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# Stock Assessment of Atlantic Mackerel in the Northwest Atlantic – 2009

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Terms of Reference:

- Review the assessment model formulation issues and recommend an approach for stock status determination.
  - Exploration of VPA models, forward projection models (e.g., ASAP), and other relevant approaches.
  - Review the retrospective pattern and consider alternative model formulations to address its impact on uncertainty in status determination and harvest forecast.

- Apply the agreed assessment approach to update the status Northwest Atlantic mackerel stock through 2008 and characterize the uncertainty of estimates.

- Review the harvest strategy biological reference points to meet management requirements of both countries.

- Review approach for the provision of projections to meet the management requirements of both countries.

- Consider the stock implications of unattained short-term yields.

- Identify potential future work (International egg survey, tagging and genetic studies, and other collaboration between both countries) that would improve the determination of stock status.

- Consider role of mackerel as forage for predators and evaluate feasibility of incorporating predatory consumptive removals into assessment models.

## Executive Summary

Atlantic mackerel *Scomber scombrus* were last assessed in 2005, and the conclusion of that assessment was that the stock was not overfished and overfishing was not occurring. The model configuration from the last assessment, which was an ASAP model that included a split in the NMFS spring survey index in 1985, was used as a starting point for this assessment using data updated through 2008. However, multiple configurations of ASAP models using the updated data sources, including models with predation removals, were not robust to various assumptions and exhibited worse retrospective patterns than comparable virtual population analysis (VPA) models. So, a VPA was considered the baseline model for this assessment.

The baseline VPA was fit to catch at age and mean weight at age data during 1962-2008, NMFS spring survey data during 1968-2008 with splits in 1985 and 1993, and commercial catch per effort data from bottom fished and mid-water otter trawls during 1978-2008. Spawning stock biomass 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. Average fishing mortality rate (ages 3-5) was relatively high during 1968-1975 peaking in that range of years at 0.36 in 1973. Average fishing mortality rate 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.

Updated reference points from this baseline VPA were $F_{0.1}$ = 0.26 with a corresponding equilibrium spawning stock biomass of 549,000 metric tons. Based on the baseline VPA and these reference points, Atlantic mackerel would be considered overfished and overfishing would be occurring.

Catchability estimates for the NMFS spring survey from the baseline VPA model differed by an order of magnitude among the 3 time blocks (i.e., splits in 1985 and 1993 resulted in 3 time blocks), with higher catchabilities in more recent years, particularly for younger ages. The higher catchability estimates in the 1994-2008 index series may be effectively down scaling the relatively high mean number per tow observations that occurred in recent years The result is that the subsequent trend in abundance estimates would not match the relatively high survey observations that occurred prior to accounting for temporal changes in catchability. VPA models fit without the splits in the NMFS

spring survey index resulted in spawning stock biomass and average fishing mortality rate estimates trending in opposite directions and leading to very different conclusions about stock status than the baseline VPA. However, these VPA runs without also exhibited severe residual and retrospective patterns. So, although the baseline VPA that was suggested was chosen based on improved model diagnostics, such as residual and retrospective patterns, such improvements came at the cost of effectively devaluing the trend in the NMFS spring survey index to an inexplicable degree. However, alternatives to the baseline VPA do not perform well from a model diagnostics standpoint.

## Introduction

Atlantic mackerel in the Northwest Atlantic are a migratory species moving seasonally between U.S. and Canadian waters. Sette (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, 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 (SAW 42, 2005). The conclusion of that assessment was that mackerel were not overfished and overfishing was not occurring. Since that assessment, there were updates to the Age Structured Assessment Program (ASAP) software used in the assessment. Differences in the results from SAW 42 and results using the new software were minimal (Figures 1 and 2). However, the new software provides an option to use a likelihood constant that was not available in the previous version. Use of the constant influenced the terminal estimates of fishing mortality (Figures 3 and 4) although the absolute values of the values were relatively similar. All subsequent runs were made using the likelihood constant.

Data available for this new assessment was reviewed and adopted at the TRAC data meeting in October 2009 (TRAC 2009). Since the conclusion of the data meeting, adjustments have been made to catch data. Foreign landings in Canada from 1968 to 1977 previously not included were added and the Canadian 1985 to 1989 catch at age data were updated to include all available length and age data from that period (Table 1). In addition, US landings at age for 2006 to 2008 were re-calculated with the inclusion of length data collected by commercial industry funded sampling.

Acknowledgements- A special thanks to Francois Gregoire, Fisheries Oceans Canada, for providing the Canadian catch at age results.

## Literature cited

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

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. Dep. Commer., Northeast Fish. Sci. Cent. Ref. Doc. 06-09a; 284 p.

Sette, O.E. 1943. Biology of Atlantic mackerel (*Scomber scombrus*) of North America. Part I: Early life history including growth, drift, and mortality of the egg and larval populations. U.S. Fish Wildl. Serv. Fish. Bull. 50: 149-237.

Sette, O.E. 1950. Biology of Atlantic mackerel (*Scomber scombrus*) of North America. Part II. Migrations and habits. U.S. Fish Wildl. Serv. Fish. Bull. 51: 251-358

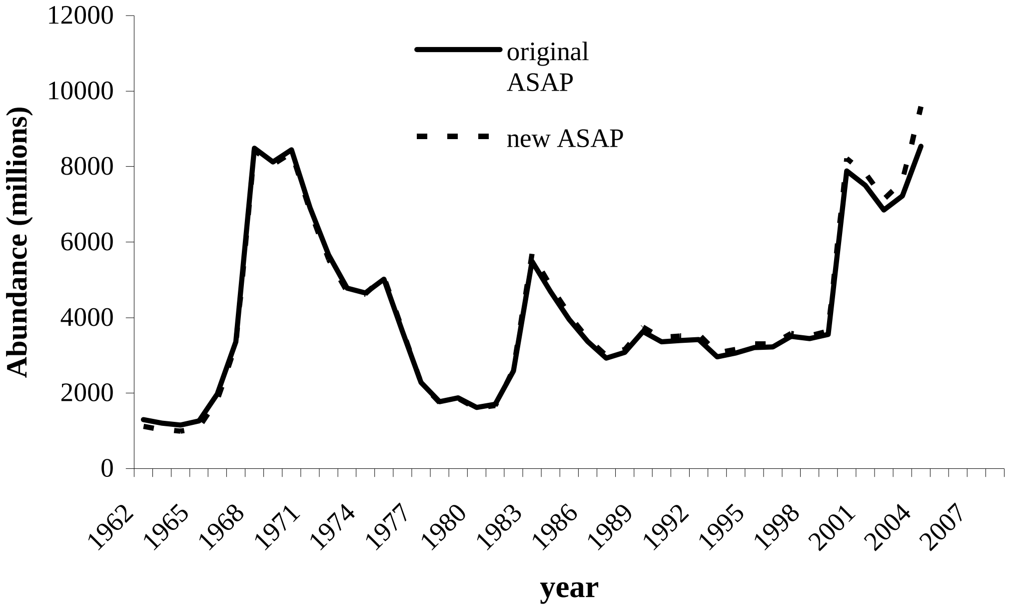

Figure 1. Comparison of abundance estimates between SAW 42 results with original and revised ASAP model.

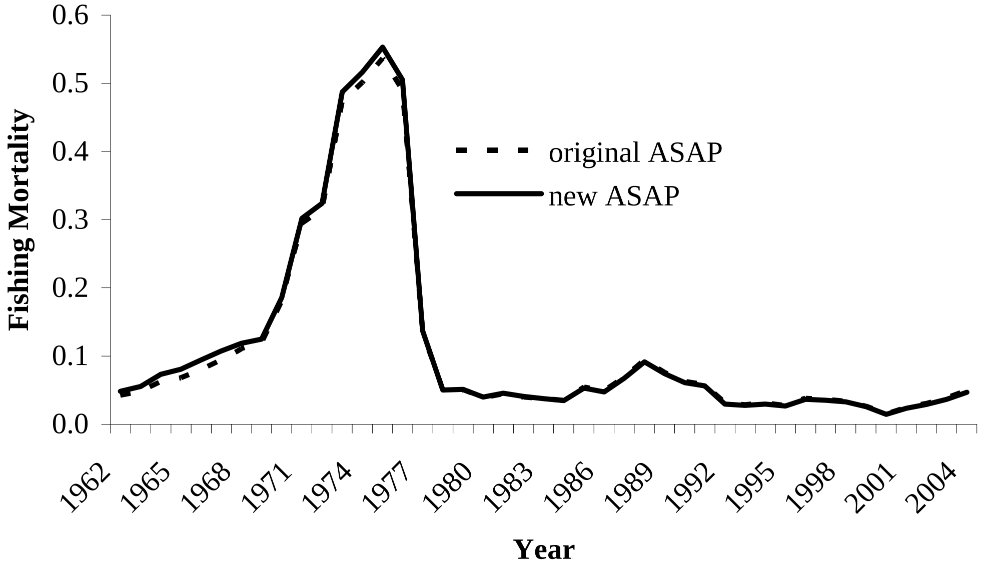

Figure 2. Comparison of F estimates between SAW 42 results with original and revised ASAP model.

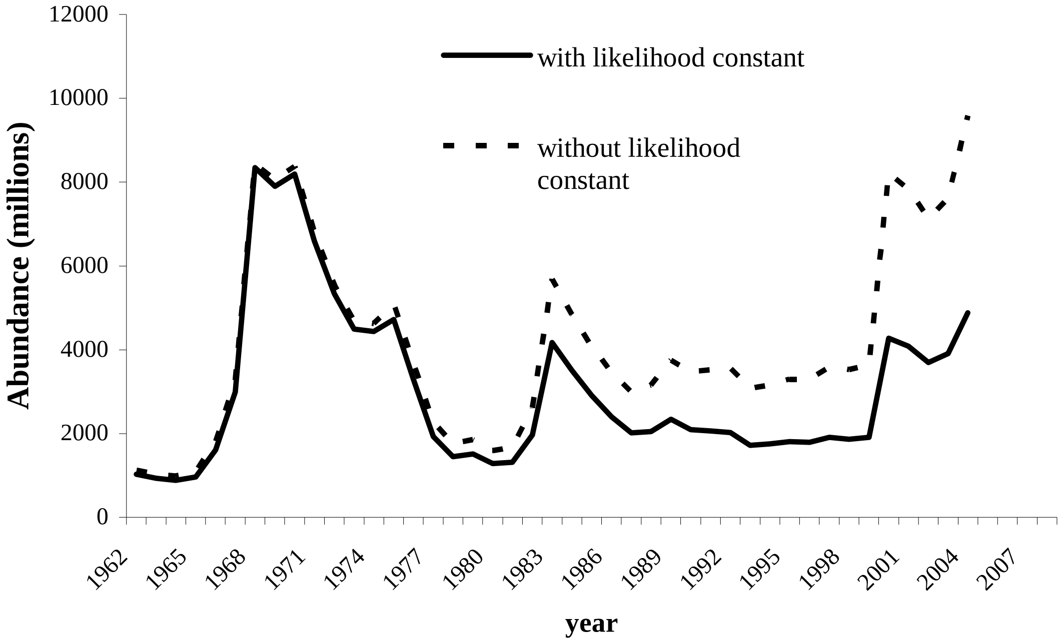

Figure 3. Comparison of abundance estimates between ASAP model with and without use of likelihood constant.

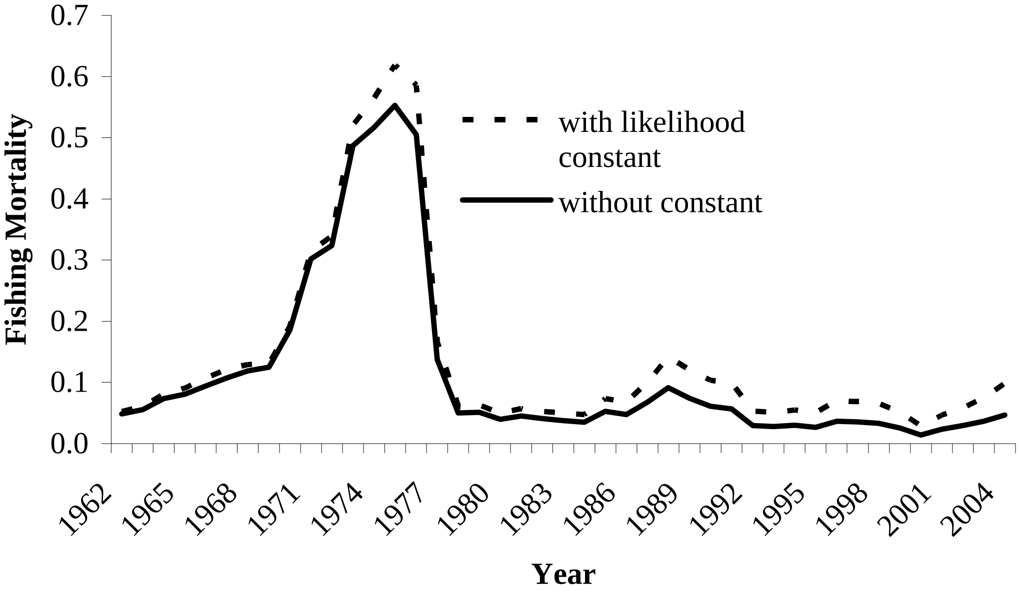

Figure 4. Comparison of F estimates between ASAP model with and without use of likelihood constant.

Table 1. Comparison between SAW 42 and TRAC catch and total catch at age.

| | 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 |

# Working Paper A

## Development of ASAP model using a U.S.A. and Canadian catch at age matrix through 2008

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Catch at age data from 1962 through 2008 approved at the October TRAC meeting were added to the previous ASAP model input (Table A1). The previous assessment model configuration, following the addition of 2005-2008 catch and indices at age, served as the basis for model comparison. The updated SAW42 model included ages through 7+, a catch series beginning in 1962 and NEFSC spring bottom trawl survey indices at age beginning in 1968. The survey indices were split into two series between 1984 and 1985. Selectivity in the catch was 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 (US and Canada), starting years in the catch series, estimation of selectivity, periods of changes in selectivity and fixed steepness values in stock-recruitment. Results of various model runs are summarized in Table A2. The diagnostics examined included the fit to indices at age and total catch, residual patterns, retrospective patterns, selectivity patterns and the objective function.

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 A1). 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 standard ASAP model incorporated 2 fleets (US 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. Total CV for the US fleet was 0.1 until 1982, 0.05 from 1982 to 1989 then 0.01. Since the Canadian catch is 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 was fixed at 0.6 in the model (corresponding to a $SPR_{40\%}$(Brooks et al. 2009)). Results show fishing mortality peaked at 0.79 in 1974 then decreased to 0.08 by 1978. F remained less than 0.1 until 1996 when it began increasing, peaking at 0.67 in 2006. F in 2008 was 0.49 (0.195 in US 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. Abundance in 2008 was 733 million fish. SSB peaked in 1985 at 1.32 million mt and steadily declined thereafter, reaching a low in 2008 of 123,100 mt.

Although the basic fit with the ASAP model was reasonable, the results showed some patterned residuals, particularly in ages 1 and 2 of the early series and 10+ in the later series. In addition, retrospective patterns in fishing mortality persisted. The influence of the under-estimated Canadian catch on 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 A19). The model fit was heavily influenced by the steepness parameter chosen. If the stock-recruitment relationship were fit, the results were unrealistic, with steepness values 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 from Atlantic mackerel. The model estimates of F, abundance and SSB from the proposed configuration are very different than the SAW42 results. However, the 2004 retrospective estimate from the current model corresponds to the 2004 SAW 42 estimates. Finally, the results of the model are dependent on the existence of a split survey series and the associated q's which vary greatly between series (Table A3). Further discussion of this issue is presented in WP B.

## Literature cited

Brooks, E. N., Powers, J. E., and Corte´s, E. 2010. Analytical reference points for age-structured models: application to data-poor fisheries. ICES Journal of Marine Science, 67: 165–175.

Figure A1. Fully recruited fishing mortality of Atlantic mackerel for combined U.S.A and Canadian fleets from ASAP model.

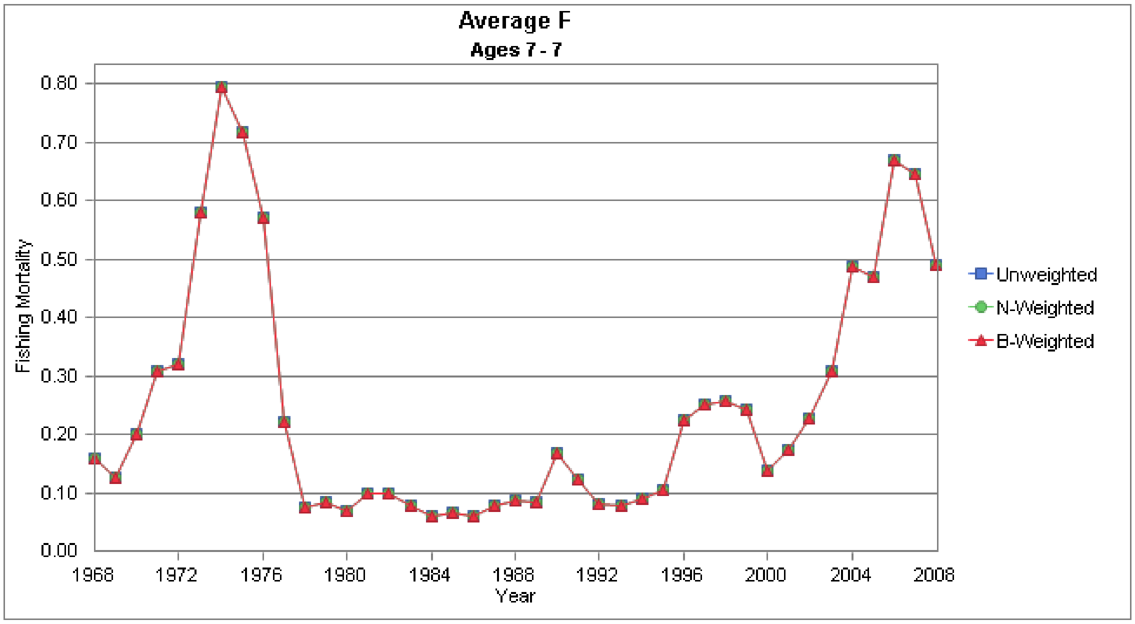


Figure A2. Selectivity at age from ASAP modeled as a logistic function for US and Canadian catch at age.

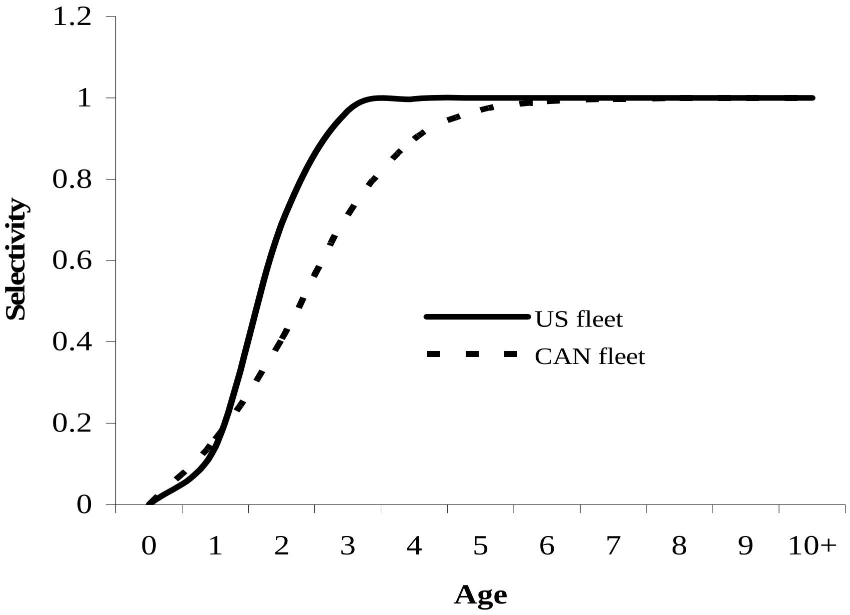


Figure A3. Total abundance (millions) of Atlantic mackerel for combined U.S.A and Canadian fleets from ASAP model.

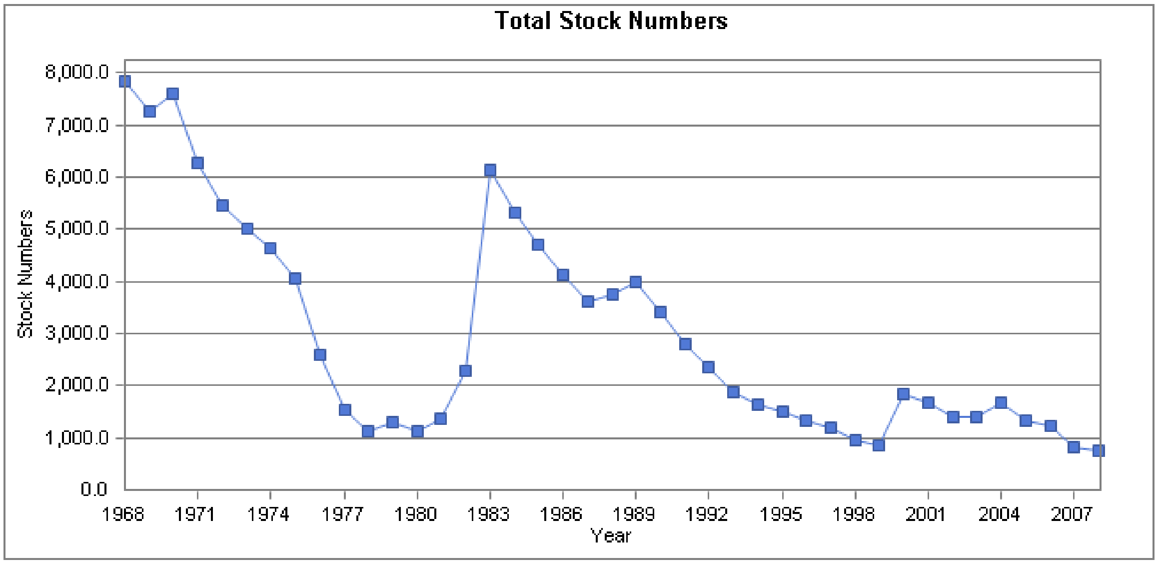


Figure A4. Spawning stock biomass (000s mt) of Atlantic mackerel for combined U.S.A and Canadian fleets from ASAP model.

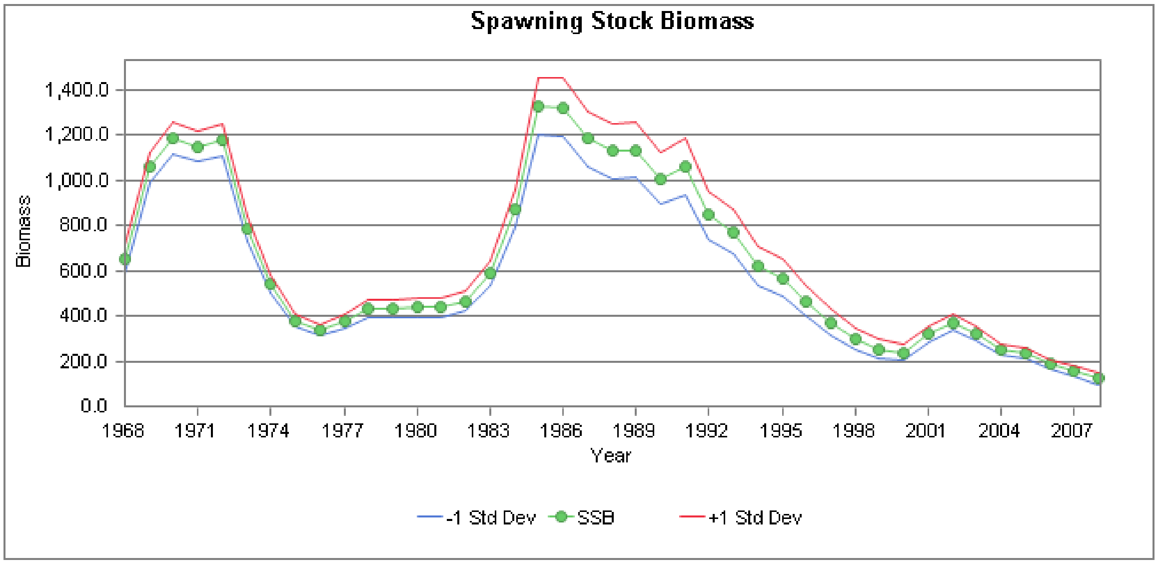


Figure A5. Estimated age 1 recruitment (millions) of Atlantic mackerel for combined USA and Canadian fleets from ASAP model.

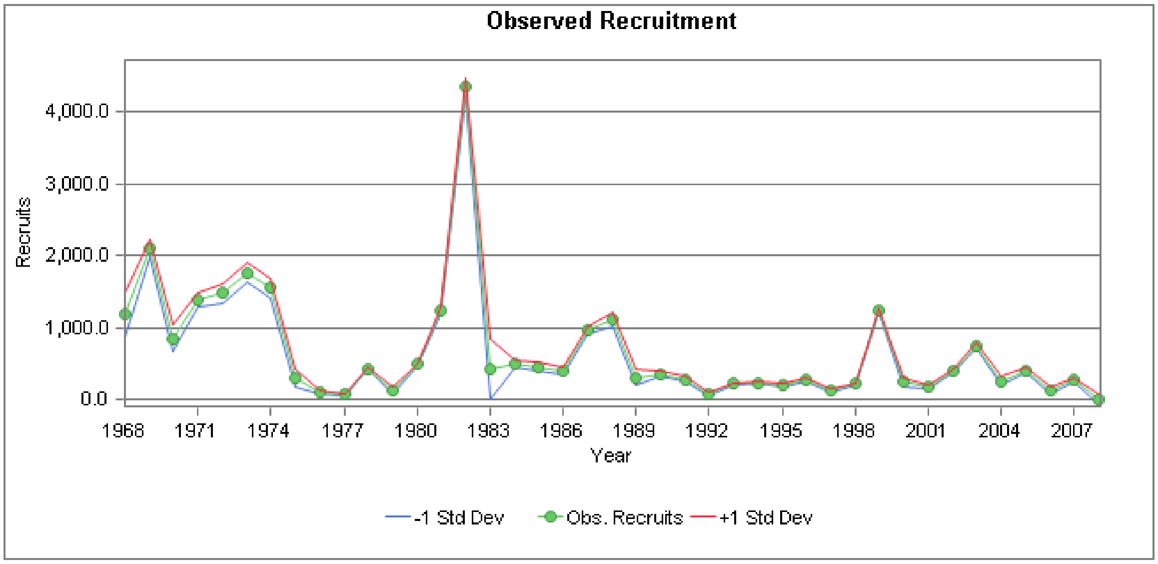


Figure A6. Comparison of ASAP model observed and predicted annual catch (000s mt) for USA fleet.

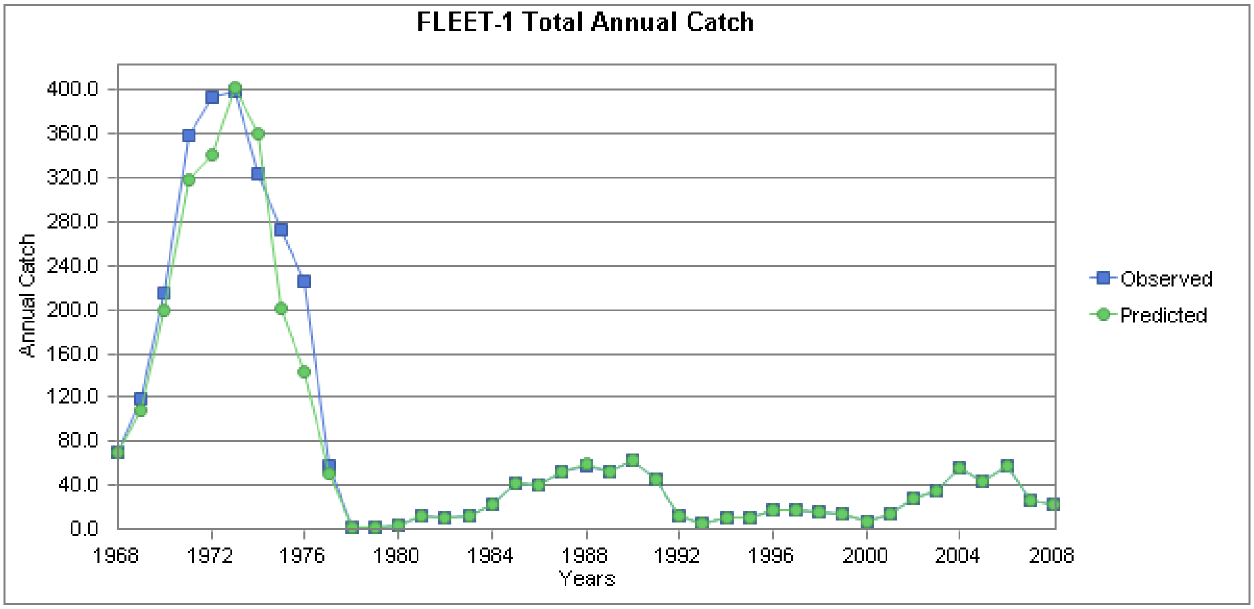


Figure A7. Comparison of ASAP model observed and predicted annual catch (000s mt) for Canadian fleet.

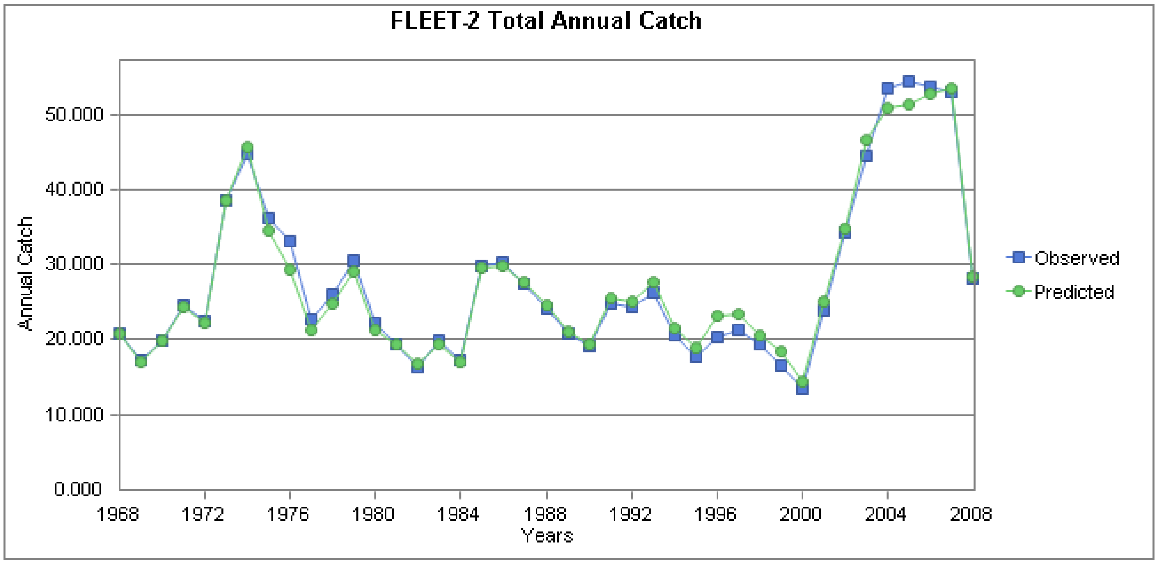
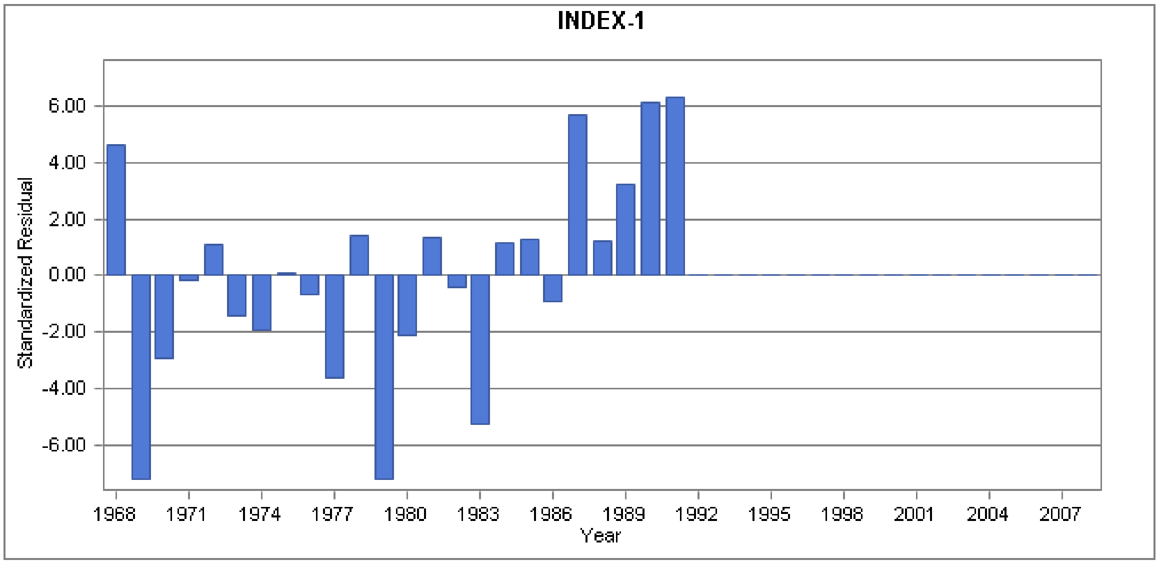
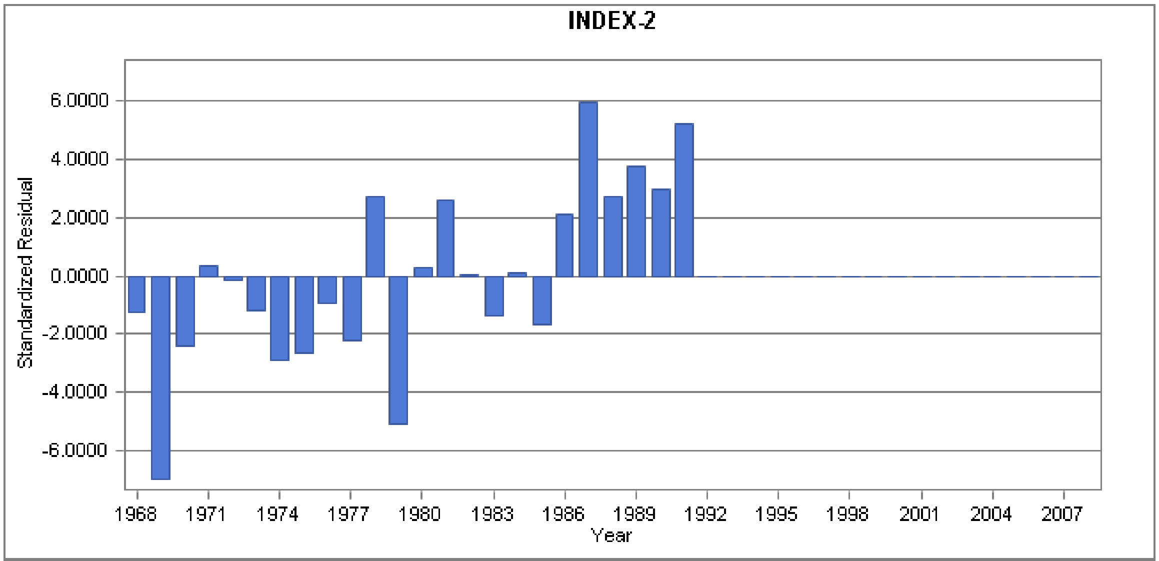


Figure A8. Standardized residuals for survey indices for 1968-1991, ages 1-10+ (indices 1-10), and 1992-2008, ages 1-10+ (indices 11-20).

