64th Northeast Regional Stock Assessment Workshop (64th SAW) Assessment Summary Report

by the Northeast Fisheries Science Center

February 2018

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NOAA Fisheries, Northeast Fisheries Science Center,
166 Water Street, Woods Hole, MA 02543

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Table of Contents

SAW-64 ASSESSMENT SUMMARY REPORT

Introduction

The 64th SAW Assessment Summary Report contains summary and detailed technical information on one stock assessment reviewed during November 28-30, 2017 at the Stock Assessment Workshop (SAW) by the 64th Stock Assessment Review Committee (SARC-64): Atlantic mackerel. The SARC-64 consisted of three external, independent reviewers appointed by the Center for Independent Experts [CIE], and an external SARC chairman from the MAFMC 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-64 are available at: https://www.nefsc.noaa.gov/saw/reports.html under the heading "SARC 64 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 $F_{THRESHOLD}$.

Another important factor for classifying the status of a resource is the current stock level, 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 ($B_{THRESHOLD}$) 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 $B_{THRESHOLD}$ and overfishing is occurring if current F is greater than $F_{THRESHOLD}$. The table below depicts status criteria.

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

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-64 Review Panel reports (available at https://www.nefsc.noaa.gov/saw/reports.html under the heading "SARC-64 Panelist Reports").

SARC-64 concluded that the stock of Atlantic Mackerel (*Scomber scombrus*) in the Northwest Atlantic is currently overfished and overfishing is occurring. An assessment model (ASAP) containing a northern and a southern contingent of the single stock was accepted by the SARC as the best scientific information available for determining stock status. As proposed by the SAW WG, $F_{40\%}$ is considered by the SARC to be an acceptable proxy for F_{MSY}, the overfishing threshold.

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 x 0.00548), leaving 994,520 alive. On day 2, another 5,450 fish die (994,520 x 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:

$N_{t+1} = 1,000,000 e^{-2} = 135,335$ 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, Fx%, 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 rebuild 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 sought 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).

