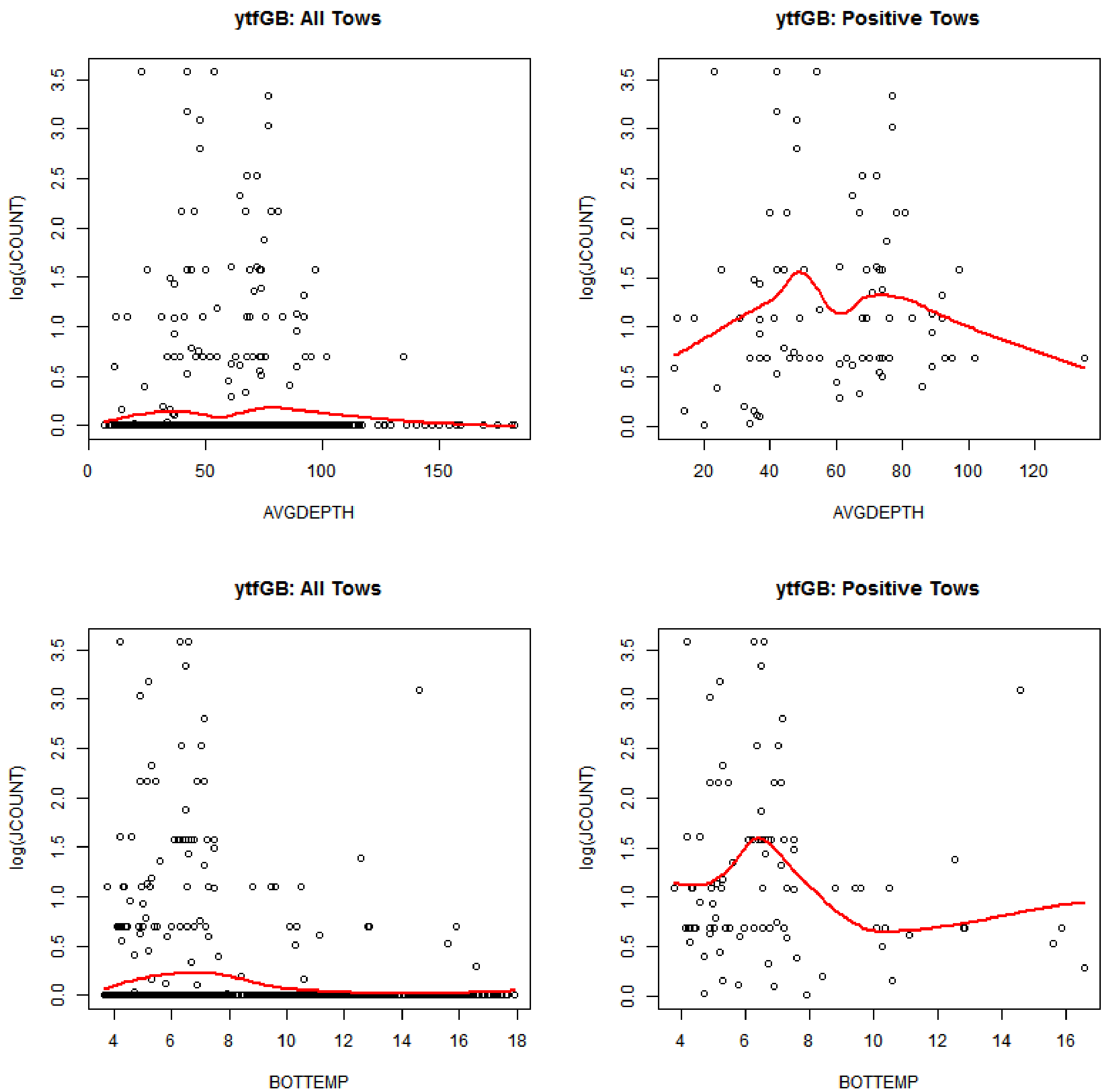

codGOM: Positive Tows
log(JCOUNT)
ZENITH

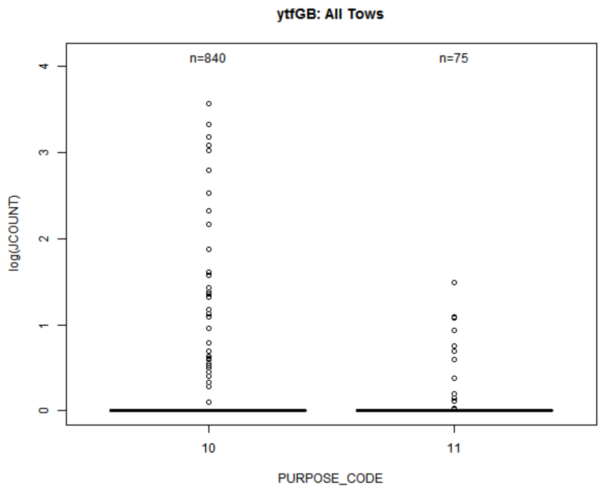
APPENDIX 5: Premodeling Georges Bank yellowtail flounder analysis

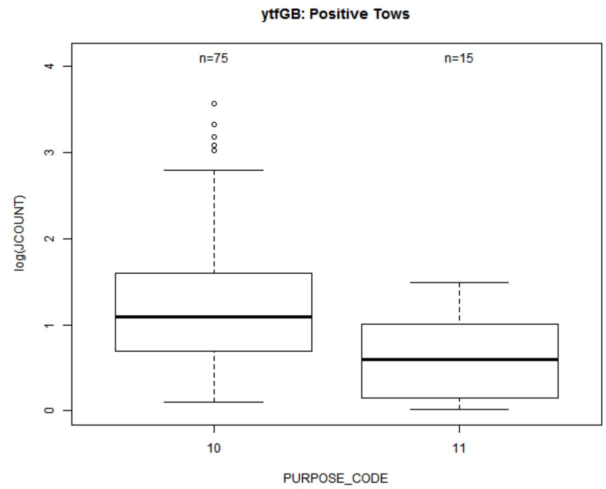


