

*A Report of the 59th Northeast Regional
Stock Assessment Workshop*

**59th Northeast Regional
Stock Assessment Workshop
(59th SAW)
Assessment Summary Report**

by Northeast Fisheries Science Center

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

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SAW-59 ASSESSMENT SUMMARY REPORT

Introduction

The 59th SAW Assessment Summary Report contains summary and detailed technical information on two stock assessments reviewed during July 15-18, 2014 at the Stock Assessment Workshop (SAW) by the 59th Stock Assessment Review Committee (SARC-59): Gulf of Maine haddock (*Melanogrammus aeglefinus*) and sea scallop (*Placopecten magellanicus*). The SARC-59 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-59 are available at website: <http://www.nefsc.noaa.gov/saw/> under the heading "SARC 59 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-59 Review Panel reports (available at <http://www.nefsc.noaa.gov/nefsc/saw/> under the heading “SARC-59 Panelist Reports”).

For **Gulf of Maine haddock** all but one of the Terms of Reference (ToRs) were fully met and the assessment results from an ASAP model can be used as a basis for management. In 2013, overfishing was not occurring, and the stock was not overfished. The Panel recommended that future work could be done on estimation of the survival rate of discards in the recreational fishery and on the natural mortality rate. Given the continued changes in fishing practices, gear and location, along with the possibility of hyper-aggregation, fishery LPUE for GoM haddock is currently not a reliable indicator of stock status or dynamics.

For **sea scallop** all of the ToRs were fully met and the assessment results can be used as a basis for management. In 2013, overfishing was not occurring, and the stock was not overfished. Stock reconstructions were conducted appropriately using a statistical length-based model (CASA). The assessment used data collected with scallop dredges, a towed digital camera, and a video drop camera. The Panel felt that uncertainty in the assessment was underestimated and identified approaches to address this in the future.

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) $\frac{1}{2}B_{MSY}$, 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.

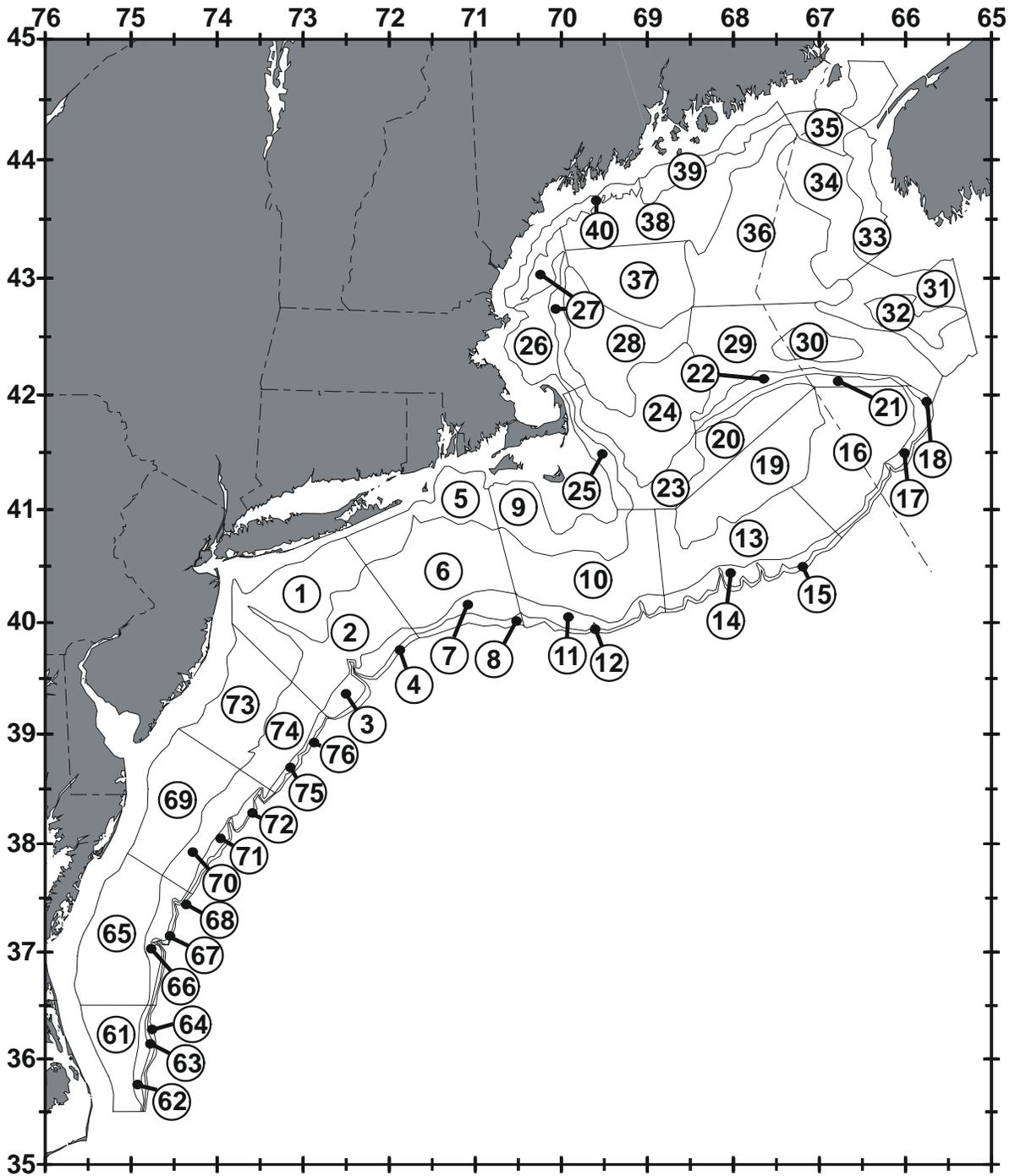


Figure 1. Offshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys. Some of these may not be sampled presently.

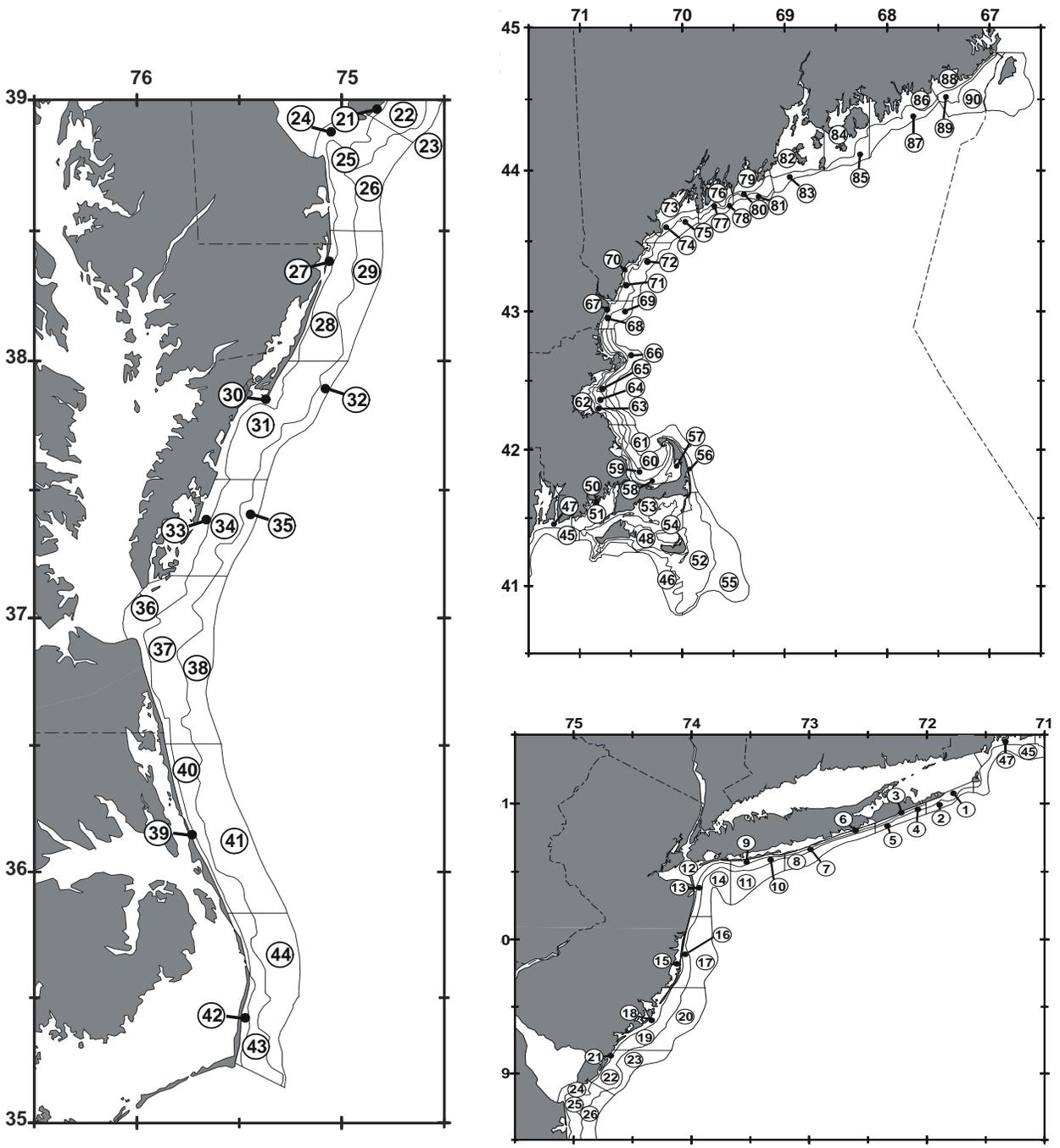


Figure 2. Inshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys. Some of these may not be sampled presently.

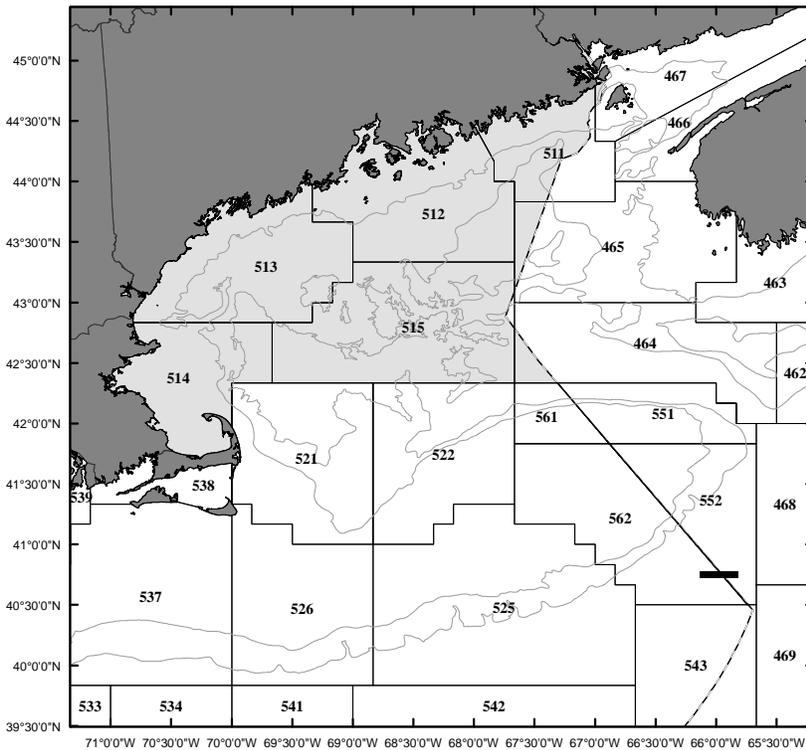
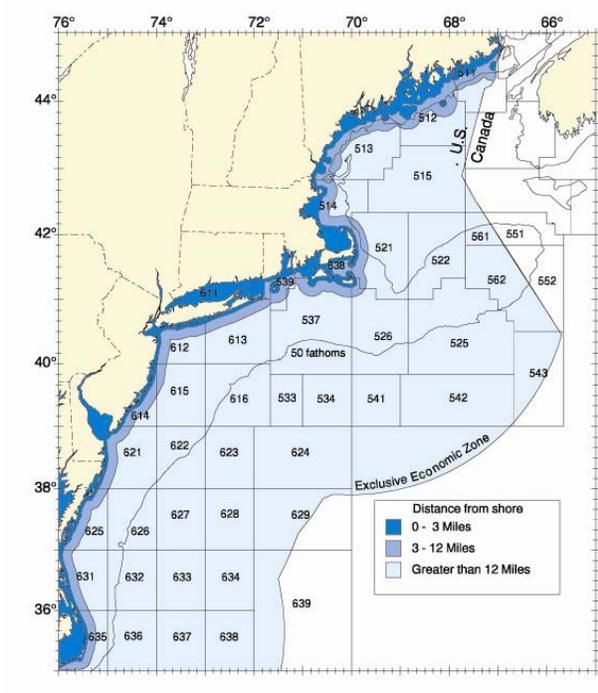


Figure 3. Statistical areas used for reporting commercial catches.