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 five 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.
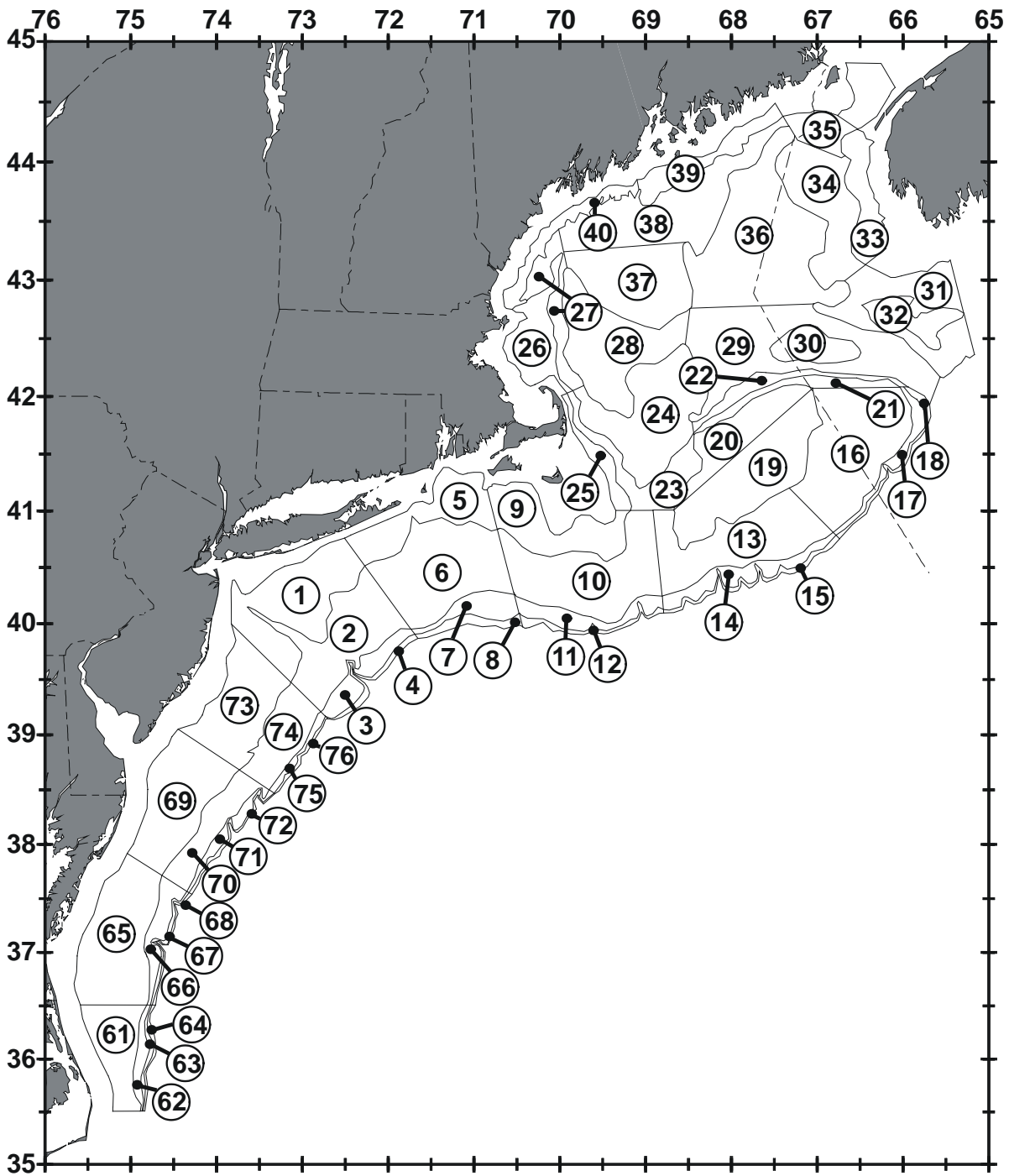
Figure 1. Offshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys. Some of these may not be sampled presently.
