

B. ATLANTIC MACKEREL STOCK ASSESSEMENT

TERMS OF REFERENCE

1. Characterize the commercial and recreational catch including landings and discards.
2. Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty of those estimates. If possible, also include estimates for earlier years.
3. Evaluate and either update or re-estimate biological reference points, as appropriate.
4. As needed by management, estimate a single-year or multi-year TAC and/or TAL by calendar year or fishing year, based on stock biomass and target mortality rate.
5. If possible,
 - a. provide short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies and
 - b. evaluate current and projected stock status against existing rebuilding or recovery schedules, as appropriate.
6. Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in previous SARC-reviewed assessments

EXECUTIVE SUMMARY

(TOR 1) Atlantic mackerel were heavily exploited by distant water fleets during the 1970's. Total landings in NAFO subareas 2-6 averaged 350,000 mt during 1970-1976, but this level was not sustainable (Figure B1). Annual landings decreased to less than 50,000 mt during 1978-1984. Landings in Canada remained relatively constant at an average of 24,000 mt during 1968-2000. Landings in the US EEZ increased during 1985-1991 to an average of 76,000m t, with the advent of a JV fishery in the Mid-Atlantic region. More recently landings by both the USA and Canada have increased as world demand has improved. Commercial landings in the U.S. increased from a low of 5,646m t in 2000 to 53,724 mt in 2004, while landings in Canada increased form 13,383 mt in 2000 to 51,444 mt in 2004. Recreational landings of mackerel in the USA averaged 1,344 mt during 1990-2000, but decreased from 1,538m t in 2001 to only 467 mt in 2004.

The northwest Atlantic mackerel stock is not overfished and overfishing is not occurring relative to the new reference points from this assessment. (TOR 2) Fishing mortality has remained low for the last decade, but increased slightly from 0.02 in 2002 to 0.05 in 2004. The confidence interval (± 2 SD) for F in 2004 ranged from 0.035 to 0.063, but retrospective analysis shows that

F has sometimes been underestimated in recent years. The overfishing reference point, F_{msy} , was re-estimated at $F_{msy}=0.16$ (previously $F_{msy}=0.45$).

(TOR 2) Spawning stock biomass increased steadily over the last several decades from a low of 663,000 t in 1976 to 2.3 million mt in 2004. The confidence interval on SSB (± 2 SD) ranged from 1.49 to 3.14 million mt in 2004; however, retrospective analysis showed that SSB has sometimes been overestimated in recent years. The biomass reference point was re-estimated in this assessment at $SSB_{msy}=644,000$ mt (previously $SSB_{msy}=890,000$ mt).

(TOR 3) Fishing mortality based biological reference points (BRP's) were re-estimated during SARC 42. Fishing mortality reference points are $F_{0.1} = 0.25$ and $F_{40\%} = 0.24$. Reference points from model estimated B-H parameters are $MSY = 89,000$ mt, $SSB_{msy} = 644,000$ mt, and $F_{msy} = 0.16$. Surplus production in the mackerel stock was available sporadically during 1962-2004. Periods of positive SP occurred before the ICNAF fishery in the late 1960s, during the early 1980s, and more recently in the late 1990s through 2003. The average SP available during 1962-2003 was 148,000 mt; this can serve as a proxy upper bound on MSY for the current assessment. Stock-recruitment BRP's were estimated prior to SARC 30 using a bootstrap method as $F_{msy}=0.45$, $F_{target}=0.25$, $MSY=326,000$ mt, and $SSB_{msy}=887,000$ mt (NEFMC 1998); these should be replaced with the more current values.

(TOR 4, 5) Deterministic projections for 2006-2008 were conducted by inputting an estimated catch of 95,000 mt in 2005 and a target fishing mortality of 0.12 (MAFMC 1998, $F_{target}=0.75 \times F_{msy}$) in 2006-2008. If 95,000 mt are landed in 2005, SSB in 2006 will increase to 2.6 million mt. If the $F_{target} F=0.12$ is attained in 2006-2008, SSB will decline to 2.3 million mt in 2007 and to 2.0 million mt in 2008. Landings during 2006-2008 would be 273,000 mt, 239,000 mt, and 212,000 mt, respectively. These landings are the result of an unusually large year-class (1999) present in 2005, and will not be sustainable in the long term. It is expected that these projected landings will decline to MSY (89,000 mt) in the future when a more average recruitment condition exists in the stock.

