



Northeast Fisheries Science Center Reference Document 13-01

55th Northeast Regional Stock Assessment Workshop (55th SAW)

Assessment Summary Report

by the Northeast Fisheries Science Center

January 2013

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Stock Assessment Workshop
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NOAA's National Marine Fisheries Serv., 166 Water St., Woods Hole MA 02543

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

January 2013

Northeast Fisheries Science Center Reference Documents

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Information Quality Act Compliance: In accordance with section 515 of Public Law 106-554, the Northeast Fisheries Science Center completed both technical and policy reviews for this report. These predissemination reviews are on file at the NEFSC Editorial Office.

This document may be cited as:

Northeast Fisheries Science Center. 2013. 55th Northeast Regional Stock Assessment Workshop (55th SAW) Assessment Summary Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 13-01; 41 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026, or online at <http://www.nefsc.noaa.gov/nefsc/publications/>

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SAW-55 ASSESSMENT SUMMARY REPORT

Introduction

The 55th SAW Assessment Summary Report contains summary and detailed technical information on two stock assessments reviewed during December 3-7, 2012 at the Stock Assessment Workshop (SAW) by the 55th Stock Assessment Review Committee (SARC-55): Gulf of Maine cod and Georges Bank cod (*Gadus morhua*). The SARC-55 consisted of 3 external, independent reviewers appointed by the Center for Independent Experts [CIE], and an external SARC chairman from the NEFMC SSC. The SARC evaluated whether each Term of Reference (listed in the Appendix) was completed successfully based on whether the work provided a scientifically credible basis for developing fishery management advice. The reviewers' reports for SAW/SARC-55 are available at website:

<http://www.nefsc.noaa.gov/nefsc/saw/> under the heading "SARC 55 Panelist Reports".

An important aspect of any assessment is the determination of current stock status. The status of the stock relates to both the rate of removal of fish from the population – the exploitation rate – and the current stock size. The exploitation rate is the proportion of the stock alive at the beginning of the year that is caught during the year. When that proportion exceeds the amount specified in an overfishing definition, overfishing is occurring. Fishery removal rates are usually expressed in terms of the instantaneous fishing mortality rate, F , and the maximum removal rate is denoted as $F_{\text{THRESHOLD}}$.

Another important factor for classifying the status of a resource is the current stock level, for example, spawning stock biomass (SSB) or total stock biomass (TSB). Overfishing definitions, therefore, characteristically include specification of a minimum biomass threshold as well as a maximum fishing threshold. If the biomass of a stock falls below the biomass threshold ($B_{\text{THRESHOLD}}$) the stock is in an overfished condition. The Sustainable Fisheries Act mandates that a stock rebuilding plan be developed should this situation arise.

As there are two dimensions to stock status – the rate of removal and the biomass level – it is possible that a stock not currently subject to overfishing in terms of exploitation rates is in an overfished condition, that is, has a biomass level less than the threshold level. This may be due to heavy exploitation in the past, or a result of other factors such as unfavorable environmental conditions. In this case, future recruitment to the stock is very important and the probability of improvement may increase greatly by increasing the stock size. Conversely, fishing down a stock that is at a high biomass level should generally increase the long-term sustainable yield. Stocks under federal jurisdiction are managed on the basis of maximum sustainable yield (MSY). The biomass that produces this yield is called B_{MSY} and the fishing mortality rate that produces MSY is called F_{MSY} .

Given this, federally managed stocks under review are classified with respect to current overfishing definitions. A stock is overfished if its current biomass is below $B_{\text{THRESHOLD}}$ and overfishing is occurring if current F is greater than $F_{\text{THRESHOLD}}$. The table below depicts status criteria.

		BIOMASS		
		$B < B_{\text{THRESHOLD}}$	$B_{\text{THRESHOLD}} < B < B_{\text{MSY}}$	$B > B_{\text{MSY}}$
EXPLOITATION RATE	$F > F_{\text{THRESHOLD}}$	Overfished, overfishing is occurring; reduce F, adopt and follow rebuilding plan	Not overfished, overfishing is occurring; reduce F, rebuild stock	$F = F_{\text{TARGET}} \leq F_{\text{MSY}}$
	$F < F_{\text{THRESHOLD}}$	Overfished, overfishing is not occurring; adopt and follow rebuilding plan	Not overfished, overfishing is not occurring; rebuild stock	$F = F_{\text{TARGET}} \leq F_{\text{MSY}}$

Fisheries management may take into account scientific and management uncertainty, and overfishing guidelines often include a control rule in the overfishing definition. Generically, the control rules suggest actions at various levels of stock biomass and incorporate an assessment of risk, in that F targets are set so as to avoid exceeding F thresholds.

Outcome of Stock Assessment Review Meeting

Text in this section is based on SARC-55 Review Panel reports (available at <http://www.nefsc.noaa.gov/nefsc/saw/> under the heading “SARC-55 Panelist Reports”).

Two issues dominated discussion of the **Gulf of Maine Atlantic cod** assessment. Issue 1 involved the use of data prior to 1982 in the assessment and in determining the stock recruitment relationship. Issue 2 involved whether natural mortality (M) was changing over time. Concerns about use of the pre-1982 data (which were not of the same detail and quality as the post-1982 data) and concerns about results from fitting stock-recruitment curves based on early data led the Review Panel to eliminate that approach from consideration. Two variations of an ASAP model, both based on data from 1982 to present are being put forward. One model has a time-varying M while the other does not. The consequences associated with using each model were outlined. The two models should be viewed separately rather than being averaged for decision making. Commercial and recreational LPUE from the fishery were explored as potential indices of population abundance to be used in the assessment. The Panel concluded that these LPUE data are not indicative of trends in the stock as a whole. Based on the reference points derived from both assessment models being put forward, the Gulf of Maine cod stock is overfished and overfishing is occurring (the same conclusion as SARC53 in 2011). The Review Panel notes a long history of overfishing this stock.

The Review Panel was able to reach consensus on a single assessment model for **Georges Bank Atlantic cod**. The assessment assuming $M = 0.2$ with bias correction was recommended. Nevertheless, the Review Panel remained uncertain about whether M has changed. Commercial and recreational LPUE were explored as potential indices of abundance to be used in the assessment. The Panel concluded that these LPUE time series are not indicative of trends in the stock as a whole. The Panel noted a reduction over time in mean weight at age in this stock, truncated age structure, and two decades of poor recruitment for this stock. The bridge from the previous assessment model to the current model was well described. As in the past, reference points were calculated using $F_{40\%SPR}$ for stock status determination. The Georges Bank stock is overfished and overfishing is taking place.

The Review Panel was unanimous regarding its conclusions, and stated that the Gulf of Maine and Georges Bank cod stock assessments represent best available science.

Glossary

ADAPT. A commonly used form of computer program used to optimally fit a Virtual Population Assessment (VPA) to abundance data.

ASAP. The Age Structured Assessment Program is an age-structured model that uses forward computations assuming separability of fishing mortality into year and age components to estimate population sizes given observed catches, catch-at-age, and indices of abundance. Discards can be treated explicitly. The separability assumption is relaxed by allowing for fleet-specific computations and by allowing the selectivity at age to change smoothly over time or in blocks of years. The software can also allow the catchability associated with each abundance index to vary smoothly with time. The problem's dimensions (number of ages, years, fleets and abundance indices) are defined at input and limited by hardware only. The input is arranged assuming data is available for most years, but missing years are allowed. The model currently does not allow use of length data nor indices of survival rates. Diagnostics include index fits, residuals in catch and catch-at-age, and effective sample size calculations. Weights are input for different components of the objective function and allow for relatively simple age-structured production model type models up to fully parameterized models.

ASPM. Age-structured production models, also known as statistical catch-at-age (SCAA) models, are a technique of stock assessment that integrate fishery catch and fishery-independent sampling information. The procedures are flexible, allowing for uncertainty in the absolute magnitudes of catches as part of the estimation. Unlike virtual population analysis (VPA) that tracks the cumulative catches of various year classes as they age, ASPM is a forward projection simulation of the exploited

population. ASPM is similar to the NOAA Fishery Toolbox applications ASAP (Age Structured Assessment Program) and SS2 (Stock Synthesis 2)

Availability. Refers to the distribution of fish of different ages or sizes relative to that taken in the fishery.

Biological reference points. Specific values for the variables that describe the state of a fishery system which are used to evaluate its status. Reference points are most often specified in terms of fishing mortality rate and/or spawning stock biomass. The reference points may indicate 1) a desired state of the fishery, such as a fishing mortality rate that will achieve a high level of sustainable yield, or 2) a state of the fishery that should be avoided, such as a high fishing mortality rate which risks a stock collapse and long-term loss of potential yield. The former type of reference points are referred to as “target reference points” and the latter are referred to as “limit reference points” or “thresholds”. Some common examples of reference points are $F_{0.1}$, F_{MAX} , and F_{MSY} , which are defined later in this glossary.

B_0 . Virgin stock biomass, i.e., the long-term average biomass value expected in the absence of fishing mortality.

B_{MSY} . Long-term average biomass that would be achieved if fishing at a constant fishing mortality rate equal to F_{MSY} .

Biomass Dynamics Model. A simple stock assessment model that tracks changes in stock using assumptions about growth and can be tuned to abundance data such as commercial catch rates, research survey trends or biomass estimates.

Catchability. Proportion of the stock removed by one unit of effective fishing effort (typically age-specific due to

differences in selectivity and availability by age).

Control Rule. Describes a plan for pre-agreed management actions as a function of variables related to the status of the stock. For example, a control rule can specify how F or yield should vary with biomass. In the National Standard Guidelines (NSG), the “MSY control rule” is used to determine the limit fishing mortality, or Maximum Fishing Mortality Threshold (MFMT). Control rules are also known as “decision rules” or “harvest control laws.”

Catch per Unit of Effort (CPUE). Measures the relative success of fishing operations, but also can be used as a proxy for relative abundance based on the assumption that CPUE is linearly related to stock size. The use of CPUE that has not been properly standardized for temporal-spatial changes in catchability should be avoided.

Exploitation pattern. The fishing mortality on each age (or group of adjacent ages) of a stock relative to the highest mortality on any age. The exploitation pattern is expressed as a series of values ranging from 0.0 to 1.0. The pattern is referred to as “flat-topped” when the values for all the oldest ages are about 1.0, and “dome-shaped” when the values for some intermediate ages are about 1.0 and those for the oldest ages are significantly lower. This pattern often varies by type of fishing gear, area, and seasonal distribution of fishing, and the growth and migration of the fish. The pattern can be changed by modifications to fishing gear, for example, increasing mesh or hook size, or by changing the proportion of harvest by gear type.

Mortality rates. Populations of animals decline exponentially. This means that the number of animals that die in an “instant” is at all times proportional to the number

present. The decline is defined by survival curves such as: $N_{t+1} = N_t e^{-Z}$

where N_t is the number of animals in the population at time t and N_{t+1} is the number present in the next time period; Z is the total instantaneous mortality rate which can be separated into deaths due to fishing (fishing mortality or F) and deaths due to all other causes (natural mortality or M) and e is the base of the natural logarithm (2.71828). To better understand the concept of an instantaneous mortality rate, consider the following example. Suppose the instantaneous total mortality rate is 2 (i.e., $Z = 2$) and we want to know how many animals out of an initial population of 1 million fish will be alive at the end of one year. If the year is apportioned into 365 days (that is, the ‘instant’ of time is one day), then $2/365$ or 0.548% of the population will die each day. On the first day of the year, 5,480 fish will die ($1,000,000 \times 0.00548$), leaving 994,520 alive. On day 2, another 5,450 fish die ($994,520 \times 0.00548$) leaving 989,070 alive. At the end of the year, 134,593 fish [$1,000,000 \times (1 - 0.00548)^{365}$] remain alive. If, we had instead selected a smaller ‘instant’ of time, say an hour, 0.0228% of the population would have died by the end of the first time interval (an hour), leaving 135,304 fish alive at the end of the year [$1,000,000 \times (1 - 0.00228)^{8760}$]. As the instant of time becomes shorter and shorter, the exact answer to the number of animals surviving is given by the survival curve mentioned above, or, in this example:

$$N_{t+1} = 1,000,000e^{-2} = 135,335 \text{ fish}$$

Exploitation rate. The proportion of a population alive at the beginning of the year that is caught during the year. That is, if 1 million fish were alive on January 1 and 200,000 were caught during the year, the exploitation rate is 0.20 ($200,000 / 1,000,000$) or 20%.

F_{MAX}. The rate of fishing mortality that produces the maximum level of yield per recruit. This is the point beyond which growth overfishing begins.

F_{0.1}. The fishing mortality rate where the increase in yield per recruit for an increase in a unit of effort is only 10% of the yield per recruit produced by the first unit of effort on the unexploited stock (i.e., the slope of the yield-per-recruit curve for the F_{0.1} rate is only one-tenth the slope of the curve at its origin).

F_{10%}. The fishing mortality rate which reduces the spawning stock biomass per recruit (SSB/R) to 10% of the amount present in the absence of fishing. More generally, F_{x%}, is the fishing mortality rate that reduces the SSB/R to x% of the level that would exist in the absence of fishing.

F_{MSY}. The fishing mortality rate that produces the maximum sustainable yield.

Fishery Management Plan (FMP). Plan containing conservation and management measures for fishery resources, and other provisions required by the MSFCMA, developed by Fishery Management Councils or the Secretary of Commerce.

Generation Time. In the context of the National Standard Guidelines, generation time is a measure of the time required for a female to produce a reproductively-active female offspring for use in setting maximum allowable rebuilding time periods.

Growth overfishing. The situation existing when the rate of fishing mortality is above F_{MAX} and when fish are harvested before they reach their growth potential.

Limit Reference Points. Benchmarks used to indicate when harvests should be constrained substantially so that the stock remains within safe biological limits. The probability of exceeding limits should be low. In the National Standard Guidelines,

limits are referred to as thresholds. In much of the international literature (e.g., FAO documents), “thresholds” are used as buffer points that signal when a limit is being approached.

Landings per Unit of Effort (LPUE). Analogous to CPUE and measures the relative success of fishing operations, but is also sometimes used a proxy for relative abundance based on the assumption that CPUE is linearly related to stock size.

MSFCMA. (Magnuson-Stevens Fishery Conservation and Management Act). U.S. Public Law 94-265, as amended through October 11, 1996. Available as NOAA Technical Memorandum NMFS-F/SPO-23, 1996.

