New England Fishery Management Council
50 WATER STREET | NEWBURYPORT, MASSACHUSETTS 01950 | PHONE 978 465 0492 | FAX 978 465 3116
John Pappalardo, *Chairman* | Paul J. Howard, *Executive Director*

ESSENTIAL FISH HABITAT (EFH) OMNIBUS AMENDMENT

"THE SWEPT AREA SEABED IMPACT (SASI) MODEL: A TOOL FOR ANALYZING THE EFFECTS OF FISHING ON ESSENTIAL FISH HABITAT"

Part 2: Spatial Components

DRAFT

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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.

Michelle Bachman, NEFMC staff*
Peter Auster, University of Connecticut
Chad Demarest, NOAA/Northeast Fisheries Science Center
Steve Eayrs, Gulf of Maine Research Institute
Kathryn Ford, Massachusetts Division of Marine Fisheries
Jon Grabowski, Gulf of Maine Research Institute
Brad Harris, University of Massachusetts School of Marine Science and Technology
Tom Hoff, Mid-Atlantic Fishery Management Council
Mark Lazzari, Maine Department of Marine Resources
Vincent Malkoski, Massachusetts Division of Marine Fisheries
Dave Packer, NOAA/ Northeast Fisheries Science Center
David Stevenson, NOAA/Northeast Regional Office
Page Valentine, U.S. Geological Survey

*Please forward any comments or suggestions to mbachman@nefmc.org

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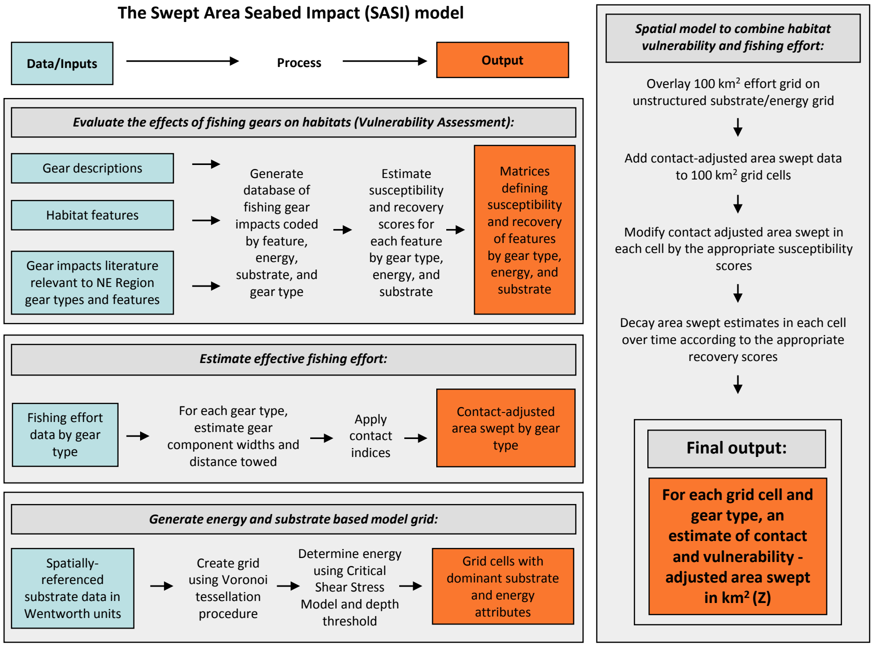
1.0 Overview of the Swept Area Seabed Impact model

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. The SASI model was developed by the New England Fishery Management Council's (NEFMC) Habitat Plan Development Team (PDT).

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 model components, including area swept, the various grids, and habitat feature vulnerability, are combined as described in Figure 1.

Figure 1 – SASI model flowchart



This document (SASI Document 2) contains the following:

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 4.0), which summarizes how fishing effort data is converted to area swept. The annual area of seabed swept for each gear type was used as the starting point for estimating the adverse effects from fishing. To generate these estimates, for each of the gear types, gear dimensions were estimated and a linear effective width was calculated for each gear component individually and for the gear as a whole. This linear effective width was then 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 were used to convert nominal area swept to contact-adjusted area swept (denoted as A). In practice, these contact adjustments were applied to trawl gears only, as all the components of all other gears were assumed to have full contact with the seabed. Area swept was calculated individually for each tow, and the resulting contact-adjusted area swept values were then summed by trip, year, gear type, etc. The details of the assumptions used in these calculations are explained in section 4.0.

Defining habitats spatially/model grid (section 5.0), which describes the substrate and energy layers used in the model. Two classes of data, substrate and energy environment, were used to define habitats. These combine to form the underlying surface onto which gear-specific habitat vulnerability information and contact-adjusted area-swept data were added.

Two data sources were 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 were classed by particle size using the Wentworth scale for five substrate classes: mud, sand, granule/pebble, cobble, and boulder. The raw substrate data were 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 was 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 was overlaid on the unstructured grid, and the substrate composition of each 100 km^2 grid cell was calculated based on the size of the unstructured cells contained within each of the 100 km^2 grid cells.

Geological and biological seabed features were 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 were coded as described in the part 1 document.

Applying susceptibility and recovery scores to fishing effort (section 6.0), which describes how fishing effort data is 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, or the realized area swept estimated from fishery-dependant data. 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. The model methods and results are discussed in section 6.0

Application of results to fishery management decision making (section 7.0), which describes the assumptions and limitations of the model, and its potential applications to fishery management.

Another document (SASI Document 1) contains the literature review and Vulnerability Assessment.

2.0 SASI model equations

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.

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 was 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:

$$Z_{t+1} = Z_t \left[1 + \left(X_t - Y_t\right)\right], \qquad \textbf{(4)}$$

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:

$$X_t = \frac{\left\lfloor \lambda (\mathrm{A}\omega)_{t_0} \right\rfloor \Delta t}{Z_t}. \qquad \textbf{(5)}$$

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 decomposed into:

$$A = (w\chi)d\ , \qquad \textbf{(2)}$$

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*:

$$Y_t = \frac{(\mathrm{A}\omega)_t}{\mathrm{Z}_t}. \qquad \textbf{(6)}$$

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 27 individual habitat features (*m*) leaves us with:

$$Z_{t+1} = Z_t + \left[\sum_{i=1}^{9} \sum_{j=1}^{n} \sum_{k=1}^{5} \sum_{l=1}^{2} \sum_{m=1}^{27} \left[\left(\lambda \left(\mathrm{A}_{i,j} \omega_{k,l} \right)_{t_0} \Delta t \right) - \left(\mathrm{A}_{i,j} \omega_{k,l} \right)_t \right] \right]. \qquad \textbf{(7)}$$

3.0 Fishing gears evaluated

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 were evaluated.

Key fishing gears were 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 were summarized (Table 1, Table 2, Table 3, Table 5, Table 6, Table 7). 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 were not evaluated in the Vulnerability Assessment due to low or no bottom contact.

Table 8 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 were combined to create one Vulnerability Assessment category, while in other cases VTR gear types were disaggregated due to trip characteristics.

Table 1 – 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 2 – 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 3 – 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 4 – 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 5 – 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 6 – 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 7 - 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 8 – 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 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). Footropes range in length from 40-100 ft (12-30 m), but most are 50-90 ft (15-27 m). 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). Shrimp trawls use 12 in (30.5 cm) or greater rockhoppers, and 1 ¾ and 2 in mesh in the codend and the body of the net, respectively. 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·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 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 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 as described in section 6.0. The following sections describe the methods used to estimate area swept, including (1) models and assumptions, and (2) data and parameterization.

4.1 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.

4.1.1 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:

$$A_{trawl}(km^2) = d_t\left[\left(2 \cdot w_o \cdot c_o\right) + \left(2 \cdot w_c \cdot c_c\right) + \left(w_s \cdot c_s\right)\right]$$

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^o and 50^o (Gomez and Jimenez 1994). A value of 40° was used. 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^o and 20^o (Gomez and Jimenez 1994, Baranov 1969). A value of 15° was used. 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 2). The contact indices assumed for the various trawl types are shown in
Table 9.

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 2 – 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 the above table; the figure below is for illustrative purposes only.

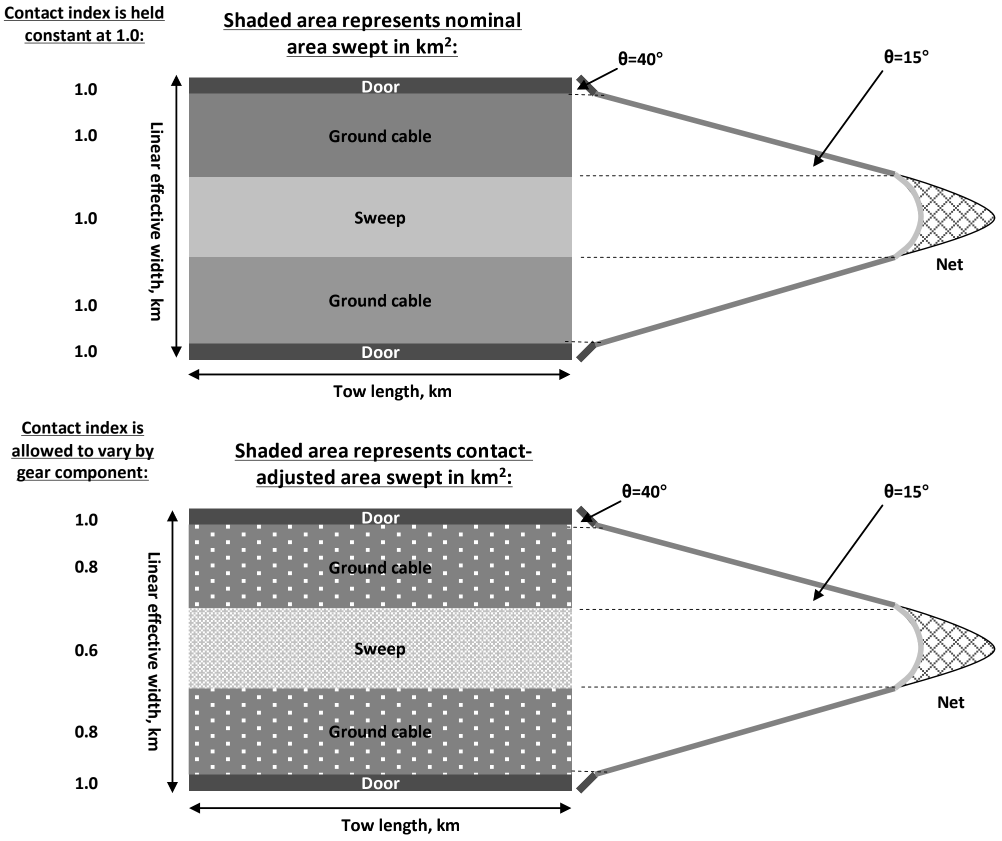


Table 9 - Contact indices for trawl gear components

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

4.1.2 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.