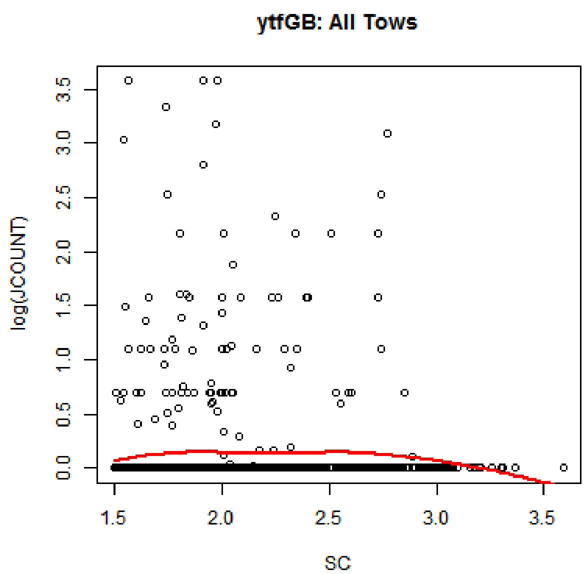


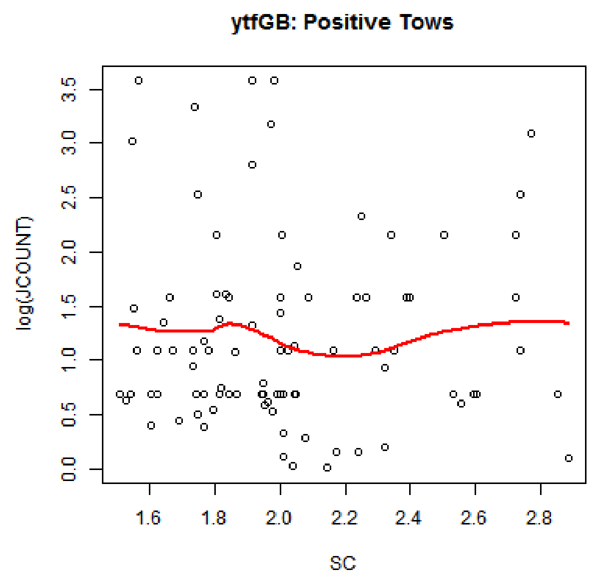
Frequency
BOTTEMP
Frequency
ZENITH
Frequency
AVGDEPTH
Frequency
SC
Frequency
SST
Frequency
log(ytfGB$JCOUNT)