Maximum Fishing Mortality Threshold (MFMT, F_{THRESHOLD}). One of the Status Determination Criteria (SDC) for determining if overfishing is occurring. It will usually be equivalent to the F corresponding to the MSY Control Rule. If current fishing mortality rates are above F_{THRESHOLD}, overfishing is occurring.

Minimum Stock Size Threshold (MSST, B_{THRESHOLD}). Another of the Status Determination Criteria. The greater of (a) ½B_{MSY}, or (b) the minimum stock size at which rebuilding to B_{MSY} will occur within 10 years of fishing at the MFMT. MSST should be measured in terms of spawning biomass or other appropriate measures of productive capacity. If current stock size is below B_{THRESHOLD}, the stock is overfished.

Maximum Spawning Potential (MSP). This type of reference point is used in some fishery management plans to define overfishing. The MSP is the spawning stock biomass per recruit (SSB/ R) when fishing mortality is zero. The degree to which fishing reduces the SSB/R is expressed as a percentage of the MSP (i.e., %MSP). A stock is considered overfished when the

fishery reduces the %MSP below the level specified in the overfishing definition. The values of %MSP used to define overfishing can be derived from stock-recruitment data or chosen by analogy using available information on the level required to sustain the stock.

Maximum Sustainable Yield (MSY). The largest average catch that can be taken from a stock under existing environmental conditions.

Overfishing. According to the National Standard Guidelines, “overfishing occurs whenever a stock or stock complex is subjected to a rate or level of fishing mortality that jeopardizes the capacity of a stock or stock complex to produce MSY on a continuing basis.” Overfishing is occurring if the MFMT is exceeded for 1 year or more.

Optimum Yield (OY). The amount of fish that will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities and taking into account the protection of marine ecosystems. MSY constitutes a “ceiling” for OY. OY may be lower than MSY, depending on relevant economic, social, or ecological factors. In the case of an overfished fishery, OY should provide for rebuilding to B_{MSY} .

Partial Recruitment. Patterns of relative vulnerability of fish of different sizes or ages due to the combined effects of selectivity and availability.

Rebuilding Plan. A plan that must be designed to recover stocks to the B_{MSY} level within 10 years when they are overfished (i.e. when $B < MSST$). Normally, the 10 years would refer to an expected time to rebuilding in a probabilistic sense.

Recruitment. This is the number of young fish that survive (from birth) to a specific age or grow to a specific size. The specific

age or size at which recruitment is measured may correspond to when the young fish become vulnerable to capture in a fishery or when the number of fish in a cohort can be reliably estimated by a stock assessment.

Recruitment overfishing. The situation existing when the fishing mortality rate is so high as to cause a reduction in spawning stock which causes recruitment to become impaired.

Recruitment per spawning stock biomass (R/SSB). The number of fishery recruits (usually age 1 or 2) produced from a given weight of spawners, usually expressed as numbers of recruits per kilogram of mature fish in the stock. This ratio can be computed for each year class and is often used as an index of pre-recruit survival, since a high R/SSB ratio in one year indicates above-average numbers resulting from a given spawning biomass for a particular year class, and vice versa.

Reference Points. Values of parameters (e.g. B_{MSY} , F_{MSY} , $F_{0.1}$) that are useful benchmarks for guiding management decisions. Biological reference points are typically limits that should not be exceeded with significant probability (e.g., MSST) or targets for management (e.g., OY).

Risk. The probability of an event times the cost associated with the event (loss function). Sometimes “risk” is simply used to denote the probability of an undesirable result (e.g. the risk of biomass falling below MSST).

Status Determination Criteria (SDC). Objective and measurable criteria used to determine if a stock is being overfished or is in an overfished state according to the National Standard Guidelines.

Selectivity. Measures the relative vulnerability of different age (size) classes to the fishing gears(s).

Spawning Stock Biomass (SSB). The total weight of all sexually mature fish in a stock.

Spawning stock biomass per recruit (SSB/R or SBR). The expected lifetime contribution to the spawning stock biomass for each recruit. SSB/R is calculated assuming that F is constant over the life span of a year class. The calculated value is also dependent on the exploitation pattern and rates of growth and natural mortality, all of which are also assumed to be constant.

Stock Synthesis (SS). This application provides a statistical framework for calibration of a population dynamics model using a diversity of fishery and survey data. SS is designed to accommodate both age and size structure and with multiple stock sub-areas. Selectivity can be cast as age specific only, size-specific in the observations only, or size-specific with the ability to capture the major effect of size-specific survivorship. The overall model contains subcomponents which simulate the population dynamics of the stock and fisheries, derive the expected values for the various observed data, and quantify the magnitude of difference between observed and expected data. Parameters are searched for which will maximize the goodness-of-fit. A management layer is also included in the model allowing uncertainty in estimated parameters to be propagated to the management quantities, thus facilitating a description of the risk of various possible management scenarios. The structure of SS allows for building of simple to complex models depending upon the data available.

Survival Ratios. Ratios of recruits to spawners (or spawning biomass) in a stock-recruitment analysis. The same as the recruitment per spawning stock biomass (R/SSB), see above.

TAC. Total allowable catch is the total regulated catch from a stock in a given time period, usually a year.

Target Reference Points. Benchmarks used to guide management objectives for achieving a desirable outcome (e.g., OY). Target reference points should not be exceeded on average.

Uncertainty. Uncertainty results from a lack of perfect knowledge of many factors that affect stock assessments, estimation of reference points, and management. Rosenberg and Restrepo (1994) identify 5 types: measurement error (in observed quantities), process error (or natural population variability), model error (mis-specification of assumed values or model structure), estimation error (in population parameters or reference points, due to any of the preceding types of errors), and implementation error (or the inability to achieve targets exactly for whatever reason)

Virtual population analysis (VPA) (or cohort analysis). A retrospective analysis of the catches from a given year class which provides estimates of fishing mortality and stock size at each age over its life in the fishery. This technique is used extensively in fishery assessments.

Year class (or cohort). Fish born in a given year. For example, the 1987 year class of cod includes all cod born in 1987. This year class would be age 1 in 1988, age 2 in 1989, and so on.

Yield per recruit (Y/R or YPR). The average expected yield in weight from a single recruit. Y/R is calculated assuming that F is constant over the life span of a year class. The calculated value is also dependent on the exploitation pattern, rate of growth, and natural mortality rate, all of which are assumed to be constant.

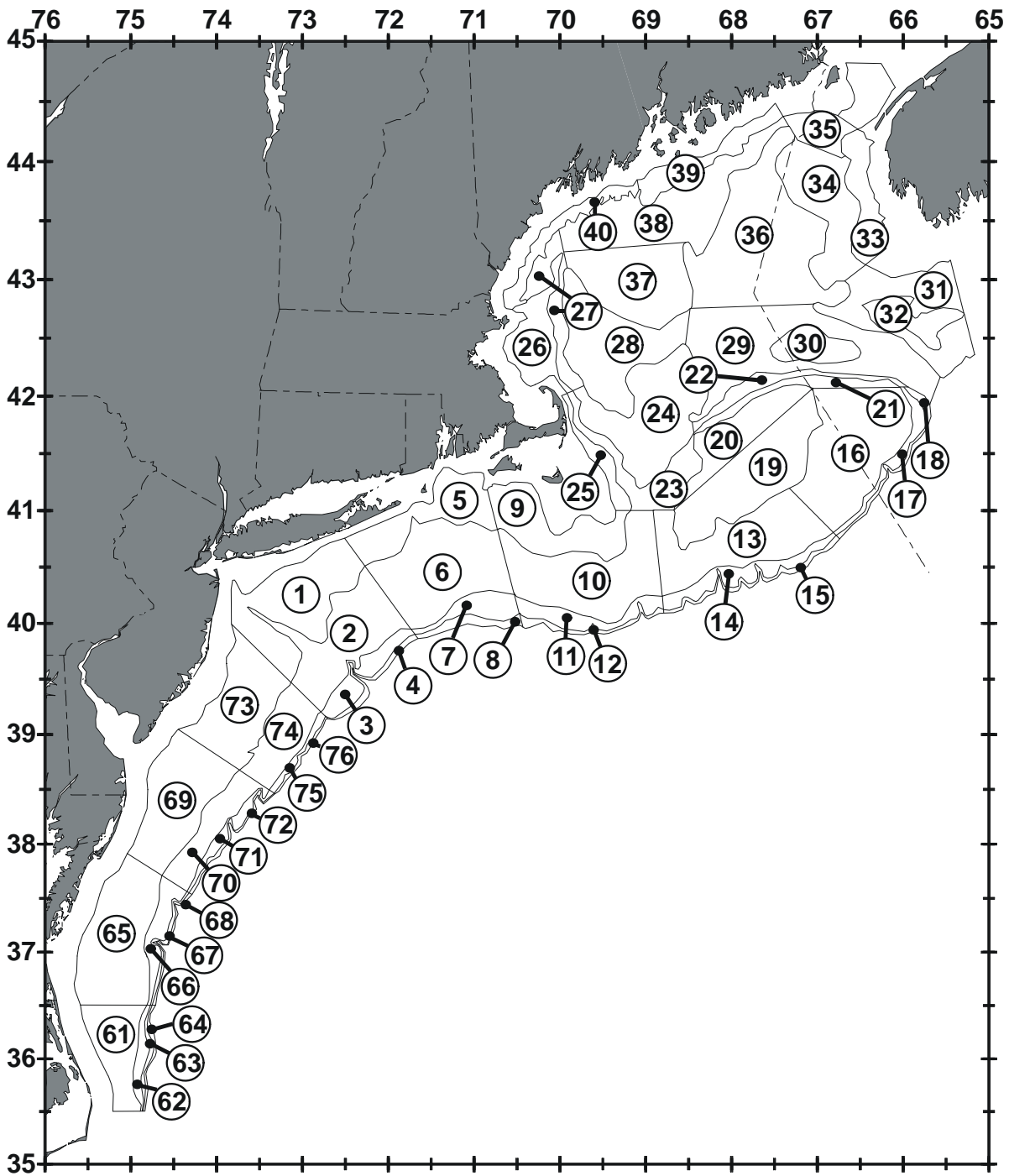


Figure 1. Offshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys. Some of these may not be sampled presently.

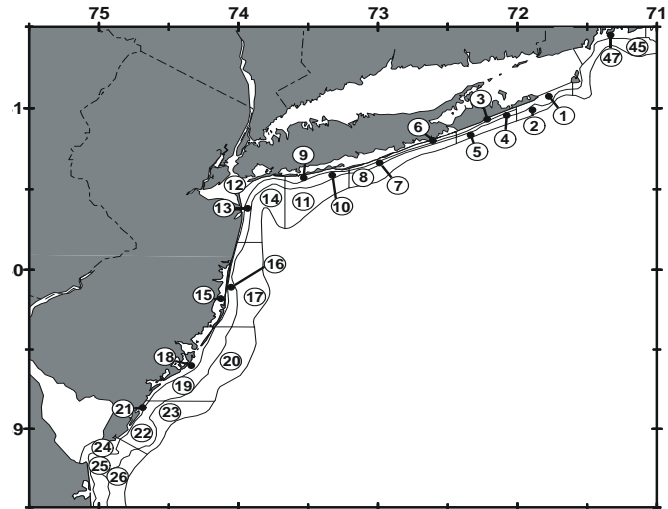
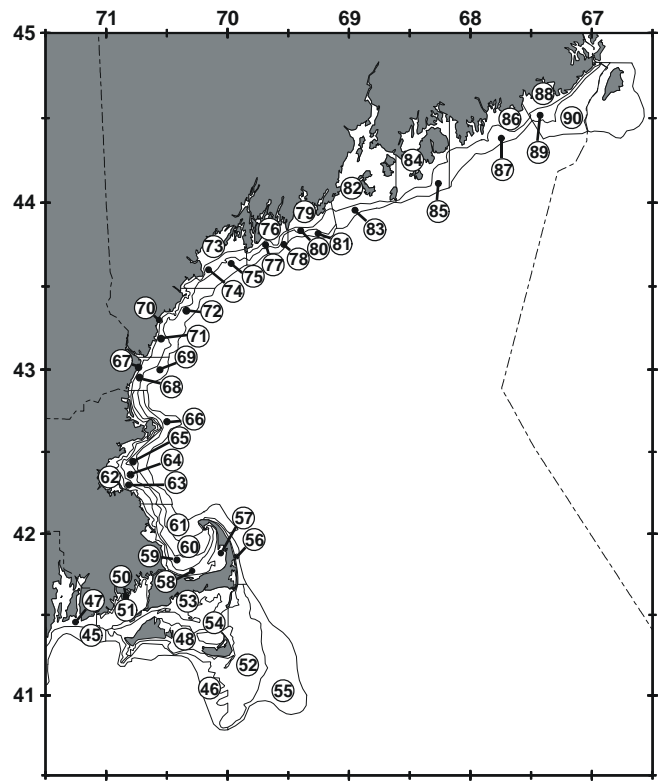
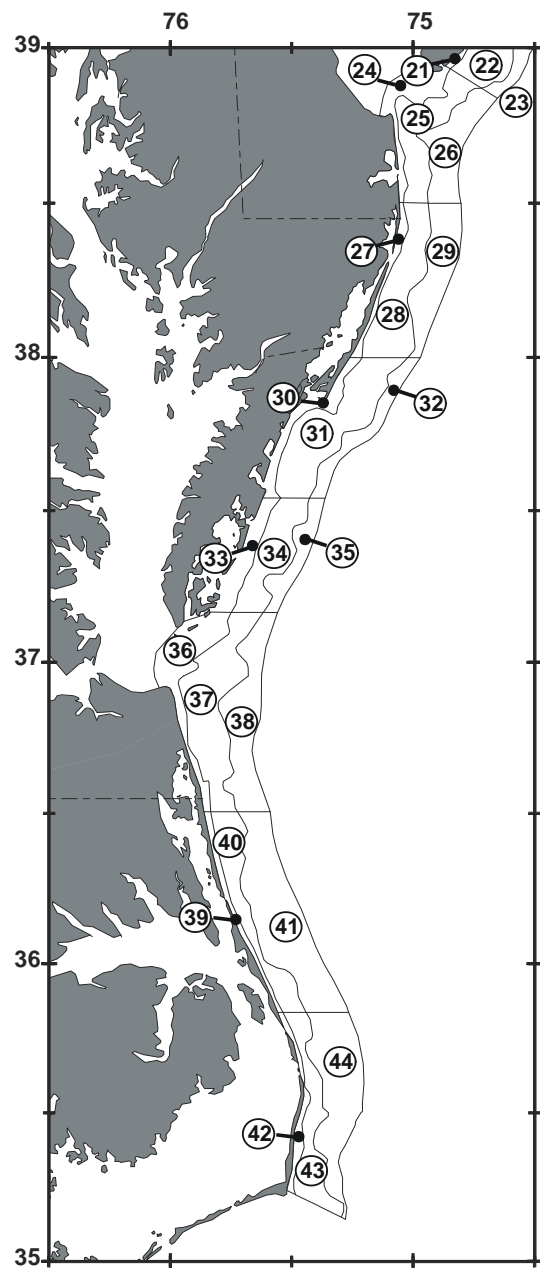


Figure 2. Inshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys. Some of these may not be sampled presently.