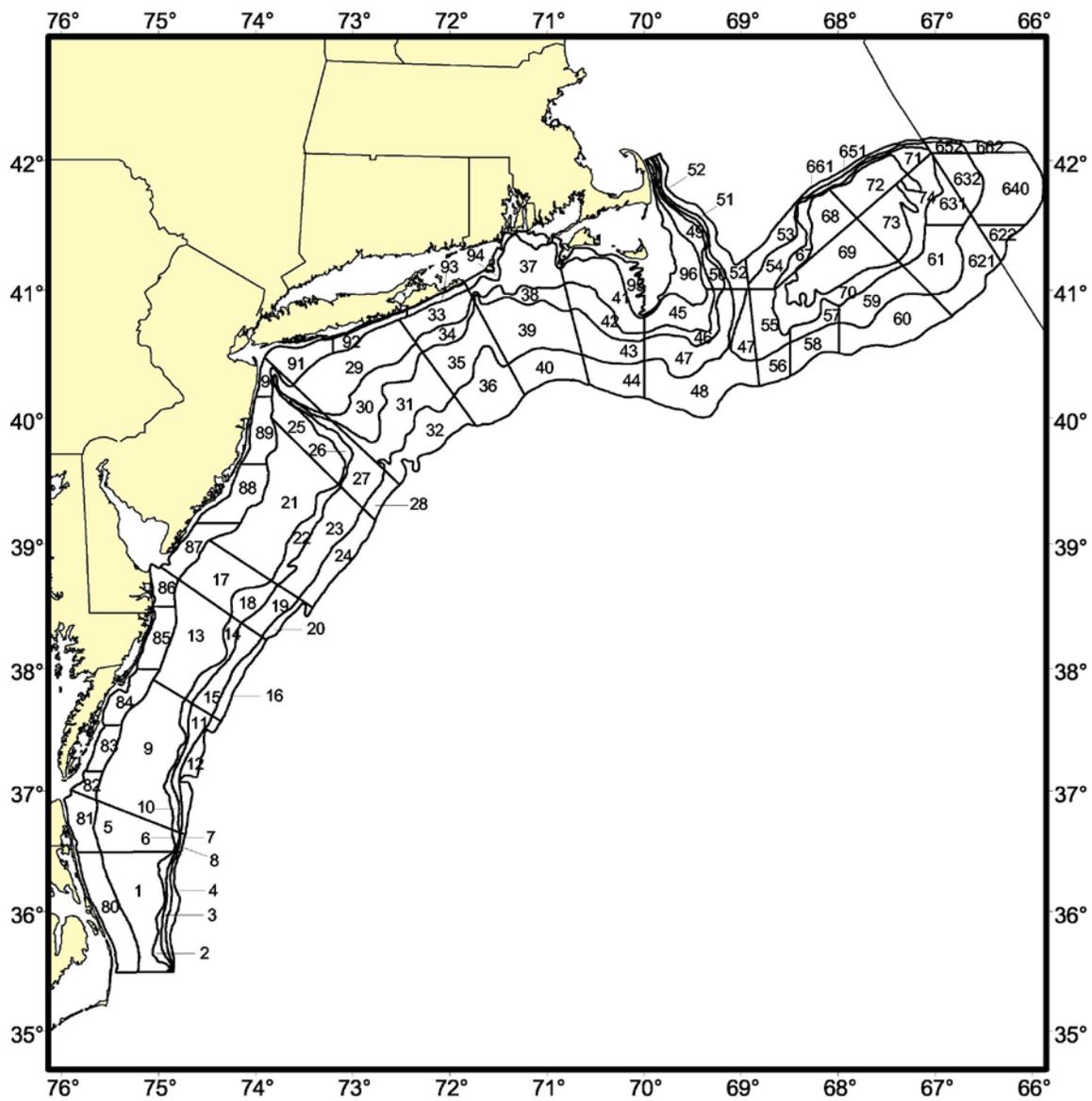


Figure 4. Northeast Fisheries Science Center clam resource survey strata, along the east coast of the US.

A. GULF OF MAINE HADDOCK ASSESSMENT SUMMARY FOR 2014

State of Stock: The Gulf of Maine haddock (*Melanogrammus aeglefinus*) stock is not overfished and overfishing is not occurring in 2013 (Figure A1). Spawning stock biomass (SSB) in 2013 is estimated to be 4,153 mt which is 101% of the SSB_{MSY} proxy (4,108 mt) (Figure A2). The 2013 fully selected fishing mortality is estimated to be 0.39 which is below the F_{MSY} proxy (0.46) (Figure A3).

Projections: The short-term projection method samples future recruitment from a cumulative density function derived from ASAP estimated age-1 recruitment between 1977 and 2011. Age-1 recruitments in 2012 and 2013 were not included in the cumulative density function due to their greater variance. No retrospective adjustment needed to be applied in the projections. Due to the high uncertainty of the size of the 2012 year class, two projection models were developed. The first is based on the final population model and the second is based on a sensitivity model that constrained the size of the 2012 year class (Table A1). Both projection models were run under two different assumptions of calendar year 2014 catch – harvest at F_{MSY} (0.46) and an assumed 2014 catch of 500 mt. The fishing year 2014 Gulf of Maine haddock Annual Catch Limit (ACL) is set at 323 mt, though the ACL does not account for recreational discards. The 500 mt estimate used in the projections was informed by the fishing year 2014 ACL and recent recreational discard amounts.

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

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Min ¹	Mean ¹	Max ¹
Commercial landings	0.95	0.98	0.62	0.68	0.54	0.50	0.62	0.50	0.42	0.21	0.12	1.54	6.32
Commercial discards	0.01	0.02	0.03	0.05	0.01	0.01	0.00	0.01	0.02	0.03	0.00	0.03	0.38
Recreational landings	0.31	0.54	0.45	0.57	0.54	0.41	0.31	0.23	0.25	0.24	0.00	0.15	0.57
Recreational discards ²	0.04	0.04	0.07	0.05	0.07	0.02	0.02	0.01	0.05	0.21	0.00	0.03	0.21
Catch used in assessment	1.31	1.58	1.17	1.34	1.16	0.95	0.96	0.74	0.74	0.69	0.19	1.93	7.66
Spawning stock biomass	9.64	8.10	7.44	6.43	5.46	4.77	3.90	3.06	2.96	4.15	0.60	6.18	15.18
F _{full} ³	0.19	0.29	0.24	0.37	0.34	0.29	0.36	0.34	0.49	0.39	0.19	0.59	1.54
Recruitment (age 1)	6.28	0.39	1.12	1.22	0.22	0.30	0.97	6.66	2.09	16.57	0.13	2.65	16.6

¹ Years 1977-2013

² Recreational discard amounts shown reflect assumption of 50% mortality

³ F_{full} is the fishing mortality on fully selected ages

Stock Distribution and Identification: Haddock (*Melanogrammus aeglefinus*) is a demersal gadoid species whose range in United States (US) waters extends from the mid-Atlantic Bight north to the Canadian border. Within the United States Exclusive Economic Zone (EEZ) there are two recognized stocks of haddock: 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).

Recent reviews of historical and contemporary tagging studies suggest that there is movement of fish between the Gulf of Maine and Georges Bank stocks, though there is considerable uncertainty

regarding the degree of mixing. Several lines of evidence examined during the SAW/SARC59 assessment indicate that annual percent mixing from Georges Bank to the Gulf of Maine is low. While low mixing considered in the models amongst the stocks has limited impacts on current stock status, catch projections for Gulf of Maine haddock were found to be sensitive to the possibility of low movement both in terms of the amount of catch (Figure A5) and the risk to the stock if the wrong mixing rate is assumed.

Catches: Since 1977, fishery removals of Gulf of Maine haddock have ranged from 187 mt to 7,656 mt. Fishery removals over the past five years have ranged from 692 mt to 958 mt. Prior to 1989 there are no direct estimates of commercial discards but discards were hindcast back to 1982 by gear. Prior to 1981 there are no direct estimates of recreational removals and no attempt was made to hindcast recreational catch pre-1981. Over the assessment time series, commercial landings have been the dominant source of fishery removals, constituting 30-100% of the total catch. Commercial discards have been a small component of fishery removals with the exception of a period between 1993 and 1997 when trip limits were 1,000 lb or less. Recreational catch (landings plus discards) has varied annually from a low of 39 mt in 1981 to a high of 618 mt in 2007. Recreational catches have constituted between <1% and 65% of total annual removals, averaging 17% over the 1977-2013 period (Figure A6). The recreational proportion of the total catch has increased in recent years.

Data and assessment: The previous benchmark assessment (i.e., NEFSC 2008) of Gulf of Maine haddock was conducted using a virtual population analysis model (ADAPT-VPA) that incorporated commercial landings and discards as well as recreational landings but not recreational discards. For this assessment, catch-at-age was re-estimated owing to minor modifications to the commercial and recreational catch estimation methodologies. The updates had only minor impacts on the estimated catch-at-age.

For SAW/SARC59, the assessment was conducted using the statistical catch-at-age model, ASAP. The catch inputs included landings and discards from both the commercial and recreational fleets. Trawl gear is the primary mode of capture in the commercial fishery, and as such, commercial discards were assumed to suffer 100% mortality. The recreational discard mortality was assumed to be 50%, though model results were relatively insensitive to alternate assumptions. Fishery removals were modeled as a single fleet, though model sensitivities which explored separate commercial and recreational fleets indicated that the model results were robust to this configuration.

Swept-area estimates of abundance from the NEFSC spring and autumn surveys (1977-2013) were used in the ASAP model along with associated estimates of uncertainty and annual age composition. Current survey indices are at, or near, time series highs (Figure A7) owing to the presence of several strong year classes.

The updated model used three fishery selectivity time blocks and allowed fishery selectivity to be freely estimated at age. Estimated selectivities were similar across time blocks, with the age 5 fish being 50% selected. Selectivity was estimated to be flat-topped in the two earlier time blocks, though there was slight doming in the final block. The model assumed flat-topped selectivity for the

NEFSC survey indices; model results were robust to this assumption.

The size of the potentially large 2012 year class is the largest source of uncertainty in this stock assessment, owing to the fact that the estimate is based on only two surveys. Model sensitivities were explored to evaluate the effects of constraining the size of the 2012 year class. The final base model (ASAP_final_temp10) applies equal constraint to all recruitment estimates. In addition, a sensitivity run placed additional constraint on the estimation of the 2012 year class to illustrate the impacts of this uncertainty on catch projections (Table A1).