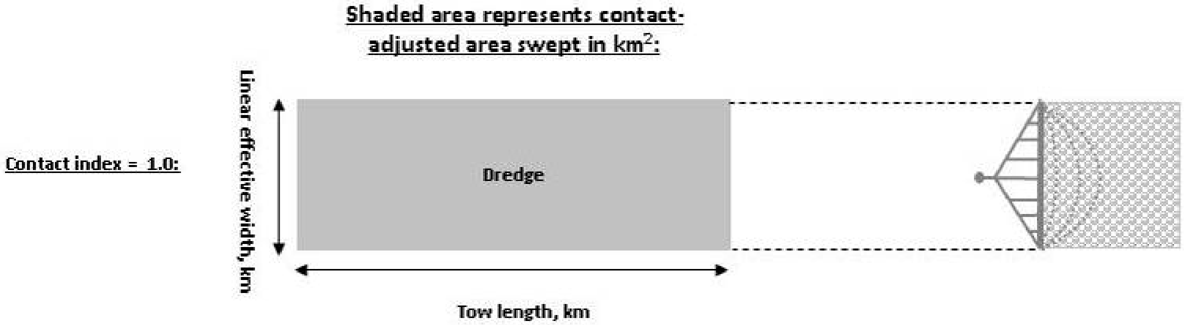
Given these simplifying assumptions, the scallop dredge SASI model is:

$$A_{scallop}(km^2) = d_t(w \cdot c)$$

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 3). The contact index is set to 1.0, which means that nominal area swept and contact-adjusted area swept are equal.

Figure 3 – 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

4.1.3 Hydraulic clam dredge

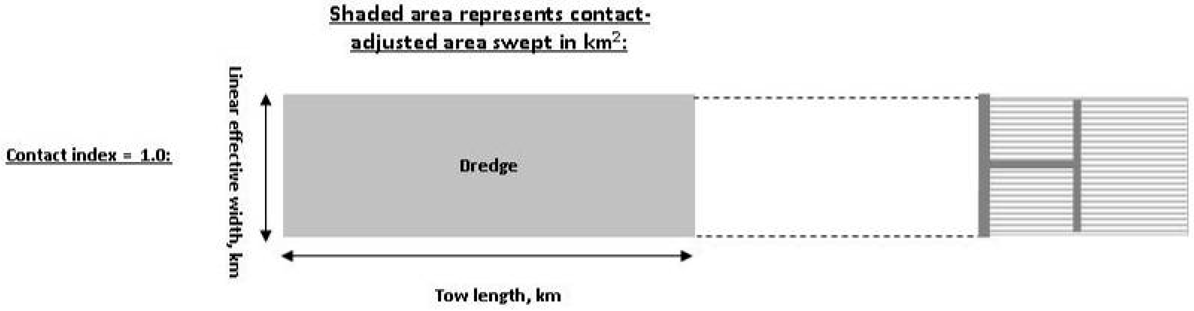
Similar to the scallop dredge model, the hydraulic clam dredge model shown below does not consider the potential impact of individual components of a dredge, but groups them together. The area swept model for hydraulic clam dredge is:

$$A_{hydraulic}(km^2) = d_t\left(w \cdot c\right)$$

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 4). The contact index was set to 1.0, which means that nominal area swept and contact-adjusted area swept are equal.

Figure 4 – 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

4.1.4 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.

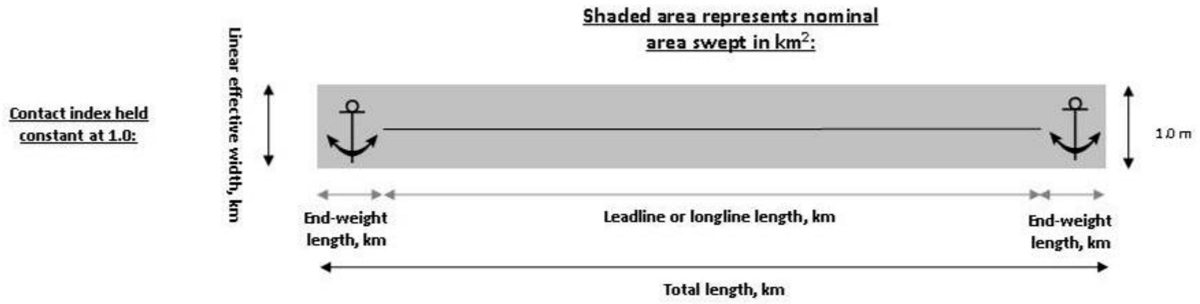
The area swept model for a demersal longline or gillnet is:

$$A_{longline/gillnet}(km^2) = 2(d_w \cdot l_w \cdot c_w) + (d_l \cdot l_l \cdot c_l)$$

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 was assumed to be one meter (i.e. d_w and d_l are specified as 0.001 km (1.0 m)), and was 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 5). Seabed contact is assumed to be 1.0 for all gear components.

Figure 5 – 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.



4.1.5 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:

$$A_{trap}(km^2) = \sum_{1}^{n}\left[d_{tn} \cdot l_{tn} \cdot c_{tn}\right] + \sum_{1}^{n-1}\left[d_{gn} \cdot l_{gn} \cdot c_{gn}\right]$$

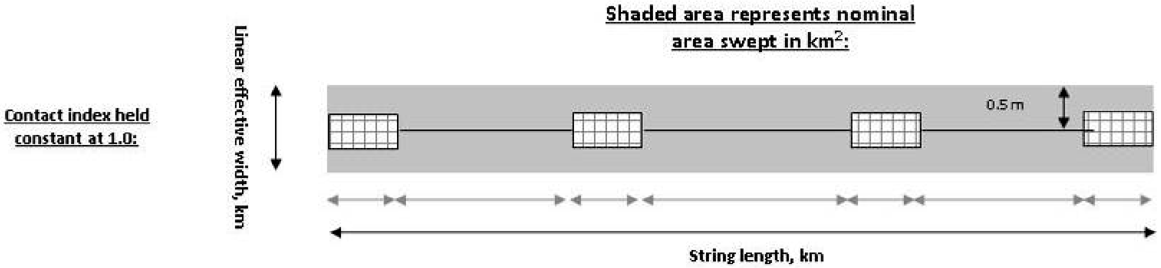
n = Number of traps
$n-1$ = Number of groundlines between traps
d_{tn} = lateral distance *n*th trap moves over the seabed (km)
l_{tn} = length of *n*th trap (km)
c_{tn} = contact index, *n*th trap
d_{gn} = lateral distance the *n*th ground line moves over the seabed (km)
l_{gn} = length of *n*th ground line (km)
c_{gn} = contact index, *n*th 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 were 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 6). The seabed contact index was assumed to be 1.0 for lines and traps.

Figure 6 – 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.



4.2 Data and parameterization

To be finalized.

5.0 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 were 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 were used to generate the model grid and energy was inferred from and oceanography model (flow) and a coastal relief model (depth).

5.1 Substrate data and unstructured grid

A geological substrate-based grid was 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 was used to represent the substrate class occurring at that particular X,Y location. Dominant substrate type was defined as the substrate type composing the largest fraction of each sample. Dominance was 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 were 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.

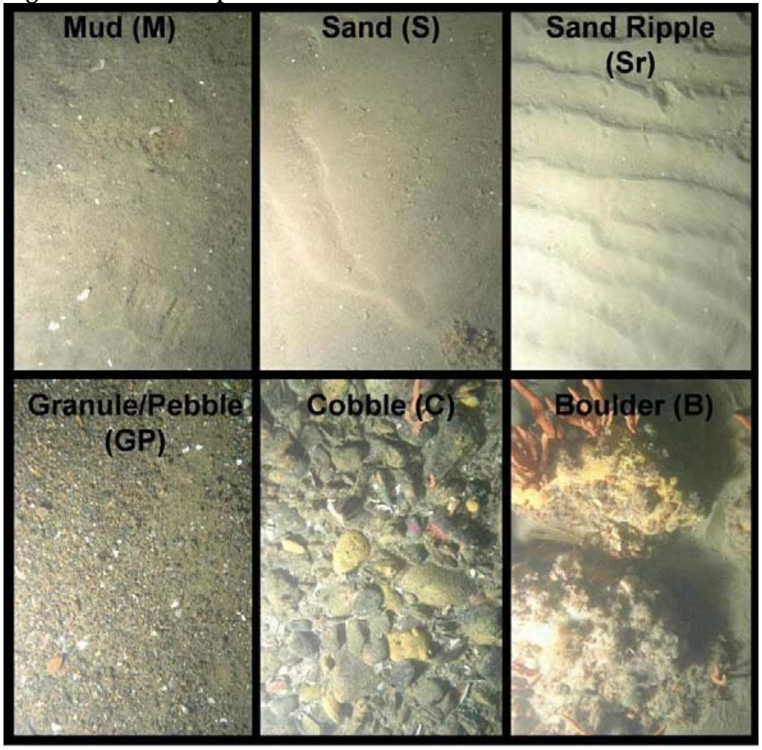
The advantage of this type of base grid is that the resulting unsmoothed surface consists of cells that maintain the spatial characteristics of their source data. For example, the sampling information associated with each data point remains accessible and where geological sampling is spare, the polygons 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 were organized into five classes according to particle size: mud, sand/sand ripple, granule-pebble, cobble, and boulder (Table 10, Figure 7, Wentworth 1922). Substrate data were 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 were 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 were 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 10 – 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 7 – 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) was 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 was 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.

