Fisheries and Oceans Canada / Pêches et Océans Canada

NOAA FISHERIES
NATIONAL MARINE FISHERIES SERVICE

CERT	***TRAC***
Comité d'évaluation des ressources transfrontalières	**Transboundary Resource Assessment Committee**
Document de référence 2010/01	**Reference Document 2010/01**
Ne pas citer sans autorisation des auteurs	Not to be cited without permission of the authors

Stock Assessment of Atlantic Mackerel in the Northwest Atlantic – 2009

Jonathan J. Deroba[1], Gary Shepherd[1],
François Grégoire[2], Julie Nieland[1], and Jason Link[1]

[1]National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole Laboratory
Woods Hole, MA 02543

[2] Fisheries and Oceans Canada
Quebec Region
Maurice Lamontagne Institute
850, route de la Mer
P.O. Box 1000, Mont-Joli (Qc)

Ce document est disponible sur l'Internet à : This document is available on the Internet at :
http://www.mar.dfo-mpo.gc.ca/science/TRAC/trac.html

Canada

TABLE OF CONTENTS

ABSTRACT

Atlantic mackerel *Scomber scombrus* were previously assessed in 2005, and the conclusion of that assessment was that the stock was not overfished and overfishing was not occurring. The status was based on results of a model fit using the Age Structured Assessment Program (ASAP) that included a split in the National Marine Fisheries Service (NMFS) spring research bottom trawl survey index in 1985. That model served as a starting point for the most recent assessment using data updated through 2008. However, multiple configurations of ASAP models using the updated data, including models with predation removals, were not robust to various assumptions and exhibited significant retrospective patterns. Due to generally better diagnostics from a virtual population analysis (VPA) model configuration, this approach was chosen by the Transboundary Resources Assessment Committee (TRAC) as the benchmark model.

The benchmark VPA model was fit to catch at age and mean weight at age data for 1962-2008, NMFS spring bottom trawl survey data from 1968-2008 with the time series split in 1985 and 1993, and commercial catch per unit effort (CPUE) data from bottom and mid-water otter trawls during 1978-2008. Estimated fishing mortality for Atlantic mackerel (F; averaged over ages 4-6) increased from 0.17 in 2000 to a peak of 1.11 in 2006 (the highest in the time series), but decreased to 0.51 in 2008. Estimated SSB declined from 1,359,003 mt in 1972 to 96,968 mt (unadjusted for retrospective) in 2008. Estimated recruitment (age 1) was characterized by occasional large year classes, especially the 1967, 1982, and 1999 cohorts. In recent years, however, recruitment has generally been lower, averaging 566 million age 1 fish during 1985-2009. By comparison, recruitment averaged 2.1 billion fish at age 1 during 1962-1984, and 1.3 billion age 1 fish over the entire assessment time series. Based on results of the benchmark VPA, 100 year projections produced an estimate of SSB40% (proxy for SSBmsy) of 194,000 mt, which implies a Maximum Sustainable Yield (MSY) proxy (yield at F40%) of 37,200 mt.

Despite having the best diagnostics of those models considered, the benchmark VPA was faced with resolving disparate trends between the NEFSC spring survey, CPUE indices, and total landings. Furthermore, splits in the NEFSC spring survey time series created large changes in catchability that could not be fully explained. These issues resulted in a benchmark model that still contained a significant retrospective pattern and produced highly uncertain estimates. Because the estimates of SSB40% and MSY40% were dependent on the assessment results, and both estimates were also highly uncertain, the TRAC did not recommend their adoption and conclusions regarding stock status relative to biological reference points were considered inappropriate.

RÉSUMÉ

Une évaluation du maquereau bleu (*Scomber scombrus*) a déjà été effectuée en 2005 et avait abouti à la conclusion que le stock n'était pas surexploité et qu'il ne faisait l'objet d'aucune surpêche. L'appréciation de l'état du stock était fondée sur les résultats d'un modèle calés d'après le Programme d'évaluation selon la structure d'âge (PESA), comprenant un fractionnement en 1985 de l'indice du relevé de printemps au chalut de fond réalisé par le National Marine Fisheries Service (NMFS). Ce modèle a servi de point de départ pour l'évaluation la plus récente, effectuée avec des données mises à jour jusqu'en 2008. Toutefois, les multiples configurations des modèles PESA avec les données actualisées, y compris les configurations tenant compte des prélèvements des prédateurs, ne résistaient pas solidement à diverses hypothèses et présentaient d'importantes tendances rétrospectives. Étant donné le diagnostic généralement meilleur produit par un modèle d'analyse de population virtuelle (APV), c'est cette approche qui a été retenue par le Comité d'évaluation des ressources transfrontalières (CERT) comme modèle de référence.

Le modèle d'APV de référence a été calé d'après les données de captures selon l'âge et de poids moyen selon l'âge pour 1962-2008, les données du relevé de printemps au chalut de fond du NMFS de 1968 à 2008 (avec fractionnement de la série en 1985 et en 1993) et les captures par unité d'effort (CPUE) dans les relevés au chalut de fond à panneaux et au chalut pélagique à panneaux pour la période 1978 2008. L'estimation de la mortalité par pêche du maquereau bleu (F moyenne parmi les âges 4-6), qui était de 0,17 en 2000, a augmenté et culminé à 1,11 en 2006 (sa plus haute valeur de la série chronologique), mais elle a diminué à 0,51 en 2008. L'estimation de la BSR a diminué, passant de 1 359 003 tm en 1972 à 96 968 tm (chiffre non corrigé en fonction de la tendance rétrospective) en 2008. Le recrutement (âge 1) estimé se caractérisait par de vastes classes d'âge occasionnelles, en particulier les cohortes de 1967, 1982 et 1999. Ces dernières années, le recrutement a été généralement plus bas, se situant en moyenne à 566 millions de maquereaux d'âge 1 de 1985 à 2009. Par comparaison, le recrutement moyen a été de 2,1 milliards de poissons d'âge 1 de 1962 à 1984 et de 1,3 milliard de poissons d'âge 1 sur toute la série chronologique des évaluations. Des projections sur 100 ans fondées sur les résultats de l'APV de référence ont produit une estimation de la BSR40 % (indice supplétif de la BSRPME) de 194 000 tm, ce qui correspond à un indice supplétif (production à F40 %) de la production maximale équilibrée (PME) de 37 200 tm.

Bien qu'elle produise le meilleur diagnostic parmi tous les modèles considérés, l'APV de référence a dû concilier des tendances disparates entre les données du relevé de printemps du NEFSC, les indices des CPUE et les débarquements totaux. De plus, les fractionnements dans la série chronologique des données du relevé de printemps du NEFSC se sont traduits par de grands changements dans la capturabilité, qui n'ont pu être entièrement expliqués. Ces problèmes ont abouti à un modèle de référence qui comportait encore une forte tendance rétrospective et produisait des estimations très incertaines. Comme les estimations de la BSR40 % et de la PME40 % dépendaient des résultats de l'évaluation et que ces deux estimations étaient aussi très incertaines, le CERT n'a pas recommandé qu'elles soient retenues et les conclusions sur l'état du stock par rapport aux points de référence biologique ont été jugées inadéquates.

INTRODUCTION

Atlantic mackerel in the Northwest Atlantic are a migratory species that move seasonally between U.S. and Canadian waters. Sette (1943; 1950) identified two distinct groups consisting of a northern contingent and a southern contingent. The two contingents overwinter primarily along the continental shelf between the Middle Atlantic and Nova Scotia, although it has been suggested that overwintering occurs as far north as Newfoundland. With the advent of warming shelf water in the spring, the two contingents begin migration, with the northern contingent moving along the coast of Newfoundland and historically into the Gulf of St. Lawrence for spawning from the end of May to Mid-August (Berrien 1982). The southern contingent spawns in the Mid-Atlantic and Gulf of Maine from mid-April to June (Berrien 1982) then moves north to the Gulf of Maine and Nova Scotia. In late fall, migration turns south and fish return to the over-wintering grounds.

Atlantic mackerel were last assessed in the United States in 2005 (NEFSC 2006). The conclusion of that assessment was that mackerel were not overfished and overfishing was not occurring.

Data available for the 2009 assessment were reviewed and adopted at the TRAC data meeting in October 2009 (TRAC 2009). In the interim between the data meeting and the TRAC model meeting in March 2010, adjustments were made to the catch data. Foreign landings that were not previously included were added to the Canadian landings from 1968 to 1977 and the Canadian catch at age data were updated to include all available length and age data from that period (Table 1). In addition, U.S. landings at age for 2006 to 2008 were re-calculated with the inclusion of length data collected by commercial industry funded sampling. Using these corrected datasets, several model configurations were developed and considered during the TRAC model meeting. The major model configurations considered and the benchmark assessment model chosen by the TRAC are discussed below.

GENERAL MODEL CONFIGURATIONS CONSIDERED

ASAP Model

Since the previous assessment in 2005 (NEFSC 2006), the ASAP software was updated. Differences in the results from the previous assessment and results using the new software were minimal (Figures 1 and 2). The new software, however, provides an option to use likelihood constants that was not available in the previous version. Likelihood constants are additive values in the likelihood equations that do not depend on the parameter estimates and so theoretically do not affect the solution. For reasons not fully understood, but that may be related to differences in computer precision bounds, relatively minor differences can occur between model solutions fit with and without the likelihood constants. Use of the constants in this case influenced the terminal estimates of fishing mortality (Figures 3 and 4) although the absolute values were similar. All subsequent runs in the new assessment were made using the likelihood constants.

The assessment model configuration used in the previous assessment, following the addition of catch and indices at age data for 2005-2008, served as the basis for model comparison during the 2009 assessment. The updated assessment model included ages through 7+, a catch series from 1962-2008 and NEFSC spring bottom trawl survey indices at age from 1968-2008 (Tables 2-5). The survey indices were split into two series between 1984 and 1985. All fishery selectivities were fixed at 0.2, 0.6 and 1.0 for ages 1, 2 and 3-7+, respectively. A series of alternative ASAP models were examined which included various index series splits, addition of multiple fleets (U.S. and Canada), starting years in the catch series, estimation of selectivity, periods of changes in selectivity and fixed steepness values in stock-recruitment (Table 6). The diagnostics examined for alternative ASAP models included the fit to indices at age and total catch, residual patterns, retrospective patterns, selectivity patterns, and the objective function value.

Model results generally showed similar patterns with peak abundance in the late 1960s-early 1970s followed by a period of high F in the mid-1970s (Figure 5). Recent years were characterized by high F and decreasing N since 2000. The exception to this pattern occurred when the survey index was input as a single series. The consequence of using one index series was a significant increase in abundance in recent years and a correspondingly low F (values <0.05).

The "preferred" ASAP model incorporated two fleets (U.S. and Canada) with the time series beginning in 1968 (to correspond to the index series). The survey indices were split at 1991-1992 to reduce patterns in the index residuals (although with little improvement from the 1984-1985 split). Selectivity was constant through time and fitted as a logistic model for each fleet (Figure 6). Total CV for the U.S. fleet was 0.1 until 1982, 0.05 from 1982 to 1989 then 0.01. Since the Canadian catch was considered underestimated, the CV for the Canadian fleet was set at 0.1 to allow greater deviation from an exact fit. Steepness in the stock recruitment function was fixed at 0.6 in the model, which corresponded to SPR40% (Brooks et al. 2010). Fishing mortality peaked at 0.79 in 1974 then decreased to 0.08 by 1978 (Figure 5). F remained less than 0.1 until 1996 when it began increasing, peaking at 0.67 in 2006 (Figure 5). F in 2008 was 0.49 (0.195 in U.S. and 0.29 in Canada). Total abundance decreased from 7.8 billion in 1968 to 1.116 billion in 1978, rose to 6.1 billion with the incoming 1982 year class and has generally declined thereafter (Figure 7). Abundance in 2008 was 733 million fish (Figure 7). SSB peaked in 1985 at 1.32 million mt and steadily declined thereafter, reaching a low in 2008 of 123,100 mt (Figure 8).

Although the basic fit with the preferred ASAP model was reasonable (Table 7; Figure 9 and 10), the results showed some patterned residuals, particularly in ages 1 and 2 of the early series and 10+ in the later series (Figure 11). In addition, retrospective patterns in fishing mortality and spawning stock biomass persisted (Figures 12-15). The influence of the under-estimated Canadian catch on the retrospective pattern was also explored. Doubling the Canadian catch since 1968 (overall average total increase of 46%) had little effect on the retrospective pattern or magnitude (Figure 16). The model fit was heavily influenced by the steepness parameter chosen. If the stock-recruitment relationship was fit, the results were unrealistic, with steepness estimates from 0.2 to 0.3. Fixed steepness values were inversely proportional with F. The value chosen was based on a generalized relationship and was not specifically developed for Atlantic mackerel. The model estimates of F, abundance, and SSB from the ASAP model are different than the previous assessment results. The 2004 retrospective estimate from the current model, however, corresponds to the 2004 estimates from the previous assessment. Finally, the results of the model are dependent on the existence of a split survey series and the associated q's which varied greatly between time blocks (Table 8).

ASAP Model with Predation

The inclusion of mackerel removals from predation was modeled as a separate fleet within the ASAP model. Consumption estimates were made for the eleven primary mackerel predators described in the TRAC data meeting (TRAC 2009). Predator abundance estimates were available for all predators beginning in 1982. Consumption between 1968 and 1981 was assumed equal to the time series average. Predator estimates based on survey swept area abundance were smoothed using a 3 year moving average and estimates based on assessment model results were unadjusted. Total consumption equaled the sum of annual consumption from all predators (Table 9). Total mackerel removals from predation averaged 29,800 mt with a high value of 139,616 mt in 1984. Estimated predation removals averaged 30% of total removals (catch plus predation).

Predation in ASAP was modeled as total removals paired with an assumed selectivity. Selectivity was fixed at 1.0 for ages 1 and 2, 0.75 at age 3 and 0.2 at age 4 based on size of mackerel measured from stomach samples. A higher proportion at age 4 resulted in a situation where a model solution was not found. The predation model that had the best relative diagnostics included three fleets (U.S., Canada and predators), with similar settings as the non-predation model. Natural mortality (M1) was fixed as 0.1 although the final M at age is the sum of M1 and predator F (fleet 3). The NMFS spring bottom trawl survey series was split at 1984-1985.

Results from the predation model followed a similar pattern as the non-predation model, with a peak fishery F in 1975 at 0.63 and 2006 at 0.47, declining in 2008 to 0.26 (Figure 17). SSB peaked in 1972 at 1,304,000 mt but since declined to 202,250 mt (Figure 18). The natural mortality (M1 plus M2) at ages 1 and 2 was time variant and averaged 0.45, peaking in 1987 at 0.87 (Figure 19). Natural mortality dropped below average in 2000 but then increased to 0.64 in 2008 (Figure 19).

The addition of removals by predators had the most influence on the estimates of abundance and spawning biomass in the mid-1980s (Figure 18; Figure 20). Fishing mortality was less influenced since predation in the model was primarily on ages 1 and 2 whereas full recruitment to the fishery of both fleets did not occur until age five (Figure 17). The addition of predation data is limited by the availability of annual consumption estimates from only the NEFSC bottom trawl survey. Predation by larger predators not captured in the survey trawl, as well as consumption in Canadian waters, limits the model to a minimal estimate of the predatory removals. Nevertheless, the assessment model with predation does provide some additional information not considered with a time and age invariant application of natural mortality rate.

VIRTUAL POPULATION ANALYSIS

Input Data

Data sources initially considered for calibrating a VPA were NMFS spring bottom trawl survey index at age data during 1968-2008 (geometric mean), NMFS winter bottom trawl survey index at age data during 1992-2007 (geometric mean), standardized bottom fished commercial otter trawl CPUE (pounds landed/days absent) data during 1978-2008 (aggregate index across all ages), and standardized mid-water commercial otter trawl CPUE data during 1994-2008 (aggregate index). A “baseline” model was developed by making iterative improvements to the VPA that addressed model diagnostic problems (e.g., residual patterns, parameter estimates at upper or lower bounds) that arose during the fitting process. Unless otherwise noted, all VPA models were fit using data on fish age-1 through an age-7 plus group.

An initial VPA model was fit using all of the above data (none of the index data split into multiple time blocks). Estimates of abundance at age in the terminal year +1 were all at the upper bound of the model (1 billion) except for age-3. The residuals for the spring survey also exhibited a pattern with negative residuals before 1985 and positive residuals after 1985

(Figure 21). Furthermore, the bottom otter trawl fishery had a residual pattern with negative residuals before 1989, positive residuals during 1989-1999, and negative residuals after 1999 (Figure 21). To address these residual patterns, a VPA was fit with a split in the NMFS spring survey at 1985 (1968-1984; 1985-2008) and in the bottom fished otter trawl CPUE data at 1989 (1978-1988; 1989-2008). The split in 1985 for the spring survey was the same as the split used in the last assessment to account for the conversion to polyvalent trawl doors (NEFSC 2006). These splits improved the pattern of the residuals (Figure 22).

The NMFS winter bottom trawl survey index was not used in the last assessment partially because the spring index was considered superior and the winter index time series was relatively flat. The pattern was similar for this assessment with the exception of 2005, which was anomalously high due to a few large tows (Figure 23). Consequently, a VPA was fit without the winter bottom trawl survey index and with the spring bottom trawl survey index and fishery bottom otter trawl index split as described above. Removing the NMFS winter survey index caused a modest increase in spawning stock biomass and decrease in average fishing mortality rate (ages 3-5) in recent years (Figure 24), but the coefficient of variation estimates for the abundances at age in the terminal year+1 were nearly zero and so may be invalid. However, the justifications for excluding the NMFS winter survey still hold for this assessment, and the VPA was generally robust to the exclusion of this data source, so the winter survey was not used in any additional VPA model fits.

The NMFS spring bottom trawl survey was the only index used in the prior assessment and indices based on commercial catch rate data may not provide an accurate index of abundance. Therefore, a VPA was fit with only the spring index, split as described above. Spawning stock biomass and average fishing mortality rate estimates were similar between VPA models with and without the commercial CPUE indices (Figure 25). Furthermore, the trends in the commercial CPUE data used here were generally similar to the NMFS spring survey index for some ranges of years (Figure 26). Consequently, the commercial CPUE indices were retained in all additional VPA model fits.

Baseline VPA

Based on the above VPA model fits, the conclusion was that the baseline VPA model should include the NMFS spring index and commercial CPUE indices, with the time series split as described above. However, the model using these data sources had a retrospective pattern suggesting consistent overestimation of spawning stock biomass and underestimation of fishing mortality (Figure 27). To explore ways of reducing this retrospective pattern, a series of VPA runs were conducted with two splits, resulting in three time blocks in the NMFS spring survey. In all of these runs, the 1985 split described above was retained. A second split that minimized the retrospective pattern was evaluated using each year from 1986-2004 as the second split point. That is, a separate VPA was fit while splitting the NMFS spring index in 1985 and 1986, 1985 and 1987, 1985 and 1988, and so on, until the retrospective pattern was minimized. The first year of the second split that minimized the retrospective pattern was 1993 (i.e., 1968-1984; 1985-1992; 1993-2008; Figure 28). This model was considered the baseline VPA because it had the best diagnostics (i.e., limited residual patterns, reduced retrospective patterns) of those models considered (Figure 28; Figure 29).

Spawning stock biomass (SSB) estimates from the baseline VPA model peaked in 1972 at 1.98 million metric tons (mt) and generally declined for the remainder of the time series to an all-time low of 0.21 million mt in 2008 (Figure 30). Total abundance generally followed the same trend as SSB. Furthermore, total abundance estimates from the baseline VPA were greater than the swept area population estimates from the NMFS spring bottom trawl survey (Table 10), which suggested that the efficiency of the spring survey was not inflated due to factors such as herding. The average fishing mortality rates (F,ages 3-5) were relatively high during 1968-1975 peaking at 0.36 in 1973 (Figure 30). Average F then declined to 0.02 in 1978, generally increased to an all-time high of 0.77 in 2006, and declined to 0.38 in 2008 (Figure 30). Recruitment at age-1 varied during 1962-2008 with generally higher average recruitment during 1962-1984 than 1985-2008 (Figure 31). During 1985-2008, only the 1999 year class estimate was above the average recruitment during 1962-1984 or the average during the entire time series (Figure 31).

Abundance estimates at age in the terminal year+1 were relatively imprecise. Coefficients of variation for all ages were greater than 1.0, except for age-4 (Table 11). Catchability at age estimates for the NMFS spring bottom trawl survey generally declined with age during all 3 time blocks used in the baseline VPA model (Figure 32; Table 12). Catchability estimates also differed by an order of magnitude among the 3 time blocks, with higher catchabilities in more recent years (Figure 32; Table 12). The higher catchability estimates in recent years may be effectively down scaling the relatively high mean number per tow observations in recent years (Figure 26), such that the subsequent trend in abundance estimates during recent years would not match the relatively high survey observations that occurred prior to accounting for temporal changes in catchability. This effective down scaling of the relatively high NMFS spring survey observations from recent years may be why SSB estimates declined and average fishing mortality rate estimates increased with each additional split in the NFMS spring survey (Figure 33 no splits; Figure 27 and Figure 25 split in 1985; Figure 28 and Figure 30 split in 1985 and 1993). So, although improvements in model diagnostics, such as residual and retrospective patterns, drove the development of the baseline VPA model, these improvements came at the cost of effectively devaluing the NMFS spring survey trend, particularly the relatively high index values in recent years.

<u>VPA Sensitivity Analysis</u>

Given the magnitude of the changes in catchability between the time blocks of the NMFS spring survey used in the baseline VPA, and the uncertainty in the explanation for those changes, a more detailed examination of the results of a VPA without those splits was warranted. Spawning stock biomass from a VPA with no splits in the spring survey generally declined during 1972-2000, but increased during 2001-2008 to an all-time high of 2.1 million metric tons, which was in contrast to the results from the baseline VPA (Figure 33). Average fishing mortality rate from this VPA was generally stable during 1980-2008 and varied around a value of approximately 0.08, which was also in contrast to the baseline model (Figure 33). However, this VPA also exhibited residual and retrospective patterns (patterns similar to Figure 21 and Figure 27), and abundance estimates in the terminal year+1 were all at the upper bound. So, although this VPA may serve to bound the model estimates, from a diagnostics standpoint it should likely not be considered a viable alternative.

In all of the VPA models described above, natural mortality (M) was equal to 0.2 and was age and time invariant. The sensitivity of the baseline VPA to this assumption was evaluated by fitting two variants of the baseline VPA with M=0.3 and M=0.1. The general trends in SSB and average fishing mortality with M=0.3 were generally similar to the baseline VPA, but SSB was higher and average fishing mortality was lower in all years (Figure 34). The retrospective patterns with M=0.3 were also slightly improved relative to the baseline VPA (Figure 35). The general trends in SSB and average fishing mortality with M=0.1 were generally similar to the baseline VPA, but SSB was lower and average fishing mortality was higher in all years (Figure 36). The retrospective patterns with M=0.1 were also slightly worse relative to the baseline VPA (Figure 37).

Statistical Catch at Age Model

A statistical catch at age (SCA) model that had been previously used for striped bass Morone saxatilis was also considered for mackerel (NEFSC 2008). Data sources considered were total annual commercial mackerel catch (i.e., sum of U.S. and Canadian) during 1962-2008, age composition of the commercial catch (age-1 to an age-7 plus group), mean weight at age during 1962-2008, annual NMFS spring bottom trawl survey index data during 1968-2008 (geometric mean; split in 1985) and the age composition for this survey, standardized bottom fished commercial otter trawl CPUE data during 1978-2008 (aggregate index), and standardized mid-water commercial otter trawl CPUE data during 1994-2008 (aggregate index). Unlike the model for striped bass, fishery and survey selectivity at age were input as constants (time invariant). Other biological parameters (e.g., natural mortality) were also constant at values equal to that used in the baseline VPA described above. This SCA model was fit using auto-differentiation model builder software by minimizing the total negative log likelihood, which was summed over the individual negative log likelihood components of each data source. Preliminary SCA model fits suggested that this model had problems with scale, was unstable, exhibited residual patterns, and was sensitive to the relative weight placed on each negative log likelihood component. Consequently, additional details for this model are not provided and this model should likely not be considered as a viable option. However, some preliminary results are provided to illustrate that the trends from the baseline VPA are not unique and can be reproduced by alternative assessment model types.

Trends in SSB and fully selected fishing mortality were similar to the baseline VPA (Figure 38). Spawning stock biomass peaked in 1970 at 0.90 million metric tons and declined to an all-time low of 0.05 million metric tons in 2008 (Figure 38). Fully selected fishing mortality was variable during 1962 to 2000, but increased to an all-time high of 1.1 in 2007 and declined to 0.9 in 2008 (Figure 38).

TRAC CONSENSUS

The TRAC benchmark review agreed to use the NEFSC spring survey index and two commercial CPUE indices (bottom-trawl and mid-water trawl) as tuning indices for the assessment. A VPA-ADAPT model was selected as the benchmark model with (a) the spring NEFSC survey index split in 1984-1985 and 1992-1993; (b) the bottom trawl CPUE index split in 1988-1989 and the mid-water trawl CPUE index with no split and (c) using a variable natural mortality (M) at age (estimates of M at age averaged among years from the ASAP predation model) to account for predation. This model was selected as the benchmark because it generally had better diagnostics than the alternatives considered. Despite the relatively better diagnostics, the benchmark VPA-ADAPT model exhibited a strong retrospective pattern (Figure 39) and had highly uncertain terminal year population estimates (high coefficients of variation) that were perhaps biased.

The assessment model was faced with resolving disparate trends between the NEFSC spring survey and CPUE indices and total landings. Despite very large annual catches in the 1970s, there was very little change in the spring survey index during these years. Later in the assessment time series, a generally increasing trend in the survey index was co-incident with a rapid disappearance of older age classes in both the survey catches and the commercial landings. This situation contributed to a large retrospective pattern (aliasing survey catchability with the two opposing trends).

The retrospective patterns in the model were addressed by applying a survey split in 1984-1985 (which was used in the 2005 U.S. assessment), as well as applying an additional split in 1992-1993. The 1984-1985 split was justified by a change in survey trawl door at this time, as well as indications in the survey of changing mackerel distribution from deeper to shallower water. The mechanism for the 1992-1993 split has not yet been established; however, this split improved model diagnostics. In both instances, the splits may be aliasing other factors. Simulations presented at previous U.S. groundfish assessments indicated that assessments that exhibit strong retrospective patterns provided more reliable catch advice (i.e., closer to Fref in the simulated population) by splitting the surveys, regardless of the cause of the retrospective pattern (GARM 2008).

Estimated fishing mortality for Atlantic mackerel (F; averaged over ages 4-6) increased from 0.17 in 2000 to a peak of 1.11 in 2006 (the highest in the time series), but decreased to 0.51 in 2008 (Figure 40). Estimated SSB declined from 1,359,003 mt in 1972 to 96,968 mt (unadjusted for retrospective) in 2008 (Figure 40).

Estimated recruitment (age 1) was characterized by occasional large year classes, especially the 1967, 1982, and 1999 cohorts (Figure 40). In recent years, however, recruitment has generally been lower, averaging 566 million age 1 fish during 1985-2009. By comparison, recruitment averaged 2.1 billion fish at age 1 during 1962-1984, and 1.3 billion age 1 fish over the entire assessment time series.

The large magnitude of the retrospective pattern warranted application of Mohn’s rho (the average of the relative difference between the terminal value and the previous 7 years; Mohn 1999) to the terminal year estimates of F, SSB and recruitment. For F, the Mohn’s rho value was 1.81, which resulted in the 2008 F being adjusted from 0.51 to 0.18. For SSB, Mohn’s rho was -0.35, which resulted in adjusting the 2008 SSB from 96,968 mt to 153,100 mt. For recruitment, Mohn’s rho was -0.20, which resulted in adjusting the size of the 2007 year class at age 1 in 2008 from 376 million to 467 million fish.