Biological Reference Points: Like many haddock stocks, recruitment of Gulf of Maine haddock is highly episodic and not well described by traditional stock recruitment relationships. Given this, an MSY proxy was 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. A deterministic value of $F_{40\%}$ was calculated from a spawner-per-recruit analysis using 2009-2013 average SSB weights, catch weights, selectivity and maturity. Expressed as a fully selected fishing mortality, $F_{40\%}$ is 0.46.

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.

Recruitment series	F_{MSY} (proxy)	F_{msy}	SSB_{MSY} (mt)	MSY (mt)	Median age1 recruitment (000s)
1977-2011	$F_{40\%}$	0.46 (0.36 - 0.54)	4,108 (1,774 - 7,861)	955 (421 - 1,807)	1,121

Intervals shown are the 5th and 95th percentiles.

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

The biological reference points estimated in the previous assessment which used a VPA model (NEFSC 2012) were $F_{MSY}=F_{40\%}=0.46$, $SSB_{MSY}=4,904$ mt, and $MSY=1,177$ mt.

Fishing Mortality: The lowest estimate of fully selected fishing mortality (F_{full}) over the assessment time series is 0.19 (2004). The 2013 F_{full} is 0.39 (90% posterior probability interval 0.24 – 0.60) which is lower than the time series average of 0.59 and the current F_{MSY} proxy of 0.46 (Figure A3).

Biomass: The estimate of 2013 spawning stock biomass (SSB) is 4,153 mt (90% posterior probability interval 2,960 – 6,043 mt). The estimate of 2013 spawning stock biomass is below the time series mean of 6,180 mt, but above the SSB_{MSY} proxy of 4,108 mt (Figure A2).

Recruitment: Recruitment patterns of Gulf of Maine haddock are highly episodic, a feature common among many haddock stocks. Several moderate to strong year classes have been spawned

in the last fifteen years, including the 1998, 2003, 2010 and most recently, the 2012 year class (Figure A8). The absolute size of the 2012 year class is highly uncertain as the estimate is based on only two surveys.

Special Comments:

- The change in stock status from the 2012 update (i.e., not overfished but approaching an overfished condition and overfishing occurring) to the current evaluation of not overfished and no overfishing is due primarily to the addition of three more years of fishery and survey data. The final assessment model updated with this new information indicates that the change in status is driven by the estimate of the very strong 2010 year class, which is estimated to be 6.7 million age-1 fish.
- The absolute size of the potentially strong 2012 year class is the largest source of uncertainty in this assessment. Based on the estimated selectivity patterns, this year class is predicted to be 50% selected by the fishery in 2017 at age 5. Recent changes to the commercial minimum retention size may result in this year class recruiting to the fishery sooner. Catch projections for 2015 reflecting a likely range of the 2012 year class size indicate that the catches vary from 1,271 to 1,871 mt (Table A1) dependent on the assumed strength of this year class and the magnitude of the 2014 catch. Given the high uncertainty with respect to this year class size, the assessment should be updated if future estimates of its size differ significantly from those used in this assessment.
- Stock structure cannot be specified conclusively with available information. If concerns remain, biological analyses such as directed tagging studies, egg dispersal modeling, genetic differentiation, or otolith microchemistry analysis would be needed to estimate the degree of mixing.
- This assessment has assumed a 50% mortality rate of recreational discards. While the assessment results were shown to be relatively insensitive to this assumption, it does have implications for management and catch allocation between the commercial and recreational fleets. Experimental work is needed to reduce the uncertainty of this 50% mortality assumption. The 2012 year class is expected to become available to the recreational fishery in 2015. Given the minimum landing size, those fish would be expected to be discarded.
- Weights at age of older fish declined between the early 1990s and the mid-2000s, but have since stabilized. The SARC 59 was unable to predict whether weights at age would change in the future, and recommends that this be monitored.

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Northeast Fisheries Science Center (NEFSC). In prep. Stock Assessment of Gulf of Maine Haddock. 59th Northeast Stock Assessment Workshop.

Table A1. Short-term projections of total fishery yield and spawning stock biomass for Gulf of Maine haddock based on a harvest scenario of a) fishing at $F_{40\%}$ between 2014 and 2017 and b) an assumed catch of 500 mt in 2014 and fishing at $F_{40\%}$ between 2015 and 2017. Projections are shown based on two different population models to highlight the sensitivity of catch projections to the size of the 2012 year class. Projection results are shown for the base ASAP model (upper table: ASAP_final_temp10) and a sensitivity model that constrains the size of the terminal year class (lower table: ASAP_final_temp11). Confidence intervals in parentheses are 90% intervals.

ASAP_final_temp10 (1977-2011 recruitment)								
Year	Input	Catch (mt)		Spawning stock biomass (mt)		Harvest strategy	F_{full}	
2013	Catch input/model result	692		4,153	(2,690 - 6,043)		0.39	(0.24 - 0.60)
2014	Projection	1,085	(713 - 1,605)	6,341	(4,272 - 9,237)	$F_{40\%}$	0.46	
2015	Projection	1,752	(1,140 - 2,633)	10,014	(6,556 - 15,250)	$F_{40\%}$	0.46	
2016	Projection	2,085	(1,367 - 3,181)	10,844	(7,036 - 16,645)	$F_{40\%}$	0.46	
2017	Projection	2,424	(1,567 - 3,755)	9,808	(6,355 - 14,914)	$F_{40\%}$	0.46	
2013	Catch input/model result	692		4,153	(2,690 - 6,043)		0.39	(0.24 - 0.60)
2014	Imputed catch	500		6,472	(4,328 - 9,473)		0.20	(0.13 - 0.31)
2015	Projection	1,871	(1,189 - 2,848)	10,507	(6,788 - 16,090)	$F_{40\%}$	0.46	
2016	Projection	2,189	(1,409 - 3,369)	11,223	(7,223 - 17,291)	$F_{40\%}$	0.46	
2017	Projection	2,512	(1,607 - 3,896)	10,078	(6,487 - 15,332)	$F_{40\%}$	0.46	
ASAP_final_temp11 (1977-2011 recruitment)								
Year	Input	Catch (mt)		Spawning stock biomass (mt)		Harvest strategy	F_{full}	
2013	Catch input/model result	692		3,643	(2,500 - 5,089)		0.43	(0.28 - 0.67)
2014	Projection	870	(563 - 1,276)	4,961	(3,323 - 7,036)	$F_{40\%}$	0.46	
2015	Projection	1,271	(843 - 1,850)	6,833	(4,620 - 9,805)	$F_{40\%}$	0.46	
2016	Projection	1,456	(989 - 2,104)	7,148	(4,869 - 10,253)	$F_{40\%}$	0.46	
2017	Projection	1,620	(1,099 - 2,376)	6,568	(4,459 - 9,719)	$F_{40\%}$	0.46	
2013	Catch input/model result	692		3,643	(2,500 - 5,089)		0.43	(0.28 - 0.67)
2014	Imputed catch	500		5,050	(3,345 - 7,213)		0.25	(0.17 - 0.40)
2015	Projection	1,350	(863 - 2,011)	7,154	(4,698 - 10,401)	$F_{40\%}$	0.46	
2016	Projection	1,524	(1,004 - 2,239)	7,388	(4,947 - 10,679)	$F_{40\%}$	0.46	
2017	Projection	1,674	(1,113 - 2,473)	6,739	(4,525 - 9,986)	$F_{40\%}$	0.46	

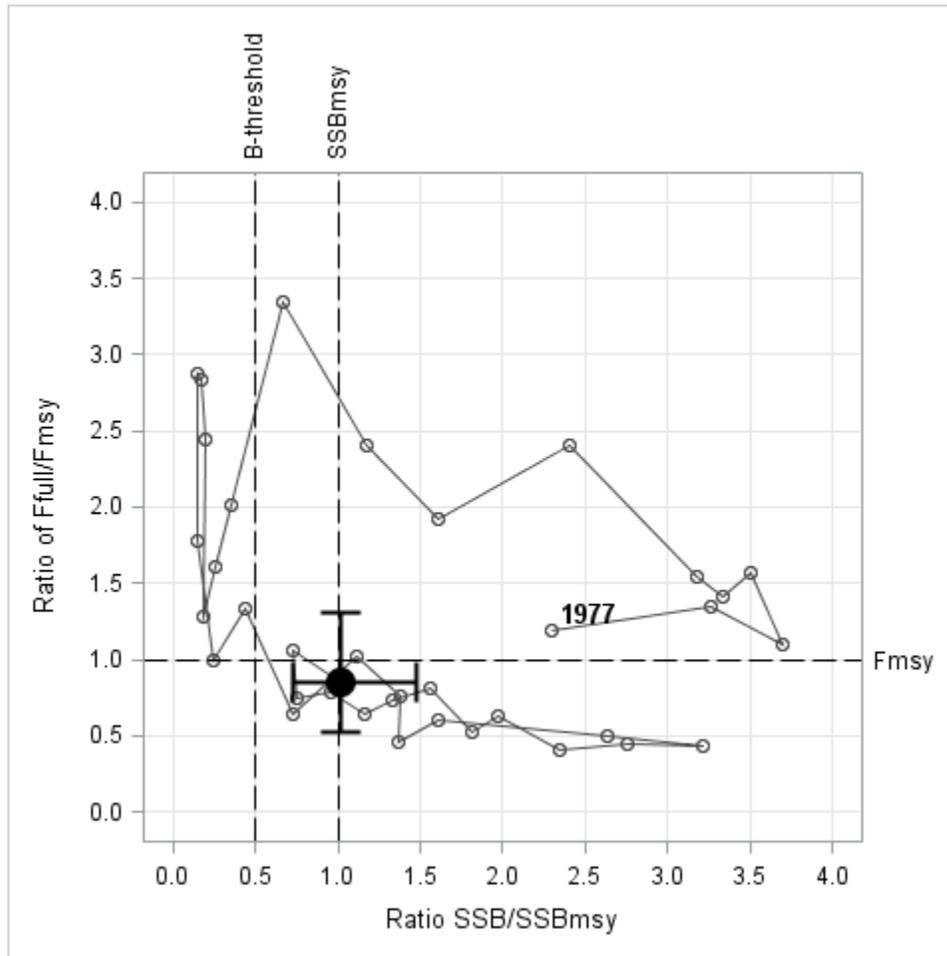


Figure A1. Time series plot of the Gulf of Maine haddock fully selected fishing mortality/ F_{MSY} ratio relative to the spawning stock biomass/ SSB_{MSY} ratio from 1977 to 2013. The current stock status is indicated with a solid black circle along with the corresponding 90% confidence intervals.