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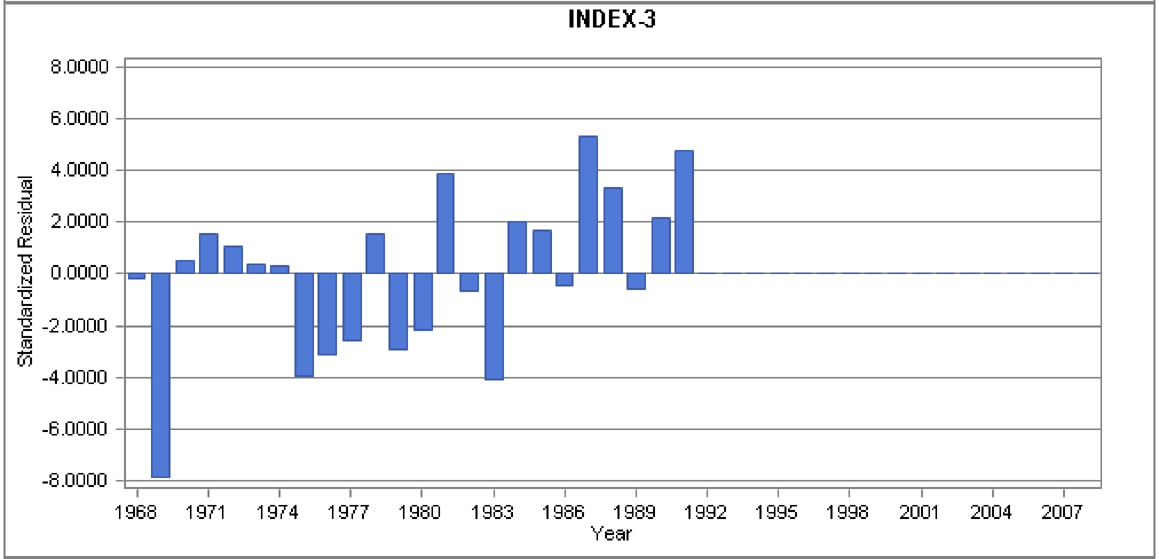
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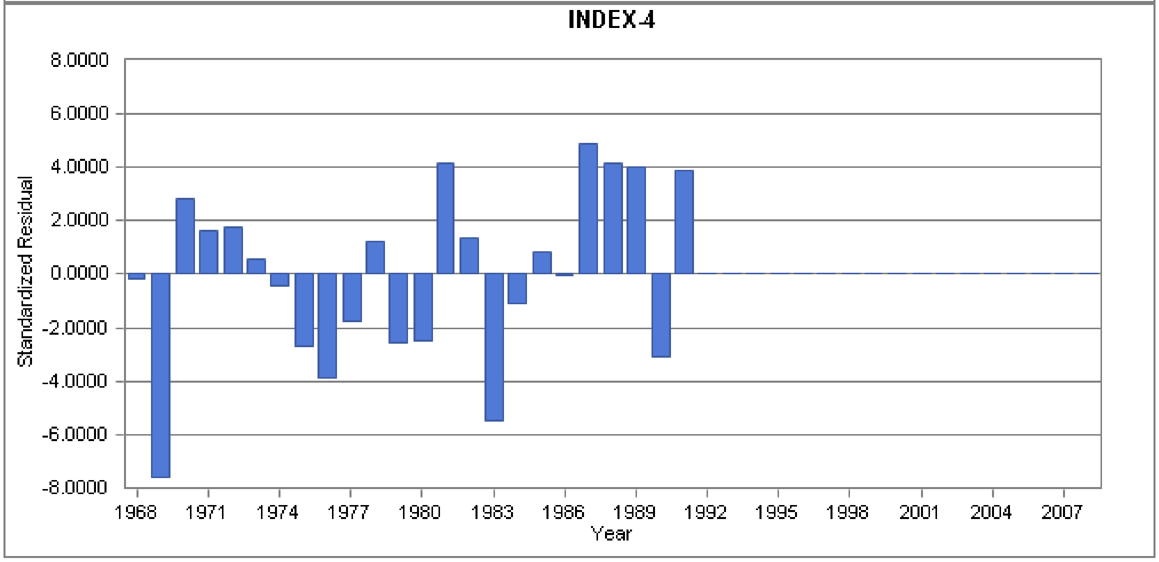
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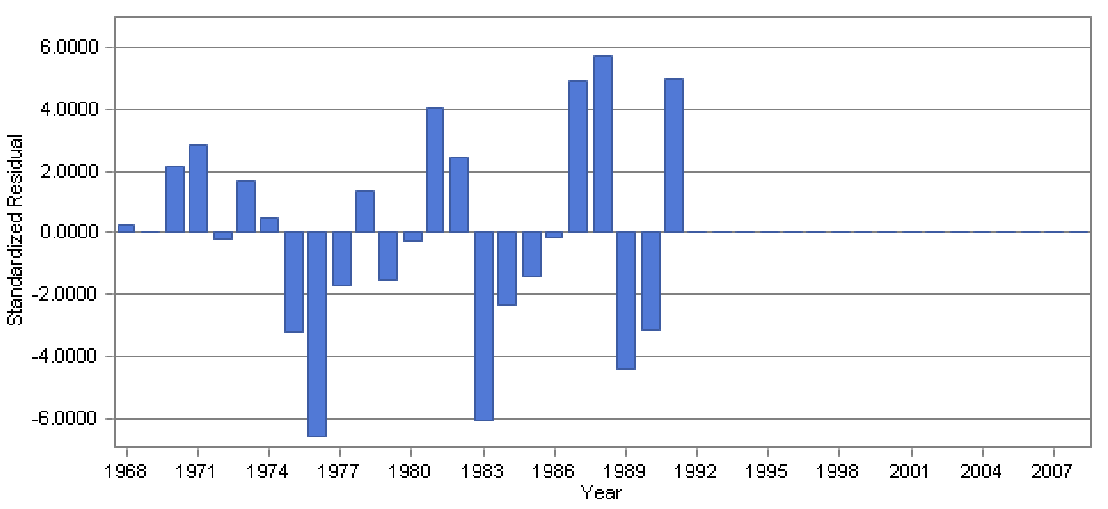
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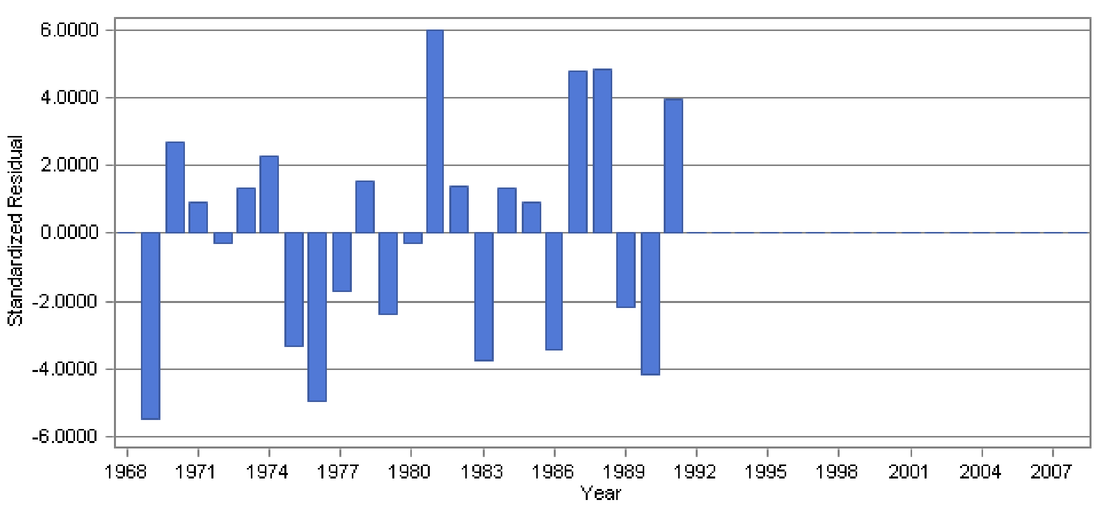
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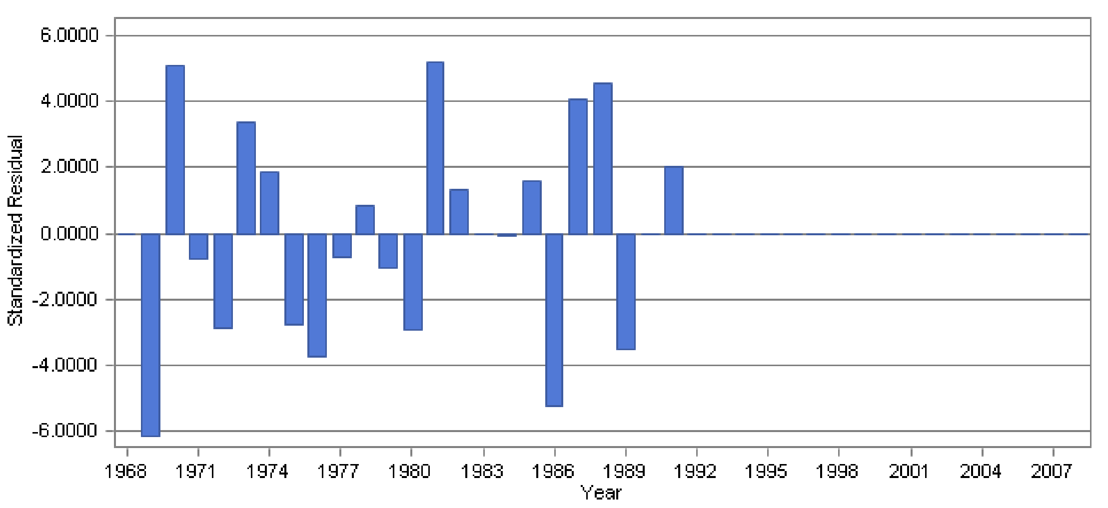
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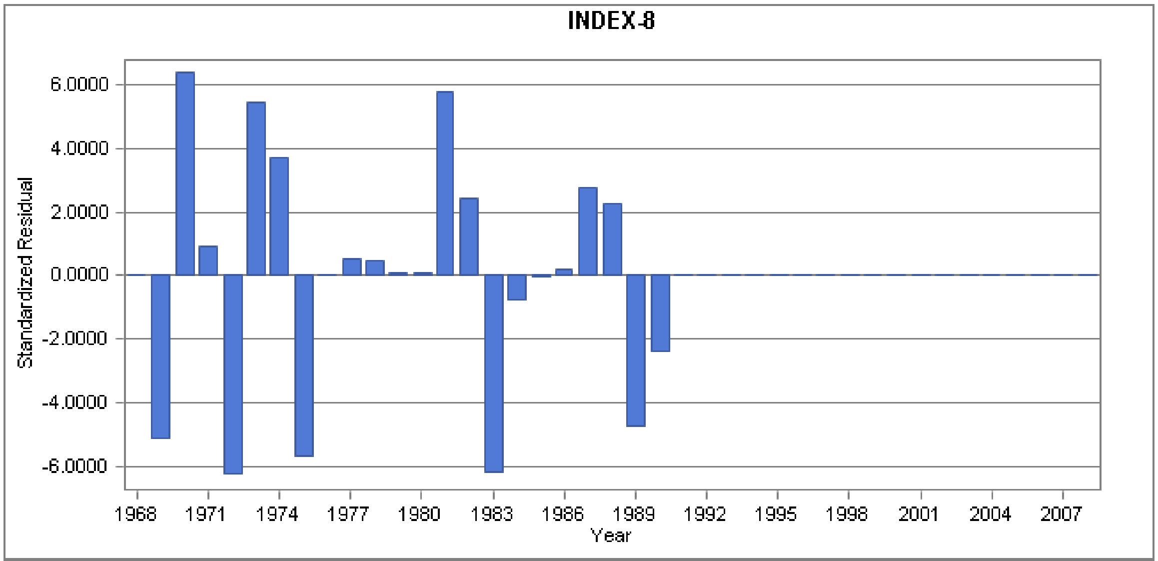

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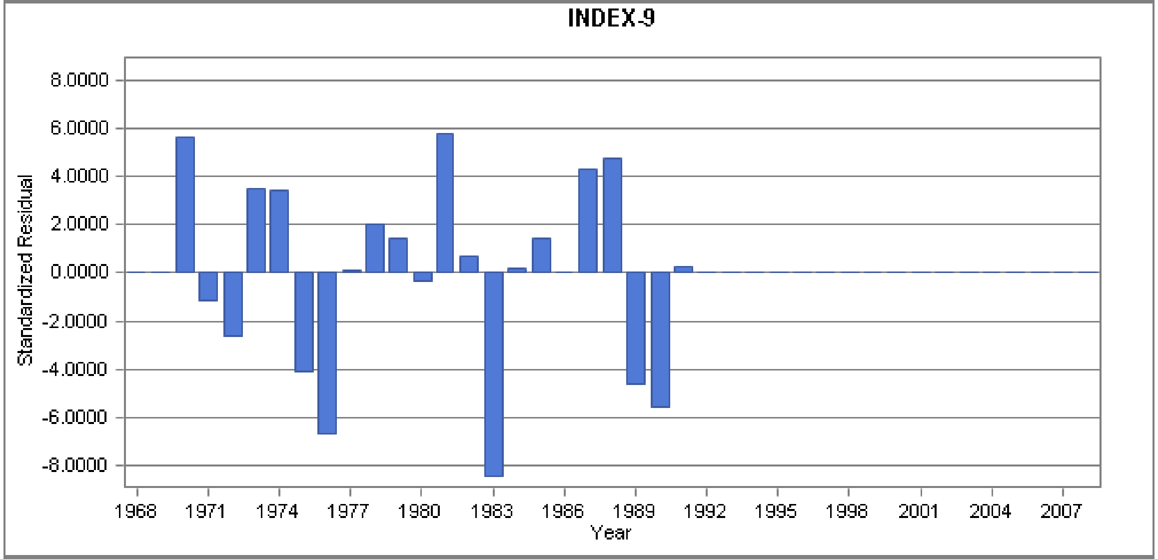

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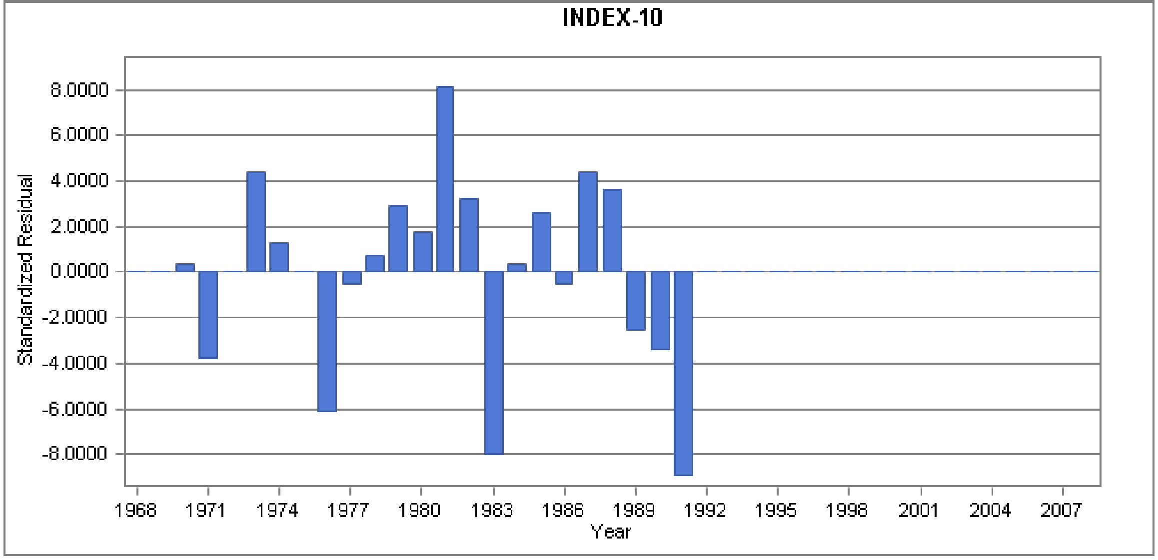

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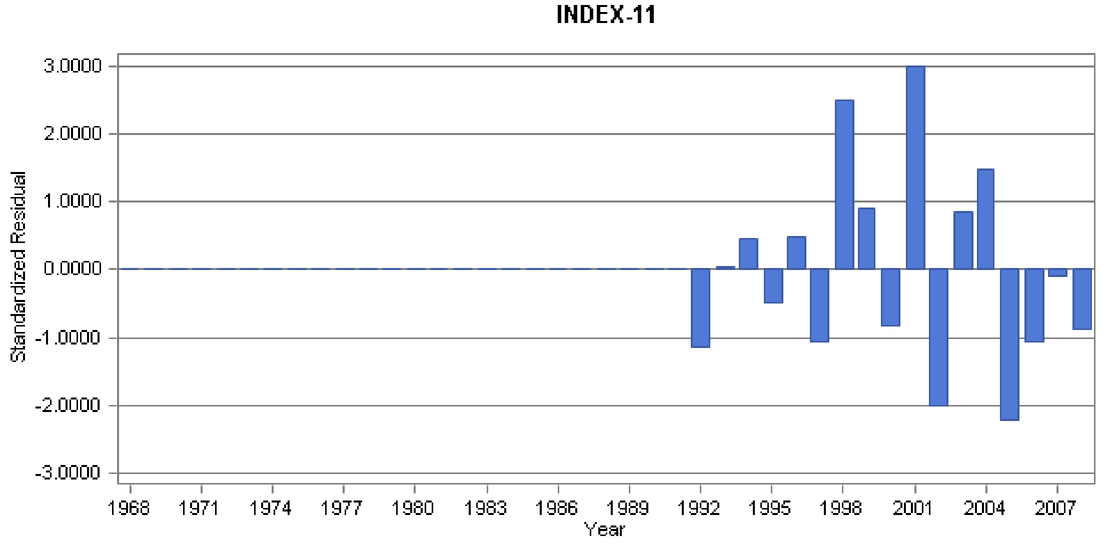
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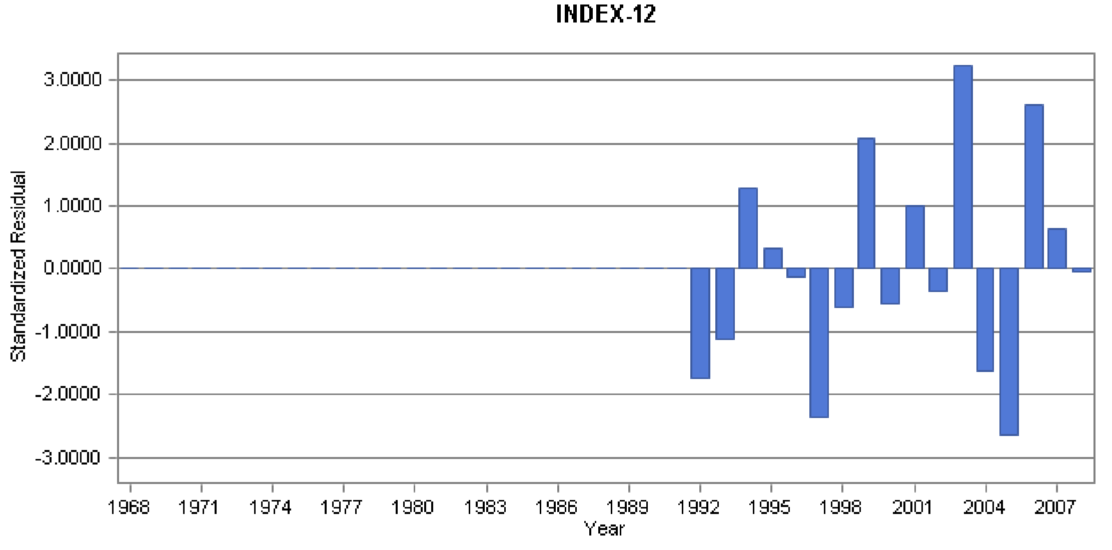
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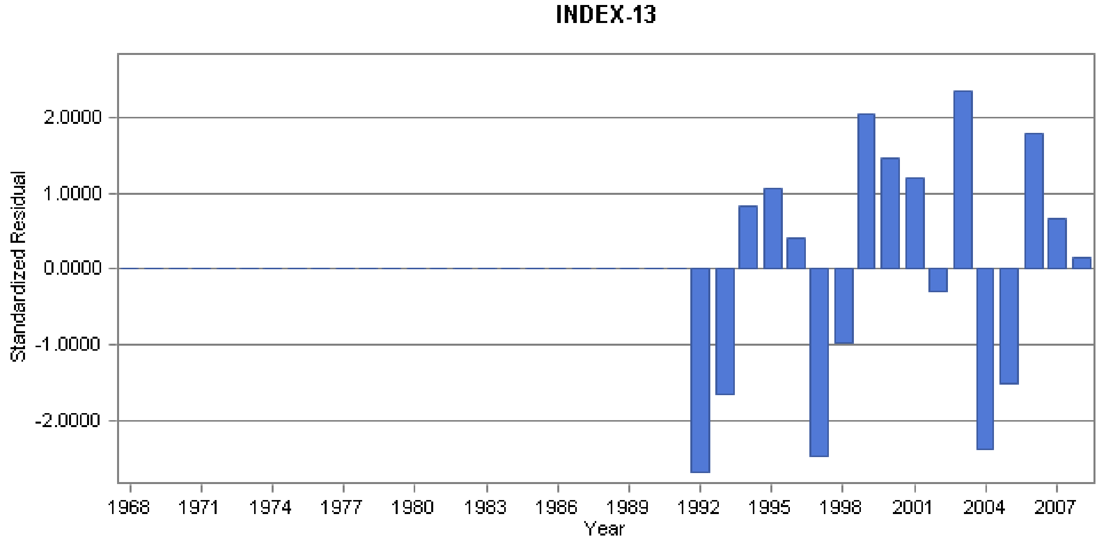
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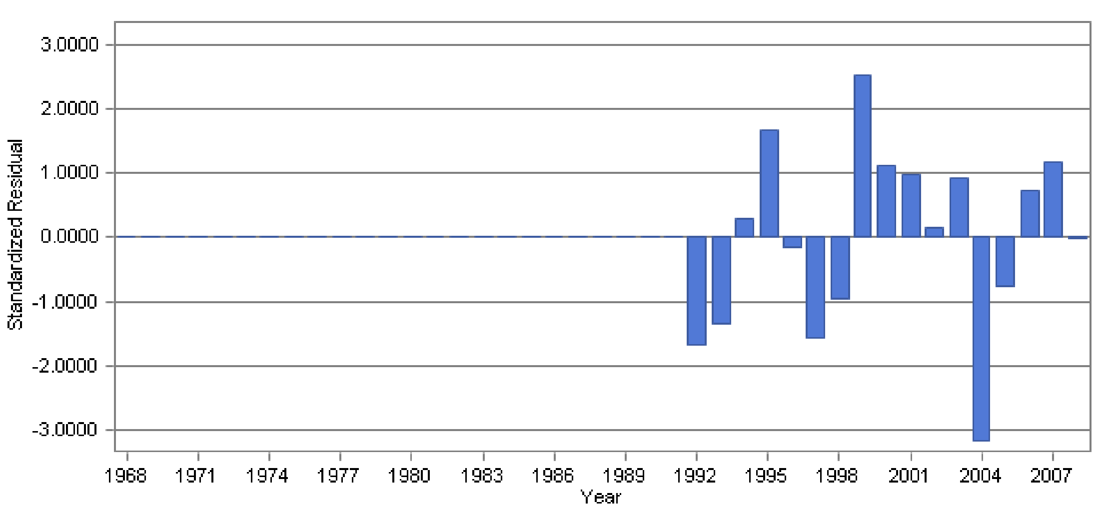

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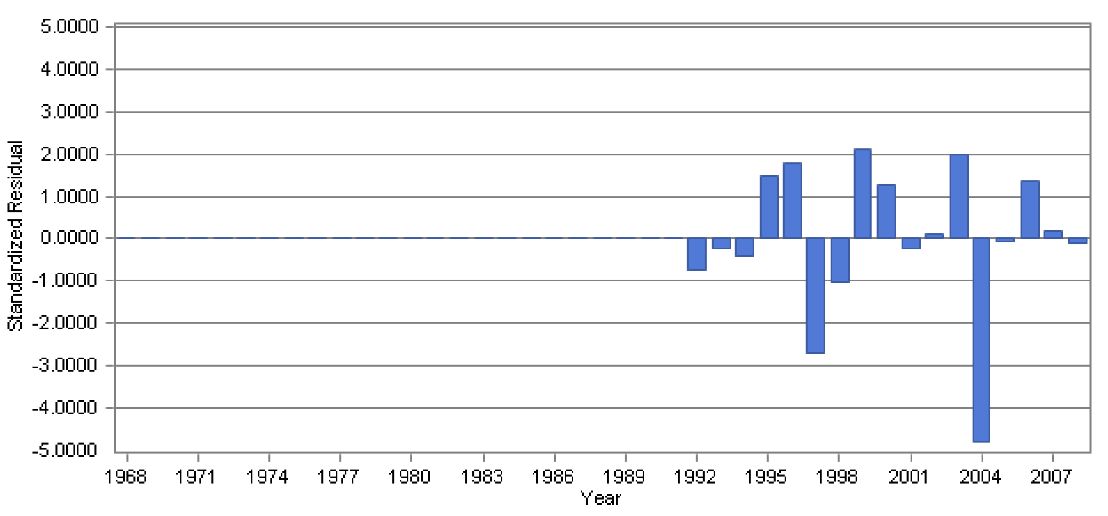

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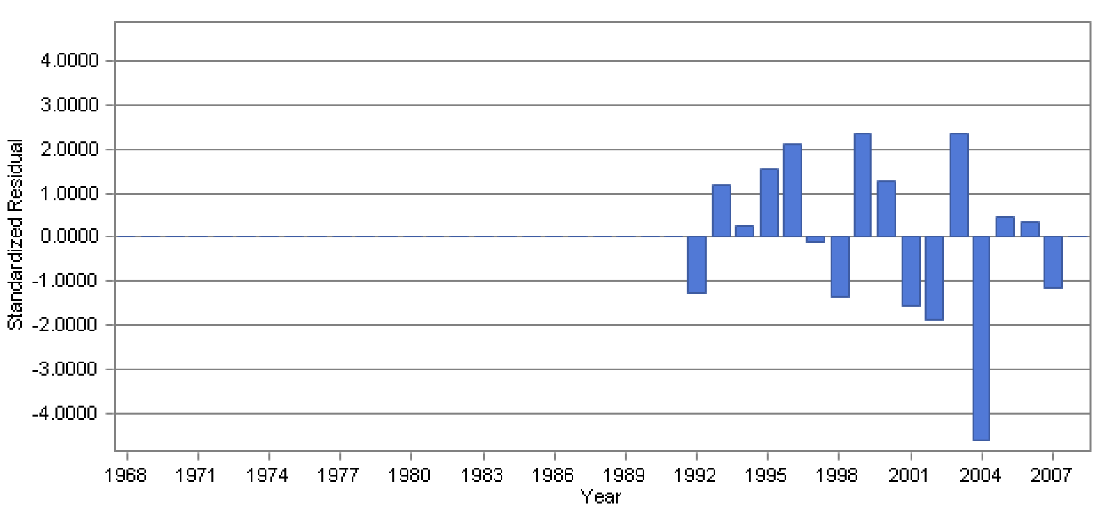

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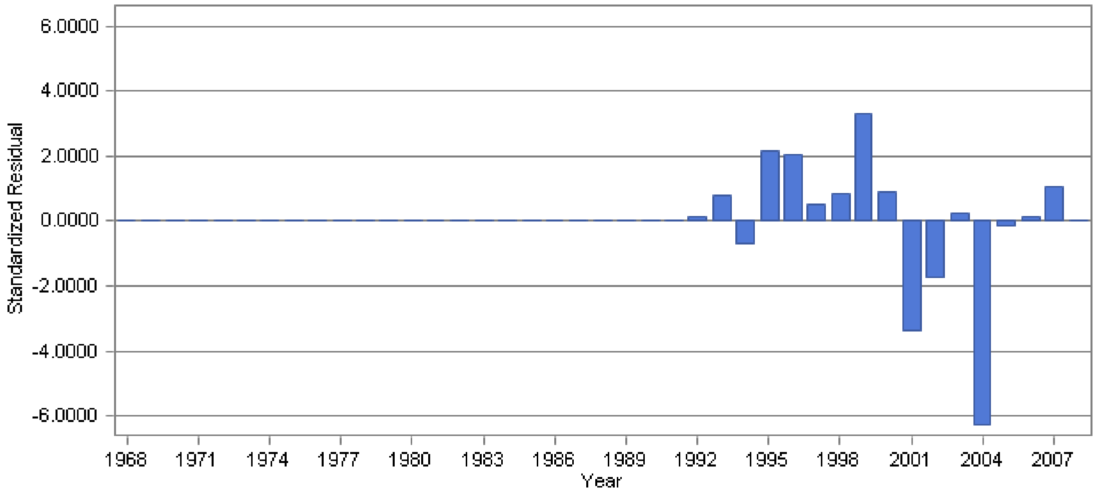

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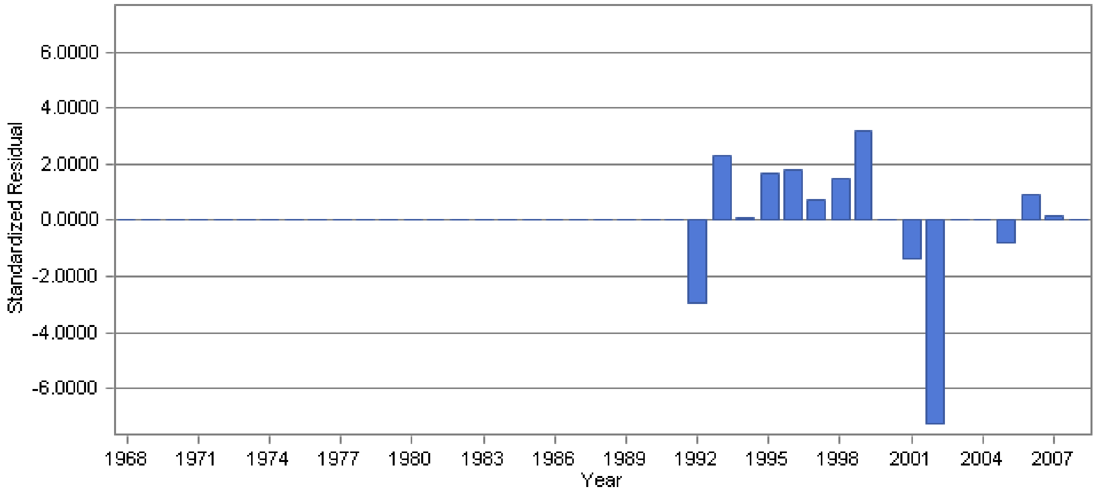

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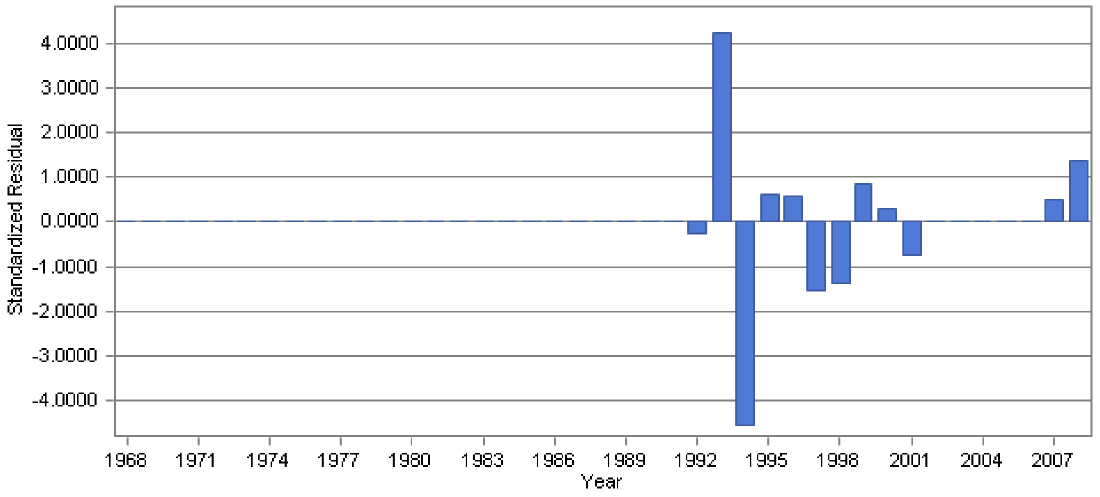


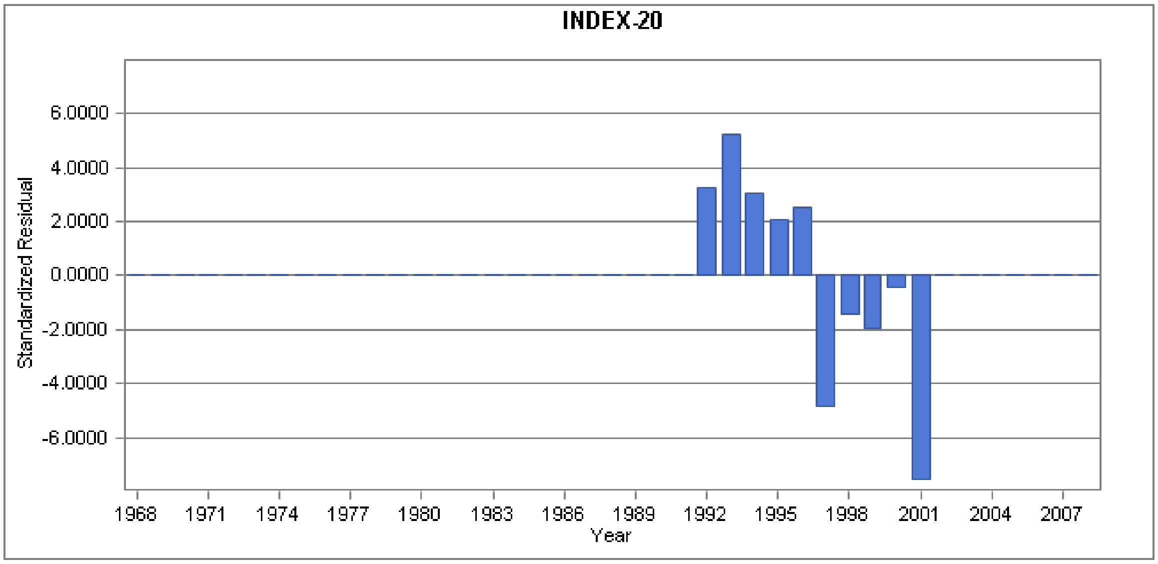


Figure A9.Effective sample size, input and estimated, for USA fleet.

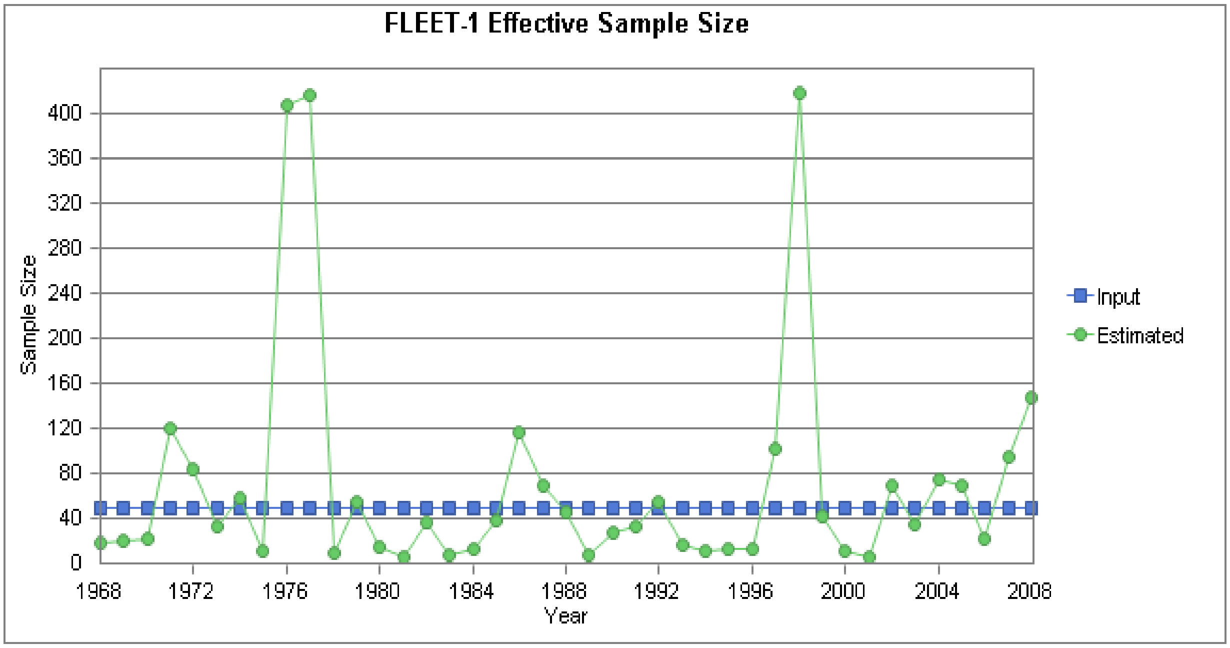


Figure A10.Effective sample size, input and estimated, for Canadian fleet.