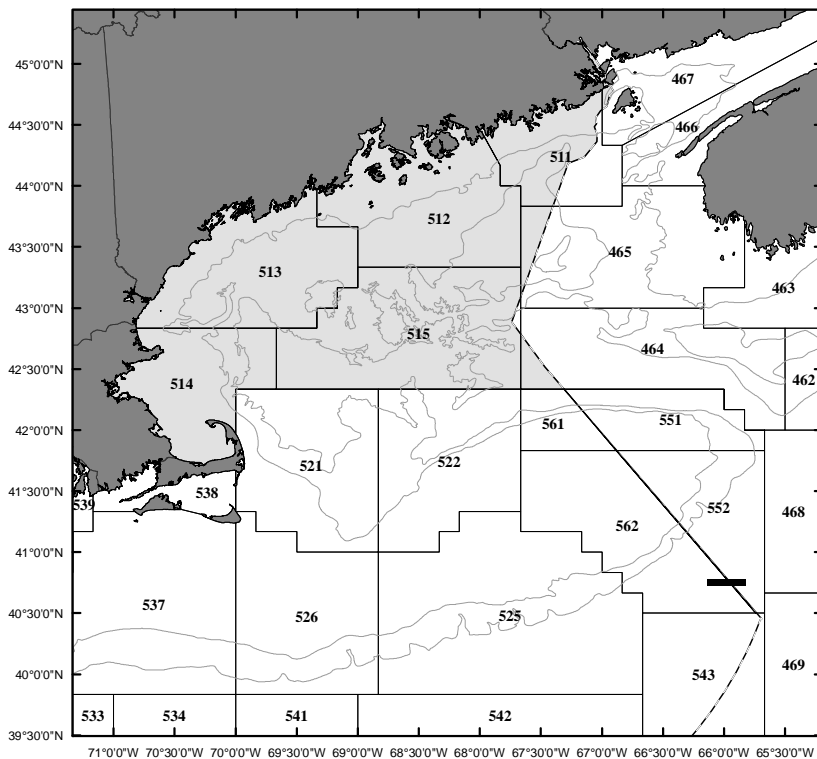
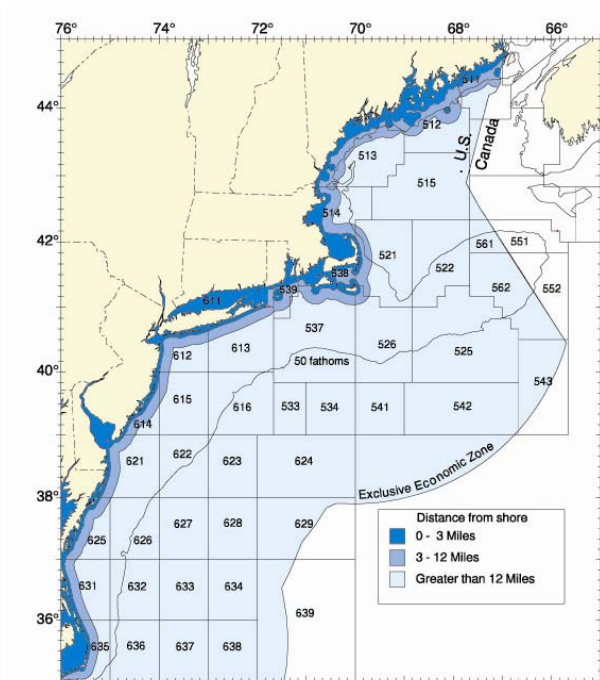


Figure 3. Statistical areas used for reporting commercial catches.

A. GULF OF MAINE ATLANTIC COD ASSESSMENT SUMMARY FOR 2012

In what follows, there are two population assessment models and a result is presented for each model. The first number is from the $M_{0.2}$ (natural mortality, $M=0.2$) assessment model and the second number is from the M_{Ramp} (M ramps from 0.2 to 0.4) assessment model (see Data and Assessment section below for a description of the models).

State of Stock: The Gulf of Maine Atlantic cod (*Gadus morhua*) stock is overfished and overfishing is occurring (Figure A1). Spawning stock biomass (SSB) in 2011 is estimated to be 9,903 mt or 10,221 mt which is 18% or 13% of the SSB_{MSY} proxy (54,743 mt or 80,200 mt) in the $M_{0.2}$ or M_{Ramp} models, respectively (Figure A2). The 2011 fully selected fishing mortality is estimated to be 0.86 or 0.90 which is about 4 or 5 times the F_{MSY} proxy (0.18 for both models) (Figure A3).

Projections: Based on recommendations made in 2011 by the SARC 53 Panel, the short term projection method samples from a cumulative density function derived from ASAP estimated age-1 recruitment between 1982 and 2009. Recruitments in 2010 and 2011 were not included due to their greater variance. No retrospective adjustment is applied in the projections. The model adjusts projected recruitment when SSB falls below the lowest spawning stock biomass estimate (6.3 kmt or 7.9 kmt) based on a linear function that declines to zero when spawning stock biomass equals 0 mt. There are two sets of projections for the M_{Ramp} assessment in addition to the single projection for the $M_{0.2}$ assessment (Table A1).

One of the consequences of going forward with multiple models is there are a different set of conditions and reference points that come out of these models. General proposals are outlined to construct projections and provide some interpretation as to how they might be used. This results in at least four cases.

1. $M_{0.2}$ model with $M=0.2$ for projections: standard procedures
2. M_{Ramp} model with $M=0.2$ for projections: standard procedures
3. M_{Ramp} model with $M=0.4$ for some period then reverting to $M=0.2$
4. M_{Ramp} model with $M=0.4$ in perpetuity (regime shift scenario)

Cases 1-3 are compared to an $M=0.2$ reference point whereas for Case 4 the reference point would change and be based on $M=0.4$. Case 4 has not been examined. Cases 1-3 are relevant for short term (3 years) catch projections. Case 3 cannot be evaluated for $F_{rebuild}$ because the timing of change in M from 0.4 to 0.2 is unknown. Cases 1-2 can be used to calculate $F_{rebuild}$. Case 4 could be done as well, however this would indicate that the stock would never rebuild to historical levels. The SARC Panel was not willing to conclude that M would remain at 0.4 in perpetuity and so did not provide reference points for Case 4.

Catch and Status Table: Gulf of Maine Atlantic cod
(weights in 000s mt, recruitment in millions, arithmetic means)

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Min ¹	Mean ¹	Max ¹
Commercial landings	3.6	3.9	3.8	3.6	3.0	4.0	5.4	6.0	5.4	4.6	1.4	7.4	18.0
Commercial discards	1.3	0.7	0.6	0.3	0.3	0.2	0.3	0.8	0.2	<0.1	<0.1	0.6	1.6
Recreational landings	1.3	1.6	1.2	1.3	0.7	1.0	1.3	1.4	1.8	1.8	0.2	1.4	3.5
Recreational discards	0.3	0.3	0.2	0.3	0.2	0.3	0.3	0.3	0.4	0.3	<0.1	0.1	0.4
Catch used in assessment	6.5	6.5	5.8	5.4	4.3	5.5	7.4	8.4	7.7	6.8	3.1	9.6	21.0
<i>ASAP (M_{0.2})</i>													
Spawning stock biomass	12.0	10.0	8.6	7.2	6.8	8.7	10.3	11.5	11.1	9.9	6.3	11.0	22.0
F _{full} ²	0.57	0.67	0.68	0.92	0.78	0.75	0.94	0.98	0.87	0.86	0.48	0.89	1.53
Recruitment (age 1)	5.2	1.9	6.3	3.9	6.6	5.3	4.5	3.5	2.2	1.2	1.2	6.8	27.9
<i>ASAP (M_{Ramp})</i>													
Spawning stock biomass	17.2	14.0	11.9	9.8	9.3	11.7	13.3	14.3	13.0	10.2	7.9	12.7	21.5
F _{full} ²	0.40	0.48	0.50	0.70	0.60	0.60	0.77	0.83	0.79	0.90	0.35	0.80	1.46
Recruitment (age 1)	11.5	4.3	14.3	8.7	14.5	11.0	8.7	6.3	3.5	1.7	1.7	9.7	30.1

¹ years 1982-2011

² F_{full} is the fishing mortality on fully selected ages

Stock Distribution and Identification: Atlantic cod is a demersal gadoid species whose range in United States (US) waters extends from Cape Hatteras north to the Canadian border. Within the United States Exclusive Economic Zone (EEZ) there are two recognized stocks of cod: Gulf of Maine and Georges Bank. The current Gulf of Maine management unit extends from the northern tip of Cape Cod east to the US/Canadian border and north to the coast of Maine (Figure A4). The regional stock structure of cod is in the process of being reviewed, but alternate stock structures were not evaluated in this assessment.

Catches: Since 1982, fishery removals of Gulf of Maine Atlantic cod have ranged from 3,078 mt to 20,978 mt. Recent fishery removals over the past five years have ranged from approximately 5,500 mt to 8,400 mt. Prior to 1989 there are no direct estimates of commercial discards but discards were hindcast back to 1982 by gear and prior to 1981 there are no direct estimates of recreational removals. Since 1982, commercial landings have been the largest source of fishery removals, constituting 40-90% of the total catch. Commercial discards were a large fraction between 1998 and 2003 when trip limits ranged from 30-500 lb/day (13.6 – 226.8 kg/day). In the most recent five years, commercial discards have accounted for <10% of fishery removals but have ranged from 1-33% since 1982 (Figure A5). Recreational catch has varied annually from a low of 295 mt in 1997 to a high of 3,595 mt in 1987. Recreational catches have constituted between 5% and 31% of total annual removals, averaging 18% over the period 1982-2011.

Data and assessment: The previous assessment (i.e., SAW/SARC53) of Gulf of Maine cod was conducted using the statistical catch-at-age model (ASAP) that incorporated commercial and recreational landings and discards. In this SAW/SARC55 assessment, two of the models put

forward by the cod working group were used (see Special Comments section). In one model ($M_{0.2}$), natural mortality, M , was assumed to be 0.2 for all years. The other model (M_{Ramp}) was implemented with $M=0.2$ from 1982 to 1988, and $M=0.4$ between 2003 and 2011, with a linear ramp between 1989 and 2002. These values of M were applied to all ages.

The assessments include updated recreational catch estimates, revised discard mortality estimates and minor modifications to the Massachusetts Department of Marine Fisheries (MADMF) spring survey. Discard mortality was assumed to vary by gear type and fishery (commercial, recreational). This represents a change from the previous assessment that assumed 100% mortality of all discarded fish. The revised discard estimates range from 20-80% depending on gear type and fishery. The revision to the recreational discard mortality assumption had the largest impact on the assessment with respect to the data changes made since the previous assessment (NEFSC 2012).

The recreational catch estimation was changed from the previous assessment from MRFSS to MRIP.

The updated models used three fishery selectivity blocks instead of two blocks used in the previous assessment model. Finally, the new models assumed flat-topped selectivity for both the catch and NEFSC survey indices whereas the previous model (NEFSC 2012) assumed flat-topped selectivity for the NEFSC surveys only. All catch sources were combined into a single fleet.

Swept-area estimates of abundance from the NEFSC spring and autumn surveys (1982-2011), and the Massachusetts Department of Marine Fisheries (MADMF) spring survey (1982-2011) were used in the ASAP models along with associated estimates of uncertainty and annual age composition. The aggregate indices of abundance (numbers) have generally declined since time series highs in the 1960/1970s. Current indices are at, or near, all time lows (Figure A6).

Biological Reference Points: An MSY could not be derived directly from the two assessments. Therefore an MSY proxy must be used for reference points. $F_{40\%}$ is the proxy used for the overfishing threshold (F_{MSY}). This is consistent with the choice of proxy in the previous assessment and the SAW 55 working group's recommendation. A deterministic value of $F_{40\%}$ was calculated from a spawner per recruit analysis using 2009-2011 average SSB weights, catch weights, selectivity and maturity. Expressed as a fully selected fishing mortality, $F_{40\%}$ is 0.18.

Stochastic projections at $F_{40\%}$ were used to determine new recommended biomass-related reference points (proxies for both SSB_{MSY} and MSY). The projection methodology used to determine SSB_{MSY} and MSY proxies was identical to those used for short-term projections.

Proxy reference points	$M_{0.2}$	M_{Ramp}
F_{MSY}	0.18	0.18
SSB_{MSY} (mt)	54,743 (40,207 - 73,354)	80,200 (64,081 - 99,972)
MSY (mt)	9,399 (6,806 - 13,153)	13,786 (10,900 - 17,329)
Median age 1 recruitment (000s)	5,254	9,446

Intervals shown are the 5th and 95th percentiles.

The biomass threshold is $\frac{1}{2}$ SSB_{TARGET} .

The biological reference points estimated in the last assessment (NEFSC 2012) using a constant $M=0.2$ were $F_{MSY}=F_{40\%}=0.20$, $SSB_{MSY}=61,218$ mt, and $MSY=10,392$ mt.

Fishing Mortality: The lowest estimate of fully selected fishing mortality (F_{full}) over the assessment time series is 0.48 or 0.35 (1999). The 2011 F_{full} is lower than the time series high of 1.53 or 1.46 (1993); it is estimated at 0.86 (90% posterior probability interval 0.53 – 1.05) or 0.90 (90% posterior probability interval 0.57 – 1.09), but still 4.7 or 5.0 times higher than the F_{MSY} proxy (Figure A3).

Biomass: The estimates of spawning stock biomass (SSB) from both models have generally declined from a time series high of 22,036 or 21,531 mt in 1982. There were small increases in SSB in the early and late 2000s, but SSB has been declining since 2009 (Figure A2). SSB in 2011 is estimated to be 9,903 mt (90% posterior probability interval 7,644 – 13,503 mt) or 10,221 mt (90% posterior probability interval 7,943 – 13,676 mt). The spawning stock biomass is well below the SSB_{MSY} proxy and the biomass threshold in both models.