REFERENCE POINTS

Projections, with stochastic sampling of recruits from 1985-2008 (range of years chosen to be more reflective of recent productivity), produced an estimate of SSB40% (proxy for SSBmsy) of 194,000 mt, which implied a Maximum Sustainable Yield (MSY) proxy (yield at F40%) of 37,200 mt. As the estimates of SSB40% and MSY40% were dependent on the model results and both estimates were also highly uncertain, the TRAC did not recommend their adoption and providing conclusions about stock status relative to biological reference points was considered inappropriate.

CONCLUDING REMARKS

The declining trends in SSB and total abundance suggested by the benchmark TRAC VPA are consistent with the decreasing trend in SSB estimates in the Gulf of St. Lawrence during the past decade (DFO 2008) and may be justified by the absence of older aged fish in both the U.S. and Canadian catch and NMFS spring surveys (Tables 2-5). The lack of older aged fish in the spring survey may be related to the potential ability of these larger faster swimming fish to avoid the trawl. The lack of older aged fish in the U.S. commercial catch may be partially driven by a general warming trend in sea temperature that has allowed mackerel, which generally prefer water temperatures greater than 5ºC, to disperse offshore to the north and east (Figure 41;

Overholtz et al. in press) where they are unavailable to the fishery that mostly operates in near shore areas off of Rhode Island and New Jersey. Alternatively, few mackerel may be surviving to older ages from the relatively poor recruitments that have occurred in recent years (Figure 40).

The magnitude of the changes in catchability among the three time blocks of the NMFS spring survey suggest that additional factors other than a switch to polyvalent trawl doors in 1985 may be affecting the availability of mackerel to the trawl gear. For example, a shift in the distribution of mackerel to the north and east (Figure 41) that may have occurred more consistently in recent years would result in mackerel inhabiting generally shallower water. When mackerel are in relatively shallow water and move deeper as an avoidance response to the approaching survey boat they would be moving to near the ocean floor where they would be more easily caught by the trawl. This increase in availability would not occur in deeper water because the trawl may still pass under the school. In support of this hypothesis, mackerel catch weighted mean depth of the NMFS spring survey has generally declined among years, and averaged 101.6m during 1968-1984 and 63.2m during 1985-2008 (Figure 42). Another hypothesis is that mackerel have increasingly occupied benthic habitats in response to the general absence of groundfish predators (e.g., Atlantic cod Gadus morhua), which would make them more susceptible to the bottom trawl. McQuinn (2009) provides support for this hypothesis for Atlantic herring Clupea harengus, but no study has been directed at mackerel.

ACKNOWLEDGEMENTS

We would like to acknowledge the contributions of William Overholtz, Brian Smith, Sandra Sutherland, Michael Jones, and Jessica Blaylock.

LITERATURE CITED

Berrien, P. 1982. Atlantic Mackerel, *Scomber scombrus*. In: M.D. Grosslein and T.R. Azarovitz (eds.) FishDistribution. p. 99-102. MESA New York Bight Atlas Monograph 15. N.Y. Sea Grant Institute, Albany, NY.

Brooks, E.N., J.E. Powers, and E. Cortés. 2010. Analytical Reference Points for Age-Structured Models: Application to Data-Poor Fisheries. ICES Journal of Marine Science, 67: 165–175.

DFO (Department of Fisheries and Oceans). 2008. Assessment of the Atlantic Mackerel Stock for the Northwest Atlantic (Subareas 3 and 4) in 2007. Department of Fisheries and Oceans Canadian Science Advisory Secretariat Scientific Advisory Report 2008/041.

GARM (Groundfish Assessment Review Meeting). 2008. Report of the Retrospective Working Group. A Working Paper in Support of Term of Reference 4. Working Paper 4.1 GARM 2008 Methods Meeting Woods Hole, MA; 25-29 February 2008. http://www.nefsc.noaa.gov/GARMPublic/2.%20Models%20Meeting/for%20review/TOR4%20Retrospective%20Patt/

McQuinn, I.H. 2009. Pelagic Fish Outburst or Suprabenthic Habitat Occupation: Legacy of the Atlantic Cod Collapse in Eastern Canada. Canadian Journal of Fisheries and Aquatic Science 66: 2256-2262.

Mohn, R. 1999. The Retrospective Problem in Sequential Population Analysis: An Investigation Using Cod Fishery and Simulated Data. ICES Journal of Marine Science 56: 473-488.

NEFSC (Northeast Fisheries Science Center). 2006. 42nd Northeast Regional Stock Assessment Workshop (42nd SAW) stock assessment report, part A: silver hake, Atlantic mackerel, and northern shortfin squid (CRD 06-09a). U.S. Department of Commerce Northeast Fisheries Science Center Reference Document 06-09a; 284 p.

NEFSC (Northeast Fisheries Science Center). 2008. 46th Northeast Regional Stock Assessment Workshop (46th SAW) Part A: Assessment Report (CRD 08-03a). U.S. Department of Commerce Northeast Fisheries Science Center Reference Document 08-03a; 258 p.

Overholtz, W.J., J.A. Hare, and C.M. Keith. (In press.) Impacts of Inter-Annual Environmental Forcing and Long-Term Climate Change on the Distribution of Atlantic Mackerel on the U.S. Northeast Continental Shelf. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science.

Sette, O.E. 1943. Biology of the Atlantic Mackerel of North America, Part I: Early Life History, Including the Growth, Drift, and Mortality of the Egg and Larval Populations. Fishery Bulletin 38. http://www.nefsc.noaa.gov/nefsc/publications/classics/index.htm.

Sette, O.E. 1950. Biology of the Atlantic Mackerel of North America, Part II: Migrations and Habits. Fishery Bulletin 49. http://www.nefsc.noaa.gov/nefsc/publications/classics/index.htm

TRAC (Transboundary Resources Assessment Committee). 2009. Atlantic Mackerel TRAC Data Meeting. Woods Hole, MA; October 2009.

Table 1. Comparison between SAW 42 and TRAC 2010 total catch.

	SAW 42			TRAC 2010	
	CAA (millions)	Catch (mt)		CAA (millions)	Catch (mt)
1962	43.7	8,078	1962	43.7	7,978
1963	40	9,081	1963	40.0	9,092
1964	57.1	13,405	1964	57.1	13,405
1965	53.1	20,825	1965	53.1	16,533
1966	78.5	23,496	1966	78.5	23,496
1967	97.9	34,181	1967	97.9	34,181
1968	329.1	90,530	1968	368.7	90,495
1969	520	137,189	1969	538.9	135,917
1970	999.4	251,958	1970	1,018.7	234,872
1971	1325.3	382,794	1971	1,353.6	382,794
1972	1070.1	415,831	1972	1,084.5	415,830
1973	1405	436,698	1973	1,448.4	436,609
1974	1073.8	367,534	1974	1,150.3	367,534
1975	1264.2	315,145	1975	1,320.1	309,951
1976	916.4	259,052	1976	961.3	259,052
1977	225.8	80,719	1977	232.4	80,209
1978	62.8	28,345	1978	62.8	28,345
1979	58.6	36,630	1979	58.6	33,042
1980	47.7	27,910	1980	56.4	25,545
1981	64.5	30,890	1981	64.5	30,806
1982	50.2	27,026	1982	50.2	27,548
1983	57	32,588	1983	57.0	32,559
1984	95.8	41,689	1984	95.8	40,638
1985	193.3	72,933	1985	184.0	71,609
1986	142.9	71,097	1986	159.3	70,692
1987	178	80,458	1987	177.5	80,394
1988	185.8	83,434	1988	185.1	82,492
1989	135.9	74,383	1989	145.7	73,961
1990	129.4	86,891	1990	160.0	82,996
1991	136	71,309	1991	140.2	70,155
1992	74	38,843	1992	76.8	36,366
1993	64.5	31,955	1993	66.0	31,424
1994	66.1	31,195	1994	121.2	31,187
1995	71	27,378	1995	77.6	27,424
1996	94.5	37,917	1996	109.6	37,547
1997	91.6	38,444	1997	91.7	38,449
1998	91	34,419	1998	91.2	34,548
1999	67.2	29,922	1999	68.2	29,927
2000	60.6	20,477	2000	61.2	20,480
2001	129.4	37,742	2001	132.8	37,826
2002	175.7	62,140	2002	175.7	62,133
2003	205.5	79,491	2003	206.8	79,543
2004	288.8	105,635	2004	297.1	108,886

Table 2. U.S. mackerel catch at age (000s).

year	1	2	3	4	5	6	7	8	9	10+
1968	118,409	57,679	53,778	34,153	12,795	5,880	315	115	534	48
1969	3,051	243,349	147,855	64,358	5,039	2,392	1,218	2,787	1,871	1,431
1970	178,335	51,767	496,983	156,882	25,733	6,663	4,982	8,720	8,770	3,358
1971	70,235	289,693	126,362	536,983	198,852	33,531	7,556	2,669	3,154	11,935
1972	22,100	85,601	253,001	178,572	372,354	83,684	20,185	4,144	7,803	4,433
1973	156,661	271,650	279,696	228,373	184,575	184,715	26,542	9,448	3,631	4,502
1974	92,677	233,097	254,413	96,039	109,590	107,156	102,549	24,184	5,759	2,646
1975	368,394	422,098	108,826	96,454	55,966	64,989	49,862	49,037	12,192	3,083
1976	11,697	343,418	259,590	80,470	48,714	25,458	38,156	32,706	21,113	14,245
1977	1,353	20,757	81,258	44,098	8,778	7,652	4,892	5,038	3,015	2,694
1978	98	18	869	2,667	1,725	2,042	1,543	551	3,098	4,803
1979	196	120	111	485	1,398	779	610	318	498	4,043
1980	1,194	9,445	1,156	463	1,813	3,967	1,448	692	604	3,202
1981	9,955	4,264	4,057	217	344	1,431	3,957	1,591	905	1,608
1982	1,555	5,901	1,091	4,096	485	291	777	3,572	1,351	2,596
1983	1,956	13,678	4,041	985	2,988	222	254	2,381	2,430	2,899
1984	440	20,626	13,140	1,787	419	3,049	261	221	1,378	8,360
1985	2,748	1,047	99,205	19,695	1,648	299	1,755	131	186	7,266
1986	926	8,433	3,449	60,057	13,872	1,171	211	2,549	98	4,173
1987	2,877	11,470	11,264	5,417	82,985	12,102	2,279	180	2,024	2,815
1988	888	12,306	9,246	8,023	9,199	82,006	18,546	2,401	1,058	4,980
1989	1,533	8,301	9,757	6,384	5,536	1,777	67,672	2,284	556	1,471
1990	3,731	23,183	37,408	6,945	5,730	3,506	161	38,427	1,711	923
1991	767	8,504	38,582	15,066	5,248	3,138	2,248	151	16,336	643
1992	105	4,124	2,278	11,546	6,750	659	821	221	455	5,606
1993	1,402	4,305	2,818	1,674	3,524	1,263	258	163	417	1,560
1994	4,315	6,126	25,083	22,836	6,333	14,288	1,480	359	214	2,820
1995	7,913	6,447	2,034	4,870	4,110	1,463	4,504	945	104	331
1996	5,180	26,922	18,745	932	7,365	3,347	931	3,125	503	591
1997	1,819	10,164	12,478	6,511	438	4,814	3,720	2,236	3,015	1,087
1998	381	11,324	9,130	7,131	4,428	650	3,449	2,117	573	933
1999	390	2,252	9,252	6,682	4,507	2,756	972	2,227	1,360	920
2000	2,418	7,354	4,680	5,754	1,985	855	321		67	67
2001	1,000	17,752	12,735	5,070	5,741	1,556	1,212	574	136	237
2002	3,934	8,571	50,604	8,277	3,012	7,606	2,575	406	140	6
2003	6,470	19,591	20,744	48,522	5,555	3,901	3,670	229		
2004	10,238	53,518	16,369	20,485	65,505	6,620	1,516	280	216	
2005	1,370	58,347	39,017	8,877	5,627	30,018	494	2,502		
2006	1,001	10,957	97,248	29,916	8,276	7,092	26,658	672	113	43
2007	2,090	29,248	20,234	28,740	5,862	925	705	2,535	129	
2008	8,644	15,723	33,744	9,253	9,904	1,927	188	248	617	23

Table 3. Canadian mackerel catch at age (000s).

	1	2	3	4	5	6	7	8	9	10+
1968	43,062	7,157	10,343	7,393	2,819	1,349	721	1,658	10,425	97
1969	5,692	26,359	18,057	2,027	929	855	1,099	440	462	9,656
1970	20,277	3,654	33,584	8,047	2,496	451	425	1,578	1,645	4,335
1971	7,156	7,389	1,702	35,931	7,620	1,753	2,203	1,526	1,879	5,517
1972	-	136	4,401	5,541	24,826	4,975	5,248	77	546	6,833
1973	9,176	20,624	9,649	9,333	13,972	22,293	8,317	2,771	837	1,603
1974	8,618	24,340	26,703	14,602	12,594	12,417	15,377	4,053	1,714	1,749
1975	14,206	24,905	13,049	11,636	7,052	7,526	5,456	3,917	825	581
1976	1,686	21,171	27,110	10,982	7,740	3,868	4,922	3,977	3,123	1,165
1977	740	7,136	22,566	11,319	3,683	2,570	809	1,443	897	1,721
1978	2	182	3,831	14,733	11,575	6,358	3,157	1,649	1,402	2,497
1979	204	480	1,189	6,615	17,202	12,321	5,590	2,282	1,702	2,457
1980	6	1,455	2,156	1,463	5,087	9,833	6,148	2,692	1,604	1,998
1981	6,145	2,836	5,143	1,183	1,656	4,669	7,743	3,309	1,595	1,892
1982	2,145	5,899	1,609	5,004	715	1,609	2,623	4,828	1,549	2,504
1983	244	1,622	2,459	915	4,012	478	946	3,119	7,770	3,601
1984	60	19,774	14,060	1,413	781	1,551	339	479	2,022	5,640
1985	357	511	23,790	12,844	1,252	656	2,197	289	551	7,605
1986	363	4,282	3,259	40,844	11,522	933	485	635	117	1,915
1987	1,291	3,118	3,358	2,288	27,133	5,692	232	183	83	716
1988	117	703	1,028	1,932	2,481	24,769	4,493	227	131	572
1989	2,399	8,862	1,276	937	1,541	575	20,957	2,693	369	781
1990	390	6,222	9,737	1,457	888	966	639	16,765	923	277
1991	646	6,106	17,808	9,560	1,212	762	1,052	849	10,964	557
1992	628	2,627	3,014	14,148	8,630	1,411	733	1,048	884	11,142
1993	117	4,900	8,493	4,497	13,011	7,686	1,660	651	699	6,882
1994	672	231	3,896	5,905	2,856	13,672	5,977	929	244	2,925
1995	10,603	14,206	698	4,674	4,093	1,768	5,757	2,281	203	590
1996	2,505	8,050	7,052	1,013	5,380	6,519	1,622	7,094	1,806	893
1997	5,083	11,823	10,923	4,604	638	3,709	3,081	545	4,212	785
1998	1,927	18,525	9,977	9,560	4,291	505	2,432	2,024	412	1,472
1999	1,348	4,463	14,625	7,509	4,698	2,049	478	681	663	354
2000	23,686	2,238	1,498	4,548	2,388	2,448	381	54	162	309
2001	8,085	59,159	11,056	2,443	4,118	828	856	142	33	94
2002	6,010	3,783	69,432	5,969	2,246	2,108	531	402	47	72
2003	3,741	4,355	5,798	73,409	8,430	1,117	1,192	32	5	
2004	27,313	24,386	5,971	4,717	55,581	2,438	1,312	601	9	
2005	17,282	42,703	24,228	3,982	3,783	40,138	1,670	741	80	45
2006	23,720	11,255	31,940	14,790	2,356	1,407	12,547	335	29	
2007	418	23,556	19,167	35,464	8,085	1,242	963	3,996	22	6
2008	9,788	3,888	21,129	4,630	8,626	947	334	86	628	4

Table 4. Total catch at age (millions) of Atlantic mackerel (U.S. and Canada combined). Catch data during 1962-1967 were only available from previous assessment documents and the relative amount of catch attributable to the U.S. and Canada was not clear. Consequently, catch during 1962-1967 was not reported by country in Tables 2 and 3.

	Total CAA (millions)				age					
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**
1962	16.1	2.8	15.2	3.8	1.2	1.6	1.4	0.8	0.4	0.4
1963	1.1	4.2	1.3	26.3	6.0	0.3	0.2	0.2	0.2	0.2
1964	12.9	7.0	4.1	4.0	19.4	4.1	3.9	0.7	0.8	0.2
1965	9.0	3.6	2.9	4.0	5.2	19.5	4.2	4.0	0.7	0.0
1966	24.0	11.5	5.3	2.6	4.7	7.9	21.8	0.5	0.2	0.0
1967	0.8	26.7	19.8	3.5	3.3	5.1	6.1	32.3	0.3	0.0
1968	161.5	64.8	64.1	41.5	15.6	7.2	1.0	1.8	11.0	0.1
1969	8.7	269.7	165.9	66.4	6.0	3.2	2.3	3.2	2.3	11.1
1970	198.6	55.4	530.6	164.9	28.2	7.1	5.4	10.3	10.4	7.7
1971	77.4	297.1	128.1	572.9	206.5	35.3	9.8	4.2	5.0	17.5
1972	22.1	85.7	257.4	184.1	397.2	88.7	25.4	4.2	8.3	11.3
1973	165.8	292.3	289.3	237.7	198.5	207.0	34.9	12.2	4.5	6.1
1974	101.3	257.4	281.1	110.6	122.2	119.6	117.9	28.2	7.5	4.4
1975	382.6	447.0	121.9	108.1	63.0	72.5	55.3	53.0	13.0	3.7
1976	13.4	364.6	286.7	91.5	56.5	29.3	43.1	36.7	24.2	15.4
1977	2.1	27.9	103.8	55.4	12.5	10.2	5.7	6.5	3.9	4.4
1978	0.1	0.2	4.7	17.4	13.3	8.4	4.7	2.2	4.5	7.3
1979	0.4	0.6	1.3	7.1	18.6	13.1	6.2	2.6	2.2	6.5
1980	1.2	10.9	3.3	1.9	6.9	13.8	7.6	3.4	2.2	5.2
1981	16.1	7.1	9.2	1.4	2.0	6.1	11.7	4.9	2.5	3.5
1982	3.7	11.8	2.7	9.1	1.2	1.9	3.4	8.4	2.9	5.1
1983	2.2	15.3	6.5	1.9	7.0	0.7	1.2	5.5	10.2	6.5
1984	0.5	40.4	27.2	3.2	1.2	4.6	0.6	0.7	3.4	14.0
1985	3.1	1.6	123.0	32.5	2.9	1.0	4.0	0.4	0.7	14.9
1986	1.3	12.7	6.7	100.9	25.4	2.1	0.7	3.2	0.2	6.1
1987	4.2	14.6	14.6	7.7	110.1	17.8	2.5	0.4	2.1	3.5
1988	1.0	13.0	10.3	10.0	11.7	106.8	23.0	2.6	1.2	5.6
1989	3.9	17.2	11.0	7.3	7.1	2.4	88.6	5.0	0.9	2.3
1990	4.1	29.4	47.1	8.4	6.6	4.5	0.8	55.2	2.6	1.2
1991	1.4	14.6	56.4	24.6	6.5	3.9	3.3	1.0	27.3	1.2
1992	0.7	6.8	5.3	25.7	15.4	2.1	1.6	1.3	1.3	16.7
1993	1.5	9.2	11.3	6.2	16.5	8.9	1.9	0.8	1.1	8.4
1994	5.0	6.4	29.0	28.7	9.2	28.0	7.5	1.3	0.5	5.7
1995	18.5	20.7	2.7	9.5	8.2	3.2	10.3	3.2	0.3	0.9
1996	7.7	35.0	25.8	1.9	12.7	9.9	2.6	10.2	2.3	1.5
1997	6.9	22.0	23.4	11.1	1.1	8.5	6.8	2.8	7.2	1.9
1998	2.3	29.8	19.1	16.7	8.7	1.2	5.9	4.1	1.0	2.4
1999	1.7	6.7	23.9	14.2	9.2	4.8	1.5	2.9	2.0	1.3
2000	26.1	9.6	6.2	10.3	4.4	3.3	0.7	0.1	0.2	0.4
2001	9.1	76.9	23.8	7.5	9.9	2.4	2.1	0.7	0.2	0.3
2002	9.9	12.4	120.0	14.2	5.3	9.7	3.1	0.8	0.2	0.1
2003	10.2	23.9	26.5	121.9	14.0	5.0	4.9	0.3	0.0	0.0
2004	37.6	77.9	22.3	25.2	121.1	9.1	2.8	0.9	0.2	0.0
2005	18.7	101.0	63.2	12.9	9.4	70.2	2.2	3.2	0.1	0.0
2006	24.7	22.2	129.2	44.7	10.6	8.5	39.2	1.0	0.1	0.0
2007	2.5	52.8	39.4	64.2	13.9	2.2	1.7	6.5	0.2	0.0
2008	18.4	19.6	54.9	13.9	18.5	2.9	0.5	0.3	1.2	0.0

Table 5. Mean number of mackerel per tow at age from the NMFS spring survey.

Year	1	2	3	4	5	6	7	8	9	10+
1968	12.9400	0.4150	0.1890	0.0520	0.0160	0.0000	0.0000	0.0000	0.0000	0.0000
1969	0.0300	0.1420	0.0170	0.0060	0.0000	0.0010	0.0010	0.0010	0.0000	0.0000
1970	0.2800	0.1850	1.3910	0.6120	0.1810	0.0620	0.0550	0.0880	0.0830	0.0470
1971	0.3280	0.9410	0.4380	1.1250	0.3930	0.0620	0.0140	0.0070	0.0060	0.0080
1972	0.8720	0.3080	0.5930	0.2260	0.3250	0.0580	0.0110	0.0010	0.0020	0.0000
1973	0.3510	0.3400	0.1760	0.2340	0.1260	0.2850	0.1820	0.1520	0.0460	0.1020
1974	0.3480	0.1800	0.2360	0.0480	0.0990	0.0600	0.2080	0.0910	0.0590	0.0230
1975	0.6540	0.2300	0.0410	0.0230	0.0060	0.0070	0.0040	0.0040	0.0030	0.0000
1976	0.0960	0.3870	0.0710	0.0140	0.0020	0.0010	0.0030	0.0000	0.0020	0.0010
1977	0.0100	0.0470	0.0850	0.0450	0.0150	0.0050	0.0030	0.0070	0.0040	0.0140
1978	0.0500	0.1100	0.1030	0.1940	0.0960	0.0280	0.0110	0.0030	0.0150	0.0180
1979	0.0110	0.0040	0.0070	0.0130	0.0500	0.0140	0.0100	0.0060	0.0060	0.0480
1980	0.0230	0.1880	0.0070	0.0050	0.0230	0.0490	0.0110	0.0110	0.0070	0.0280
1981	0.3360	0.1370	0.4290	0.0480	0.0460	0.1610	0.4040	0.2300	0.1390	0.4020
1982	0.4320	0.1950	0.0220	0.0980	0.0180	0.0100	0.0250	0.0970	0.0440	0.0840
1983	0.2360	0.2870	0.0220	0.0020	0.0040	0.0010	0.0000	0.0010	0.0020	0.0020
1984	0.2600	1.8010	0.6060	0.0420	0.0050	0.0430	0.0040	0.0030	0.0160	0.0840
1985	0.3380	0.0850	1.8510	0.2350	0.0280	0.0110	0.0470	0.0030	0.0100	0.1860
1986	0.1300	0.4500	0.0780	0.5910	0.1180	0.0080	0.0010	0.0200	0.0000	0.0470
1987	1.4840	1.7950	0.8740	0.3720	2.9450	0.4970	0.1430	0.0160	0.1380	0.2560
1988	0.6340	0.4580	0.3670	0.3360	0.3750	1.7690	0.4430	0.0510	0.0480	0.2230
1989	1.5830	1.6410	0.0710	0.2840	0.0090	0.0110	0.0670	0.0090	0.0050	0.0180
1990	1.3000	1.3850	0.5010	0.0160	0.0130	0.0060	0.0000	0.0760	0.0090	0.0160
1991	1.6700	0.8890	1.4840	0.5370	0.2400	0.1140	0.0580	0.0000	0.2690	0.0030
1992	2.9790	2.6422	0.5558	1.1593	0.7247	0.1156	0.1304	0.0199	0.0488	0.3450
1993	1.2070	2.6595	1.0091	0.3813	1.0544	0.7203	0.1492	0.1330	0.3325	0.6099
1994	4.1386	1.7436	2.1139	0.8699	0.2815	0.6019	0.2070	0.0512	0.0105	0.2251
1995	3.1701	3.4871	0.5893	1.1824	0.7122	0.2848	0.7191	0.2258	0.0655	0.1310
1996	4.0058	3.2257	1.3258	0.1481	0.6175	0.4196	0.1927	0.2800	0.1539	0.1317
1997	2.9998	1.1619	0.4485	0.2247	0.0254	0.1244	0.1149	0.0452	0.0702	0.0066
1998	5.6474	3.1195	0.6787	0.2863	0.1211	0.0171	0.0867	0.0634	0.0179	0.0240
1999	4.9932	4.1347	2.9206	0.9221	0.4061	0.1784	0.0498	0.0819	0.0436	0.0145
2000	14.7693	2.4561	1.1156	0.7272	0.2514	0.1189	0.0500	0.0000	0.0236	0.0194
2001	12.4608	26.5956	1.7582	0.3622	0.2115	0.0375	0.0114	0.0093	0.0042	0.0012
2002	1.2662	2.9770	5.7418	0.4438	0.1229	0.0494	0.0192	0.0014	0.0000	0.0000
2003	9.1159	8.3906	2.9148	3.2997	0.4028	0.1207	0.0555	0.0000	0.0000	0.0000
2004	21.9188	3.0060	0.3165	0.1166	0.1516	0.0121	0.0020	0.0000	0.0000	0.0000
2005	1.7745	3.7293	0.9319	0.1697	0.1354	0.3667	0.0258	0.0050	0.0000	0.0000
2006	4.4389	9.5737	6.2724	0.6548	0.1372	0.0521	0.1267	0.0120	0.0000	0.0000
2007	1.9963	6.9564	1.2098	1.2239	0.1565	0.0135	0.0224	0.0320	0.0062	0.0000
2008	3.2617	1.6649	1.6213	0.2450	0.2289	0.0000	0.0000	0.0000	0.0305	0.0000

Table 6. Summary of ASAP model configurations examined.