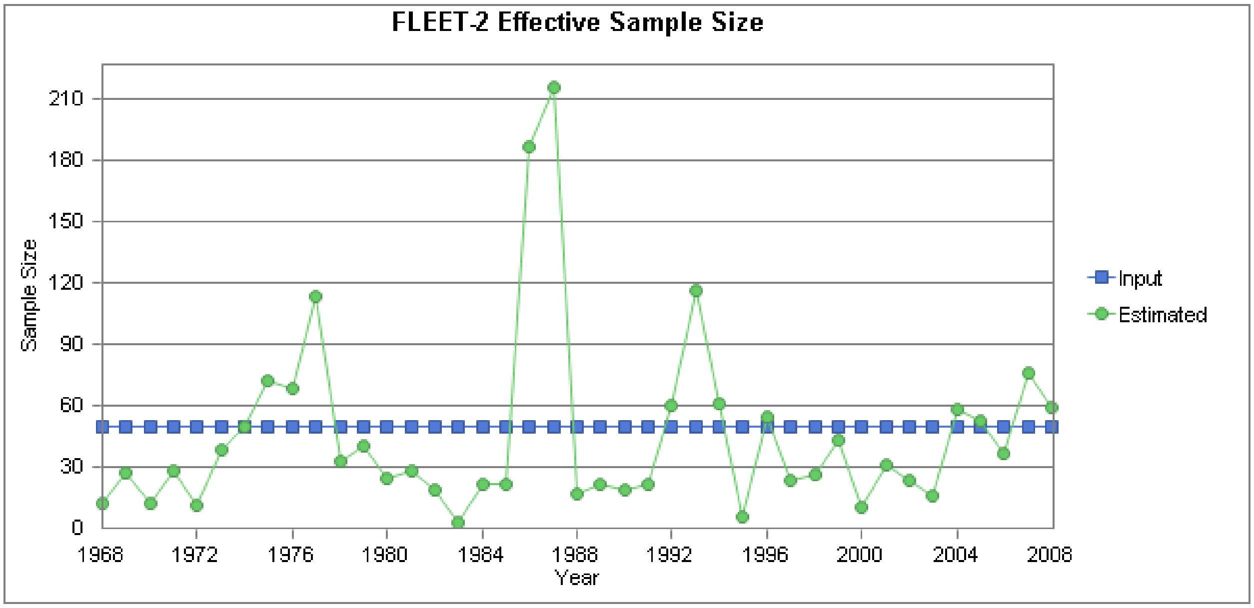
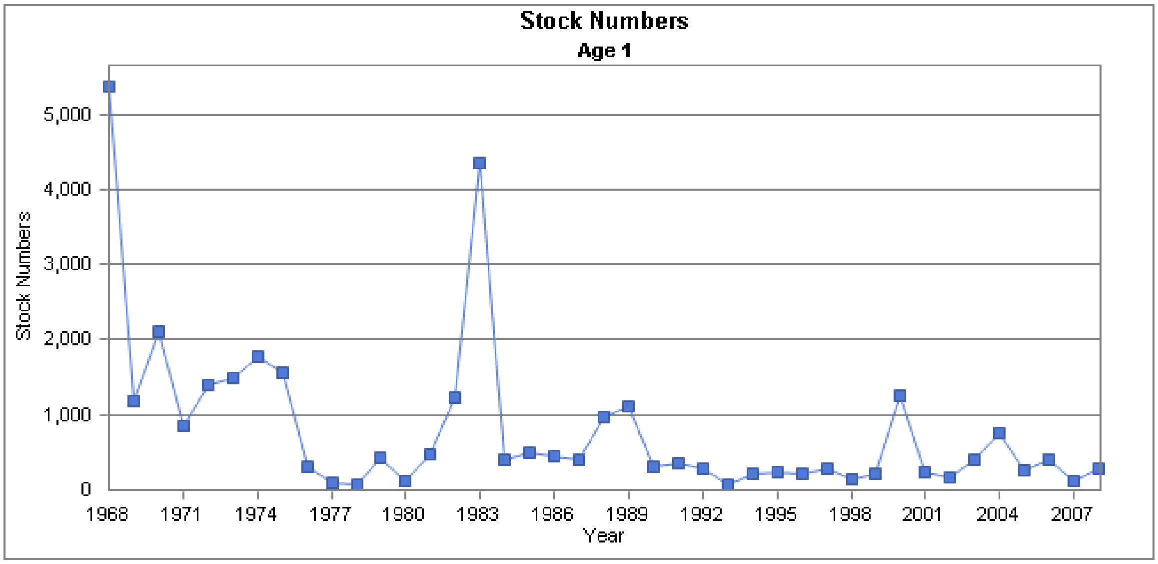
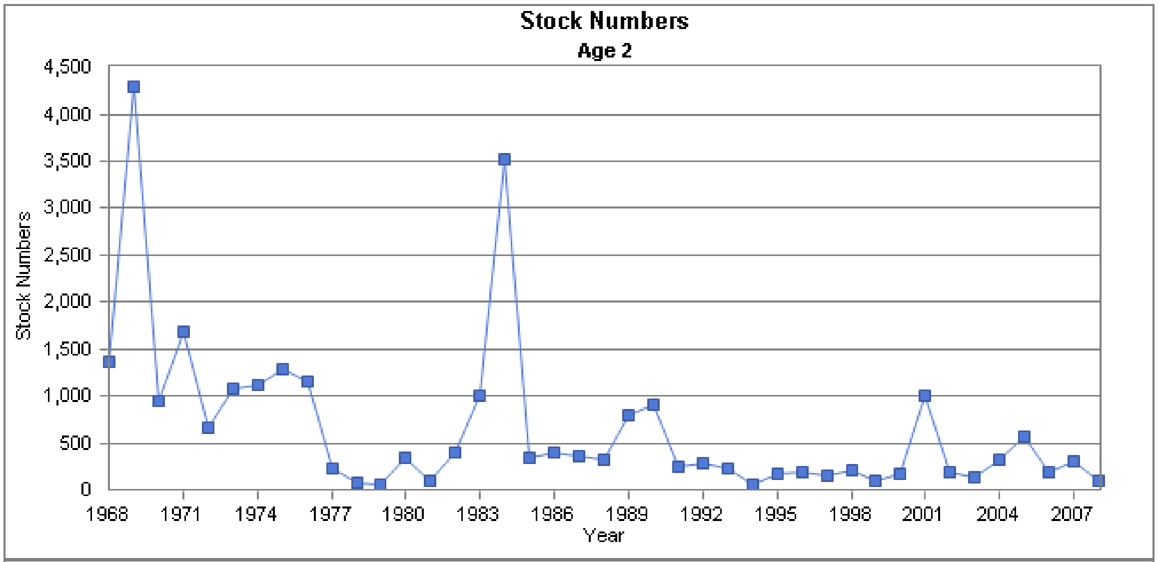
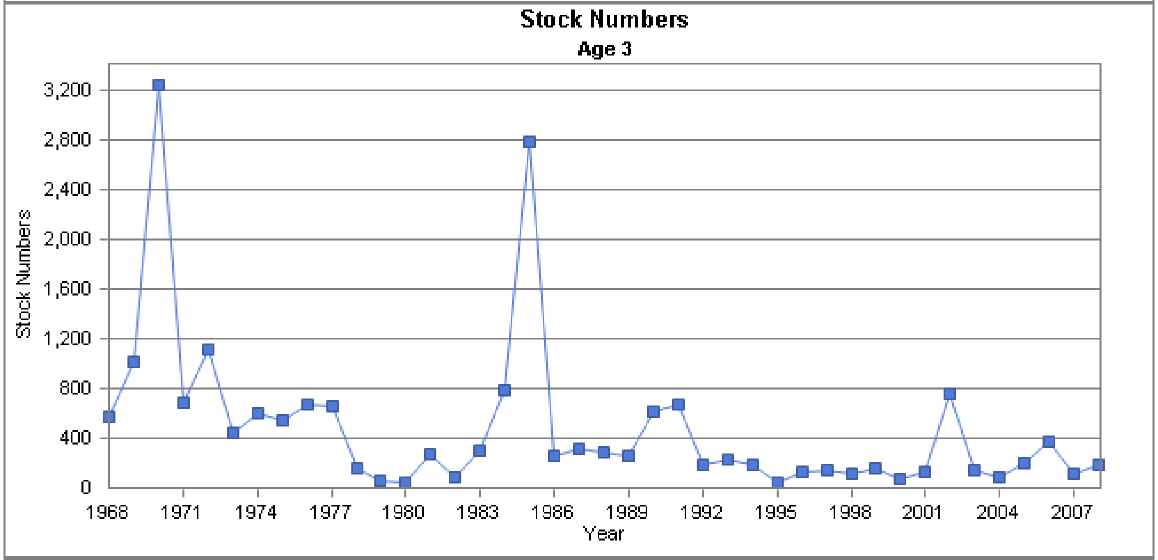
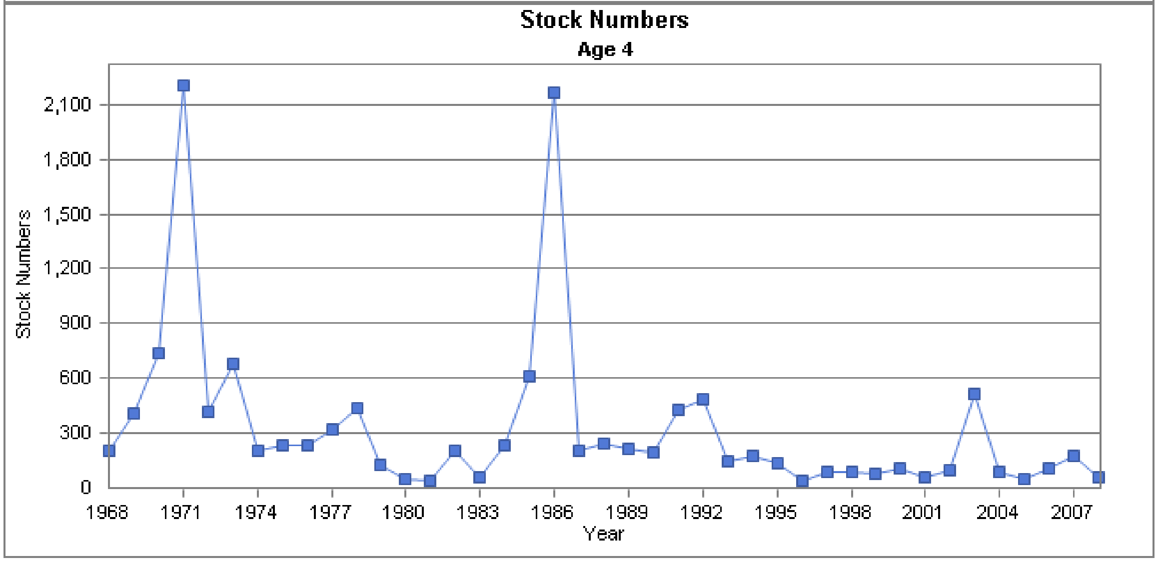


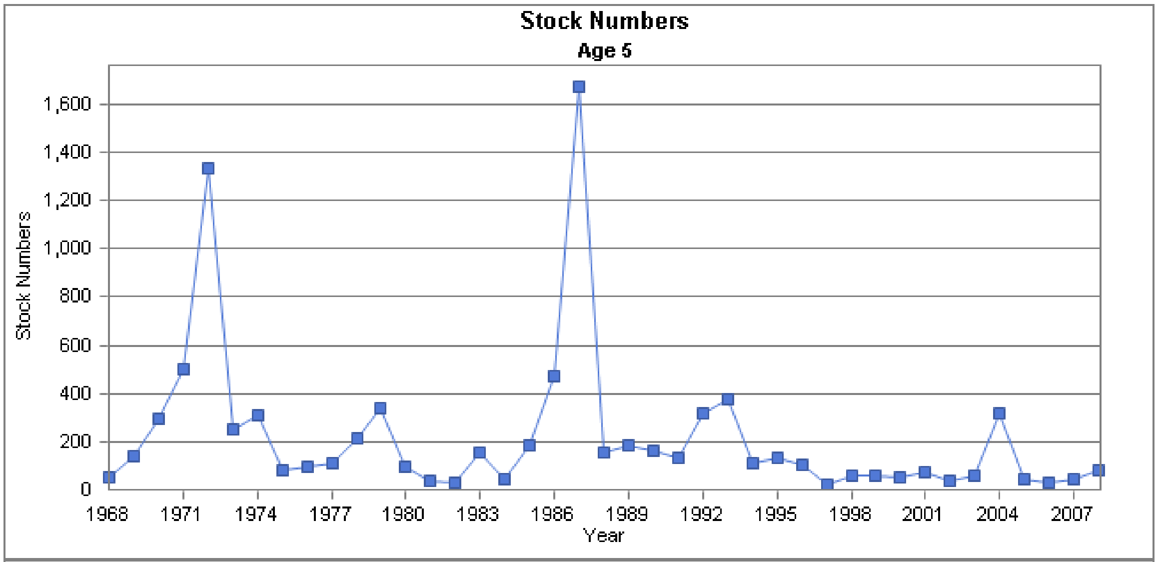
Figure A11. Estimated Atlantic mackerel stock size (millions), by age, from ASAP model.

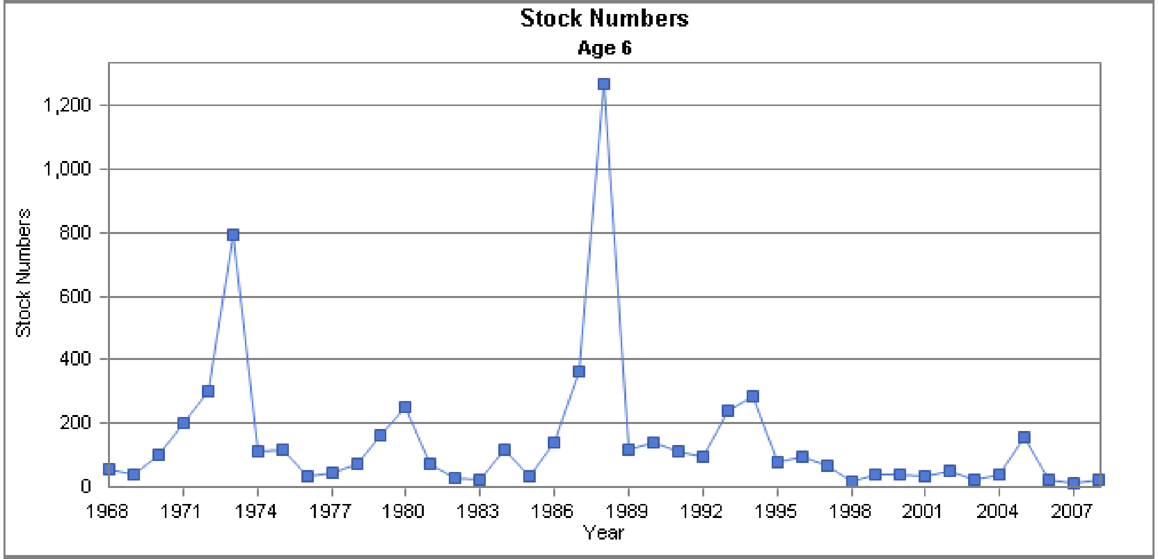


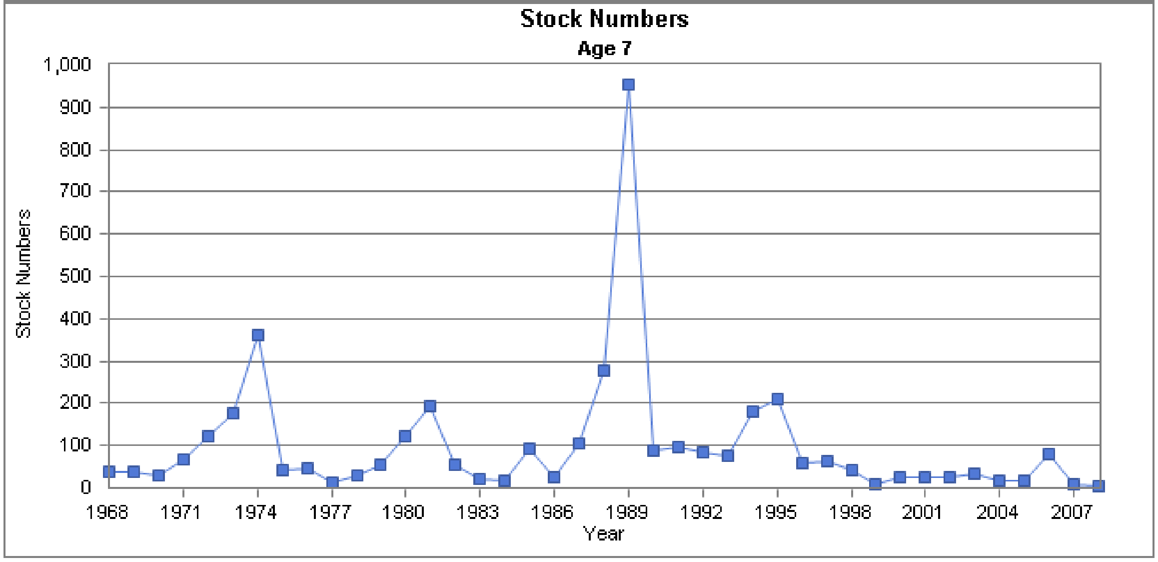

Stock Numbers
Age 2

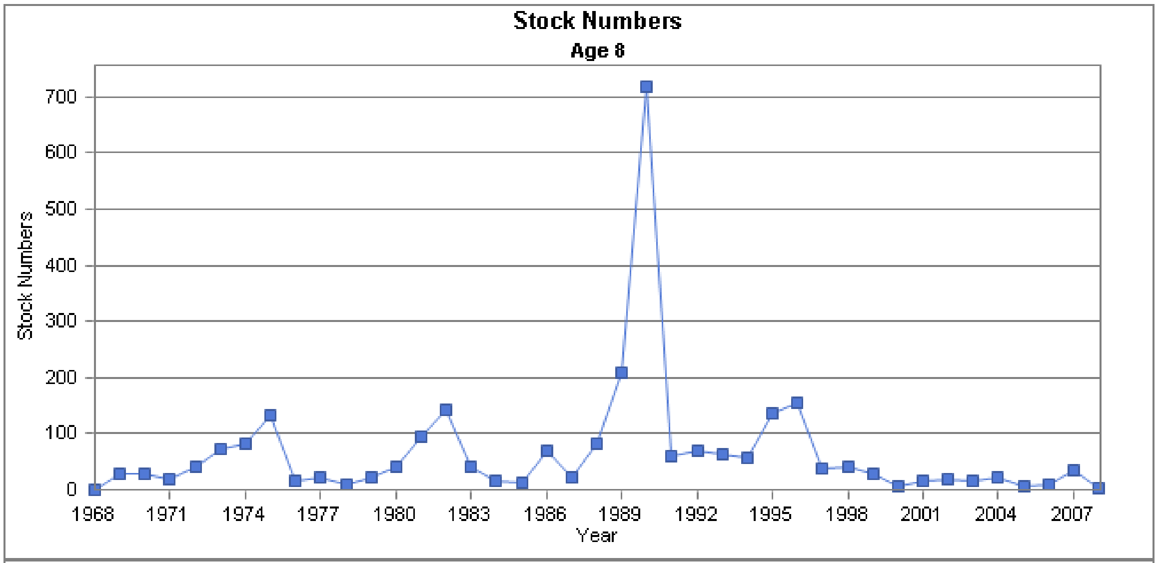

Stock Numbers
Age 3

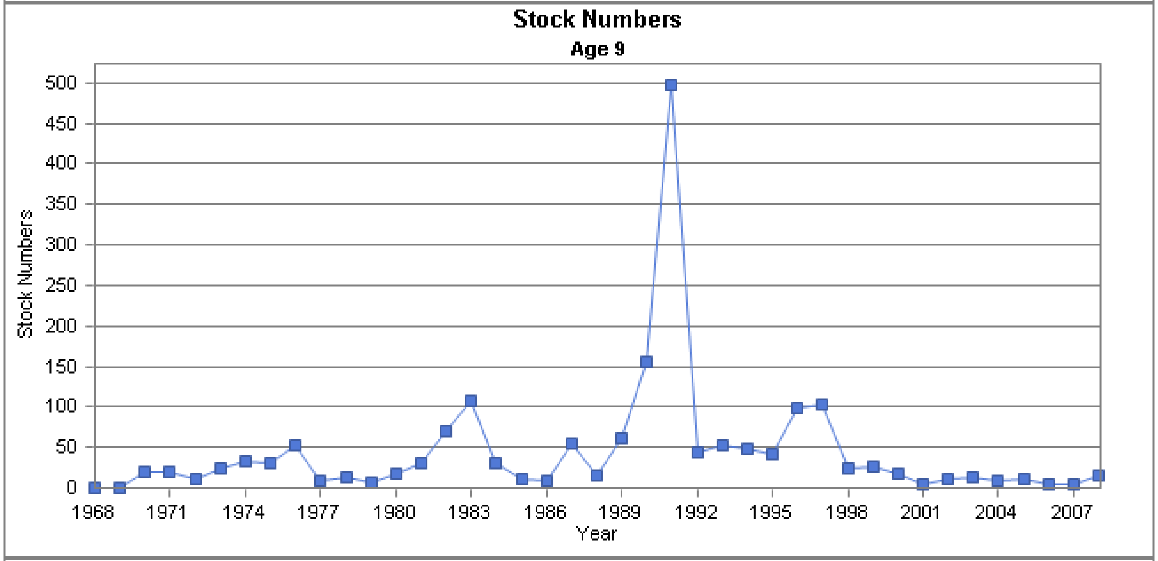

Stock Numbers
Age 4


Stock Numbers
Age 5
Stock Numbers
1,600
1,400
1,200
1,000
800
600
400
200
0
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year


Stock Numbers
Age 6
Stock Numbers
1,200
1,000
800
600
400
200
0
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year


Stock Numbers
Age 7
Stock Numbers
1,000
900
800
700
600
500
400
300
200
100
0
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year


Stock Numbers
Age 8
Stock Numbers
700
600
500
400
300
200
100
0
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year


Stock Numbers
Age 9
Stock Numbers
500
450
400
350
300
250
200
150
100
50
0
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year

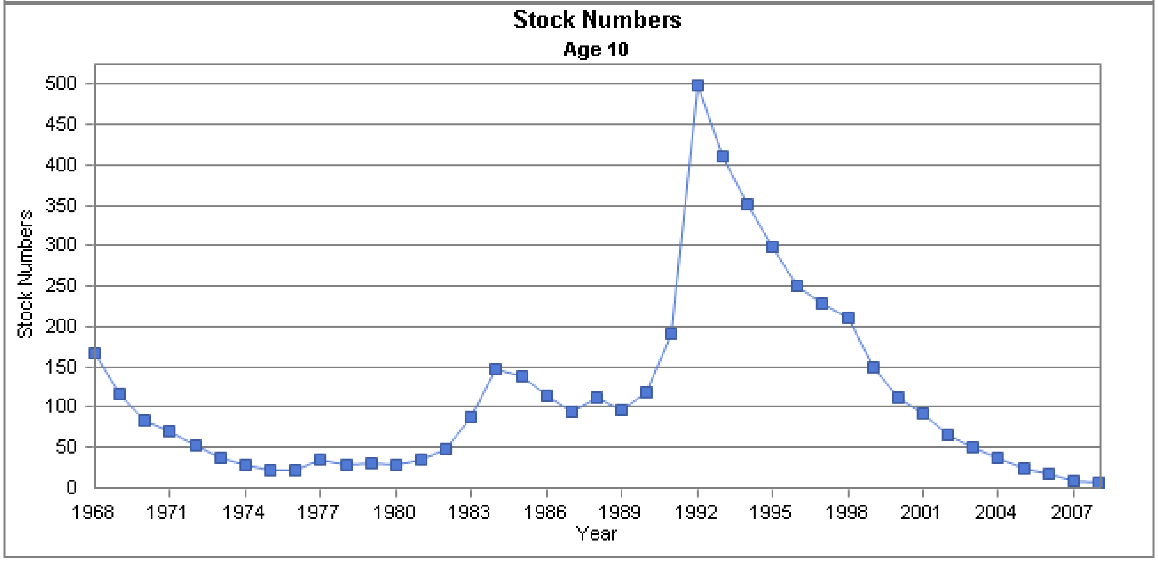

Stock Numbers
Age 10
Stock Numbers
500
450
400
350
300
250
200
150
100
50
0
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year

Figure A12. ASAP model objective function components.

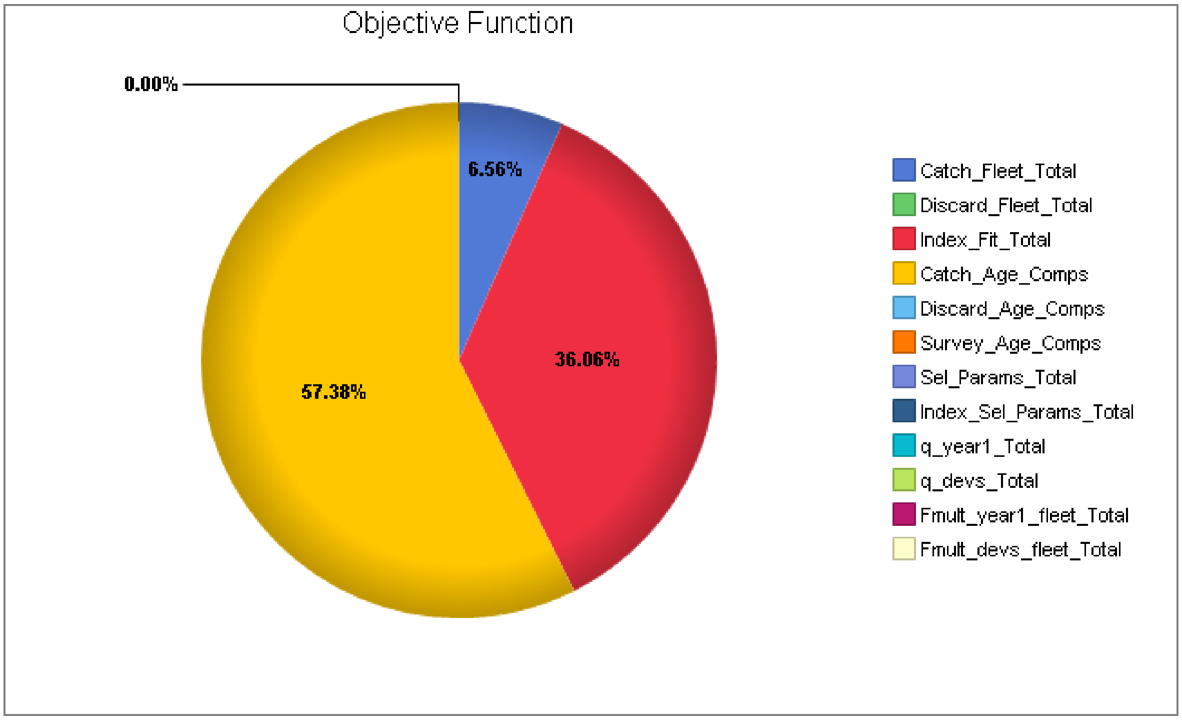


Figure A13. Retrospective pattern of average F.

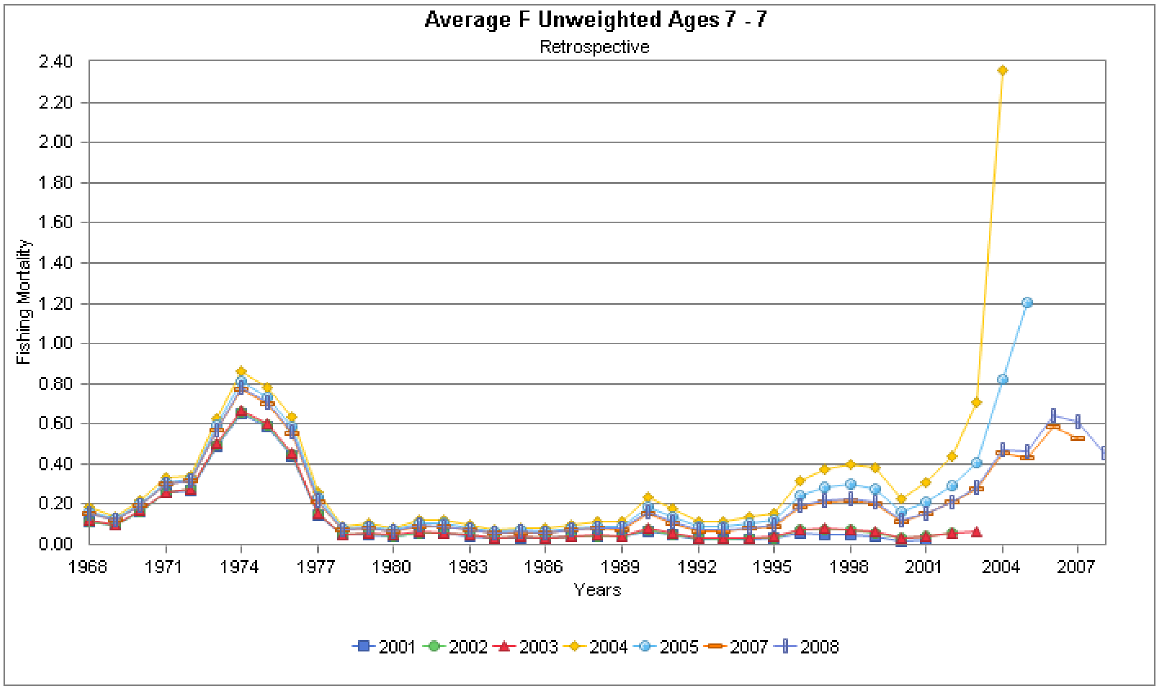


Figure A14. Standardized retrospective pattern of average F.

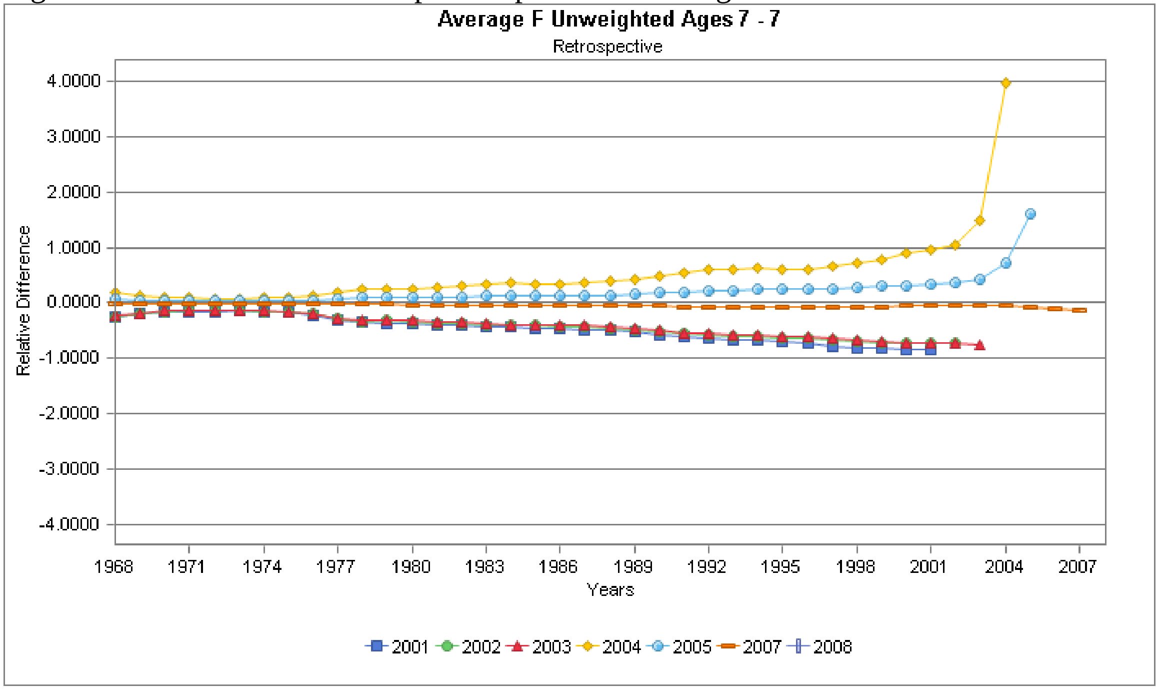


Figure A15. Retrospective pattern of spawning stock biomass (000s mt).

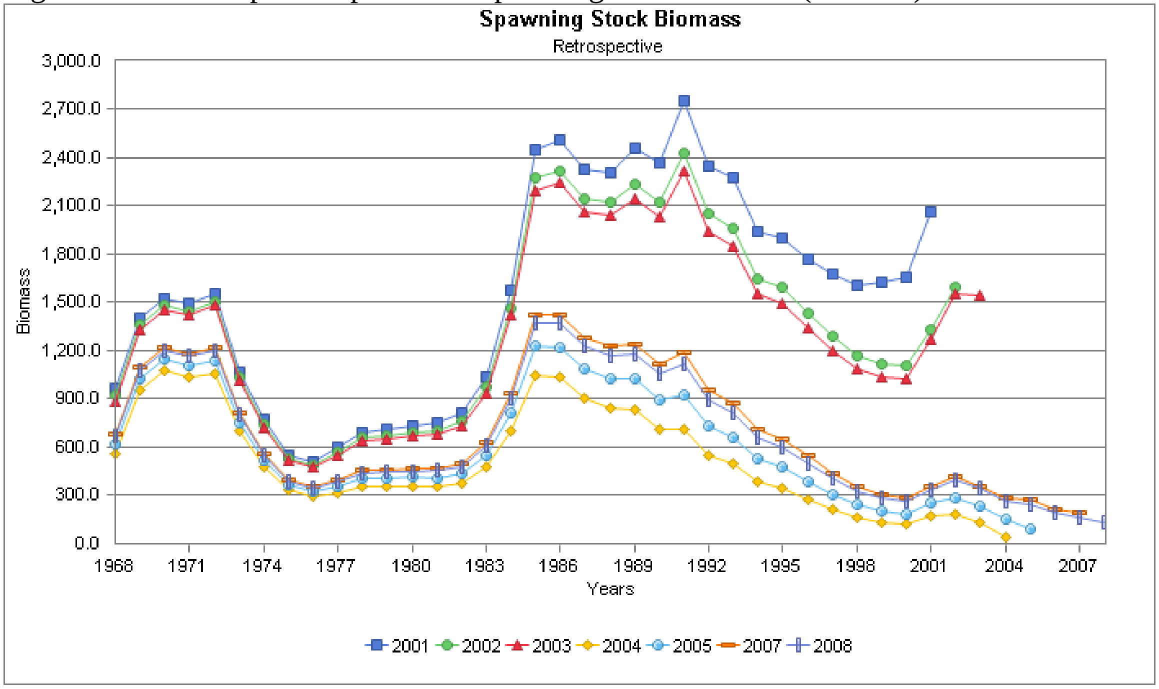


Figure A16. Standardized retrospective pattern of spawning stock biomass.