1.0 INTRODUCTION

Atlantic mackerel (*Scomber scombrus*) are distributed from North Carolina to the Gulf of St. Lawrence, and on occasion as far north as Labrador (Bigelow and Schroeder 2002). Mackerel are a fast moving, schooling species that undergo extensive seasonal migrations. The northern and southern components generally over-winter on the continental shelf off the Mid-Atlantic bight and begin their spring migration in April. The southern component spawns along the Southern New England corridor and disperses throughout the Gulf of Maine-Georges Bank region during summer (Sette 1950; Morse et al. 1987; O'Brien et al. 1993). It is believed that the northern component crosses Georges Bank during April-May reaches the Scotian shelf in late May or early June and moves into the Gulf of St Lawrence during late June and early July to spawn in the Magdalen shallows region (Sette 1950; Gregoire et al. 2003; DFO 2004; Gregoire 2005). Post spawning fish disperse into the Gulf as far east as Newfoundland. This schooling species often attains ages greater than 10; ages up to 14 are not uncommon. Mackerel begin to mature at age 2, and are generally fully mature at age 3 (Bigelow and Schroeder 2002; Gregoire et al. 2003). They exhibit a planktivorous diet, feeding mainly on zooplankton, chaetognaths,

euphasids; and larval fish (Bigelow and Schroeder 2002). Mackerel are preyed upon by a large number of medium-sized predatory fishes such as cod, white hake, and spiny dogfish; marine mammals such as pilot whales, white-sided dolphins, and common dolphins; seabirds such as greater shearwaters and northern gannets; and large pelagic fish such as swordfish and blue shark, throughout their range.

The Mid Atlantic Fishery Management Council manages mackerel as part of the Atlantic mackerel, Squid, and Butterfish (MSB) Fishery Management Plan. The current overfishing definition is based on an MSY of 326,000 mt, a B_{msy} of 890,000 mt, and a limit fishing rate of $F_{msy} = 0.45$ (MAFMC 1998; NEFMC 1998). Overfishing for this species is defined as occurring when F_{msy} is exceeded, and the overfishing limit is $F_{msy} = 0.45$ when the SSB is greater than 890,000 mt. An MSY of 326,000 mt represents the current estimate of long-term potential catch for the stock and was revised in Amendment 8 of the FMP. The F target is defined as the tenth percentile of F_{msy} and is set at $F=0.25$. If SSB is less than 890,000, F target decreases linearly from 0.25 at 890,000 mt to zero at 450,000 mt. The biomass target for this stock is defined as B_{msy} and the minimum biomass threshold is defined as $\frac{1}{2} B_{msy}$. There have been a series of amendments to the MSB Fishery Management Plan; the most recent amendment (Amendment 9) does not propose any changes for the mackerel OFD.

The most recent assessment for this stock was completed in 1999 (SARC 30) (NEFSC 2000). Although no quantitative assessment was accepted, conclusions were that the stock was at a high level of biomass, F was low, and that catches were well below the MSY of 326,000 mt.

2.0 THE FISHERY

Commercial Landings

Commercial mackerel landings by the United States averaged 2,368 mt from 1960-1983, peaked at 31,261 mt in 1990, and declined to 4,666 mt in 1993 (Table B1; Figure B1). USA landings increased to 16,137 mt in 1996, declined to 5,646 mt in 2000 and steadily increased to 53,724 mt in 2004. Recreational landings in the USA have generally declined during 1979-2004. Landings averaged 2,945 mt during 1979-1988 and declined to a low of 344 mt in 1992 (Table B1; Figure B1). Landings in the US sport fishery peaked at 1,735 mt in 1997, declining slightly thereafter, but remaining relatively steady until declining to 724 mt in 2003 and 467 mt in 2004. Landings by Canada averaged 6,891 mt during 1960-1967, and 23,882 during 1968-2000 (Table B1; Figure B1). Canadian landings increased steadily from 23,868 mt in 2001 to 51,444 mt in 2004. For details of Canadian landings see Gregoire et al. (2003), DFO (2004), and Gregoire (2005) available online at www.dfo-mpo.gc.ca/csas. Landings by foreign countries, primarily during the ICNAF era, averaged 143,532 mt during 1961-1977, and 18,315 mt during 1978-1991 (Table B1; Figure B1). Foreign countries were excluded from fishing in the US EEZ after 1991.