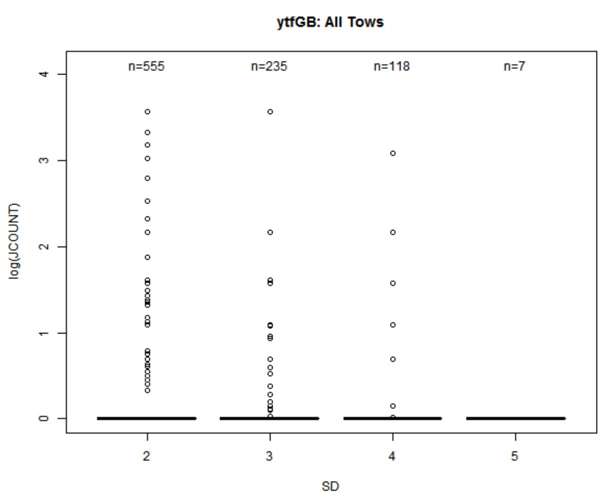

ytfGB: All Tows
log(JCOUNT)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
50
100
150
AVGDEPTH
ytfGB: Positive Tows
log(JCOUNT)
20
40
60
80
100
120
AVGDEPTH
ytfGB: All Tows
log(JCOUNT)
4
6
8
10
12
14
16
18
BOTTEMP
ytfGB: Positive Tows
log(JCOUNT)
4
6
8
10
12
14
16
BOTTEMP