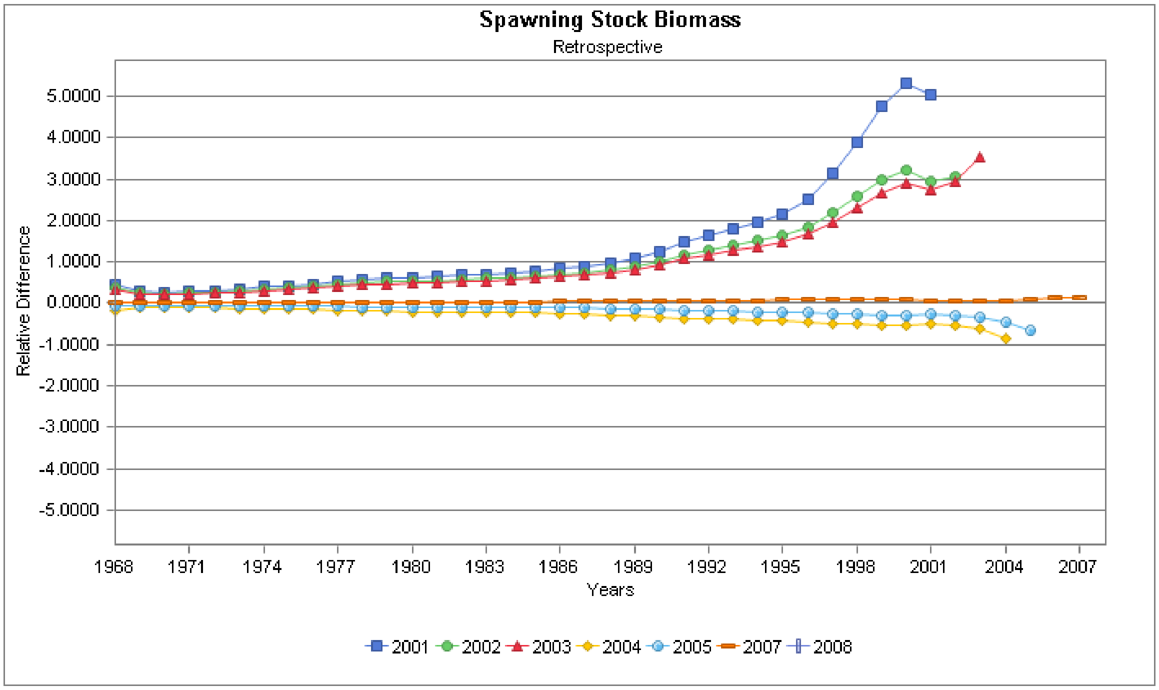


Figure A17. Retrospective pattern of total abundance (ages 1-10+, millions).

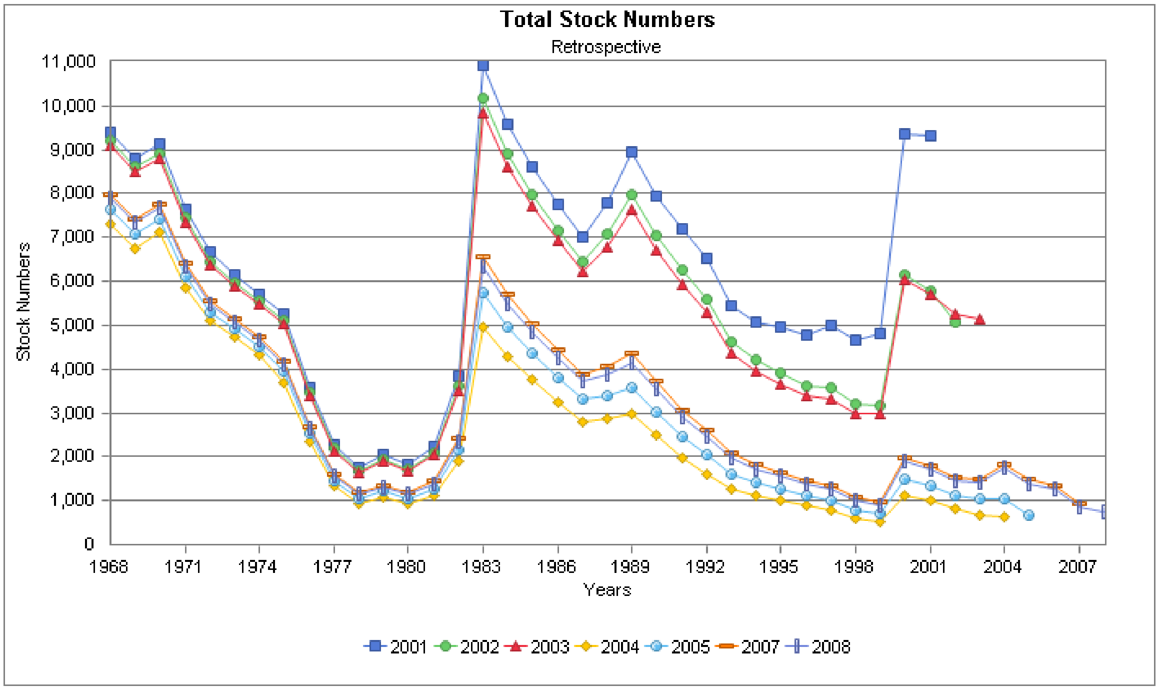


Figure A18. Standardized retrospective pattern of total abundance (ages 1-10+).

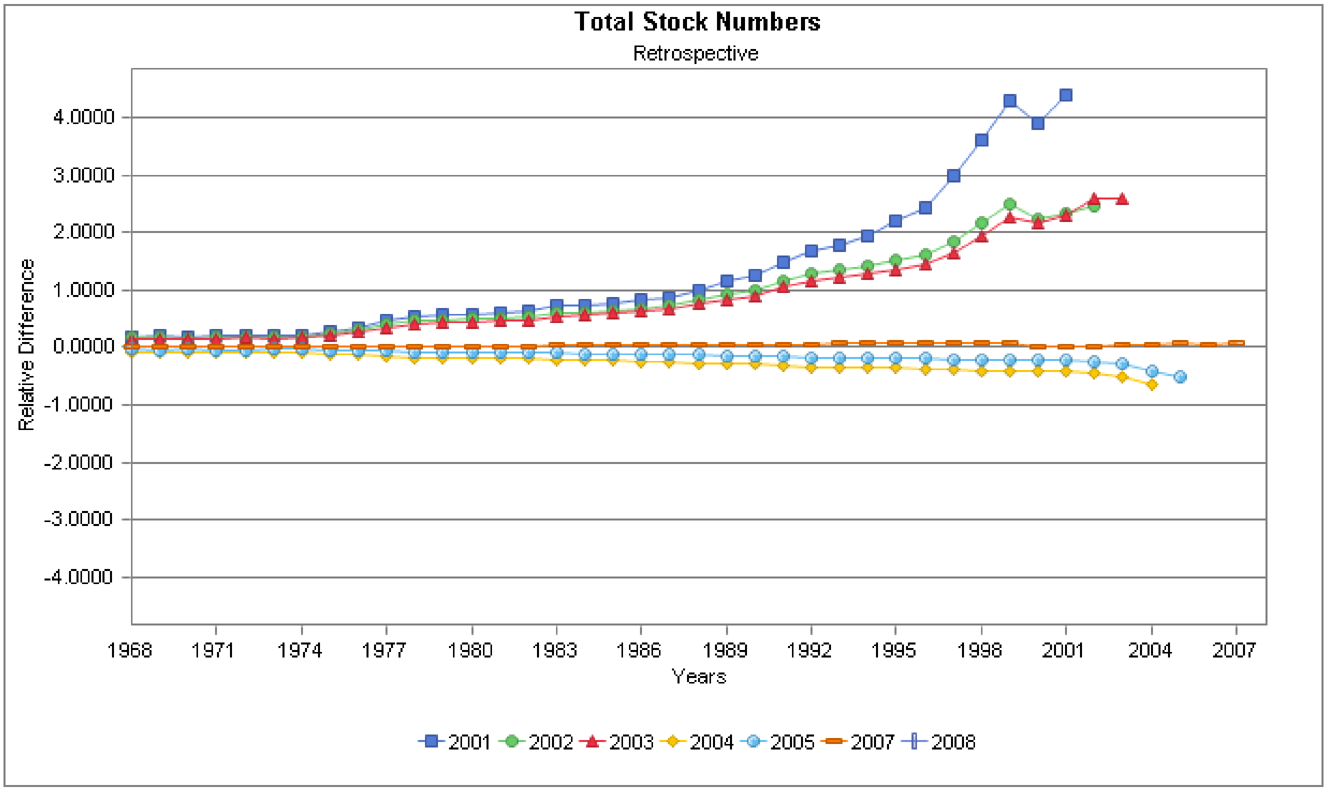
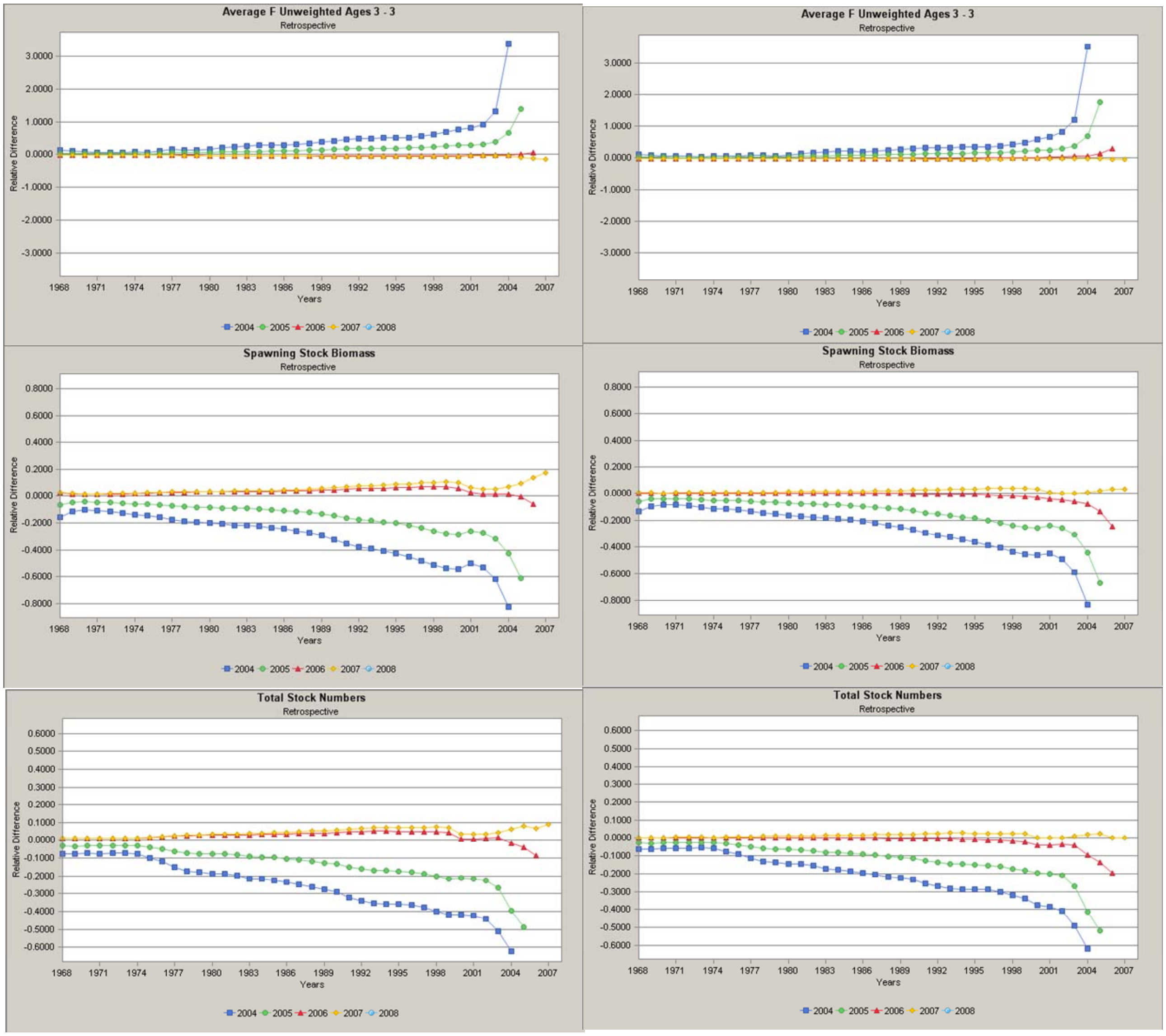


Figure A19. Effect of doubling Canadian mackerel catch on relative difference in retrospective pattern.



Retrospective base run

Retrospective with Canada catch x2

Table A1.Total catch at age (millions) of Atlantic mackerel (US and Canada combined) used in TRAC 2010.

| | 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 A2.  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 A2 continued.

| | | | Lambda 2 | | | Lambda 3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lambda 1 | | Recruitment | | Index | Catchability | Catchability | **Objective** | **terminal** | **terminal** | |
| | CV | ESS | CV | Deviations | lambda | lambda | CV | **Function** | **$F_1$** | **$F_2$** | comments |
| 1 | 0.01 | 50 | 0.5 | 1 | 0.912 | 0 | 0.9 | 4640.16 | 0.53 | | neg likelihood in catch_fleet total |
| 2 | 0.01 | 50 | 0.5 | 1 | 0.912 | 0 | 0.9 | 1837.37 | 0.48 | | |
| 3 | 0.01 | 40 | 0.5 | 1 | 0.912 | 0 | 0.9 | 1775.09 | 0.46 | | changed lambda for catchability to 0.1, |
| 4 | 0.1 | 10 | 0.5 | 1 | 0.912 | 0 | 0.9 | 1874.22 | 0.01 | | |
| 5 | 0.1 | 20 | 0.5 | 1 | 0.912 | 0 | 0.9 | 2066.34 | 0.004 | | |
| 6 | 0.25 | 10 | 0.1 | 1 | 0.912 | 0 | 0.9 | 2086.82 | 0.04 | | |
| 7 | 0.1 | 10 | 0.5 | 1 | 0.912 | 0 | 0.9 | 1915.01 | 0.005 | | |
| 8 | 0.01 | 50 | 0.5 | 1 | 0.912 | 0 | 0.9 | 1839.31 | 0.47 | | |
| 9 | 0.1 | 50 | 0.5 | 1 | 0.912 | 0 | 0.9 | 1885.18 | 0.50 | | |
| 10 | 0.01 | 50 | 0.2 | 1 | 0.912 | 0 | 0.9 | 2138.65 | 0.35 | | |
| 11 | 0.01 | 50 | 0.5 | 1 | 0.912 | 0 | 0.9 | 1831.72 | 0.49 | | |
| 12 | .1 62-(81) and 0.05 (82-88 | 50 | 0.5 | 1 | 0.912 | 0.1 | 0.9 | 1945.94 | 0.47 | | |
| 13 | .1 62-(81) and 0.05 (82-88 | 50 | 0.5 | 1 | 0.912 | 0.1 | 0.9 | 2560.36 | 0.32 | | Estimated covariance matrix may not b |
| 14 | .1 62-(81) and 0.05 (82-88 | 50 | 0.5 | 1 | 0.912 | 0.1 | 0.9 | 2556.99 | 0.09 | | Estimated covariance matrix may not b |
| 15 | 0.01 | 15 | 0.5 | 1 | 0.912 | 0.1 | 0.9 | 1086.43 | 0.56 | | |
| 16 | 0.1,0.05,0.01 | 50 | 0.5 | 1 | 0.912 | 0 | 0.9 | 2430.49 | 0.19 | 0.28 | |
| 17 | 0.1,0.05,0.01 | 50 | 0.5 | 1 | 0.912 | 0 | 0.9 | 2428.36 | 0.20 | 0.30 | |
| 18 | 0.1,0.05,0.01 | 50 | 0.5 | 1 | 0.912 | 0 | 0.9 | 2434.33 | 0.17 | 0.25 | |
| 19 | 0.1,0.05,0.01 | 50 | 0.5 | 1 | 0.912 | 0 | 0.9 | 2432.5 | 0.18 | 0.26 | |
| 20 | 0.1,0.05,0.01 | 50 | 0.5 | 1 | 0.912 | 0 | 0.9 | 2426.42 | 0.21 | 0.31 | |
| 21 | 0.1,0.05,0.01 | 50 | 0.5 | 1 | 0.912 | 0 | 0.9 | 2425.53 | 0.22 | 0.33 | |
| 22 | 0.1,0.05,0.01 | 50 | 0.5 | 1 | 0.912 | 0 | 0.9 | 2429.10 | 0.24 | 0.37 | |

Table A3. 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 A4. 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 |

# Working Paper B

## Development of a Baseline Virtual Population Analysis, Consideration of a Statistical Catch at Age Model, and Reference Point and Stock Status Conclusions for Atlantic Mackerel

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### Virtual Population Analysis Model Development

Data sources initially considered for calibrating a virtual population analysis (VPA) were Atlantic mackerel (*Scomber scombrus*) commercial catch at age (i.e., sum of US and Canadian) and mean weight at age during 1962-2008, National Marine Fisheries Service (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 catch per effort (CPE; pounds landed/days absent) data during 1978-2008 (aggregate index), and standardized mid-water commercial otter trawl CPE 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 (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 B1). 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 B1). 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 CPE 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 (SAW 42). These splits improved the residuals (Figure B2).

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 indices were also 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 B3). Consequently, a VPA was fit without the winter survey index and with the spring index and bottom otter trawl index split as described above. Removing the NMFS winter index caused a modest increase in spawning stock biomass and decrease in average fishing mortality rate (ages 3-5) in recent years (Figure B4), 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 spring 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. So, 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 CPE indices (Figure B20). Furthermore, the trends in the commercial CPE data used here were generally similar to the NMFS spring survey index for some ranges of years (Figure B5). So, the commercial CPE indices were retained in all additional VPA model fits.

## Suggested Baseline VPA and Results

Based on the above VPA model fits, the conclusion was that the baseline VPA model should include the NMFS spring index and commercial CPE indices, each split as described above. The model using these data sources, however, had a retrospective pattern suggesting the consistent overestimation of spawning stock biomass and underestimation of fishing mortality (Figure B6). To explore the possibility 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. The year for the second split that minimized the retrospective pattern was found by fitting a VPA 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 year of the second split that minimized the retrospective pattern was 1993 (i.e., 1968-1984; 1985-1992; 1993-2008; Figure B7). 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 B7; Figure B8).

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 B9). Total abundance generally followed the same trend among years 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 B3), which suggested that the efficiency of the spring survey was not inflated due to factors such as herding. Average fishing mortality rate (ages 3-5) was relatively high during 1968-1975 peaking in that range of years at 0.36 in 1973 (Figure B9). Average fishing mortality rate 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 B9). Recruitment at age-1 varied during 1962-2008 with generally higher average recruitment during 1962-1984 than 1985-2008 (Figure B10). 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 B10).

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 B1). 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 B11; Table B2). Catchability estimates also differed by an order of magnitude among the 3 time blocks, with higher catchabilities in more recent years (Figure B11; Table B2). The higher catchability estimates in recent years may be effectively down scaling the relatively high mean number per tow observations in recent years (Figure B5), 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 B15 no splits; Figure B6 & Figure B20 split in 1985; Figure B7 & Figure B9 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.

## Discussion of Baseline VPA Results

The declining trends in SSB and total abundance suggested by the baseline VPA may be justified by the absence of older aged fish in both the US and Canadian catch and NMFS spring survey (Table B4; Table B5; Table B6). The lack of older aged fish in the spring survey may be related to the ability of these larger faster swimming fish to avoid the trawl. The lack of older aged fish in the US 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 $5^{o}$C, to disperse offshore to the north and east (Figure B12) 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 B10; Figure B13).

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 B12) 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 B14). 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.

## Sensitivity Analysis

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 B15). 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 the baseline model (Figure B15). However, this VPA also exhibited residual and retrospective patterns (patterns similar to Figure B1 and Figure B6), 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 B16). The retrospective patterns with M=0.3 were also slightly improved relative to the baseline VPA (Figure B17). 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 B18). The retrospective patterns with M=0.1 were also slightly worse relative to the baseline VPA (Figure B19).

## Preliminary 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. Data sources considered were total annual commercial mackerel catch (i.e., sum of US 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 CPE data during 1978-2008 (aggregate index), and standardized mid-water commercial otter trawl CPE data during 1994-2008 (aggregate index). Unlike the model for striped bass, fishery and survey selectivity at age were input as constants (time invariant; Table B7). 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 that of the baseline VPA (Figure B21). Spawning stock biomass peaked in 1970 at 0.90 million metric tons and has generally declined to an all-time low of 0.05 million metric tons in 2008 (Figure B21). 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 B21).

## Reference Points – Yield per Recruit and Equilibrium Projections

Yield per recruit (YPR) analyses and deterministic projections were conducted using the YPR and AgePro software (versions 2.7.2 and 3.3.8 respectively) from the NMFS National Fisheries Toolbox (NFT). Biological parameters required in each case were based on estimates or calculations from the baseline VPA, or were set equal to values also used in the baseline VPA (Table B7). Preliminary results of deterministic projections seemed to be at equilibrium after 30 years, and so all simulations used a 30 year planning horizon. Recruitment in each year of the projections was randomly drawn from the age-1 recruitment estimates during 1962-2008 from the baseline VPA model.

The dome of the YPR versus fishing mortality relationship was relatively flat, and so $F_{max}$ may not be well-defined. Therefore, $F_{0.1}$ was used as the proxy for $F_{MSY}$ in deterministic projections (Table B8). Equilibrium average SSB at a fishing mortality rate equal to $F_{0.1}$ (0.26) equaled 549,000 metric tons (Figure B23).

## Stock Status Conclusions

Based on results of the baseline VPA, SSB in 2008 was 210,000 metric tons. Half of the $B_{MSY}$ proxy (549,000mt) equals 274,500mt, and so the stock would be categorized as overfished. $F_{0.1}$ equaled 0.26, which is less than the baseline VPA 2008 average fishing mortality rate of 0.38 (ages 3-5), and so overfishing is occurring.

Assuming that the average age-1 recruitment estimated by the baseline VPA model during 1962-2008 represents expected future recruitment, deterministic projections at the current fishing mortality rate estimated by the baseline VPA (i.e., 2008 fishing mortality rate = 0.38) suggested that average SSB may decline to approximately 177,000mt in 2010 and 160,000mt in 2011, with increasing SSB thereafter (Figure B23).

Table B1. 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 B2. 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 |

Table B3. Swept area abundance estimates from the NMFS spring survey (arithmetic mean #/tow) (SurveyPopEstimate), 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 B4. US 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 B5. 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 B6.  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 B7. Input biological data used for yield per recruit and deterministic projections. Some inputs were also used for a statistical catch at age model (see text).

| Age | Selectivity | Natural Mortality | Stock Weights | Catch Weights | Spawning Weights | Proportion Mature |
|---|---|---|---|---|---|---|
| 1 | 0.15 | 0.2 | 0.15 | 0.15 | 0.15 | 0.1 |
| 2 | 0.53 | 0.2 | 0.24 | 0.24 | 0.24 | 0.6 |
| 3 | 0.91 | 0.2 | 0.34 | 0.34 | 0.34 | 1 |
| 4 | 1 | 0.2 | 0.4 | 0.4 | 0.4 | 1 |
| 5 | 1 | 0.2 | 0.47 | 0.47 | 0.47 | 1 |
| 6 | 1 | 0.2 | 0.51 | 0.51 | 0.51 | 1 |
| 7 | 1 | 0.2 | 0.61 | 0.61 | 0.61 | 1 |

Table B8. Results of yield per recruit calculations.

|  | F | YPR | SSBR | Total Biomass/R | Mean Age | Mean Generation Time | Expected Spawnings |
|---|---|---|---|---|---|---|---|
| **F zero** | 0.000 | 0.000 | 1.796 | 2.198 | 5.442 | 7.746 | 2.398 |
| **F 0.1** | 0.257 | 0.163 | 0.648 | 1.013 | 2.977 | 4.650 | 1.310 |
| **Fmax** | 0.776 | 0.187 | 0.244 | 0.572 | 2.027 | 3.161 | 0.565 |
| **F 40%** | 0.221 | 0.156 | 0.718 | 1.088 | 3.136 | 4.878 | 1.412 |

Figure B1. 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.

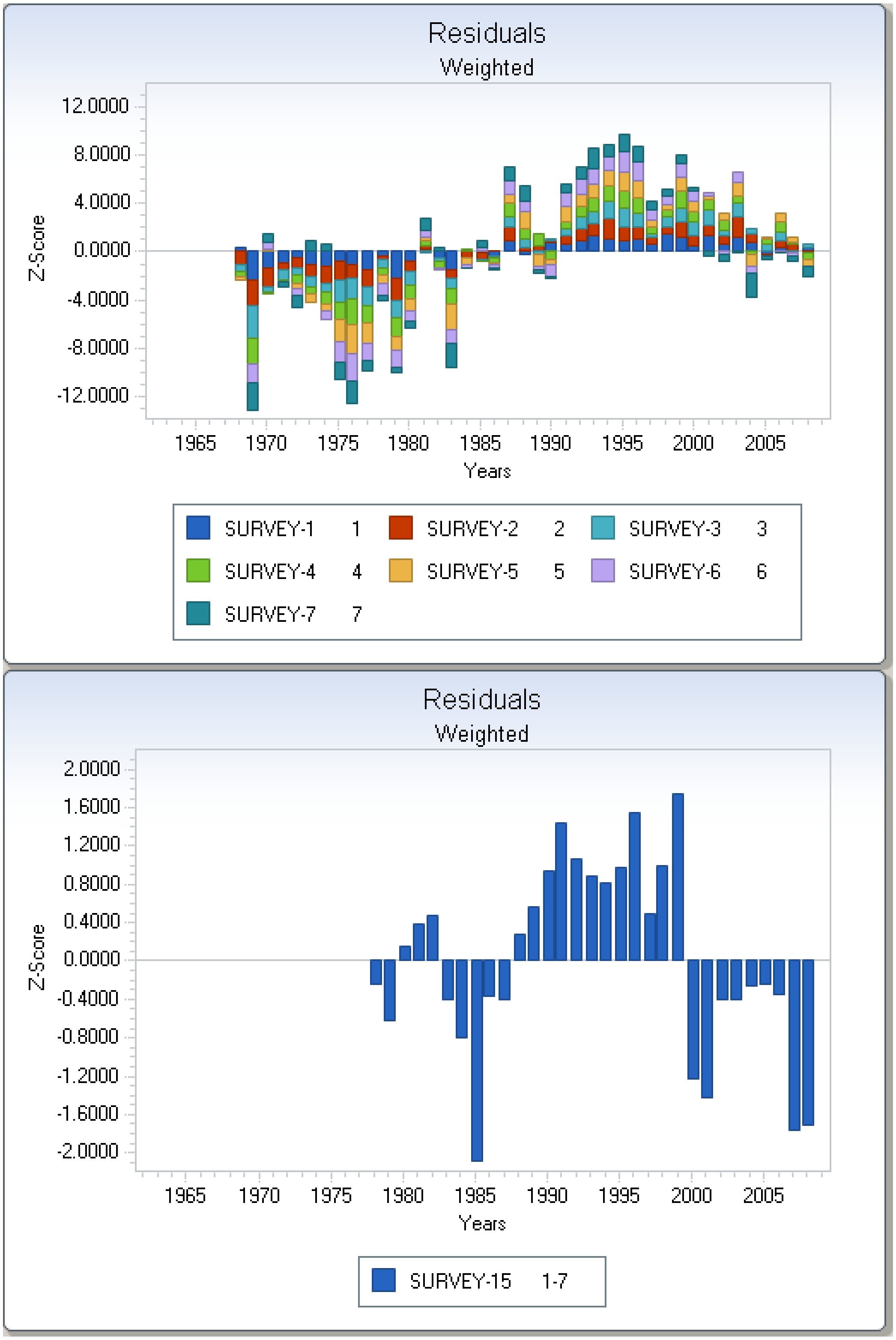
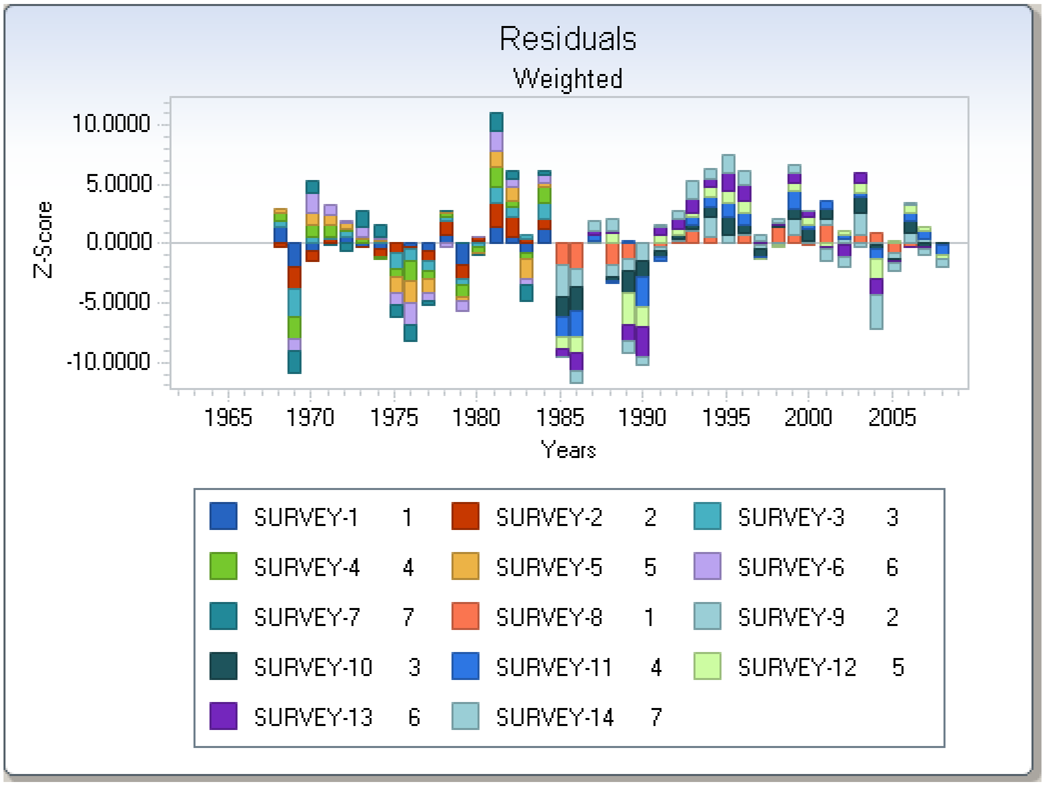


Figure B2. Residuals from a VPA for the NMFS spring survey at age index split in 1985 and for the bottom fished otter trawl fishery index split in 1989.



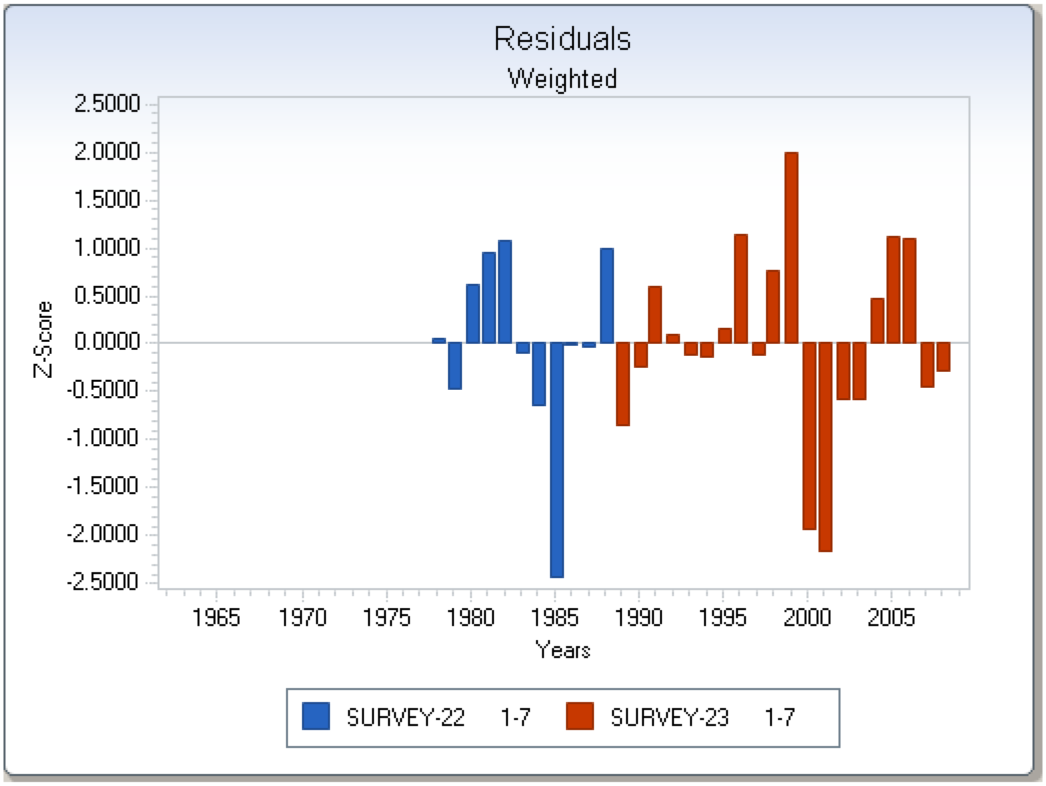


Figure B3. NMFS winter bottom trawl mackerel survey index (stratified ln retransformed mean number per tow with 95% confidence interval).

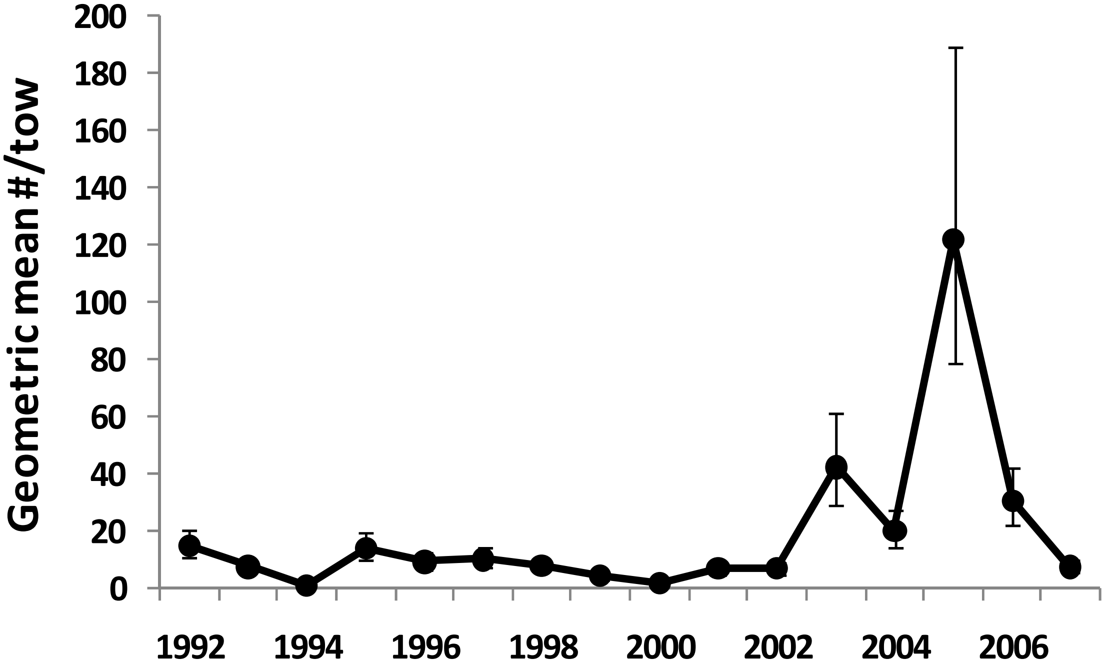
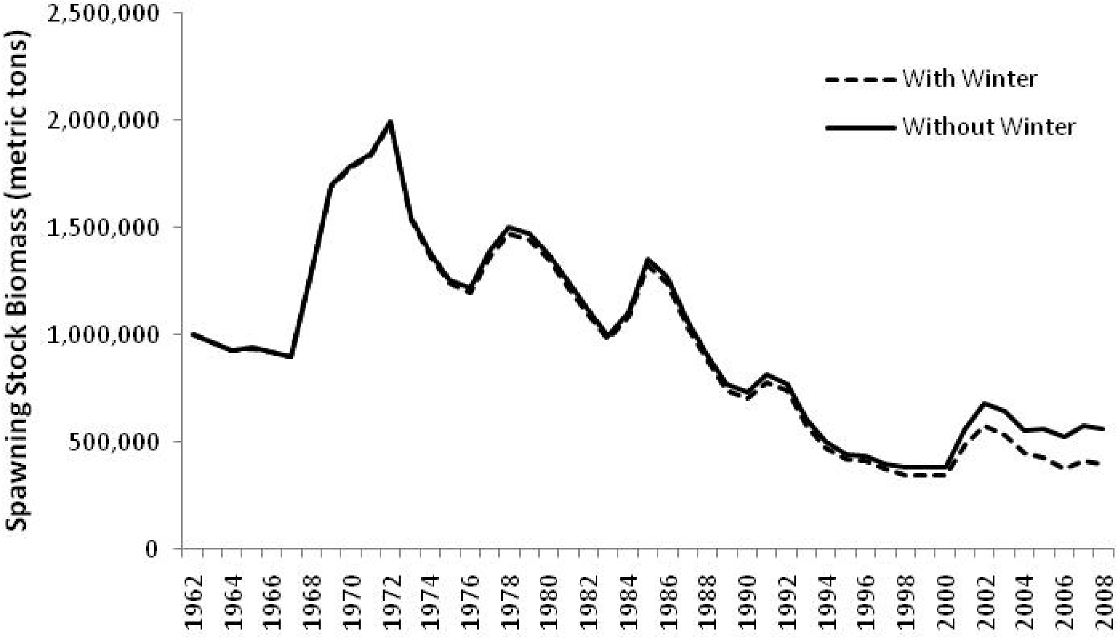


Figure B4. Spawning stock biomass and fishing mortality (averaged for ages 3 to 5) for VPA models with and without the NMFS winter survey (see text for details).