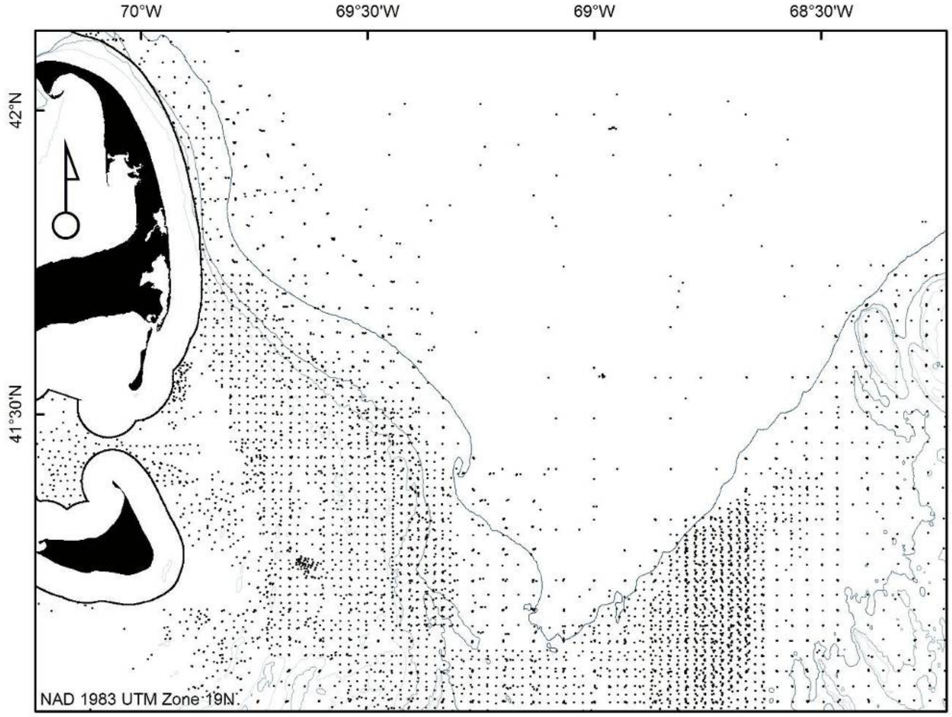
Limitations:

- 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.

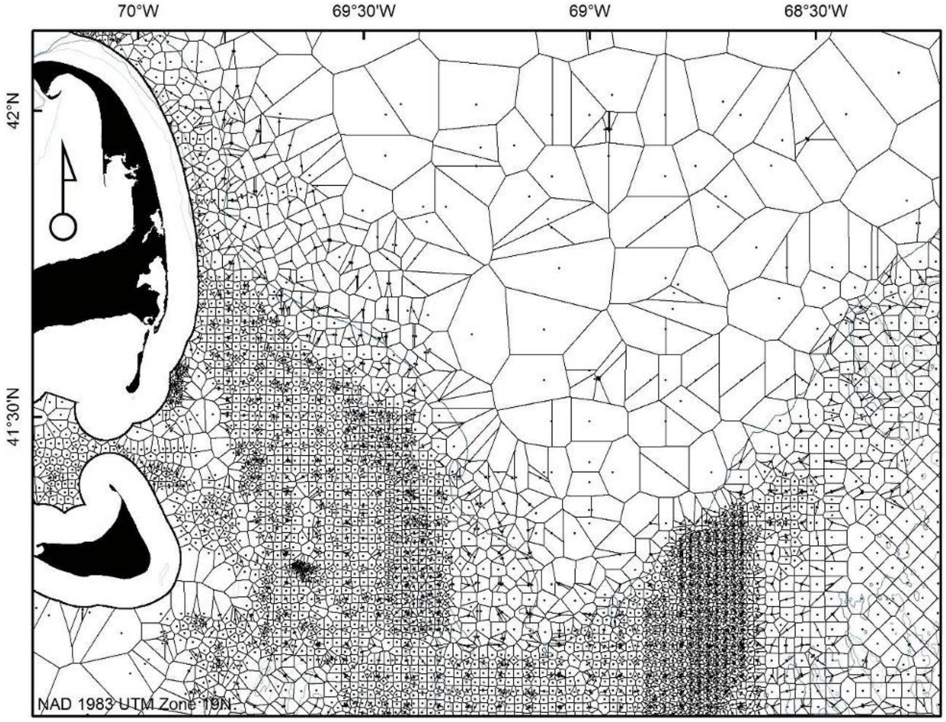
Developing the base grid

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 were merged, and the X, Y locations of the samples were tessellated to create the Voronoi diagram which serves as the base grid for the SASI model. Each polygon was 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.

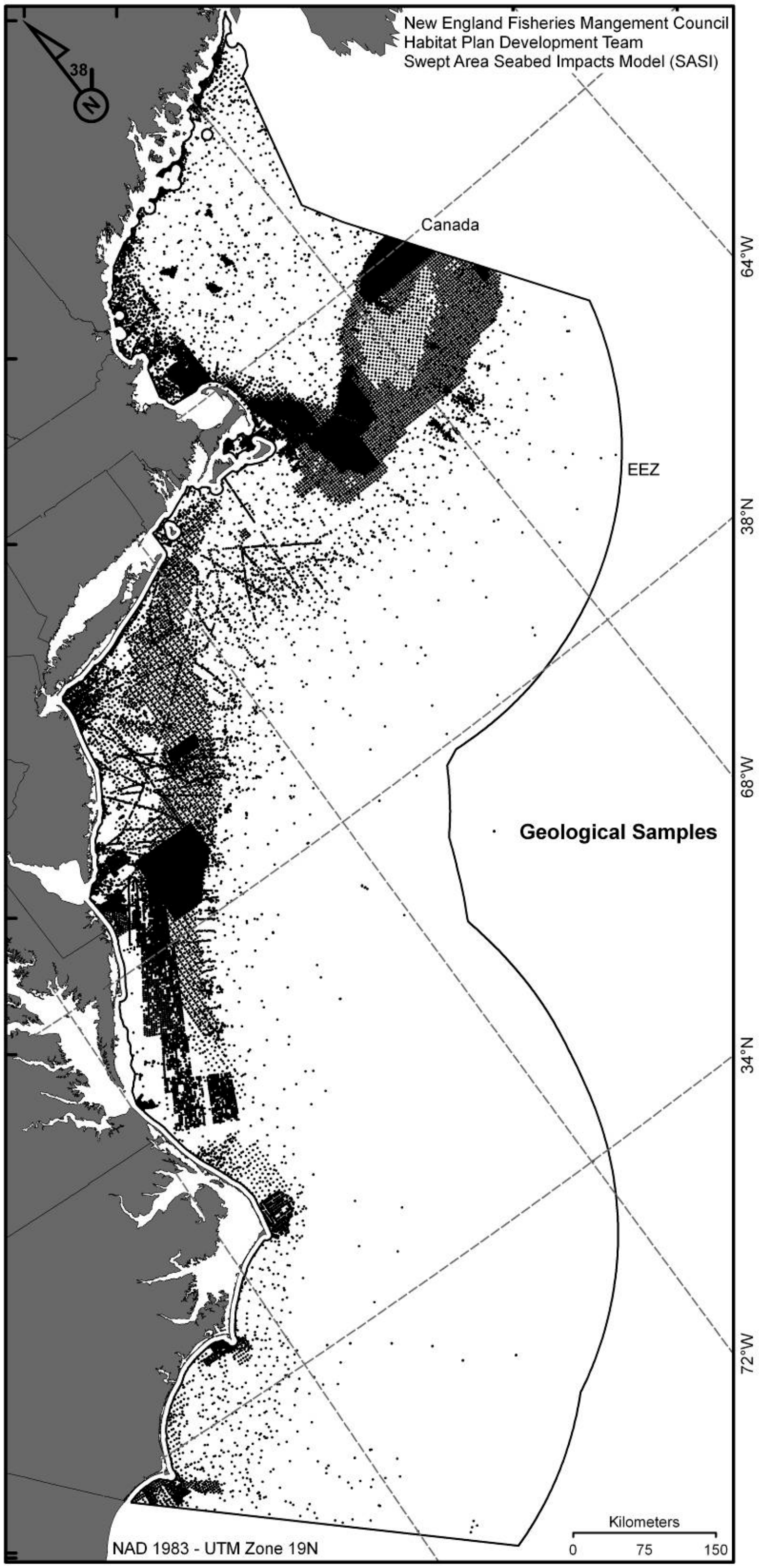
Map 1 – Construction of a Voronoi diagram, part one. This zoomed-in view of the model domain shows the individual substrate data sampling points.