	Years	Likelihood Constant	Indices	Selectivity estimated	Selectivity Periods	Selectivity Ages	S/R	steepness	Predation
1	1962-2008	no	spr,'84-85 split	no	1962-2008	1.0 at 3>	yes		no
2	1962-2008	yes	spr,'84-85 split	no	1962-2008	1.0 at 3>	yes		no
3	1962-2008	yes	spr,'84-85 split	no	1962-2009	1.0 at 3>	yes		no
4	1962-2008	yes	spr, '68-08 no split	no	1962-2008	1.0 at 3>	yes		no
5	1962-2008	yes	spr, '68-08 no split	no	1962-2008	1.0 at 3>	no	0.7	no
6	1962-2008	yes	spr,'84-85 split	yes	1962-2008	1.0-3,4,5,	no	1.0	no
7	1962-2008	yes	spr, '68-08 no split	no	1962-2008	1.0 at 3>	no	0.7	no
8	1962-2008	yes	spr,'84-85 split	no	1962-2008	1.0 at 3>	no	0.5	no
9	1962-2008	yes	spr,'84-85 split	no	1962-2008	1.0 at 3>	yes	0.287	no
10	1962-2008	yes	spr,'84-85 split	yes	1962-1981,1982-2008	1.0 at 3	yes	0.278	no
11	1962-2008	yes	spr,'84-85 split	yes	1962-2008	1.0 at 3	yes	0.360	no
12	1962-2008	yes	spr,'84-85 split	yes	1962-1981,1982-2008	1.0 at 3,4	yes	0.278	no
13	1962-2008	yes	spr,'84-85 split,CPUE 88-89 split	yes	1962-1981,1982-2009	1.0 at 3,5	yes	0.256	no
14	1962-2008	yes	spr,'84-85 split,CPUE 88-89 split	yes	1962-1981,1982-2009	1.0 at 3,5	no	0.500	no
15	1982-2008	yes	spr,'84-85 split	no	1962-2008	1.0 at 3>	yes	0.448	no
16	1968-2008	yes	spr 91-92	logistic	1962-2008, 2 fleets		no	0.7	no
17	1968-2008	yes	spr 91-92	logistic	1962-2008, 2 fleets		no	0.6	no
18	1968-2008	yes	spr 91-92	logistic	1962-2008, 2 fleets		no	0.9	no
19	1968-2008	yes	spr 91-92	logistic	1962-2008, 2 fleets		no	0.8	no
20	1968-2008	yes	spr 91-92	logistic	1962-2008, 2 fleets		no	0.5	no
21	1968-2008	yes	spr 91-92	logistic	1962-2008, 2 fleets		no	0.4	no
22	1968-2008	yes	spr 91-92	logistic	1962-2008, 2 fleets		no	0.3	no

Table 7. ASAP model fit summary.

obj_fun	=	2428.36
Component	Lambda	obj_fun
__Catch_Fleet_1	1	55.0889
__Catch_Fleet_2	1	81.3547
Catch_Fleet_Total	2	136.444
Discard_Fleet_Total	0	0
__Index_Fit_1	0.912	115.056
__Index_Fit_2	0.912	72.6354
__Index_Fit_3	0.912	58.6318
__Index_Fit_4	0.912	55.2916
__Index_Fit_5	0.912	50.1455
__Index_Fit_6	0.912	32.4328
__Index_Fit_7	0.912	32.4244
__Index_Fit_8	0.912	52.2182
__Index_Fit_9	0.912	70.5035
__Index_Fit_10	0.912	101.454
__Index_Fit_11	0.912	37.0999
__Index_Fit_12	0.912	40.2973
__Index_Fit_13	0.912	23.702
__Index_Fit_14	0.912	3.52031
__Index_Fit_15	0.912	-0.113499
__Index_Fit_16	0.912	-9.09479
__Index_Fit_17	0.912	-6.35201
__Index_Fit_18	0.912	-0.653328
__Index_Fit_19	0.912	-16.0625
__Index_Fit_20	0.912	37.439
Index_Fit_Total	18.24	750.576
Catch_Age_Comps	see_below	1194.22
Discard_Age_Comps	see_below	0
Survey_Age_Comps	see_below	0
__Sel_Param_1	0.1	0.0548012
__Sel_Param_2	0.1	0.0338946
__Sel_Param_3	0.1	0.0495444
__Sel_Param_4	0.1	-0.0414241
Sel_Params_Total	0.4	0.096816
Index_Sel_Params_Total	0	0
q_year1_Total	0	0
q_devs_Total	200000	0
__Fmult_year1_fleet_1	0	0
__Fmult_year1_fleet_2	0	0
Fmult_year1_fleet_Total	0	0
Fmult_devs_fleet_Total	0	0
N_year_1	0	0
Recruit_devs	1	347.022
SRR_steepness	0	0
SRR_unexpl_stock	0	0
Fmult_Max_penalty	1000	0
F_penalty	0	0

Table 8. Survey index q's from ASAP model

	period	
age	1968-1991	1992-2008
1	0.00041	0.0164
2	0.00049	0.0181
3	0.00035	0.00853
4	0.00028	0.00451
5	0.00027	0.00307
6	0.00022	0.00193
7	0.00028	0.00148
8	0.00026	0.000883
9	0.00049	0.001233
10+	0.00049	0.000198

Table 9. Estimates of total mackerel consumption by predator based on NEFSC spring and autumn stomach samples.

mackerel consumption - MT

	str bass	bluefish	red hake	white hake	silver hake	winter skate	sp dogfish	goosefish	pollock	cod	fluke	consumption total (mt)
1982	0.0	0.0	0.0	0.0	188.8	0.0	1,640.7	7,187.0	0.0	0.0	0.0	9016.5
1983	0.0	0.0	107.9	0.0	0.0	0.0	10,540.4	0.0	899.0	8,366.4	0.0	19913.7
1984	0.0	0.0	0.0	8,056.6	0.0	2,476.9	46,168.8	45,312.3	0.0	37,601.0	0.0	139615.7
1985	0.0	0.0	0.0	0.0	0.0	0.0	9,642.6	8,839.6	0.0	0.0	0.0	18482.2
1986	0.0	0.0	0.0	13,342.4	47.7	0.0	41,341.9	2,624.9	0.0	6,791.8	0.0	64148.7
1987	0.0	0.0	0.0	0.0	513.9	0.0	44,602.0	0.0	0.0	4,907.9	0.0	50023.8
1988	0.0	2,881.4	0.0	144.0	269.1	0.0	10,667.3	1,584.3	0.0	75.4	0.0	15621.5
1989	0.0	27.0	0.0	0.0	82.6	0.0	13,536.5	0.0	0.0	0.0	0.0	13646.0
1990	0.0	0.0	1,012.9	1,186.5	483.2	1,031.2	25,944.8	0.0	0.0	0.0	0.0	29658.6
1991	0.0	4,179.9	56.8	338.2	234.9	402.9	27,334.6	0.0	0.0	354.7	0.0	32901.9
1992	0.0	0.0	0.0	0.0	28.0	1,151.8	6,086.4	0.0	0.0	0.0	0.0	7266.2
1993	0.0	0.0	572.9	0.0	221.3	0.0	9,518.4	0.0	0.0	0.0	3,790.8	14103.4
1994	0.0	0.0	0.0	0.0	86.4	0.0	4,386.9	0.0	0.0	0.0	617.0	5090.2
1995	0.0	0.0	0.0	0.0	79.2	0.0	8,739.4	0.0	0.0	0.0	0.0	8818.6
1996	0.0	2,411.3	0.0	0.0	63.0	0.0	9,700.7	944.2	0.0	733.2	0.0	13852.4
1997	0.0	2,359.9	0.0	1,696.7	372.4	0.0	7,158.0	0.0	0.0	273.0	0.0	11860.0
1998	0.0	3,584.8	0.0	3,100.4	347.6	766.9	5,703.4	2,740.1	8,233.7	3,019.1	1,514.4	29010.5
1999	0.0	0.0	34.2	0.0	254.4	1,138.6	8,386.4	2,937.6	0.0	0.0	0.0	12751.3
2000	4,089.1	0.0	0.0	1,442.3	3,668.6	1,028.3	9,999.8	8,615.0	0.0	3,014.4	1,789.1	33646.6
2001	46.5	8,151.8	0.0	0.0	371.3	1,177.8	10,772.0	9,407.4	0.0	2,046.3	0.0	31973.2
2002	1,412.7	0.0	0.0	0.0	0.0	0.0	15,375.8	7,996.6	20,169.3	1,964.5	1,065.1	47983.9
2003	103.0	9,792.2	0.0	0.0	122.8	0.0	5,527.1	0.0	0.0	3,709.5	4,116.5	23371.1
2004	0.0	5,118.0	0.0	0.0	14.4	0.0	8,163.7	0.0	0.0	2,782.3	2,572.1	18650.5
2005	168.4	0.0	0.0	3,604.7	0.0	0.0	17,070.2	0.0	0.0	0.0	497.7	21341.0
2006	0.0	0.0	0.0	0.0	54.0	2,266.2	7,513.3	0.0	0.0	0.0	1,809.4	11642.9
2007	182.3	0.0	0.0	0.0	0.0	1,723.1	29,247.9	0.0	0.0	0.0	3,944.7	35098.0
2008	0.0	0.0	0.0	0.0	0.0	0.0	6,036.3	0.0	0.0	0.0	0.0	6036.3

Table 10. Swept area abundance estimates based on the NMFS spring bottom trawl survey (arithmetic mean number/tow), the baseline VPA estimates of total abundance, and the ratio of the two.

Year	SurveyPopEstimate	VPA(000's)	Survey/VPA
1968	305836000	9800178	0.0312
1969	2088090	10292353	0.0002
1970	40608200	10782378	0.0038
1971	54473800	9365243	0.0058
1972	36640800	8085417	0.0045
1973	293858000	7782619	0.0378
1974	31393500	7754532	0.0040
1975	28135900	7859494	0.0036
1976	25225500	5806313	0.0043
1977	4020820	4007538	0.0010
1978	13587800	3144079	0.0043
1979	2416680	3154305	0.0008
1980	7837460	2596178	0.0030
1981	81948100	2222144	0.0369
1982	22385800	2507199	0.0089
1983	3866420	5339870	0.0007
1984	70033300	4482400	0.0156
1985	35568100	3852569	0.0092
1986	18029500	3149861	0.0057
1987	152038000	2592623	0.0586
1988	72290400	2505348	0.0289
1989	52964200	2638376	0.0201
1990	46197000	2170484	0.0213
1991	100398000	1896417	0.0529
1992	104186000	1670440	0.0624
1993	111972000	1336589	0.0838
1994	166062000	1257505	0.1321
1995	105244000	1257768	0.0837
1996	176447000	1155999	0.1526
1997	94552300	1202367	0.0786
1998	108213000	1024660	0.1056
1999	218439000	964352	0.2265
2000	303624000	2346968	0.1294
2001	502557000	2074228	0.2423
2002	151912000	1729615	0.0878
2003	261037000	1628489	0.1603
2004	477652000	1778710	0.2685
2005	139487000	1414483	0.0986
2006	299558000	1301302	0.2302
2007	130056000	928281	0.1401
2008	312040000	803102	0.3885

Table 11. Abundance estimates at age in the terminal year+1, their standard errors (SE), and coefficients of variation (CV) from the baseline VPA model.

Age	N Estimate in Terminal yr+1	SE	CV
2	153051	175497	1.15
3	57154	57999	1.01
4	113964	107421	0.94
5	37123	38740	1.04
6	26275	40301	1.53

Table 12. Catchability estimates, their standard errors (SE), and coefficients of variation (CV) from the baseline VPA model.

Survey	Year Block	Age	Survey Number	Catchability	SE	CV
Spring	1968-1984	1	1	2.31E-07	8.45E-08	0.37
Spring	1968-1984	2	2	2.69E-07	7.77E-08	0.29
Spring	1968-1984	3	3	1.98E-07	5.88E-08	0.30
Spring	1968-1984	4	4	1.45E-07	4.49E-08	0.31
Spring	1968-1984	5	5	1.28E-07	4.48E-08	0.35
Spring	1968-1984	6	6	9.53E-08	3.38E-08	0.35
Spring	1968-1984	7	7	5.64E-08	2.52E-08	0.45
Spring	1985-1992	1	8	3.41E-06	1.34E-06	0.39
Spring	1985-1992	2	9	3.95E-06	1.45E-06	0.37
Spring	1985-1992	3	10	2.04E-06	6.59E-07	0.32
Spring	1985-1992	4	11	1.46E-06	6.00E-07	0.41
Spring	1985-1992	5	12	1.10E-06	5.99E-07	0.55
Spring	1985-1992	6	13	8.30E-07	4.11E-07	0.50
Spring	1985-1992	7	14	3.34E-07	1.30E-07	0.39
Spring	1993-2008	1	15	1.80E-05	2.85E-06	0.16
Spring	1993-2008	2	16	1.98E-05	3.52E-06	0.18
Spring	1993-2008	3	17	9.82E-06	1.54E-06	0.16
Spring	1993-2008	4	18	5.49E-06	7.68E-07	0.14
Spring	1993-2008	5	19	3.81E-06	7.72E-07	0.20
Spring	1993-2008	6	20	2.32E-06	5.27E-07	0.23
Spring	1993-2008	7	21	3.57E-07	1.24E-07	0.35
OTF	1978-1988	1-7	29	6.87E-03	7.75E-04	0.11
OTF	1989-2008	1-7	30	1.83E-02	1.61E-03	0.09
OTM	1994-2008	1-7	31	7.31E-03	9.19E-04	0.13

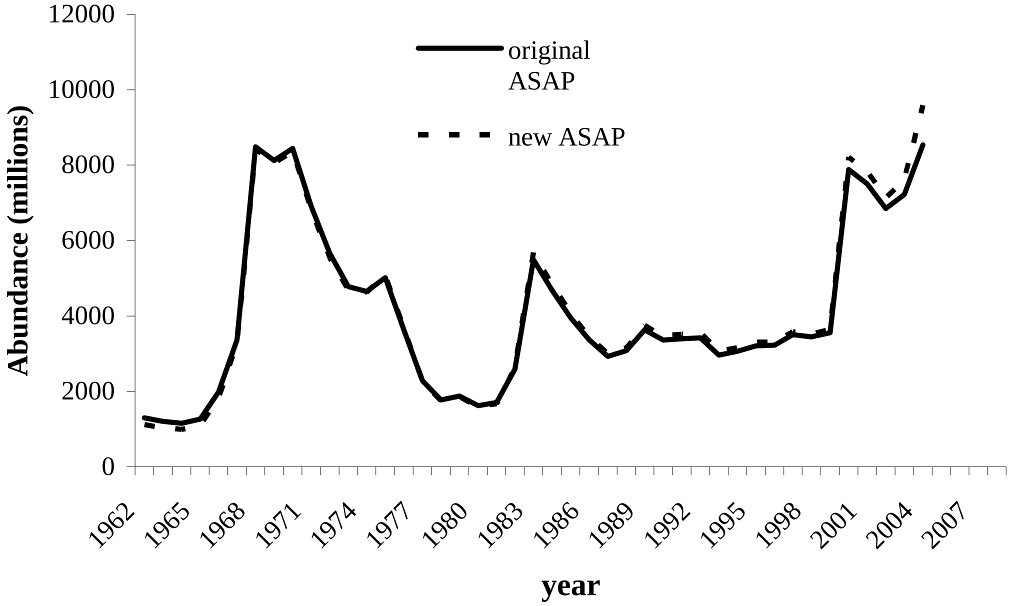


Figure 1. Comparison of abundance estimates between SAW 42 results with original and revised ASAP model.

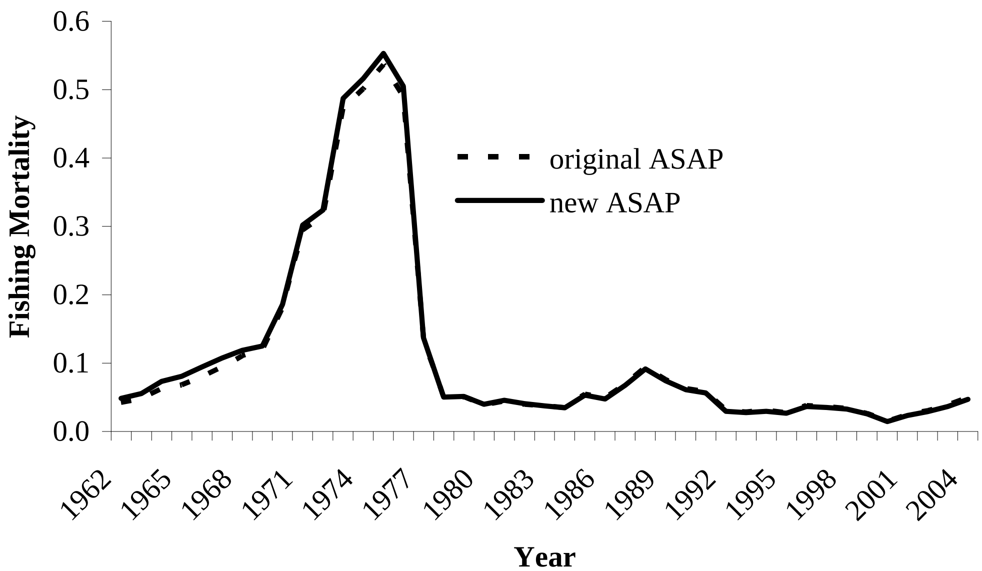


Figure 2. Comparison of F estimates between SAW 42 results with original and revised ASAP model.

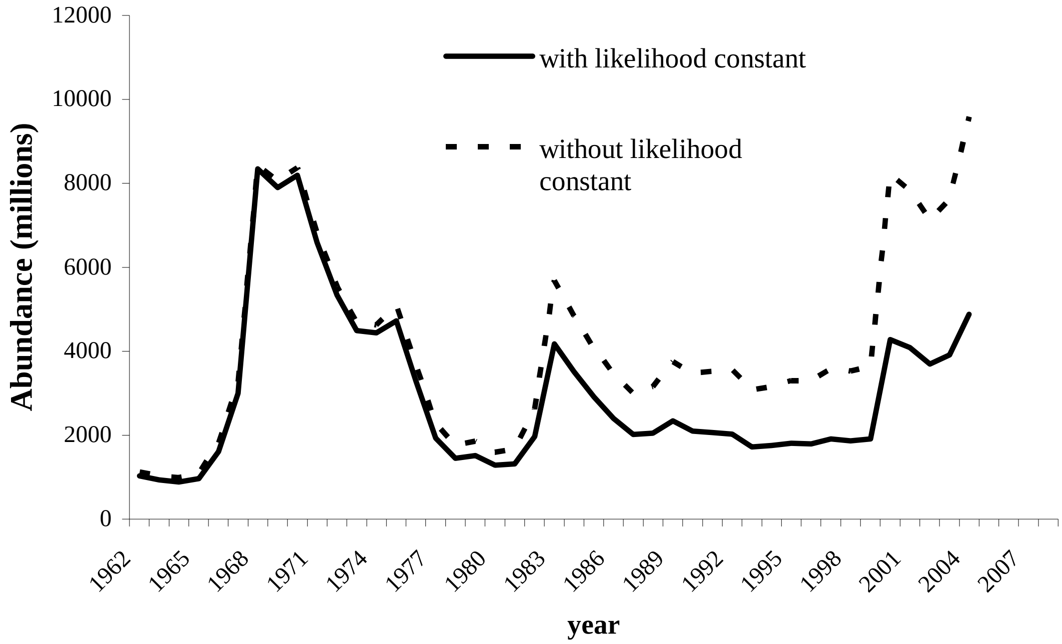


Figure 3. Comparison of abundance estimates between ASAP models fit with and without the use of likelihood constants.

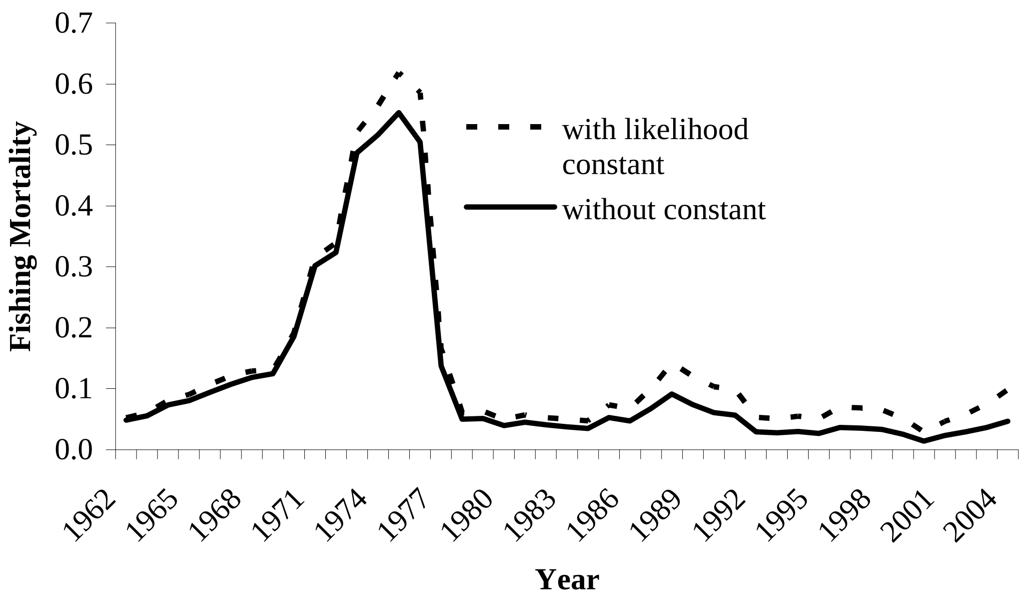


Figure 4. Comparison of F estimates between ASAP models fit with and without the use of likelihood constants.

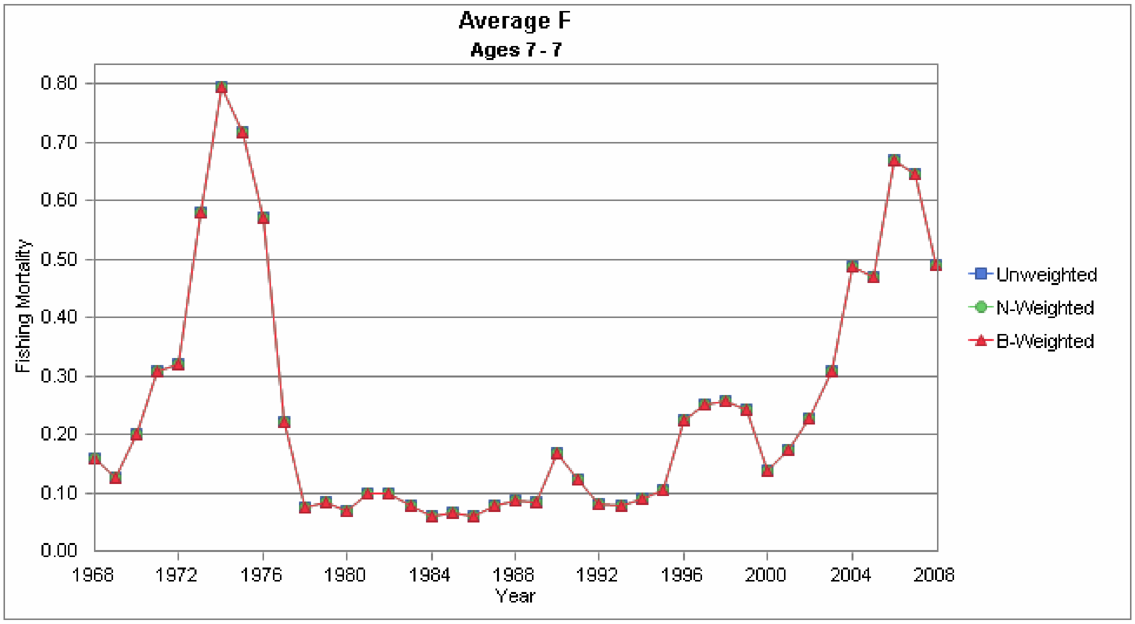


Figure 5. Fully recruited fishing mortality of Atlantic mackerel for combined U.S.A and Canadian fleets from ASAP model.

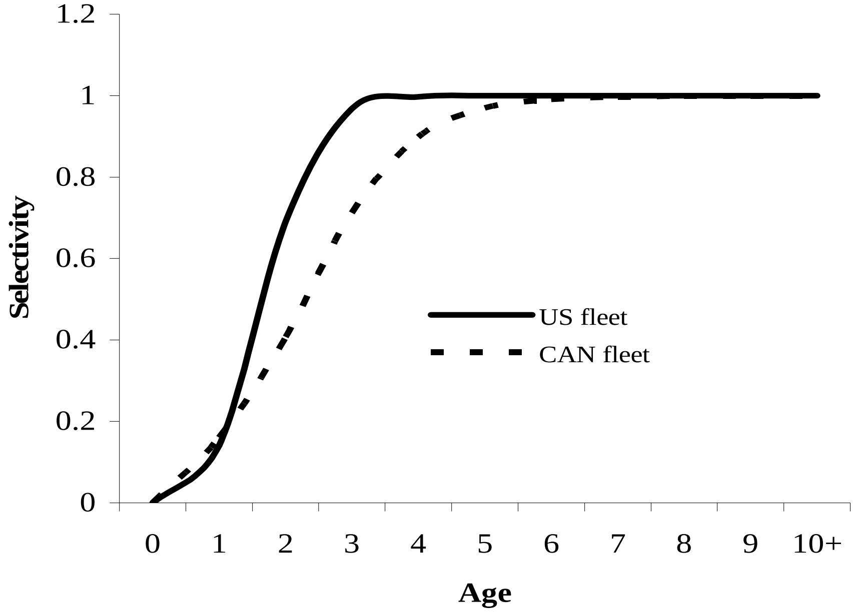


Figure 6. Selectivity at age from ASAP modeled as a logistic function for U.S. and Canadian catch at age.

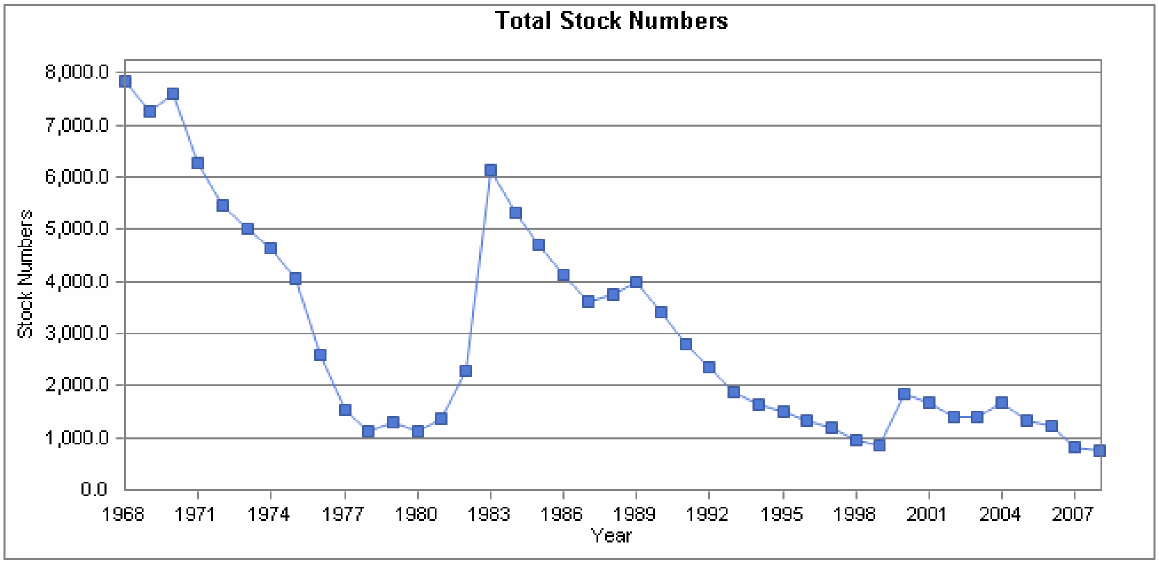


Figure 7. Total abundance (millions) of Atlantic mackerel for combined U.S.A and Canadian fleets from ASAP model.