Recruitment: The time series mean recruitment (age 1) was around 6.8 million fish or 9.7 million fish. Strong year classes were produced in 1981-1987. Subsequently, the recruitment estimates differ due to the different assumptions about natural mortality (Figure A7). Over the last five years recruitment estimates have declined to a low level in both assessments.

Special Comments:

- Since the mid-1990s the distribution of cod has become increasingly concentrated in the western part of the Gulf, with a gradual loss of cod from the coastal and central Gulf.
- Since the mid-2000s, the fishing fleet has become particularly concentrated in a small region of the western Gulf due to the fine scale aggregation of cod in an area where their prey (sand lance) were increasingly available. This biases fishery CPUE as an indicator of the abundance of the stock as a whole.
- If recent weak recruitment of Gulf of Maine cod continues, productivity and rebuilding of the stock will be less than projected.
- The NEFSC 2011 fall and 2012 spring survey abundance indices were the 4th lowest and the lowest in their respective time series. The MADMF 2012 spring survey index was also the lowest in its time series. As the 2012 observations were not incorporated into the assessment formulations, the projections are likely to be optimistic.

- For both Georges Bank and Gulf of Maine cod stocks there is considerable uncertainty associated with natural mortality rates. With the **Georges Bank** stock there were multiple assessments presented, but for the ones considered the projections and reference points were very similar. Furthermore, the results of the ramp mortality model that was considered could be taken to imply that the apparent changes in the system were likely due to changes in natural mortality when in fact this is uncertain. Consequently, a different approach was needed. In this circumstance the SARC Panel decided to work with a single model with constant natural mortality rate and a retrospective adjustment to better reflect an inability to identify the causal mechanisms of the changes in the system.
- In contrast, in the **Gulf of Maine** stock the biomass reference points and some of the projections showed a greater difference than the Georges Bank projections especially under alternative future natural mortality regimes. In the end, the set of projections considered in these comparisons differed between the two cod stocks. Given the pros and cons presented by the working group regarding natural mortality, the SARC Panel was unable to decide between two natural mortality assumptions. So a range of scenarios was selected and is being carried forward. A number of scenarios are being explored and the state of nature as reflected in the natural mortality rates included in the models is uncertain. Although it is not straightforward to determine the numeric values for stock status, the stock is overfished and overfishing is occurring based on both models.
- The SARC Panel concluded that if M is currently 0.4 then it seemed more reasonable to assume that in the short-term M would remain at 0.4 rather than reduce to 0.2.
- If M stays at 0.4 levels in the M_{ramp} model (Case 4), then the stock could only return to levels much below those associated with an $M=0.2$ scenario.
- A Delphi method had been applied prior to the working group meetings to find alternative values of discard mortality rates for different gears. The retrospective pattern was worse with the lower discard mortality rates, implying that the ramp M approach could be partially aliasing fishing mortality. However returning all the discard mortality rates to 100% from those specified by the Delphi method resulted in marked differences in SSB estimates and a reduction in the retrospective pattern.

References:

- Northeast Fisheries Science Center (NEFSC). 2012. Stock Assessment of Gulf of Maine Atlantic cod. 53th Northeast Stock Assessment Workshop. NEFSC Ref. Doc. 12-05.
- Northeast Fisheries Science Center (NEFSC). In prep. Stock Assessment of Gulf of Maine Atlantic cod. 55th Northeast Stock Assessment Workshop.

Table A1. Short term projections of total fishery yield and spawning stock biomass for Gulf of Maine Atlantic cod based on a harvest scenario of fishing at 75% F_{MSY} between 2013 and 2015. Catch in 2012 has been estimated at 3,767 mt. There are two sets of projections for the M_{Ramp} assessment in addition to the single projection for the $M_{0.2}$ assessment. The two M_{Ramp} projections differ in the assumed natural mortality rate in subsequent years starting in 2012. One is set at $M=0.2$ while the other is set at $M=0.4$, to bracket the range of natural mortality rates used in the M_{Ramp} model.

Year	Input	ASAP, 1982 BASE			ASAP, 1982 M-RAMP					
		M=0.2			M=0.2			M=0.4		
		Fmsy = 0.18, Bmsy = 54,743 mt			Fmsy = 0.18, Bmsy = 80,200 mt			Fmsy = 0.18, Bmsy = 80,200 mt		
		Rebuild year at 75% F_{MSY} = 2022			Rebuild year at 75% F_{MSY} = 2022			NO REBUILD at 75% F_{MSY}		
		Catch (mt)	Spawning stock biomass (mt)	F_{full}	Catch (mt)	Spawning stock biomass (mt)	F_{full}	Catch (mt)	Spawning stock biomass (mt)	F_{full}
2011	Model result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	10,221	0.90
2012	Assumed catch	3,767	8,995	0.46	3,767	8,196	0.52	3,767	7,711	0.58
2013	Projection	1,249	9,406	0.14	1,142	9,163	0.14	822	6,927	0.14
2014	Projection	1,503	12,143	0.14	1,563	13,916	0.14	935	8,875	0.14
2015	Projection	2,030	16,802	0.14	2,582	22,124	0.14	1,313	12,234	0.14

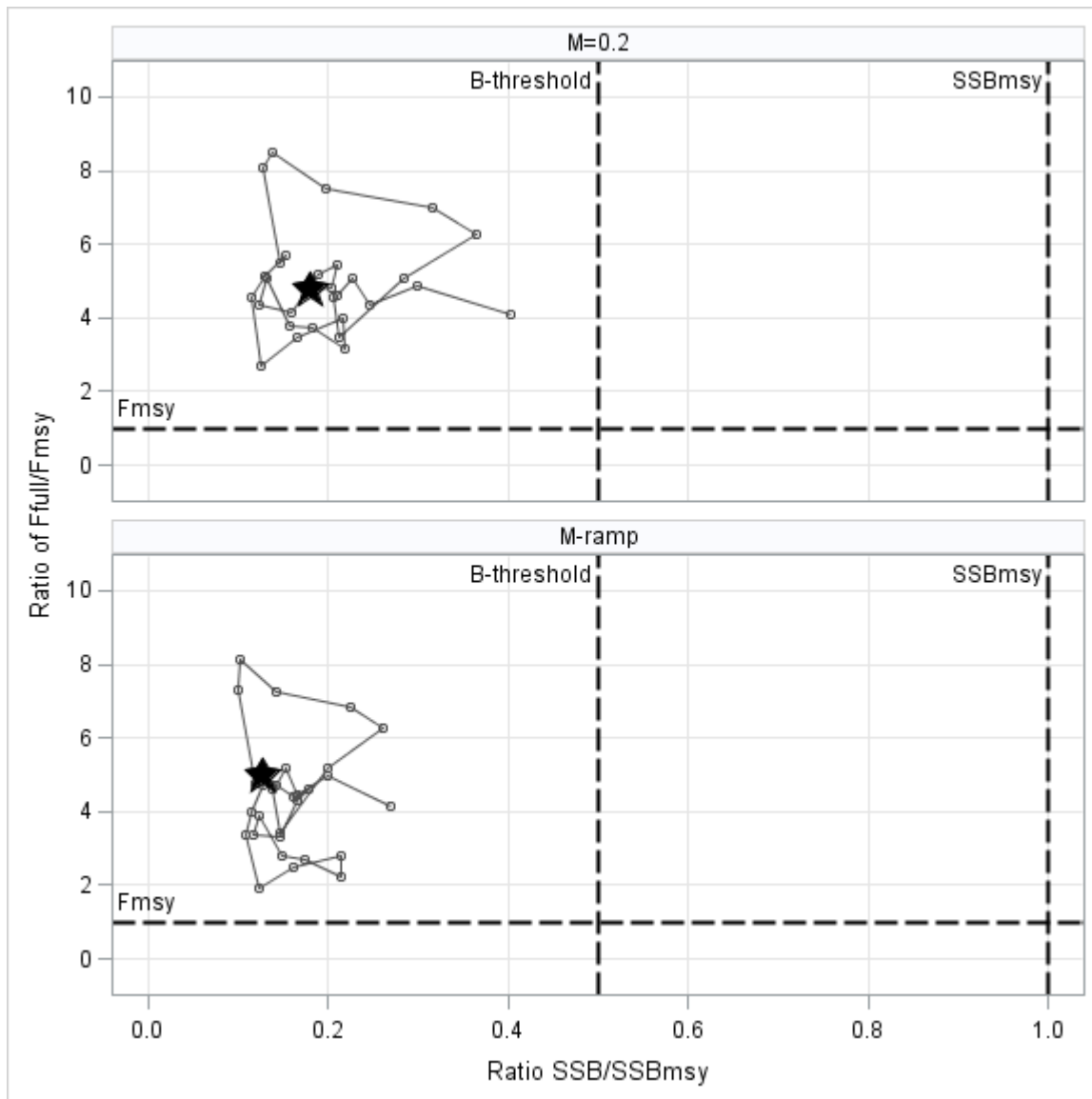


Figure A1. Time series plot of the Gulf of Maine Atlantic cod fully selected fishing mortality/2011 F_{MSY} ratio relative to the spawning stock biomass/2011 SSB_{MSY} ratio from 1982 to 2011. Results are shown for both the $M_{0.2}$ (top) and M_{Ramp} (bottom) models. Most recent value is indicated by a star.

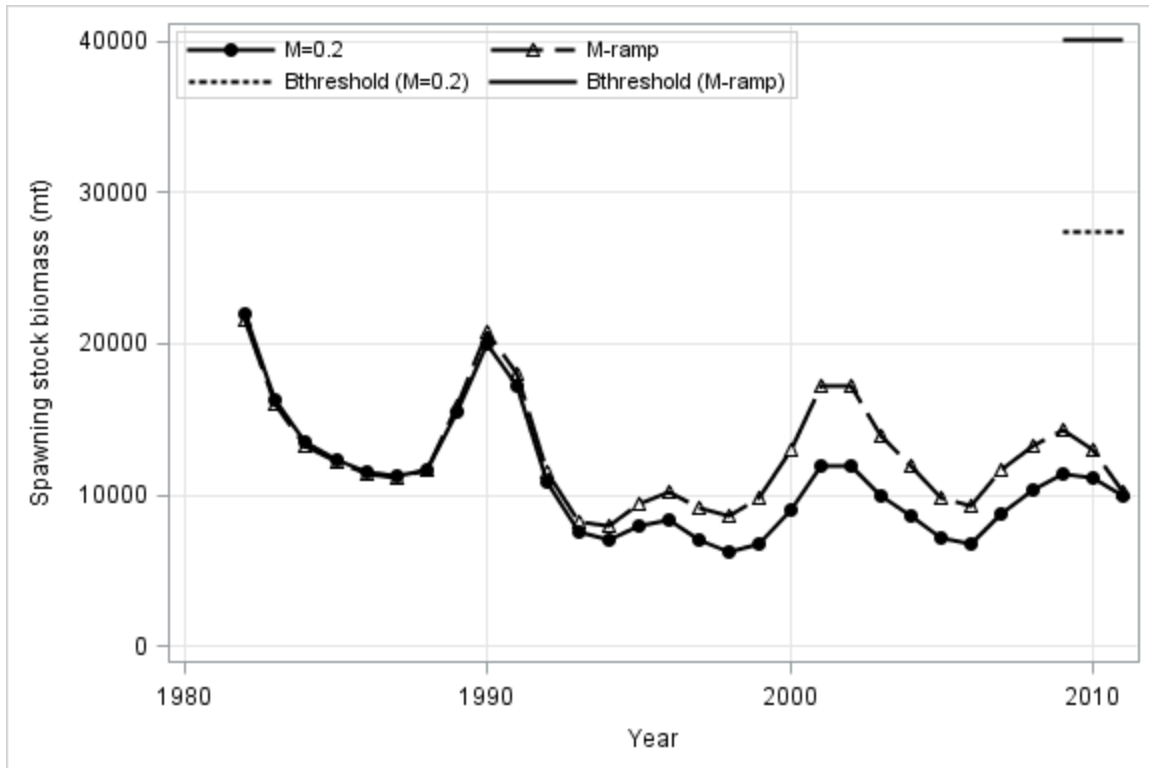


Figure A2. Estimated trends in the spawning stock biomass of Gulf of Maine Atlantic cod between 1982 and 2011 and the corresponding $SSB_{\text{threshold}}$ ($1/2 SSB_{\text{MSY}}$) based on the 2012 assessment. Results are shown for both the $M_{0.2}$ and M_{Ramp} models.

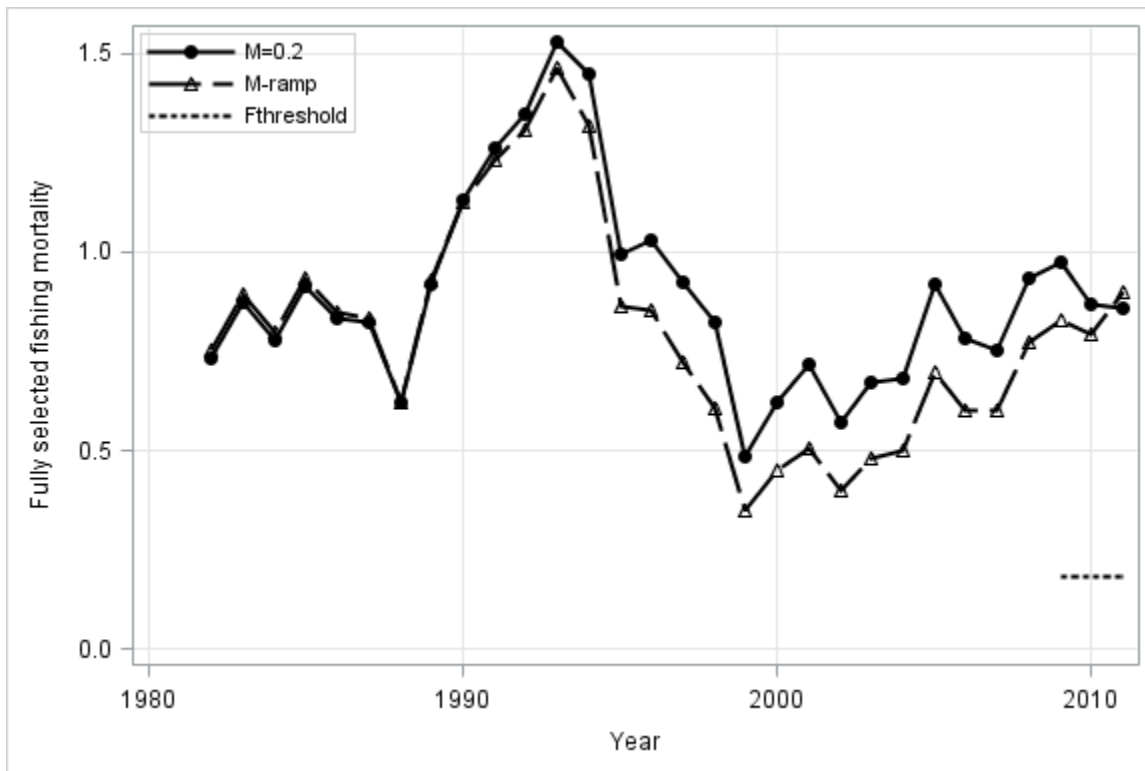


Figure A3. Estimated trends in the fully selected fishing mortality (F_{full}) of Gulf of Maine Atlantic cod between 1982 and 2011, and the corresponding F_{MSY} based on the 2012 assessment. Results are shown for both the $M_{0.2}$ and M_{Ramp} models. Both assessment models had identical F_{MSY} proxies.