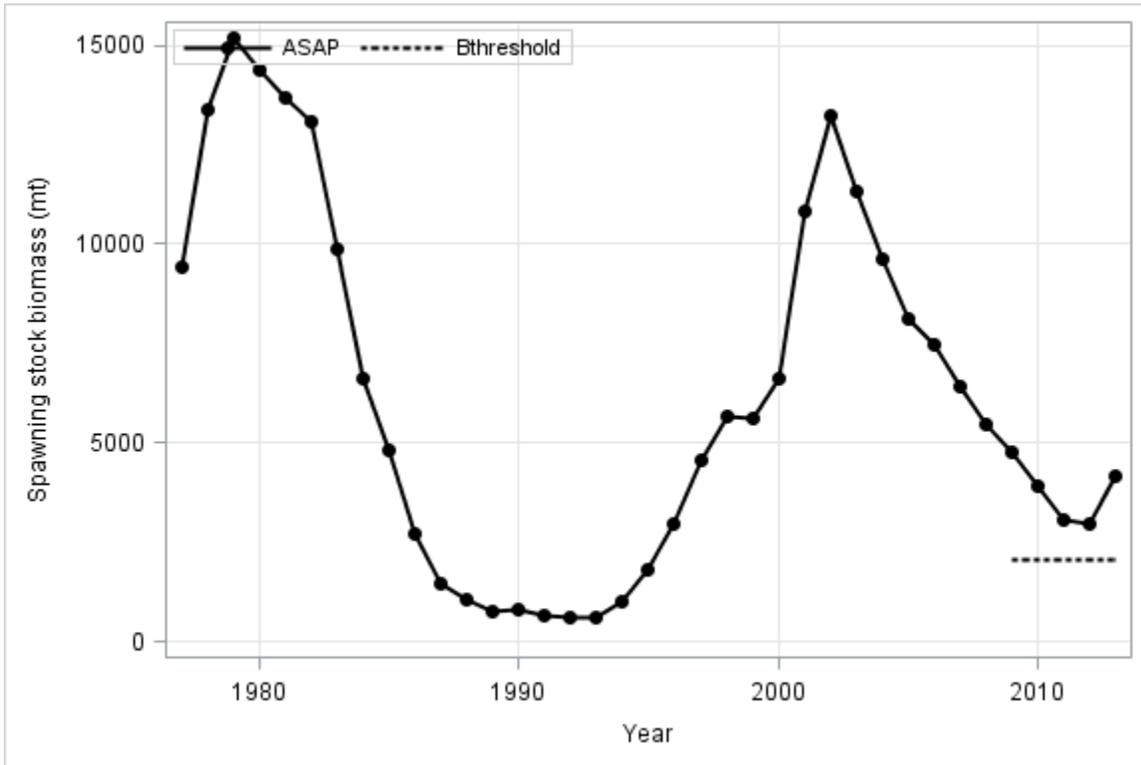


Figure A2. Estimated trends in the spawning stock biomass of Gulf of Maine haddock between 1977 and 2013 and the corresponding $B_{\text{threshold}}$ ($1/2 \text{ SSB}_{\text{MSY}}$) based on the 2014 assessment.

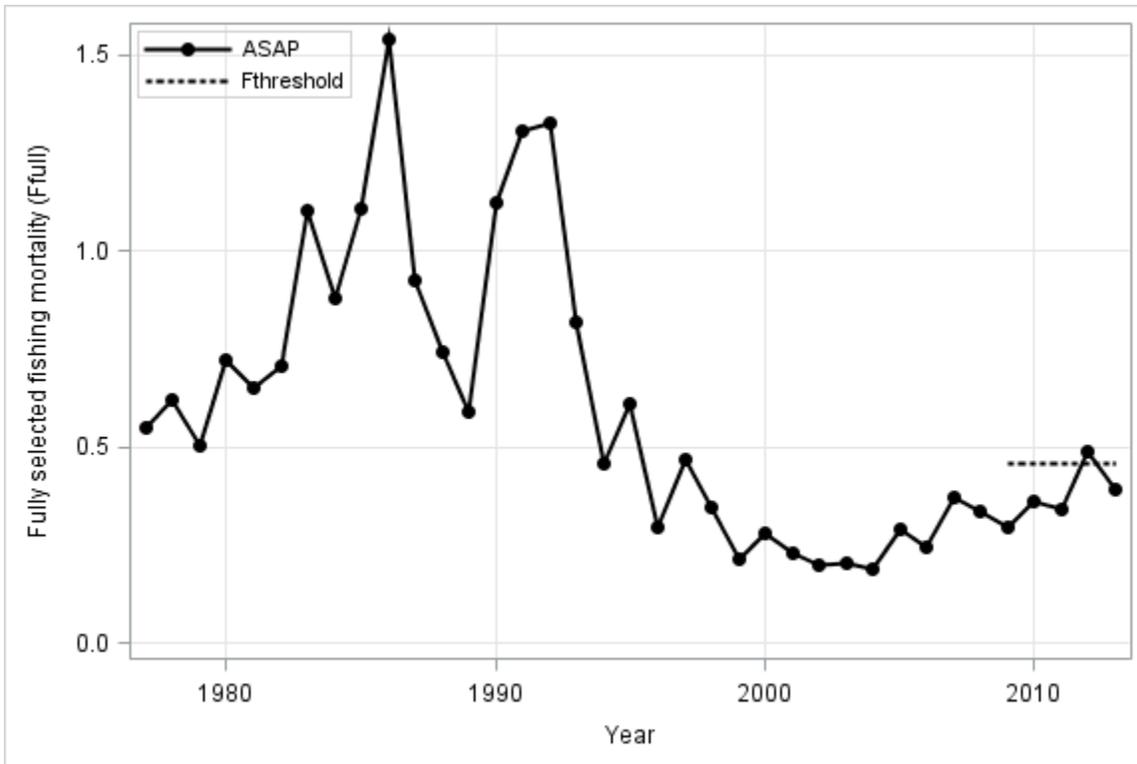


Figure A3. Estimated trends in the fully selected fishing mortality (F_{full}) of Gulf of Maine haddock between 1977 and 2013, and the corresponding F_{MSY} based on the 2014 assessment.

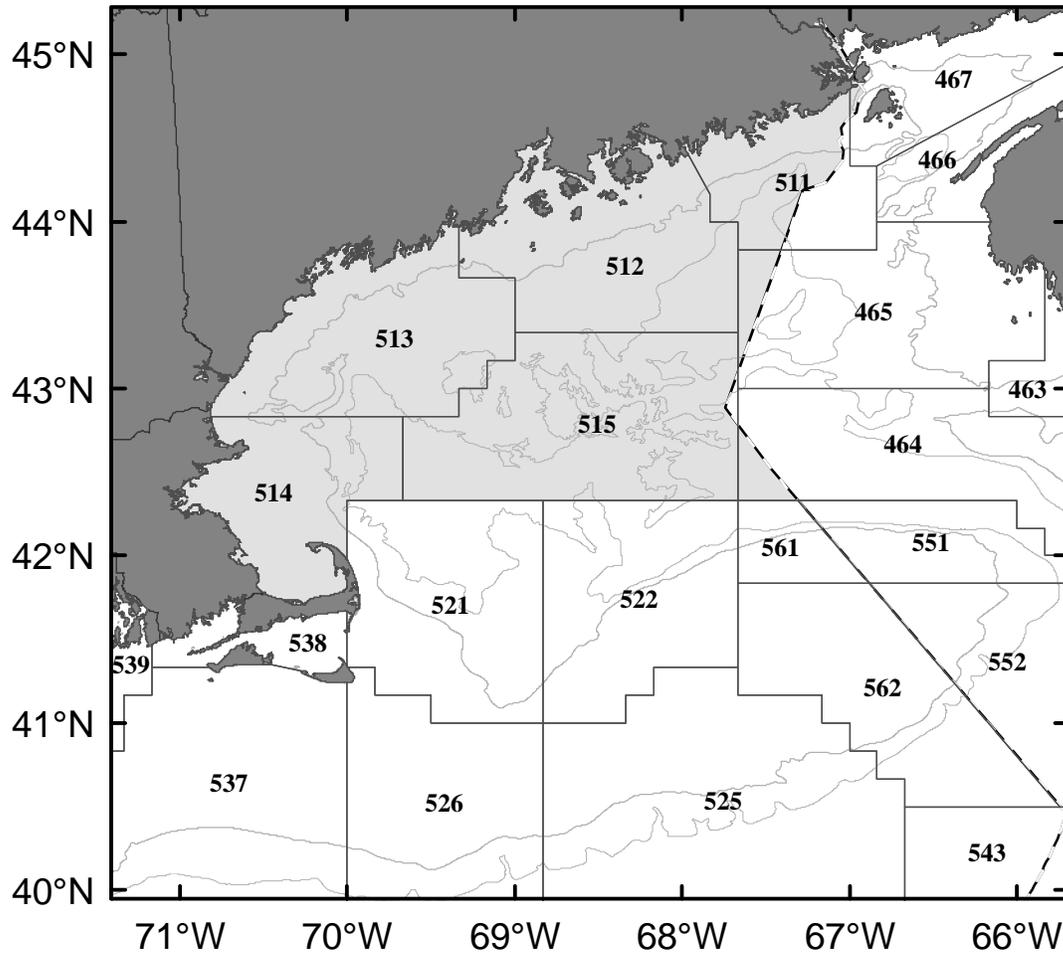


Figure A4. Map of the Gulf of Maine haddock (*Melanogrammus aeglefinus*) management and assessment area (shaded grey). The United States exclusive economic zone (EEZ) is defined by the dashed line.

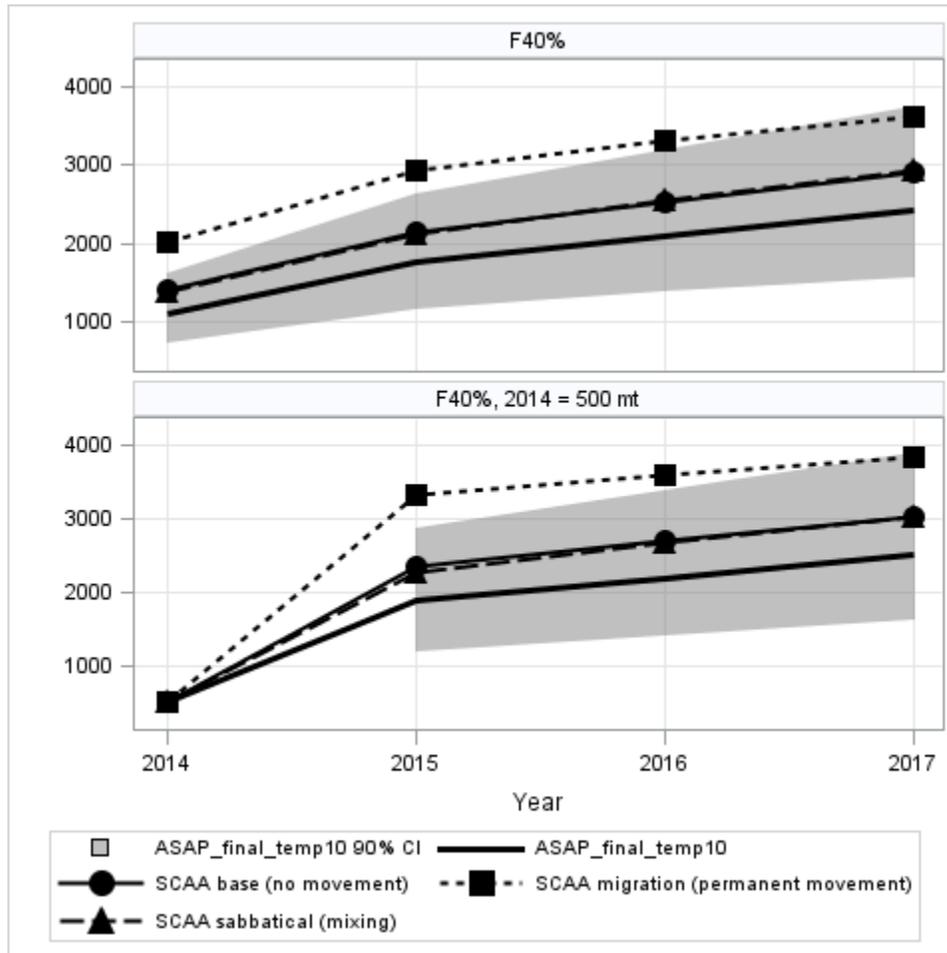


Figure A5. Short-term projections of total fishery yield and spawning stock biomass for Gulf of Maine haddock based on a harvest scenario of a) fishing at $F_{40\%}$ between 2014 and 2017 [upper panel] and b) an assumed catch of 500 mt in 2014 and fishing at $F_{40\%}$ between 2015 and 2017 [lower panel]. Projections from the base ASAP model (ASAP_final_temp10) are compared to three alternate runs from the SCAA model, two of which incorporate mixing between the Gulf of Maine and Georges Bank stocks.