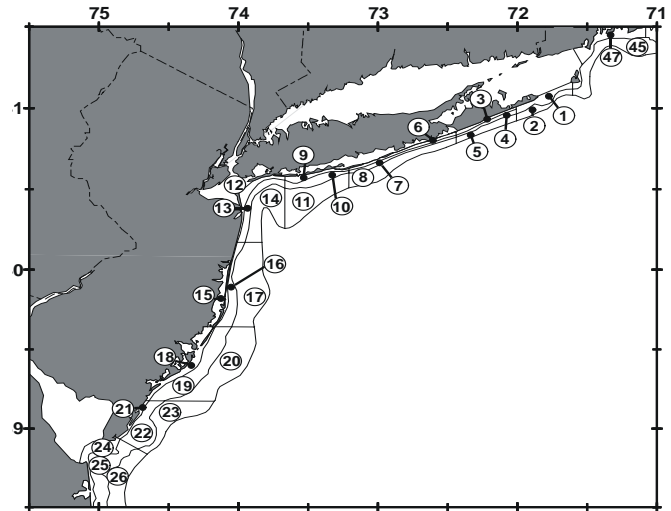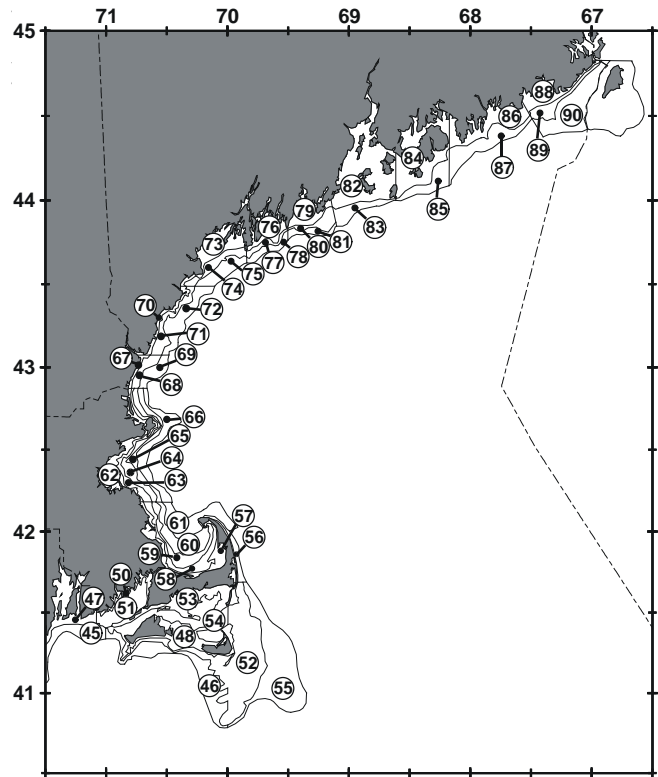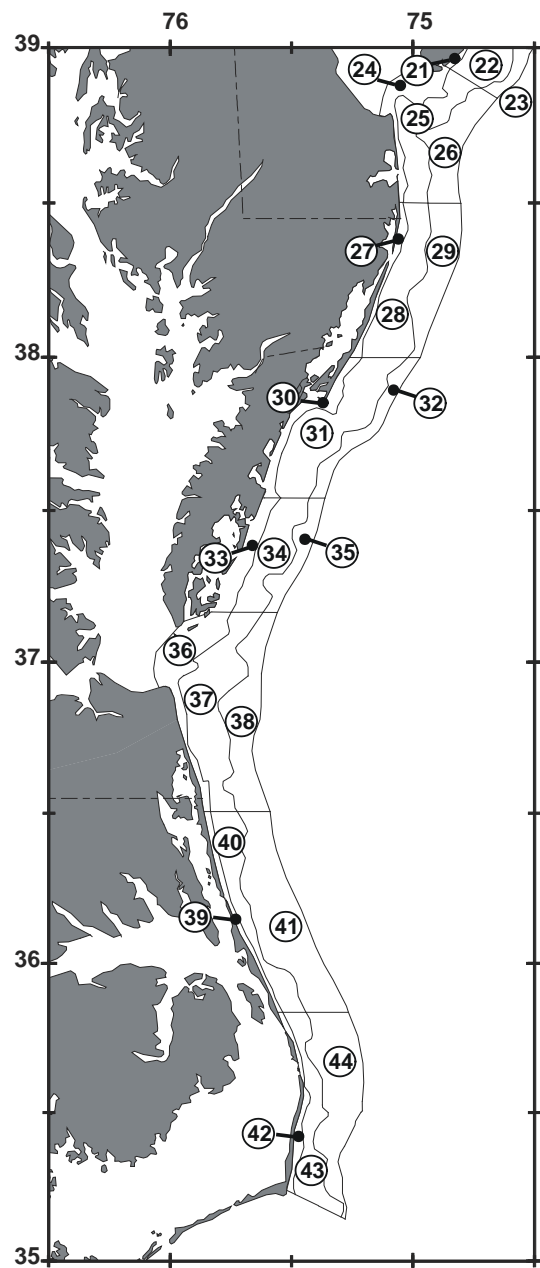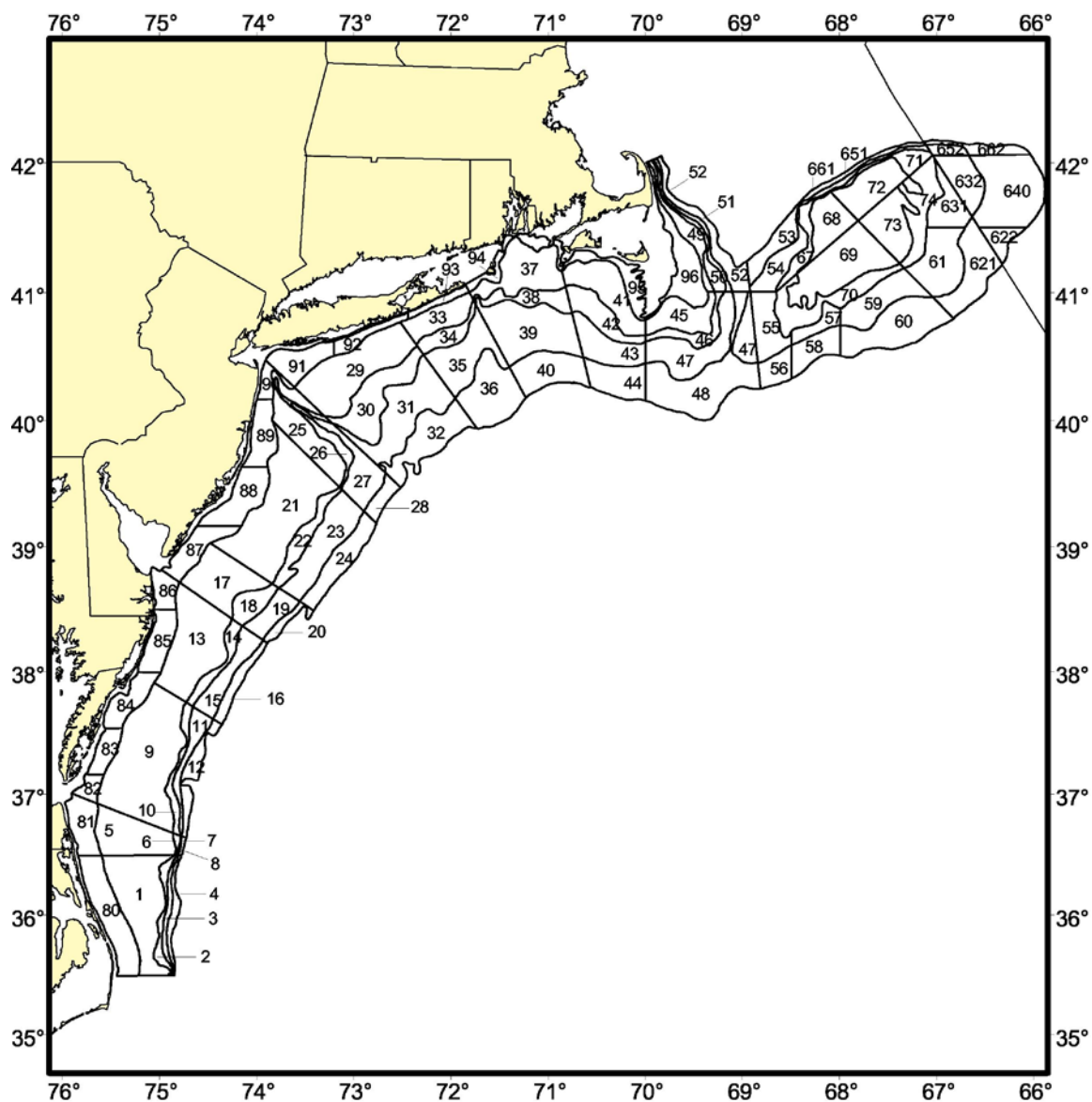
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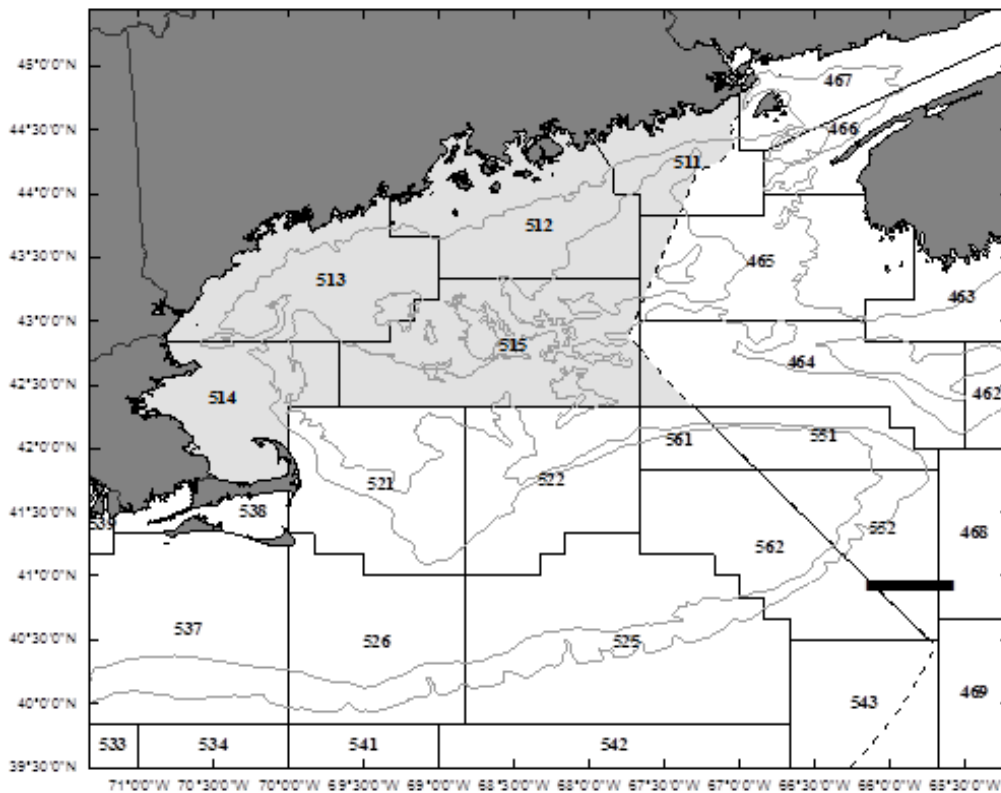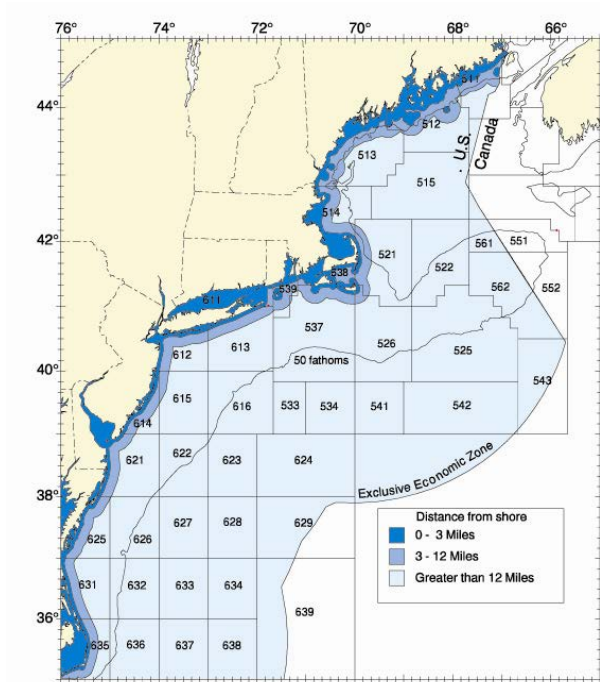
Figure 3. Statistical areas used for reporting commercial catches.