**Note that the time series includes three selectivity blocks (1982-1988, 1989-2004, 2005-2011) and the F_{full} values are not necessarily comparable between blocks.*

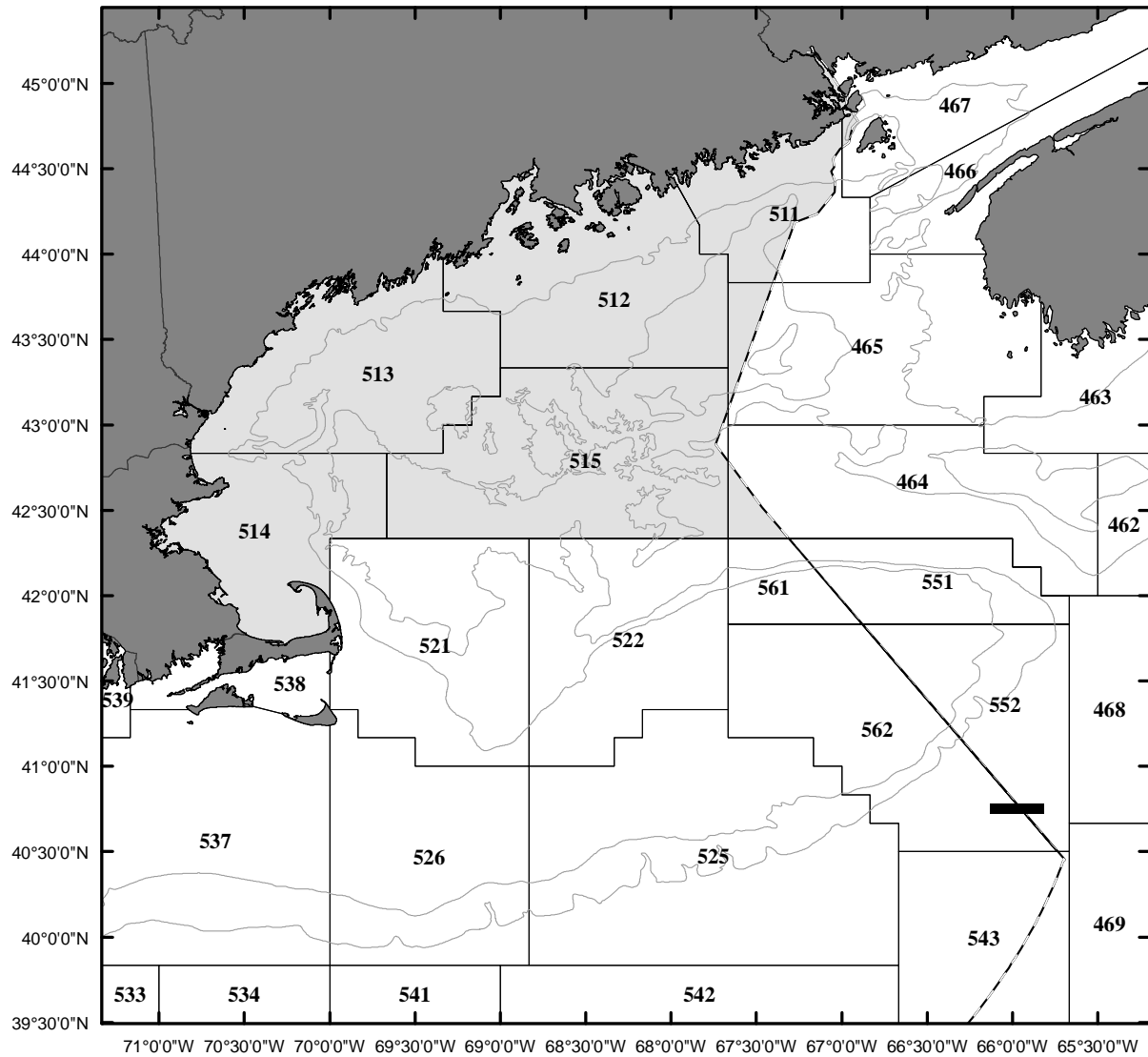


Figure A4. Map of the Gulf of Maine Atlantic cod (*Gadus morhua*) management and assessment area (shaded grey). The United States exclusive economic zone (EEZ) is defined by the dashed line.

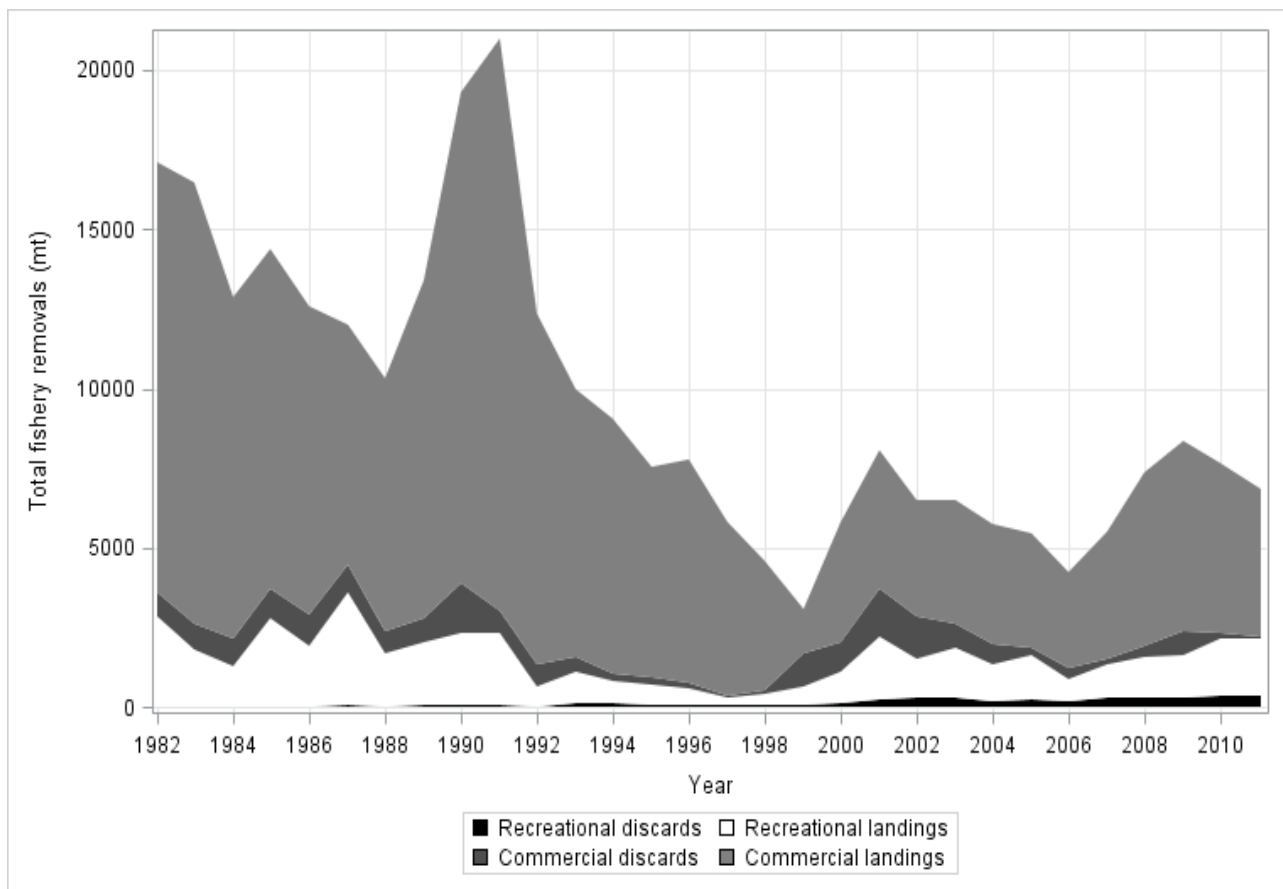


Figure A5. Total catch of the Gulf of Maine Atlantic cod between 1982 and 2011 by fleet (commercial and recreational) and disposition (landings and discards).

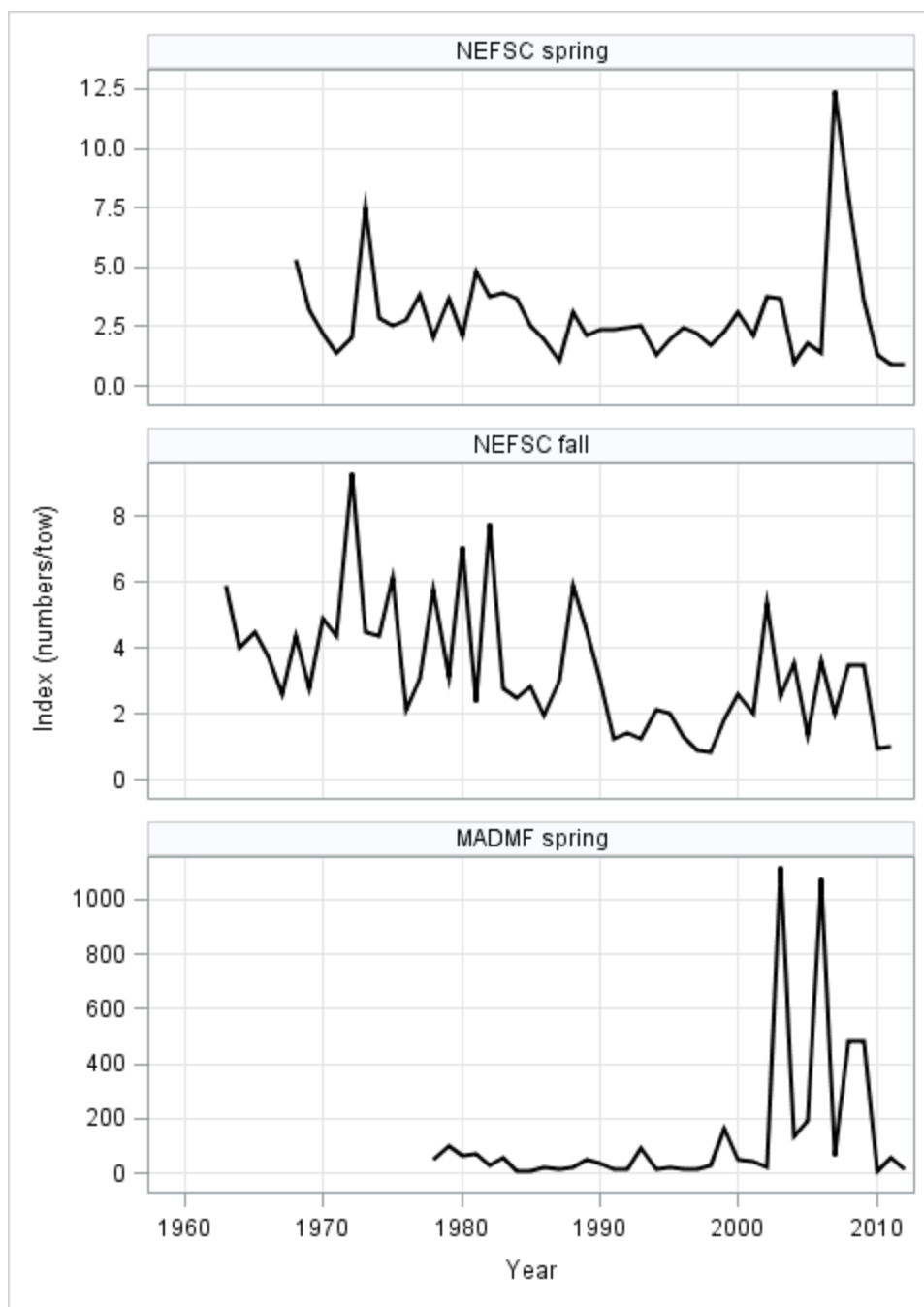


Figure A6. Indices of abundance for the Gulf of Maine Atlantic cod between 1963 and 2012 for the Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl surveys and the Massachusetts Department of Marine Fisheries (MADMF) spring bottom trawl survey.