Sampling Intensity

Commercial length frequencies used to characterize USA landings were obtained from port samples obtained in the Northeast Region. The mackerel fishery is strongly seasonal, with most of the landings occurring during the first 5 months of the calendar year and any remaining landings during November and December. Because of stable growth patterns, length samples

were aggregated over the first and second half of each year. Most of the landings occurred during the first half of the year in all years from 1998-2004, but in some landings occurred in the second half of the year during 2001-2004 (Table B2). Sample size for commercial length compositions ranged from 907 in 2000 to 4,297 in 1999 for the first half of each year (Table B2). Sample size for length data for the commercial fishery in the second half of 2001-2004 ranged from 116 in 2001 to 322 in 2003. Landings at age for the second half of 2001-2004 were estimated with length data from the 4th quarters of each year (Table B2). A length-weight relationship was used to estimate sample weight and expansion factors for commercial samples from 1998-2004. Length-weight parameters used in the last assessment ($a=0.0059$, $b=3.154$) were used for the estimation of commercial catch at length.

Recreational length samples obtained from the MRFSS data base were used to characterize the landings of this species by sport fisherman. Sample numbers and lengths were judged to be adequate enough to estimate recreational catch at length. Recreational length samples were available for each year during 1998-2004 and ranged from 483-1,347 fish measured (Table B2). The same length-weight equation was used to estimate sample parameters and expansion factors for the recreational landings data.

Age length data used for estimating commercial and recreational catch at age were obtained from commercial port samples, sea sampling, and NEFSC Spring and Winter bottom trawl surveys. Combined age-length keys from these sources were used to age commercial and recreational landings from the first half of 1998-2004 (Table B2). Sample size for the first part of the year during 1998-2004 ranged from 719-1901 (Table B2). Generally only fall survey ages in small numbers were available to age the second half of each year during 2001-2004, samples sizes ranged from 71-121. Catch-at-age for Canada was developed using similar procedures, although many more length samples were available. For details of Canadian commercial length and age sampling see Gregoire et al. (2003), DFO (2004), and Gregoire (2005) available online at www.dfo-mpo.gc.ca/csas.

Catch-at-Age

USA commercial and recreational catch at age for 1962-1997 were taken from the previous assessment (NEFSC 2000). Catch at age for the USA during 1998-2004 were estimated from the length and age composition and landings data previously cited (Table B3). Canadian catch at age data for 1998-2004 were obtained from DFO Canada (Gregoire et al. 2003) and are included in Table (B3). Canadian catch-at-age data for 1990-1993 were updated based on a revision in Canadian landings for 1990-1993. For details of Canadian catch-at-age see Gregoire et al. (2003), DFO (2004), and Gregoire (2005) available online at www.dfo-mpo.gc.ca/csas.

Commercial Mean Weights

Commercial mean weights used in the current assessment were obtained from the previous assessment for 1962-1997 and were estimated for 1998-2004. The length weight relationship used to estimate sample weights ($a=0.0059$, $b=3.154$) was used to calculate the mean weights at age for the USA commercial fishery for 1998-2004. Mean weights for the commercial fishery

during 1998-2004 were calculated as weighted means of the USA and Canadian fishery catch-at-age and mean weights-at-age (Table B4).

3.0 RESEARCH SURVEY ABUNDANCE INDICES FOR TREND

Research survey abundance indices are available from winter and spring NEFSC bottom trawl surveys for assessing the status of the mackerel resource. Survey indices are available from NMFS surveys for the winter 1992-2005 and spring 1968-2005. The autumn survey series from 1963-2004 was investigated for use as a tuning index, but very few mackerel are taken in this survey and an unknown proportion, perhaps large, is distributed in Canadian waters, and is unavailable to the USA survey.

Standard and ln transformed spring survey indices were updated for 1998-2005. Standard indices in weight and number per tow continued to show improving trends for the stock during 1989-2005 (Table B5; Figure B2). The biomass index generally increased from 1989-1996, declined slightly in 1997-1998, and increased from 1999-2004. Mean number per tow indices followed nearly the same trends, increasing over the early 1990s, decreasing in 1997-1998, and increasing again from 1999-2004. The index reached 116 in 2001, the highest value in the 43 year series (Table B5; Figure B2).

Spring indices for 1998-2004 were recomputed to produce aggregated ln retransformed catch per tow indices. The standard number per tow index increased by an order of magnitude from the 1980s to the 1990s and increased further from 1998-2004. The index was high and relatively stable throughout the 1990s, except for 1997 and increased in 2000 and 2001 (Table B5; Figure B4). The highest value in the series was obtained in 2001 (59.106). Number per tow indices at age (ln retransformed) were updated for 1998-2005. Indices at age were generally higher, with a few exceptions, for ages 1-6 during 1997-2004 than for all other years in the 1968-2005 time-series (Table B6).