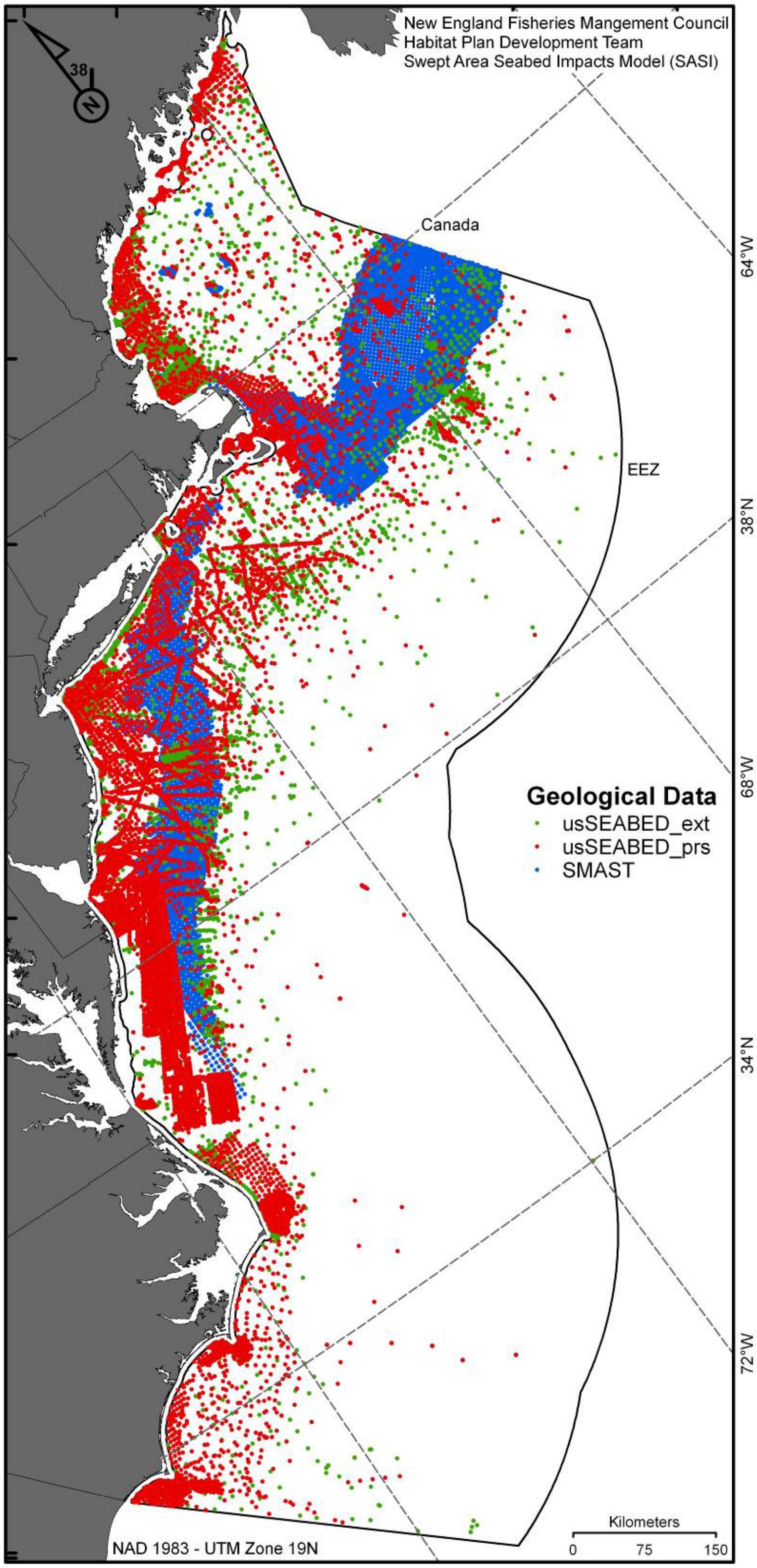
Map 2 – Construction of a Voronoi diagram, part two. This zoomed-in view of the model domain gives an example of how a Voronoi grid is drawn around individual sampling points.



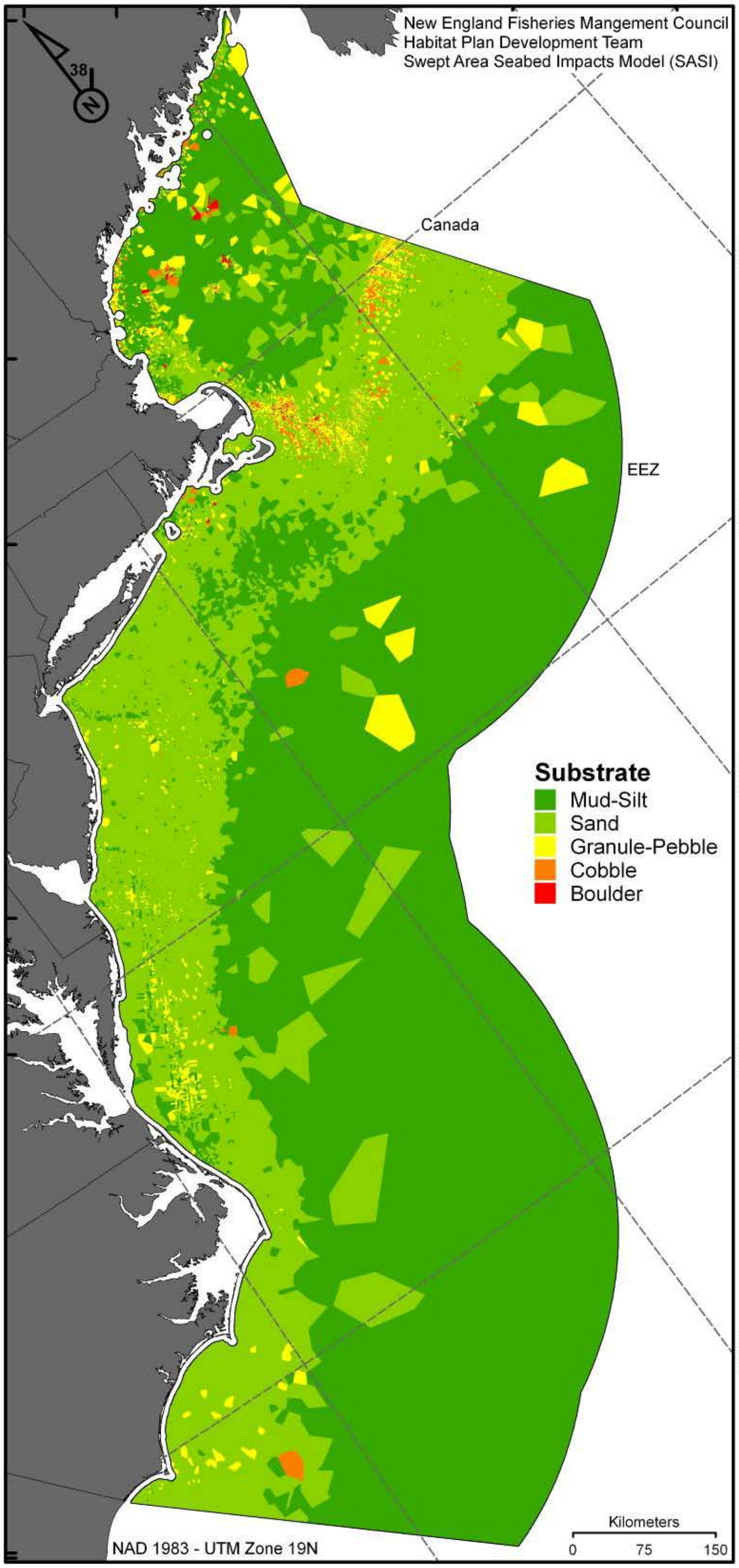
Map 3 – Geological sample locations.



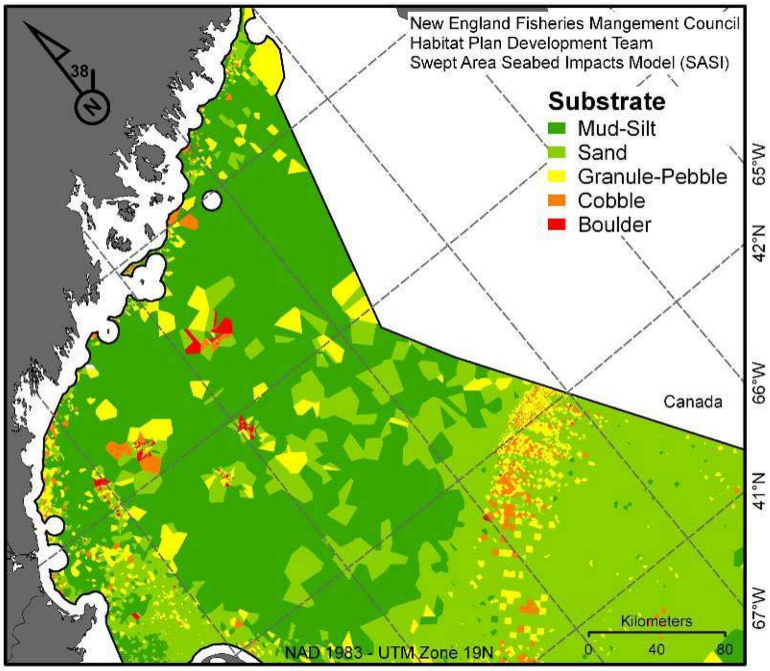
Map 4 – Geological samples by source.



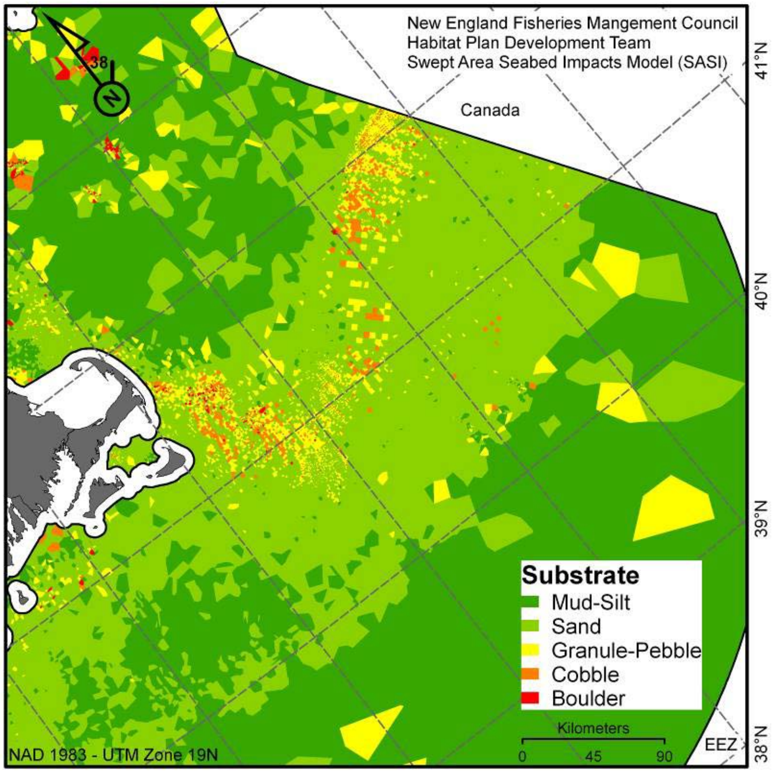
Map 5 - Dominant substrate coding for the entire model domain.