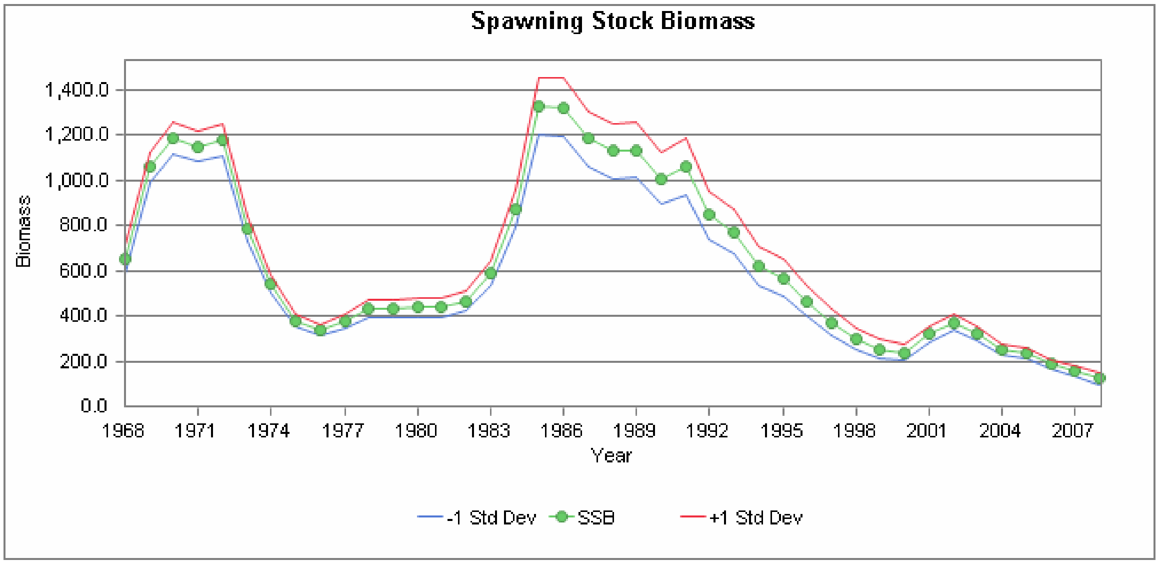


Figure 8. Spawning stock biomass (000s mt) of Atlantic mackerel for combined U.S.A and Canadian fleets from ASAP model.

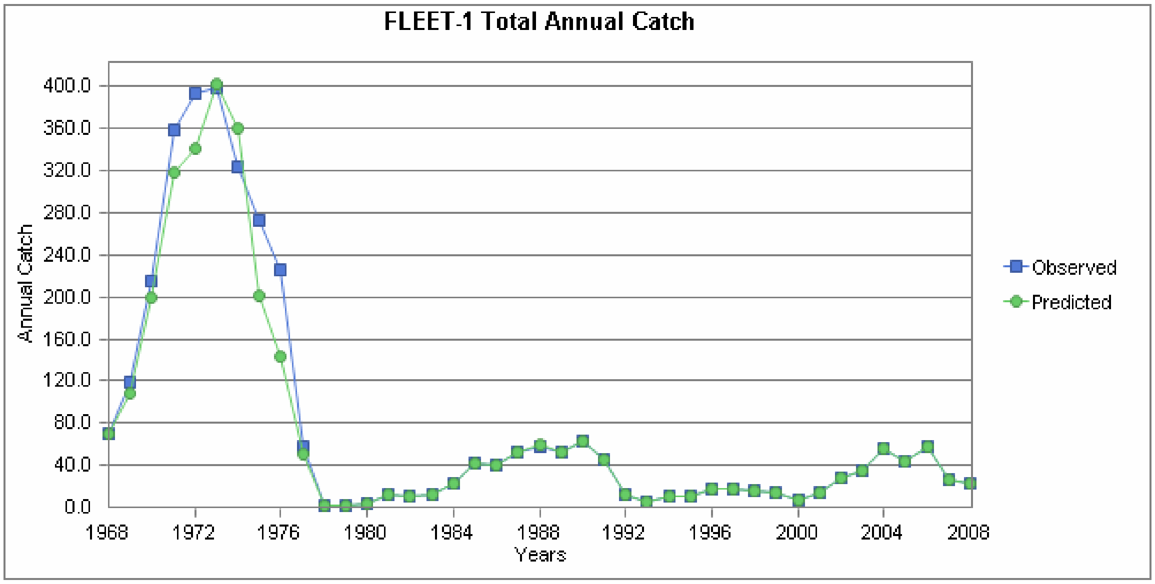


Figure 9. Comparison of ASAP model observed and predicted annual catch (000s mt) for U.S. fleet.

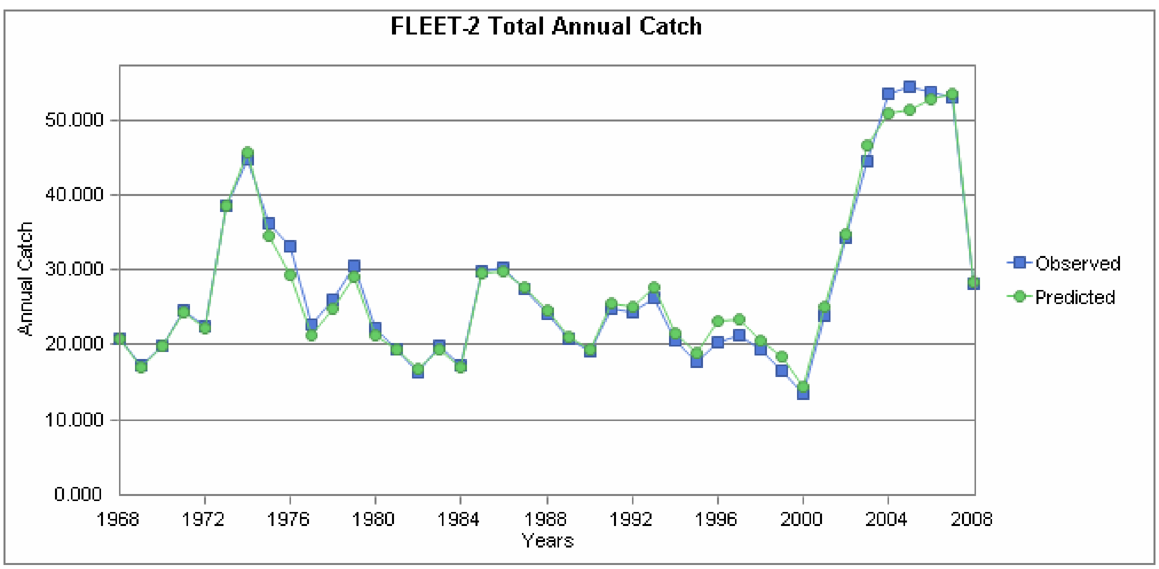


Figure 10. Comparison of ASAP model observed and predicted annual catch (000s mt) for Canadian fleet.

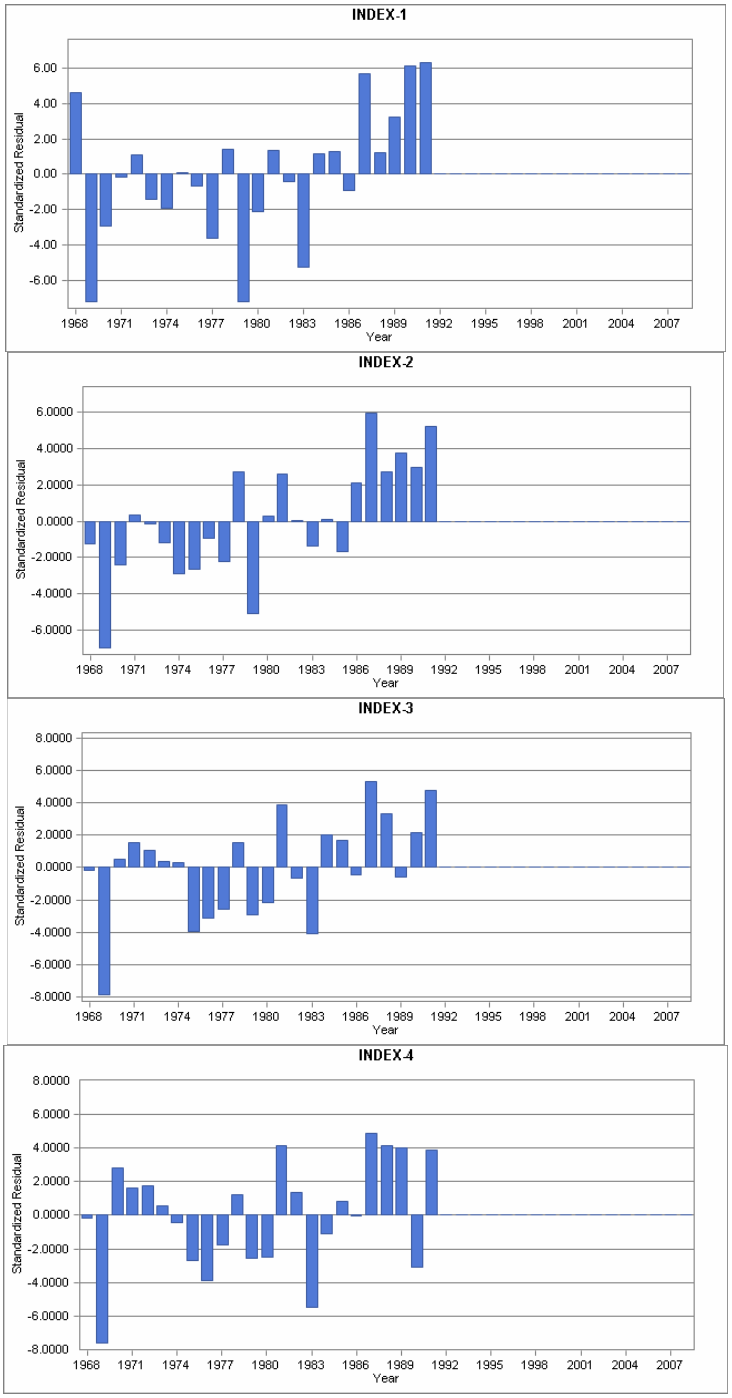


Figure 11. Standardized residuals for NEFSC survey indices for 1968-1991, ages 1-10+ (indices 1-10), and 1992-2008, ages 1-10+ (indices 11-20).

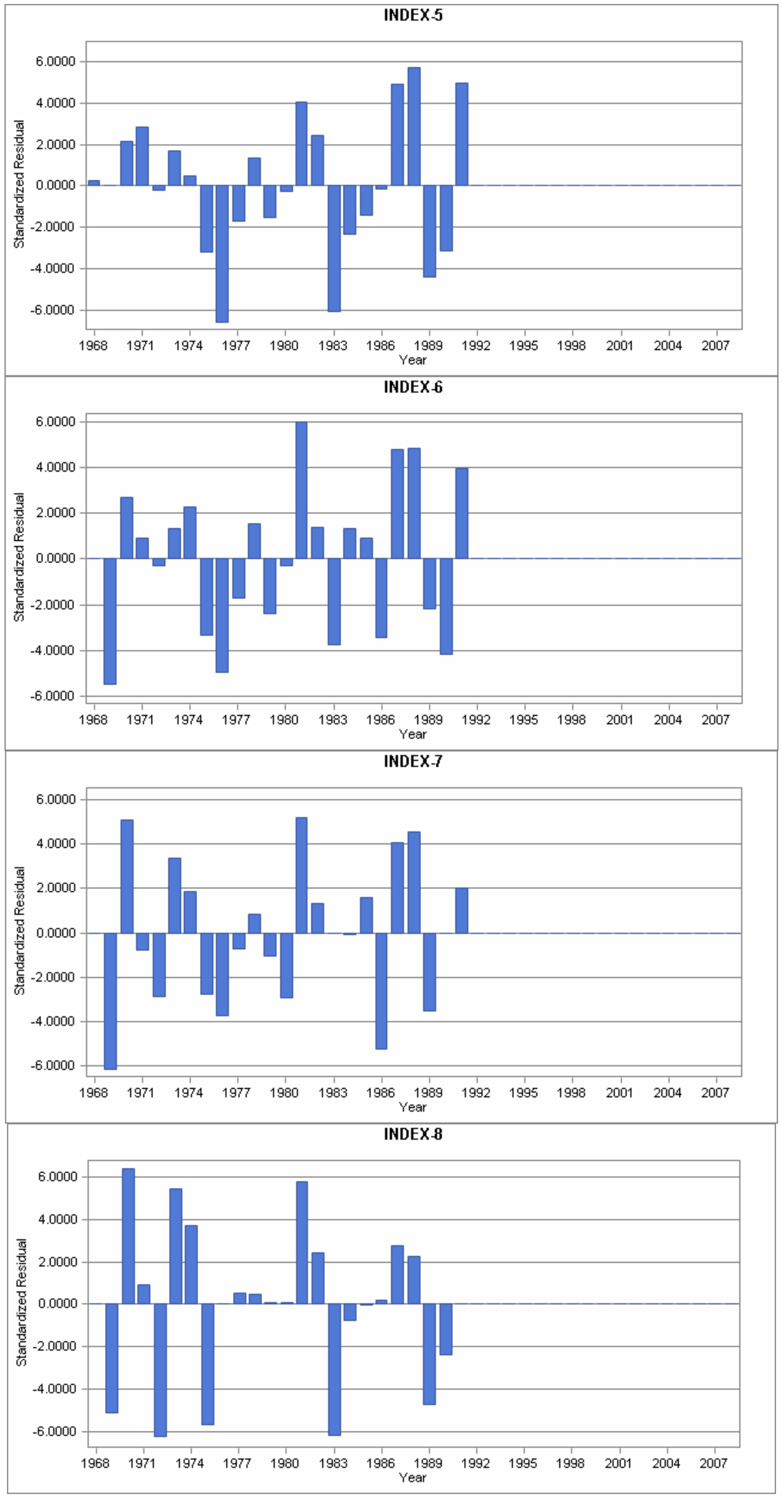


Figure 11. (Continued.)

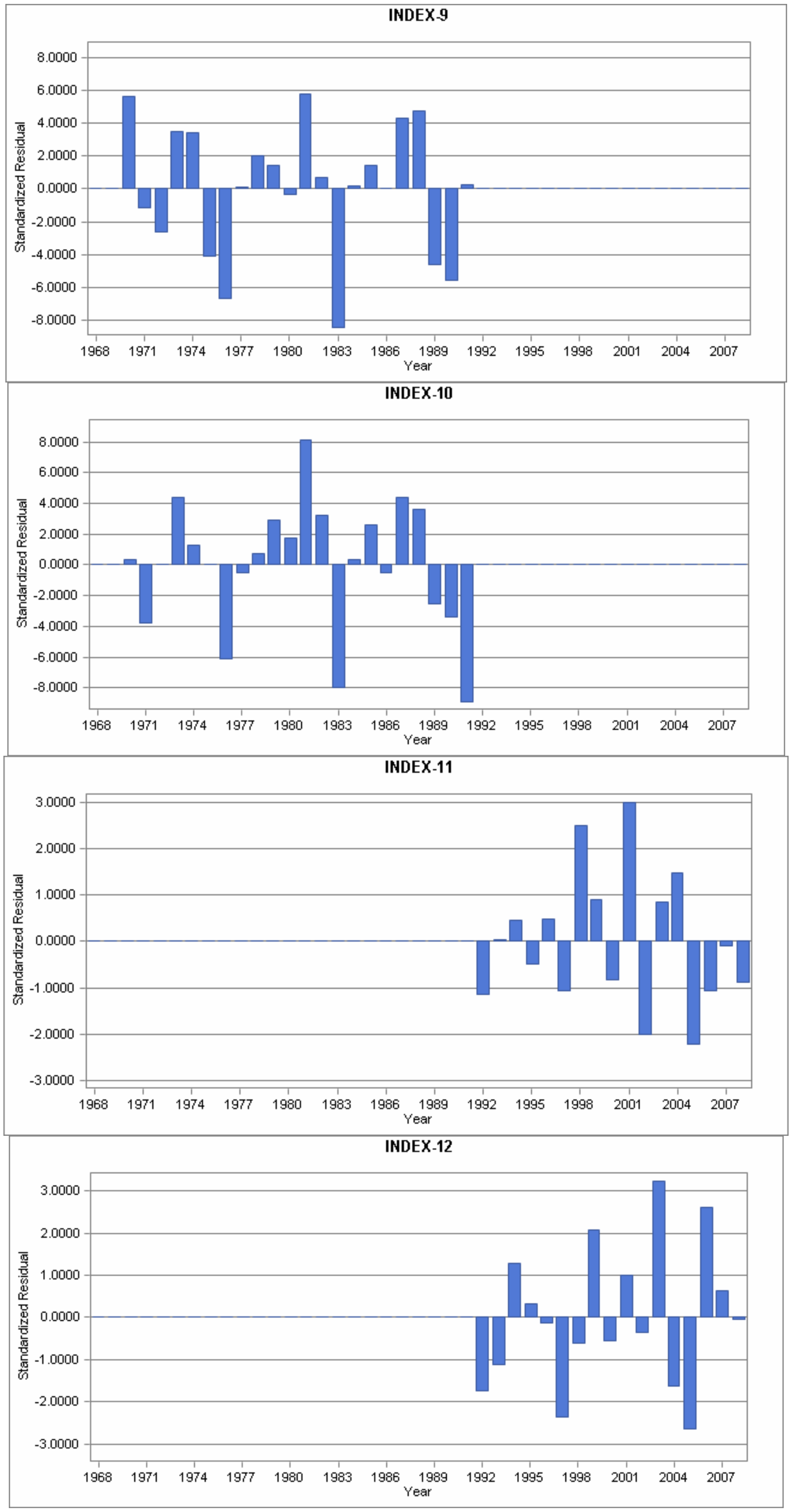


Figure 11. (Continued.)

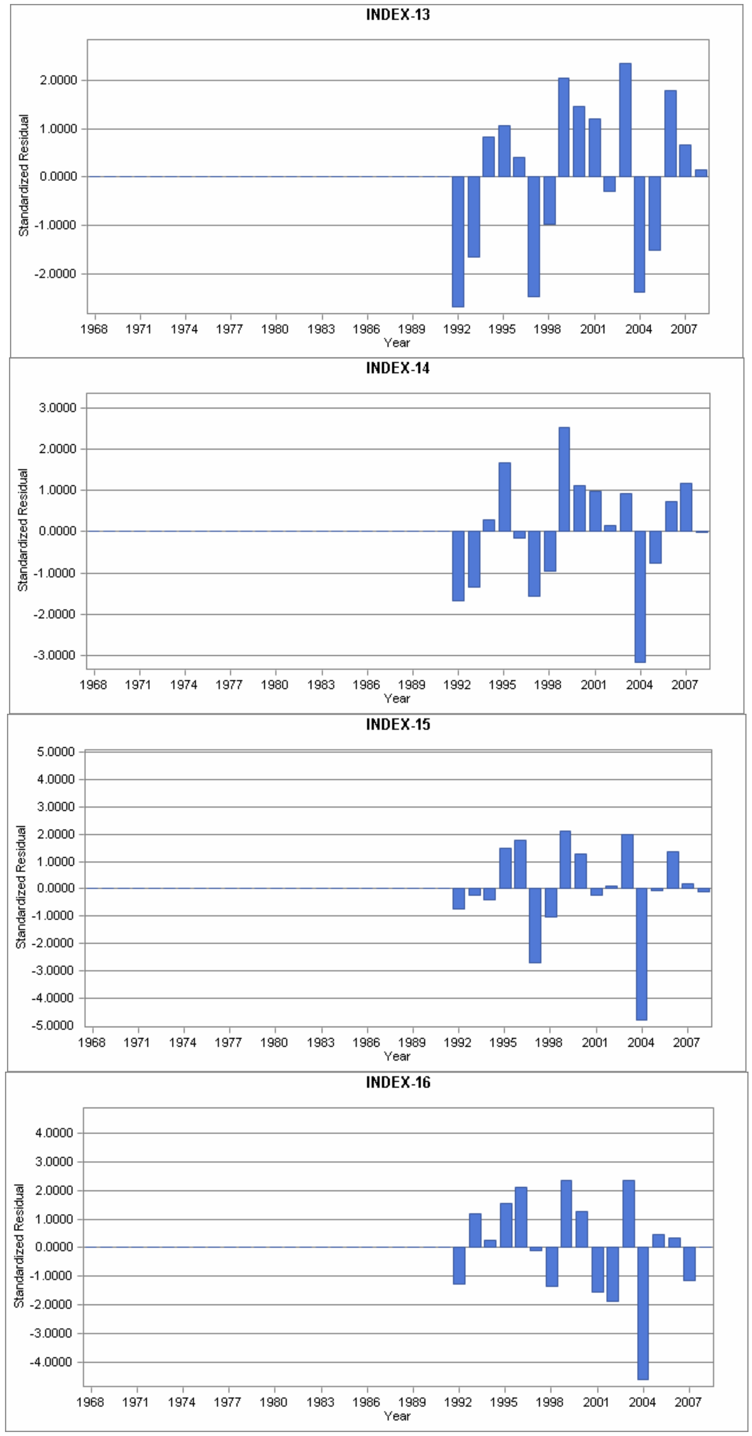


Figure 11. (Continued.)

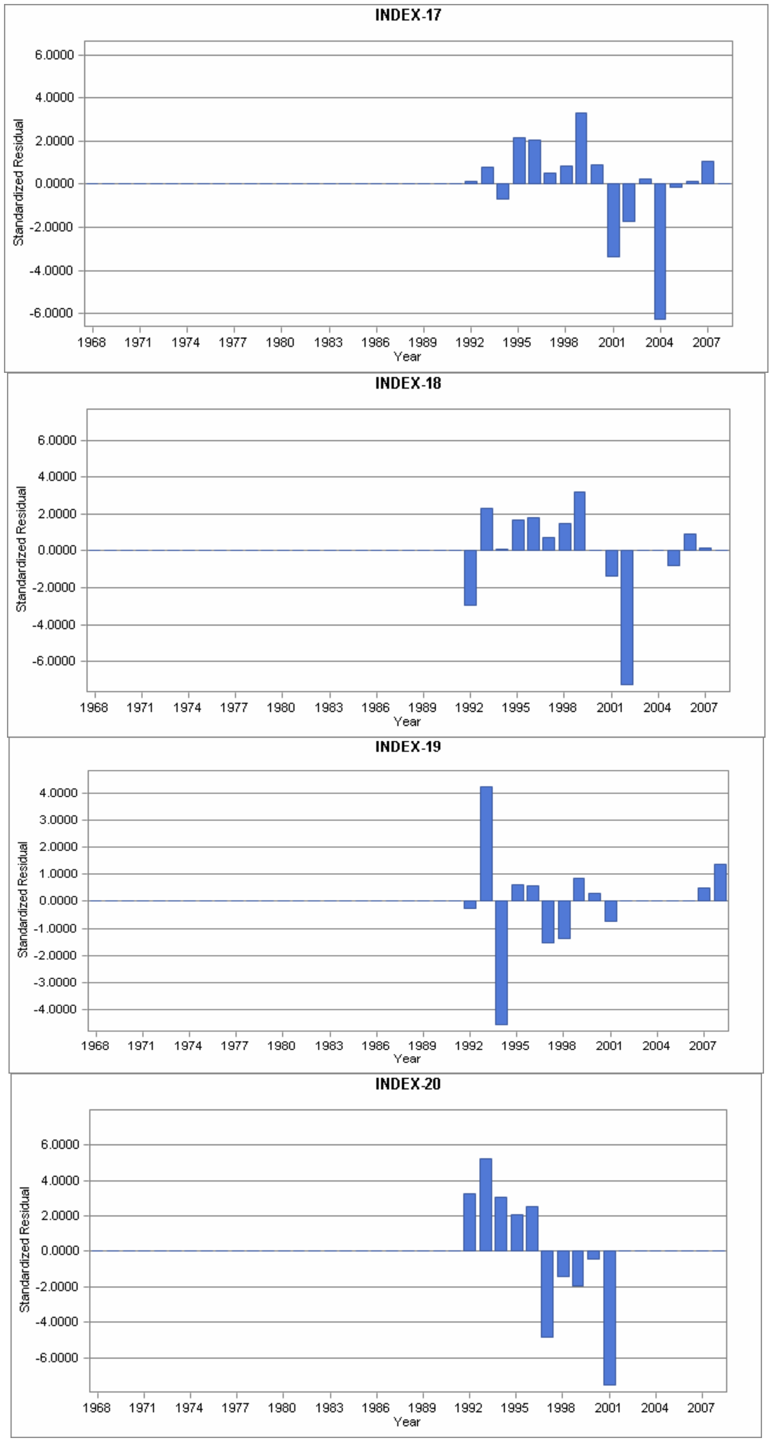


Figure 11. (Continued.)

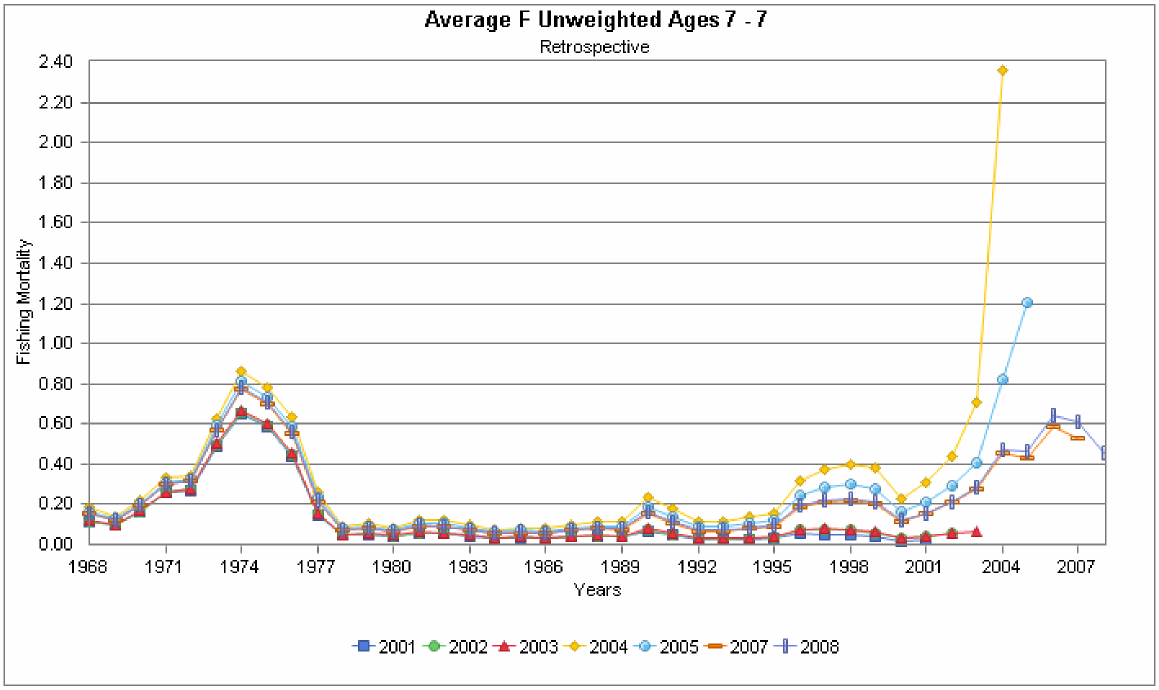


Figure 12. Retrospective pattern of average fishing mortality from ASAP.