The winter bottom trawl survey began in 1992 and was included as an index for this stock in the previous assessment. The standard biomass and abundance indices for mackerel are generally high, but variable (Table B7). The biomass index ranged from 0.25-32.05 kg/tow during 1992-2005 (Table B7; Figure B4). Number per tow ranged from 1.16 to 245.58 during this same period. Some of the variation in survey indices may be attributed to the more inconsistent coverage of survey strata during the winter survey. Number per tow at age indices (ln retransformed) were produced for the winter survey, including ages 1-10+ (Table B8). Indices in this survey have also increased in recent years (Table B8).

Growth

Trends in average weight from the spring survey were examined to see if there were any changes during 1968-2005. With the exception of the period after the ICNAF fishery in the 1970s, average weights have fluctuated between 100-200 grams, but there appears to be a slight overall decline from 1985 onward (Figure B6). Average weight-at-age from the USA and Canadian fishery were also examined for trends (Figure B7). The same increase in weight occurred

following the ICNAF era, but mean weights have been relatively constant since then and very similar to weights in the 1960s through the mid-1970s (Figure B7).

Predation Mortality

Evidence suggests that natural mortality rates for this species may be more variable than the current constant value ($M=0.2$) used in assessments. Overholtz et al. (2000) studied consumption of pelagic fishes and squids in the Northeast shelf ecosystem and found that the pelagic fish community in the region is heavily consumed by predatory fishes in the region. This study suggested that mackerel were important in the diets of predatory fish in the region during 1973-1997. Consumption by predatory fish as a group was certainly important during this time (Figure B8). Spiny dogfish are an important consumer of mackerel, removing significant quantities of this prey species during 1979-1997 (Figure B9).

Mackerel Distribution

The positions of mackerel survey catches during 2002-2005 from the NEFSC spring survey were plotted to observe if any changes in distribution had taken place over that time period. Mackerel were widely distributed over the Mid-Atlantic-Georges Bank region during 2002 (Figure B10). During 2003, mackerel were further to the south and distributed about midway along the Mid-Atlantic continental shelf (Figure B11). In 2004, the mackerel distribution was further to the south and further offshore than in 2003 (Figure B12). Mackerel survey catches were much further to the south and more offshore in 2005 than during the three previous years (Figure B13).

4.0 VPA CALIBRATION AND DIAGNOSTICS

Catch-at-age and mean weight data for 1962-2004 and bottom trawl survey data for winter 1992-2004 and spring 1968-2004 (ages 1-10+), were used in a VPA calibration to update the previous assessment (NEFSC 2000). Results from this run suggest that current spawning stock biomass is rebuilding, but much below levels observed in the early 1970s (Figure 1 App1). Fishing mortality increased steadily from 1980 through 2002, reaching very high values of 0.7 in 1999 and over 1.0 in 2002 (Figure 2 App1). Trends in the observed vs./ predicted series for the spring survey show patterning with a block of negative residuals prior to 1984 and positive residuals thereafter (Figure 3 App1). Observed-predicted trends from the winter survey are mixed, but the fit is reasonable (Figure 4 App1). Since there was a prominent retrospective pattern in the previous assessment, a new analysis was completed. There is still a prominent retrospective pattern for spawning stock biomass in the current VPA with successive years from 2002-2004 showing major declines in SSB when compared to the previous year (Figure 5 App1). Fishing mortality also had a pattern indicating that F was underestimated during 2002-2004 (Figure 6 App1).

Since the retransformed winter trawl series is relatively flat (Figure B5) and residual patterns for the spring survey from the previous run were poor, the next VPA run utilized only the spring survey time-series. The spring series is the longest time-series available and has long been considered the best available index for monitoring trends in this stock. Scaling was a problem

with this model run, spawning stock biomass increased to very high values, exceeding 40 million mt during 2000-2004 (Figure 7 App1). The pattern in fishing mortality was much different than in the first run, with higher mortality rates in the 1970s and much lower F's from the 1980s onward (Figure 8 App1). Model fit improved greatly in this model formulation (Figure 9 App1). However, because of the many problems encountered in the VPA formulations, another more flexible modeling approach (ASAP), that can be used to address issues such as fishery selectivity, biomass scaling, and recruitment estimation, was utilized.