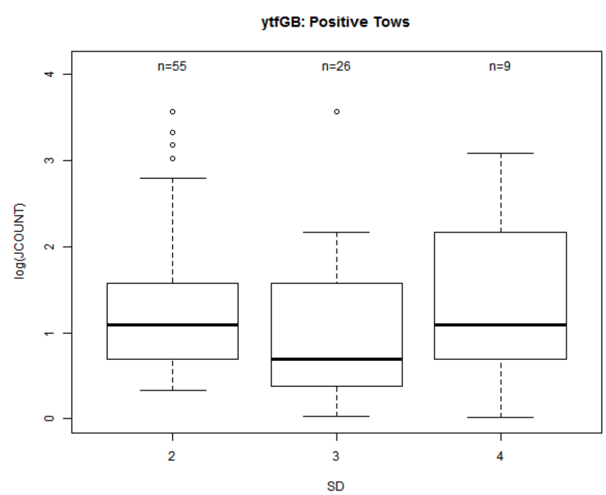

ytfGB: All Tows
n=840
n=75
log(JCOUNT)
PURPOSE_CODE

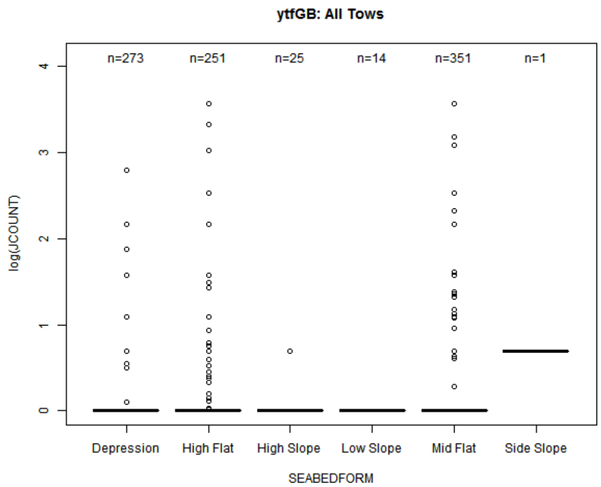

ytfGB: Positive Tows
n=75
n=15
log(JCOUNT)
PURPOSE_CODE

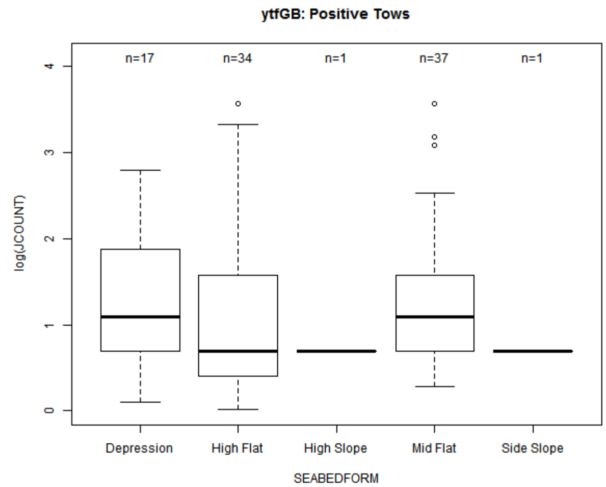

ytfGB: All Tows
log(JCOUNT)
SC

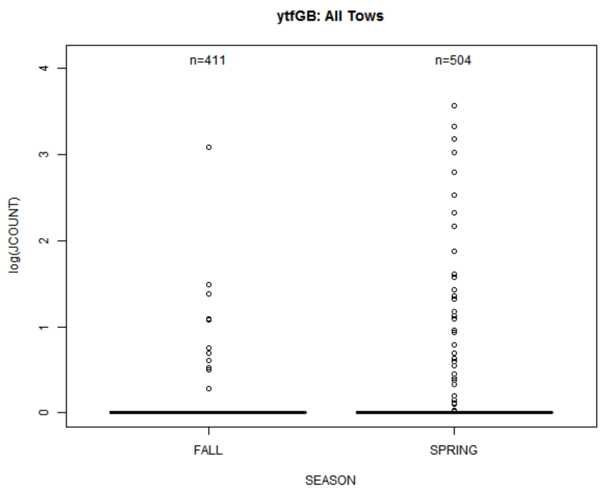

ytfGB: Positive Tows
log(JCOUNT)
SC