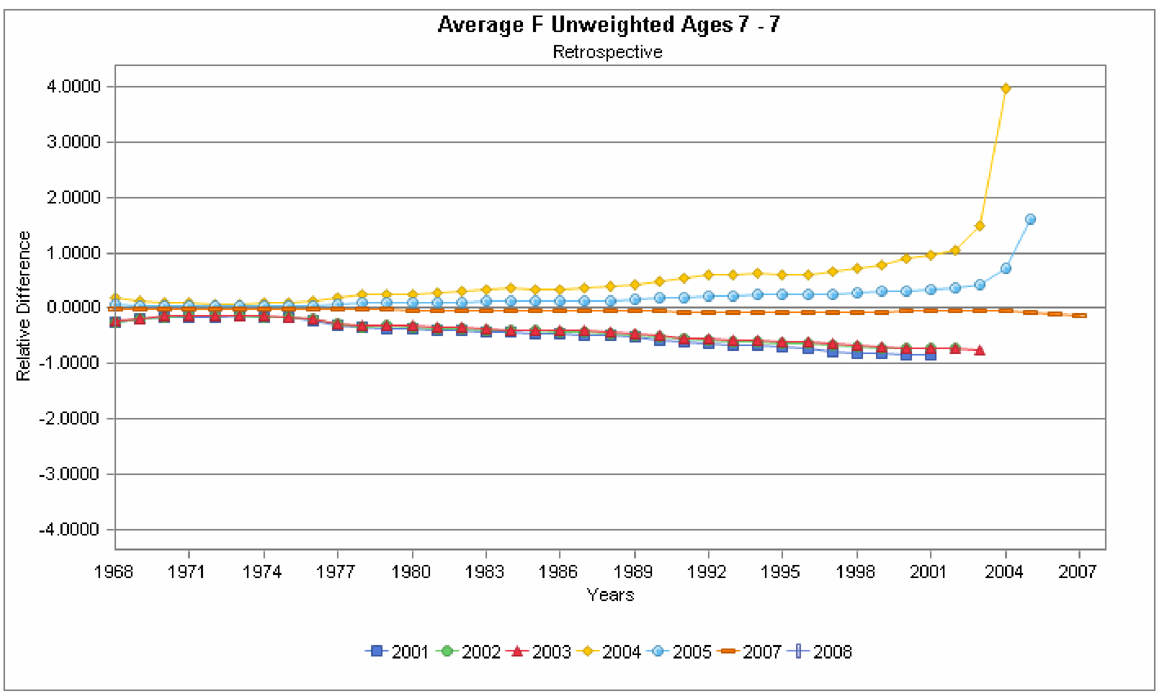


Figure 13. Standardized retrospective pattern of average fishing mortality from ASAP.

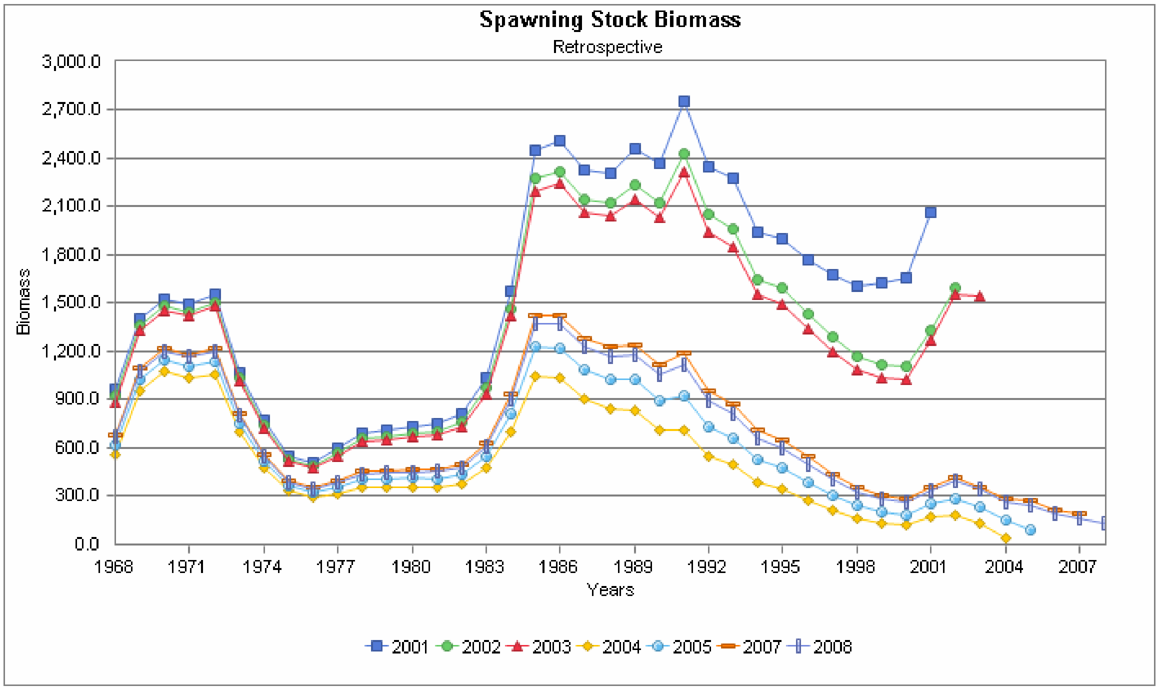


Figure 14. Retrospective pattern of spawning stock biomass (000s mt) from ASAP.

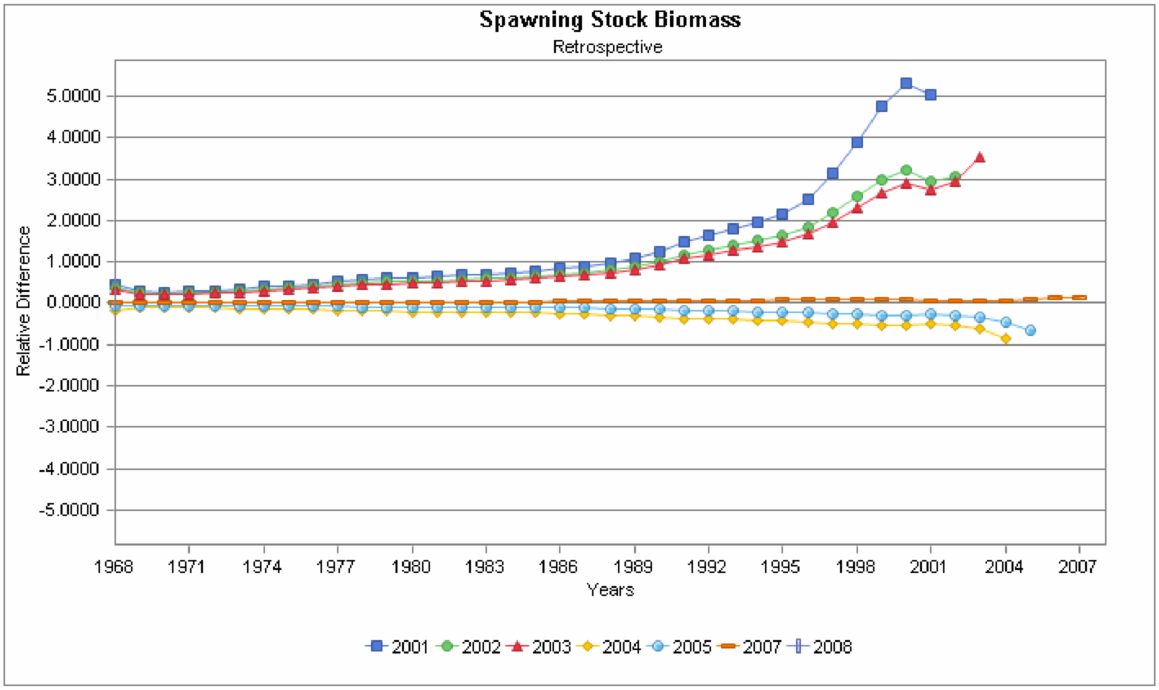


Figure 15. Standardized retrospective pattern of spawning stock biomass from ASAP.

Retrospective base run

Retrospective with Canada catch x2

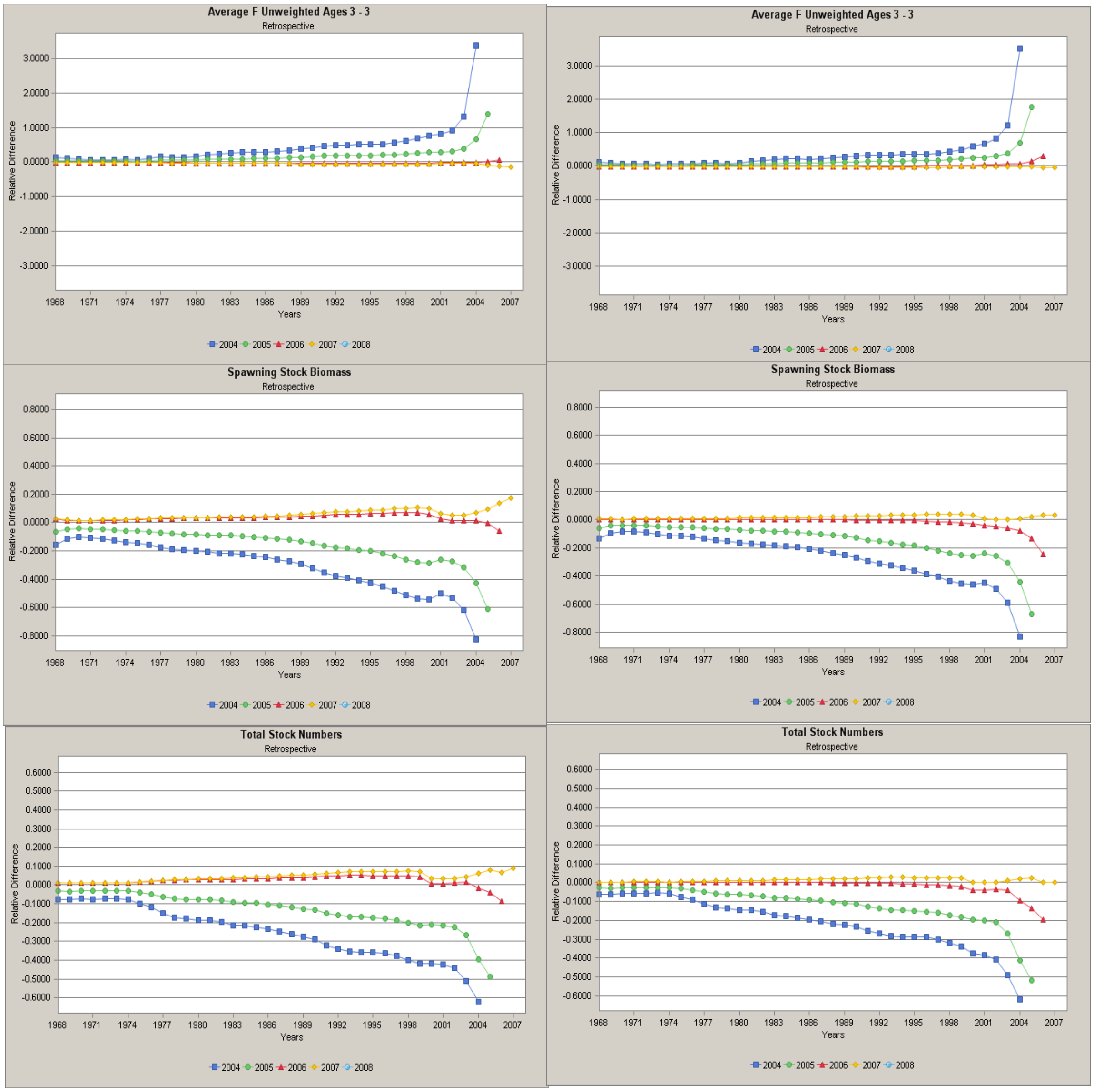


Figure 16. Effect of doubling Canadian mackerel catch on relative difference in retrospective pattern.

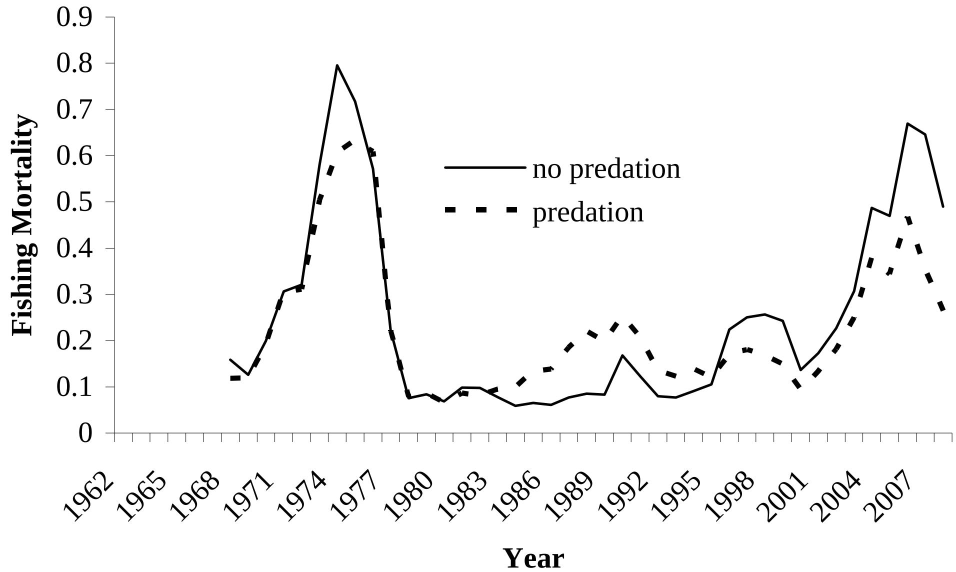


Figure 17.Comparison of mackerel fishing mortality from models with and without predation.

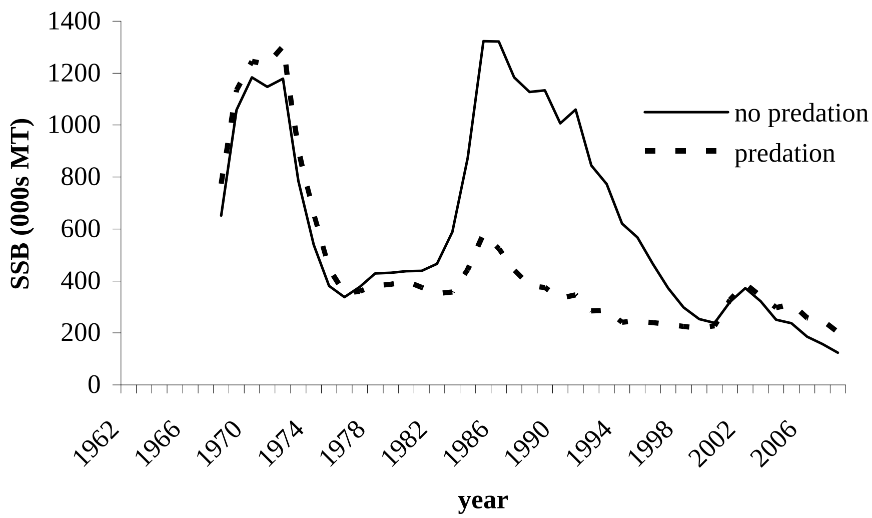


Figure 18. Comparison of mackerel spawning stock biomass (000s mt) from models with and without predation.

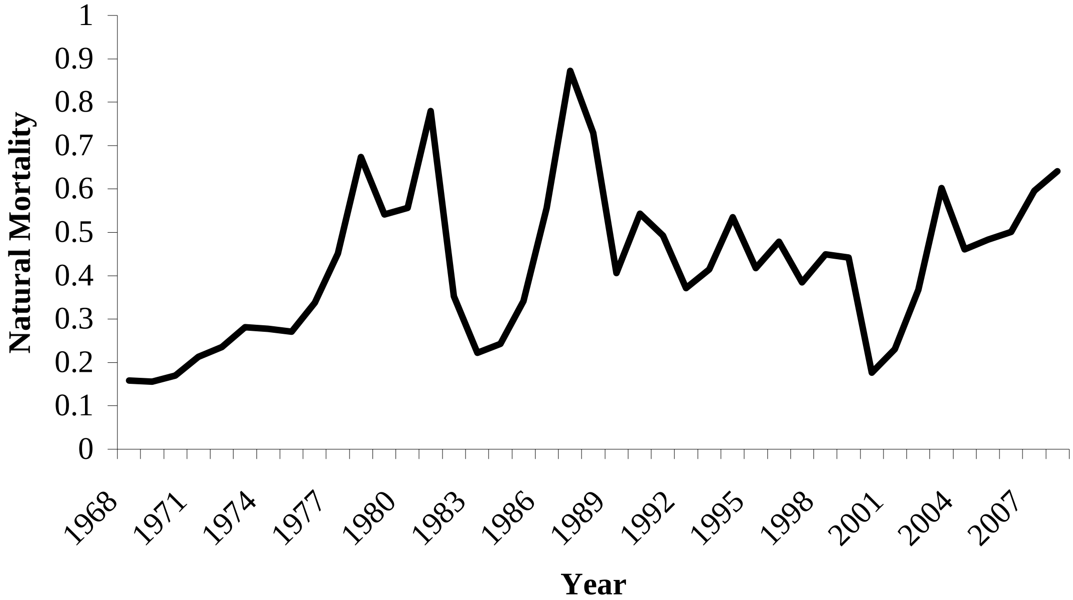


Figure 19. Age-1 and age-2 Atlantic mackerel natural mortality (M1 + predation fleet F) estimated with an ASAP model that included predation.

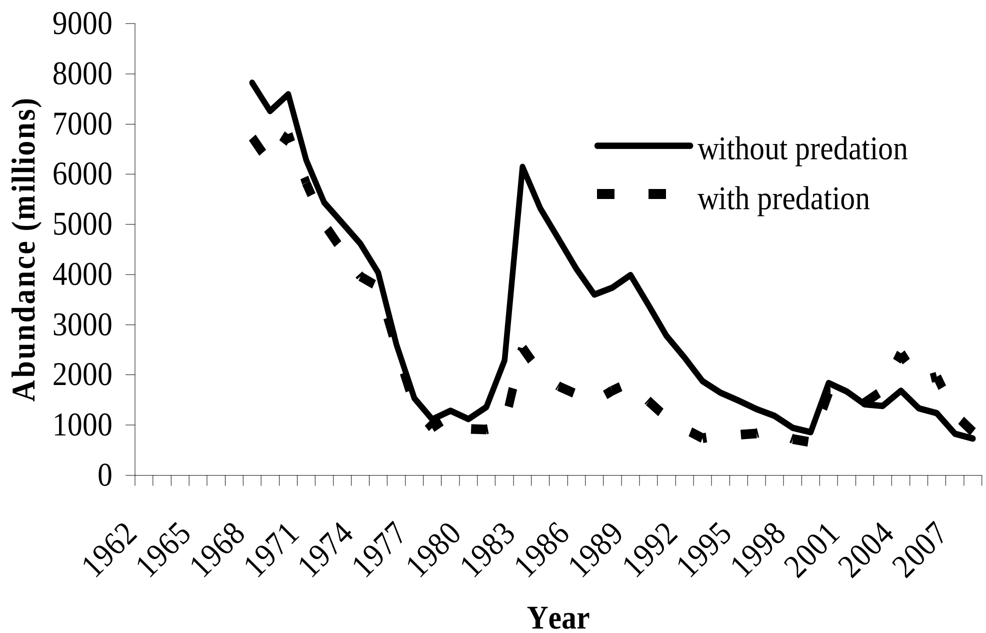
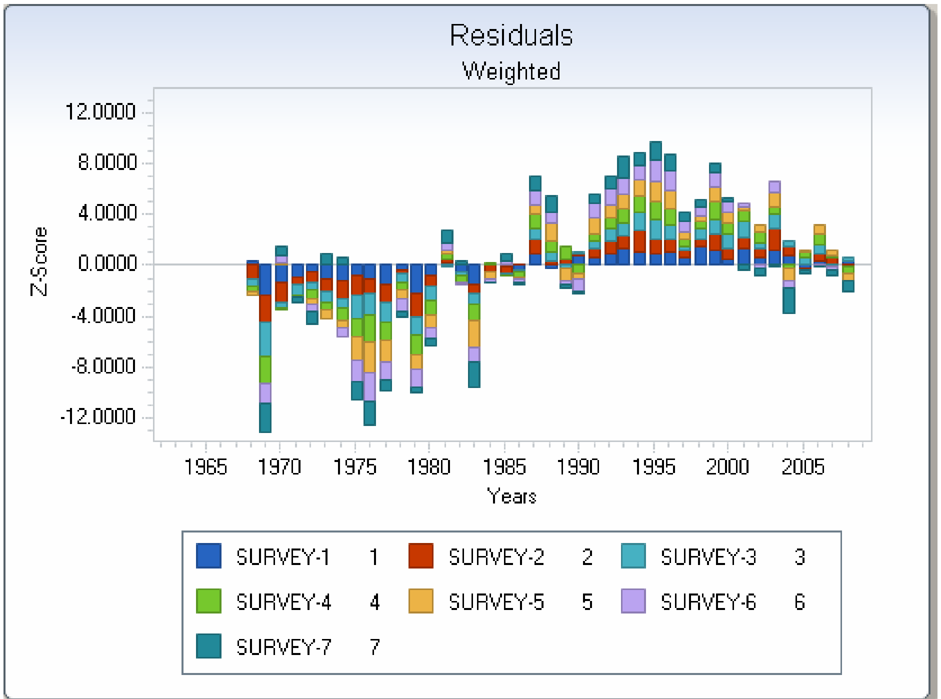


Figure 20. Comparison of mackerel total abundance from models with and without predation.



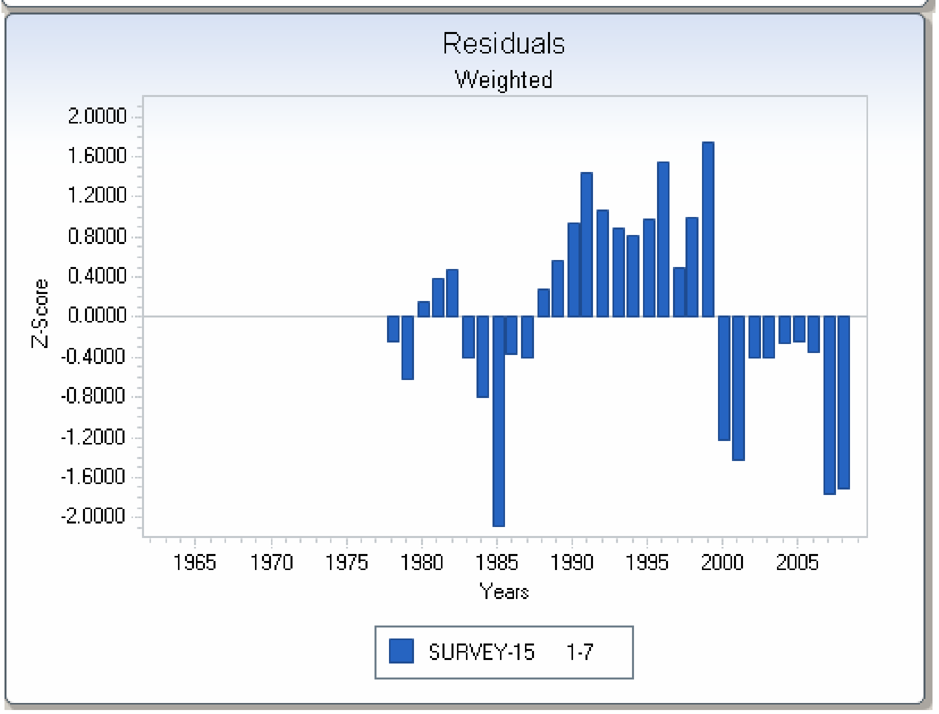


Figure 21. Residuals for the NMFS spring survey at age (top panel) and bottom fished mackerel otter trawl fishery (bottom panel) for a VPA fit with no splits (time blocks) in any index data source.

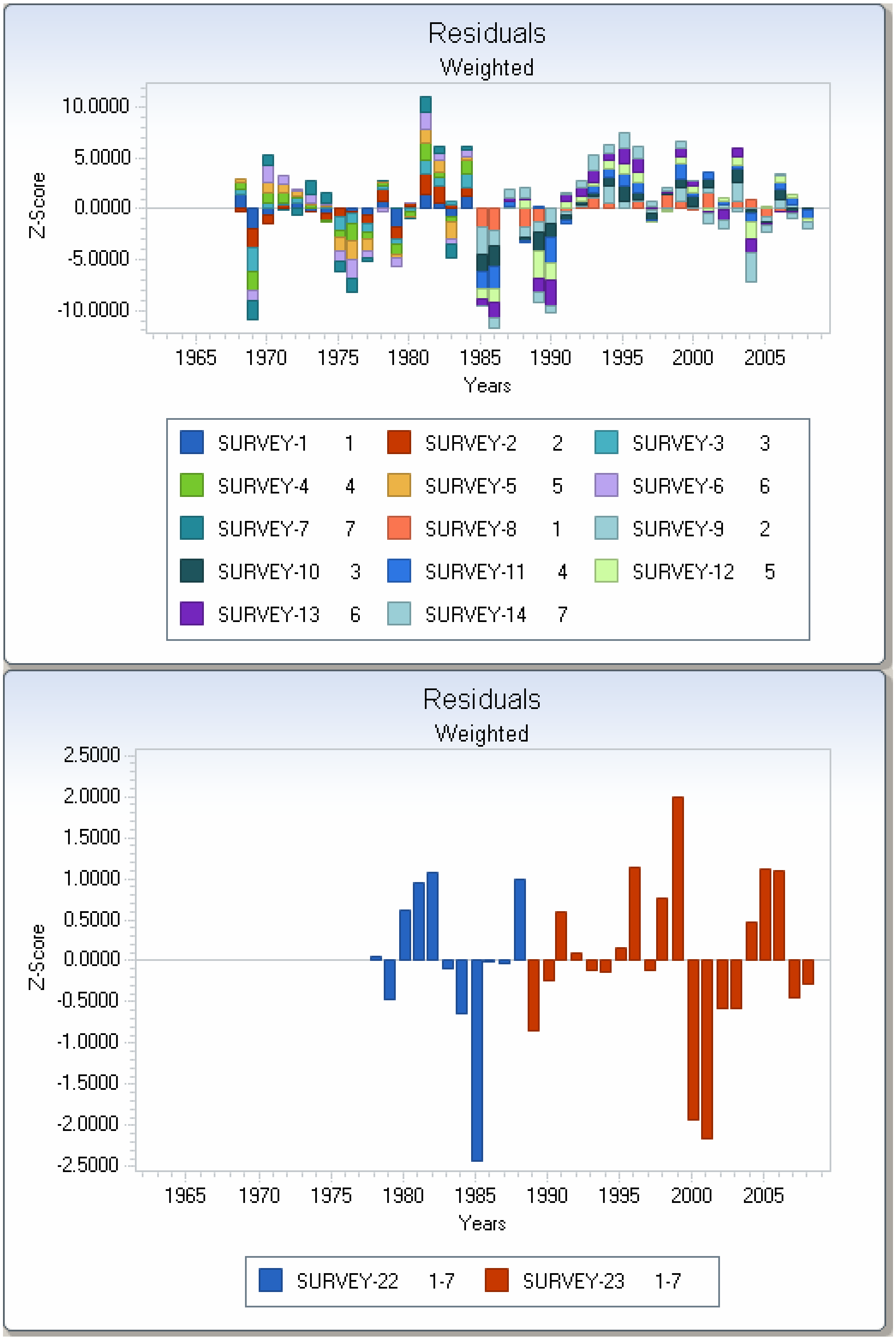


Figure 22. Residuals for the NMFS spring survey at age index from a VPA split in 1985 and for the bottom fished otter trawl fishery index split in 1989.