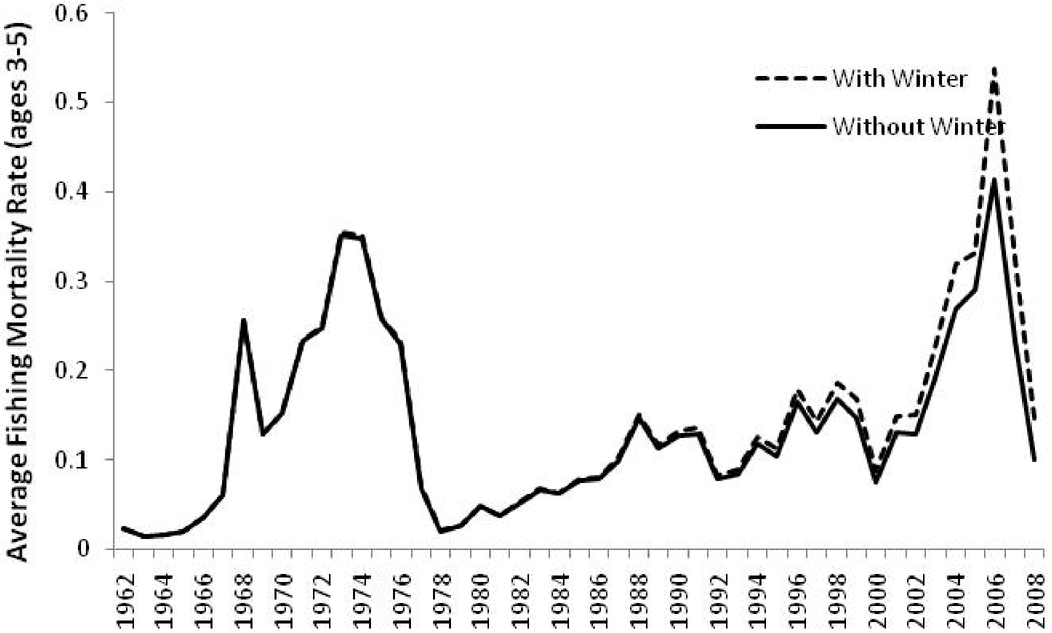


Figure B5. Standardized commercial mackerel catch per effort (CPE) data from bottom fished otter trawls (top panel), mid-water otter trawls (bottom panel), and the NMFS spring bottom trawl survey (both panels).

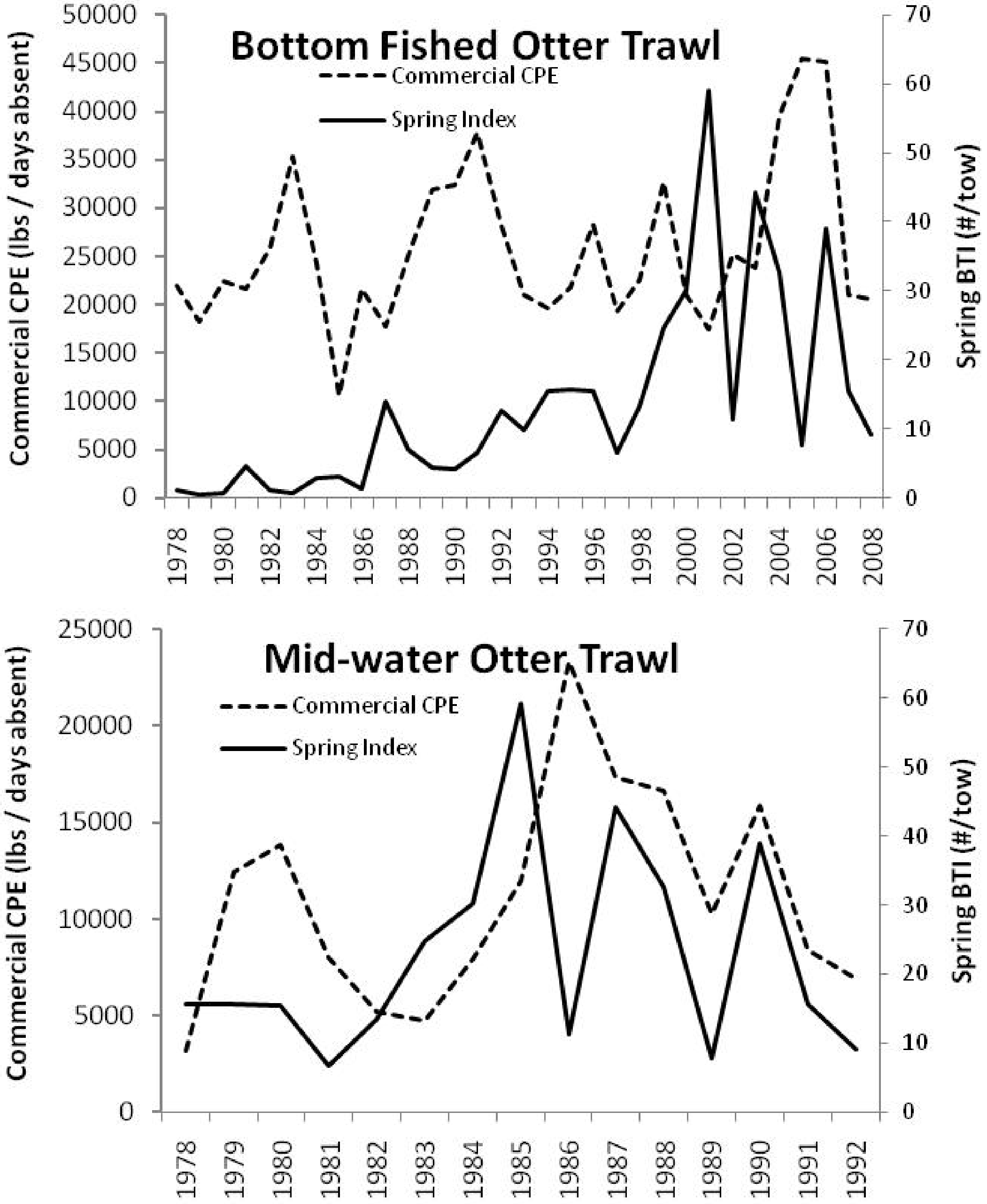
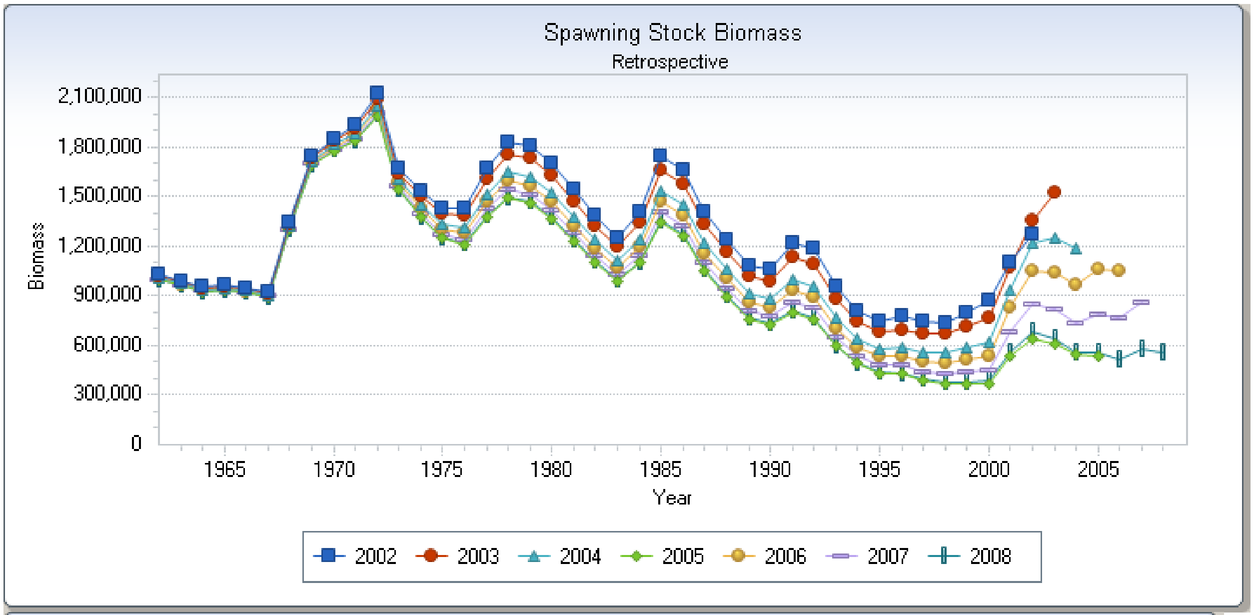


Figure B6. Retrospective pattern in spawning stock biomass (mt) and average fishing mortality rate from a VPA fit using the NMFS spring survey, bottom fished otter trawls, and mid-water otter trawls.



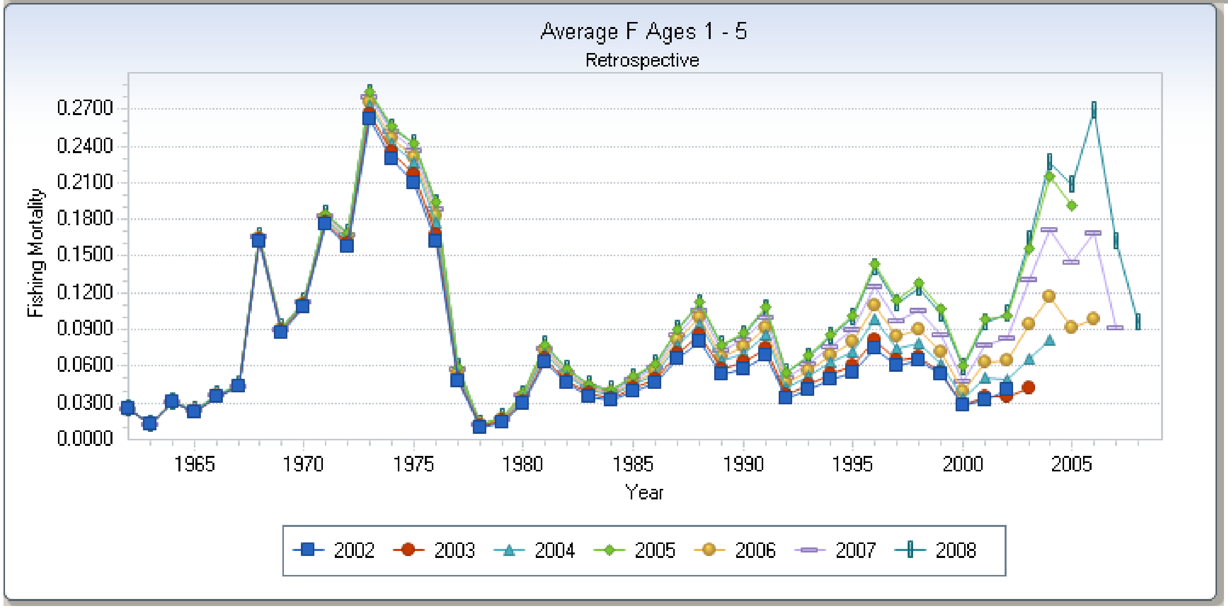
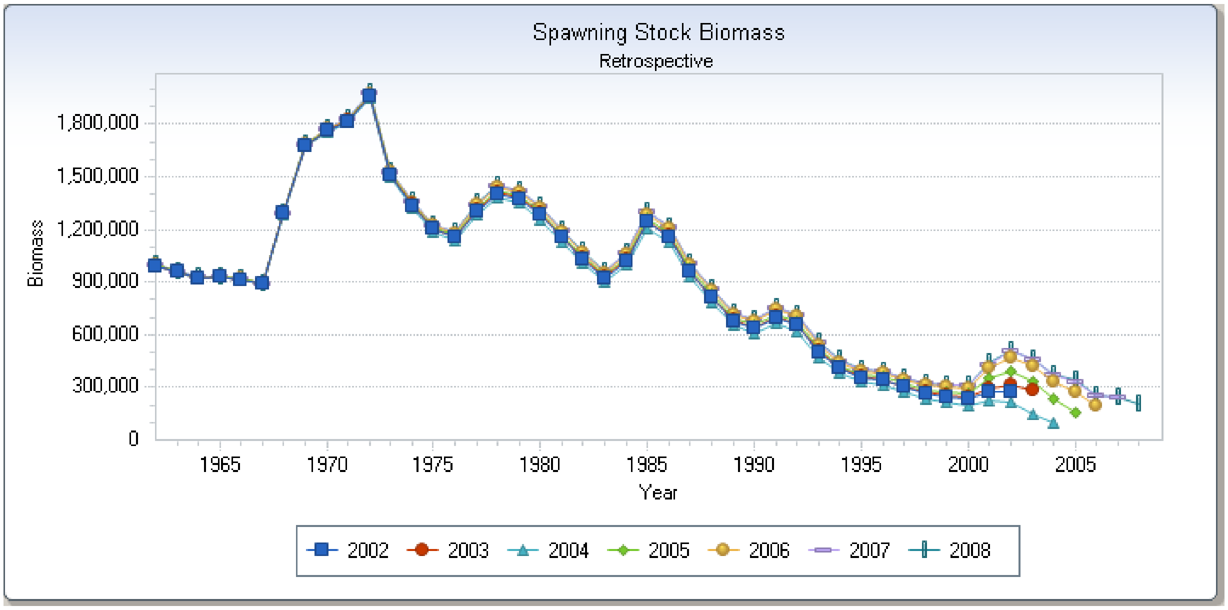


Figure B7. Retrospective pattern in spawning stock biomass (mt) and average fishing mortality rate from a VPA with the NMFS spring index split in 1985 and 1993.



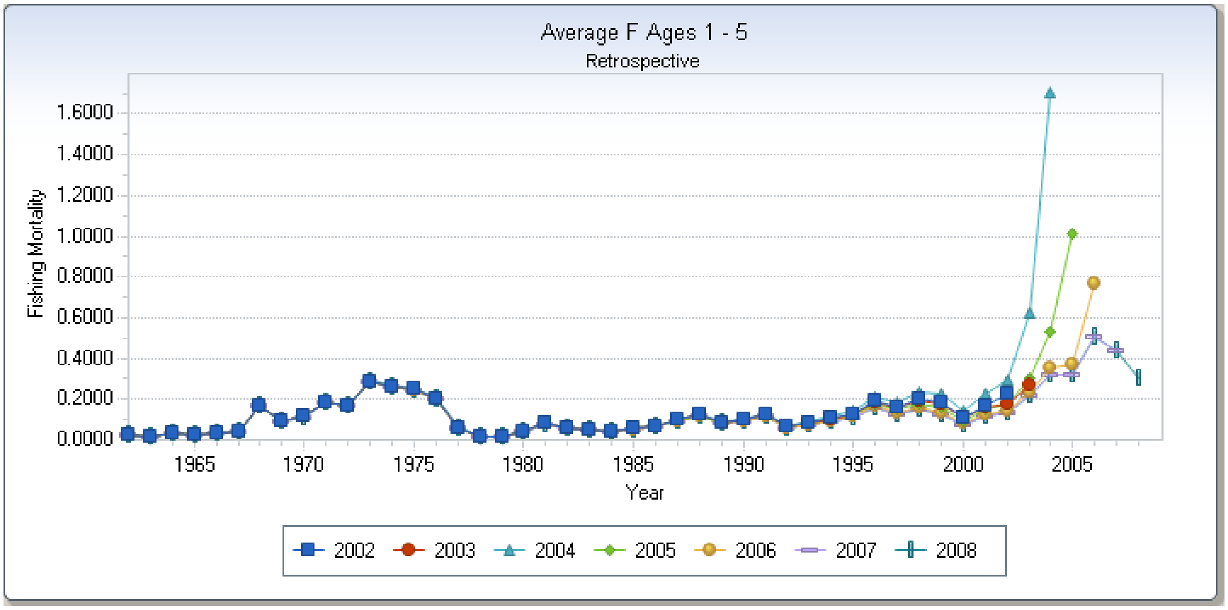
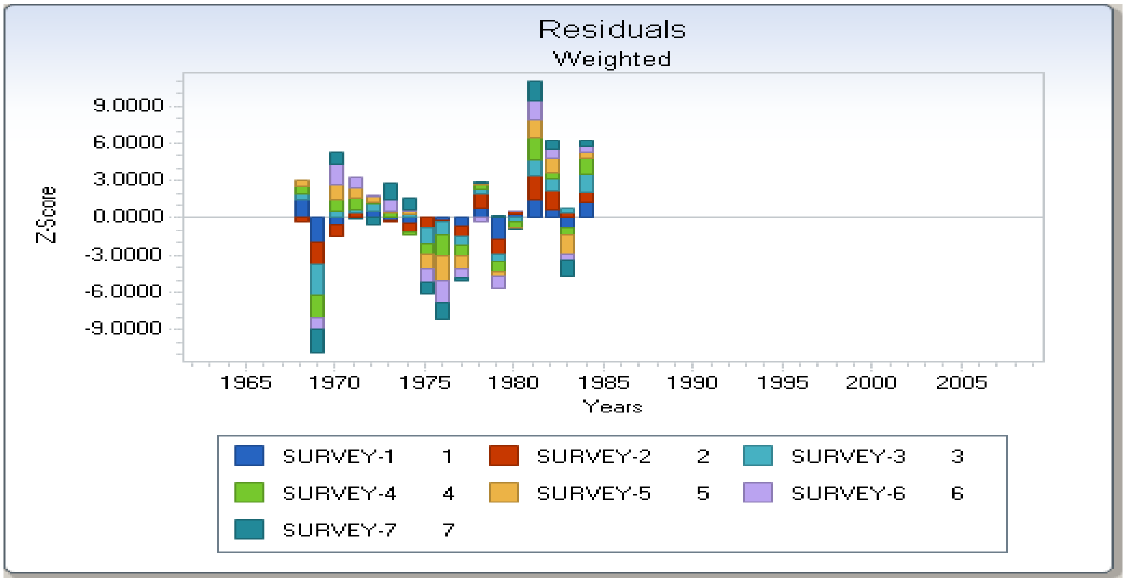


Figure B8. Residuals for the NMFS spring survey index at age (top 3 panels), bottom fished otter trawl CPE index (4th panel), and mid-water otter trawl CPE index (bottom panel) for the baseline VPA model.



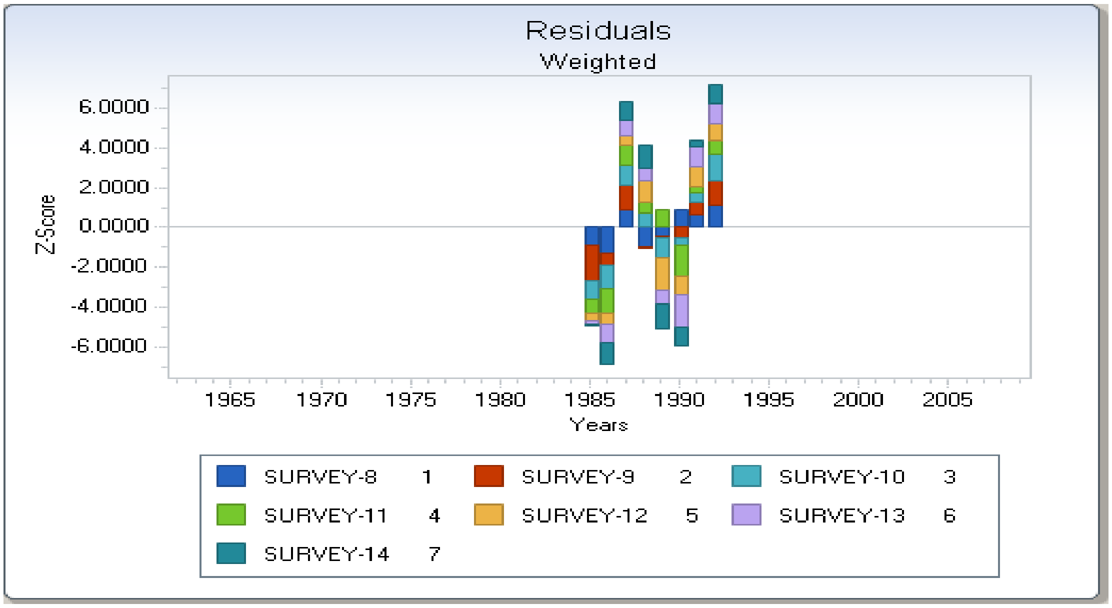
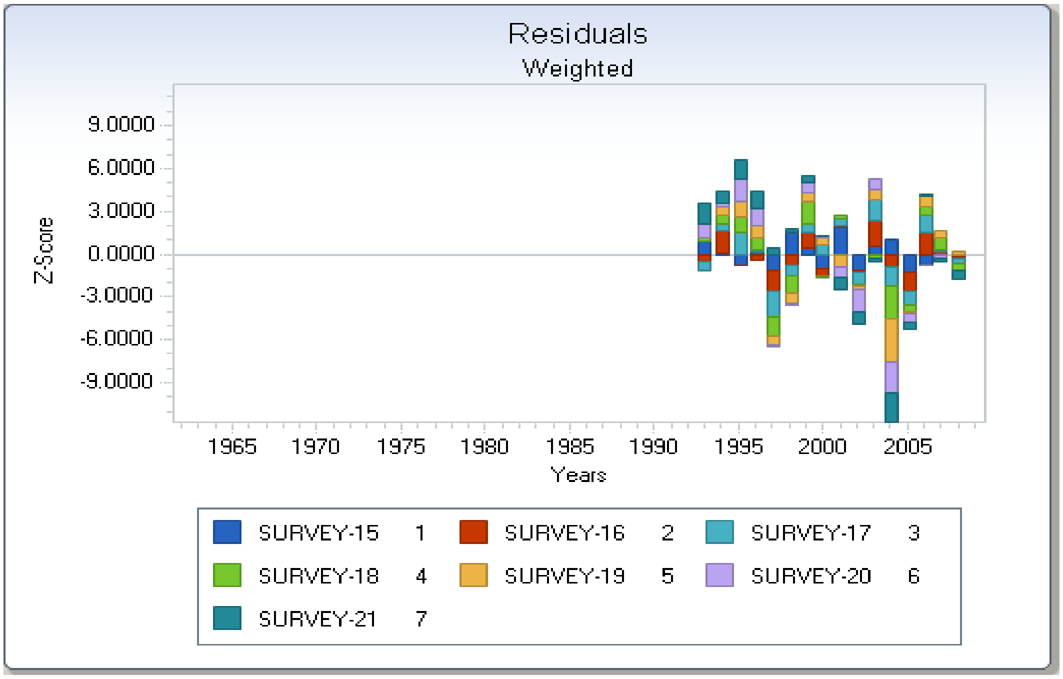


Figure B8 (continued)



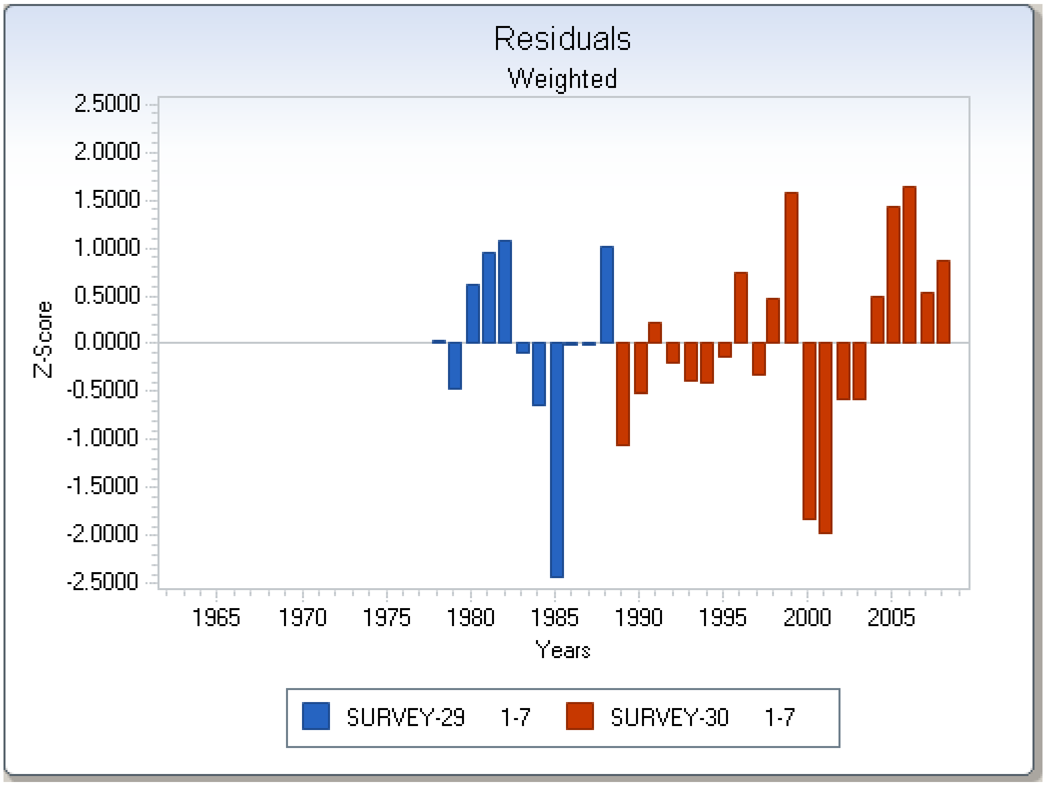


Figure B8 (continued)

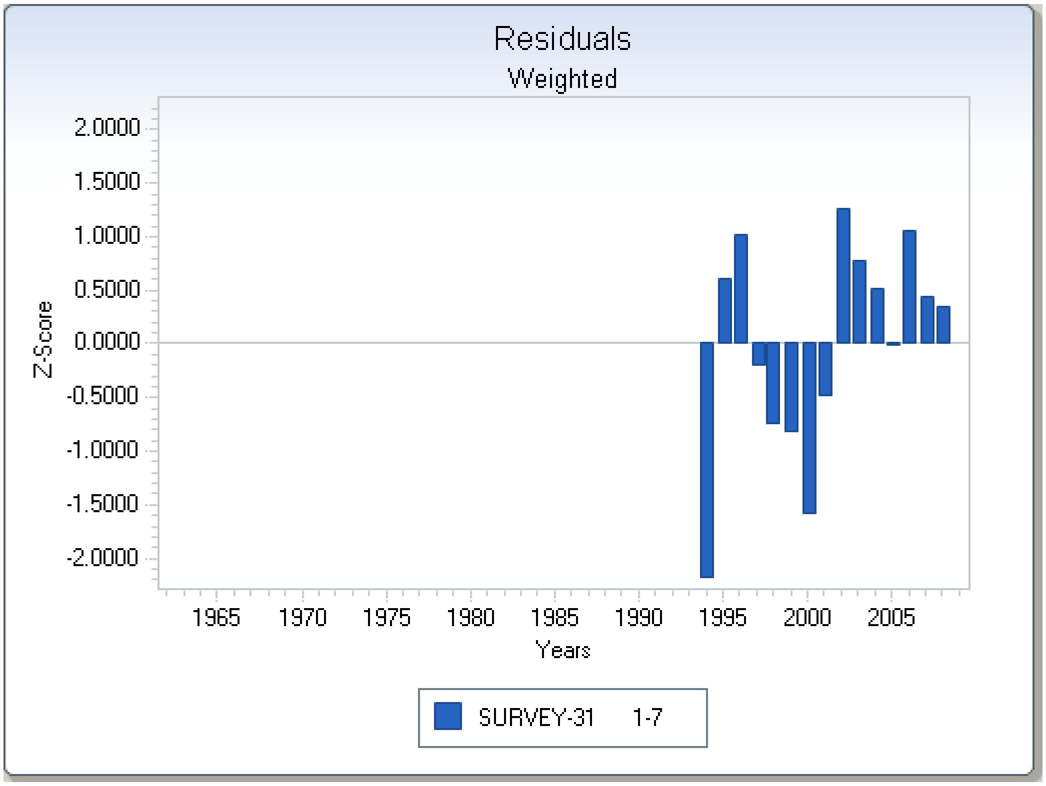


Figure B9. Spawning stock biomass and average fishing mortality rate estimates during 1962-2008 from the baseline VPA model.

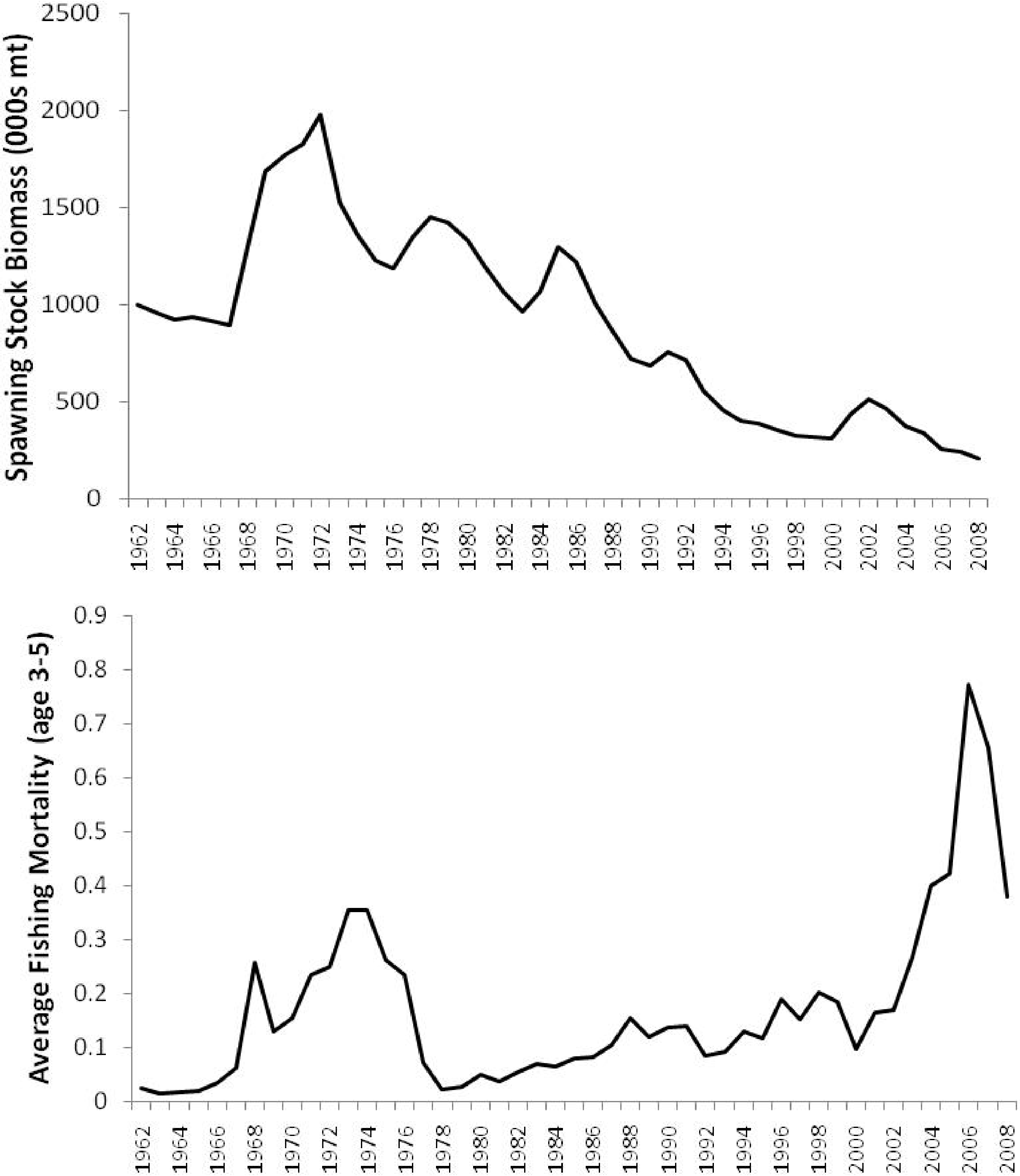


Figure B10. Age-1 recruit estimates during 1962-2008 from the baseline VPA model. The top horizontal long dashed line is the average age-1 recruitment during 1962-1984; the middle horizontal dotted line is the average age-1 recruitment over the entire time series, and the bottom horizontal short dashed line is the average age-1 recruitment during 1985-2008.

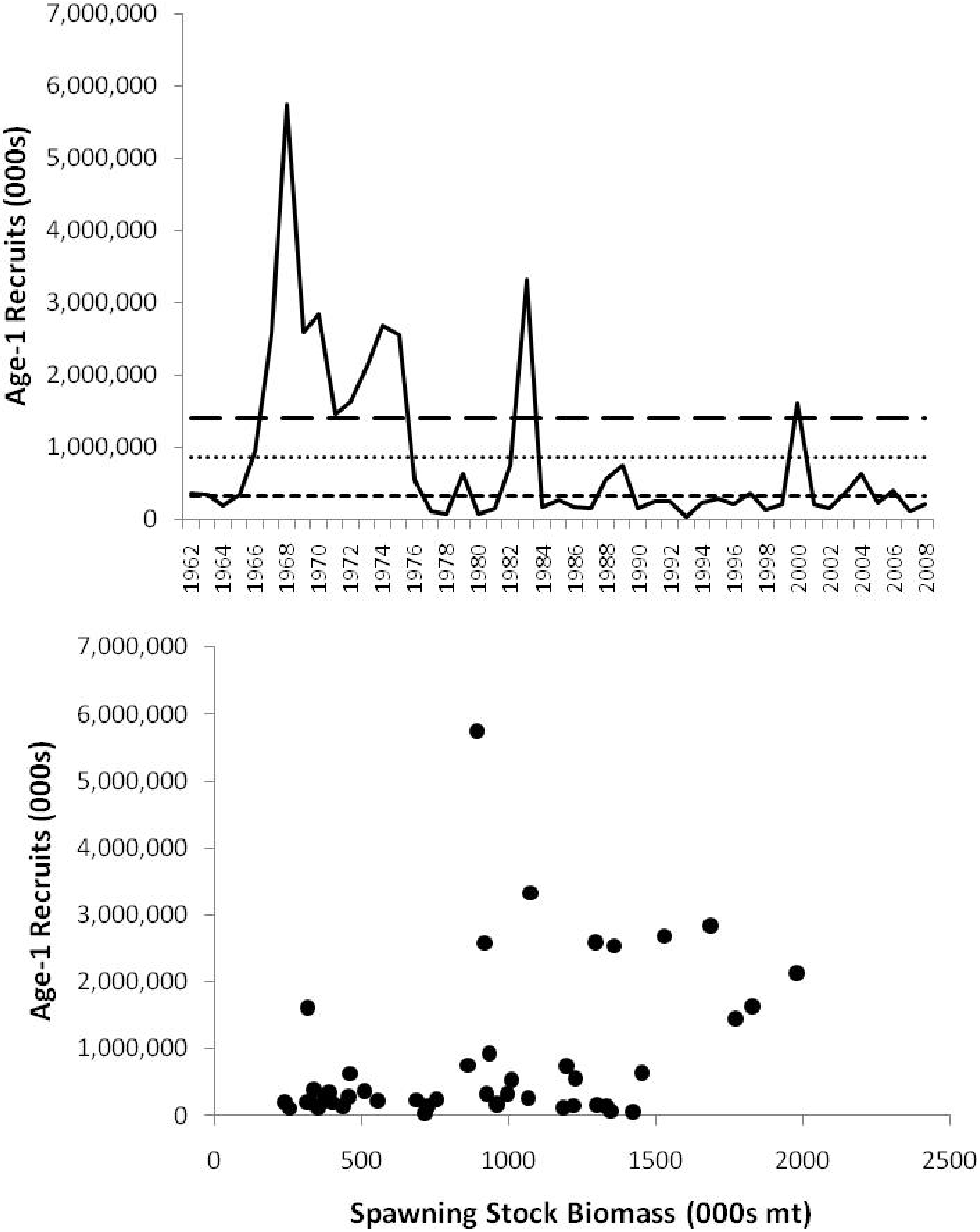


Figure B11. Catchability at age estimates for the NMFS spring bottom trawl survey for the 3 time blocks used in the baseline VPA model.