5.0 ASAP FORWARD PROJECTION DESCRIPTION

ASAP is an age structured forward projection model with flexibility to address fishery selectivity, stock-recruitment, and constraints on virgin biomass, steepness, scale and other factors. The analysis for Atlantic mackerel starts in 1962 and projects forward through 2004. Total biomass, spawning stock biomass, recruitment, fishing mortality, and surplus production are estimated in the model.

Growth

The same mean weight data from the VPA (1962-2004 ages 1-10+) were used in ASAP model runs.

Maturity

Maturity was assumed to be 0.2 at age 2 and 1.0 at age 3 and older for mackerel.

Natural Mortality

Natural mortality was assumed to be 0.2 as in previous assessments.

Partial Recruitment

Partial recruitment was assumed to be 0.2 at age 1, 0.6 at age 2 and 1.0 for age 3 and older. These data were based on the old VPA run (NEFSC 2000), the new VPA run and results in the recent USA fishery.

Recruitment

A Beverton-Holt stock-recruitment model was used to model recruitment with the alpha and beta parameters estimated internally in the model. In ASAP runs 1 and 2 the SR relationship was assumed to be fit without any error, while in run 3 and the base case run the relationship was fit with error ($\lambda=1$).

Surplus Production

Surplus production for the mackerel stock was estimated by using parameters from the B-H model fit. Stock recruitment parameters were estimated internally and used to calculate management parameters such as MSY and Fmsy. In addition output from the model was used to fit a Fox model (Fox 1975) and a Schaefer model (Schaefer 1954).

Landings

The total catch-at-age for the USA and Canada model were included in the ASAP formulations (Figure B3). For details of Canadian CAA see Gregoire et al. (2003), DFO (2004), and Gregoire (2005) available online at www.dfo-mpo.gc.ca/csas.

Research Surveys for Trend

The spring survey (1968-2004 ages 1-10+, and 1-7+) was used to tune the mackerel ASAP model.

6.0 ASAP INITIAL MODEL TRIALS AND RESULTS

A series of ASAP model runs were conducted to address various aspects of model scale and goodness of fit. The first model run repeated the last formulation used in the VPA, a run that utilized only the spring survey. Results from this trial showed an improvement in scale for spawning stock biomass when compared to the VPA (Figure 10 App1). The historic period during 1962-1977 was very similar in magnitude to the VPA, but the spawning stock increased steadily thereafter to over 6.5 million mt in 2003 (Figure 10 App1). The pattern in fishing mortality showed a large increase in the mid 1970s followed by very low rates thereafter (Figure 11 App1). However, a comparison of the observed vs. predicted survey series indicated that this model run produced estimated values that were functionally a smoothed series through the survey index values (Figure 12 App1). This occurred because the SR relationship was fit without error, resulting in a smooth trend in predicted survey values. Overall, this model run resulted in a large improvement in scaling when compared to the similar VPA run, but diagnostics (residuals) were very poor. To further address issues of scale and poor model fit, another ASAP model run was completed.

It is hypothesised that another important issue related to the spring time series is a change in catchability due to a conversion to polyvalent doors that occurred in 1985. After 1984, survey catches of mackerel on average increased dramatically when compared to values prior to the door change (Table B5; Figure B2). The GARM and trawl warp investigation in 2002 suggested that the current door configuration for the 36-Yankee trawl results in an overspread condition for the net (S. Murawski, pers. comm., 2002). This means that now the net is always open both high and wide. Evidence suggests that historically the 36-Yankee survey gear probably did not operate in this fashion because water hauls were common and the net probably functioned in a more compressed state (Pers. Comm. NEFSC Survey Group, *various years*). Results from door

comparison work that was completed on a variety of species, were not available for mackerel, because the design was oriented toward groundfish and few mackerel were available during the experiment (Byrne and Forrester 1991). Coefficients for Atlantic herring from this same gear study were not significant, but these experiments were not designed to estimate the effects of door changes on herring. Extensive work on herring in subsequent studies confirmed that the door change was an important factor in explaining survey catchability changes in the spring survey for this species (Overholtz et al. 2004). Therefore, the spring survey was split in 1985 to address the survey catchability issue for mackerel. The two separate series were used to tune the mackerel ASAP model in this model run.

Results from the ASAP model utilizing the split spring time-series showed an improvement in scale, but a continued smoothing of survey predicted values. Again, the smoothing resulted from the assumption of no error in the SR relationship. Spawning stock biomass increased steadily from the late 1970s to 4 million mt in 2003 (Figure 13 App1). Fishing mortality was high in the 1970s, increased in the late 1980s and early 1990s, and slightly increased in recent years (Figure 14 App1). Patterns in the observed vs. predicted spring survey series were apparent in the pre-1985 and post 1985 periods, as the ASAP model smoothed the predicted values (Figure 15; 16 App1).