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

A. ATLANTIC MACKEREL ASSESSMENT SUMMARY FOR 2017

State of Stock

The SAW64 peer review panel recommends that the northwest stock of Atlantic Mackerel (*Scomber scombrus*) be considered overfished with overfishing occurring (Figure A1). An assessment model (ASAP) for the unit stock is accepted as appropriate for determining the stock status for Atlantic Mackerel. The 2016 spawning stock biomass (SSB) is estimated to be 43,519 mt and the fully selected fishing mortality is estimated to be 0.47.

$F_{40\%}$ is recommended as the proxy for F_{MSY} (the overfishing threshold) and was estimated to be 0.26. The distribution of the $SSB_{MSY\ proxy}$ (the biomass target) was calculated from 100-year projections at $F_{40\%}$ and was estimated to have a median of 196,894 mt with 90% credible intervals of 108,161 - 429,550 mt. The peer review panel recommends that the northwest Atlantic Mackerel stock be considered overfished if spawning stock biomass is less than half of $SSB_{MSY\ PROXY}$, which for this assessment equaled 98,447 mt.

Based on model results and sensitivity analyses, it is almost certain that the stock is overfished and undergoing overfishing. The stock was estimated to be at an all-time low in 2012 having experienced increasing exploitation (overfishing) through the early 2000s to a high in 2010. Indications are that recent recruitment is near the time series mean but highly uncertain.

No previously accepted assessment results are available for comparison.

Projections

Short-term (2018-2020) projections were conducted assuming a harvest at $F_{MSY\ proxy}$ (0.26) and a 2017 catch of 21,898 mt. This catch equaled the 2017 stock-wide Allowable Biological catch (ABC) set by the Mid-Atlantic Fishery Management Council's (MAFMC) Science and Statistical Committee (SSC) plus an additional 2,000 mt added due to a subsequent increase in the 2017 Canadian TAC. Recruitment was modeled by sampling from an empirical cumulative density function derived from the 1975-2016 recruitment estimates of the ASAP model because estimates from 1968-1974 were not considered representative of current conditions. Three-year projections indicated OFLs of 24,948 mt in 2018, 30,023 mt in 2019, and 33,250 mt in 2020 (Table A1). These projections are influenced by the 2015 year class, which was estimated at a relatively high level but with higher uncertainty than other recruitment estimates, as is typical for the terminal year recruitment estimate.

Catch and Status Table

(Weights in metric tons (mt), recruitment in millions, arithmetic means; min, max and mean values for years 1968-2016)

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Commercial landings	25,546	21,734	22,634	9,877	533	5,333	4,372	5,905	5,616	5,687
Commercial discards	159	747	125	97	38	33	20	52	13	18
Recreational catch	633	857	684	938	1,042	767	951	1,142	1,384	1,611
Canadian catch	53,394	29,671	42,232	38,736	11,534	6,468	9,017	6,872	4,937	8,000
Catch used in assessment	79,733	53,008	65,675	49,648	13,147	12,601	14,360	13,971	11,950	15,316
Spawning stock biomass	103,390	66,969	43,732	24,001	16,899	16,837	18,849	17,007	24,328	43,519
Recruitment (age 1)	99.1	216.9	156.8	18.0	115.8	82.9	37.8	91.2	162.7	455.4
Fully selected F	1.02	0.93	1.62	2.09	1.06	1.21	1.12	1.01	0.75	0.47

Year	Min	Max	Mean
Commercial landings	533	56,640	12,093
Commercial discards	13	5,409	808
Recreational catch	365	4,223	1,651
Canadian catch	4,937	55,282	25,777
Catch used in assessment	11,950	432,608	93,917
Spawning stock biomass	16,837	1,134,034	309,108
Recruitment (age 1)	18.0	5,254.0	532.4
Fully selected F	0.08	2.09	0.51

Stock Distribution and Identification

The MAFMC's Fishery Management Plan for Atlantic Mackerel defines the management unit as all northwest Atlantic Mackerel under U.S. jurisdiction. Fishery removals comprise both U.S. and Canadian reported catches; therefore, a stock-wide ABC is set by the MAFMC's SSC and the U.S. ABC is set to the stock-wide ABC minus estimated Canadian catch (MAFMC 2011). Based on the work of Sette (1943, 1950), the stock is considered to comprise two spawning contingents: a northern contingent spawning primarily in the southern Gulf of St. Lawrence and a southern contingent spawning in the Mid-Atlantic Bight, Southern New England and the western Gulf of Maine. The two contingents mix during winter months on the Northeast U.S. shelf; however, the degree of mixing and natal homing is unknown. Mackerel in the northwest Atlantic were modeled as one stock for this assessment. The Canadian fishery catches largely the northern contingent while the US fishery likely catches both contingents.