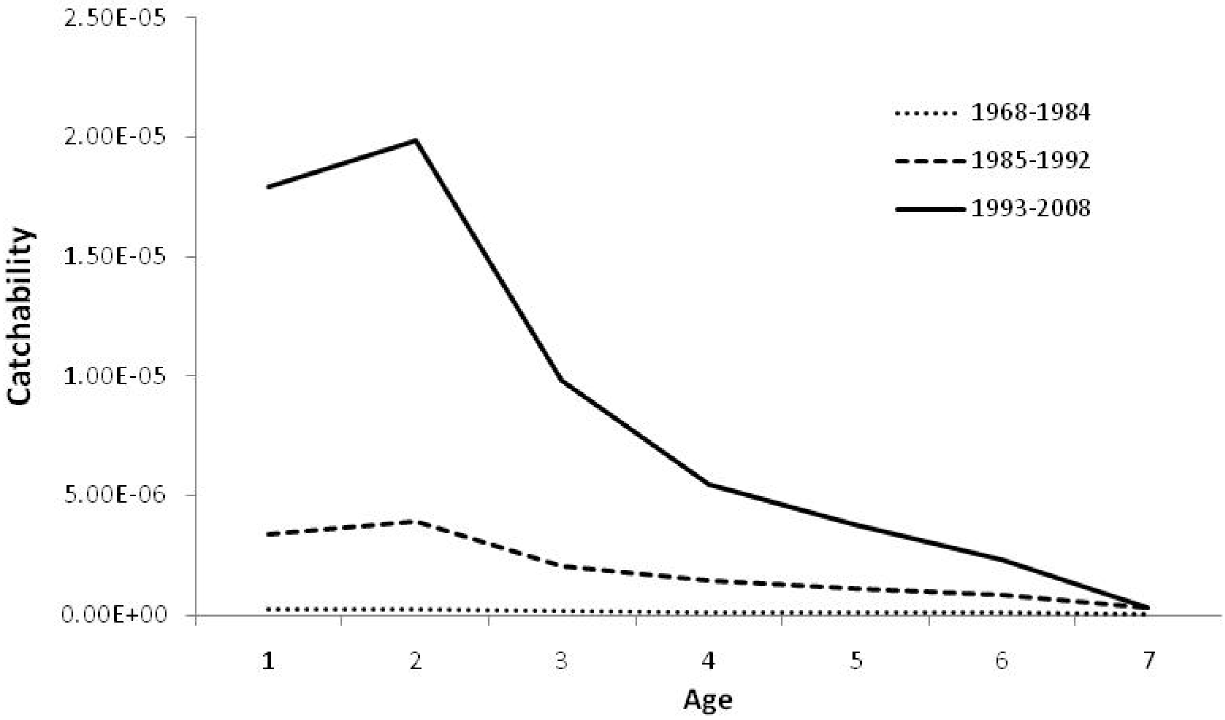
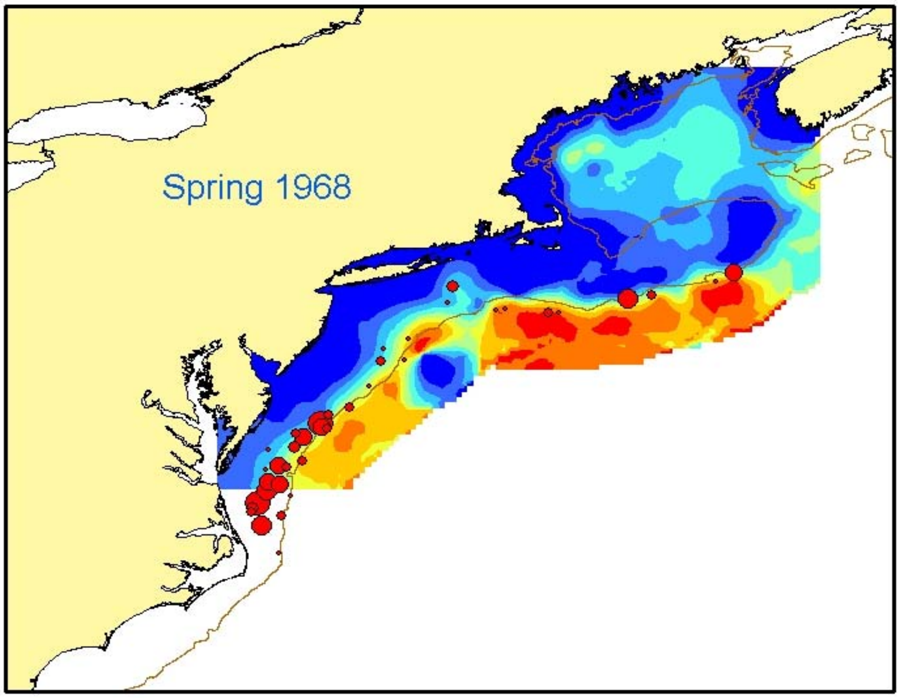


Figure B12.Distribution of Atlantic mackerel and bottom temperature isotherms from NEFSC spring surveys during 1968 (A) and 2001 (B). Figures from Overholtz et al. (“Impacts of inter-annual environmental forcing and long-term climate change on the distribution of Atlantic mackerel on the U.S. Northeast continental shelf”).



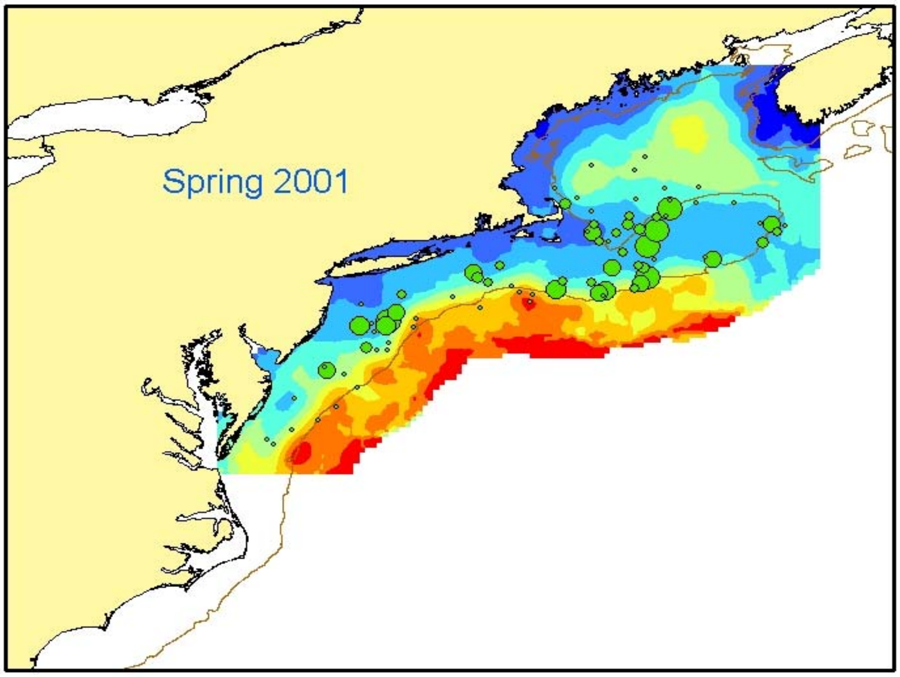


Figure B13. Time series of the larval index. Filled dots correspond to years during which sampling occurred near to the peak of the spawning season. White dots are years when sampling occurred well before or after the spawning season. During these years a larval index can be calculated, though with low reliability. The analyses presented here are preliminary – a routine has been developed to estimate the uncertainty in the larval index, but this routine has not yet been applied to Atlantic mackerel. Figure from Richardson and Hare ("Time series of larval Atlantic mackerel on the northeast United States continental shelf").

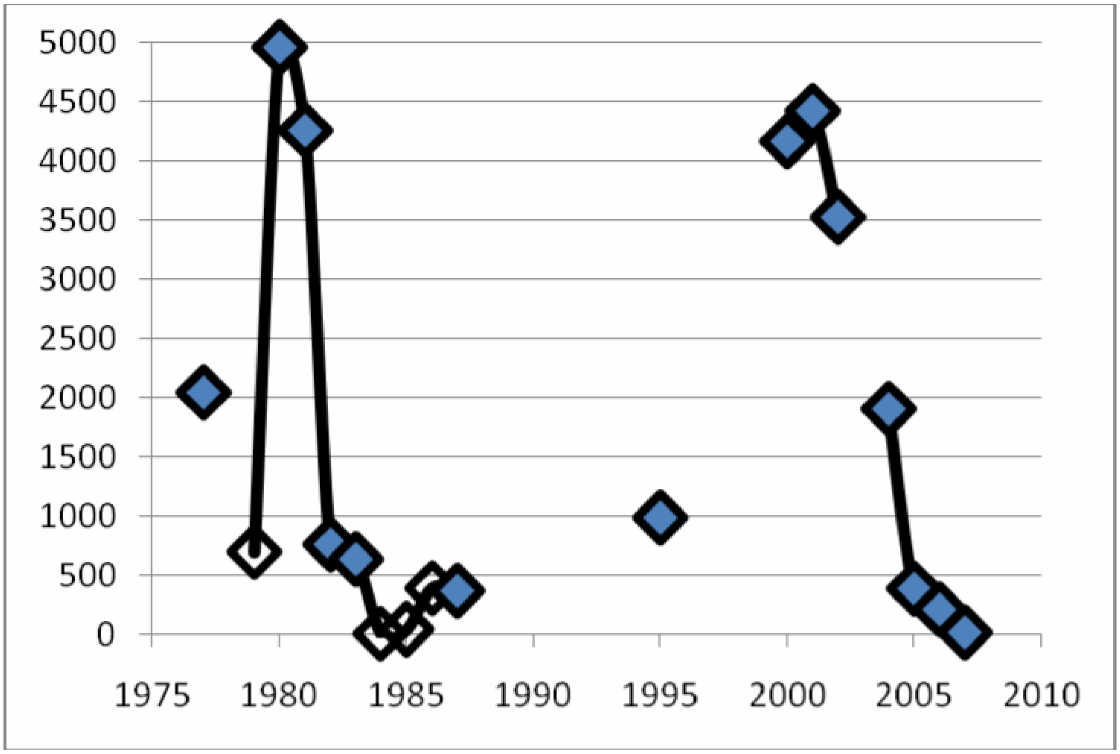


Figure B14. Mackerel catch weighted mean depth (meters) of the NMFS spring survey during 1968-2008.

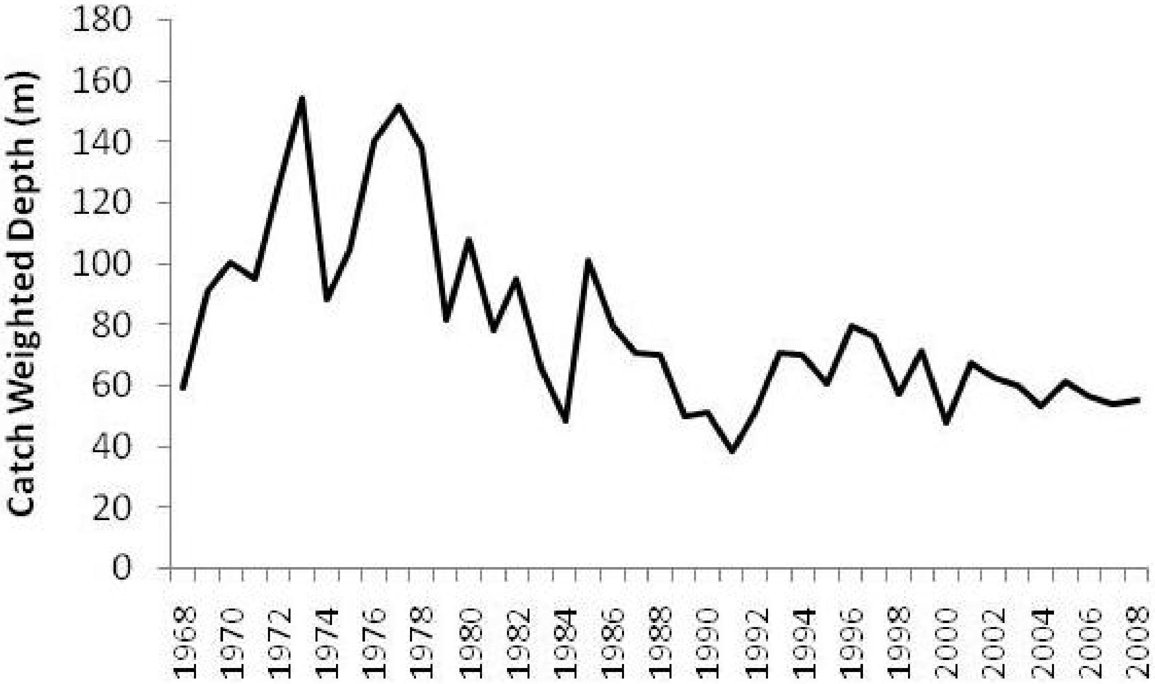


Figure B15. Spawning stock biomass (metric tons) and average fishing mortality rate estimates during 1962-2008 from a VPA with no splits in the NMFS spring survey.

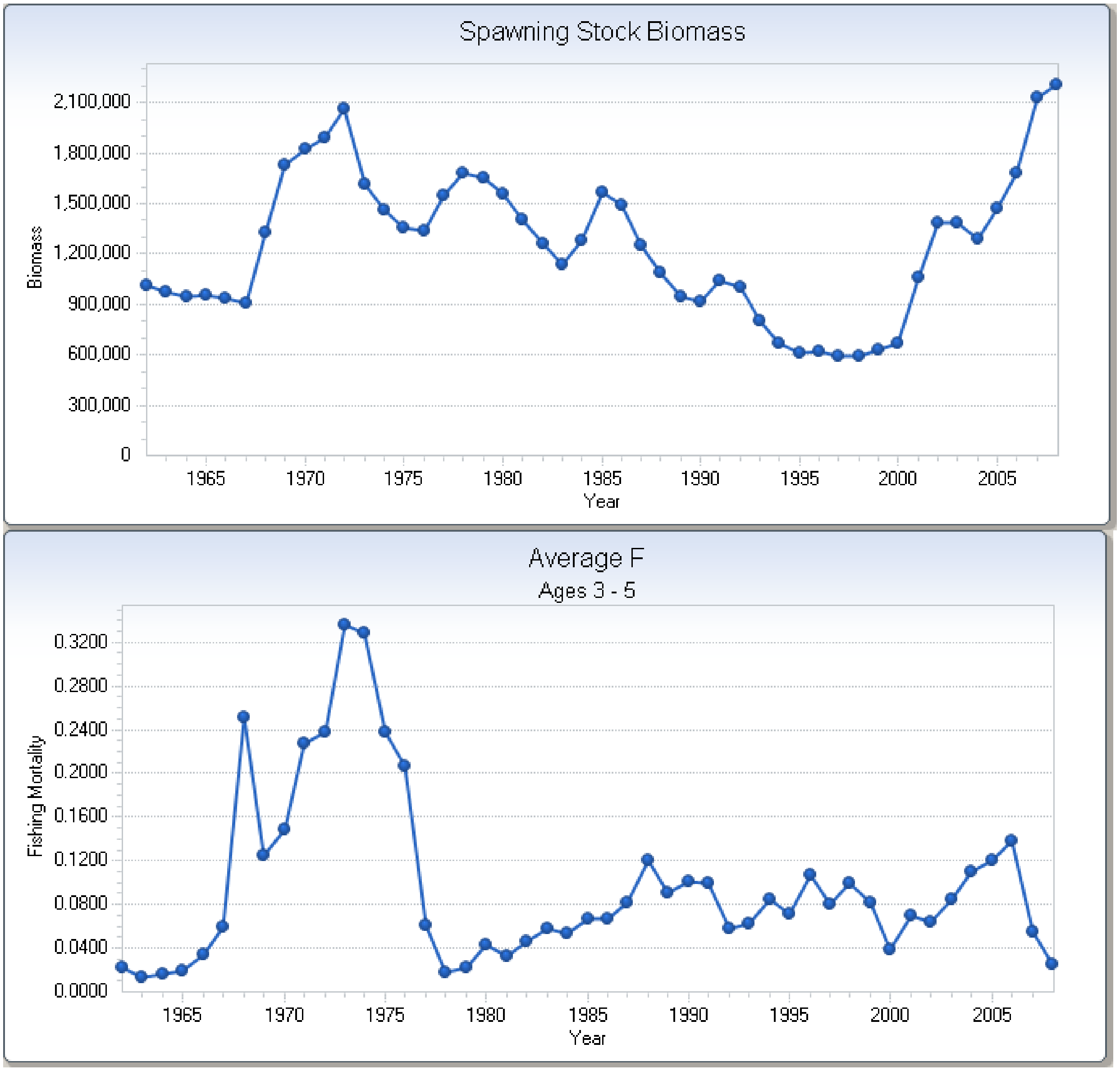
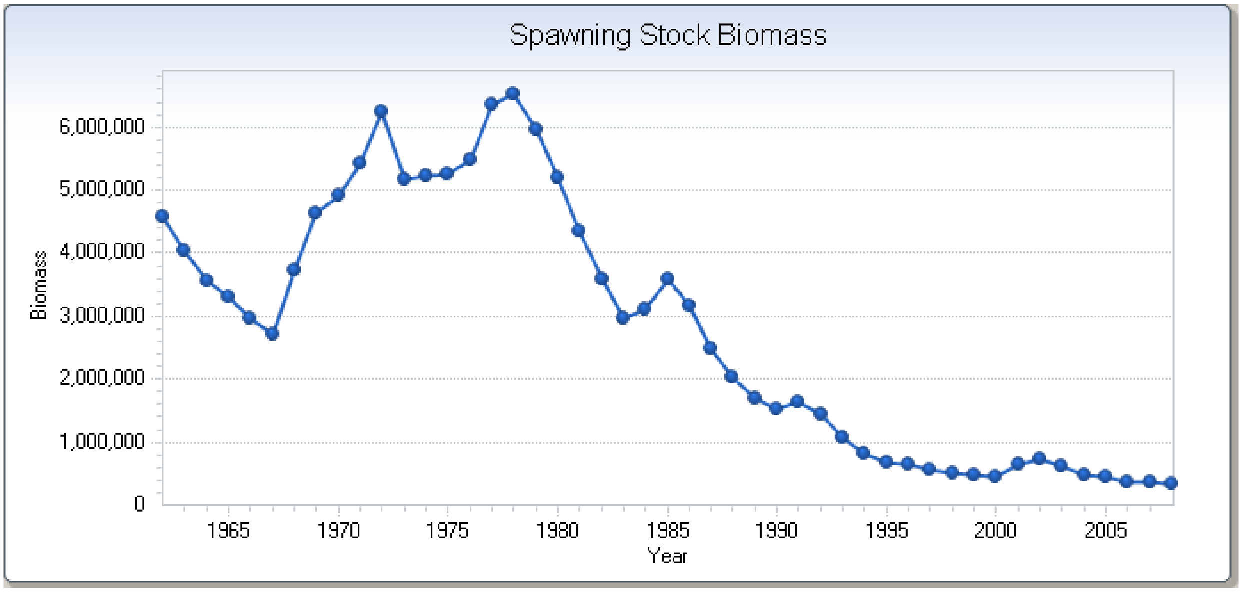


Figure B16. Spawning stock biomass (metric tons) and average fishing mortality rate estimates during 1962-2008 from the baseline VPA, except with natural mortality equal to 0.3.



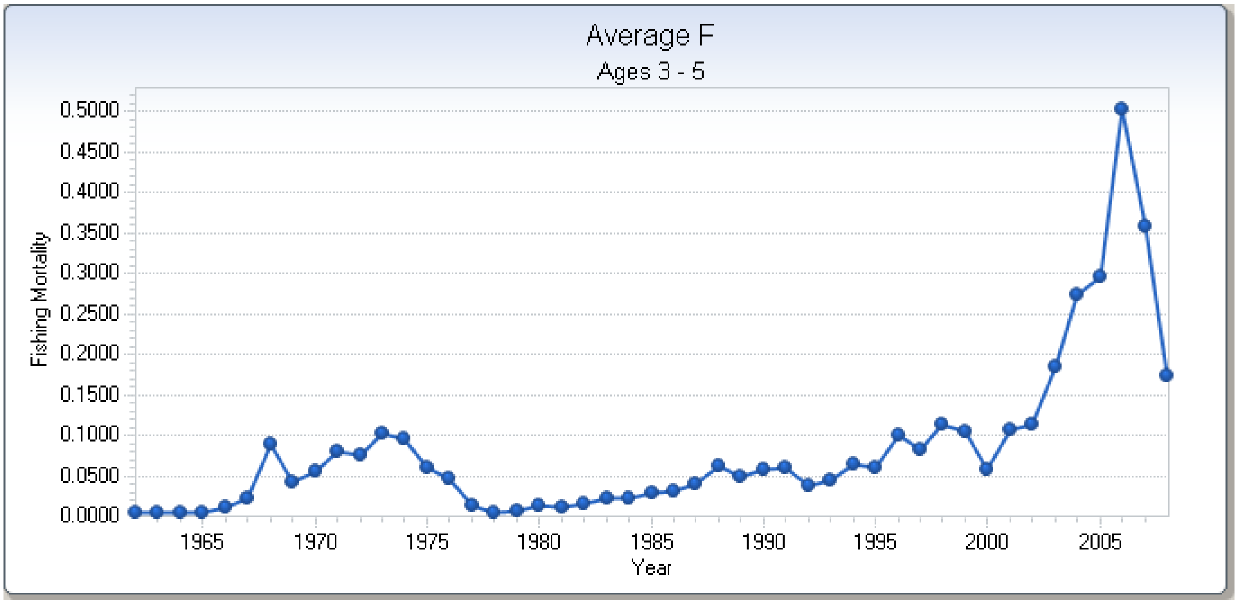


Figure B17. Retrospective pattern in spawning stock biomass and average fishing mortality rate from the baseline VPA, except with M=0.3.

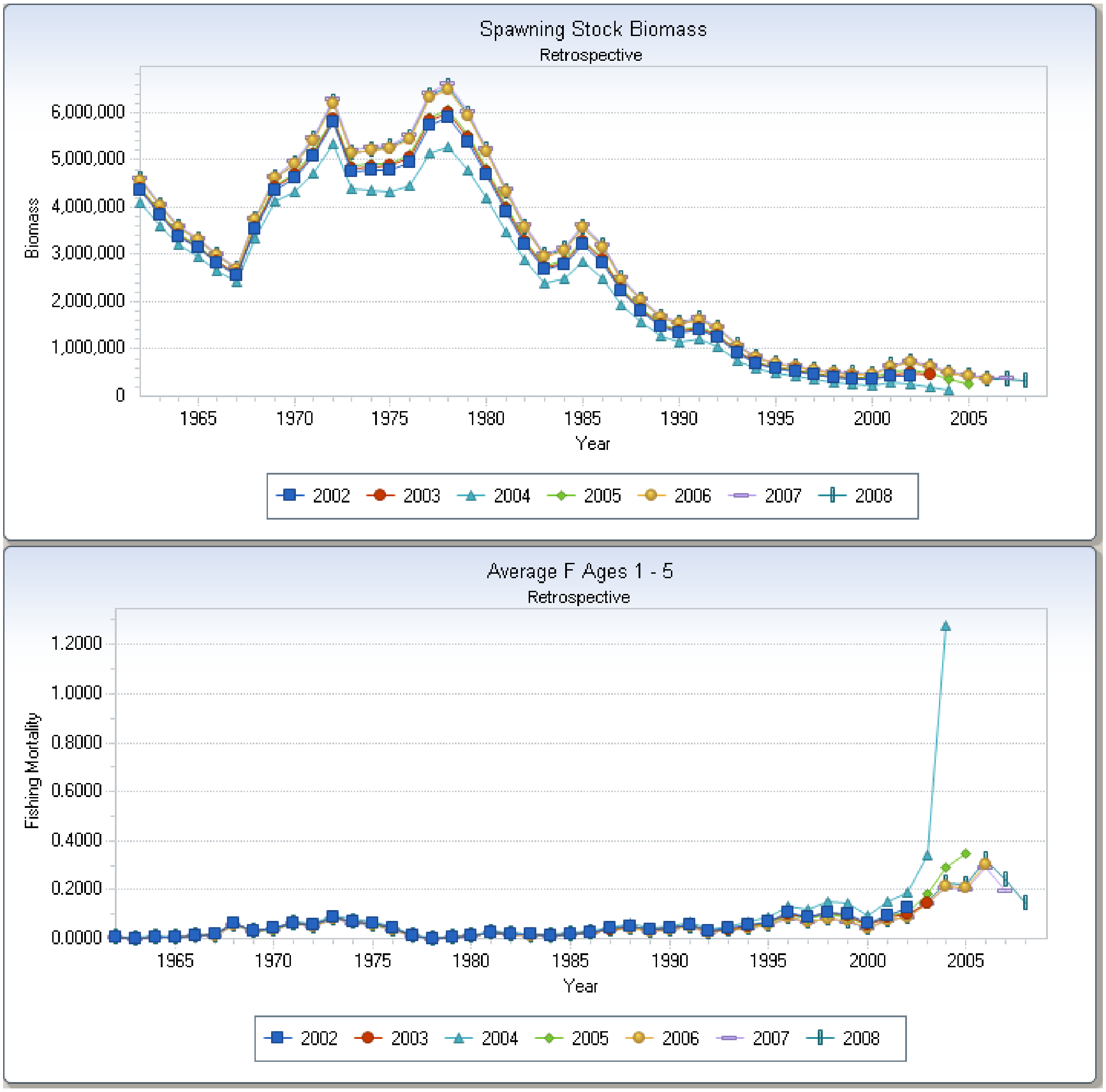
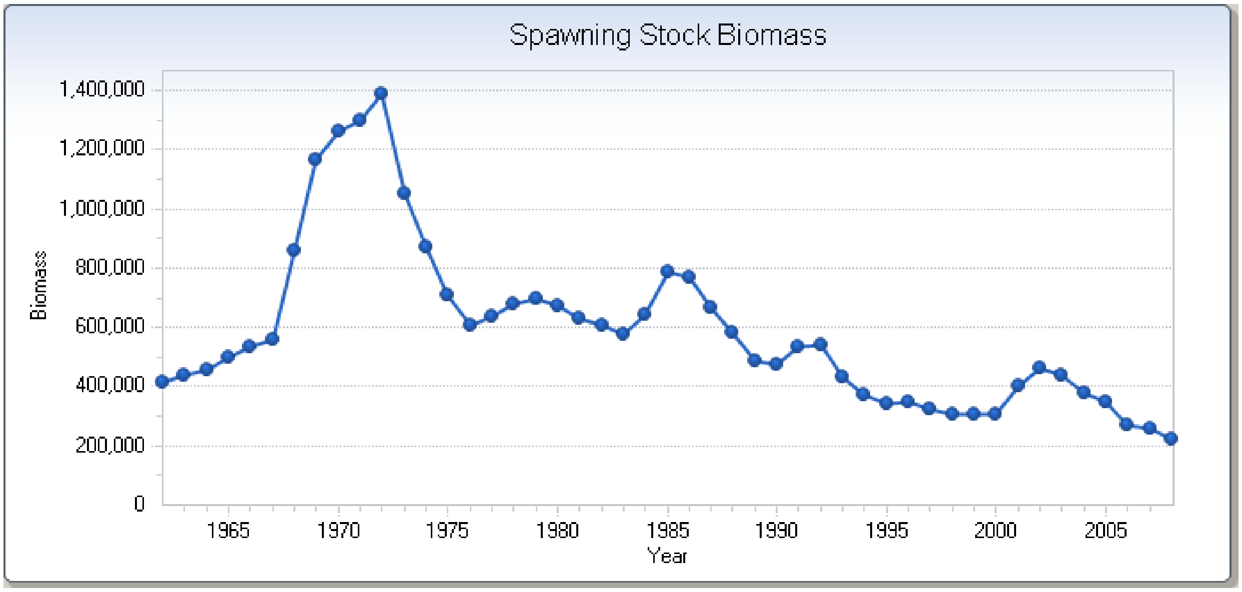


Figure B18. Spawning stock biomass (metric tons) and average fishing mortality rate estimates during 1962-2008 from the baseline VPA, except with natural mortality equal to 0.1.



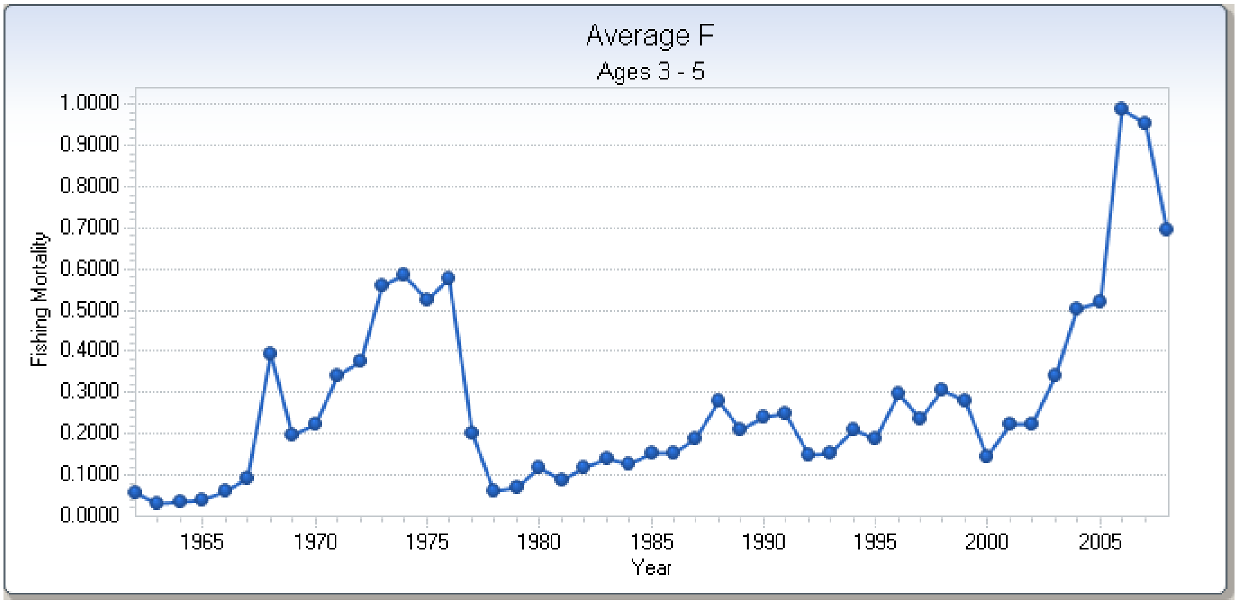
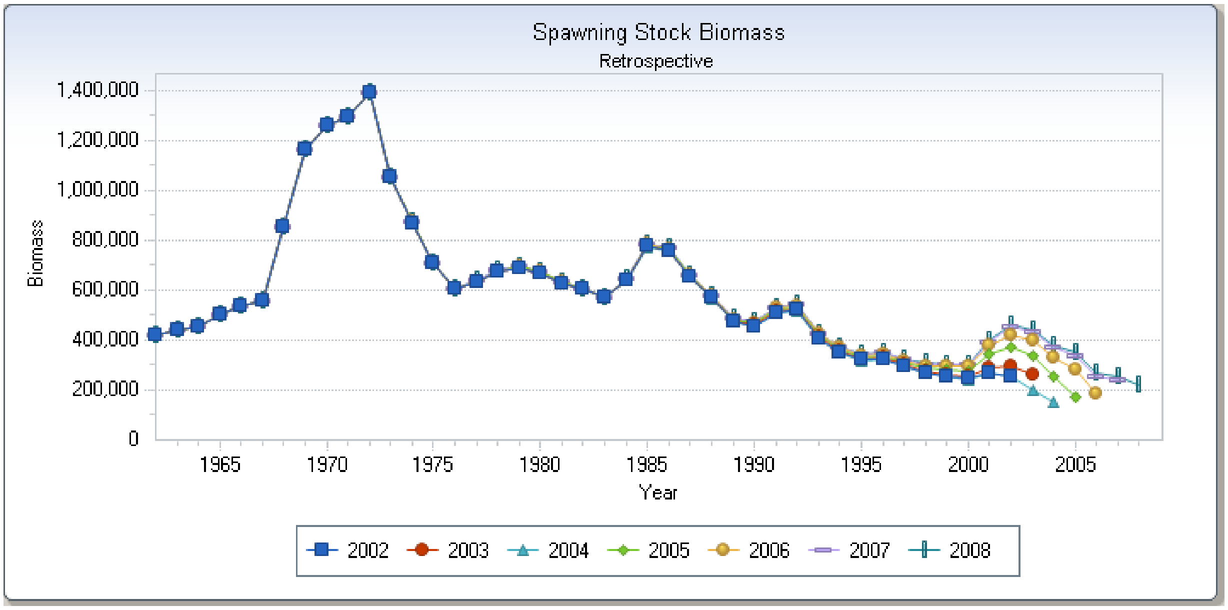


Figure B19. Retrospective pattern in spawning stock biomass and average fishing mortality rate from the baseline VPA, except with M=0.1.