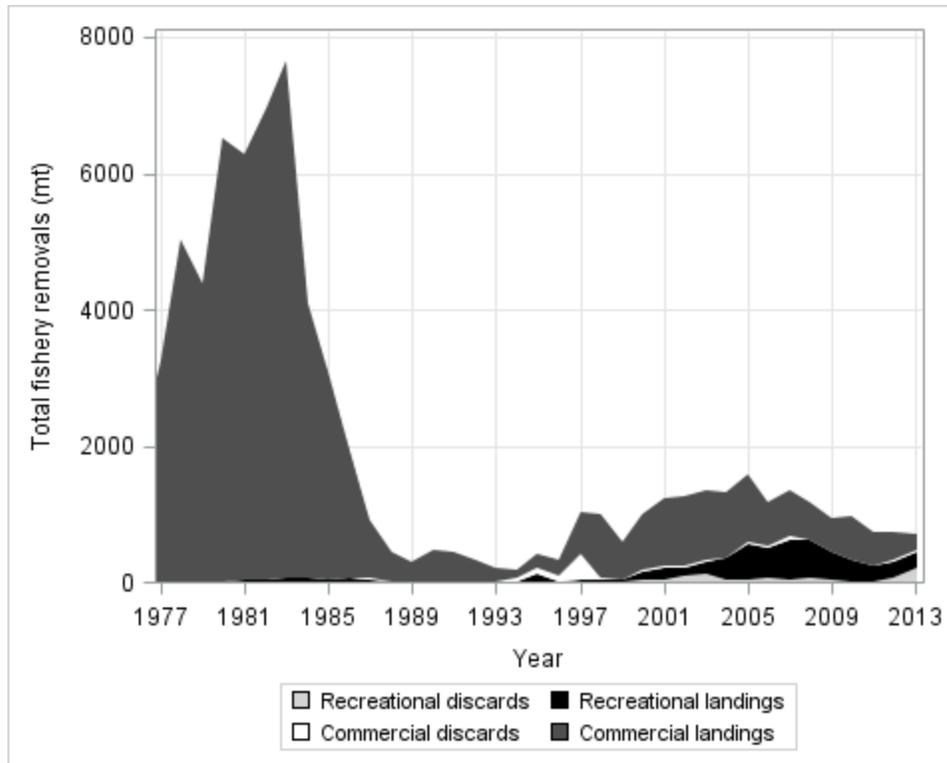


Figure A6. Total catch of Gulf of Maine haddock from 1977 to 2013 by fleet (commercial and recreational) and disposition (landed, discarded).

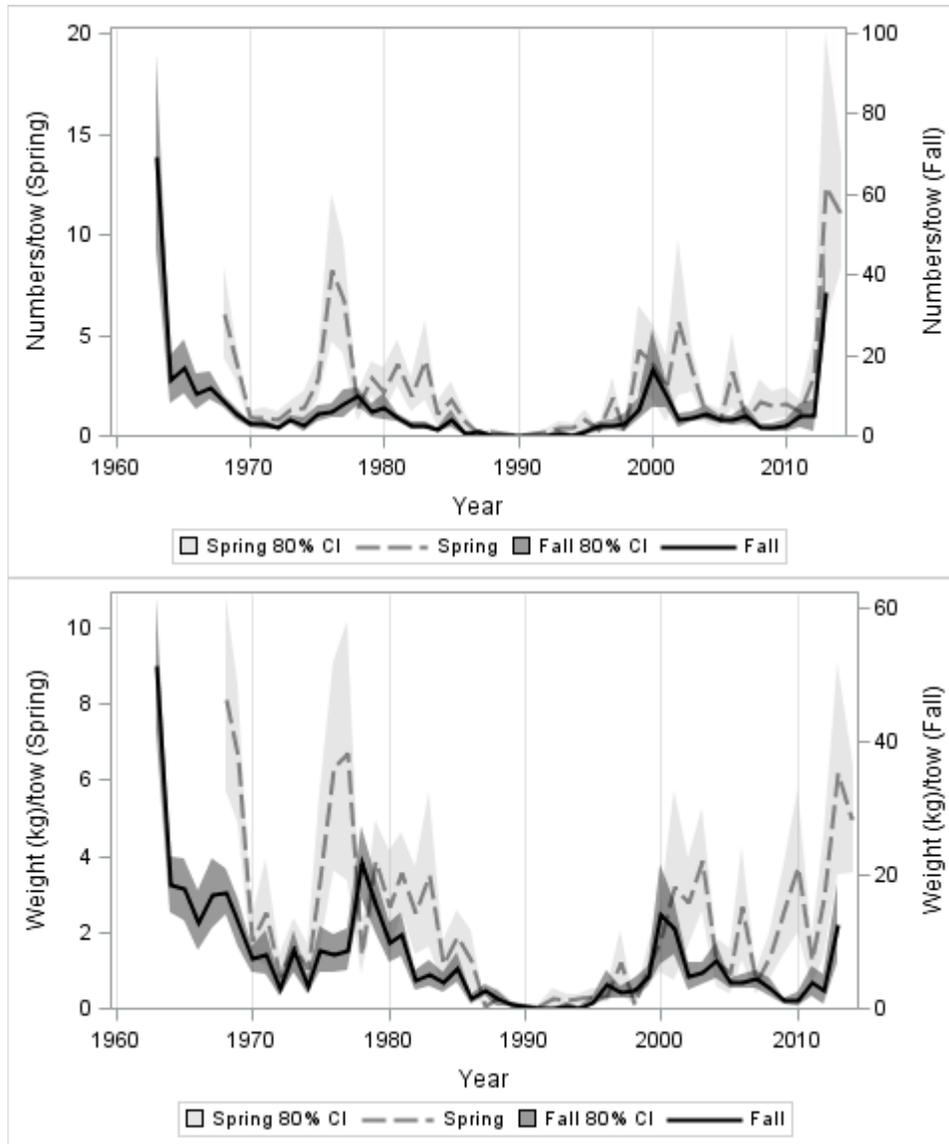


Figure A7. Indices of abundance (numbers/tow; top) and biomass (weight/tow; bottom) for the Gulf of Maine haddock between 1963 and 2014 (spring only) for the Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl surveys. *Note that the 2014 spring value was not used in the assessment model.*

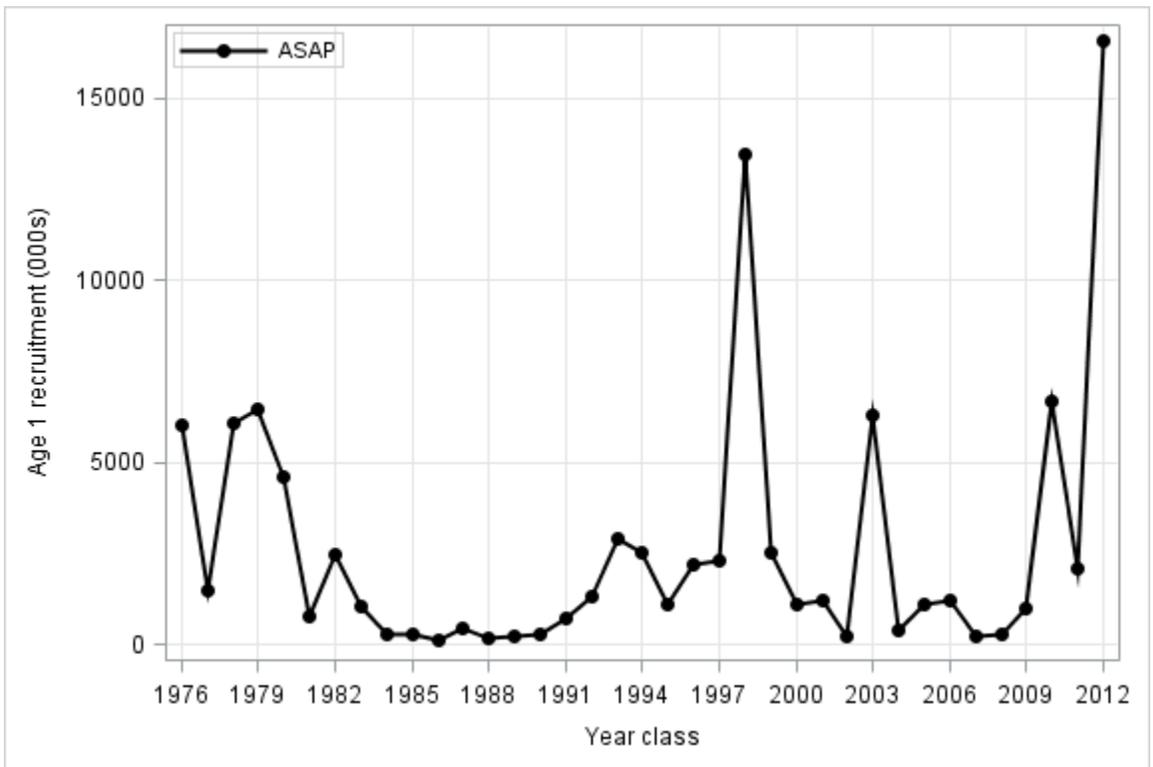


Figure A8. Estimated annual age-1 recruitment (000s fish) of Gulf of Maine haddock between 1977 and 2013 (1976 to 2012 year classes) based on the 2014 assessment.

B. SEA SCALLOP ASSESSMENT SUMMARY FOR 2014

Status of Stock: During 2013, the sea scallop stock was not overfished and overfishing was not occurring. Estimated biomass (40+ mm SH) was 132.561 thousand mt meats (Figure B1). Using the new recommended reference points, biomass was well above the $B_{TARGET}=B_{MSY}= 96.480$ thousand mt meats, and the $B_{THRESHOLD}=\frac{1}{2}B_{MSY}=48.240$ thousand mt meats. The probability that the stock was overfished in 2013 is near zero based on the new SARC-59 reference points (Figure B8). Compared with reference points from the previous assessment (NEFSC 2010), biomass during 2013 was also above that earlier $B_{TARGET}=B_{MSY}= 125.358$ thousand mt meats, and the $B_{THRESHOLD}=\frac{1}{2}B_{MSY}=62.679$ thousand mt meats. Past assessments have overestimated biomass, in particular when strong recruitment year classes have entered the population, and may continue to do so.

The estimated fishing mortality rate during 2013 was $F=0.32$ (Figure B2). Based on the new SARC-59 overfishing threshold reference point $F_{MSY}=0.48$, overfishing was not occurring in 2013. The probability that overfishing occurred during 2013 was about 13% based on the recommended reference points (Figure B8). Overfishing was also not occurring using the reference point from the previous assessment, $F_{MSY}=0.38$. Past assessments have underestimated fishing mortality and may continue to do so.

Projections: Projections are carried out by the Sea Scallop Plan Development Team (PDT) using a spatially structured model (SAMS) that accommodates variability in recruitment, vital rates and fishing among management areas. Scallop management approaches are complex because they are spatially explicit and dependent on regional recruitment and other factors. SAMS was used in this assessment to provide example projection results (Figures B4 and B5). These example projections indicate that stock biomass would increase slightly during 2014-2017 under current management policies ($F=F_{MSY}$ in “open” areas outside of rotational and closed areas, rotational management as currently planned). Past projections have been optimistic and may continue to be so.