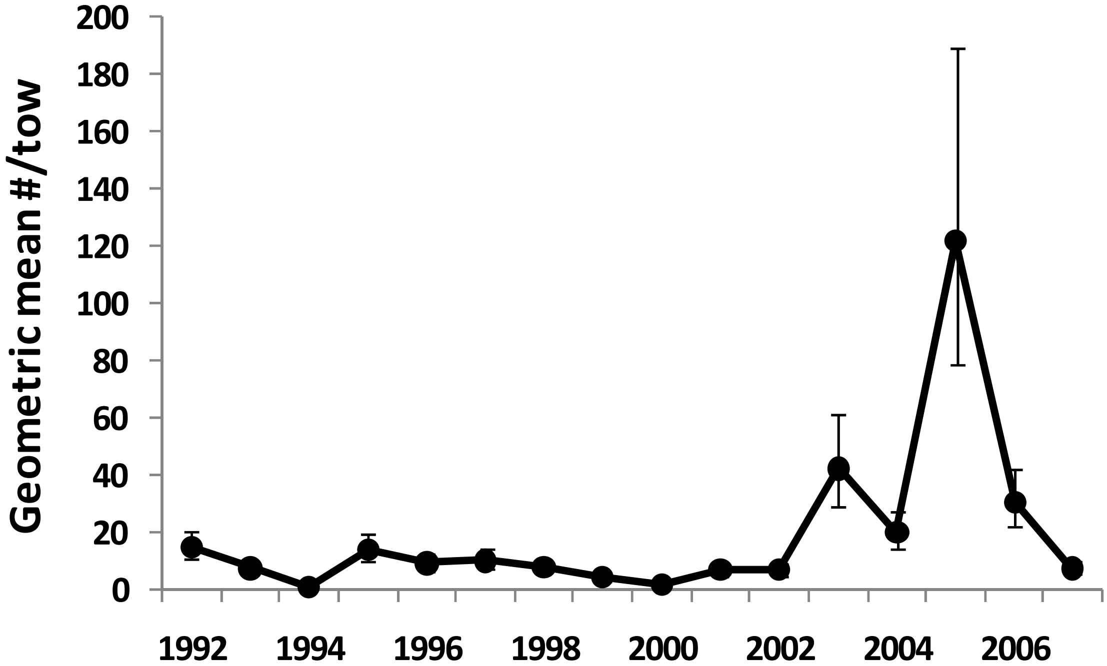


Figure 23. NMFS winter bottom trawl mackerel survey index (stratified ln retransformed mean number per tow with 95% confidence interval).

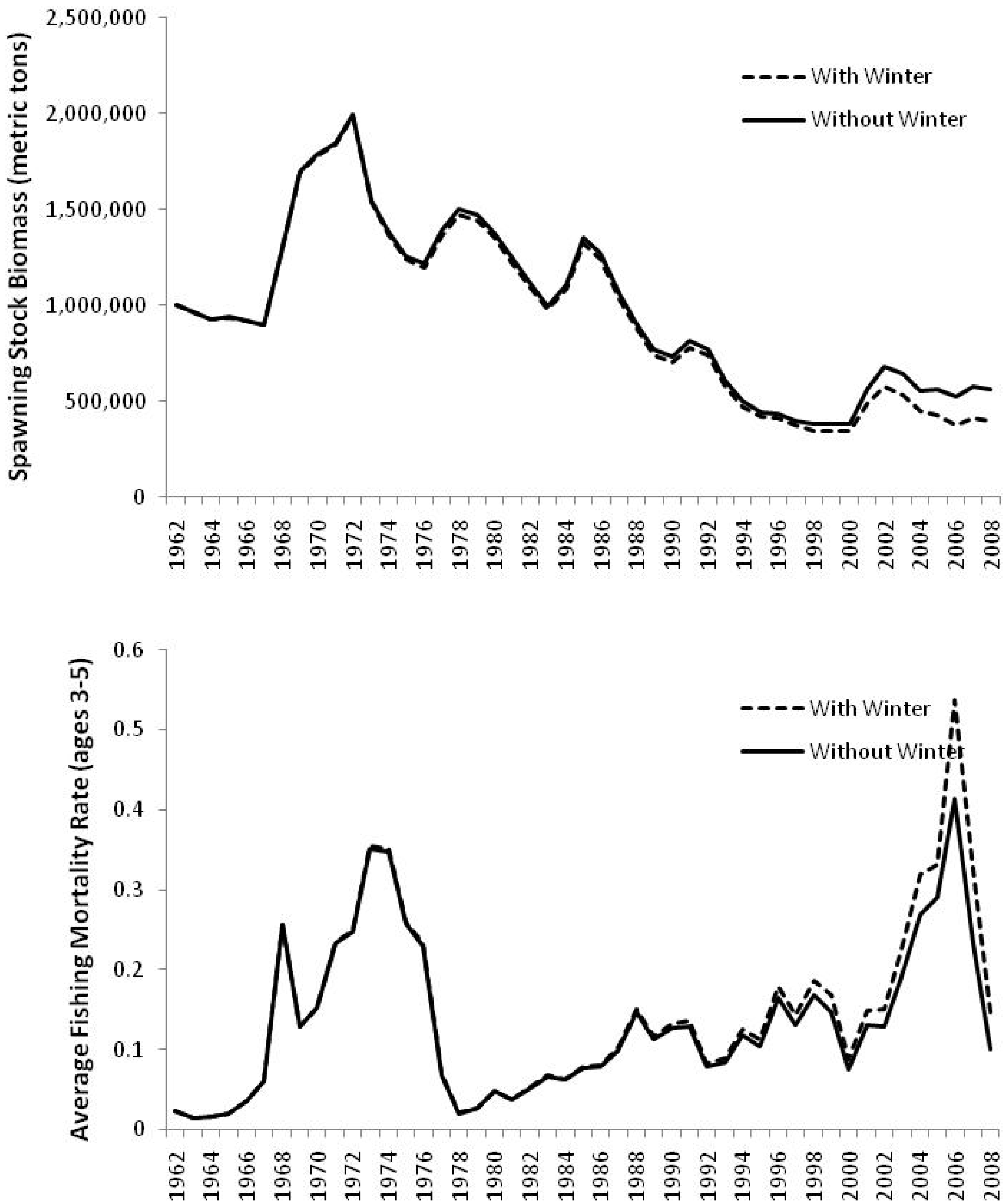


Figure 24. Spawning stock biomass and fishing mortality (averaged for ages 3 to 5) for VPA models with and without the NMFS winter survey (see text for details).

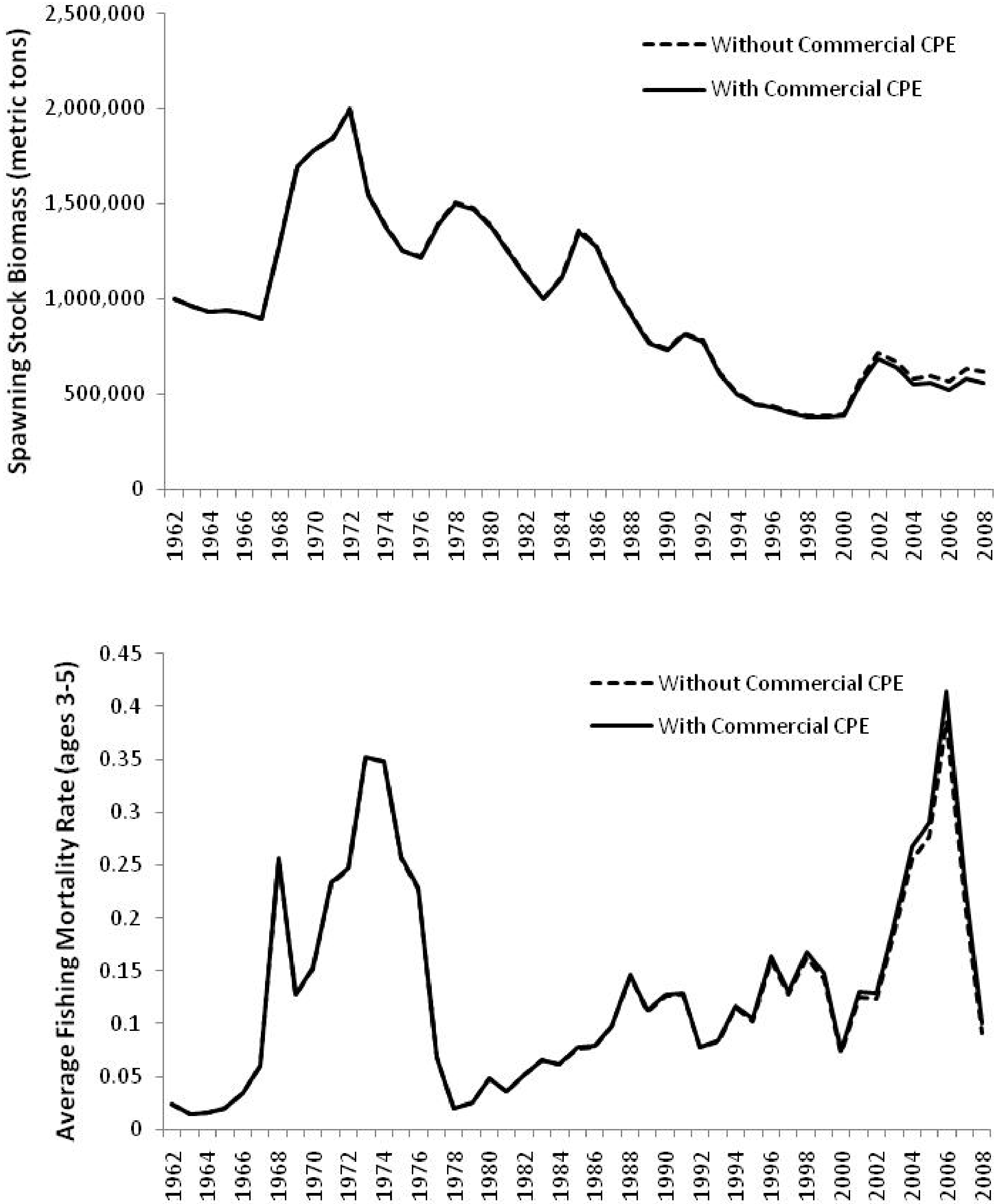


Figure 25. Spawning stock biomass and fishing mortality (averaged for ages 3 to 5) for VPA models with and without commercial mackerel CPUE indices from bottom fished and mid-water otter trawls (see text for details). In each of these VPA models, the spring bottom trawl survey index was split in 1985 (1968-1984; 1985-2008).

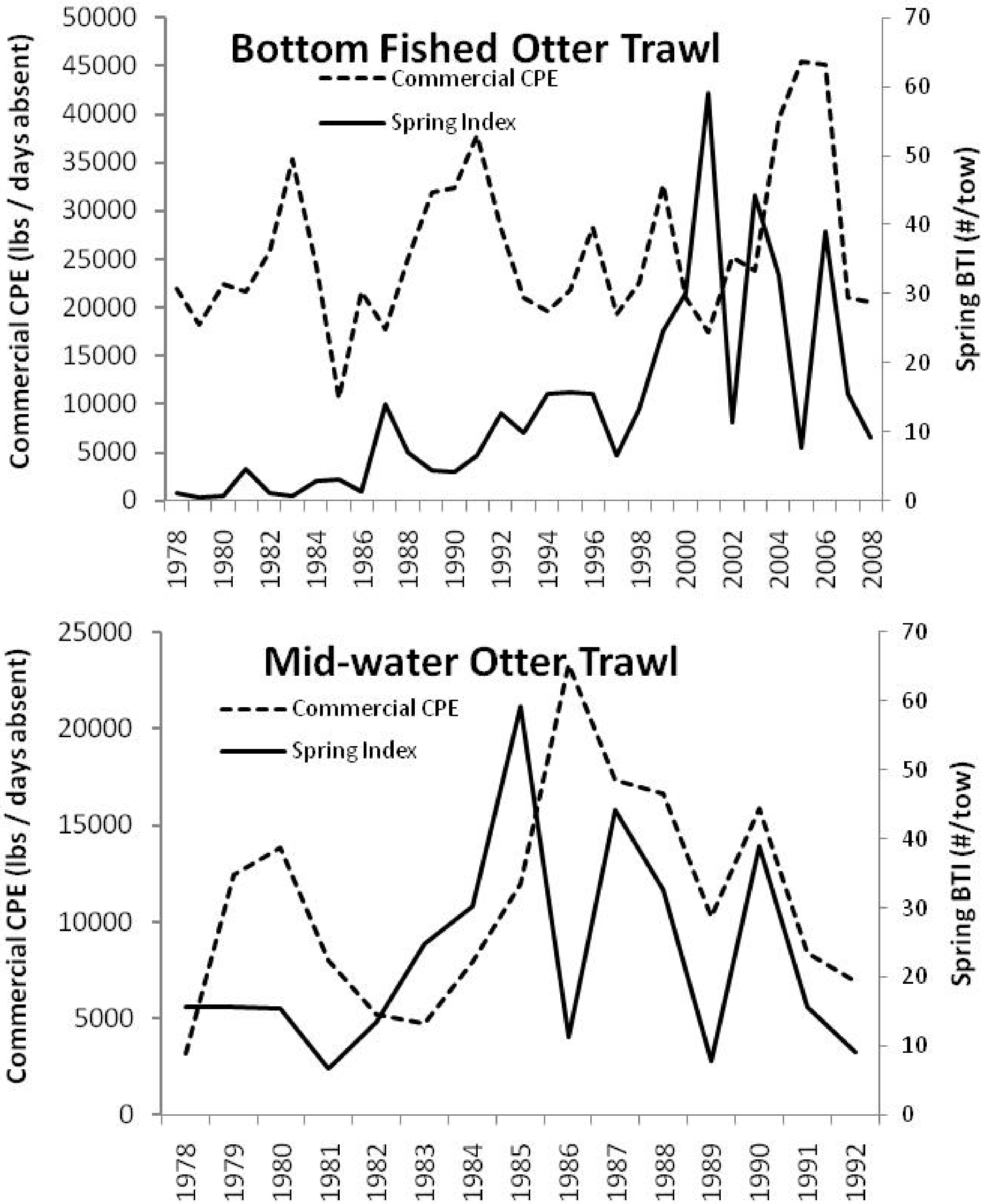


Figure 26. Standardized commercial mackerel catch per effort (CPUE) data from bottom fished otter trawls (top panel), mid-water otter trawls (bottom panel), and the NMFS spring bottom trawl survey (both panels).

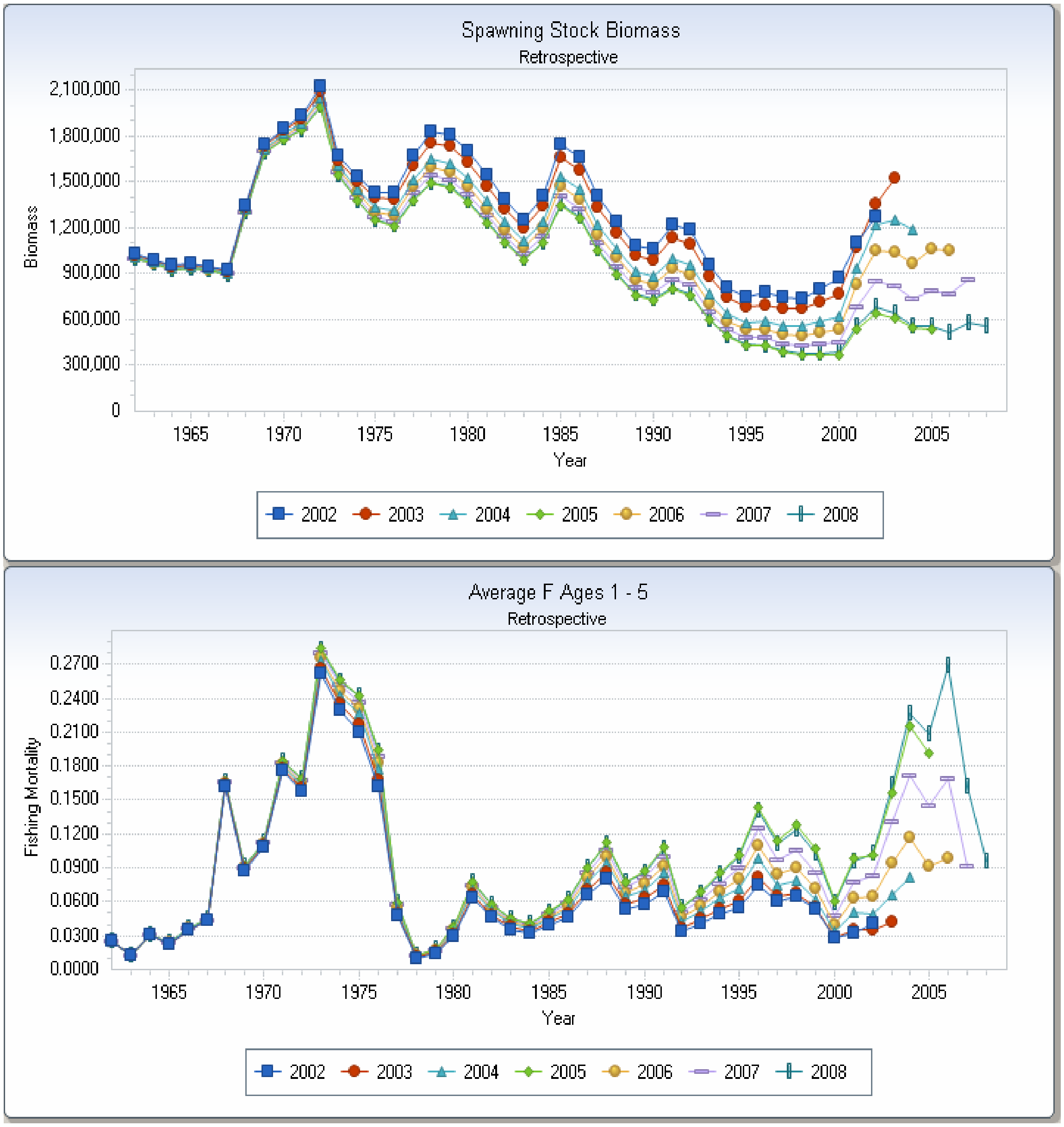
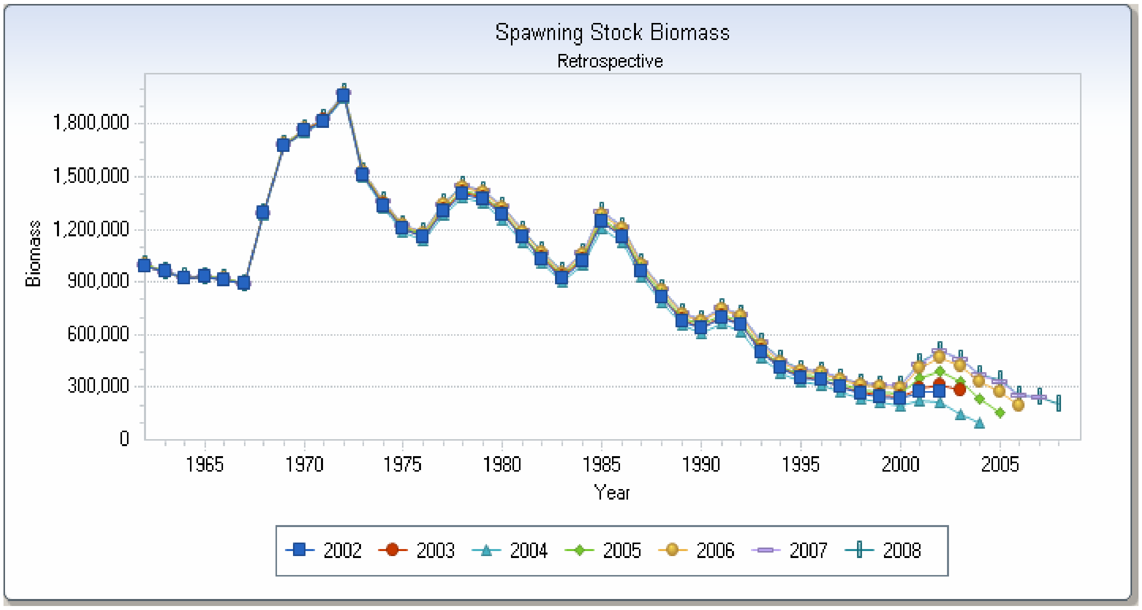


Figure 27. Retrospective pattern in spawning stock biomass (mt) and average fishing mortality rate from a VPA fit using the NMFS spring survey, bottom fished otter trawls, and mid-water otter trawls.



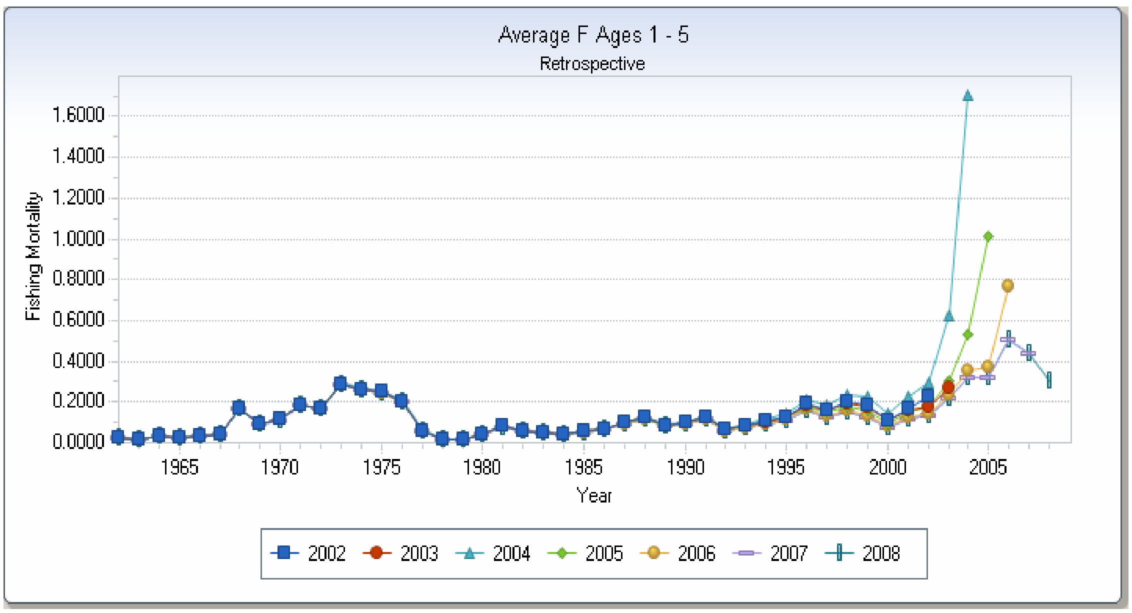
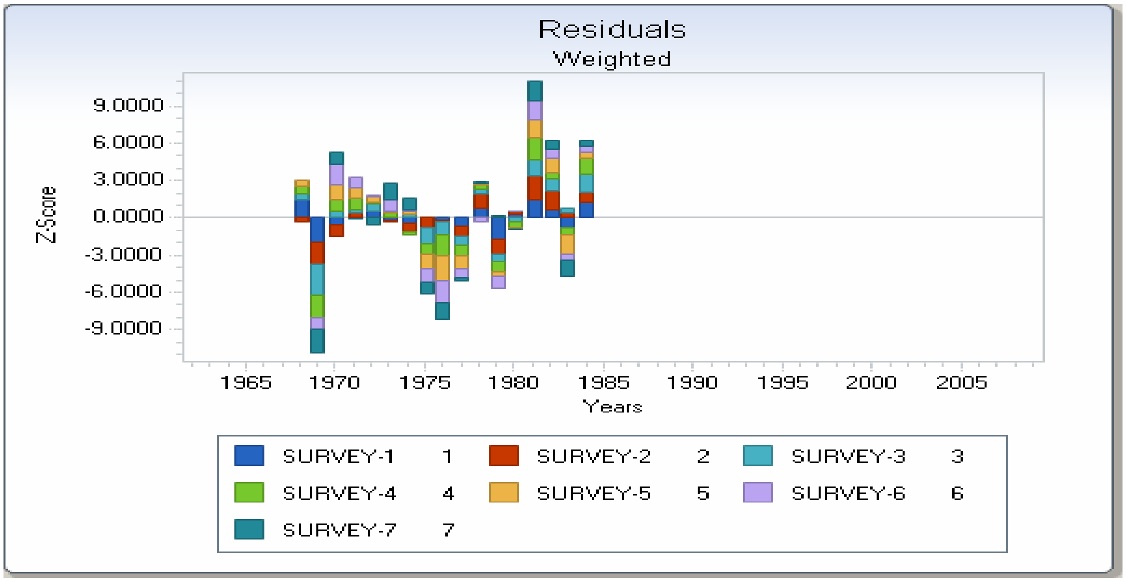


Figure 28. Retrospective pattern in spawning stock biomass (mt) and average fishing mortality rate from a VPA with the NMFS spring bottom trawl survey index split in 1985 and 1993.



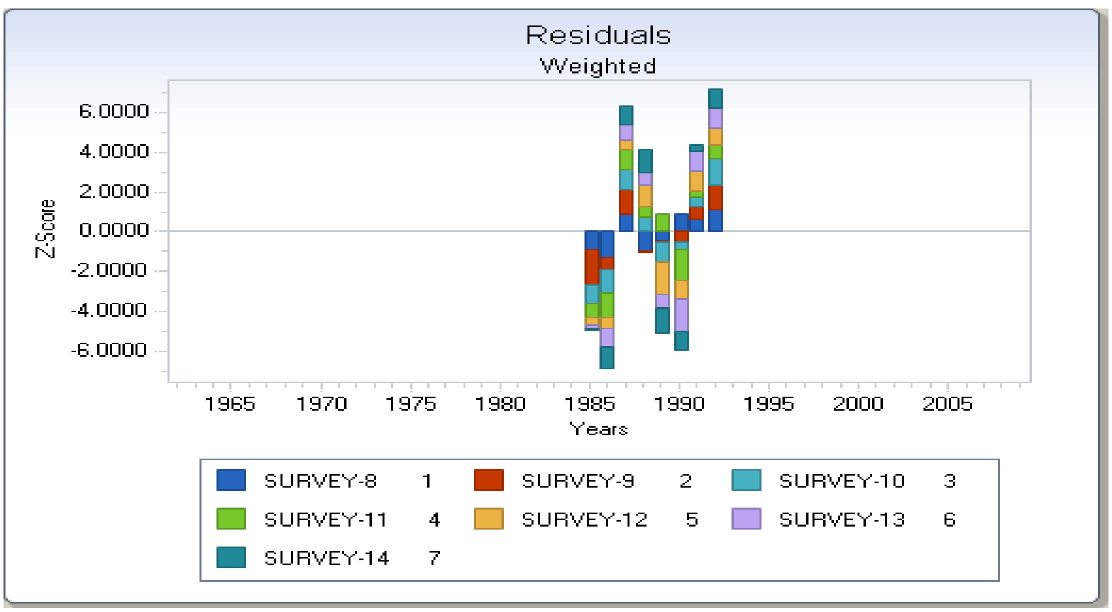
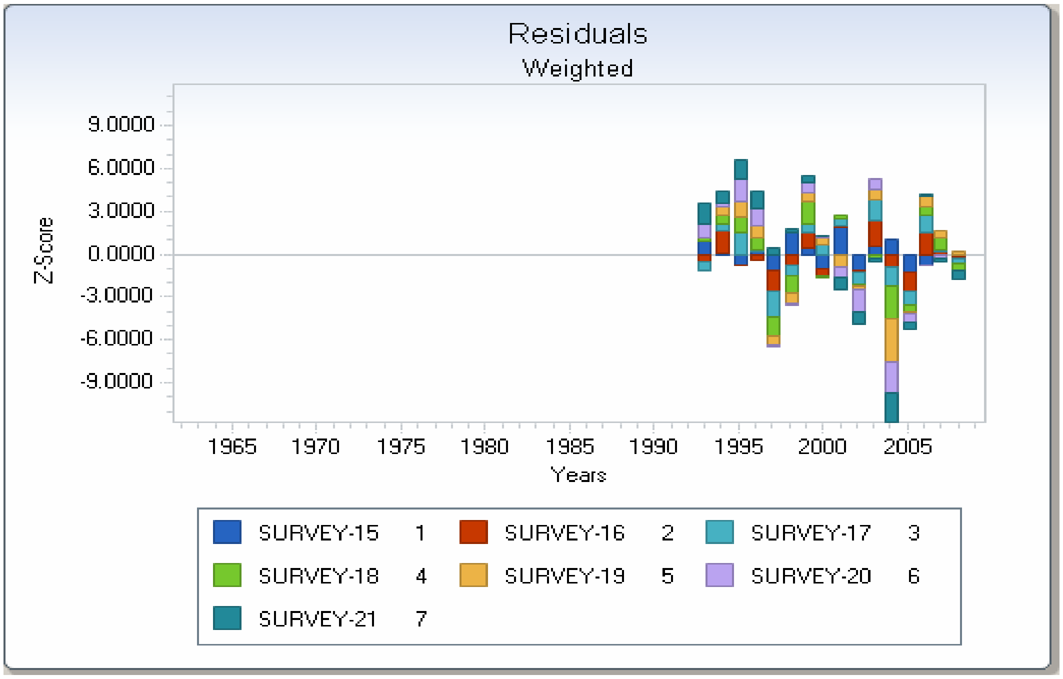


Figure 29. Residuals for the NMFS spring survey index at age (top 3 panels), bottom fished otter trawl CPUE index (4th panel), and mid-water otter trawl CPUE index (bottom panel) for the baseline VPA model.