Catches

Aggregate total catch across all countries increased from 7,353 mt in 1960 to a high of 432,608 mt in 1973 during the peak of the distant water fleets (Figure A2). With the development of 200-mile exclusive economic zones, total catch declined to an average of approximately 30,000 mt from 1978-1983 before increasing to a peak of 86,423 mt in 1990, likely due to the 1982 year class as well as the operation of the U.S. joint-venture fishery. From 1992-2001, total catch averaged approximately 35,000 mt and then increased to a peak of 112,425 mt in 2006, presumably due to the 1999 year class. Total catch then declined and has averaged 13,558 mt since 2011. Over the 1968-2016 time series, the progression of multiple large year classes through the fishery, including the 1967, 1982, and 1999 cohorts, was evident. In recent years, a truncation in age structure is apparent with fish older than 6 years not regularly caught.

In Canada, reported catches represent a subset of total Canadian catch because the bait fishery, recreational fishery and commercial discards are not monitored. Unreported catches in Canada have been estimated to be approximately 6,000 mt in recent years. In the U.S., commercial discards have been a relatively minor component of the catch, ranging from 13 mt in 2015 to 5,409 mt in 1994 and averaging less than 800 mt annually since 1989. Recreational catch (assuming discarded fish do not survive) averaged 2,957 mt between 1981 and 1991, peaking in 1986 at 4,223 mt and generally declining thereafter, averaging only 1,170 mt between 1992 and 2016.

Data and Assessment

A statistical catch-at age-model (ASAP) was developed to estimate fishing mortality, recruitment and abundance from 1968-2016. While the primary model framework was ASAP, a censored catch assessment model (CCAM) and a state-space stock assessment model (SAM) were developed to examine model uncertainty. Relative abundance indices used in the ASAP and SAM models included NEFSC spring bottom trawl survey indices for ages 3^+ and a range-wide SSB index developed from a dedicated Mackerel egg survey in Canada and ecosystem surveys in the U.S.. The censored catch model could only incorporate one index; therefore, the range-wide SSB index was used. Resulting estimates of F and SSB did not show significant retrospective bias; therefore, retro-adjustments were unnecessary. Consideration of the ASAP, CCAM, and SAM models suggests that results are robust to model choice.

Biological Reference Points

A stock-recruitment relationship was not clear for this stock. As a result, $F_{40\%}$ was selected as a proxy for F_{MSY} due to consistency with the Canadian reference point and ability to prevent stock collapse for stocks with similar life histories. Total spawning stock biomass at $F_{40\%}$ ($SSB_{40\%}$) was selected as the stock biomass reference point. $F_{40\%}$ equals 0.26 and based on a long-term projection at $F_{MSY\ proxy}$, the associated $SSB_{MSY\ proxy}$ equals 196,894 mt (90% CIs of 108,161 – 429,550 mt) and $B_{MSY\ proxy}$ equals 255,646 mt (90% CIs of 140,103 – 534,278 mt). The overfishing threshold

has been defined as ½ SSB$_{MSY\ proxy}$, which equals 98,447 mt. MSY equals 41,334 mt (90% CIs of 22,878 – 87,281 mt).

Fishing Mortality

Estimates of fishing mortality at full selection (ages 6+) during the early portion of the time series exhibited a peak of 0.74 in 1976 and then sharply declined as foreign catches decreased (Figure A3). Fishing mortality then slowly increased during the 1980s and 1990s before spiking to a high of 2.1 in 2010. Between 2006 and 2014, fishing mortality approached or exceeded 1.0. Since 2010, fishing mortality generally decreased and was estimated to be 0.47 in 2016 (90% CI of 0.25 - 0.93).

Biomass

With the exception of two periods of increasing SSB trends during the mid-1980s and early-2000s as the 1982 and 1999 cohorts moved through the stock, the northwest Atlantic Mackerel stock exhibited a dramatic drop in spawning stock biomass from a peak in 1972 of approximately 1.1 million mt to 16,837 mt in 2012 (Figure A4). Since 2012, spawning stock biomass increased to 43,519 mt in 2016 (90% CI of 23,462 - 77,672 mt).

Total January 1 biomass in 2016 was estimated to be 101,687 mt (90% CI of 56,692 – 185,921 mt). With the exception of the early portion of the time series, total stock biomass was very similar to spawning stock and exploitable biomass estimates. However, during the early period total biomass was much larger than spawning stock biomass due to a large portion of juveniles (Figure A4).

Recruitment (at age 1)

Recruitment from 1968-1975 was estimated to be high, averaging 1,917 million fish (Figure A5), corresponding with high catches during this period. With the exception of strong year classes in 1982 (2,030 million fish), 1999 (1,223 million fish) and to a lesser extent 2003 (744 million fish), recruitment has been comparatively low since. Recruitment from 1975-2016 averaged 285 million fish although from 2006-2015, averaged only 136 million fish. The estimated recruitment in 2016 was 455 million fish.

Ecosystem Considerations

Analyses of the diets of predator species well sampled by the NEFSC bottom trawl surveys indicated a low occurrence of Mackerel in predator diets from 1973-2016 with approximately 0.2% of all predator stomachs containing Mackerel, including undentified Scombridae. Additional potentially important predators of Mackerel are not sampled by the NEFSC trawl surveys, including highly migratory species, marine mammals, and

seabirds. Consumption by these predators is more difficult to estimate due to incomplete information on population levels and annual diet information. Predator food habits were not available for the months the northern contingent was outside of the area sampled by the NEFSC trawl survey.

Changes in the distribution of Atlantic Mackerel to the north and east have been observed. Several working papers suggested that some of these changes could be associated with environmental variables, but cause and effect could not be formally identified.

Special Comments

The current assessment overcomes many of the problems encountered in the previous assessments. The current assessment does not exhibit a retrospective pattern and uses a stockwide egg survey for the first time. The current assessment is able to provide a stock status recommendation and biological reference points, which based on previous assessments were unknown.

Research and monitoring should emphasize:

- Updating and improving fishery-independent surveys, particularly the egg survey and bottom trawl survey. Processing of the US egg survey is particularly important.

- Continuing work to understand the mechanisms that affect the distribution of the northern and southern contingents.

- Continuing cooperation with industry to understand factors affecting fishery performance.