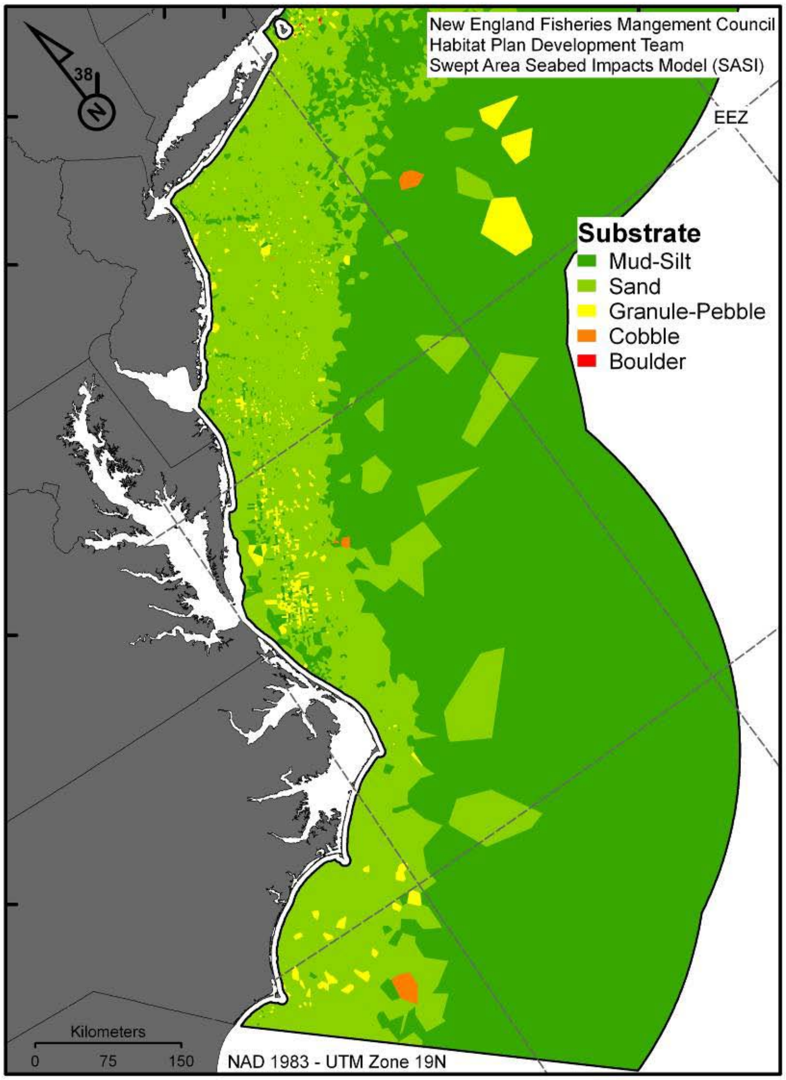
Map 6 –Dominant substrate coding for Gulf of Maine.



Map 7 – Dominant substrate coding for Georges Bank.



Map 8 – Dominant substrate coding for the Mid-Atlantic Bight.



5.2 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 were 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 was unavailable, depth was used as shown below (Table 11). Depth is used as a proxy for wave-driven annual flow events. A depth of 60 m was selected as the boundary for high-energy levels based on the average depth where annual storm-event wave height conditions occur (Butman 1986).

Table 11 – 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 were 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 were 4,000,000 records in the model domain and depth was 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.

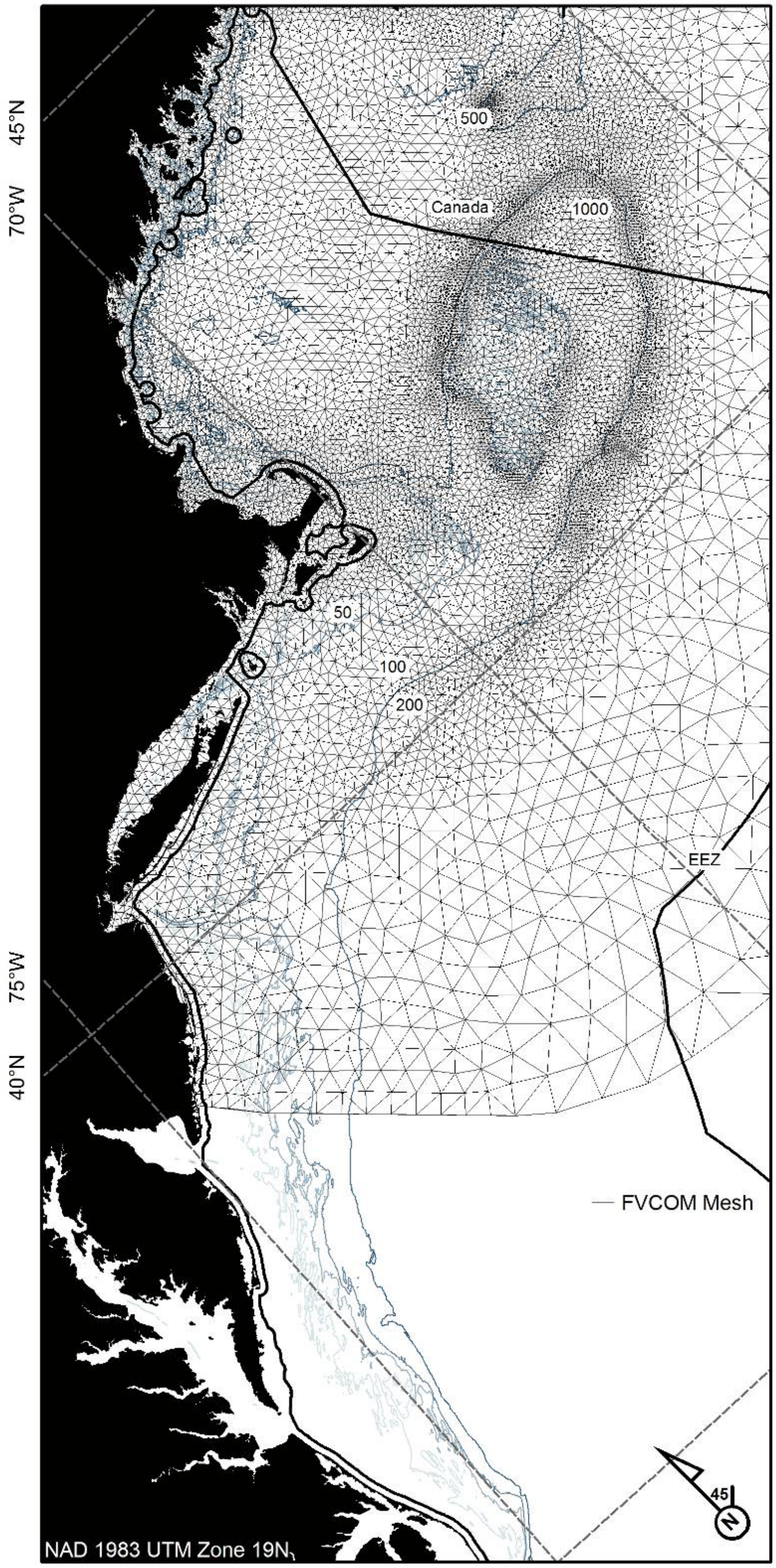
FVCOM is an open source Fortran90 software package for the simulation of ocean processes in coastal regions run by the Marine Ecosystem Dynamics Modeling Group at the University of Massachusetts Dartmouth, Department of Fisheries Oceanography (http://fvcom.smast.umassd.edu/FVCOM/index.html). The kernel 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).

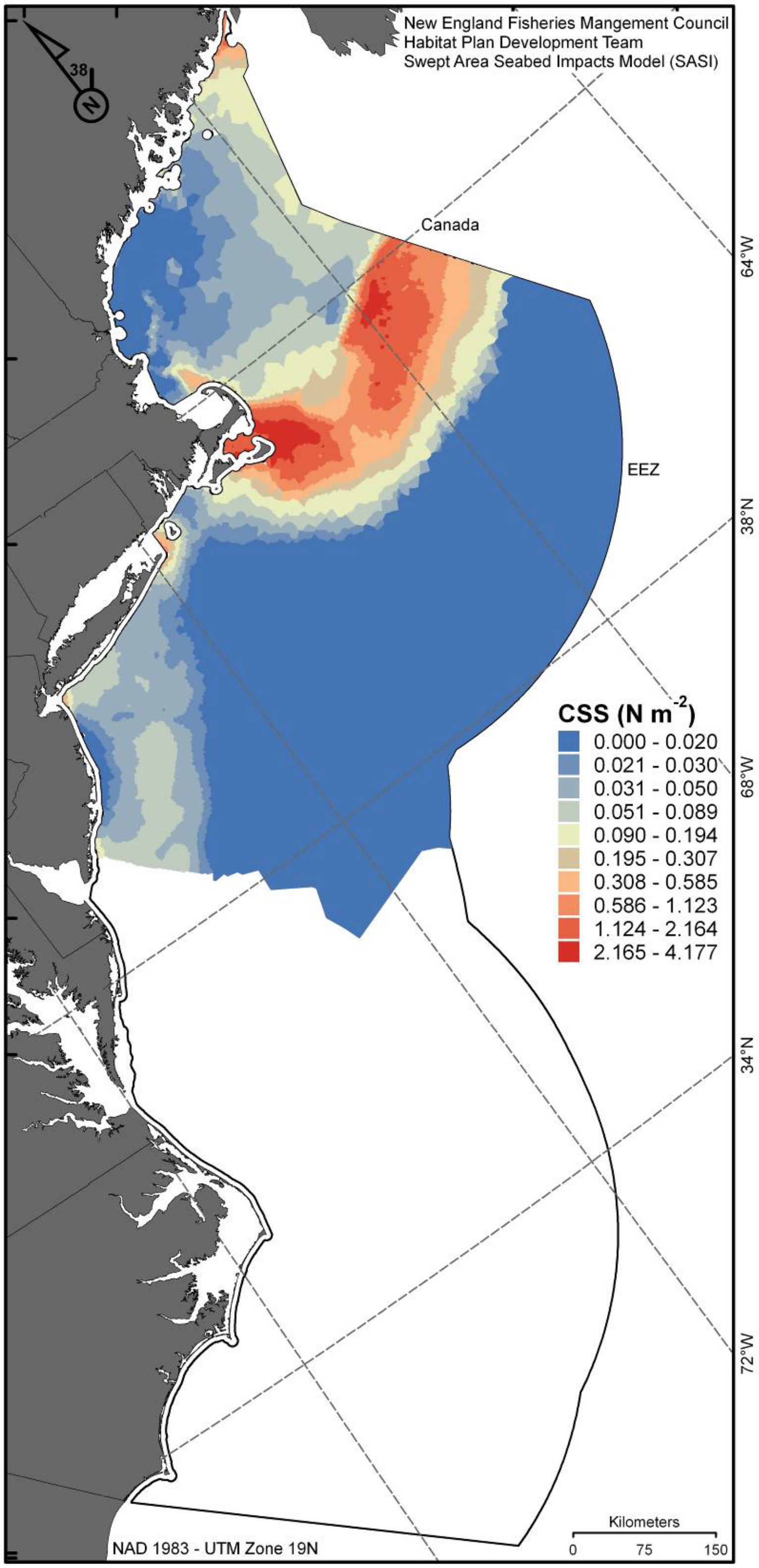
The circulation in the Gulf of Maine, Georges Bank and the New England Shelf regions was simulated from 1995-present. Hourly model hydrographic and velocity data fields were computed at each cell in the domain. Shear stress was computed from the model velocity fields using the “law of the wall” with a depth-based estimate of bottom roughness (Bradshaw and Huang 1995).