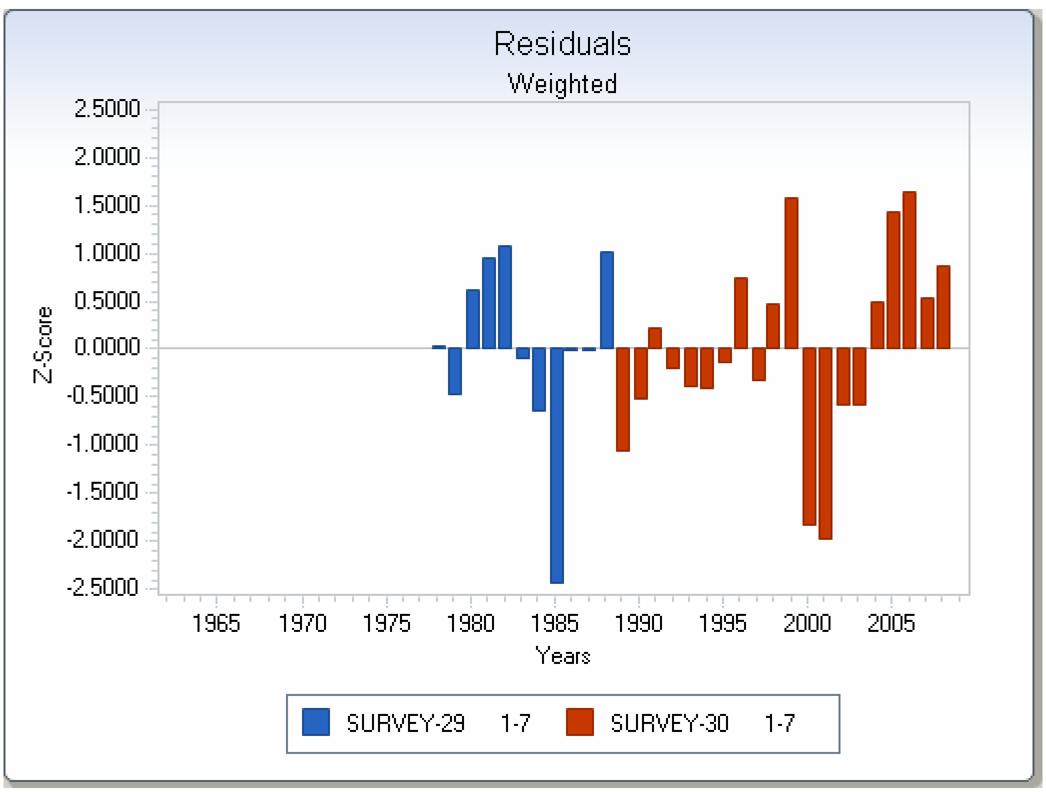


Figure 29. (Continued.)

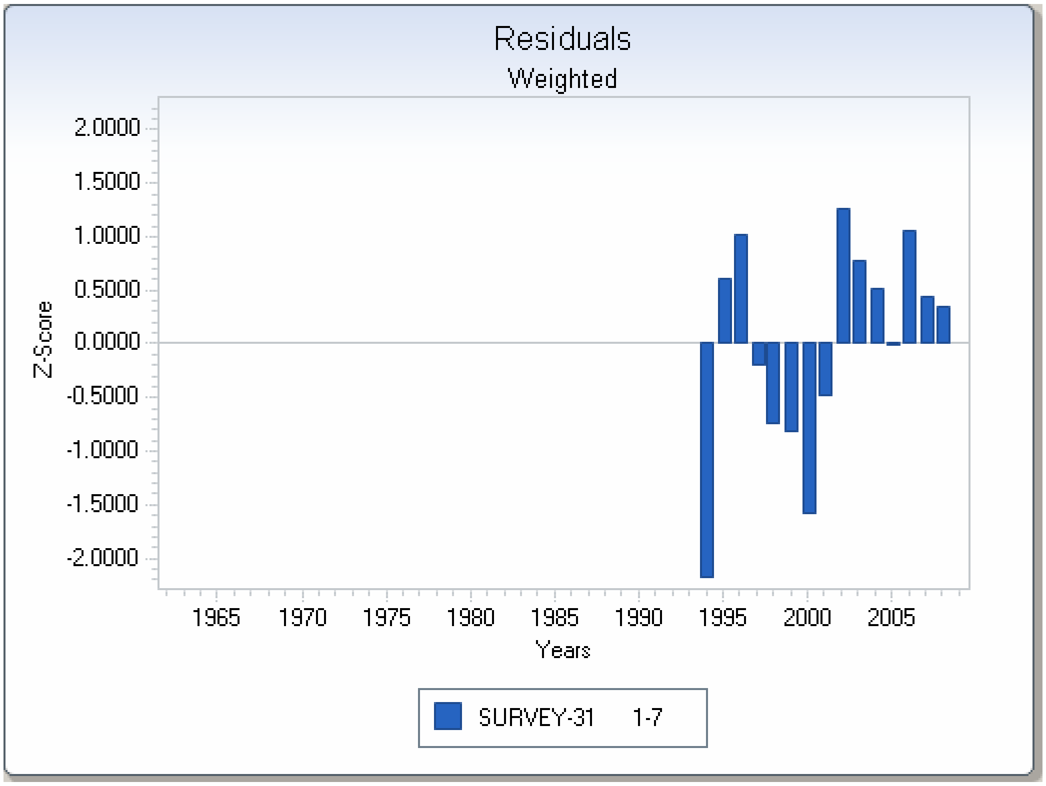


Figure 29. (Continued.)

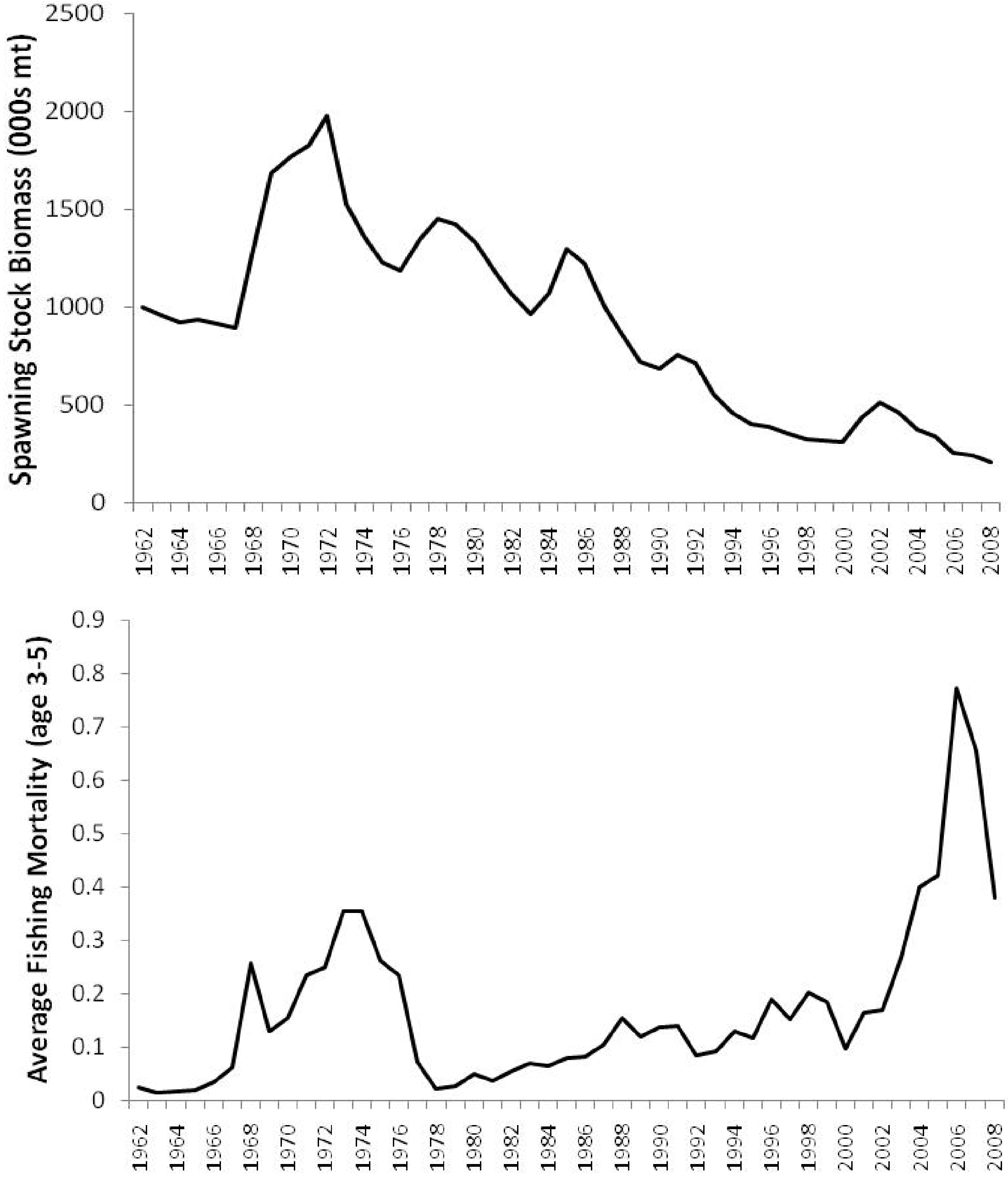


Figure 30. Spawning stock biomass and average fishing mortality rate estimates during 1962-2008 from the baseline VPA model.

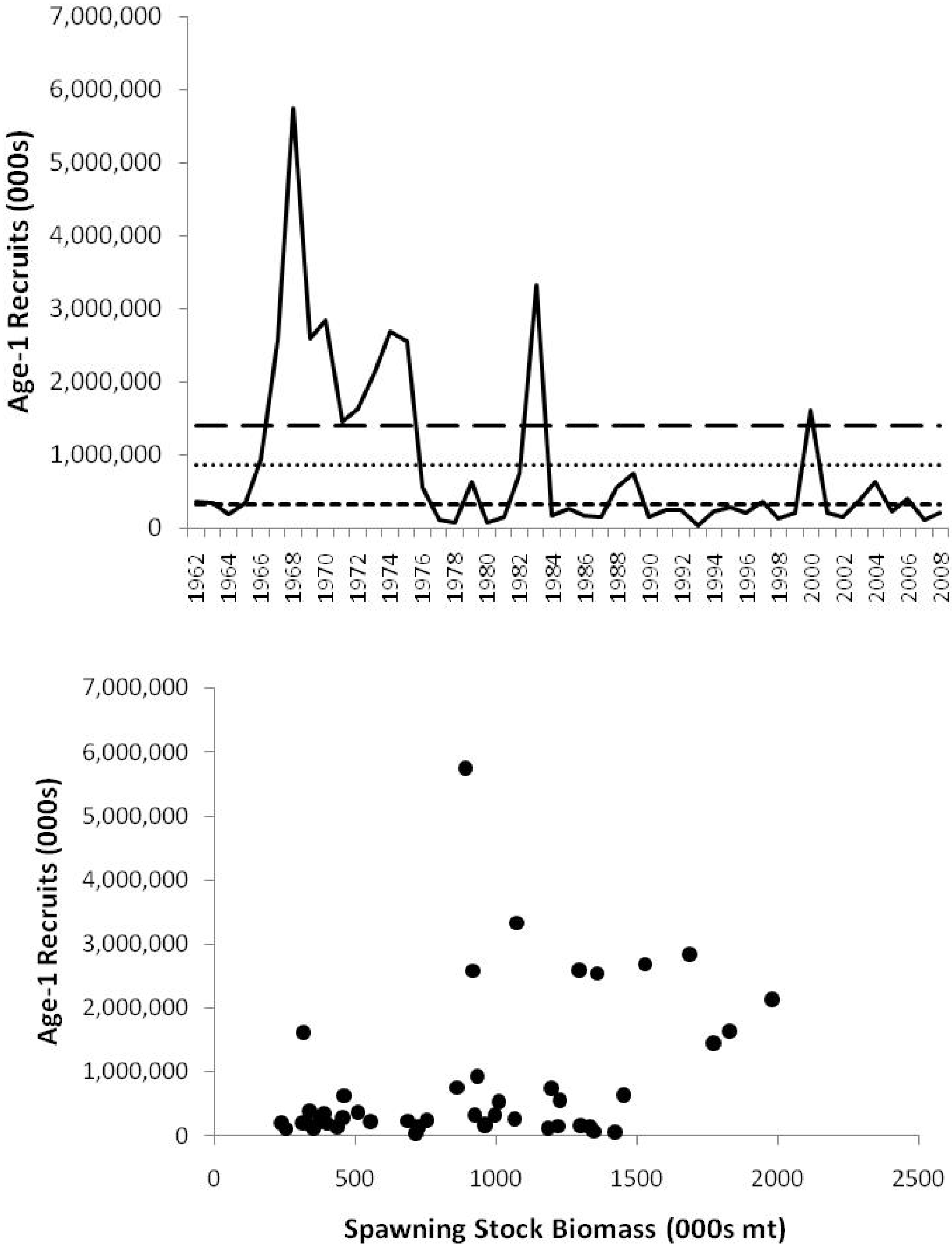


Figure 31. Age-1 recruit estimates during 1962-2008 from the baseline VPA model. The top horizontal long dashed line is the average age-1 recruitment during 1962-1984; the middle horizontal dotted line is the average age-1 recruitment over the entire time series, and the bottom horizontal short dashed line is the average age-1 recruitment during 1985-2008.

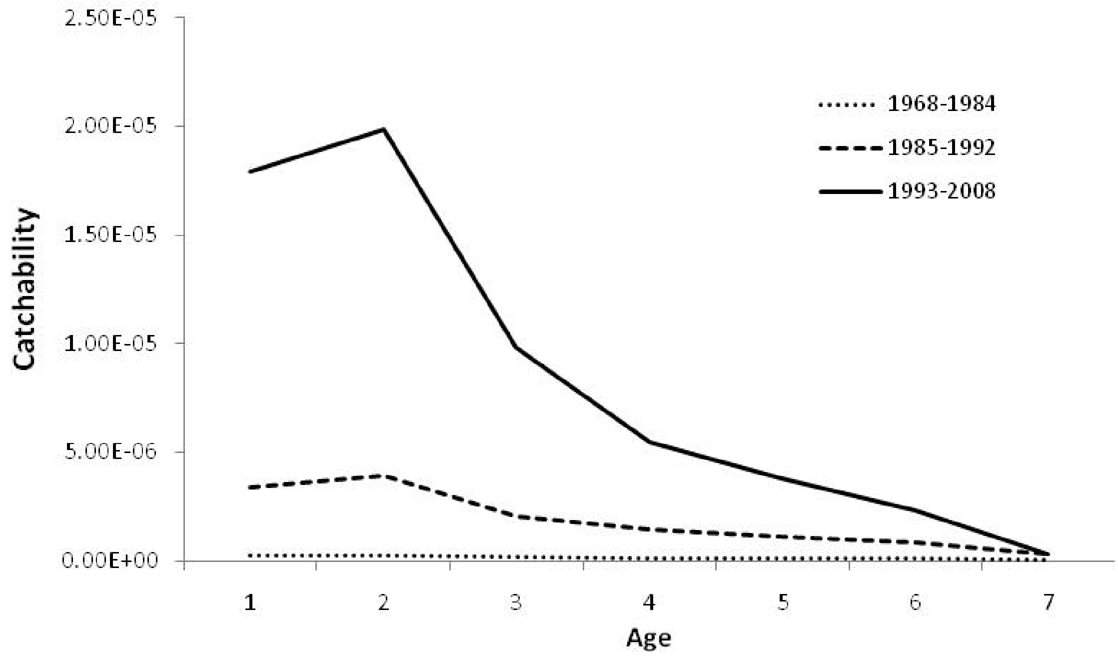


Figure 32. Catchability at age estimates for the NMFS spring bottom trawl survey for the 3 time blocks used in the baseline VPA model.

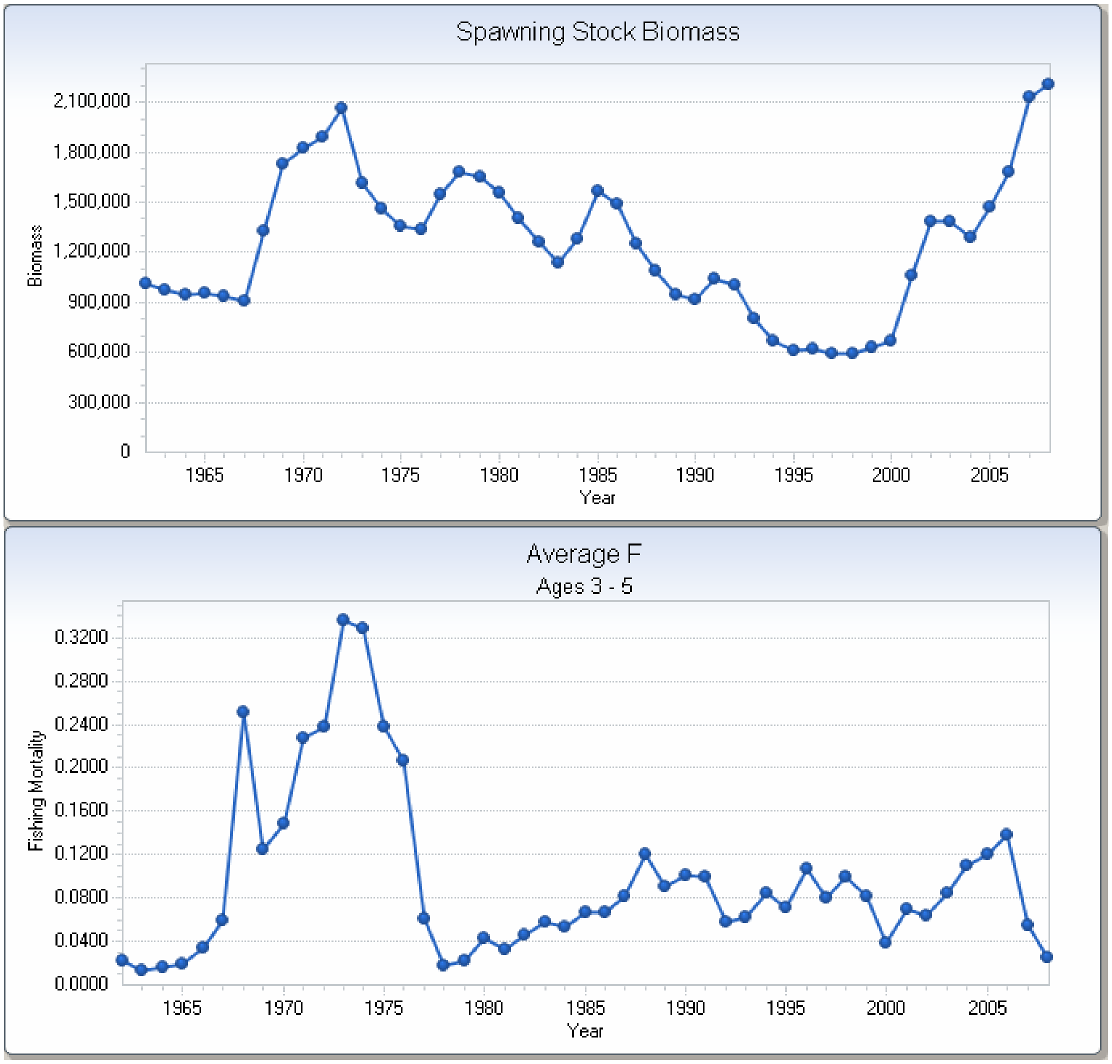


Figure 33. Spawning stock biomass (metric tons) and average fishing mortality rate estimates during 1962-2008 from a VPA with no splits in the NMFS spring survey.

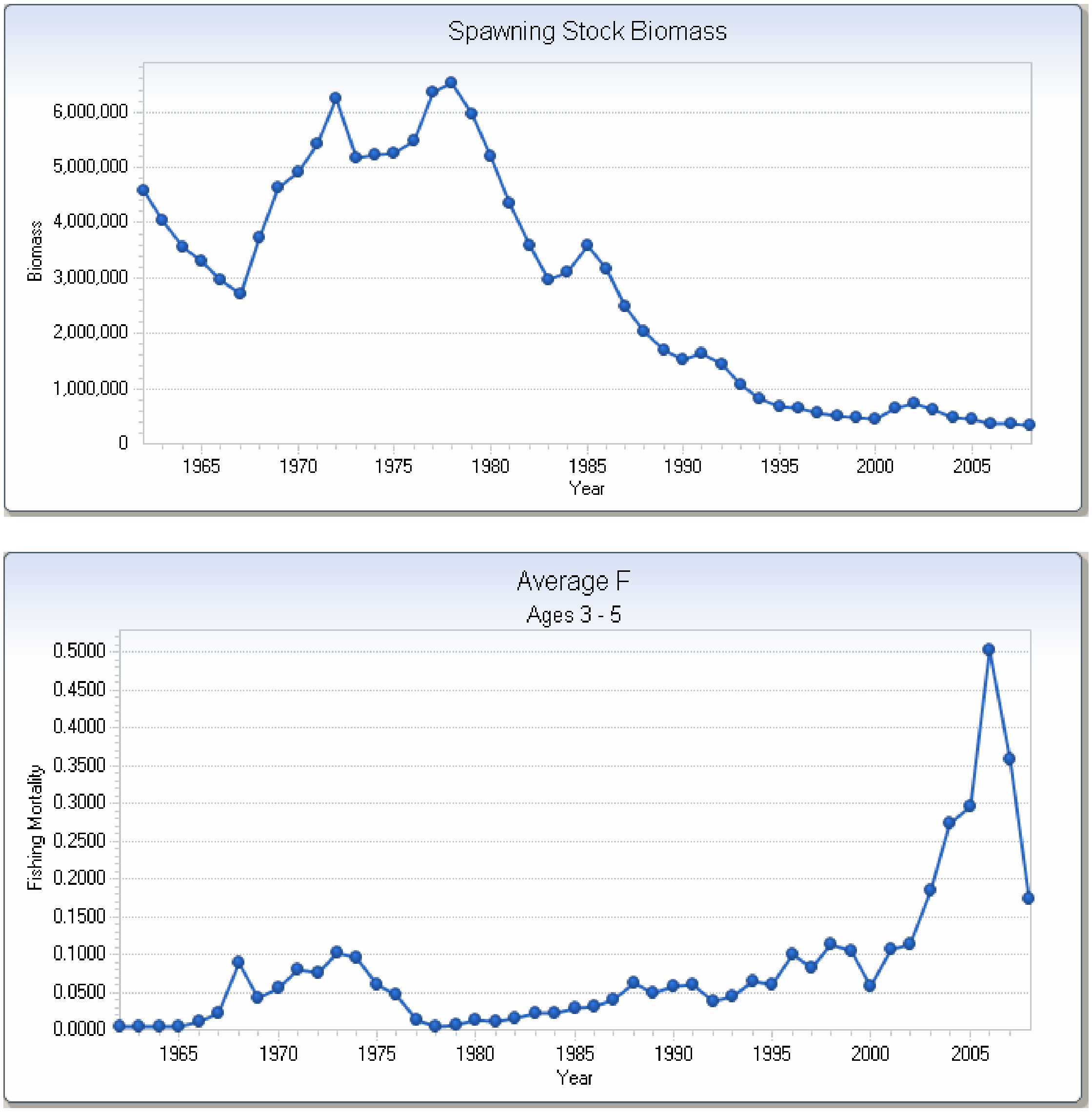


Figure 34. Spawning stock biomass (metric tons) and average fishing mortality rate estimates during 1962-2008 from the baseline VPA, except with natural mortality equal to 0.3.