Stock Distribution and Identification: Sea scallops are distributed from Cape Hatteras to Newfoundland. US populations are found on Georges Bank (GBK), Southern New England (SNE), the Gulf of Maine (GOM), and the Mid-Atlantic Bight (MAB). Sea scallops in US waters were assessed based on three main stock regions – Georges Bank open and closed, including Southern New England, and the Mid-Atlantic. Results for GBK open and closed, and MAB were combined to characterize the entire (i.e. total) EEZ stock. Overfishing and overfished status were evaluated for the entire stock, as specified by the current Sea Scallop Fishery Management Plan (NEFMC 2010). The small component of the stock that occurs in the GOM was not included in the assessment of overfishing or overfished status although an assessment for sea scallops in federal waters off Maine was completed (Appendix B7 in the assessment report).

Catch: Annual landings increased from about 8,000 mt meats in the mid-1980s to over 17,000 mt meats in 1990-1991, and then fell to between 5,000 and 8,000 mt meats during 1993-1998 (Figure B6). Landings increased considerably from 1998-2003, remained high and relatively stable during 2003-2012, and then declined in 2013. US landings during 2004-2013 averaged 25,566 mt (meats), about twice the long-term mean.

Discarding occurs due to catch of undersized scallops and high-grading; the latter mainly occurs in

rotational access areas that are managed under a form of individual allocations. Discards averaged about 969 mt during 1992–2013. Discards were the highest during 2000-2004, peaking at 2,603 mt meats, but have declined since, likely due to changes in gear regulations. Discards are implicitly included in the CASA assessment model as part of the incidental mortality term.

Data and Assessment: Three main survey time series were used in this assessment (dredge, SMAST and Habcam, Figure B9). Sea scallop dredge surveys have been conducted since 1975 and with the same lined gear since 1979. For the first time, data from NEFSC dredge surveys and cooperative dredge surveys conducted by the Virginia Institute of Marine Science (VIMS) during 2005-2013 were combined. VIMS surveys use commercial vessels and the same gear as the NEFSC dredge survey. Broad scale video drop camera survey data for 2003-2012 provided by the School for Marine Science and Technology (SMAST) were also used. Finally, survey data from broadscale Habcam surveys for 2011-2013 (GBK) and 2012-2013 (MAB) were used for the first time. Habcam is a towed digital still camera system. Analytical and survey design procedures for Habcam data were tested extensively during this assessment (Appendix B6 in assessment report). Biomass and abundance estimates from these three independent sources are generally similar (Figure B9).

A size-structured forward projecting stock assessment model (CASA) used in previous assessments (NEFSC 2007; NEFSC 2010) was also used in this assessment. Model data include the three main surveys listed above, the NEFSC winter bottom trawl (MAB only), commercial landings, commercial kept and discarded shell heights from port and sea sampling, and growth increment data from analysis of shell growth rings. Separate CASA models were used for MAB and the open and closed portions of GBK (one model was used for GBK previously). The Georges Bank open area model had trends and biomass estimates similar to those from the surveys with no retrospective pattern. Biomass estimates and trends from the CASA models for the other two areas were similar to survey estimates for some periods but the models were not able to fit large peaks in survey indices. The combined CASA model biomass estimate for 2013 was 132,561 mt meats, slightly greater than the estimates from the dredge and Habcam surveys. Abundance and mortality during 2005-2013 were also estimated “empirically” using simple techniques applied to survey and catch data for comparison to CASA results (Appendix B5 in assessment report). The empirical estimates are consistent with conclusions about stock status.

The assumed natural mortality for all but the plus group was increased from 0.12 to 0.16 on Georges Bank and 0.15 to 0.2 in the Mid-Atlantic. Increases in natural mortality were supported by all the CASA models. Based on a likelihood profile for the natural mortality on the plus group in the Georges Bank closed areas, combined with experimental evidence, natural mortality on the plus group was increased to 1.5 times that of smaller sizes (i.e., 0.24 on Georges Bank and 0.3 in the Mid-Atlantic). Experimental runs were conducted assuming density-dependent natural mortality among juveniles, with promising results.

Fishing Mortality: Fully recruited fishing mortality rates for the whole stock ranged from 0.32 to 0.49 during 2009-2013 and averaged 0.40 (Figure B2). Fully-recruited fishing mortalities prior to 2005 cannot be directly compared to the new recommended F_{MSY} estimate due to changes in fishery size-selectivity over time. The estimated fishing mortality rate during 2013 was $F=0.32$ (CV 9%). The CV from the CASA models likely underestimates the uncertainty.

The ratio of total catch number to January 1 estimated abundance from CASA for sea scallops greater than 80 mm is more interpretable than F as a measure of exploitation trends. This index shows increasing exploitation from 1975-1994, and low exploitation since about 1999 (Figure B3).

Recruitment: Estimated recruitment has generally been higher since the late 1990s than before (Figure B7). Recruitment on Georges Bank was relatively low during 2002-2006, but has increased since. The strength of the apparently strong 2011 year class is uncertain and more data will be required to fully evaluate its size. Recruitment in the Mid-Atlantic was above average during 1998-2008 and 2012, but below average in 2009-2011 and 2013.

Stock and Spawning Stock Biomass: Total and spawning stock biomass are approximately equivalent for sea scallops. Stock biomass rapidly increased during 1995-2003 and has been relatively stable since (Figure B1). Coincident with initial area closures and effort reduction measures, stock biomass increased rapidly between 1995 and 2000 on Georges Bank and between 1998 and 2003 in the Mid Atlantic Bight. Estimated biomass (40+ mm shell height) on July 1, 2013 was 132,561 mt meats. Biomass in 2013 was almost twice as high on Georges Bank (86,460 mt) than in the Mid-Atlantic (46,101 mt).

Biological Reference Points (whole stock)

Reference point	SARC-50	SARC-59
F_{MSY}	0.38	0.48
$B_{TARGET}=B_{MSY}$ (mt, meats)	125,358	96,480
$B_{THRESHOLD}=1/2 B_{MSY}$ (mt, meats)	62,679	48,240
MSY (mt, meats)	24,975	23,798

As in the last assessment, reference points were calculated using the SYM model (Hart 2013), which includes spawner-recruit relationships, per recruit calculations, and uncertainty in all parameters. SYM is configured to be consistent with assumptions and calculations of the CASA model. In particular, selectivity, spawning biomass and recruitment estimates in SYM are obtained from the CASA model. The new recommended biological reference points for the whole stock in the SARC-59 assessment are $F_{MSY}=0.48$ and $B_{MSY}=96,480$ mt (Figure B8). The basis for the changes in the F_{MSY} and B_{MSY} estimates are detailed in the full report, but are primarily due to the increases in M , and poor recruitment at high biomass in the Mid-Atlantic for three of the four year classes observed since the last benchmark assessment.

Special Comments

- Area management plays an important role in sea scallop stock dynamics, with much of the biomass located in long-term or rotational closures. Under area management, the reported whole-stock fishing mortalities underestimate fishing mortalities in open areas where fishing occurs continuously. It is possible that these open areas might be depleted even if overfishing is not occurring on the whole-stock (Hart 2001; 2003).
- The model results show slightly decreasing biomass from 2005 to 2012 with a sharp increase in 2013 to the maximum in the time series (Figure B1). The survey biomass estimates do not suggest an increase in biomass in 2013 (Figure B9). SARC-59 noted that stock biomass has

been overestimated by an average of 24% in the last seven years based on a retrospective analysis. Management should be aware of these trends and results.

- SARC-59 noted that natural mortality is simulated as a density-independent process and that might not reflect reality. It is suggested that further work be done to evaluate the effects of density on mortality, and incorporate those effects in future assessments.
- SARC-59 noted that F_{MSY} estimates for Georges Bank (0.30) and for the Mid Atlantic Bight (0.74) differ greatly. SARC-59 is concerned that applying the combined estimate (0.48) to the whole stock uniformly could imply that GB would be fished harder than biologically advisable and the MAB would be fished more lightly than biologically advisable.
- Multiple surveys estimating absolute abundance reduce the uncertainty in this assessment. However, the model assumption that survey catchabilities are independent causes the model to underestimate uncertainty in absolute abundance estimates.
- This stock is a good candidate for an explicitly spatial assessment model.

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Table B1. Catch and Status Table: Sea scallops

U.S Landings (mt meats)														
<i>Year</i>	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Min ²	Max ²	Mean ²	Median ²
<i>GBK</i>	5,398	9,940	17,807	9,842	6,765	6,695	6,119	8,242	13,474	12,154	1,040	17,807	6,099	5,783
<i>MAB</i>	23,533	15,566	8,772	16,634	17,388	18,808	19,561	17,748	11,533	5,935	731	23,533	8,256	5,965
<i>GOM</i>	177	187	155	117	120	84	168	212	417	498	84	1,614	467	407
<i>SNE</i> ⁶	992	898	2,047	360	325	220	290	386	154	326	7	2,047	214	89
<i>Total</i>	29,108	25,693	26,734	26,593	24,273	26,129	25,898	26,653	25,915	18,664	3,212	29,108	14,903	13,666
U.S. Discards (mt meats)														
<i>Year</i>	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Min ³	Max ³	Mean ³	Median ³
<i>GBK</i>	102	238	378	236	341	389	672	675	610	306	4	991	321	319
<i>MAB</i>	2,559	424	244	294	457	1,013	724	508	245	150	11	2,559	690	440
<i>Total</i>	2,661	662	622	530	798	1,402	1,397	1,183	855	456	57	2,261	1,011	688
Estimated abundance (July 1, 40+ mm SH, millions, from CASA model)														
<i>Year</i>	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Min ²	Max ²	Mean ²	Median ²
<i>GBK</i>	3,008	2,933	2,593	2,921	3,070	3,403	3,551	3,923	3,948	4,762	543	4,762	1,875	1,268
<i>MAB</i>	3,801	3,790	3,856	3,681	3,879	3,209	2,343	1,675	2,808	3,253	318	3,991	1,734	1,212
<i>Combined</i>	6,809	6,723	6,449	6,602	6,948	6,612	5,894	5,598	6,756	8,014	1,092	8,014	3,609	2,256
Estimated biomass for status determination (July 1, 40+ mm SH, thousand mt meats, from CASA model)														
<i>Year</i>	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Min ²	Max ²	Mean ²	Median ²
<i>GBK</i>	74,899	73,672	63,925	57,733	59,489	64,600	71,109	78,037	81,166	86,460	5,903	86,460	33,855	24,202
<i>MAB</i>	50,849	52,694	61,284	62,298	58,561	54,706	44,283	33,973	30,516	46,101	4,820	62,298	22,686	10,541
<i>Combined</i>	125,748	126,366	125,209	120,031	118,050	119,306	115,392	112,010	111,682	132,561	12,284	132,561	56,541	32,023

¹Region abbreviations: Georges Bank (GBK), Mid-Atlantic Bight (MAB), Gulf of Maine (GOM), Southern New England (SNE). For assessment modeling purposes, SNE landings are lumped with the GBK region.

² 1975-2013

³ 1992-2013

⁴ 1976-2013

⁵Values are comparable to reference points for 2005-2013 only; other years not comparable due to changes in fishery selectivity.