High or low energy values were 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 was used. Outside the FVCOM model domain energy values were 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.

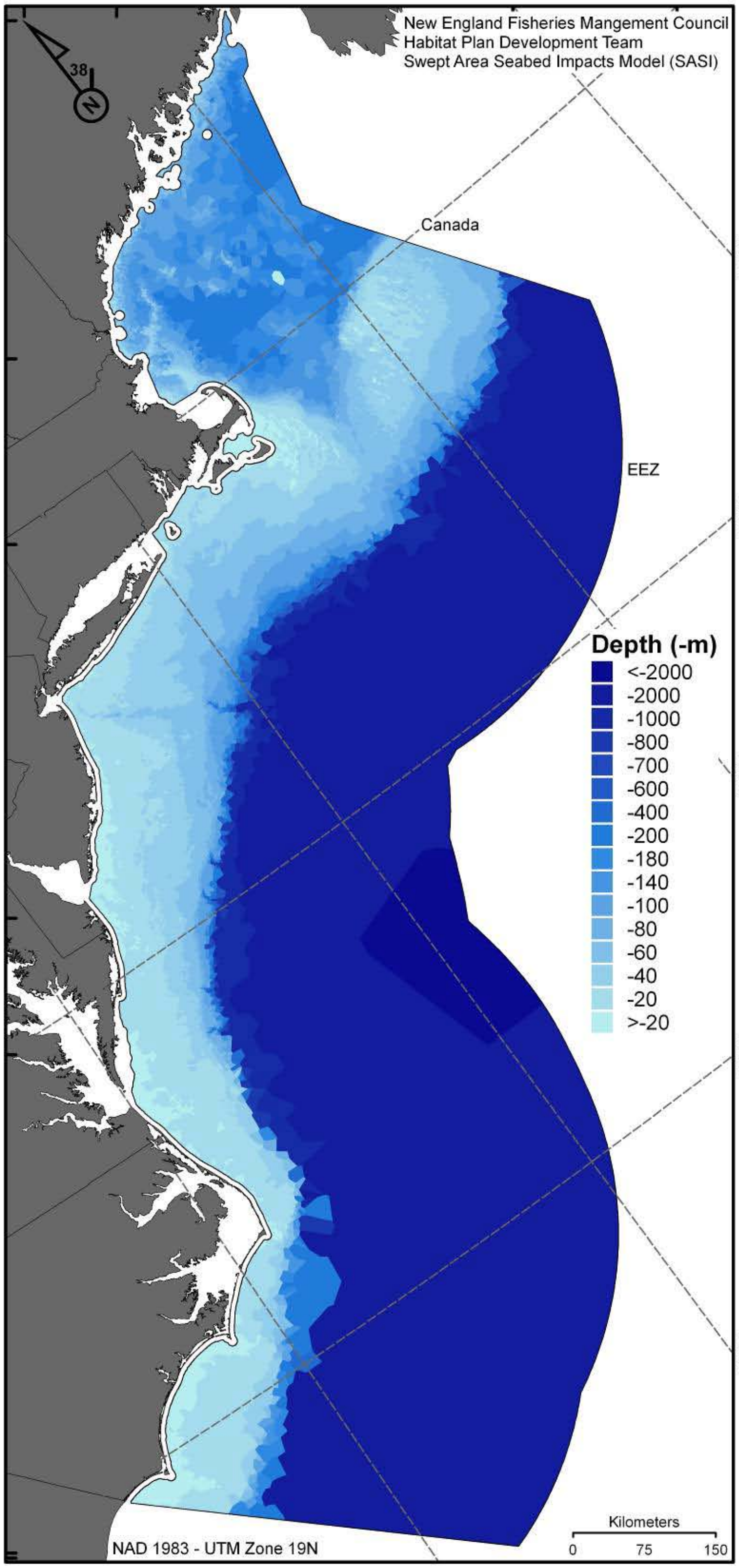
Map 9 - FVCOM domain and nodes.



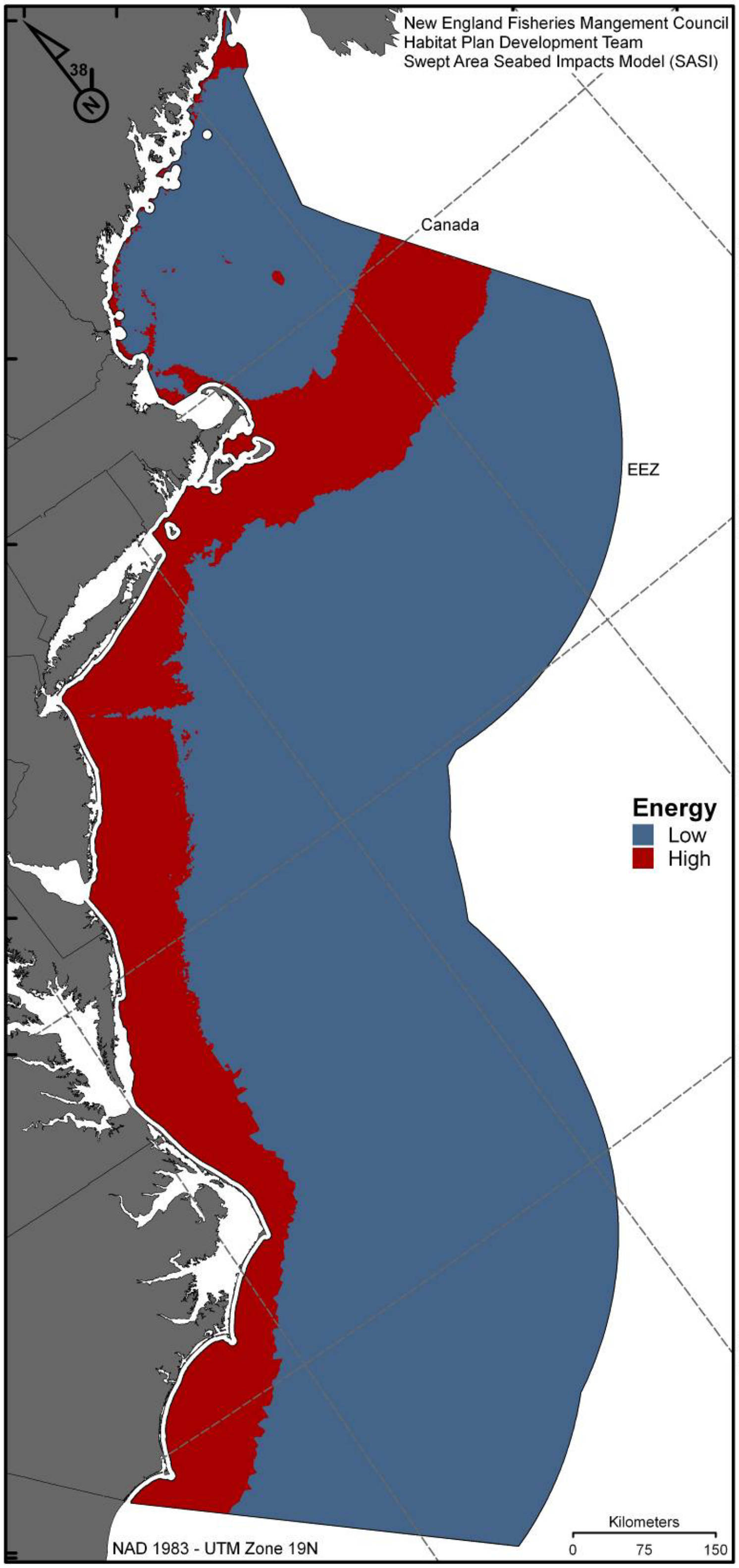
Map 10 – Base grid cell coding of energy resulting from critical shear stress model.



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°.



6.0 Applying susceptibility and recovery scores to fishing effort

6.1 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 was that the 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 was created to overlay the unstructured grid (Map 13). A higher resolution map showing the overlay between the structured and unstructured grids is also shown (Figure 8).