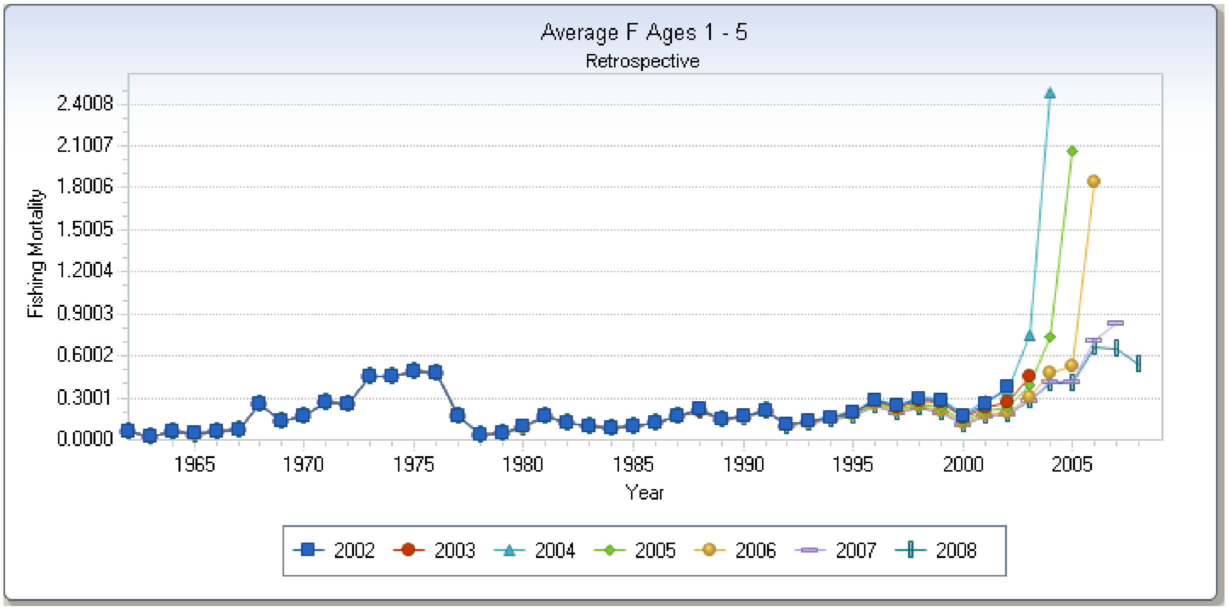
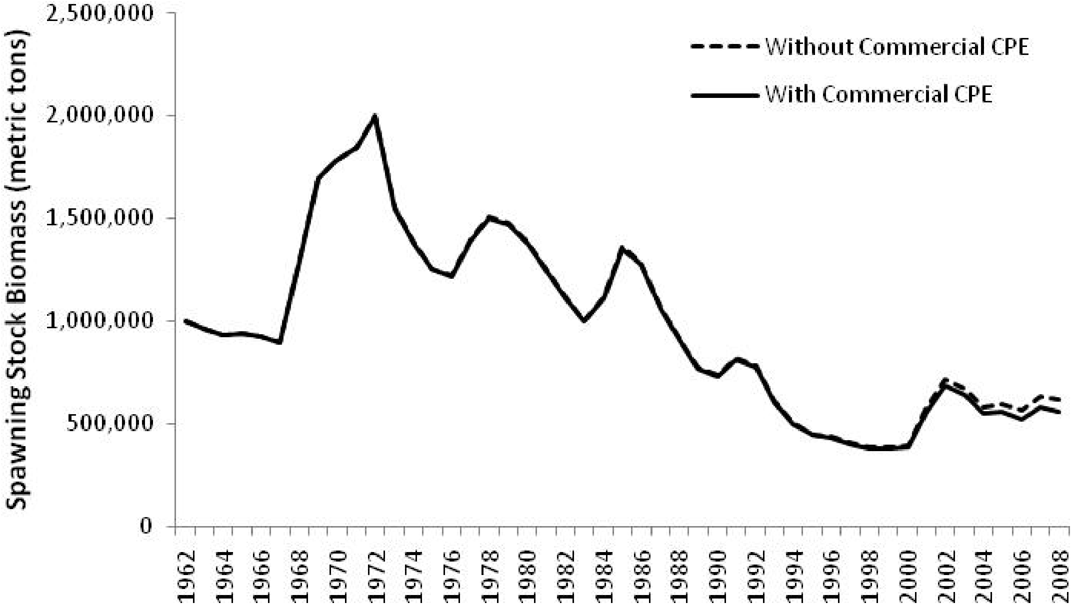


Figure B20. Spawning stock biomass and fishing mortality (averaged for ages 3 to 5) for VPA models with and without commercial mackerel CPE indices from bottom fished and mid-water otter trawls (see text for details). In each of these VPA model, the spring index was split in 1985 (1968-1984; 1985-2008).



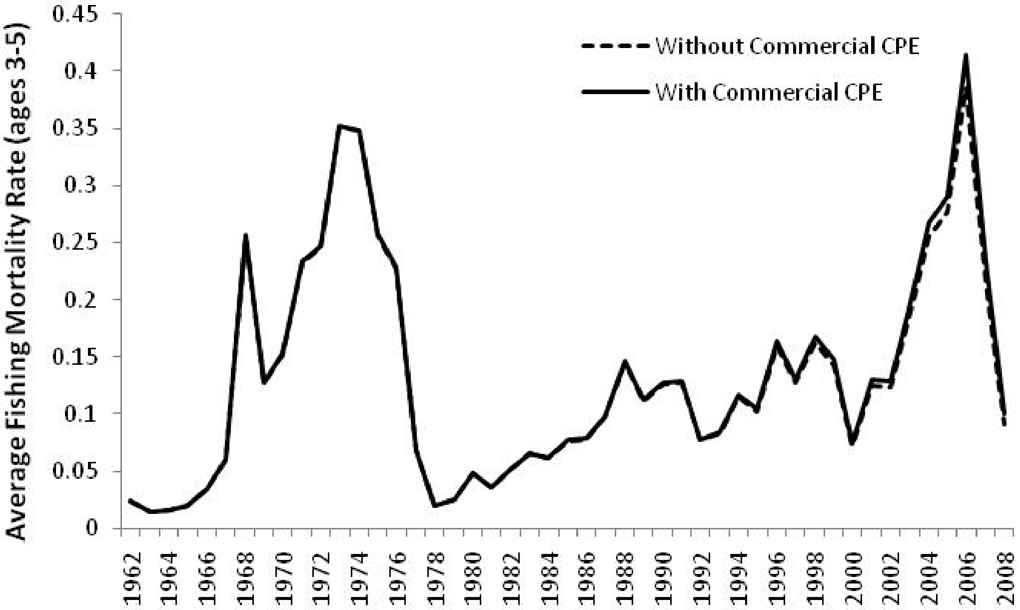


Figure B21. Preliminary spawning stock biomass (mt) and fully selected fishing mortality rate estimates from a statistical catch at age model for Atlantic mackerel during 1962-2008.

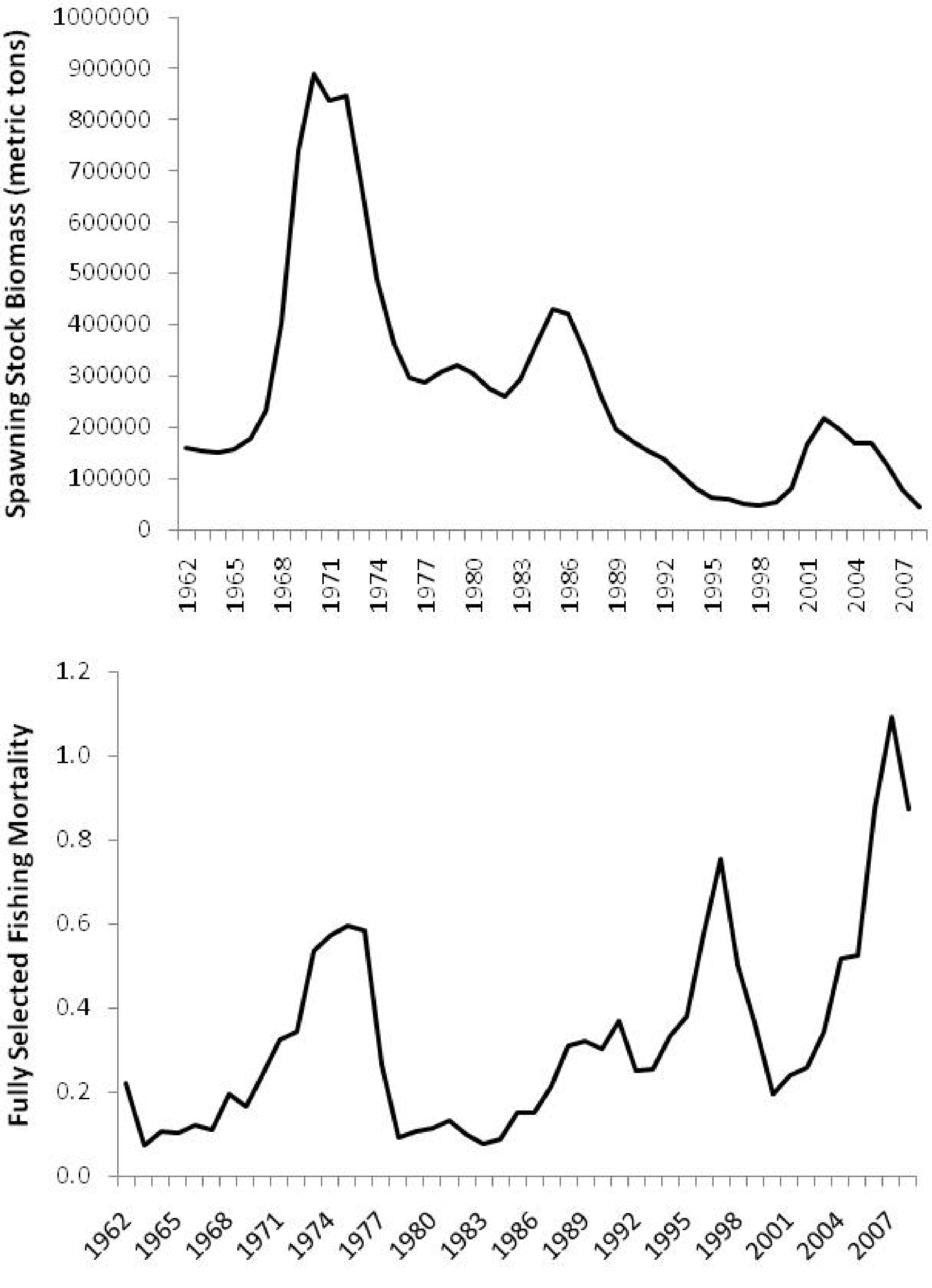


Figure B22. Yield per recruit and spawning stock biomass per recruit versus fishing mortality (see text for details).

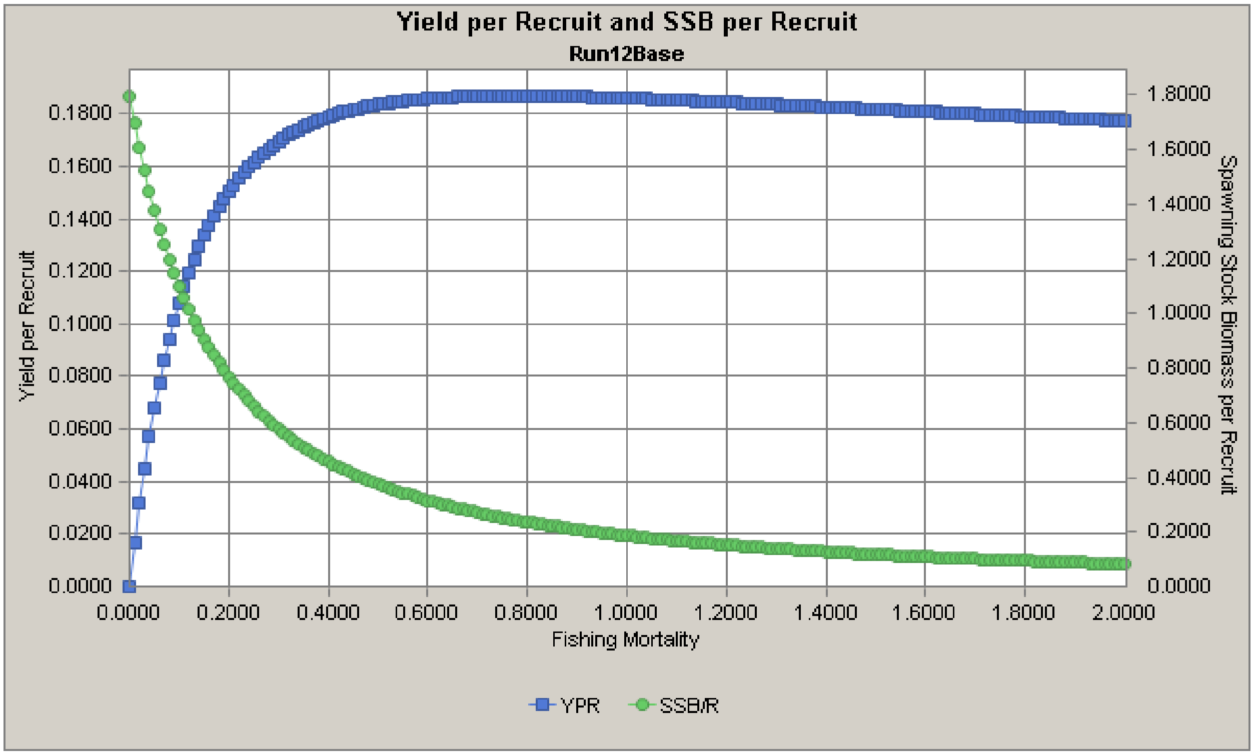
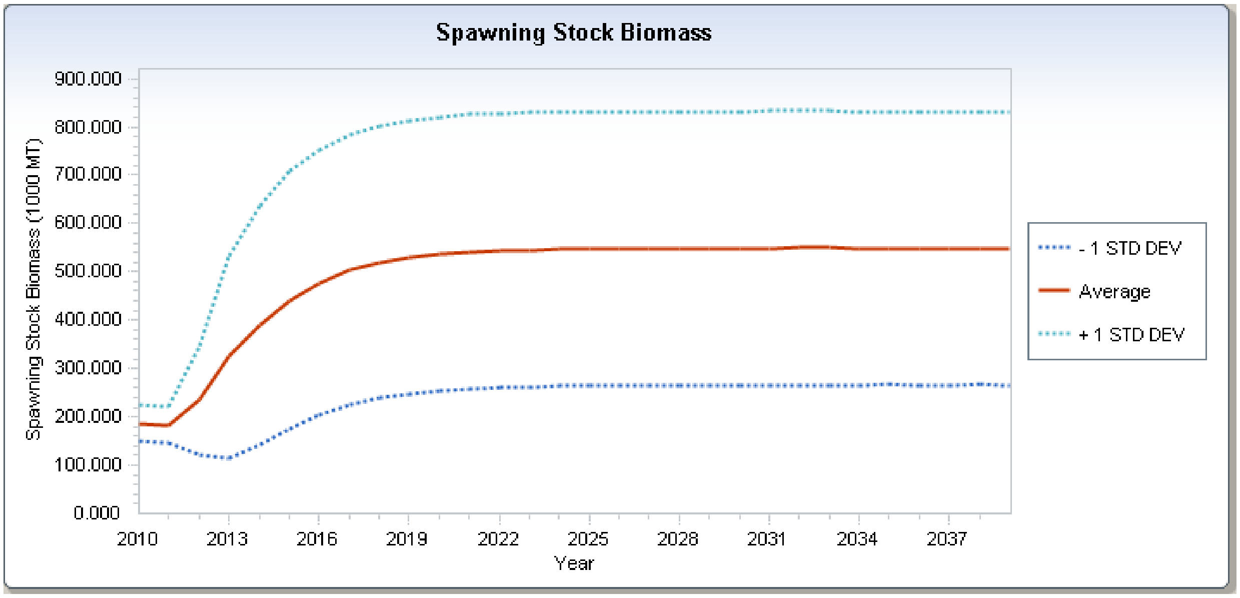
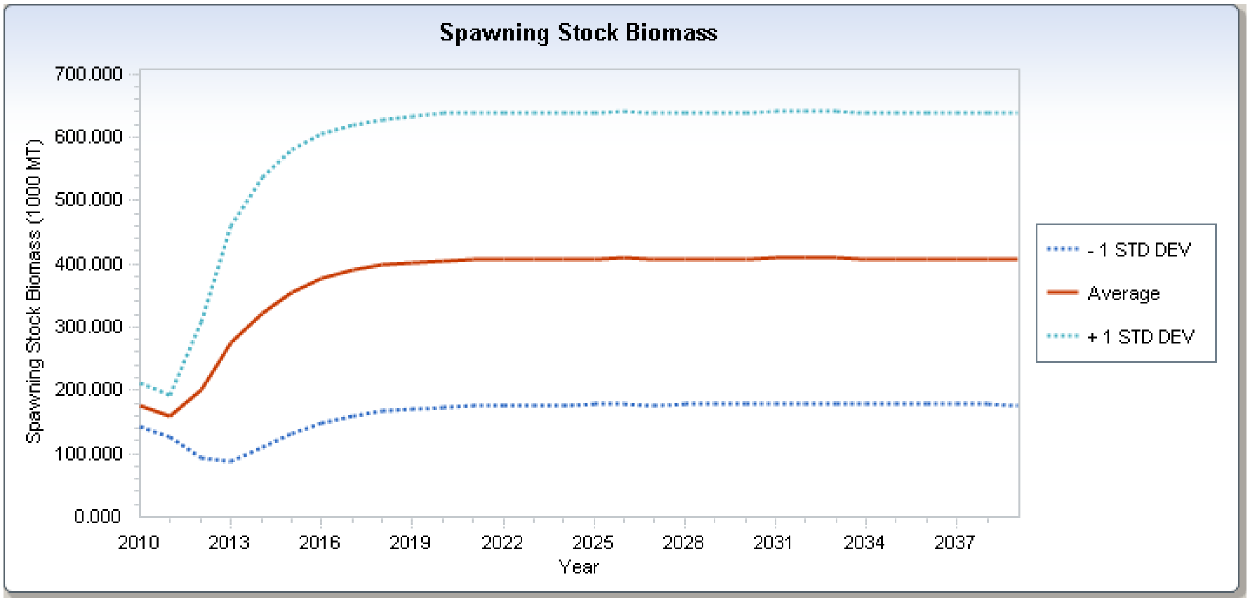


Figure B23. Spawning stock biomass (000s metric tons) from deterministic projections using a fully selected fishing mortality rate equal to $F_{0.1}$ (0.26; top panel) and the 2008 estimate (0.38; bottom panel) from the baseline VPA.

**$F_{0.1}$ = 0.26**



**$F_{2008}$=0.38**



# Working Paper C

## Incorporation of mackerel predation removals into assessment models

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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. 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 C1). 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 model which provided appropriate diagnostics included three fleets (US, 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). Survey series was split at 1984-1985.

Results from the predation model followed the same 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. SSB peaked in 1972 at 1,304,000 mt but since declined to 202,250 mt. The natural mortality (M1 plus M2) at ages 1 and 2 was time variant and averaged 0.45, peaking in 1987 at 0.87. Natural mortality dropped below average in 2000 but has since risen to 0.64 in 2008. F0.1, with average M of 0.45 varying by age (Table C2 and C3) was equal to 0.21 with the associated SSB/R of 0.508. Assuming average recruitment from the time series (average 1968-2008 age 1 recruits equal 688.5 million), SSB at F0.1 would equal 350,000 mt. Consequently, the stock would be not be considered overfished (<1/2 SSBmsy) but overfishing is occurring.

The addition of removals by predators had the most influence on the estimates of abundance and spawning biomass in the mid-1980s. 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. 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, it does provide some additional information not considered with a time and age invariant application of natural mortality rate.

Table C1. 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 C2. Input for yield per recruit analysis using variable M from ASAP predation model.

| age | Selectivity on F | Selectivity on M =0.45 | Stock weights | Catch weights | Spawning stock wts | fraction mature |
|---|---|---|---|---|---|---|
| 1 | 0.13 | 1.00 | 0.14 | 0.14 | 0.14 | 0.10 |
| 2 | 0.48 | 1.00 | 0.24 | 0.24 | 0.24 | 0.60 |
| 3 | 0.81 | 0.81 | 0.35 | 0.34 | 0.34 | 1.00 |
| 4 | 0.95 | 0.38 | 0.43 | 0.42 | 0.42 | 1.00 |
| 5 | 0.99 | 0.22 | 0.50 | 0.49 | 0.49 | 1.00 |
| 6 | 1.00 | 0.22 | 0.55 | 0.54 | 0.54 | 1.00 |
| 7 | 1.00 | 0.22 | 0.60 | 0.59 | 0.59 | 1.00 |
| 8 | 1.00 | 0.22 | 0.64 | 0.63 | 0.63 | 1.00 |
| 9 | 1.00 | 0.22 | 0.67 | 0.66 | 0.66 | 1.00 |
| 10+ | 1.00 | 0.22 | 0.70 | 0.69 | 0.69 | 1.00 |

Table C3. Results of yield per recruit analysis using variable M from ASAP predation model.

|  | F | YPR | SSB/R | B/R | mean age | mean gen. time | expected spawnings |
|---|---|---|---|---|---|---|---|
| F zero | 0 | 0 | 1.302 | 1.621 | 4.935 | 7.712 | 1.852 |
| F0.1 | 0.210 | 0.101 | 0.508 | 0.819 | 2.961 | 5.266 | 0.968 |
| Fmax | N/A |  |  |  |  |  |  |
| F40% | 0.203 | 0.100 | 0.521 | 0.833 | 3.001 | 5.330 | 0.986 |

Figure C1. Estimates of fishing mortality for U.S. and Canadian fleets from ASAP model with predation.

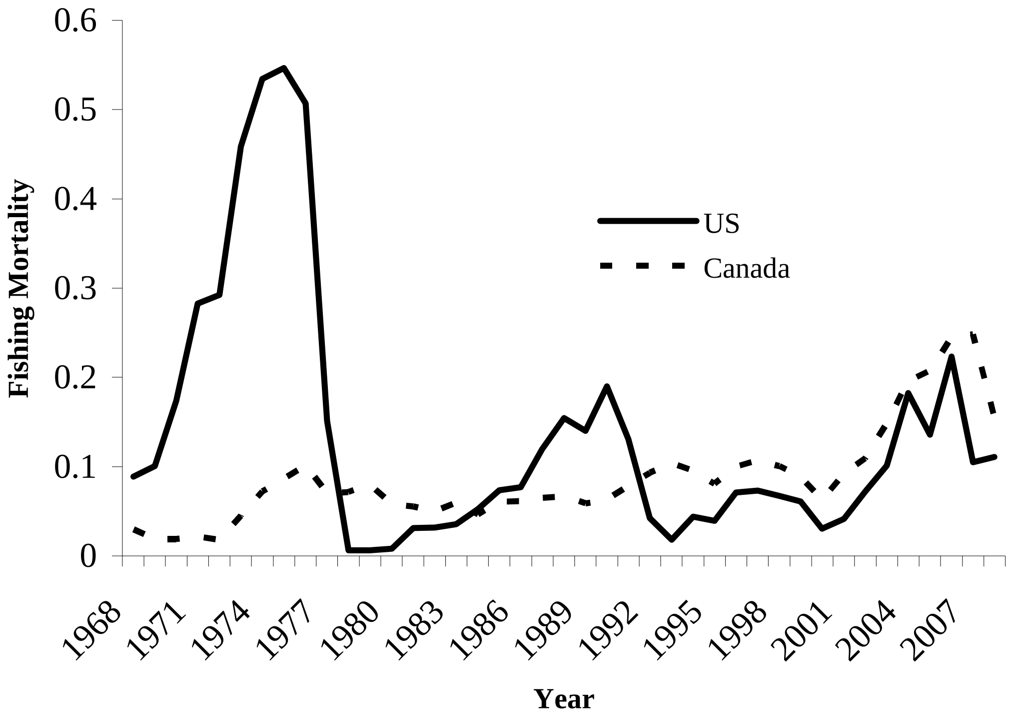


Figure C2. Estimates of total abundance (millions) from ASAP model with predation.

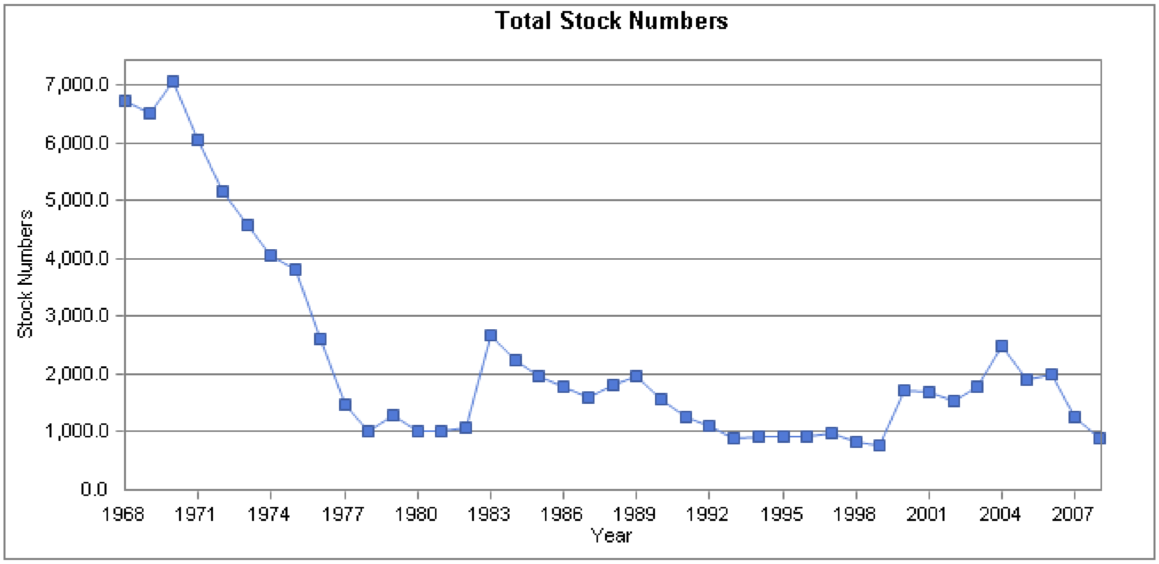


Figure C3. Estimates of spawning stock biomass (000s mt) from ASAP model with predation.

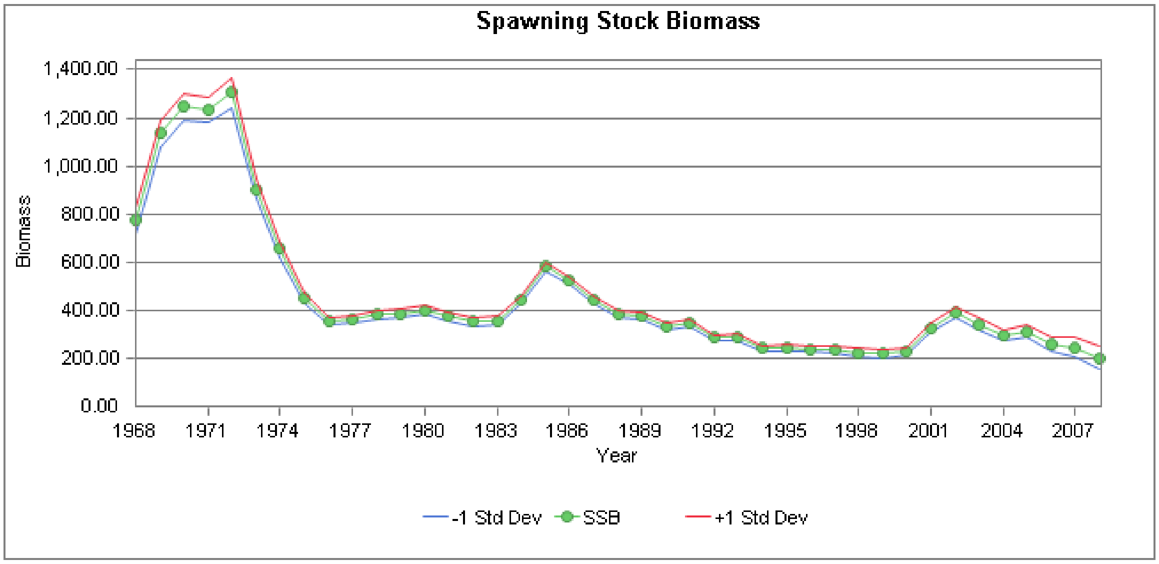


Figure C4. Estimates of age 1 recruitment (millions) from ASAP model with predation.

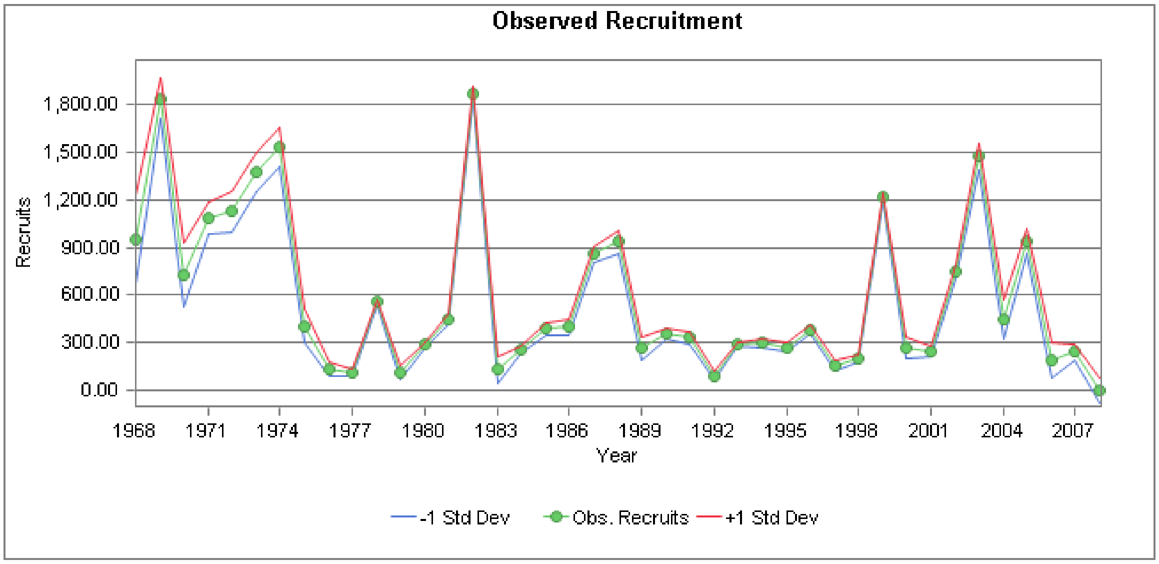
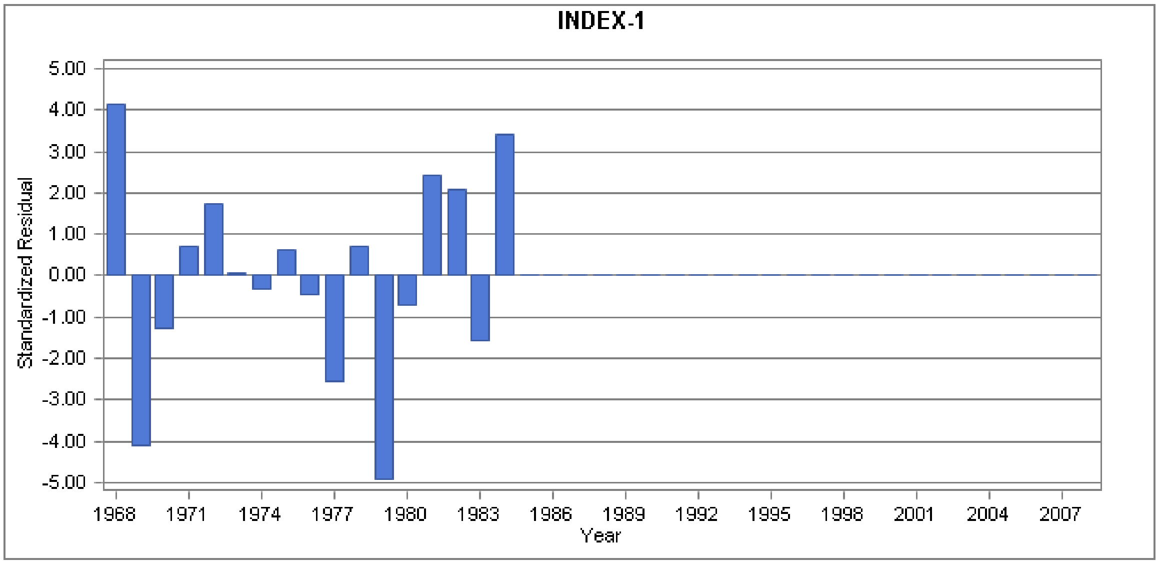
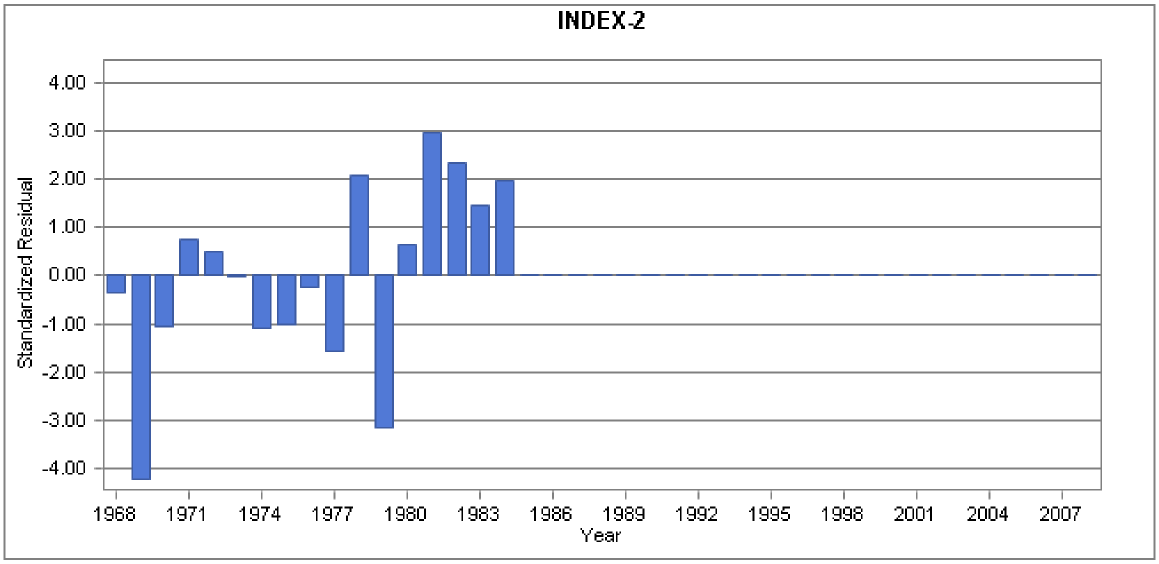
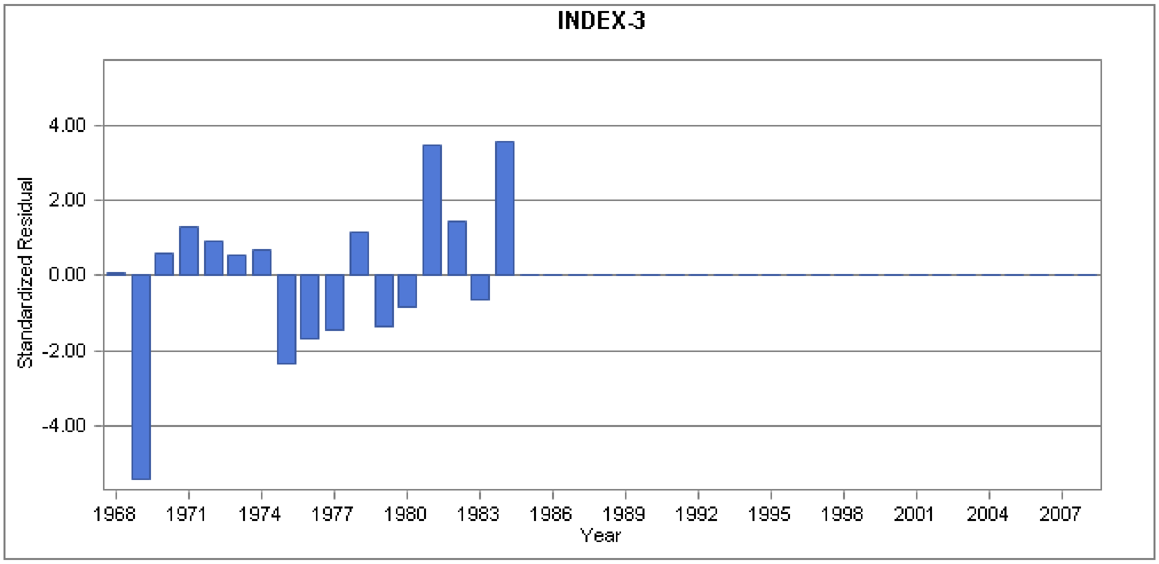


Figure C5. Standardized residuals for survey indices for 1968-1984, ages 1-10+ (indices 1-10), and 1985-2008, ages 1-10+ (indices 11-20).