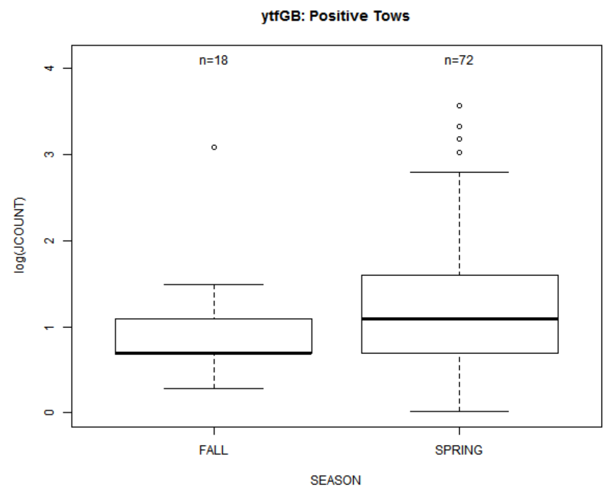

ytfGB: All Tows
n=555
n=235
n=118
n=7
log(JCOUNT)
SD

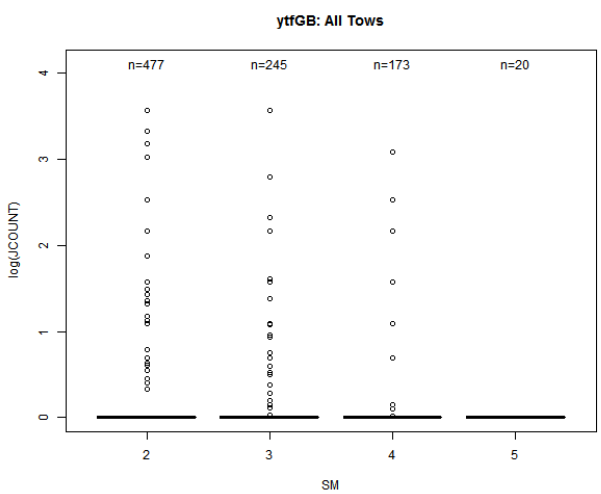

ytfGB: Positive Tows
n=55
n=26
n=9
log(JCOUNT)
SD

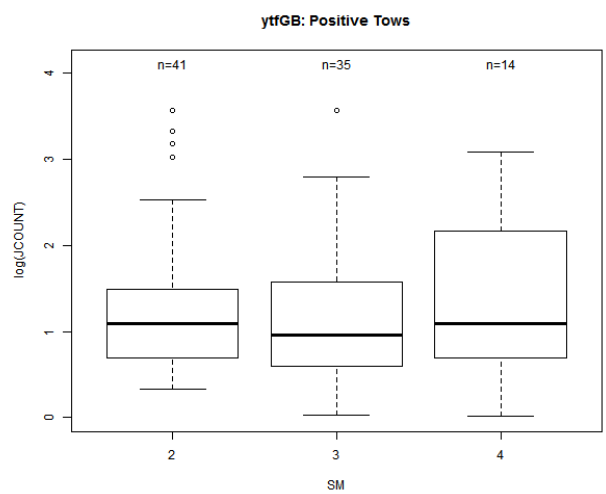

ytfGB: All Tows
n=273
n=251
n=25
n=14
n=351
n=1
log(JCOUNT)
0
1
2
3
4
Depression
High Flat
High Slope
Low Slope
Mid Flat
Side Slope
SEABEDFORM