As a further approach for addressing the problem of scale and patterns in residuals, some of the features of the ASAP model that are useful for addressing issues of scale directly were used. A stock-recruitment function (Beverton-Holt) was fit with a low emphasis coefficient ($\lambda = 1$) to attempt to improve these factors. Results suggest that biomass decreased substantially and the pattern in the residuals improved greatly. Spawning biomass in the 1970s peaked at over 1.5 million mt, declined, and then increased steadily from the late 1970s onward to a maximum of 2.7 million mt in 2003 (Figure 17 App1). Fishing mortality increased slightly in the 1970s over previous runs, but remained relatively low from 1980-2004 (Figure 18 App1). Patterns in the survey residuals improved greatly, with observed and predicted series tracking nicely for both the pre 1985 and post 1985 series, and with little patterning in both series (Figures 19; 20 App1). Results for the various likelihood components in the trial, base case, and sensitivity runs are presented in Table (B11).

7.0 BASE CASE MODEL

The base case model for mackerel used a CAA that was further aggregated to 7+. The recent lack of older aged fish in the spring survey (Table B6) is probably related to availability of these larger faster swimming fish to the survey gear. The Yankee-36 trawl has always had a tendency to under-sample large mackerel over the years, but for some unknown reason survey catches in the most recent years have been low or zero (Table B6). One explanation is that large mackerel have moved further offshore or south during recent cold winters. The average temperature in the spring survey during 2002-2004 was much below the average from the preceding decade (Figure B14). The commercial fishery in recent years has also caught few larger fish, but this may be explainable since the fishery has been narrowly focused in inshore areas off Rhode Island and New Jersey and apparently large fish have not been available in those areas (Figure B15). Commercial vessels have done little searching in offshore areas that are far removed from inshore fishing grounds that are close to ports. Therefore, to further address issues of scale and

goodness-of-fit caused by low survey and commercial landings of older fish, the CAA was aggregated at 7+. Preliminary model runs with a delay-difference biomass model (Schnute 1985) (biomass, age 2 and 3+) also indicated that aggregating over older age groups might be a useful approach. Emphasis coefficients for the base case model are listed in Table (B9). The working group decided that this was the best model formulation currently available for determining the status of the mackerel stock. Several additional sensitivity runs were examined by the WG and results are presented in subsequent pages. Results for the accepted base case run are as follows.

Total Biomass

Total biomass reached 1.9 million mt in 1969 and declined to just over 0.7 million mt in 1977 (Figure B16). Total biomass increased steadily to 1.4 million mt in 1999 and then increased rapidly to 2.9 million mt in 2004 (Figure B16). Total biomass ranged between 2.3 and 2.9 million mt during 2000-2004, averaging 2.5 million mt.

Spawning Biomass

Spawning biomass peaked in 1972 at 1.7 million mt, declined until 1976, and began to increase thereafter (Figure B17). During 1978-2000 spawning biomass increased steadily to 1.3 million mt in 2000. SSB continued to increase and then stabilized at 2.3 million mt in 2003-2004 (Figure B17). Spawning biomass ranged between 1.3 and 2.3 million mt in 2000-2004 and averaged 2.0 million mt.

Fishing Mortality

Fishing mortality was relatively high during 1969-1975, peaking at 0.54 in 1975 (Figure B18). Fishing rates dropped dramatically to a low of 0.05 in 1978 followed by a very low and stable period during 1979-1986. Fishing mortality reached a small peak in 1988 of 0.09, coincident with the joint venture (JV) fishery that operated for several years, and then declined to a low of 0.02 in 2000 (Figure B18). The average fishing rate during 2001-2004 was 0.04 and F in 2004 was 0.05.

Stock-Recruitment, Recruitment

Recruitment has been highly variable for the mackerel stock over a range of spawning biomass between about 0.3-2.3 million mt (Figure B19). Recruitment ranged between 0.1-5.8 billion fish during 1962-2004 and averaged 1.1 billion fish (Figure B20). There have been three large year classes during that period, the 1967, 1982, and 1999 year-classes (Figure B20). Recruitment from the 2002 and 2003 year-class appears promising, but is difficult to quantify at this time. The recent average recruitment during 2001-2004 was 1.6 billion fish and recruitment in 2004 was estimated at 2.8 billion.