Map 13 - Structured SASI grid

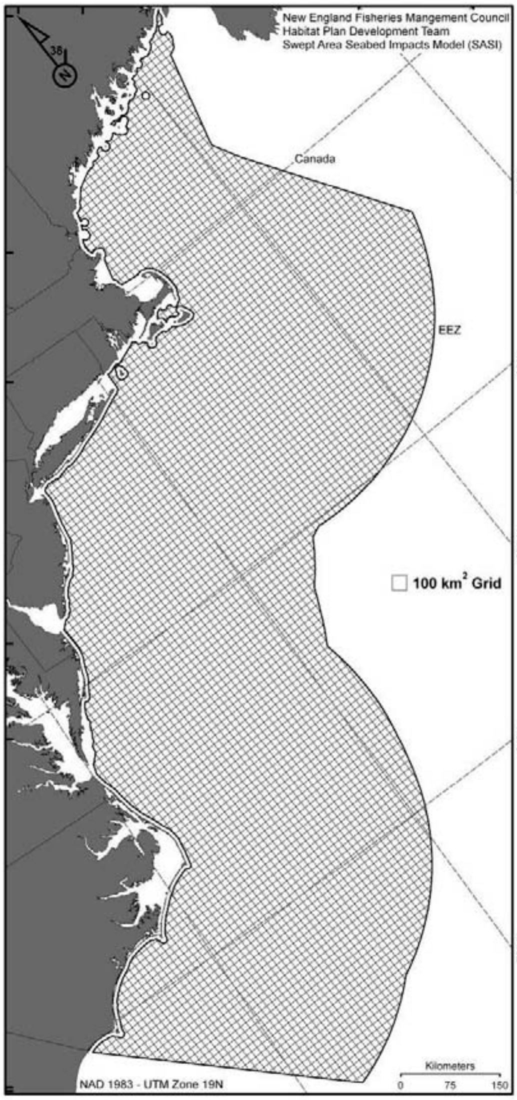
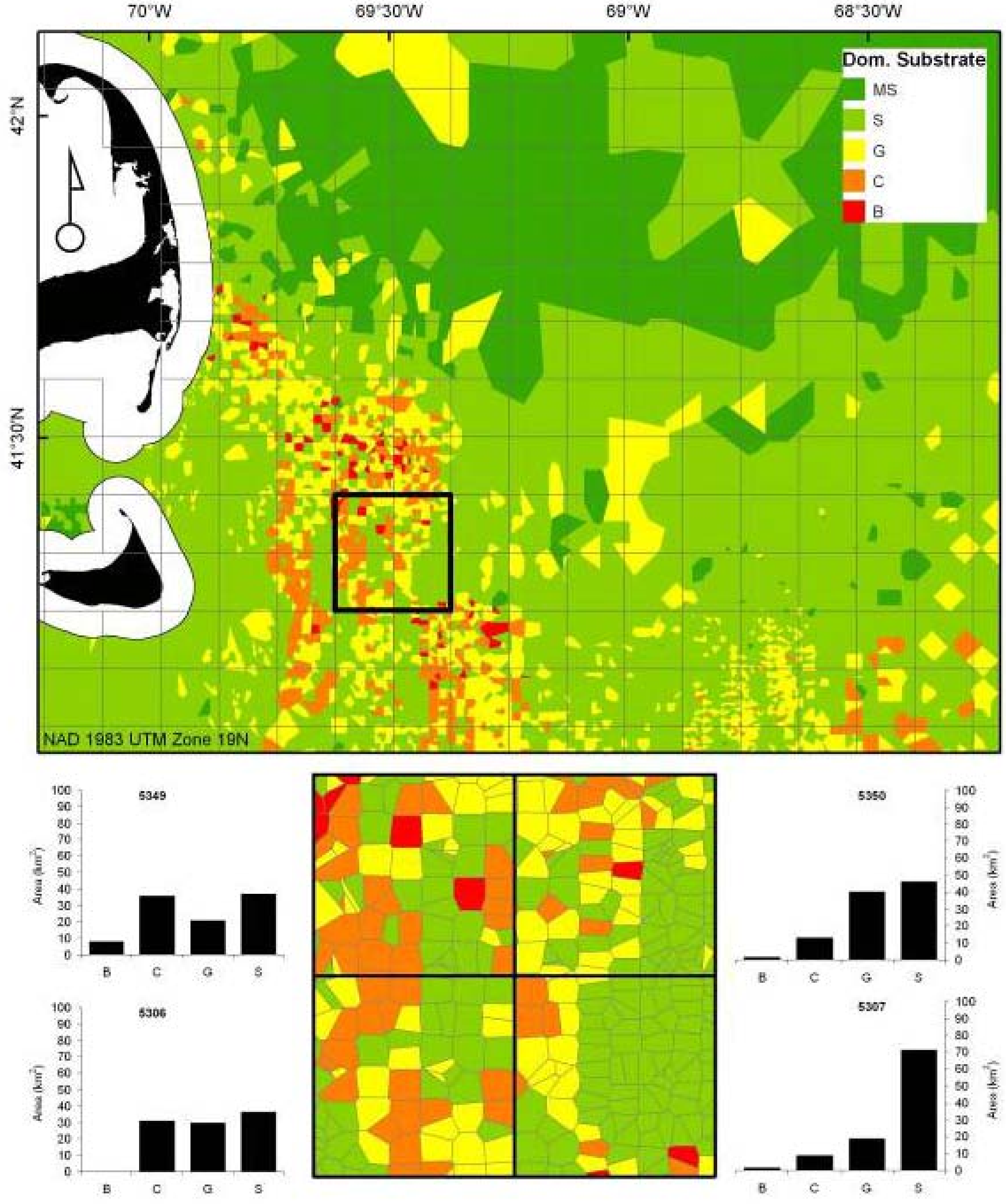


Figure 8 – Structured and unstructured grid overlay.



The lower part of the figure above shows the proportions of each 100 km² grid cell that are coded as sand, granule-pebble, cobble, and boulder dominated. If a unit of fishing effort occurs within a 100 km² 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 12 shows the ten habitat types identified in the Vulnerability Assessment, broken down into their geological and biological components.

Table 12 – 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 either percent reduction (S) or recovery time (R) as indicated by the 0-3 scores. These scores are defined in the Part 1 document. **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 were 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 was 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 was expected to have a significant effect on how much area swept accumulates under a given model run. A value of 10 years was 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.

6.2 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. Two classes of outputs are generated: simulated, and realized.

6.2.1 Simulation runs

Simulated model outputs 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. Simply put, this is the assessment of the underlying vulnerability of a given location to a given gear type. Between gear types, 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). Currently, this equilibrium is reached in year 11 because the maximum recovery time that may be assigned to a habitat feature is 10 years. This asymptotically stable equilibrium is referred to as Z∞ (Z infinity). Z∞ is only calculated for grid cells with average depths shallower than 300 m.

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 13, Table 14, and Table 15 show the implicit interactions of gears and features from the SASI model. Within a particular substrate/energy and within the biological or geological habitat component, an equal distribution of each individual biological or geological feature was 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.

Table 13– Percent contribution of each feature to the Z_infinity value for each gear type

	Gillnet	**Hydraulic**	**Longline**	**Scallop**	**Trap**	**Trawl**
feature name			*Z_inf*			
Amphipods, tube-dwelling	9.1%	2.0%	28.2%	2.1%	10.6%	11.4%
Anemones, actinarian	17.2%	3.1%	3.7%	5.8%	7.4%	4.9%
Anemones, cerianthid burrowing	9.8%	69.7%	6.3%	16.7%	26.0%	17.0%
Ascidians	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bedforms	0.2%	0.9%	0.0%	0.1%	0.0%	0.9%
Biogenic burrows	12.1%	1.4%	8.3%	31.0%	8.8%	4.6%
Biogenic depressions	0.2%	0.0%	0.1%	0.9%	0.3%	0.1%
Boulder, piled	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Boulder, scattered, in sand	6.1%	0.0%	1.4%	5.2%	2.9%	1.5%
Brachiopods	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bryozoans	9.8%	13.3%	18.2%	13.5%	25.6%	16.8%
Cobble, pavement	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Cobble, piled	1.2%	0.0%	2.4%	0.1%	0.0%	8.1%
Cobble, scattered in sand	0.1%	0.0%	0.1%	0.5%	0.1%	0.1%
Corals, sea pens	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Granule-pebble, pavement	3.5%	1.6%	2.4%	4.7%	1.4%	10.2%
Granule-pebble, scattered, in sand	7.6%	1.4%	0.1%	5.5%	0.7%	11.0%
Hydroids	3.4%	2.7%	2.7%	4.2%	5.4%	3.5%
Macroalgae	0.1%	0.2%	0.0%	0.1%	0.1%	0.1%
Mollusks, epifaunal bivalve, Modiolus modiolus	3.8%	0.9%	0.9%	1.4%	1.7%	1.1%
Mollusks, epifaunal bivalve, Placopecten magellanicus	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Polychaetes, Filograna implexa	5.0%	0.7%	0.7%	1.1%	1.4%	0.9%
Polychaetes, other tube-dwelling	8.2%	1.0%	14.7%	2.0%	1.1%	0.7%
Sediments, surface and subsurface	2.5%	0.6%	9.7%	4.3%	6.1%	7.1%
Shell deposits	0.3%	0.5%	0.1%	0.9%	0.3%	0.1%
Sponges	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table 14– Percent contribution of each feature to the Z_infinity value for each gear type, high energy only

feature name		Gillnet	Hydraulic	Longline	Scallop	Trap	Trawl
biological feature	*geological feature*			*Z_inf, low energy*			
Amphipods, tube-dwelling		11.32%	2.92%	31.17%	4.05%	40.04%	0.00%
Anemones, actinarian		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Anemones, cerianthid burrowing		12.00%	84.93%	10.10%	11.71%	0.00%	0.00%
Ascidians		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Bedforms	0.40%	0.00%	0.08%	0.05%	0.00%	2.27%
	Biogenic burrows	14.21%	1.48%	3.95%	34.32%	16.98%	16.76%
	Biogenic depressions	0.11%	0.03%	0.02%	1.67%	0.60%	0.21%
	Boulder, piled	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Boulder, scattered, in sand	14.24%	0.00%	3.91%	19.86%	20.06%	12.15%
Brachiopods		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Bryozoans		12.09%	6.83%	16.94%	12.75%	0.00%	0.00%
	Cobble, pavement	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Cobble, piled	2.39%	0.00%	1.86%	0.17%	0.05%	23.20%
	Cobble, scattered in sand	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Corals, sea pens		0.01%	0.01%	0.01%	0.03%	0.00%	0.00%
Granule-pebble, pavement		8.07%	0.00%	6.50%	1.12%	0.00%	21.07%
Granule-pebble, scattered, in sand		5.08%	1.43%	0.07%	2.65%	0.31%	24.15%
Hydroids		2.06%	0.00%	0.00%	0.00%	0.00%	0.00%
Macroalgae		0.07%	0.00%	0.06%	0.02%	0.00%	0.00%
Mollusks, epifaunal bivalve, Modiolus modiolus		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Mollusks, epifaunal bivalve, Placopecten magellanicus		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Polychaetes, Filograna implexa		6.53%	0.90%	0.00%	0.00%	0.00%	0.00%
Polychaetes, other tube-dwelling		8.17%	0.47%	19.22%	2.53%	0.00%	0.00%
	Sediments, surface and subsurface	2.98%	0.83%	6.10%	7.48%	21.34%	0.00%
	Shell deposits	0.25%	0.15%	0.02%	1.60%	0.61%	0.18%
Sponges		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	All	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table 15– Percent contribution of each feature to the Z_infinity value for each gear type, low energy only