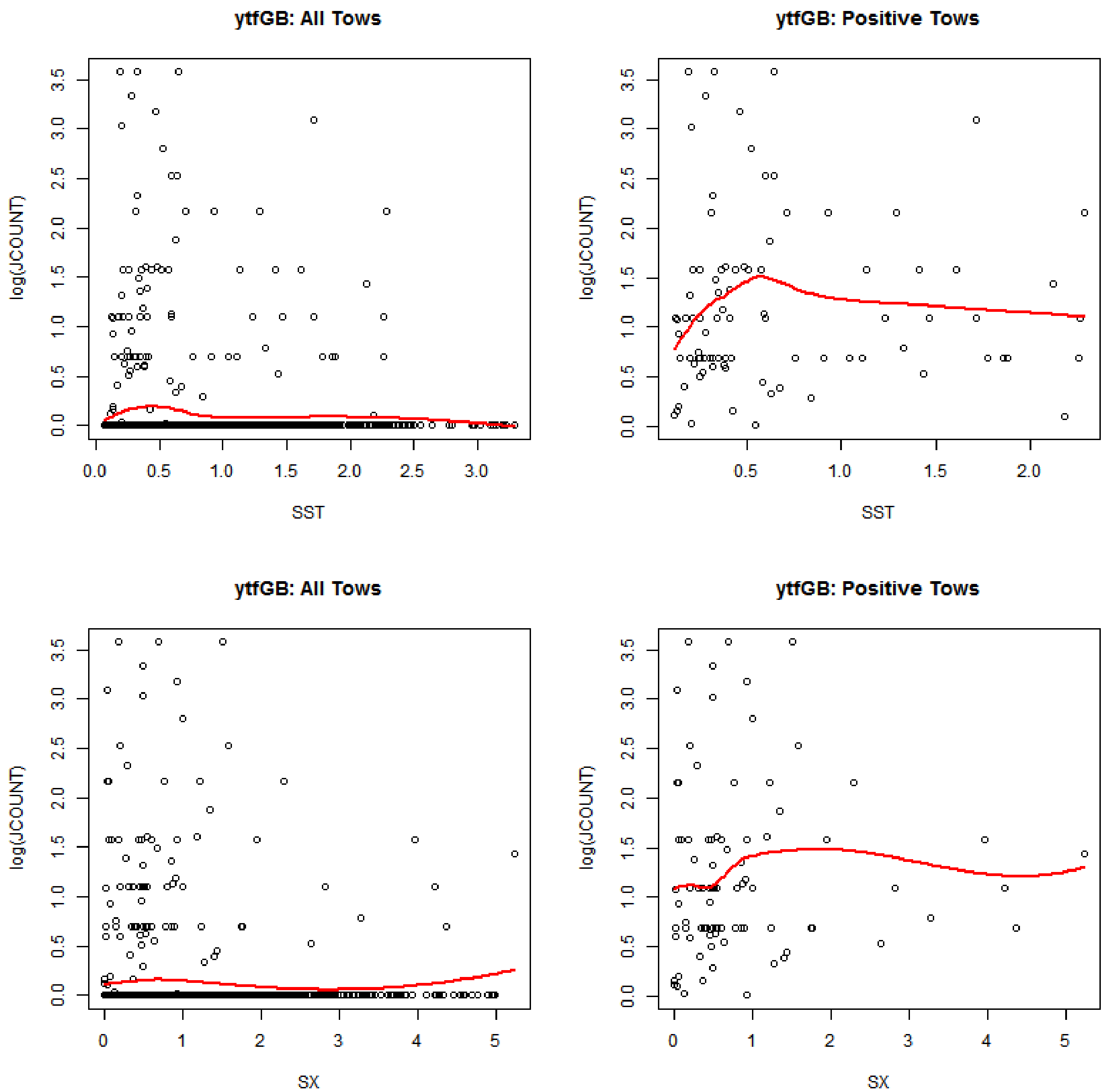

ytfGB: Positive Tows
n=17
n=34
n=1
n=37
n=1
log(JCOUNT)
0
1
2
3
4
Depression
High Flat
High Slope
Mid Flat
Side Slope
SEABEDFORM


ytfGB: All Tows
n=411
n=504
log(JCOUNT)
0
1
2
3
4
FALL
SPRING
SEASON

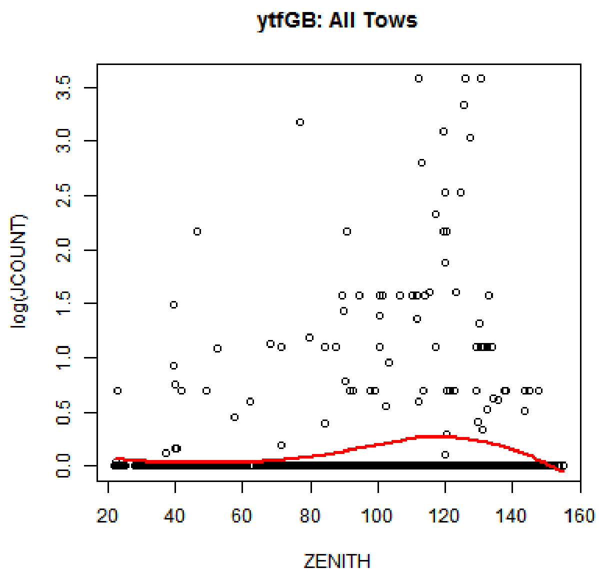

ytfGB: Positive Tows
n=18
n=72
log(JCOUNT)
0
1
2
3
4
FALL
SPRING
SEASON


ytfGB: All Tows
n=477
n=245
n=173
n=20
log(JCOUNT)
0
1
2
3
4
2
3
4
5
SM

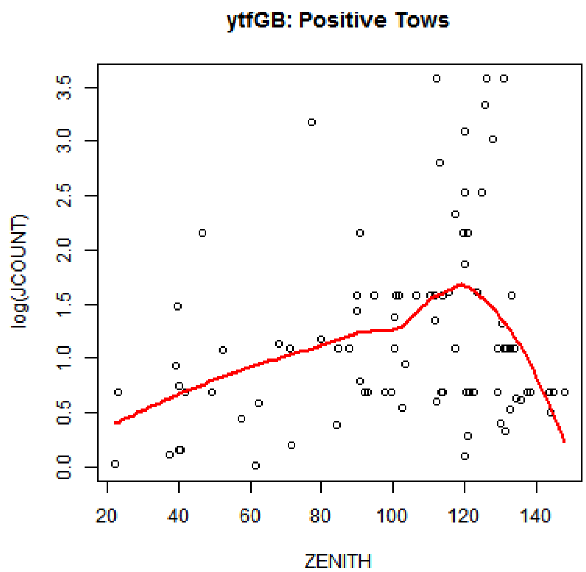

ytfGB: Positive Tows
n=41
n=35
n=14
log(JCOUNT)
0
1
2
3
4
2
3
4
SM



ytfGB: All Tows
ytfGB: Positive Tows
log(JCOUNT)
SST
ytfGB: All Tows
ytfGB: Positive Tows
log(JCOUNT)
SX



ytfGB: All Tows
log(JCOUNT)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
20
40
60
80
100
120
140
160
ZENITH



ytfGB: Positive Tows
log(JCOUNT)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
20
40
60
80
100
120
140
ZENITH