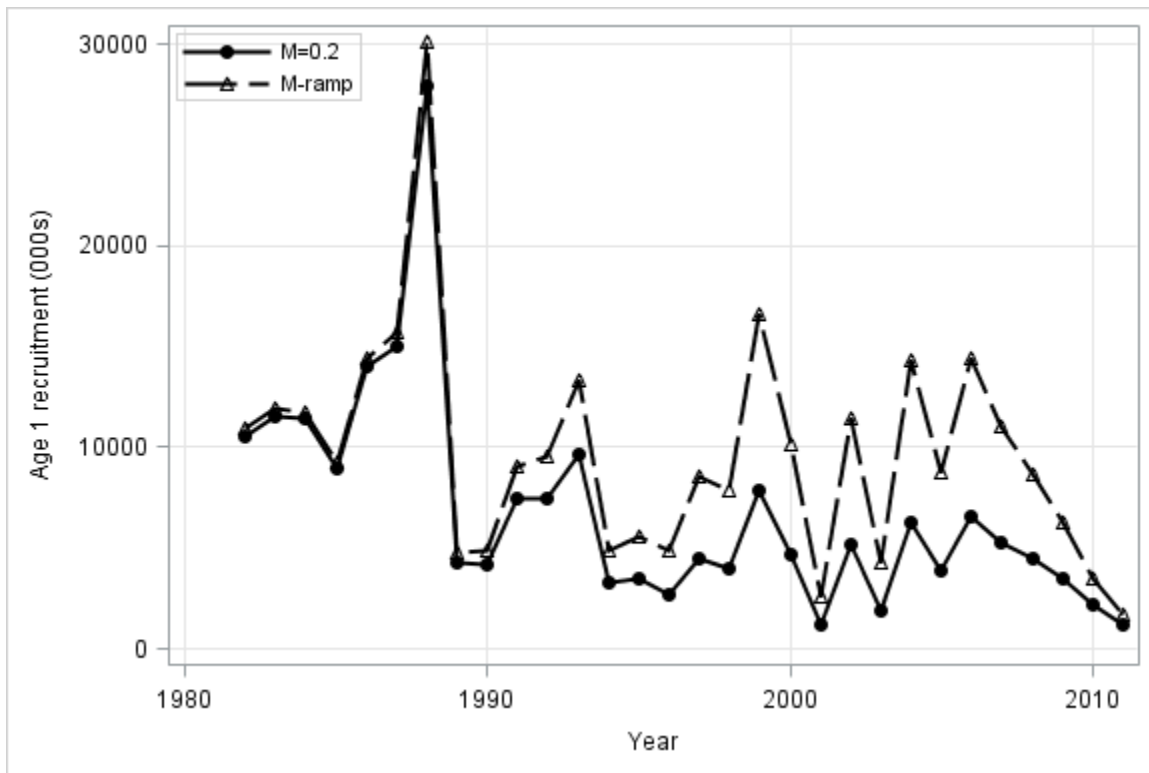


Figure A7. Estimated trends in age 1 recruitment (000s fish) of Gulf of Maine Atlantic cod between 1982 and 2011 based on the 2012 assessment. Results are shown for both the $M_{0.2}$ and M_{Ramp} models.

B. GEORGES BANK ATLANTIC COD ASSESSMENT SUMMARY FOR 2012

State of Stock: The Georges Bank cod stock is overfished and overfishing is occurring (Figure B1). Spawning stock biomass (SSB) in 2011 is estimated to be 13,216 mt which is 7% of the SSB_{msy} (186,535 mt) (Figure B1). The 2011 fully recruited fishing mortality (ages 5+) is estimated to be 0.43 which is more than twice as high as the F_{msy} (0.18) (Figure B1).

This benchmark assessment is based on a newly formulated model (see Data and Assessment section below).

The assessment model exhibits a strong retrospective pattern (tending to overestimate SSB and underestimate F) which was corrected for when providing the estimates of SSB and F for 2011, stock status and projection starting points.

Projections: Short term projections (3-years) of catch and SSB were made under an assumption of $F = 0.75 \cdot F_{MSY \text{ Proxy}}$ (Table B1). Based on the recommendations of the GARM III Panel (O'Brien et al. 2008) and reviewed by the SAW 55 WG, recruitment is estimated from one of two distributions based upon the magnitude of SSB. Recruitment is generally lower when SSB is less than 50,000 mt. Thus the 1978-2011 ASAP estimated age-1 fish recruitment is separated into two distributions based on the SSB breakpoint of 50,000 mt. Recruitment is estimated from the low recruitment distribution when SSB is < 50,000 mt or from the high recruitment distribution when SSB > 50,000 mt (Figure B2).

Catch and Status Table: Georges Bank Atlantic cod (weights in 000s mt, recruitment in millions, arithmetic means)

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2011 ²	Min ¹	Mean ¹	Max ¹
USA Commercial Landings	9.5	6.9	3.5	2.8	2.7	3.7	3.3	3.0	2.7	3.4		2.7	16.1	40.1
USA Commercial Discards	0.2	0.2	0.1	0.4	0.2	0.7	0.3	0.4	0.3	0.1		0.1	0.3	0.8
CDN Commercial Landings	1.3	1.3	1.1	0.6	1.1	1.1	1.4	1.0	0.7	0.7		0.6	5.8	17.8
CDN Commercial Discards	0.1	0.2	0.1	0.2	0.3	0.1	0.1	0.2	0.1	<0.1		<0.1	0.1	0.5
Recreational Landings	0.3	0.3	0.3	0.9	0.1	<0.1	0.1	<0.1	0.1	0.2		<0.1	1.7	5.4
Recreational Discards	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	0.0	0.1
Catch used in assessment	11.4	8.9	5.2	5.0	4.4	5.7	5.2	4.6	3.9	4.5		3.9	24.0	62.1
Spawning Stock Biomass	20.5	15.0	11.9	10.1	10.4	11.0	11.5	14.7	17.2	22.2	13.2	10.1	40.6	96.9
Recruitment (age 1)	4.0	1.3	7.0	1.5	4.0	5.8	5.3	8.1	8.1	7.3	5.1	1.3	13.6	47.1
F (ages 5-8)	0.76	0.80	0.54	0.65	0.50	0.65	0.58	0.42	0.29	0.23	0.43	0.23	0.65	1.10

¹ During 1978-2011

² retrospective adjusted; previous 6 years are not adjusted but should be considered biased

Stock Distribution and Identification: The Atlantic cod, *Gadus morhua*, is a demersal gadoid species found on both sides of the North Atlantic. In the Northwest Atlantic, cod

occur from Greenland to North Carolina. Cod are assessed and managed as two stocks: (i) Gulf of Maine and (ii) Georges Bank and southward. Georges Bank cod is a transboundary stock fished by both the US and Canada (Figure B3).

Catches: Total USA commercial landings ranged between 11,000 mt to 40,000 mt during 1960-1993, averaging about 21,000 mt. As stock biomass declined and year round closures were implemented in Dec 1994, landings declined, ranging between 3,000 mt – 15,000 mt during 1994-2011, averaging about 6,000 mt. Total Canadian (CDN) landings ranged between 19 mt to 18,000 mt during 1960-1993 and after large quota restrictions in 1993, CDN landings ranged between 600 mt to 8,500 mt with an average of about 1,600 mt during 1994-2011. USA and CDN commercial discards combined accounted for less than 5% of the annual catch during 1978-2005 and have averaged about 10% of the catch during 2005-2011. USA recreational catch is generally less than 10% of total catch of GB cod. Total catch of all fleets combined has ranged from 3,950 mt to 5,660 mt during 2007-2011 (Catch and Status Table above; Figure B4).

Data and assessment: The previous assessment of Georges Bank cod was conducted using virtual population analysis (VPA). The new benchmark assessment applies a statistical catch-at-age model (ASAP; Legault and Restrepo 1999) which can more fully account for the uncertainties in the catch and surveys. The ASAP model incorporates the total catch of USA and CDN commercial and recreational landings and discards. The model uses two fishery selectivity blocks assuming flat-topped selectivity for both the catch and research survey indices. The catch-at-age for 1978-2011 includes catch by all gear types, though Georges Bank cod are primarily caught using otter trawl (USA) and longline (CDN) (with minor contributions from hook and gillnet gear). USA commercial discards were estimated for 1989 to 2011, and were hindcasted from 1978-1988. CDN discards were estimated from 1978-2011. Discard mortality was assumed to vary by gear type, but only for USA fisheries. This represents a change from previous assessments that assumed 100% mortality of discarded fish. Recreational landings and discards estimates were included for 1978 onward. All catch sources were combined into a single fleet.

Swept-area estimates of abundance from the NEFSC spring and autumn surveys (1978-2011), and the Department of Fisheries and Oceans (DFO) survey (1986-2011) were used in the ASAP model along with associated estimates of uncertainty and annual age composition. Survey indices were variable but relatively stable between 1963 and the early 1980s, then gradually declined until about 1995 and have remained low since that time (Figure B5).

Natural mortality was assumed to be 0.2 for all ages and years. Other models were considered which changed the natural mortality rate over time. Annual estimates of maturity at age varied over time and a decline in median age (A_{50}) from 2.4 in 1978 to 1.7 in 1988 was observed, and A_{50} subsequently increased to 2.4 in 2011.

Biological Reference Points: An MSY could not be derived directly from the assessment, therefore an MSY proxy must be used for reference points.

$F_{40\%}$ is the proxy for the overfishing threshold (F_{MSY}). This is as has been used in the previous assessment and consistent with the choice of proxy and the SAW 55 working group's recommendation. A deterministic value of $F_{40\%}$ was estimated from a spawner per recruit analysis using 2007-2011 average SSB weights, catch weights, maturity and selectivity at age. Expressed as a fully recruited fishing mortality (ages 5+), $F_{40\%}$ is 0.18.

Stochastic projections at $F_{40\%}$ were used to determine newly recommended biomass-related reference points (proxies for both SSB_{MSY} and MSY). The projection methodology used to determine SSB_{MSY} and MSY proxies was identical to those used for short-term projections. The proxy for SSB_{MSY} is estimated at 186,535 mt, the median of the stochastic projections, with 10th and 90th percentiles spanning 155,398 – 220,756 mt. One half of SSB_{MSY} is 93,268 mt, the $B_{THRESHOLD}$.

Age specific retrospective pattern adjustments to the abundance at age were used to start the projections. This same procedure should be used in additional short term management projections. However, the source of the retrospective pattern is unresolved and therefore an $F_{REBUILD}$ cannot be determined at this time. The proxy for MSY is 30,622 mt, with 10th and 90th percentiles spanning 25,450 – 36,302 mt. The median recruitment at SSB_{MSY} is 23.3 million age 1 fish.

The biological reference points estimated in the last assessment (O'Brien et al. 2012) were $F_{MSY}=F_{40\%}=0.23$, $SSB_{MSY}=140,424$ mt, and $MSY=28,774$ mt.

Fishing Mortality: In 1978, the fully recruited F_{5+} was 0.40. It increased to 0.87 in 1985, declined to 0.54 in 1989 and then increased to a record high of 1.10 in 1994. Fishing mortality subsequently fluctuated but generally decreased through 2007, and then declined steadily since that time. The 2011 F_{5+} is estimated at 0.23 (90% posterior probability interval 0.15 – 0.34). The uncertainty in F_{2011} is presented in Figure B6. For stock status determination, the 2011 F estimate is adjusted to 0.43 to account for the retrospective pattern (Figure B4).

Biomass: The ASAP model estimate of spawning stock biomass (SSB) was 96,864 mt in 1980, the time series high. SSB then declined with some fluctuation to 19,220 mt in 1995 and then gradually increased to 25,624 mt in 2001. Since that time, SSB declined with no fluctuation to a time series low of 10,121 mt in 2005 and has since gradually increased (Figure B7). SSB in 2011 is estimated to be 22,217 mt (90% posterior probability interval 15,809 – 31,993 mt). The uncertainty in 2011 SSB is presented in Figure B8. For stock status determination, the 2011 SSB estimate is adjusted to 13,216 mt to account for the retrospective pattern (Figure B7).

Recruitment: The time series mean recruitment (age 1) is approximately 13.6 million fish. Strong year classes were produced in 1979, 1981, 1982, 1983, 1987, and 1991 with below average recruitment for the last two decades (Figure B7). Recruitment has not exceeded the long-term mean since the 1991 year class. Recruitment in 2011 is estimated to be 7.3 million fish. For short term projections, the 2011 recruitment estimate is adjusted to 5.1 million fish to account for the retrospective pattern.

Special Comments:

- The last above average year class was 1991. Until spawning stock biomass gets above about 50,000 mt, recruitment is likely to remain low and rebuilding will be slow.
- The assessment model continues to exhibit a strong retrospective pattern. One possible cause of which could be increased recent natural mortality. Status evaluation and short term projected catches based on 75% Fmsy were very similar compared to an alternative assessment formulation that included an increase in M from 0.2 to 0.4 between 1990 and 2002. However, the source of the retrospective pattern remains unresolved.
- The model accepted (base case) for setting reference points and as a basis for catch advice does not imply that the SARC Panel believes constant natural mortality rate of 0.2 necessarily reflects the state of nature. The model formulation encapsulates through the retrospective adjustment the possibility that factors, including natural mortality, are different or changing in the system.
- Given the uncertainty in the retrospective adjustment, downward trends in mean weight at age, and a potential recent increase in natural mortality (the key elements of the productivity processes), the projections may be optimistic.

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- O'Brien, L., N.Shepherd, and Y. Wang. 2012. A. Georges Bank Atlantic Cod *in* Northeast Fisheries Science Center. 2012. Assessment or Data Updates of 13 Northeast Groundfish Stocks through 2010. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 12-06; 789 p. <http://www.nefsc.noaa.gov/nefsc/publications/>.

Table B1. Short term projections of total fishery yield and spawning stock biomass for Georges Bank Atlantic cod based on a harvest scenario of fishing at 75% F_{MSY} between 2013 and 2015. Catch in 2012 has been estimated at 2,910 mt.

Year	Catch	SSB	F
2012	2.910	18.184	0.17
2013	2.594	20.174	0.14
2014	2.816	21.415	0.14
2015	3.265	26.005	0.14

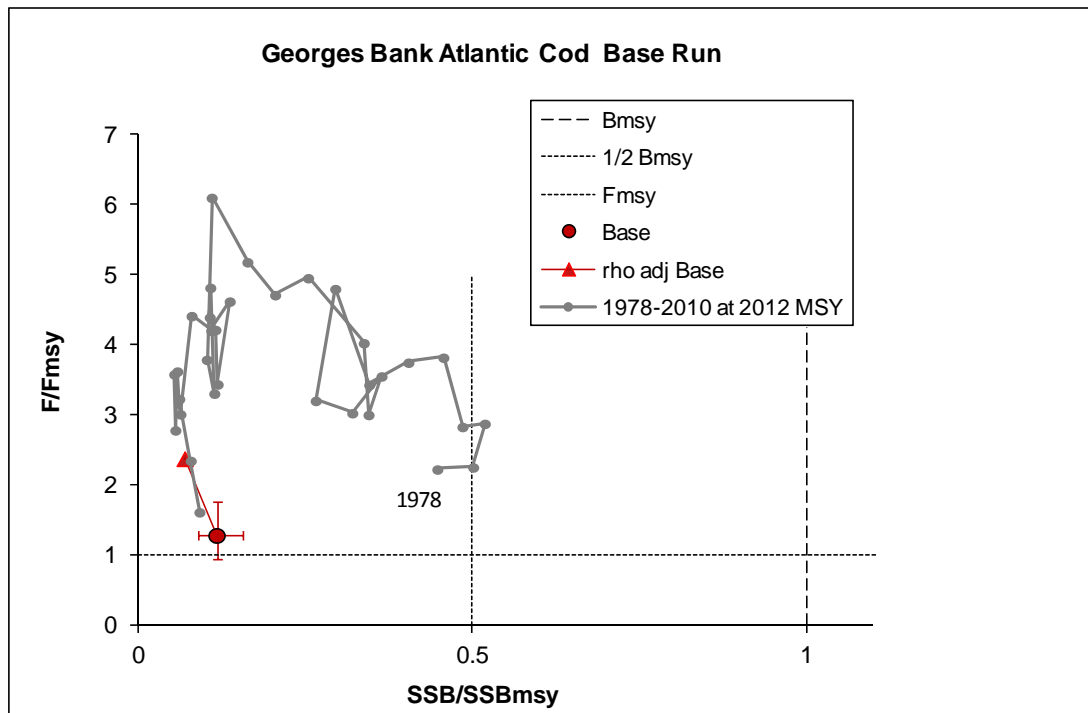


Figure B1. Stock status of Georges Bank Atlantic cod for 2011 relative to MSY reference points for spawning stock biomass (SSB) and fishing mortality (F_{5+}); 2011 estimate is the colored dot, error bars represent 80% posterior probability intervals; colored triangle represents the value for 2011 when it is rho adjusted for the retrospective pattern. Gray dotted line is the 1978-2010 time series ratio based on 2012 MSY reference points.