- Continuing characterization of total removals, particularly catch that is not well-sampled (e.g., recreational catch, bait catch, and discards).

- Continuing collaborations with Canadian scientists.

References

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Sette OE. 1943. Biology of the Atlantic Mackerel (*Scomber scombrus*) of North America, Part I: Early Life History, Including the Growth, Drift, and Mortality of the Egg and Larval Populations. Fishery Bulletin 38 (50): 149-237.

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Tables

Table A1: Three-year (2018-2020) projections of Atlantic Mackerel at $F_{MSYproxy}$, assuming a 2017 harvest of 21,898 mt.

|		**2017**	**2018**	**2019**	**2020**
SSB (mt)	Median	101,825	132,532	153,198	165,487
	5th Percentile	44,017	62,299	81,410	92,754
	95th Percentile	207,193	260,273	305,940	359,842
Recruitment (000s)	Median	164,337	164,359	164,453	164,332
	5th Percentile	35,335	35,381		35,315
	95th Percentile	1,169,815	1,179,224	1,201,696	1,178,003
January 1 biomass (mt)	Median	135,714	172,598	200,558	216,681
	5th Percentile	71,745	84,355	107,435	121,498
	95th Percentile	252,303	344,668	401,743	455,147
Catch (mt)	Median	21,898	24,948	30,023	33,250
	5th Percentile	-	11,069	15,549	18,428
	95th Percentile	-	50,317	56,857	68,034