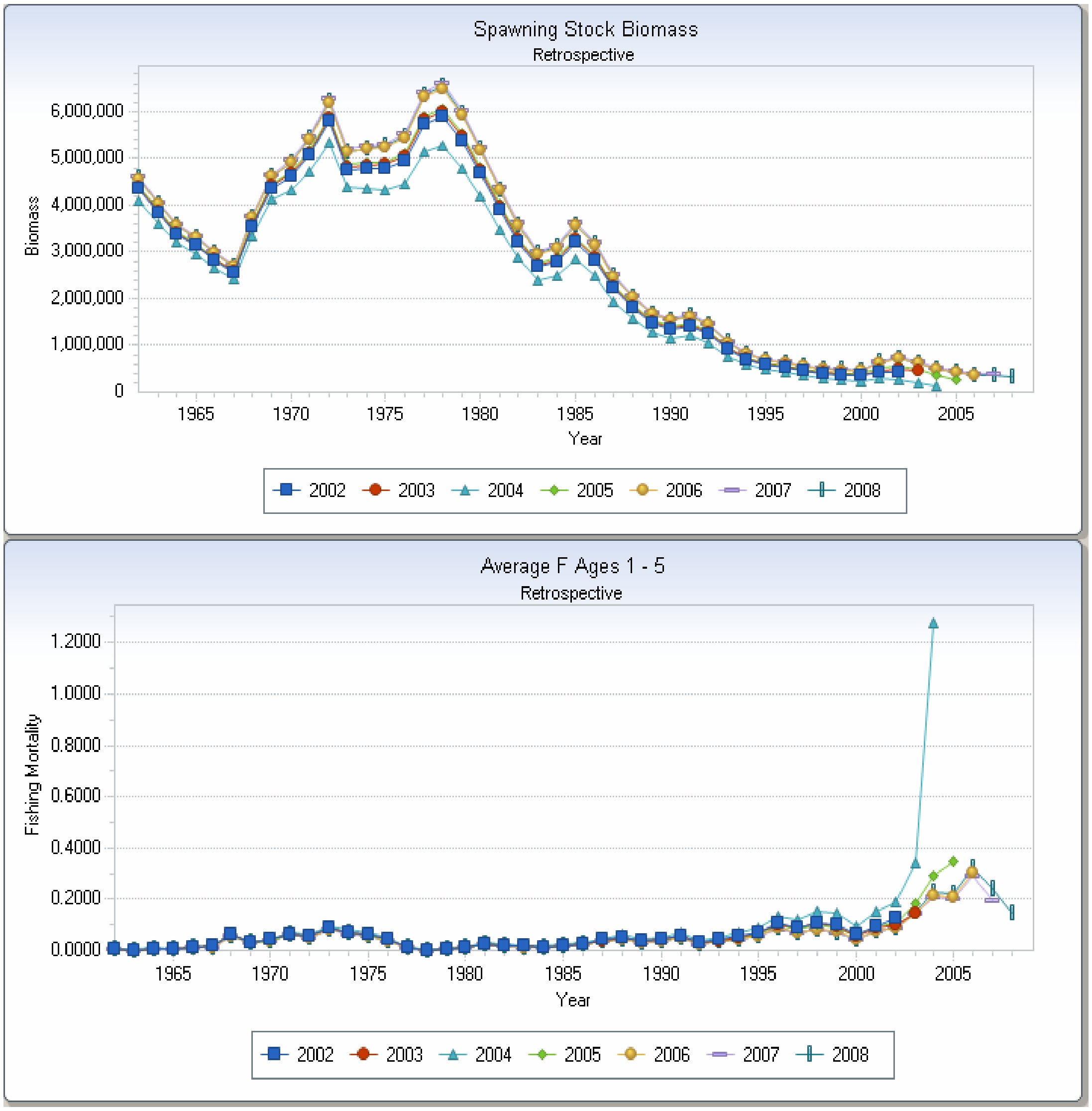
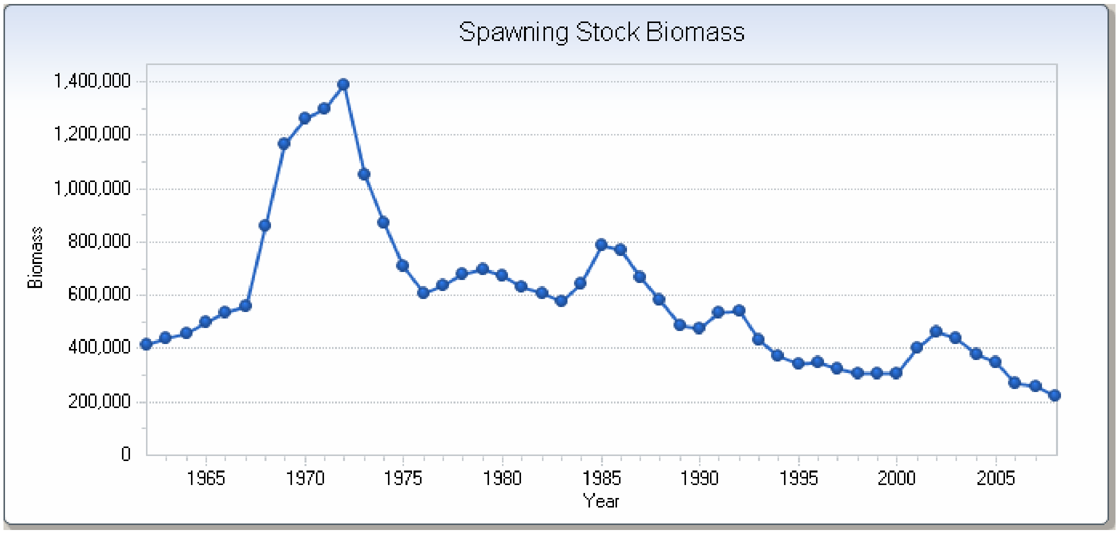


Figure 35. Retrospective pattern in spawning stock biomass and average fishing mortality rate from the baseline VPA, except with M=0.3.



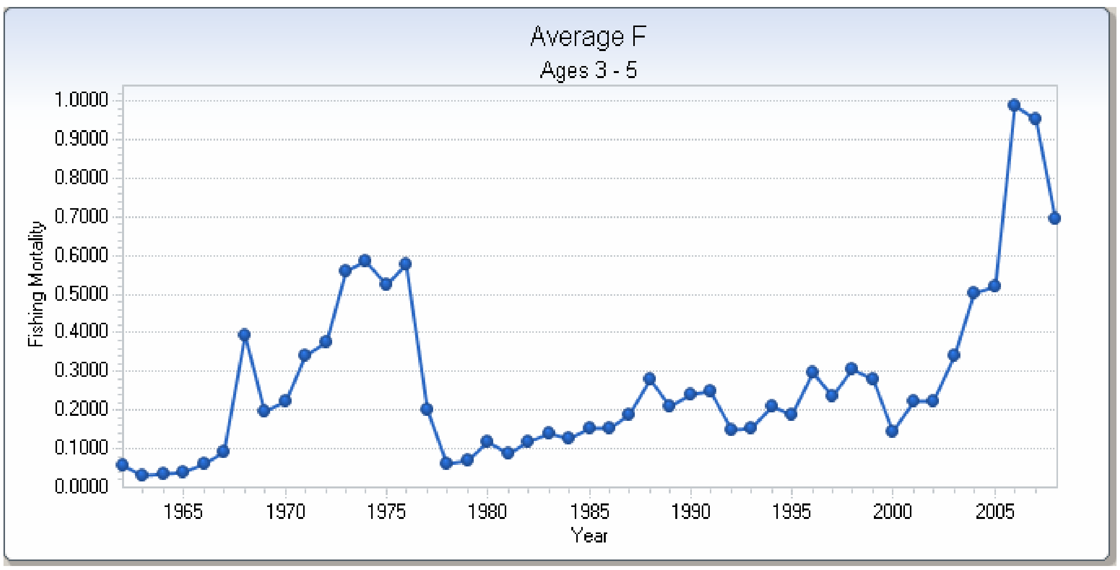
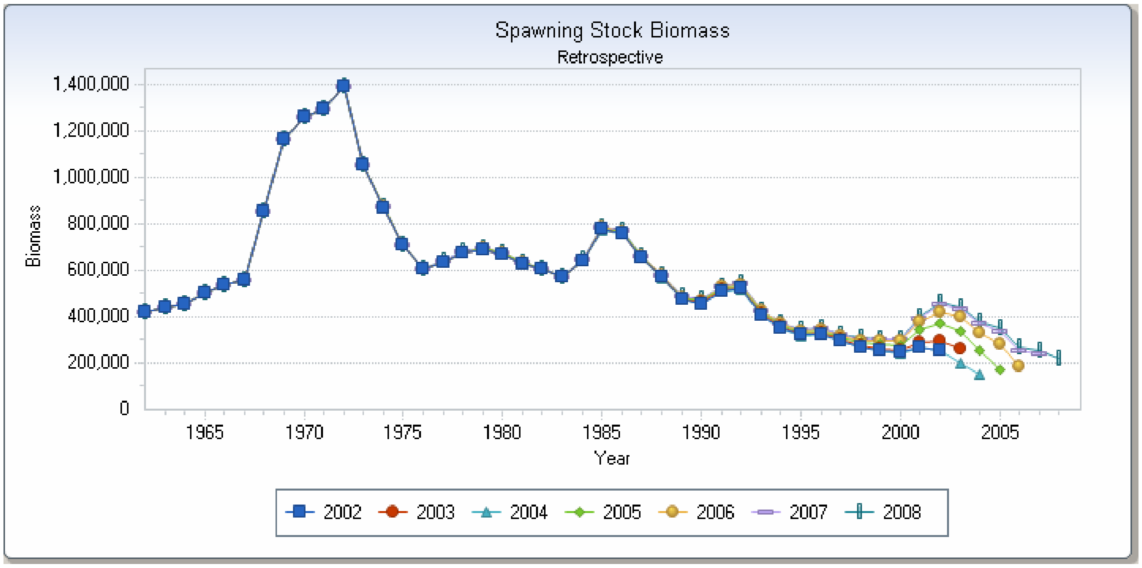


Figure 36. Spawning stock biomass (metric tons) and average fishing mortality rate estimates during 1962-2008 from the baseline VPA, except with natural mortality equal to 0.1.



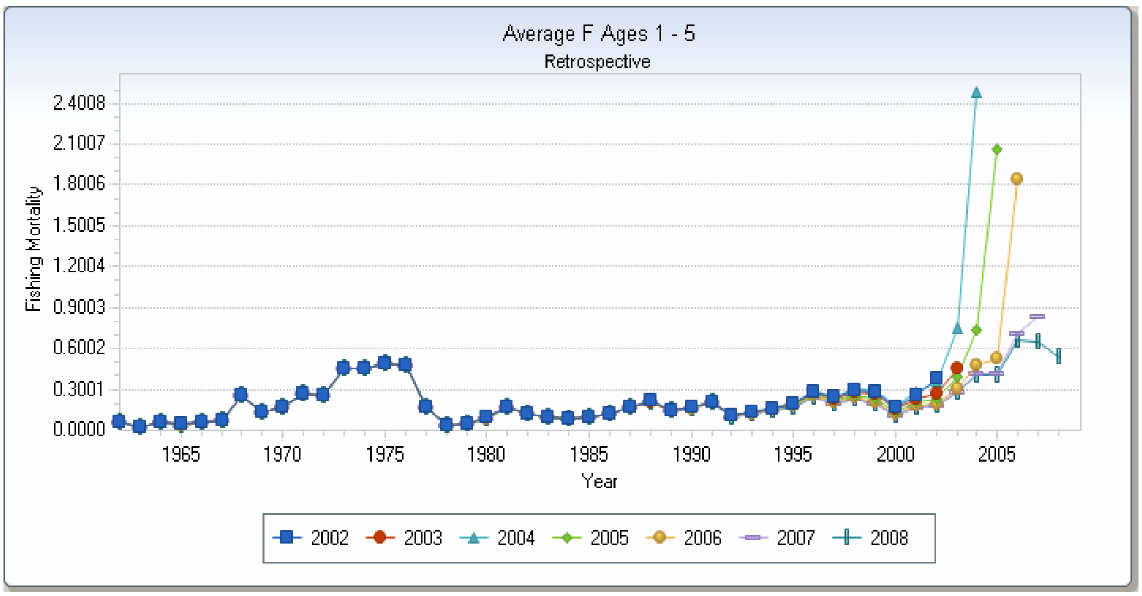


Figure 37. Retrospective pattern in spawning stock biomass and average fishing mortality rate from the baseline VPA, except with M=0.1.

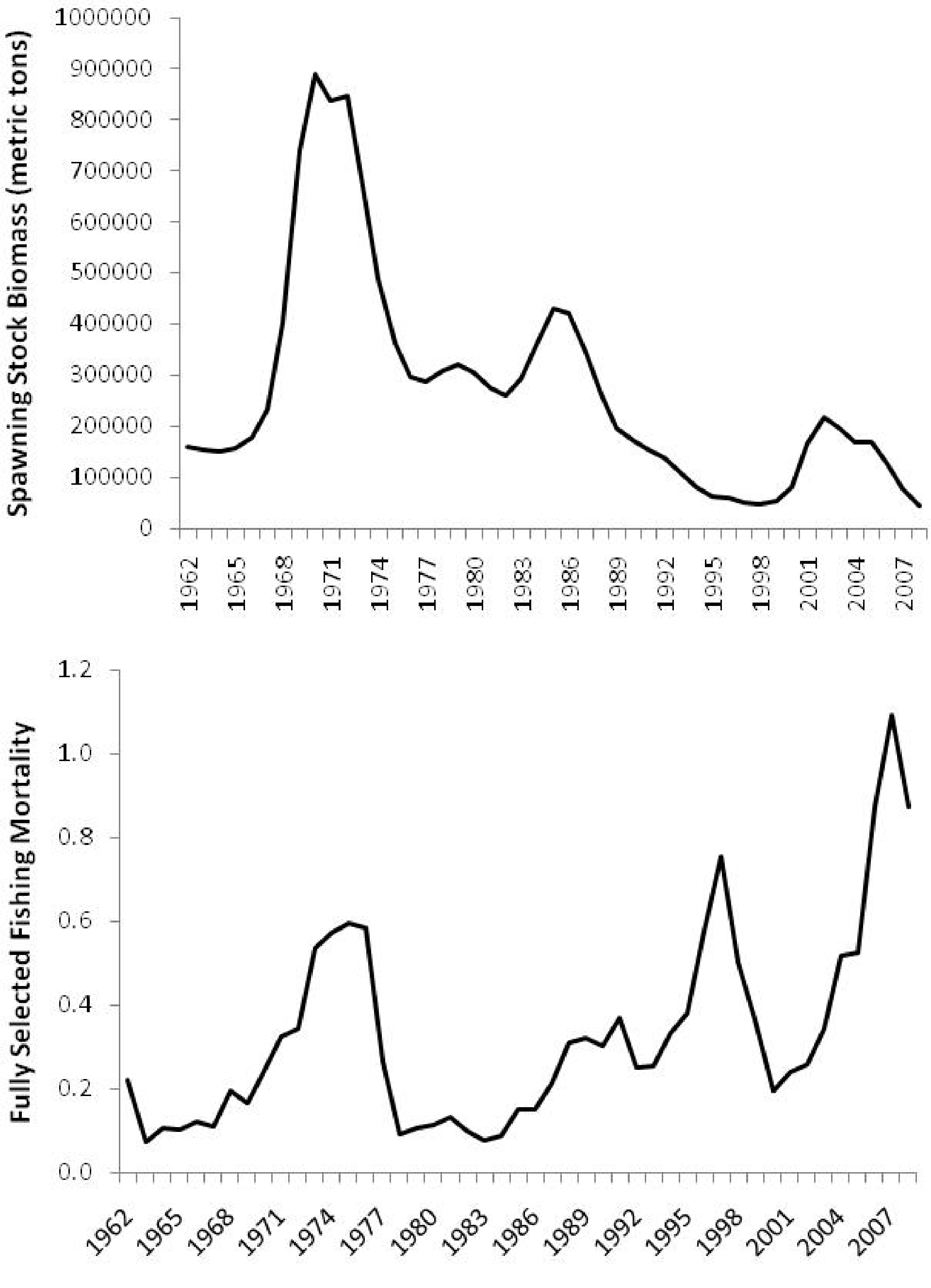


Figure 38. Preliminary spawning stock biomass (mt) and fully selected fishing mortality rate estimates from a statistical catch at age model for Atlantic mackerel during 1962-2008.

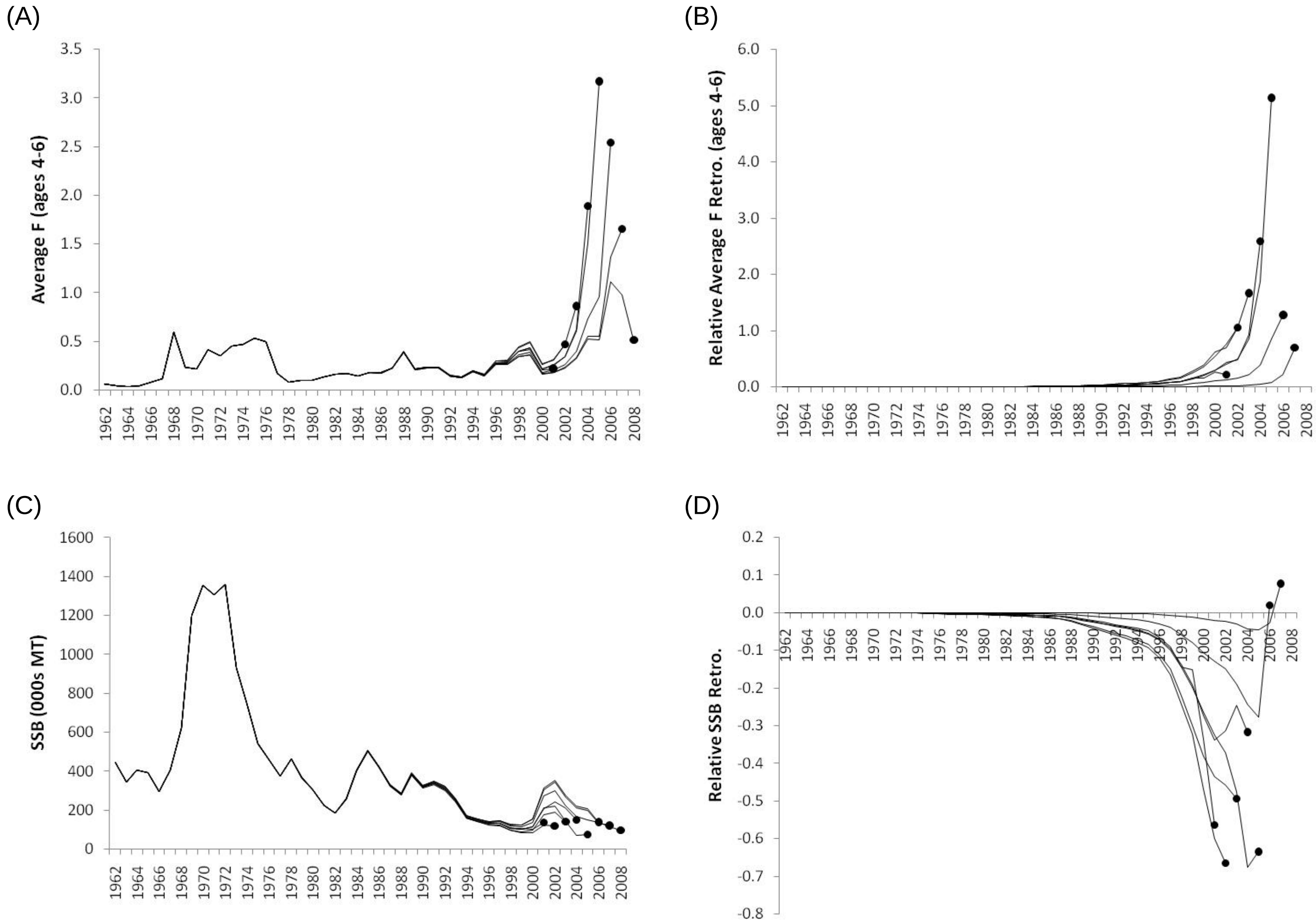


Figure 39. Retrospective patterns in average fishing mortality rate (ages 4-6) (A and B) and spawning stock biomass (C-D) from the final VPA model selected by the TRAC.

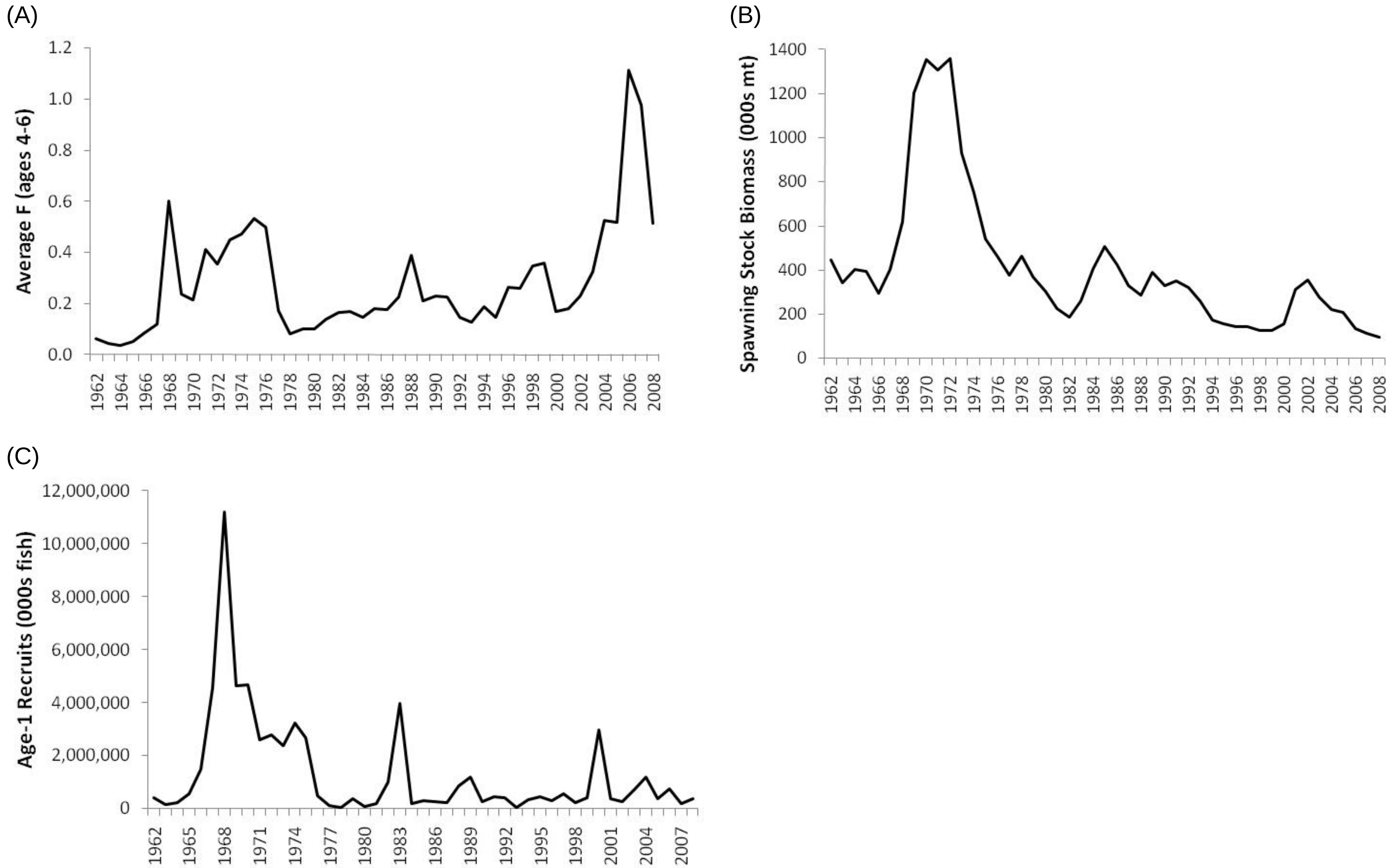


Figure 40. Average fishing mortality rate (ages 4-6) (A), spawning stock biomass (B), and age 1 recruitment (C) from the final VPA model selected by the TRAC.

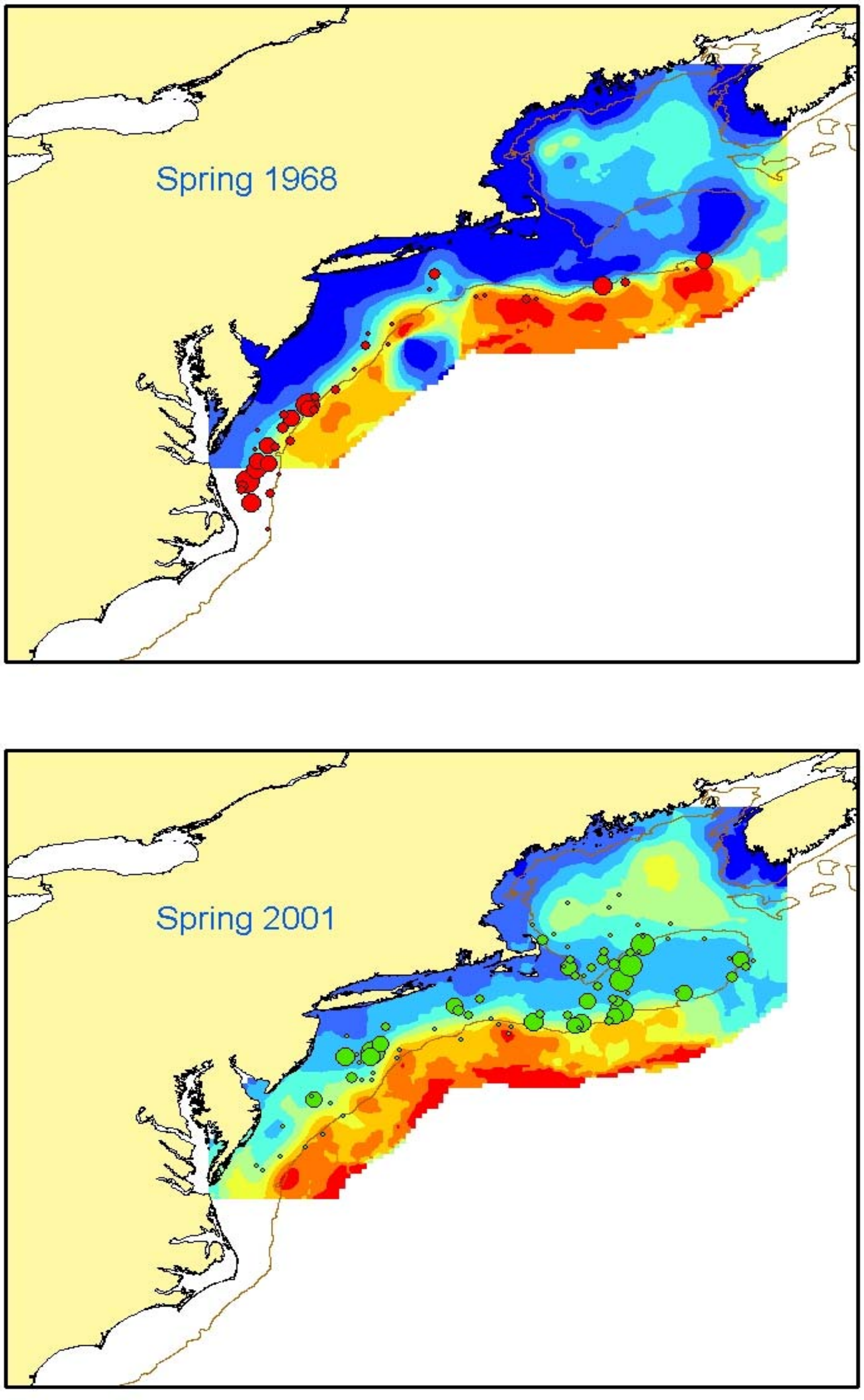


Figure 41. Distribution of Atlantic mackerel and bottom temperature isotherms from NEFSC spring surveys during 1968 (A) and 2001 (B). Figures from Overholtz et al. (in press).

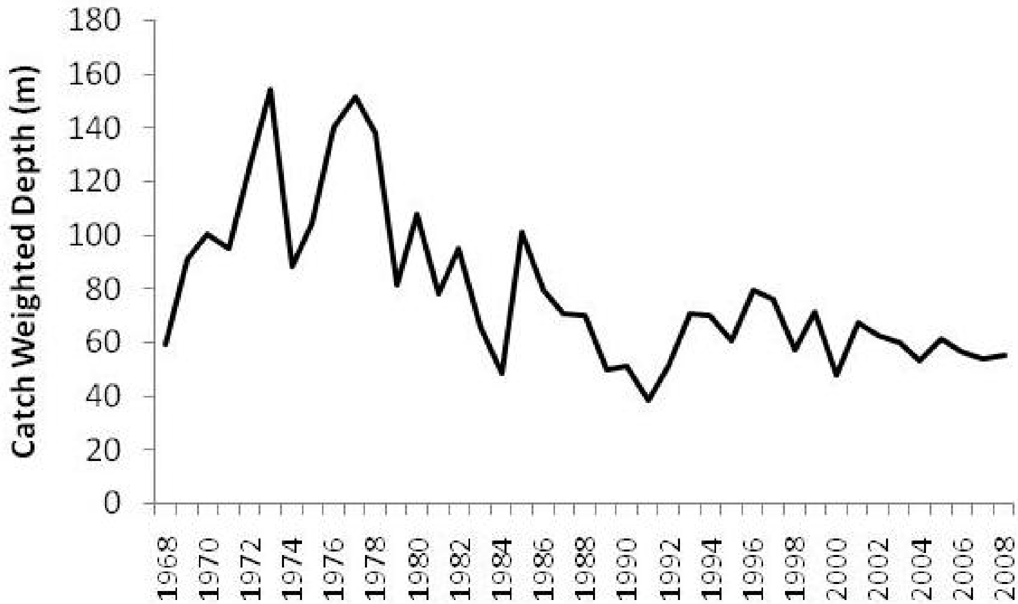


Figure 42. Mackerel catch weighted mean depth (meters) of the NMFS spring survey during 1968-2008.