APPENDIX 5: R output for Generalized Additive Models

GB COD

Presence-absence:

```
Family: binomial
Link function: logit

Formula:
JPA ~ s(SC) + s(SST) + s(BOTTEMP) + s(ZENITH) + s(AVGDEPTH) +
    PURPOSE_CODE + SEASON
<environment: 0x000000000cfa3a40>

Parametric coefficients:
                Estimate Std. Error  z value   Pr(>|z|)
(Intercept)    -0.737896   0.252449 -2.92295  0.0034673 **
PURPOSE_CODE11  2.999776   0.555045  5.40457 6.4966e-08 ***
SEASONSPRING   -2.938084   0.479922 -6.12200 9.2409e-10 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                edf  Ref.df   Chi.sq    p-value
s(SC)       1.00003 1.00006 36.94210 1.2176e-09 ***
s(SST)      2.33007 2.94928  6.21400 0.09800112 .
s(BOTTEMP)  2.02435 2.55942 66.22891 6.9660e-14 ***
s(ZENITH)   1.00011 1.00021  4.48607 0.03418393 *
s(AVGDEPTH) 5.82263 6.90603 24.75804 0.00080294 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =   0.33   Deviance explained = 31.8%
UBRE score = -0.29305  Scale est. = 1         n = 901
```

Conditional presence:

```
Family: gaussian
Link function: identity

Formula:
LJCOUNT ~ s(SST) + PURPOSE_CODE + SEASON
<environment: 0x000000000d3f7218>

Parametric coefficients:
               Estimate Std. Error  t value   Pr(>|t|)
(Intercept)    1.634190   0.274850  5.94576 1.4956e-08 ***
PURPOSE_CODE11 0.420564   0.407628  1.03173    0.30365
SEASONSPRING  -0.310542   0.352346 -0.88135    0.37936
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
       edf Ref.df       F  p-value
s(SST)   1      1 4.96494 0.027137 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0448   Deviance explained = 6.11%
GCV score = 4.3217  Scale est. = 4.2235    n = 176
```

GOM COD

Presence-absence:

```
Family: binomial
Link function: logit

Formula:
JPA ~ SEDIMENT + SEABEDFORM + s(BOTTEMP) + s(AVGDEPTH) + PURPOSE_CODE +
    SEASON
<environment: 0x000000000d3a6100>

Parametric coefficients:
                   Estimate  Std. Error  z value   Pr(>|z|)
(Intercept)      -1.02655076 0.13251625 -7.74660 9.4384e-15 ***
SEDIMENTSandL    -0.33211052 0.22657209 -1.46581  0.1427014
SEDIMENTSandM     0.00755436 0.13386025  0.05643  0.9549955
SEDIMENTSandS    -0.28345951 0.10980305 -2.58153  0.0098364 **
SEDIMENTSandXL   -0.33175598 0.19585904 -1.69385  0.0902936 .
SEDIMENTSiltMud  -0.78397190 0.10351551 -7.57347 3.6338e-14 ***
SEABEDFORMHghFlt  0.70570896 0.12627017  5.58888 2.2854e-08 ***
SEABEDFORMHghSlp  0.54682707 0.23807505  2.29687  0.0216263 *
SEABEDFORMLwSlp   0.04026009 0.13453752  0.29925  0.7647508
SEABEDFORMMidFlt  0.20738550 0.13766122  1.50649  0.1319410
SEABEDFORMSdeSlp  0.10661293 0.64902397  0.16427  0.8695213
PURPOSE_CODE5     0.05166306 0.32139607  0.16075  0.8722936
PURPOSE_CODE10   -0.18276372 0.12173152 -1.50137  0.1332606
PURPOSE_CODE11    1.06381109 0.11463685  9.27984 < 2.22e-16 ***
SEASONSPRING     -0.22420977 0.14147846 -1.58476  0.1130203
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                edf  Ref.df   Chi.sq    p-value
s(BOTTEMP)  7.15089 8.02022  99.5606 < 2.22e-16 ***
s(AVGDEPTH) 2.99783 3.79881 154.6007 < 2.22e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.233   Deviance explained = 20.7%
UBRE score = 0.0031764  Scale est. = 1         n = 4030
```