Surplus Production

Biological reference points were estimated with a Fox model (Fox 1975), Schaefer model (Schaefer 1954) and from an internal B-H stock-recruitment relationship. Reference points from the B-H parameters were $MSY = 89,000$ t, $SSB_{msy} = 644,000$ t, and $F_{msy} = 0.16$. Surplus production (SP) in the mackerel stock was available sporadically during the 1962-2004 time-period (Figure B21). Periods of SP occurred before the ICNAF fishery in the late 1960s, during the early 1980s, and more recently in the late 1990s through 2003 (Figure B21). Results from the Schaefer and Fox models were not used because the surplus production (SP) data surfaces for both model was flat over a wide range of SSB, resulting in very high estimates of K and B_{msy} . Only the results from the B-H model were deemed to be useful by the committee. The average SP for this stock during 1962-2003 was 148,000 mt; this value can serve as a proxy upper bound on MSY for the current assessment.

Precision of ASAP Estimates

The relative precision of the estimates for spawning stock biomass and fishing mortality were calculated using the Hessian matrix from the ASAP model fitting procedure. This approach produces a mean and standard deviation for every parameter in the model (Table B12). Results indicate that estimates for both SSB and F are moderately precise. The estimated mean SSB was 2.32 million mt, ranging from 1.49-3.14 million mt, for a two standard deviation interval. The average estimate of F was 0.05, ranging from 0.035-0.063, again for a 2 SD interval. Results from an MCMC run of the ASAP model indicated that these 2SD intervals are comparable to a 95% CI.

Model Diagnostics

Plots of observed-predicted series for the spring NEFSC survey used to tune the ASAP model for trend were produced as a diagnostic measure of goodness of fit. Plots of observed vs. predicted data series (log scale) are shown in Figures (B22; B23) for the base case model. Survey observed and predicted series for the pre 1985 and post 1985 period track nicely with few indications of patterning. The committee examined all the available ASAP diagnostics such as age and year specific observed vs. predicted CAA, indices at age, effective sample size, stock-recruitment plot, and population by year, and concluded that these were also reasonable.

Retrospective Analysis

A retrospective analysis was conducted to observe if there are any patterned trends in SSB and recruitment of the ASAP base model. Results for SSB indicate a moderate pattern for 2001-2003 and larger difference for 2004 (Figure B24). There also appeared to be a change in trend for 2004. For recruitment there appears to be some consistent patterning for years prior to 1999. For the large 1999 year-class the pattern is not consistent among years, but estimates are highly variable across years (2000-2004) (Figure B25).

Projections

Natural mortality was set at $M=0.2$ for the projections. Partial recruitment to the fishery was set at 0.2 for age 1, 0.6 for age 2, and 1.0 for age 3 and older. Maturity was held constant a 0.2 at age 2 and 1.0 at age 3 and older. Mean weights used in the projections were held constant, the values used were for 2004 (Table B4).

Deterministic projections for 2006-2008 were conducted by inputting an estimated catch of 95,000 mt (209 million lbs) in 2005, a target fishing mortality of 0.12 (MAFMC 1998, $F_{target}=0.75 \times F_{msy}$) in 2006-2008, and annual recruitment values based on the S/R curve that was estimated from data. If 95,000 mt (209 million lbs) are landed in 2005, SSB in 2006 will increase to 2,640,210 mt (5.8 billion lbs) (Table B13). If the $F_{target} F=0.12$ is attained in 2006-2008, SSB will decline to 2,304,020 mt (5.1 billion lbs) in 2007 and to 2,043,440 mt (4.5 billion lbs) in 2008. Landings during 2006-2008 would be 273,290 mt (603 million lbs), 238,790 mt (527 million lbs), and 211,990 mt (467 million lbs), respectively (Table B13). These landings are the result of an unusually large year-class (1999) present in 2005, and will not be sustainable in the long term. It is expected that these projected landings will decline to MSY (89,000 mt (196 million lbs)) levels in the future when a more average recruitment condition exists in the stock.

8.0 SENSITIVITY ANALYSIS

An additional trial run was conducted to address the retrospective problem that occurred in the base run. It was assumed that there is still a great deal of variability in the model fit caused by the lack of older fish in the CAA and survey. Even aggregating the CAA and survey to 7+ did not appear to alleviate this problem fully. We therefore decided to allow the model to estimate selectivity during 1995-2004 in the fishery to see if this impacted the results. Emphasis coefficients for this model are listed in Table (B10). This approach changed and improved the retrospective pattern in SSB and recruitment. The retrospective for SSB appears to have been minimized as all the trajectories are consistent and there is no apparent pattern (Figure 1 App2). The retrospective pattern for recruitment also appears to be lessened, but there is still some sequential patterning for year-classes prior to 1999 and a clear pattern for the 1999 year-class (Figure 2 App2).