Figures
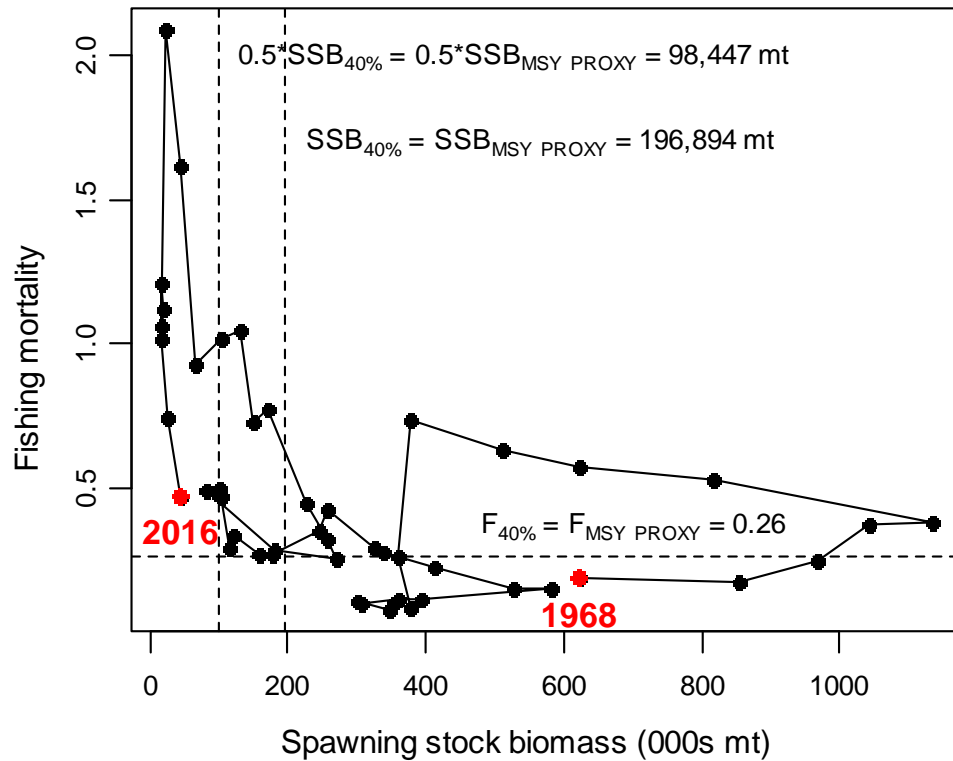
Figure A1: Time series trajectory of Atlantic Mackerel fully selected fishing mortality and spawning stock biomass estimates from 1968 to 2016 relative to the corresponding biological reference points.
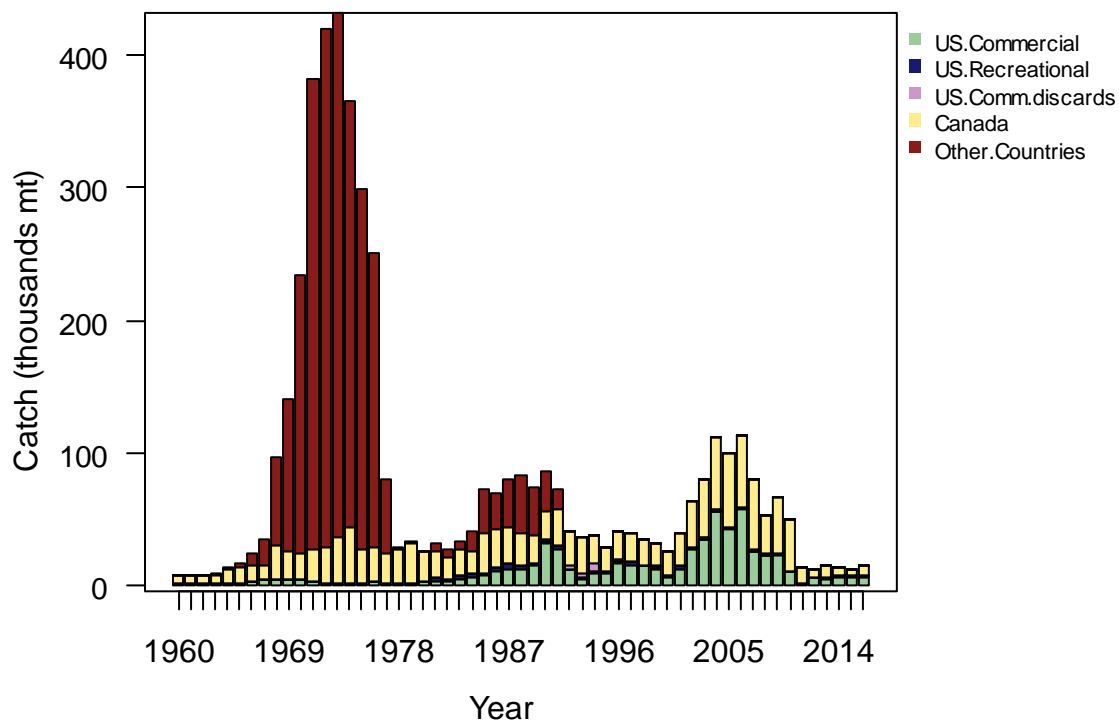
Figure A2: Total catch of Atlantic Mackerel by all sources from 1960 through 2016. US.Commercial represents U.S. commercial landings, US.Recreational represents U.S. recreational catch (landings plus discards), US.Comm.discards, represents discards by the U.S. commercial fishery, Canada represents Canadian landings (discards are not available), and Other.Countries represents landings by all other countries.
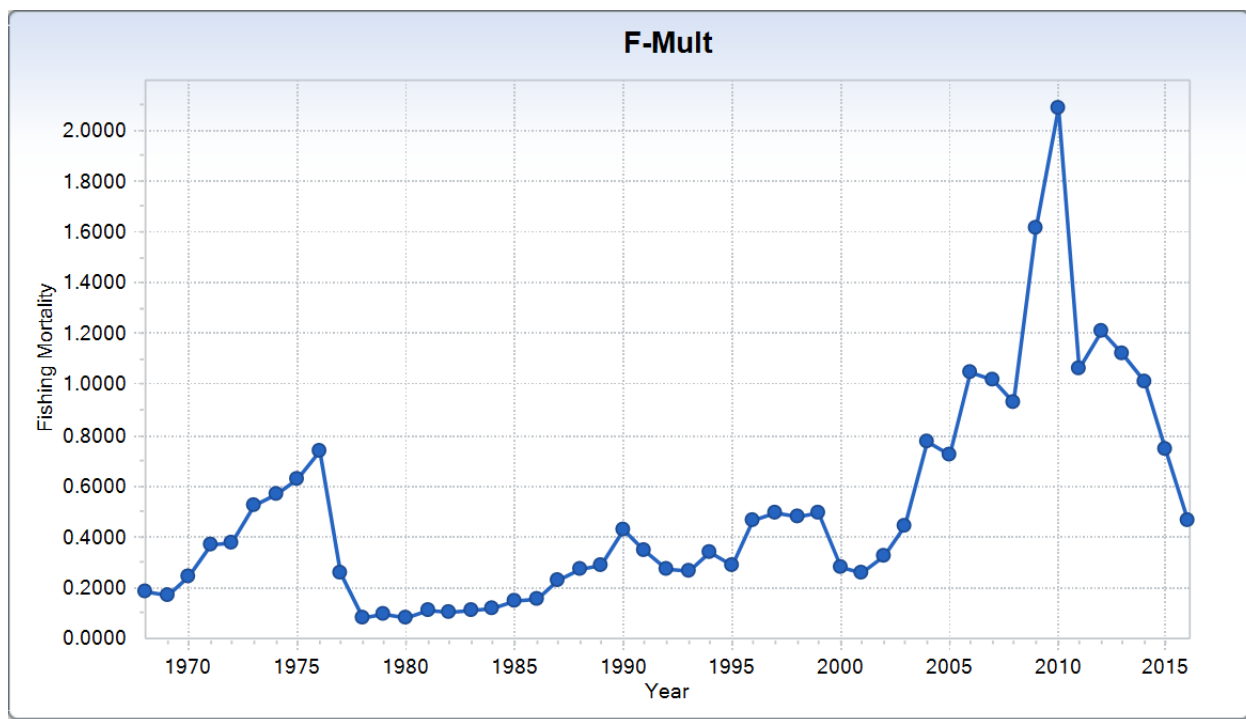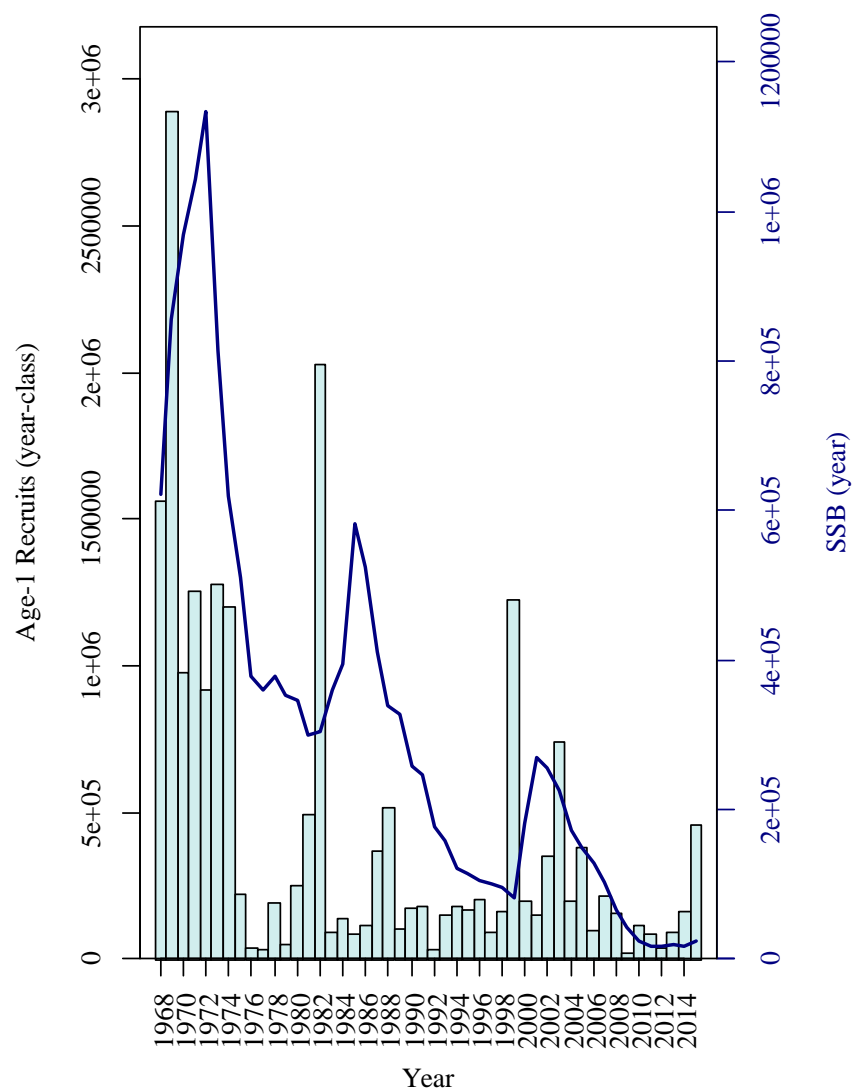
Figure A3: Estimates of Atlantic Mackerel fishing mortality from 1968-2016.