Conditional presence:

```
Family: gaussian
Link function: identity

Formula:
LJCOUNT ~ SEDIMENT + s(BOTTEMP) + s(ZENITH) + s(AVGDEPTH) + PURPOSE_CODE +
    SEASON
<environment: 0x000000000c858308>

Parametric coefficients:
                 Estimate Std. Error  t value   Pr(>|t|)
(Intercept)      1.248910   0.191071  6.53637 9.1365e-11 ***
SEDIMENTSandL    0.784456   0.343634  2.28283  0.0226067 *
SEDIMENTSandM    0.381939   0.203525  1.87662  0.0608012 .
SEDIMENTSandS   -0.132415   0.182710 -0.72473  0.4687536
SEDIMENTSandXL   0.274475   0.320227  0.85713  0.3915384
SEDIMENTSiltMud -0.503095   0.192048 -2.61963  0.0089084 **
PURPOSE_CODE5   -0.566216   0.482631 -1.17319  0.2409434
PURPOSE_CODE10  -0.169725   0.214314 -0.79195  0.4285412
PURPOSE_CODE11  -0.710416   0.171520 -4.14188 3.6745e-05 ***
SEASONSPRING     1.201488   0.214426  5.60328 2.5816e-08 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
               edf  Ref.df        F    p-value
s(BOTTEMP)  6.94784 8.01288  6.29133 5.0284e-08 ***
s(ZENITH)   1.10171 1.19648  2.60141   0.097887 .
s(AVGDEPTH) 1.00000 1.00000 15.67671 7.9248e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
R-sq.(adj) =    0.1   Deviance explained = 11.3%
GCV score = 5.3659  Scale est. = 5.2859    n = 1277
```

GB YELLOWTAIL FLOUNDER

Presence-absence:

```
Family: binomial
Link function: logit

Formula:
JPA ~ SEABEDFORM + s(SC) + s(ZENITH) + s(AVGDEPTH) + PURPOSE_CODE +
    SEASON
<environment: 0x000000000c45d8e0>

Parametric coefficients:
                         Estimate   Std. Error  z value   Pr(>|z|)
(Intercept)           -4.69930e+00 4.32743e-01 -10.85934 < 2.22e-16 ***
SEABEDFORMHigh Flat    8.47769e-01 3.58846e-01   2.36249   0.018153 *
SEABEDFORMHigh Slope   1.13286e-01 1.11495e+00   0.10161   0.919070
SEABEDFORMLow Slope   -1.29852e+02 1.79356e+07  -0.00001   0.999994
SEABEDFORMMid Flat     5.44139e-01 3.39981e-01   1.60050   0.109488
SEABEDFORMSide Slope   1.45514e+02 6.71089e+07   0.00000   0.999998
PURPOSE_CODE11         3.44180e+00 6.54014e-01   5.26258 1.4205e-07 ***
SEASONSPRING           1.57767e+00 3.07405e-01   5.13223 2.8633e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                edf  Ref.df   Chi.sq    p-value
s(SC)       2.20239 2.76797  6.89979   0.063309 .
s(ZENITH)   2.54518 3.21132 44.74094 2.2056e-09 ***
s(AVGDEPTH) 4.32232 5.18676 11.78614   0.042646 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.151   Deviance explained = 23.3%
UBRE score = -0.46944  Scale est. = 1         n = 915
```

Conditional presence:

```
Family: gaussian
Link function: identity

Formula:
LJCOUNT ~ s(SC) + s(BOTTEMP) + s(AVGDEPTH) + PURPOSE_CODE + SEASON
<environment: 0x000000000bd95f58>

Parametric coefficients:
                Estimate Std. Error  t value   Pr(>|t|)
(Intercept)     1.541077   0.455266  3.38500  0.0011424 **
PURPOSE_CODE11 -2.700304   0.430554 -6.27169 2.1756e-08 ***
SEASONSPRING   -0.625619   0.530054 -1.18029  0.2416687
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                edf  Ref.df       F   p-value
s(SC)       8.39251 8.89552 3.44734 0.0013499 **
s(BOTTEMP)  3.71048 4.56325 2.68667 0.0317813 *
s(AVGDEPTH) 1.00000 1.00000 7.98539 0.0060276 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.432   Deviance explained = 52.9%
GCV score = 1.4111  Scale est. = 1.1586    n = 90
```