The working group also wanted to see an ASAP model run that included the NEFSC winter bottom trawl survey to compare the results to the VPA. SSB in this model run showed the familiar peak in biomass in the early 1970s, but this was followed by a steep decline in SSB to a low of 99,000 mt in 2004 (Figure 3 App2). This steep decline in SSB was the result of a very sharp increase in fishing mortality during the late 1990s and 2000-2004 (Figure 4 App2). The observed vs. predicted series for the winter (Figure 5 App2), and spring 1 (Figure 6 App2) were reasonable, but the pattern for the spring2 series deteriorated, with a series of negative residuals from 1990-2003 (Figure 7 App2). Adding the winter series to the ASAP model obviously caused the model fit to deteriorate seriously, producing infeasible trends in SSB and fishing mortality.

The final sensitivity run requested by the committee was a model that allowed selectivity to be estimated for the entire time-series from 1962-2004. This run was accomplished by using the same parameter setup as for the base case, but designating two separate time-blocks, one from 1962-1994 and the other from 1995-2004, and letting the model estimate fishery selectivity. In this run, SSB increased to over 1.6 million mt in 1972, declined sharply, and then steadily increased to about 1.4 million mt in 2004 (Figure 8 App2). As in several of the previous runs, fishing mortality peaked in the 1970s, declined, and remained low during the 1980s-2004. However, in this run F was much more asymptotic during the early years and then more dome shaped during the late 1990s, through 2004 (Figure 9 App2). The observed vs. predicted series for this model show that goodness of fit was reasonable with both the spring1 and spring2 series showing little patterning (Figure 10; 11 App2). The fishery selectivity for this model was asymptotic for the early years of the time-series and showed a moderate dome thereafter (Figure 12 App2).

9.0 SARC-30 RESEARCH RECOMMENDATIONS (TOR 6)

a. Explore logbook data for information on catch rates and geographic distribution.

No analysis was completed on this recommendation. Previous analyses have suggested that catch rates from the mackerel are an unreliable index of abundance because electronics are used to actively search for this species. Frequent technological improvements in winches, nets, doors, and other equipment also make it very difficult to compare fishery dependent catch rates among years. The fishery also tends to be aggregated in isolated small areas, piggybacked on the success of other vessels during the season. The recent and current fishery in the USA takes place along the inshore areas of New Jersey and Rhode Island depending on the location of mackerel on the continental shelf during winter. This factor means that very little information on the distribution of mackerel can probably be obtained from fishery dependent data.

b. Explore Canadian trawl survey indices for use in VPA calibrations.

Several additional trawl survey indices and egg indices were explored as tuning indices, but currently they do not appear useful in resolving assessment issues with this stock (Pers. comm. F. Gregoire DFO 2005)

c. Explore the feasibility of acoustic surveys for monitoring stock size.

Several attempts have been made to use acoustics to survey mackerel during recent winter cruises on the RV Delaware II. To date there has been little success, but this does not preclude the use of acoustics on this species, especially with the RV Bigelow in future.

d. Examine estimates of Z calculated from research vessel survey data with respect to their usefulness in estimating natural mortality.

No progress was made on this recommendation during the interim period.

10.0 RESEARCH RECOMMENDATIONS

- Currently there are historical age data that are only in hard copy form. These data should be put into an electronic database to allow examination of alternative methods, such as non-transformed indices.
- The current approach of transforming the survey indices should be expanded to include an exploratory analysis of geometric mean or other distributions instead of retransformed mean.
- Examine NEFSC Spring survey since 1999 to see what may have caused large increases in catch/tow.
- Explore use of environmental covariates to help explain recruitment deviations from the stock recruitment relationship.
- Consider the use of environmental variables to adjust the NEFSC Winter and Canadian surveys for changes in availability and consider their use as tuning indices in modeling.
- Increase sampling of commercial landings and survey catches to better characterize age and length composition.
- Conduct simulation exercises to determine the sample sizes required to detect old fish with high probability in commercial samples assuming they are present.
- Explore discard estimation, especially for years when large year classes are first entering the fishery.
- Pilot survey to explore for old fish to test hypothesis regarding dome in commercial fishery selectivity.

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