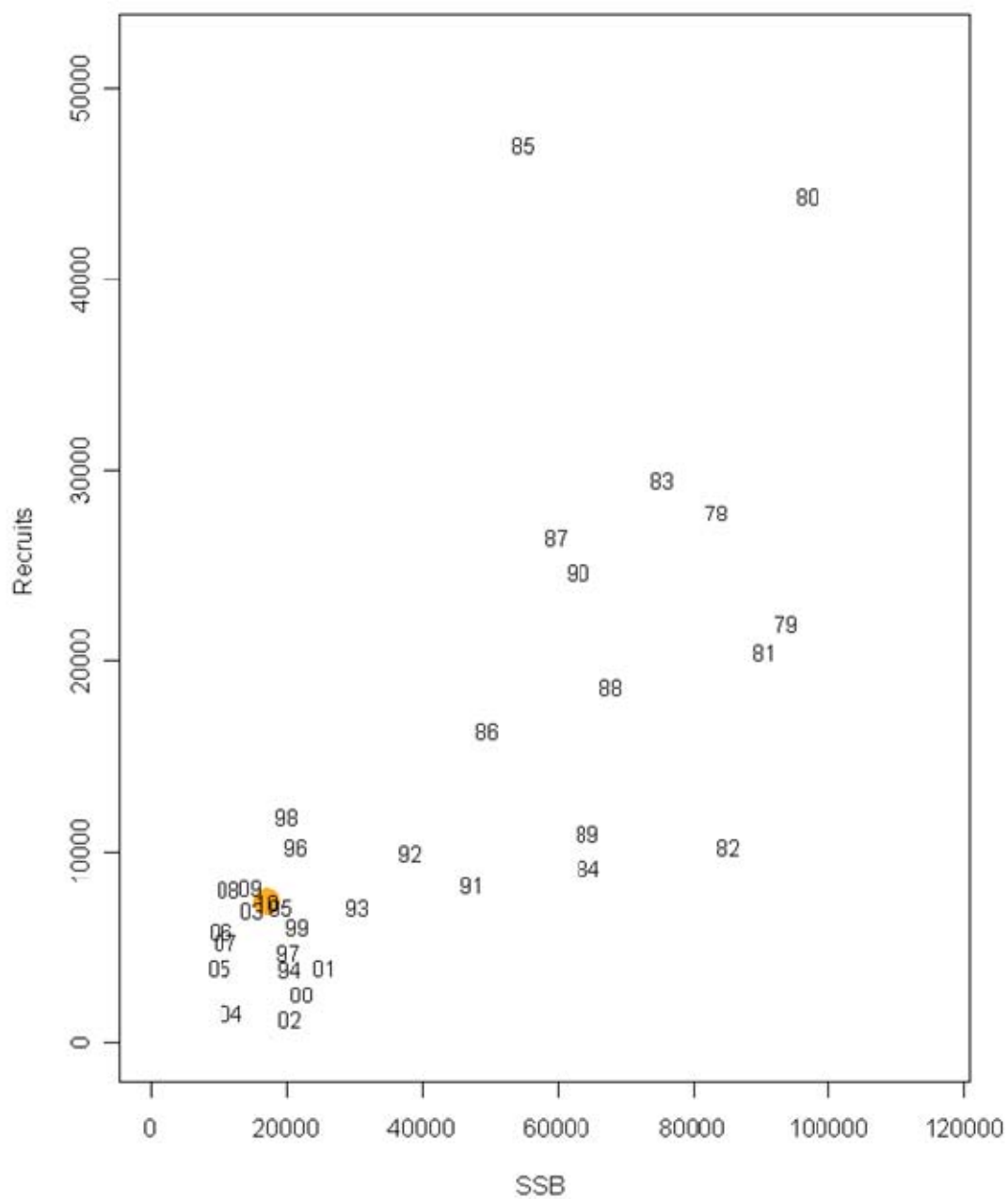


Figure B2. Spawning stock and recruitment of Georges Bank Atlantic cod, 1978-2010.

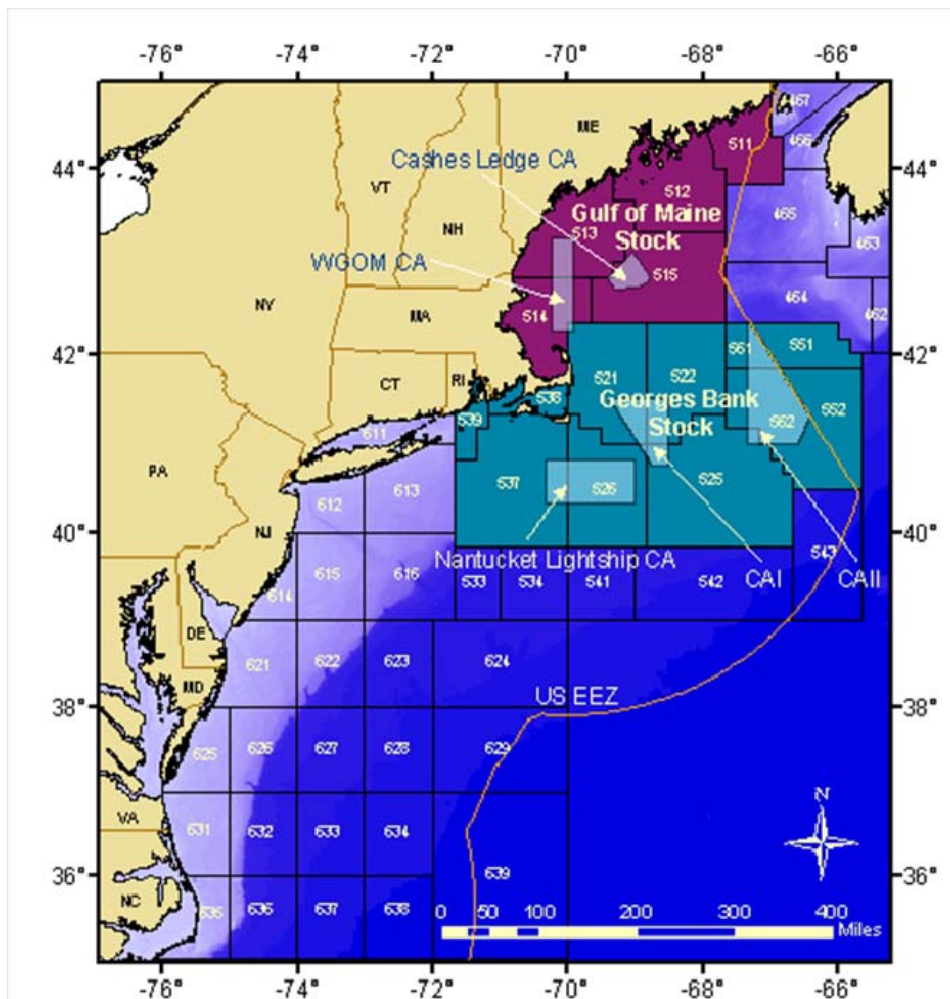


Figure B3. Stock area of Georges Bank cod as defined by Northwest Atlantic Fisheries Organization (NAFO) Div 5Z and Subarea 6 (NMFS statistical areas: 521-526, 551-552, 561-562, 537-539 and south).

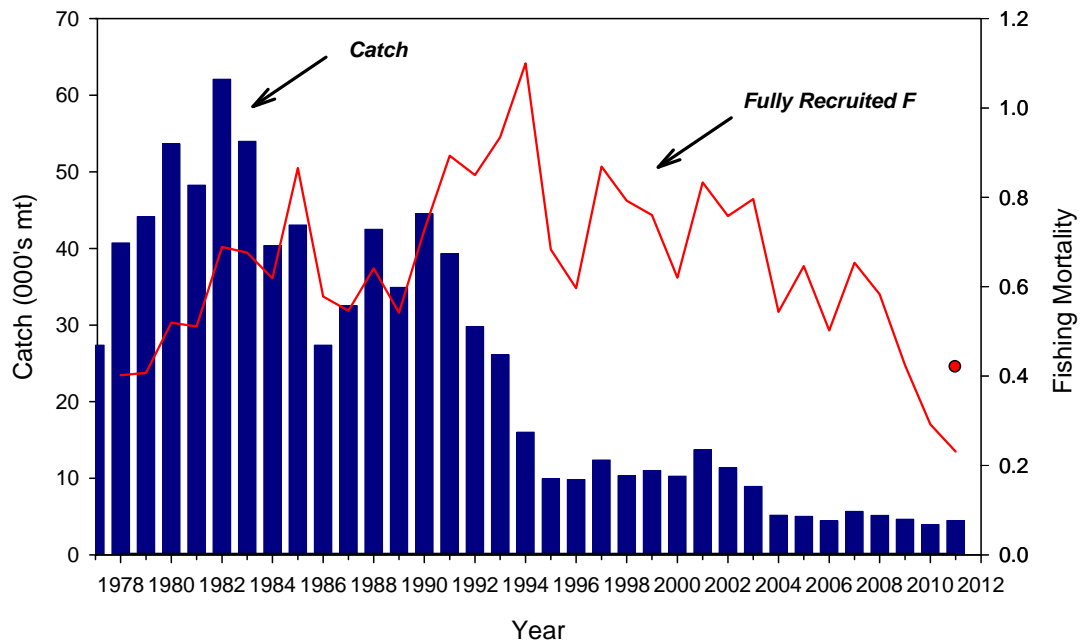


Figure B4. Catch and fully recruited F (ages 5+) for Georges Bank Atlantic cod, 1978-2011. Red dot is the retrospective adjusted 2011 F.

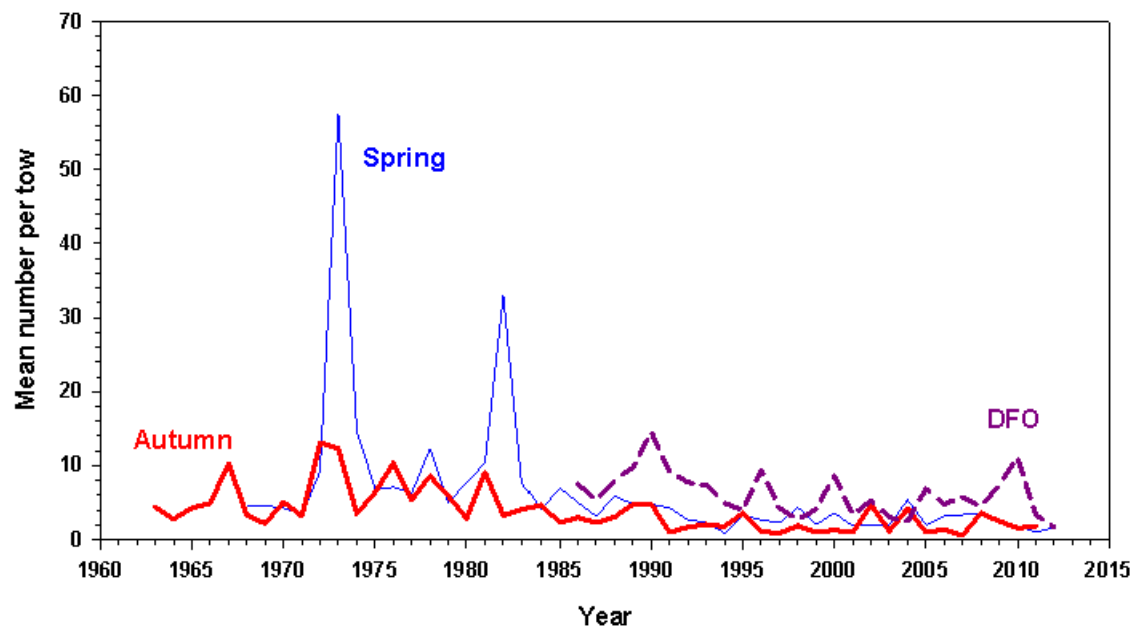


Figure B5. Standardized stratified mean number per tow of Atlantic cod in NEFSC spring, DFO, and NEFSC autumn research survey vessel bottom trawl surveys (NEFSC strata 13-25; DFO strata 5Z1-5Z8) on Georges Bank, 1963-2012.