Recruitment, (millions, approximate age 2 y, from CASA model)

<i>Year</i>	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Min ⁴	Max ⁴	Mean ⁴	Median ⁴
<i>GBK</i>	455	794	719	1,505	1,057	1,351	1,034	1,363	1,131	2,336	207	2,336	795	746
<i>MAB</i>	580	2,615	936	1,660	2,256	286	777	385	3,685	323	73	3,877	994	712
<i>Combined</i>	1,035	3,409	1,656	3,164	3,314	1,637	1,811	1,748	4,816	2,660	280	5,005	1,789	1,560

Estimated fully recruited fishing mortality for status determination (from CASA model)⁴

<i>Year</i>	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Min ²	Max ²	Mean ²	Median ²
<i>GBK</i>	0.14	0.21	0.44	0.30	0.25	0.24	0.16	0.17	0.29	0.30	0.09	1.69	0.48	0.31
<i>MAB</i>	0.93	0.80	0.35	0.62	0.70	0.82	0.85	0.87	0.74	0.39	0.17	1.51	0.78	0.77
<i>Combined</i>	0.43	0.41	0.40	0.46	0.47	0.49	0.43	0.39	0.40	0.32	0.17	1.47	0.58	0.49

Exploitation index (catch number/ abundance 80+mm on January 1)

<i>Year</i>	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Min ²	Max ²	Mean ²	Median ²
<i>GBK</i>	0.08	0.11	0.23	0.15	0.11	0.11	0.08	0.08	0.14	0.14	0.08	0.88	0.31	0.22
<i>MAB</i>	0.27	0.19	0.11	0.21	0.24	0.23	0.27	0.33	0.29	0.08	0.08	0.72	0.38	0.33
<i>Combined</i>	0.18	0.16	0.16	0.19	0.18	0.17	0.17	0.18	0.18	0.11	0.11	0.77	0.34	0.29

¹Region abbreviations: Georges Bank (GBK), Mid-Atlantic Bight (MAB), Gulf of Maine (GOM), Southern New England (SNE). For assessment modeling purposes, SNE landings are lumped with the GBK region.

² 1975-2013

³ 1992-2013

⁴ 1976-2013

⁵Values are comparable to reference points for 2005-2013 only; other years not comparable due to changes in fishery selectivity.

Figures

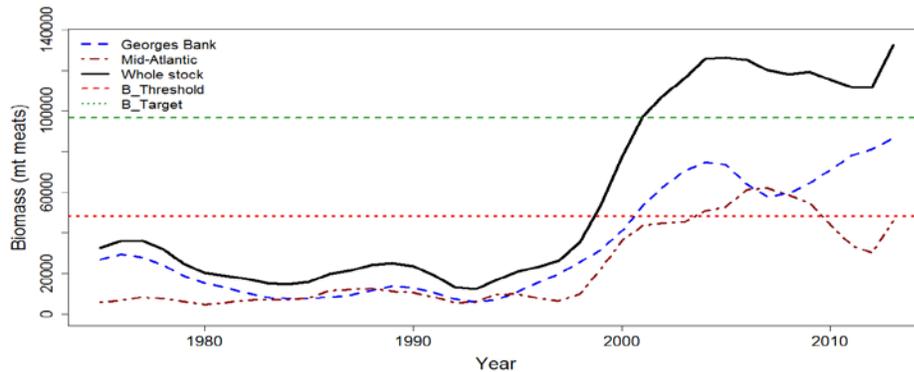


Figure B1. Sea scallop biomass (40+ mm SH) during 1975-2013, compared to whole stock biomass reference points.

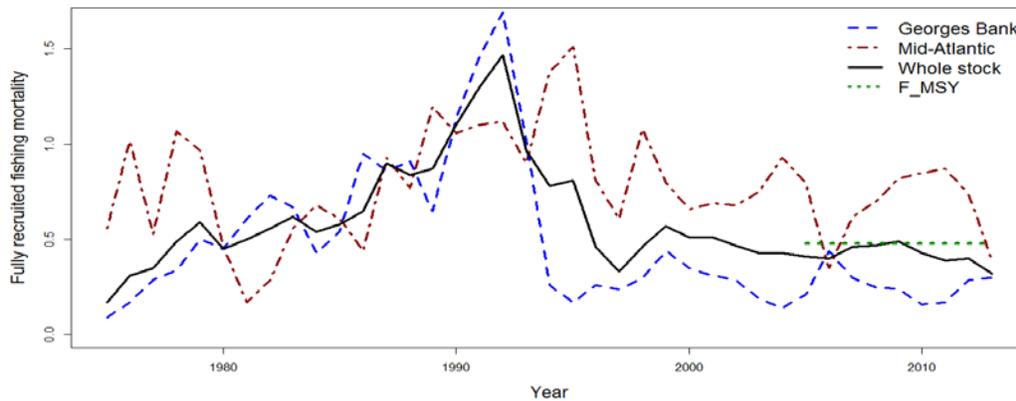


Figure B2. Fully recruited annual fishing mortality rate for sea scallops during 1975-2013. Trends are different for partially recruited scallops because of changes in commercial size-selectivity. The SARC-59 F_{MSY} is shown for the most recent period; F_{MSY} would have been smaller in past years when the selectivity was different.

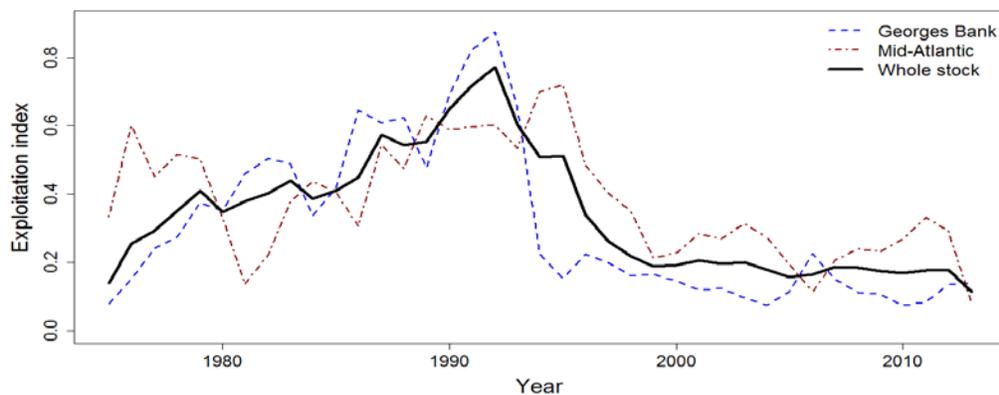


Figure B3. Simple exploitation index for sea scallops during 1975-2013 (Catch in numbers divided by population number for >80 mm shell height).

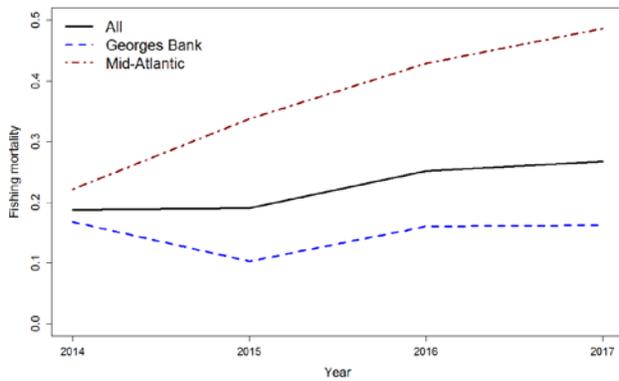
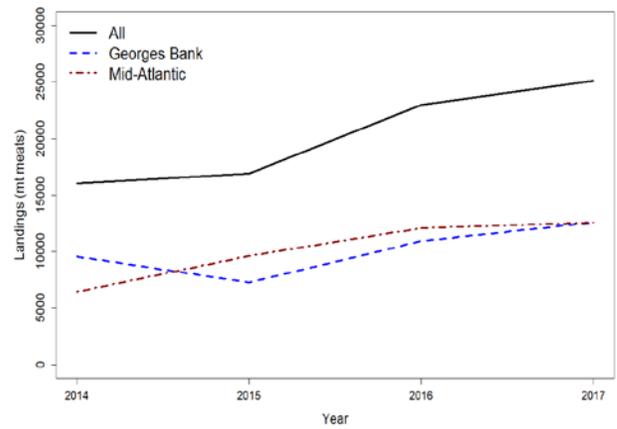
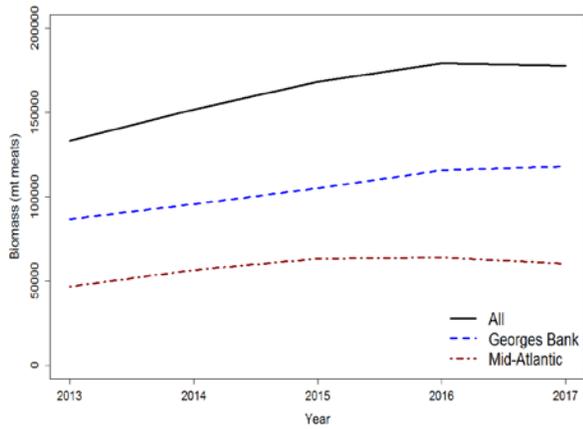


Figure B4. Projected sea scallop biomass, landings and fully recruited fishing mortality for Georges Bank, the Mid-Atlantic Bight and the entire (i.e., total) stock under an example management scenario during 2013-2017.

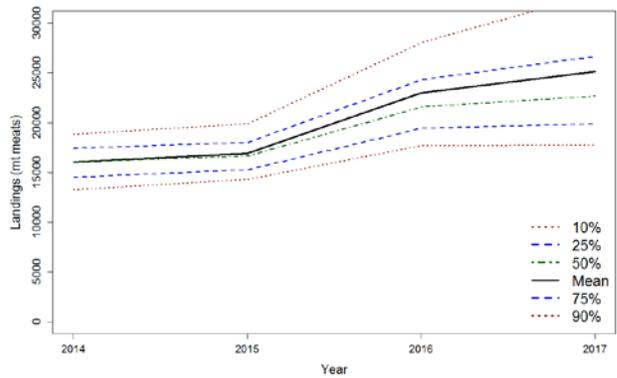
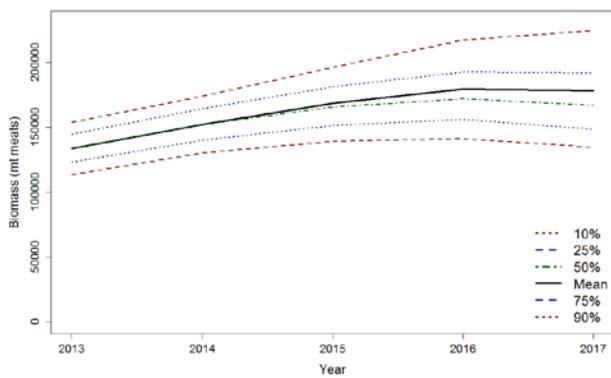


Figure B5. Mean and 10th, 25th, 50th, 75th, and 90th percentiles of projected sea scallop biomass and landings for the combined stock under an example management scenario during 2013-2017.