Comparison of January 1 Biomass
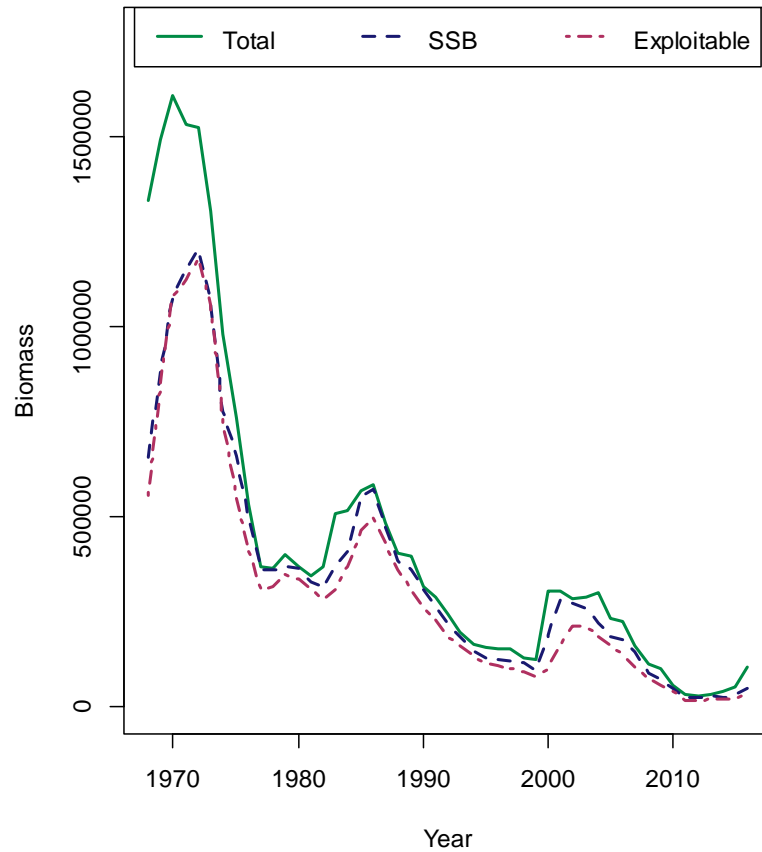
Figure A4: Atlantic Mackerel total, spawning stock and exploitable biomass estimates between 1968-2016.

Figure A5: Estimates of Atlantic Mackerel spawning stock biomass (solid blue line) and lagged age-1 recruitment (light blue bars) from the final ASAP model.

Appendix

Stock Assessment Terms of Reference for SAW/SARC-64, Nov. 28-30, 2017

A. Atlantic mackerel (NAFO Subareas 3-6)

1. Spatial and ecosystem influences on stock dynamics:
   a. Evaluate possible spatial influences on the stock dynamics. Recommend any need to modify the current stock definition for future stock assessments.
   b. Describe data (e.g., oceanographic, habitat, or species interactions) that might pertain to Atlantic mackerel distribution and availability. If possible, integrate the results into the stock assessment (TOR-4).

2. Estimate catch from all sources including landings and discards. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these sources of data.

3. Evaluate fishery independent and fishery dependent indices being used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, etc.). Characterize the uncertainty and any bias in these sources of data.

4. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Develop alternative approaches which might also be able to estimate population parameters. Include a comparison of new assessment results with those from previous assessment(s).

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. Make a recommended stock status determination (overfishing and overfished) based on new results developed for this peer review. Include qualitative written statements about the condition of the stock that will help to inform NOAA Fisheries[a] about stock status.

7. Develop approaches and apply them to conduct stock projections.
   a. Provide numerical annual projections (3 years) and the statistical distribution (e.g., probability density function) of the catch at F_{MSY} or an F_{MSY} proxy (i.e. the overfishing level, OFL) (see Appendix to the SAW TORs). 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. Identify reasonable projection parameters (recruitment, weight-at-age, retrospective adjustments, etc.) to use when setting specifications.

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 peer reviewed assessment and review panel reports. Identify new research recommendations.

aNOAA Fisheries has final responsibility for making the stock status determination based on best available scientific information.

Appendix to SAW TORs: Clarification of Terms used in the SAW Terms of Reference

On "Acceptable Biological Catch" (DOC National Standard Guidelines Federal Register 74 (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 ≥ 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 National Standard Guidelines Federal Register 74 (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 Maximum Sustainable Yield (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)

Participation among members of a Stock Assessment Working Group:

Anyone participating in SAW 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.

Guidance to SAW WG about "Number of Models to include in the Assessment Report":

In general, for any TOR in which one or more models are explored by the WG, give a detailed presentation of the "best" model, including inputs, outputs, diagnostics of model adequacy, and sensitivity analyses that evaluate robustness of model results to the assumptions. In less detail, describe other models that were evaluated by the WG and explain their strengths, weaknesses and results in relation to the "best" model. 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. It should be highlighted whether any models represent a minority opinion.

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