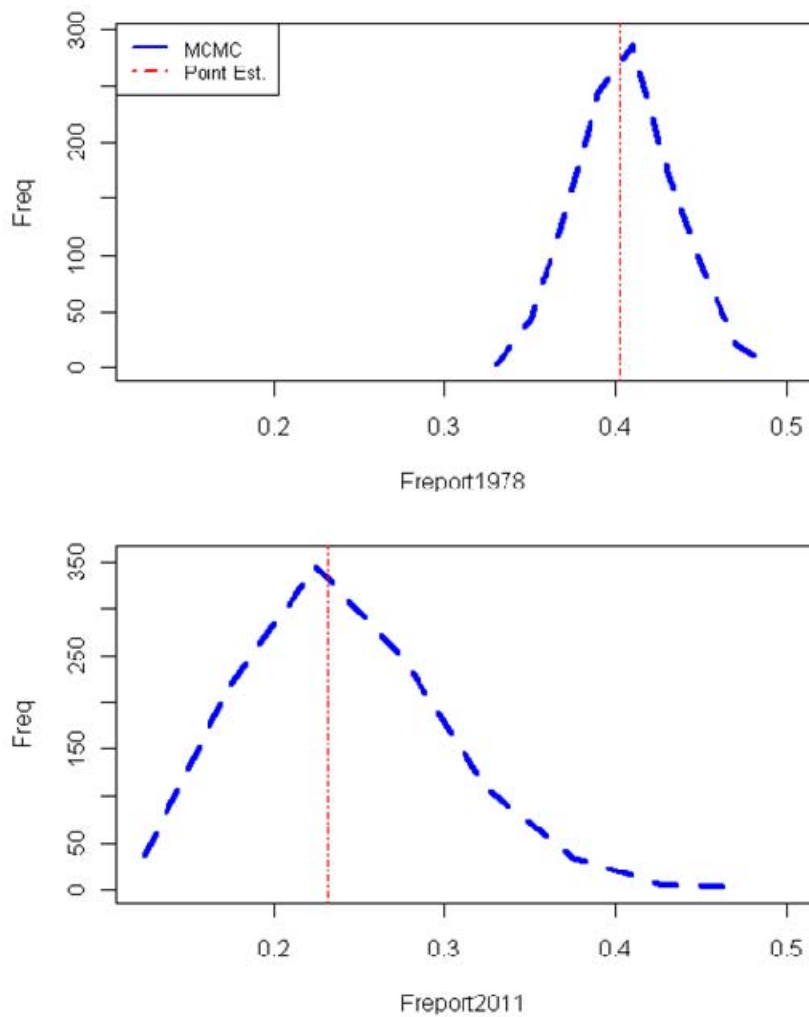


Figure B6. MCMC distribution of Georges Bank Atlantic cod fishing mortality (ages 5+) in 1978 and 2011 estimated from the BASE ASAP model. The model point estimate is indicated by the dashed red line.

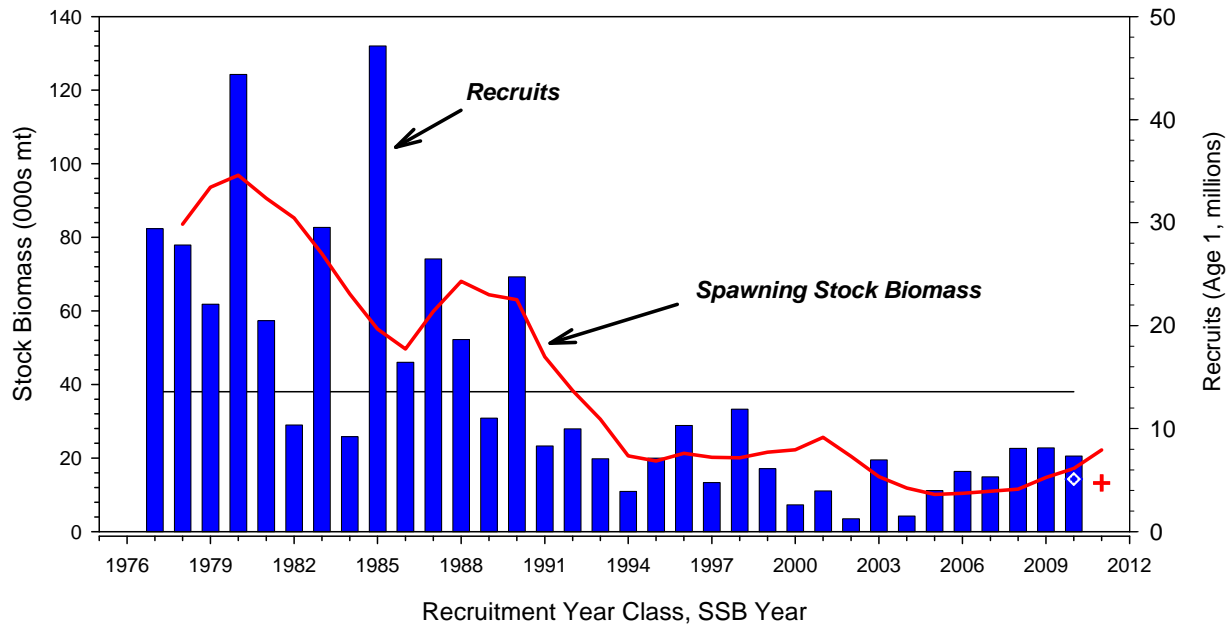


Figure B7. Spawning stock biomass (SSB-line) and recruitment (age 1-bar plot) for Georges Bank Atlantic cod, 1978-2011. The colored plus sign is the retrospective adjusted 2011 SSB and the white diamond with blue dot is the retrospective adjusted 2010 recruitment.

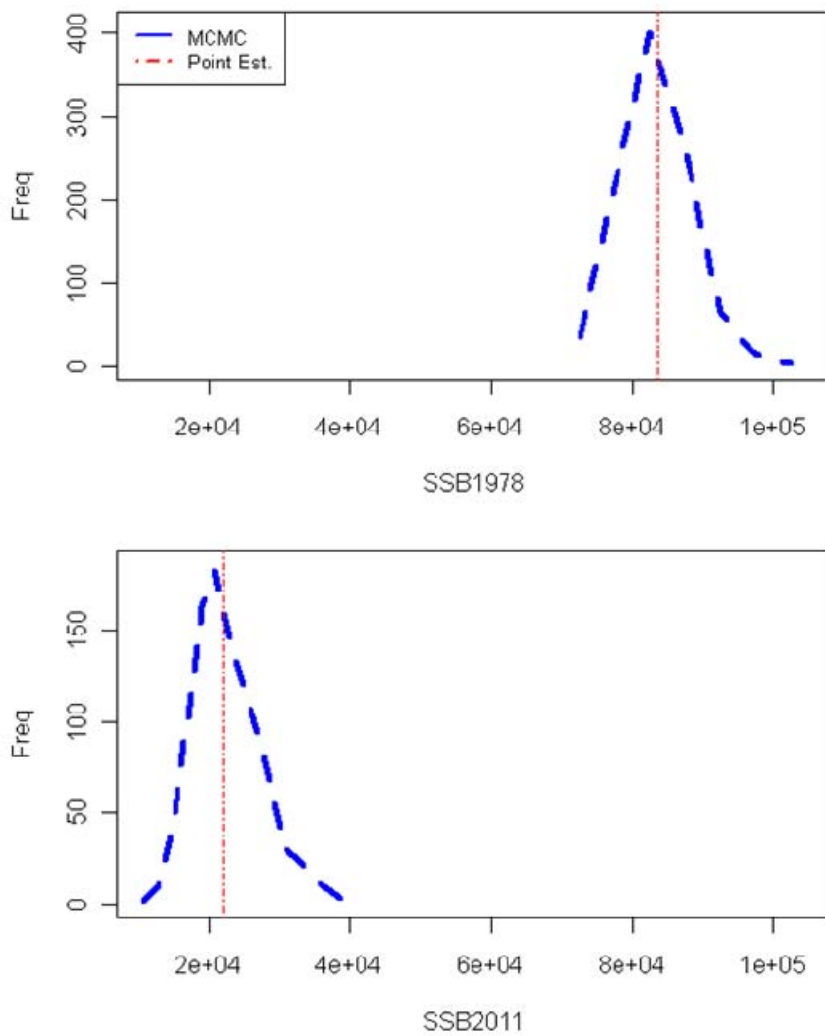


Figure B8. MCMC distribution of Georges Bank Atlantic cod spawning stock biomass in 1978 and 2011 estimated from the BASE ASAP model. The model point estimate is indicated by the dashed red line.

Appendix: Stock Assessment Terms of Reference for SAW/SARC55, December 3-7, 2012
(To be carried out by SAW Working Groups) (v. 5/30/2012)

A. Gulf of Maine cod stock

1. Estimate catch from all sources including landings and discards. Characterize the uncertainty in these sources of data and take into account the recommendations and subsequent work from the March 2012 MRIP workshop. Evaluate available information on discard mortality and, if appropriate, update mortality rates applied to discard components of the catch.
2. Present the survey data and calibration information being used in the assessment (e.g., indices of abundance, recruitment, state surveys, age-length data, etc.). Consider model-based (e.g. GLM) as well as design-based analyses of the survey data in developing trends in relative abundance. Investigate the utility of commercial or recreational LPUE as a measure of relative abundance. Characterize the uncertainty and any bias in these sources of data.
3. Summarize the findings of recent workshops on stock structure of cod of the Northeastern US and Atlantic Canada.
4. Investigate the evidence for natural mortality rates which are time- and/or age-specific. If appropriate, integrate these into the stock assessment (TOR 5).
5. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Consider feasibility of survey catchability estimates, the starting year for the assessment, estimation of the stock recruitment curve, inclusion of multiple fleets, and whether to use domed or flat selectivity-at-age for the NEFSC surveys. Provide a summary of steps in the model building process. Include a historical retrospective analysis to allow a comparison with previous assessment results. Review the performance of historical projections with respect to stock size, catch recruitment and fishing mortality.
6. State the existing stock status definitions for “overfished” and “overfishing”. Then update or redefine biological reference points (BRPs; point estimates or proxies for B_{MSY} , $B_{THRESHOLD}$, F_{MSY} , and MSY) and provide estimates of their uncertainty. Consider alternative parametric models of the stock recruitment relationship. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the appropriateness of existing BRPs and any “new” (i.e., updated, redefined, or alternative) BRPs.
7. Evaluate stock status with respect to the existing model (from the most recent accepted peer reviewed assessment) and with respect to a new model developed for this peer review. In both cases, evaluate whether the stock is rebuilt.
 - a. When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.
 - b. Then use the newly proposed model and evaluate stock status with respect to

“new” BRPs (from Cod TOR-6).

8. Develop and apply analytical approaches to conduct single and multi-year stock projections to compute the pdf (probability density function) of the OFL (overfishing level) and candidate ABCs (Acceptable Biological Catch; see Appendix to the SAW TORs).
 - a. Provide numerical annual projections (3-5 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment).
 - b. Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.
 - c. Describe this stock’s vulnerability (see “Appendix to the SAW TORs”) to becoming overfished, and how this could affect the choice of ABC.
9. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

B. Georges Bank cod stock

1. Estimate catch from all sources including landings and discards. Characterize the uncertainty in these sources of data and take into account the recommendations and subsequent work from the March 2012 MRIP workshop. Evaluate available information on discard mortality and, if appropriate, update mortality rates applied to discard components of the catch.
2. Present the survey data and calibration information being used in the assessment (e.g., indices of abundance, recruitment, state surveys, age-length data, etc.). Consider model-based (e.g. GLM) as well as design-based analyses of the survey data in developing trends in relative abundance. Investigate the utility of commercial or recreational LPUE as a measure of relative abundance. Characterize the uncertainty and any bias in these sources of data.
3. Summarize the findings of recent workshops on stock structure of cod of the Northeastern US and Atlantic Canada.
4. Investigate the evidence for natural mortality rates which are time- and/or age-specific. If appropriate, integrate these into the stock assessment (TOR 5).
5. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Consider feasibility of survey catchability estimates, the starting year for the assessment, estimation of the stock recruitment curve, inclusion of multiple fleets, and whether to use domed or flat selectivity-at-age for the NEFSC surveys. Provide a summary of steps in the model building process. Include a historical retrospective analysis to allow a comparison with previous assessment results. Review the performance of historical projections with respect to stock size, catch recruitment and fishing mortality.
6. State the existing stock status definitions for “overfished” and “overfishing”. Then update or redefine biological reference points (BRPs; point estimates or proxies for B_{MSY} , $B_{THRESHOLD}$, F_{MSY} , and MSY) and provide estimates of their uncertainty. Consider alternative parametric models of the stock recruitment relationship. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the appropriateness of existing BRPs and any “new” (i.e., updated, redefined, or alternative) BRPs.
7. Evaluate stock status with respect to the existing model (from the most recent accepted peer reviewed assessment) and with respect to a new model developed for this peer review. In both cases, evaluate whether the stock is rebuilt.
 - a. When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.
 - b. Then use the newly proposed model and evaluate stock status with respect to “new” BRPs (from Cod TOR-6).
8. Develop and apply analytical approaches to conduct single and multi-year stock

projections to compute the pdf (probability density function) of the OFL (overfishing level) and candidate ABCs (Acceptable Biological Catch; see Appendix to the SAW TORs).

- a. Provide numerical annual projections (3-5 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment).
 - b. Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.
 - c. Describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming overfished, and how this could affect the choice of ABC.
9. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

Appendix to the SAW Assessment TORs:

**Clarification of Terms
used in the SAW/SARC Terms of Reference**

On “Acceptable Biological Catch” (DOC Nat. Stand. Guidel. Fed. Reg., v. 74, no. 11, 1-16-2009):

Acceptable biological catch (ABC) is a level of a stock or stock complex’s annual catch that accounts for the scientific uncertainty in the estimate of [overfishing limit] OFL and any other scientific uncertainty...” (p. 3208) [In other words, $OFL \geq ABC$.]

ABC for overfished stocks. For overfished stocks and stock complexes, a rebuilding ABC must be set to reflect the annual catch that is consistent with the schedule of fishing mortality rates in the rebuilding plan. (p. 3209)

NMFS expects that in most cases ABC will be reduced from OFL to reduce the probability that overfishing might occur in a year. (p. 3180)

ABC refers to a level of “catch” that is “acceptable” given the “biological” characteristics of the stock or stock complex. As such, [optimal yield] OY does not equate with ABC. The specification of OY is required to consider a variety of factors, including social and economic factors, and the protection of marine ecosystems, which are not part of the ABC concept. (p. 3189)

On “Vulnerability” (DOC Natl. Stand. Guidelines. Fed. Reg., v. 74, no. 11, 1-16-2009):

“Vulnerability. A stock’s vulnerability is a combination of its productivity, which depends upon its life history characteristics, and its susceptibility to the fishery. Productivity refers to the capacity of the stock to produce MSY and to recover if the population is depleted, and susceptibility is the potential for the stock to be impacted by the fishery, which includes direct captures, as well as indirect impacts to the fishery (e.g., loss of habitat quality).” (p. 3205)

Rules of Engagement among members of a SAW Assessment Working Group:

Anyone participating in SAW assessment working group meetings that will be running or presenting results from an assessment model is expected to supply the source code, a compiled executable, an input file with the proposed configuration, and a detailed model description in advance of the model meeting. Source code for NOAA Toolbox programs is available on request. These measures allow transparency and a fair evaluation of differences that emerge between models.

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