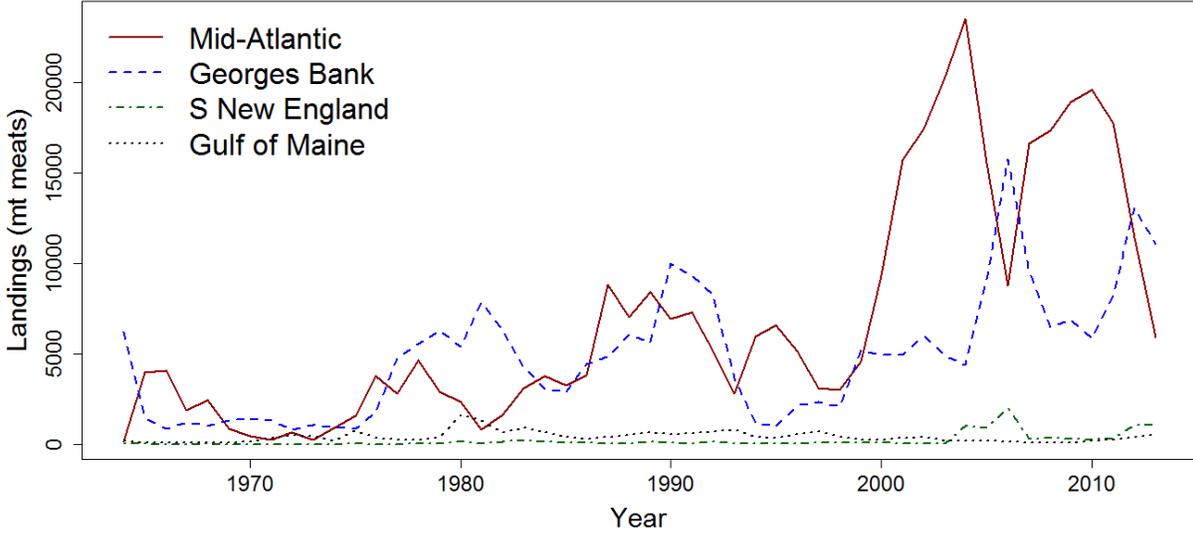


Figure B6. Sea scallop landings by region during 1975-2013.

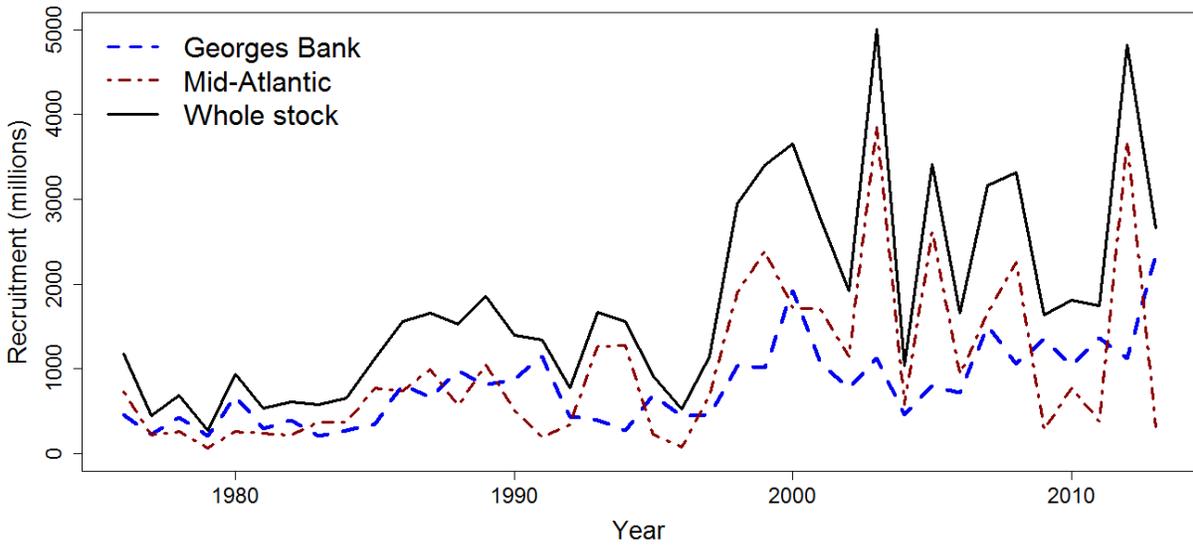


Figure B7. Sea scallop recruitment (millions, approximate age 2) during 1976-2013, as estimated by the CASA model.

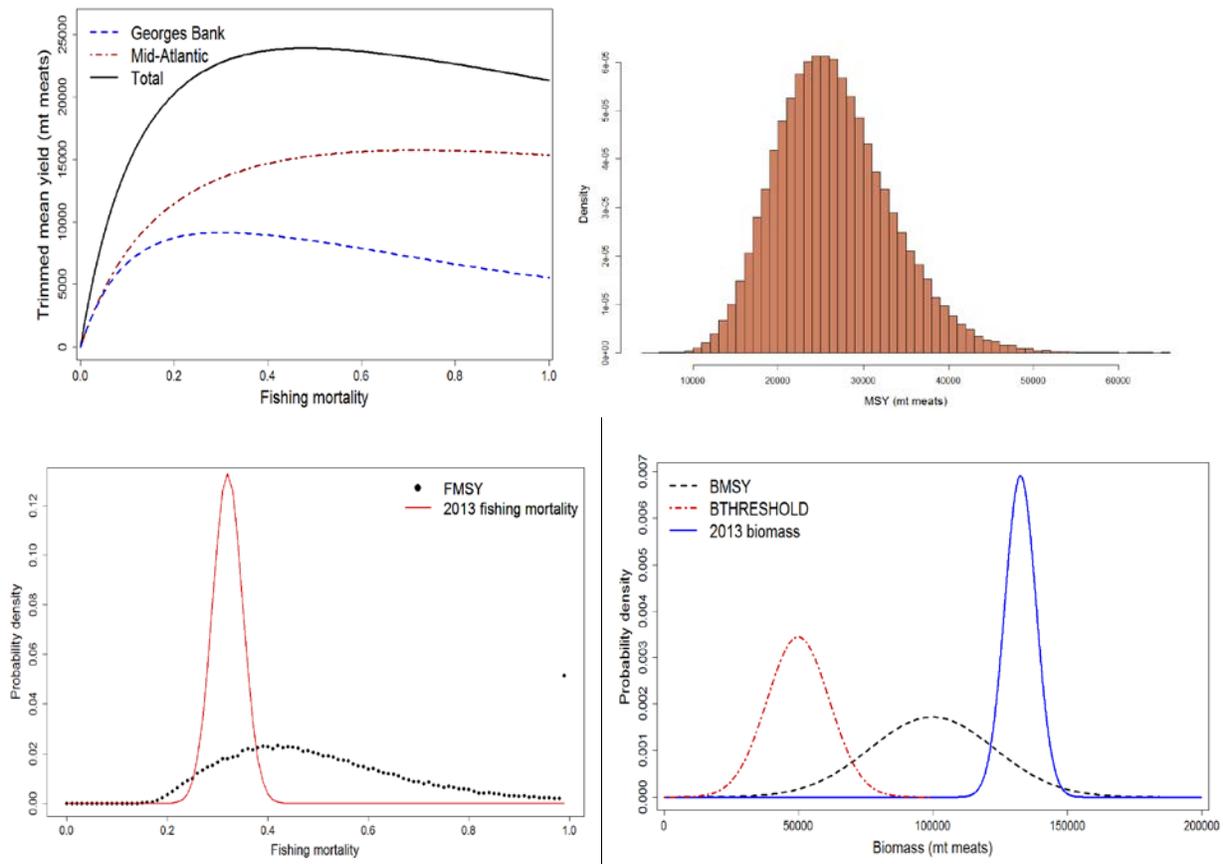


Figure B8. SYM reference point model results. *Top left:* Trimmed mean yield curves for Georges Bank, the Mid-Atlantic Bight, and the whole sea scallop stock. *Top right:* Probability density of whole-stock MSY. *Bottom Left:* Probability density of whole-stock F_{MSY} , compared to probability density of 2013 fishing mortality estimate. *Bottom right:* Probability density for whole-stock B_{MSY} , $B_{MSY}/2 = B_{THRESHOLD}$, and the probability density for the 2013 estimated biomass. The uncertainty in 2013 fishing mortality and biomass is understated.

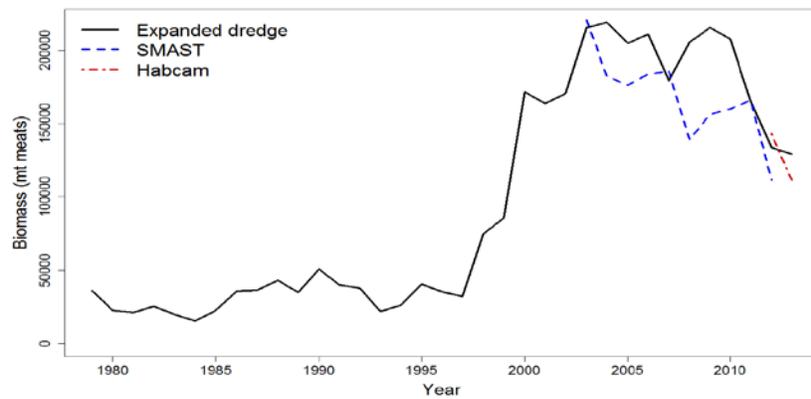


Figure B9. Estimates of sea scallop biomass expanded from the lined dredge, SMAST drop camera and Habcam towed camera surveys.

Appendix: Stock Assessment Terms of Reference for SAW/SARC59, July 15-18, 2014
(To be carried out by SAW Working Groups) (v. 1/17/2014)

A. Gulf of Maine (GOM) haddock

1. Estimate catch from all sources including landings and discards. Include recreational discards, as appropriate. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these sources of data. Investigate the utility of commercial or recreational LPUE as a measure of relative abundance.
2. Present the survey data being used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, etc.). If available, consider whether tagging information could be used in estimation of stock size or exploitation rate. Characterize the uncertainty and any bias in these sources of data.
3. Evaluate the hypothesis that haddock migration from Georges Bank influences dynamics of GOM stock. Consider role of potential causal factors such as density dependence and environmental conditions.
4. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series (integrating results from TOR-3), and estimate their uncertainty. Include a historical retrospective analysis to allow a comparison with previous assessment results and previous projections.
5. 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. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the “new” (i.e., updated, redefined, or alternative) BRPs.
6. Evaluate stock status with respect to the existing model (from previous peer reviewed accepted assessment) and with respect to a new model developed for this peer review. In both cases, evaluate whether the stock is rebuilt (if in a rebuilding plan).
 - 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 and their estimates (from TOR-5).
7. Develop approaches and apply them to conduct stock projections and to compute the statistical distribution (e.g., probability density function) of the OFL (overfishing level) (see Appendix to SAW TORs for definitions).
 - a. Provide numerical annual projections (3 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, migration from Georges Bank).
 - 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.
- 8. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in most recent SARC reviewed assessment and review panel reports. Identify new research recommendations.

B. Sea scallop

1. Estimate removals from all sources including landings, discards, incidental mortality, and natural mortality. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these assumptions and sources of data. If possible using sensitivity analyses, consider the potential effects that changes in fishing gear, fishing behavior, and management may have on the assumptions.
2. Present the survey data being used in the assessment (e.g., regional indices of relative or absolute abundance, recruitment, size data, etc.). Characterize the uncertainty and any bias in these sources of data.
3. Investigate the role of environmental and ecological factors in determining recruitment success. If possible, integrate the results into the stock assessment.
4. Estimate annual fishing mortality, recruitment and stock biomass for the time series, and estimate their uncertainty. Report these elements for both the combined resource and by sub-region. Include a historical retrospective analysis to allow a comparison with previous assessment results and previous projections.
5. 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. Comment on the scientific adequacy of existing BRPs and the “new” (i.e., updated, redefined, or alternative) BRPs.
6. Evaluate stock status with respect to the existing model (from previous peer reviewed accepted assessment) and with respect to a new model or model formulation developed for this peer review.
 - a. Update the existing model 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 and their estimates (from TOR-5).
7. Evaluate the realism of stock and catch projections and compute the statistical distribution (e.g., probability density function) of the OFL (overfishing level).
 - a. Provide numerical annual projections (through 2016). 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 the realism of the projections. 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.
8. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in most recent SARC reviewed assessment 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 annual catch that is consistent with 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.

One model or alternative models:

The preferred outcome of the SAW/SARC is to identify a single “best” model and an accompanying set of assessment results and a stock status determination. If selection of a “best” model is not possible, present alternative models in detail, and summarize the relative utility each model, including a comparison of results.

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