feature name		Gillnet	Hydraulic	Longline	Scallop	Trap	Trawl
biological feature	*geological feature*			*Z_inf, low energy*			
Amphipods, tube-dwelling		11.32%	2.92%	31.17%	4.05%	40.04%	0.00%
Anemones, actinarian		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Anemones, cerianthid burrowing		12.00%	84.93%	10.10%	11.71%	0.00%	0.00%
Ascidians		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Bedforms	0.40%	0.00%	0.08%	0.05%	0.00%	2.27%
	Biogenic burrows	14.21%	1.48%	3.95%	34.32%	16.98%	16.76%
	Biogenic depressions	0.11%	0.03%	0.02%	1.67%	0.60%	0.21%
	Boulder, piled	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Boulder, scattered, in sand	14.24%	0.00%	3.91%	19.86%	20.06%	12.15%
Brachiopods		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Bryozoans		12.09%	6.83%	16.94%	12.75%	0.00%	0.00%
	Cobble, pavement	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Cobble, piled	2.39%	0.00%	1.86%	0.17%	0.05%	23.20%
	Cobble, scattered in sand	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Corals, sea pens		0.01%	0.01%	0.01%	0.03%	0.00%	0.00%
Granule-pebble, pavement		8.07%	0.00%	6.50%	1.12%	0.00%	21.07%
Granule-pebble, scattered, in sand		5.08%	1.43%	0.07%	2.65%	0.31%	24.15%
Hydroids		2.06%	0.00%	0.00%	0.00%	0.00%	0.00%
Macroalgae		0.07%	0.00%	0.06%	0.02%	0.00%	0.00%
Mollusks, epifaunal bivalve, Modiolus modiolus		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Mollusks, epifaunal bivalve, Placopecten magellanicus		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Polychaetes, Filograna implexa		6.53%	0.90%	0.00%	0.00%	0.00%	0.00%
Polychaetes, other tube-dwelling		8.17%	0.47%	19.22%	2.53%	0.00%	0.00%
	Sediments, surface and subsurface	2.98%	0.83%	6.10%	7.48%	21.34%	0.00%
	Shell deposits	0.25%	0.15%	0.02%	1.60%	0.61%	0.18%
Sponges		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	All	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table 16 (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 16 – Distribution of dominant substrates, by 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.

		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*

6.2.2 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 4.0. 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.

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 values in the first ten years after 1996 incorporate decaying adverse effect from each of the ten previous years, as applicable, a starting Z condition was required. To approximate a starting condition, area swept from 1996 was assumed for eleven years, and the resulting equilibrium Z values were used as a starting point for the model. For the hydraulic dredge gear type, 2000 area swept data were used, and for raised footrope trawls, area swept data from 2003 were used.

7.0 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.

7.1 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 were made. 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. 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 assume **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.

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, the adverse effects of 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. 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.

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**.

Certain limitations are the result of data availability. **A major limitation is that the 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 desired, larger (or smaller) structured grid cells could be used.

In addition, **the ability of the model to produce differential estimates between similar gear types is limited by the lack of information about gear configurations.** For example, both the susceptibility values and the contact indices average between trawl tows that in reality represent a variety of sweep configurations. Because data on sweep types are not available, the model cannot distinguish impacts between different types of sweeps, except to the extent that contact indices for shrimp, raised footrope, and squid trawls were 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.

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.

7.2 Spatial and temporal scale

It is critical to understanding 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). 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). 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).

main scaling components are grain, lag (or interval), and extent. 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 17). 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 17 – 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 18 – 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
SASI output		**I year**	**1 year**	**25 years**

7.3 The application of SASI results to the development of management measures

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 the New England Council are consistent with this guidance, and include:

- gear restrictions, including the inshore GOM 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 were 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 was 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.

7.4 Possible 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)

8.0 References

8.1 Acronyms

EFH	Essential Fish Habitat
GIS	Geographic Information System
NEFMC	New England Fishery Management Council
MAFMC	Mid-Atlantic Fishery Management Council
PDT	Plan Development Team
SASI	Swept Area Seabed Impact (model)

8.2 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 spawning, 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.
Lambda (λ)	The decay rate at which X is removed from the model; equals $1/\tau$.
Omega (ω)	Initial modifier of adverse effect (A) indexed across features, gears, substrates, and energies. Y equals A modified by ω.
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	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 spatial components 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	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.
Tau (τ)	τ is the total number of time steps over which the adverse effects of fishing will decay; equals $1/\lambda$.
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.
X	Recovery vector (see equations 4, 5, 6 in SASI doc 2). X is the proportion of total adverse effect, Z, that recovers within a given time step, such that X in time step two is equal to the total adverse effect (Z) in time step one multiplied by the proportion of that effect which recovered during that time step.

Y	Impact vector. Y is the proportion of total adverse effect, Z, that is introduced into the model at time t. It results from the combination of A with the appropriate S scores. Y is positive, as is X. Z is negative because for all years, Y is greater than X, and Z=X-Y.
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
$\bar{Z}$	The asymptotically stable equilibrium level of Z. $\bar{Z}$ is reached when a constant level of fishing area swept is applied to 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.

8.3 Literature cited

Backus, R. H., ed. (1987). The Georges Bank. The MIT Press, Cambridge, MA. 632p.

Carr, H. A. and H. Milliken (1998). Conservation engineering: options to minimize fishing's impacts to the sea floor. Pp 100-103 in: Effects of Fishing Gear on the Sea Floor of New England (E.L. Dorsey and J. Pederson eds). Boston, MA, Conservation Law Foundation.

Chen, C., R. C. Beardsley, et al. (2006). "An unstructured grid, finite-volume coastal ocean model (FVCOM) system. Special Issue entitled "Advances in Computational Oceanography"." Oceanography **19**(1): 78-89.

Chen, C., H. Liu, et al. (2003). "An unstructured, finite-volume, three-dimensional, primitive equation ocean model: application to coastal ocean and estuaries." J. Atmos. Oceanic Technol. **20**: 159-186.

Chen, C., Q. Xu, et al. (2008). "A model-dye comparison experiment in the tidal mixing front zone on the southern flank of Georges Bank." J. Geophys. Res. Oceans **113**(c2): C02005.

Cowles, G. W., S. J. Lentz, et al. (2008). "Comparison of observed and model-computed low frequency circulation and hydrography on the New England Shelf." J. Geophys. Res. Oceans **113**: C09015.

Everhart, W. H. and W. D. Youngs (1981). Principles of Fishery Science. Ithaca, NY, Cornell University Press.

Fortin, M.-J. and M. R. T. Dale (2005). Spatial Analysis: A Guide for Ecologists. Cambridge, U.K., Cambridge University Press.

Gold, C. M. (1991). "Problems with handling spatial data - the Voronoi approach." Canadian Institute of Surveying and Mapping Journal **45**: 65-80. (Reference #621)

Isaaks, E. H. and R. M. Srivastava (1989). An Introduction to Applied Geostatistics. New York, NY, Oxford University Press.

Kostylev, V.E., B.J. Todd, G.B.J. Fader, R.C. Courtney, G.D.M. Cameron, and R.A. Pickrill 2001. Benthic habitat mapping on the Scotian shelf based on multibeam bathymetry, surficial geology, and sea floor photographs. Mar. Ecol. Progr. Ser. 219:121-137.

Legendre, P. and L. Legendre (1998). Numerical ecology. 2nd English edition. Amsterdam, Elsevier Science, BV.

NEFMC (2002). Fishery Management Plan for Deep-Sea Red Crab (*Chaceon quinquedens*), including an Environmental Impact Statement, an Initial Regulatory Flexibility Act Analysis, and a Regulatory Impact Review. Volume I. 446pp.

NEFMC (2010). Deep-Sea Red Crab 2010 Fishing Year Specifications (March 1, 2010 – February 28, 2011) and Stock Assessment and Fishery Evaluation (SAFE) Report including the Environmental Assessment (EA), Regulatory Impact Review (RIR), and Initial Regulatory Flexibility Analysis (IRFA). Prepared by the New England Fishery Management Council in consultation with the National Marine Fisheries Service. 87pp.

Okabe, A., B. Boots, et al. (1992). Spatial Tessellations: Concepts and Applications of Voronoi Diagrams (Wiley Series in Probability and Statistics) West Sussex, England, John Wiley & Sons.

Reid, J. M., J. A. Reid, et al. (2005). usSEABED: Atlantic Coast offshore surficial sediment data release, U.S. Geological Survey Data Series 118, Version 1.0. Online at http://pubs.usgs.gov/ds/2005/118/. (Reference #641)

Sainsbury, J. C. (1996). Commercial Fishing Methods: An Introduction to Vessels and Gears. Oxford, U.K., Fishing News (Books) Ltd. (Reference #318)

Smolowitz, R. (1998). Bottom Tending Gear Used in New England. Pp 46-52 in: Effects of Fishing Gear on the Sea Floor of New England, E.L. Dorsey and J. Pederson (eds.). Boston, MA, Conservation Law Foundation.

Stokesbury, K. D. E. (2002). "Estimation of Sea Scallop Abundance in Closed Areas of Georges Bank, USA." Transactions of the American Fisheries Society **131**(6): 1081-1092.

Stokesbury, K. D. E. and B. P. Harris (2006). "Impact of limited short-term sea scallop fishery on epibenthic community of Georges Bank closed areas." Mar. Ecol. Prog. Ser. **307**: 85-100. (Reference #352)

Stokesbury, K. D. E., B. P. Harris, et al. (2004). "Estimation of sea scallop abundance using a video survey in off-shore US waters." J. Shellfish Res. **23**(1): 33-40. (Reference #563)

Thiessen, A. H. and J. C. Alter (1911). Climatological Data for July, 1911: District No. 10, Great Basin. Monthly Weather Review July 1911:1082-1089.

Wentworth, C. K. (1922). "A grade scale and class terms for clastic sediments." J. Geol. **30**: 377-392.

Williamson, J. (1998). Gillnet Fishing. Pp 87-89 in: Effects of Fishing Gear on the Sea Floor of New England, E.L. Dorsey and J. Pederson (eds.). Boston, MA, Conservation Law Foundation.