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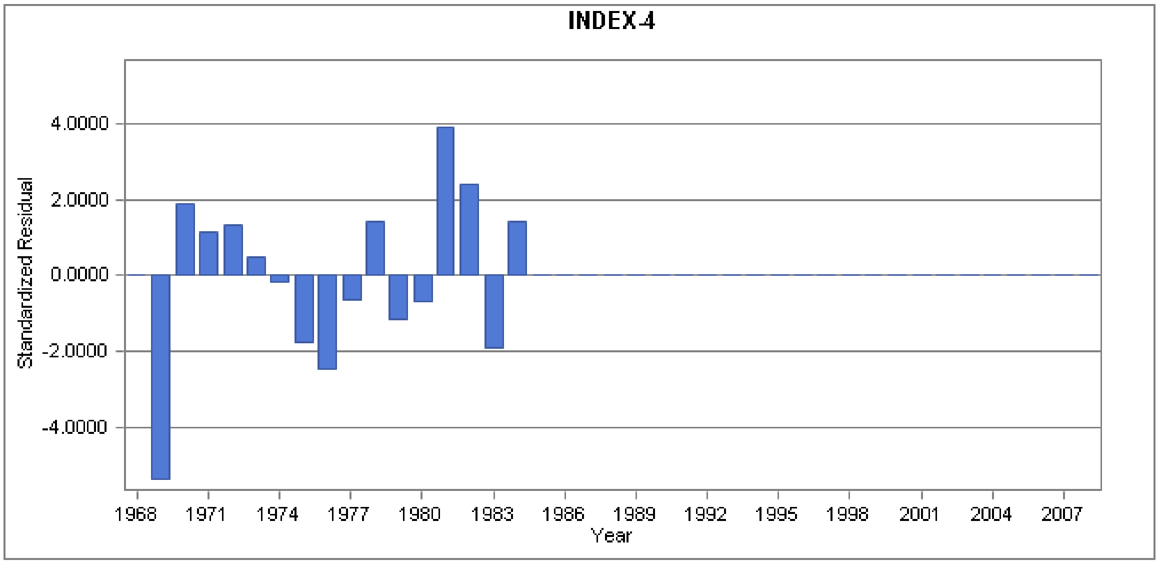
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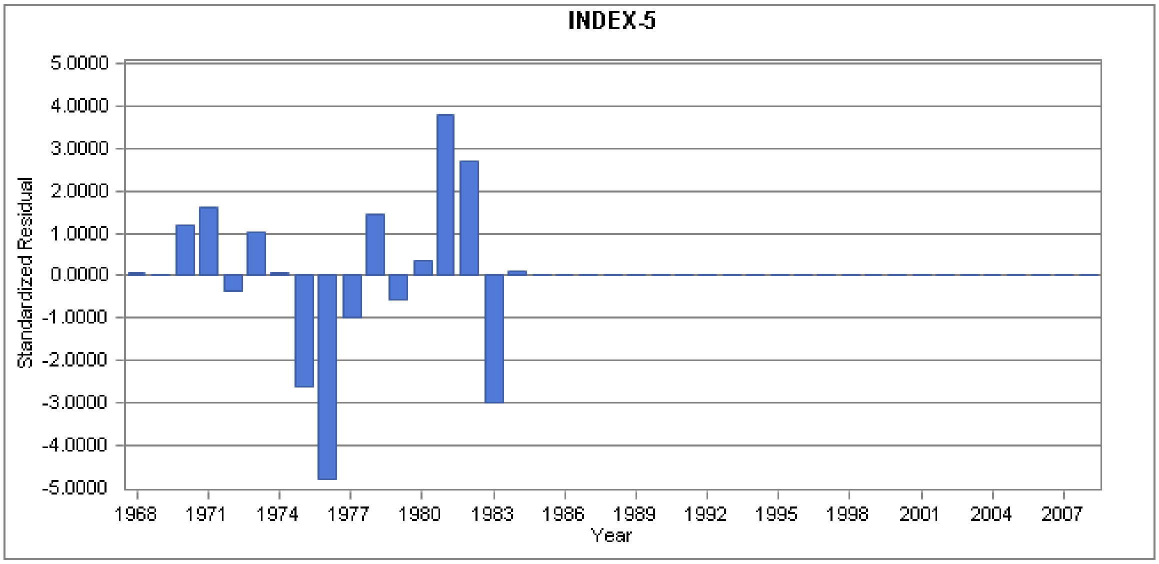
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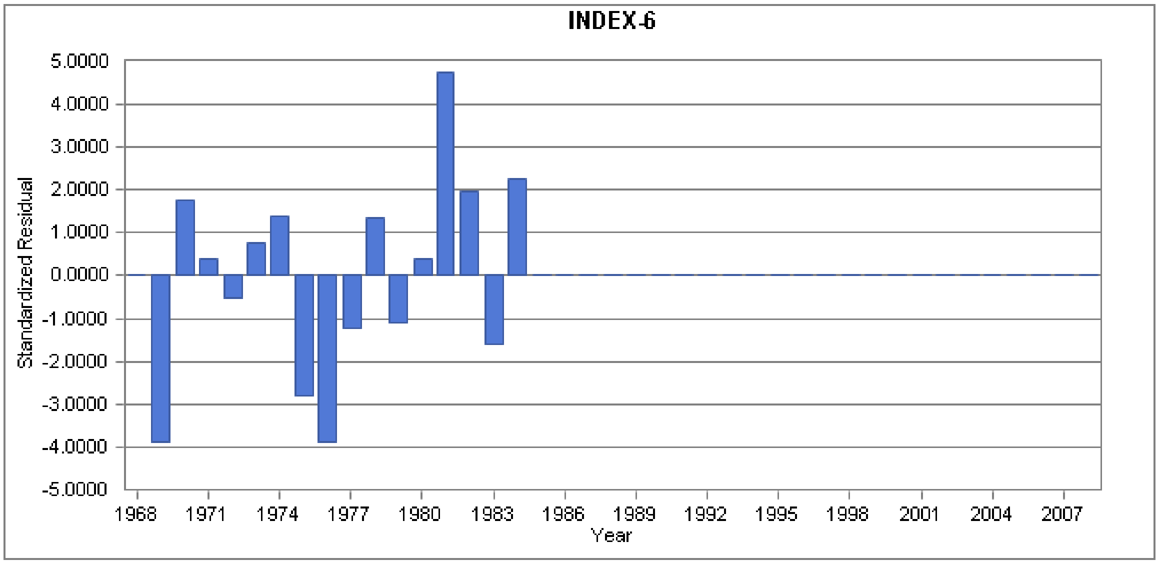
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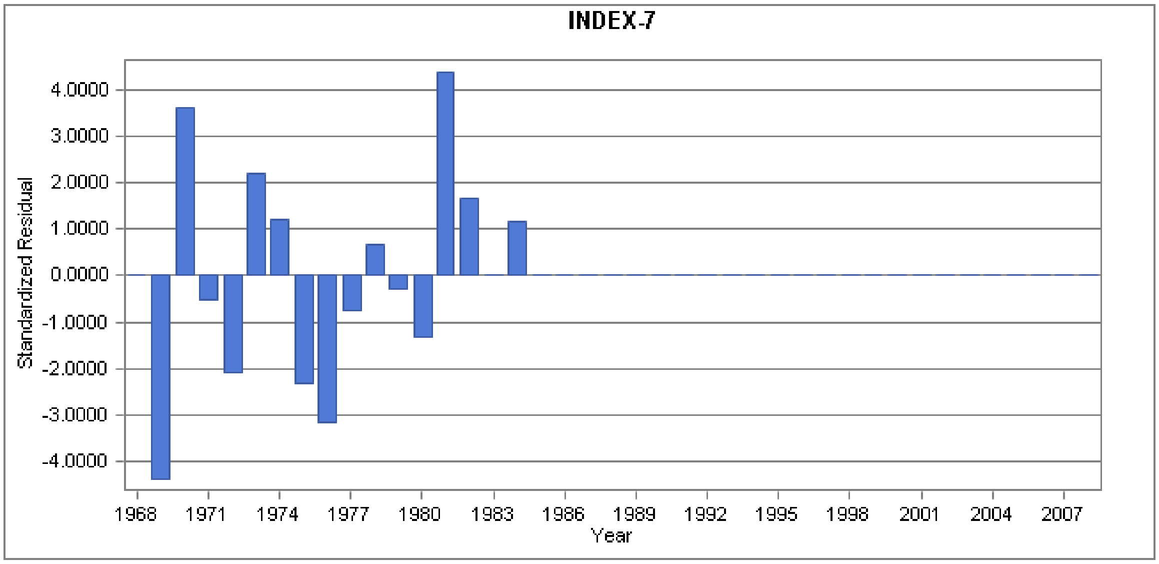
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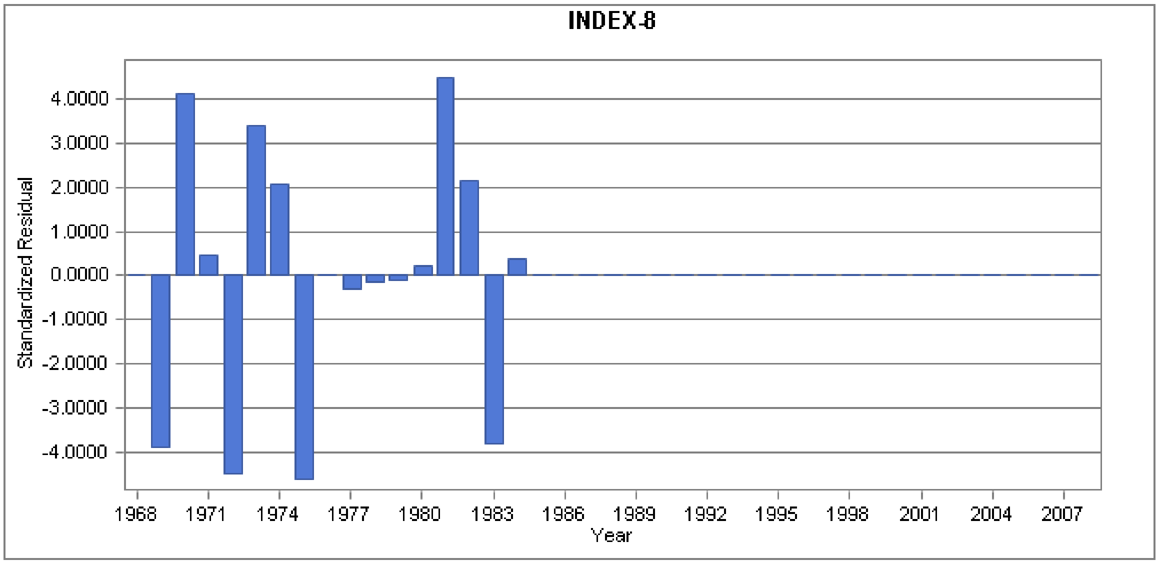
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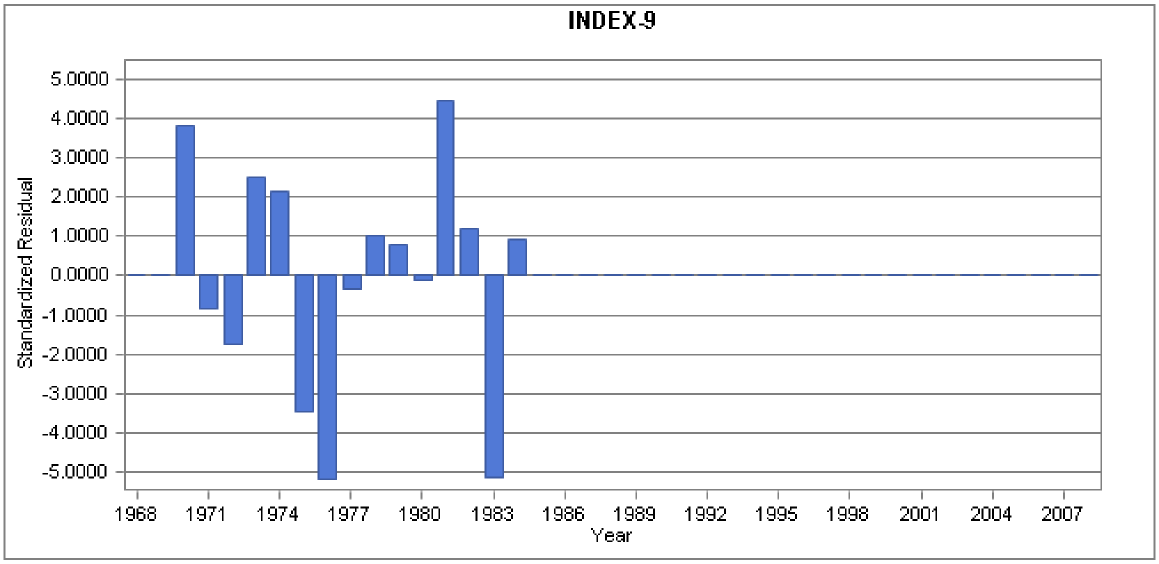
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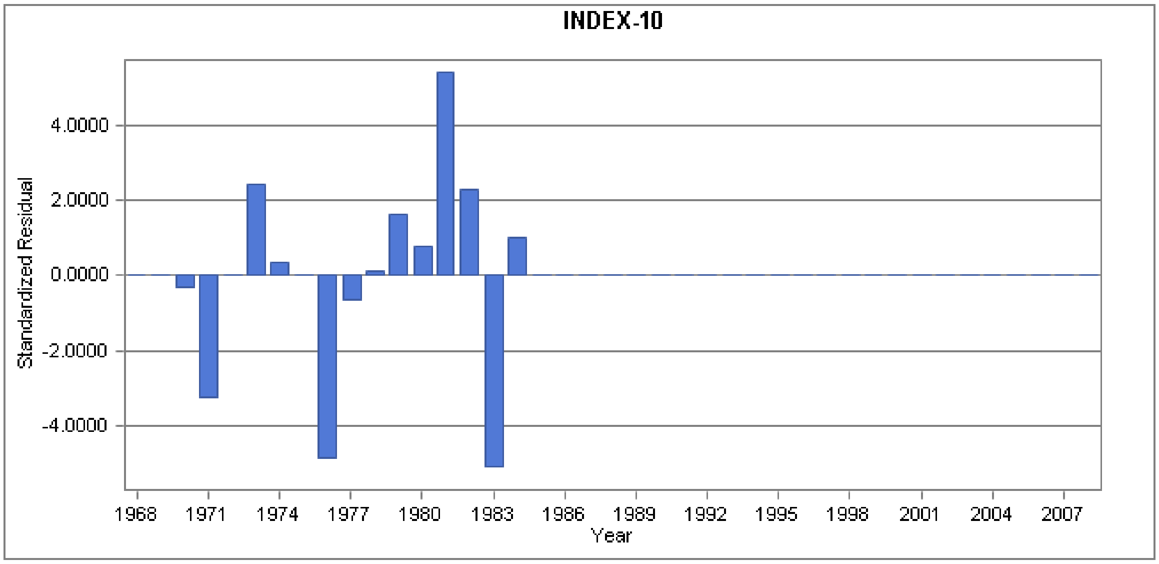
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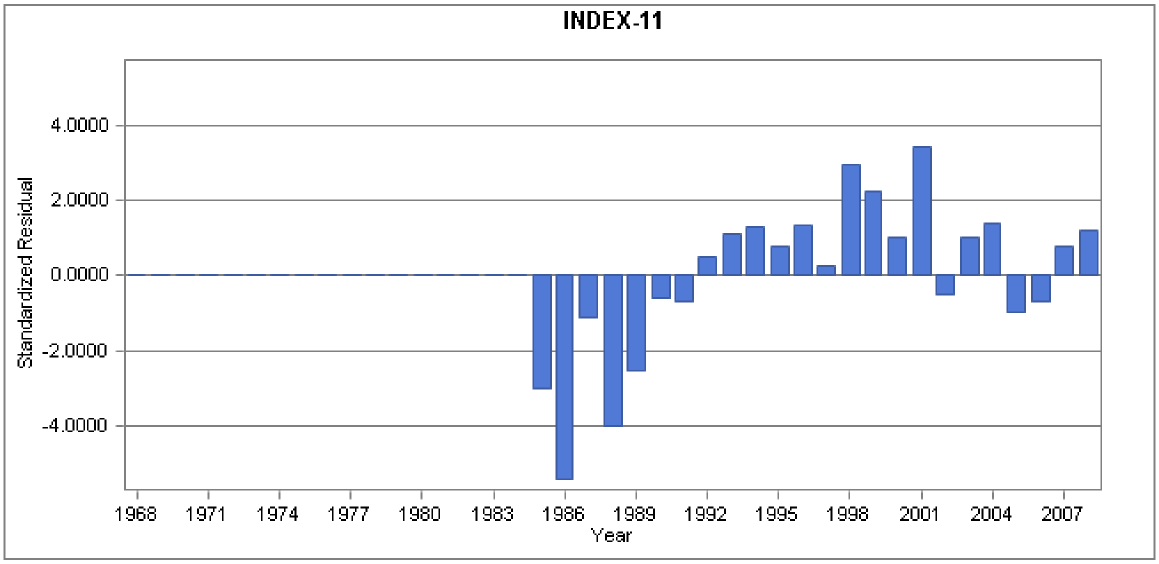
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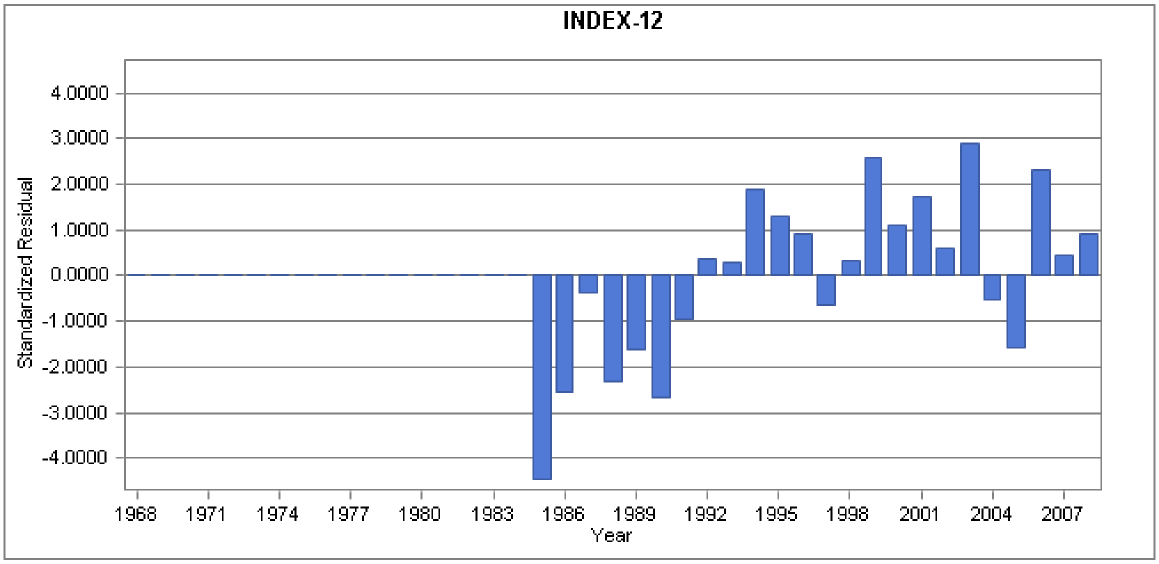
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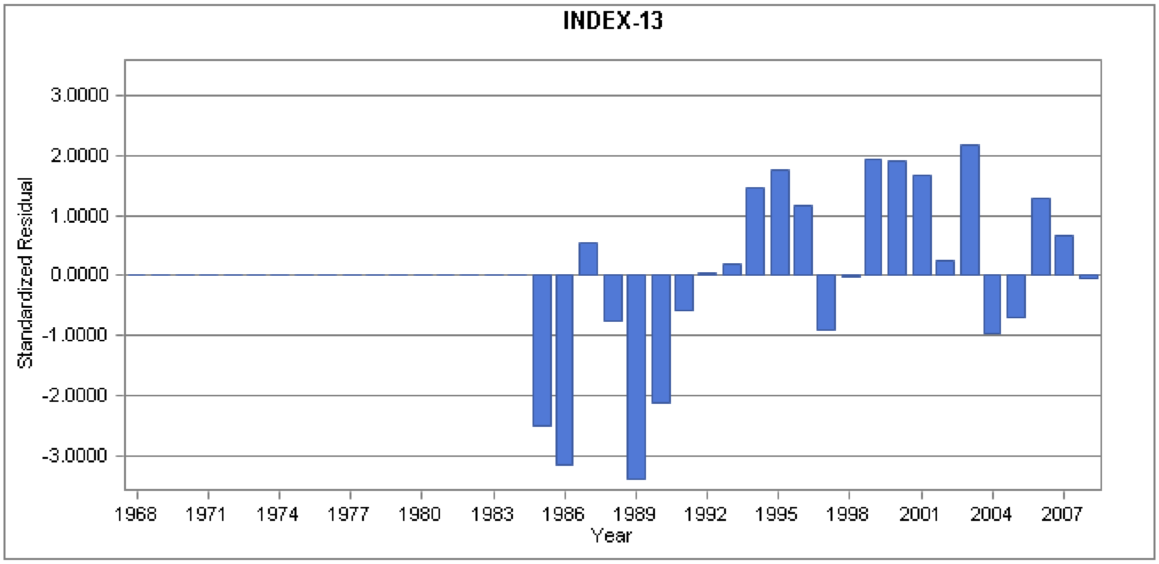
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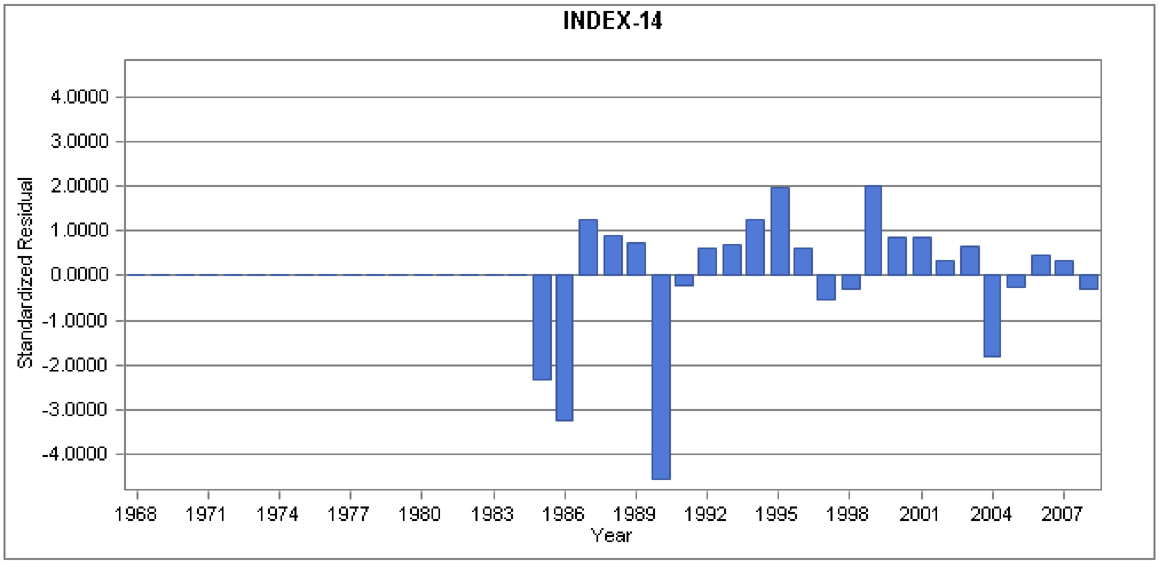
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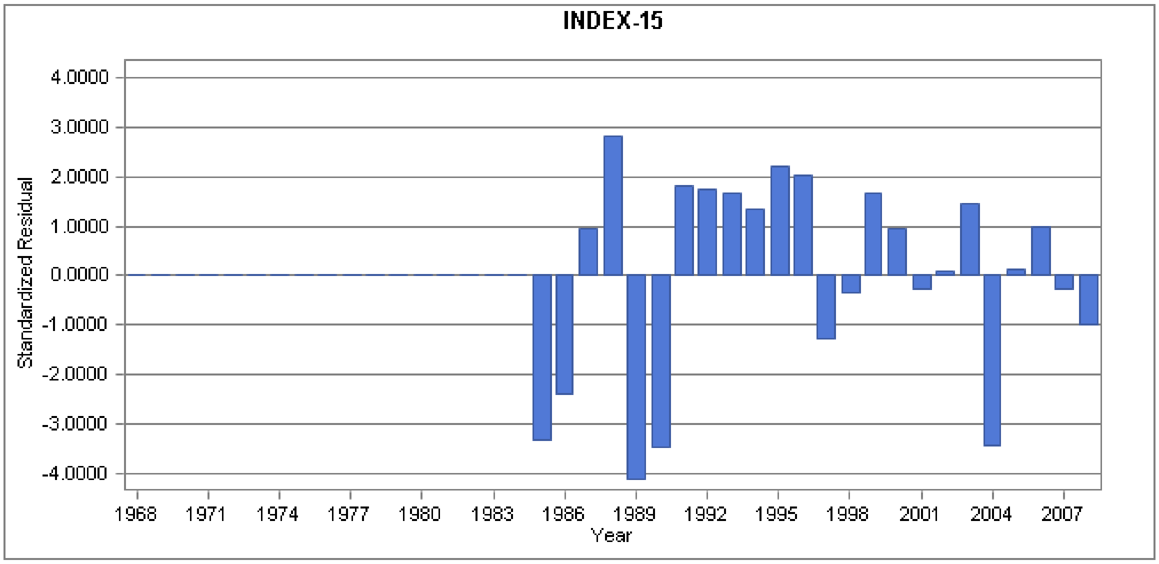
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1971
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1989
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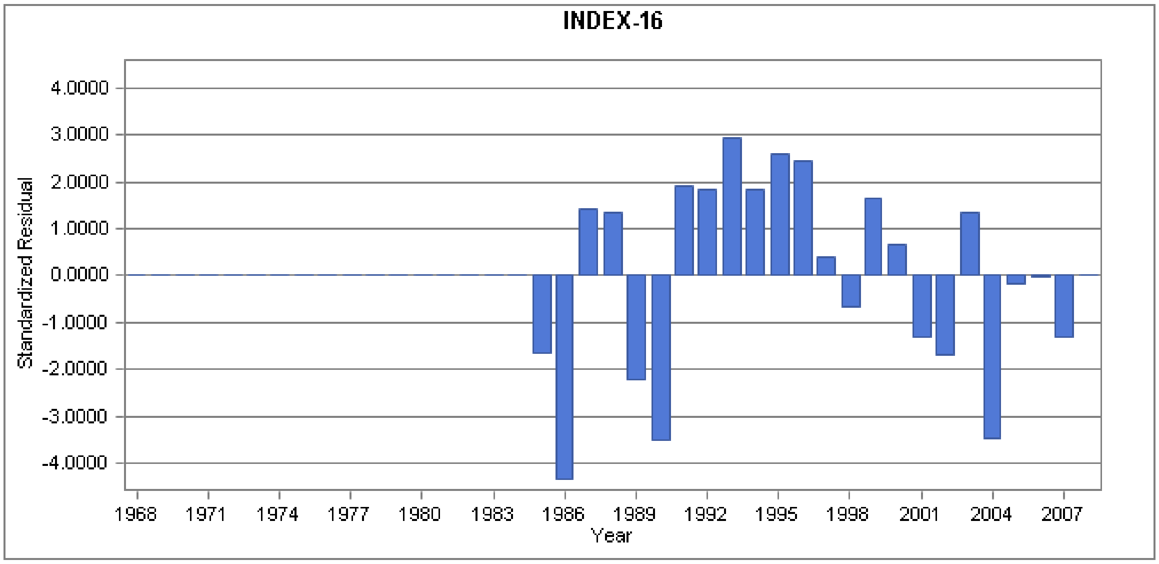
1998
2001
2004
2007
Year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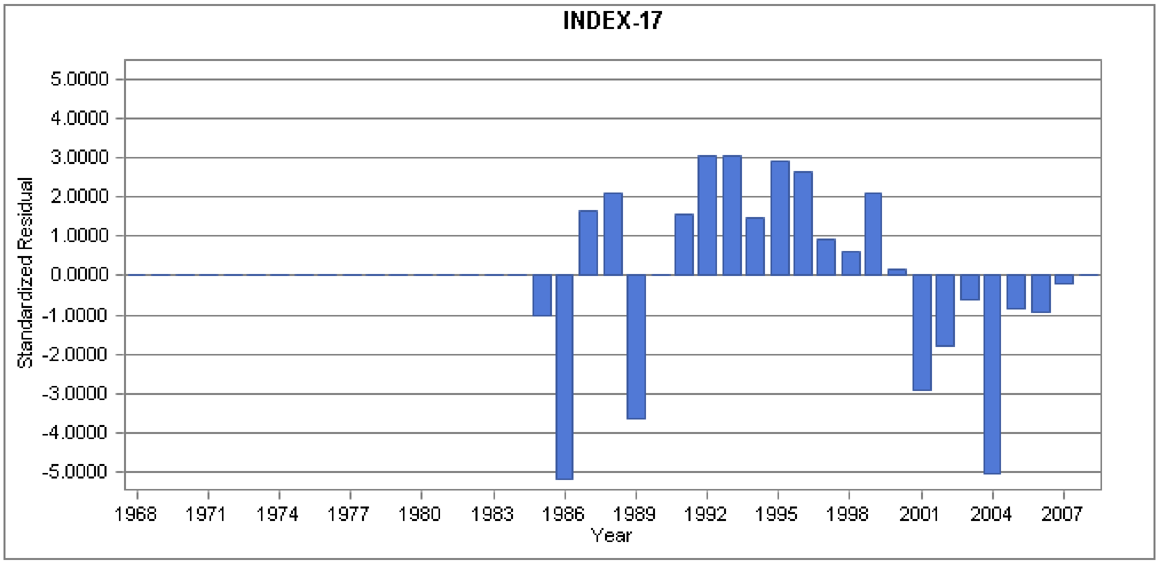
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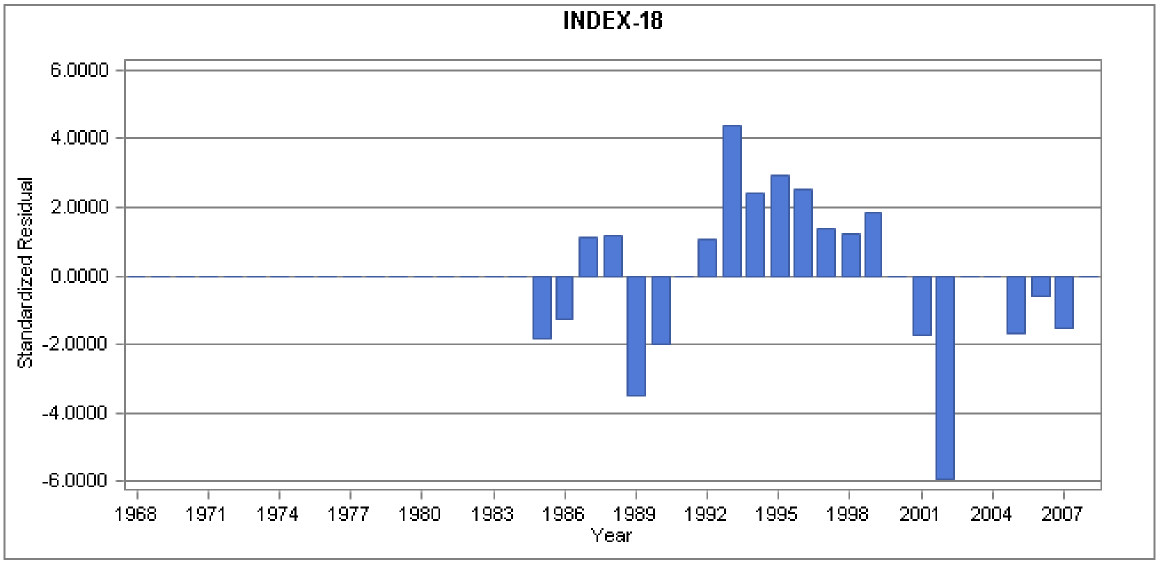
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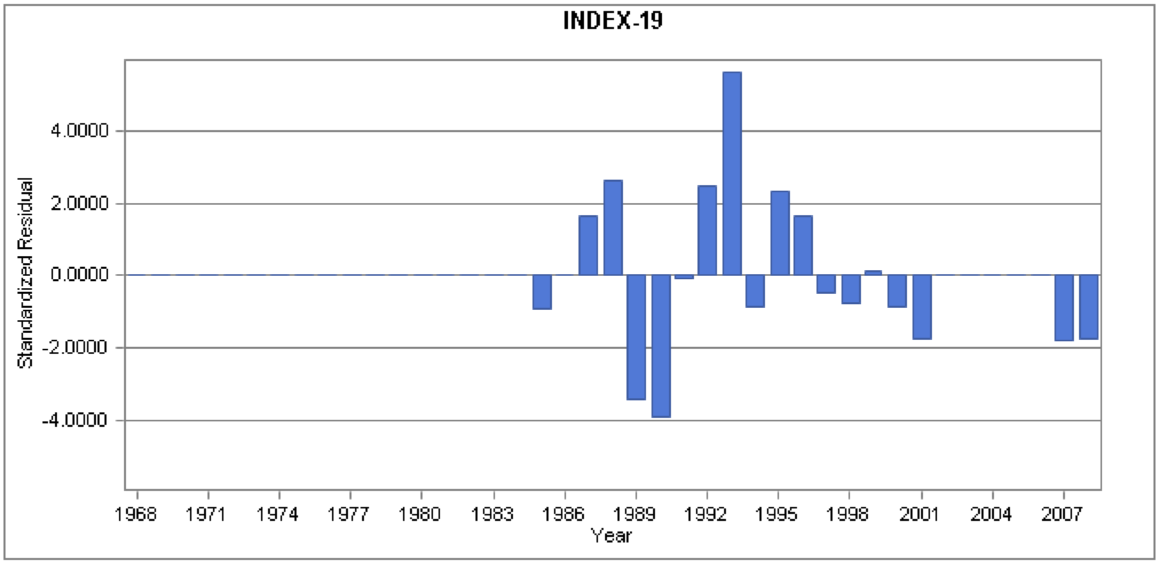
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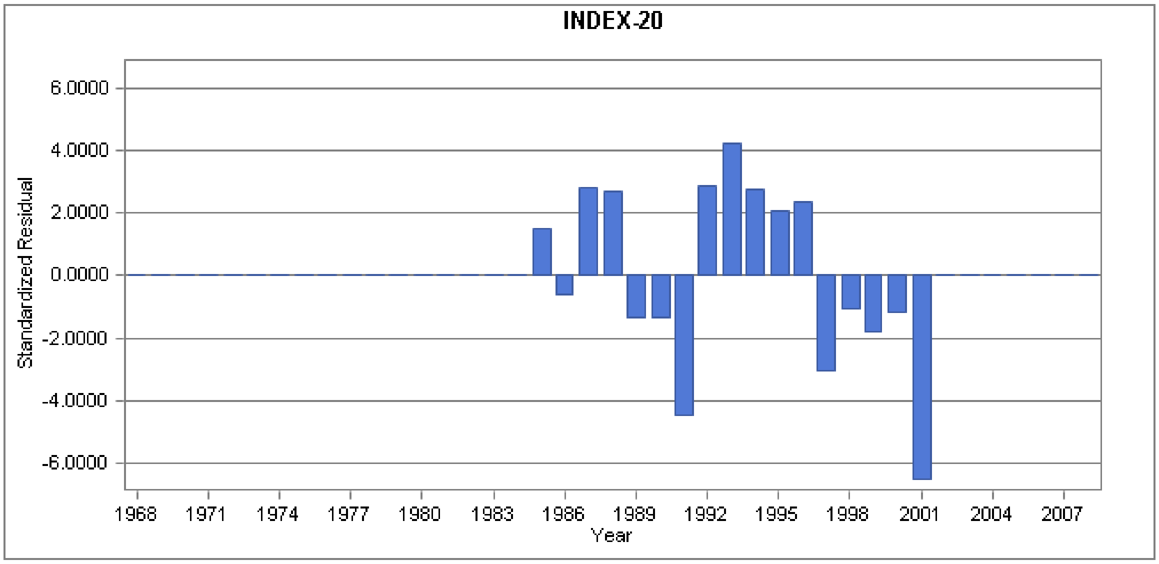
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1980
1983
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2004
2007
Year

Figure C6. Natural mortality of Atlantic mackerel estimated from ASAP model with predation (age 1, M1 + predation fleet F).

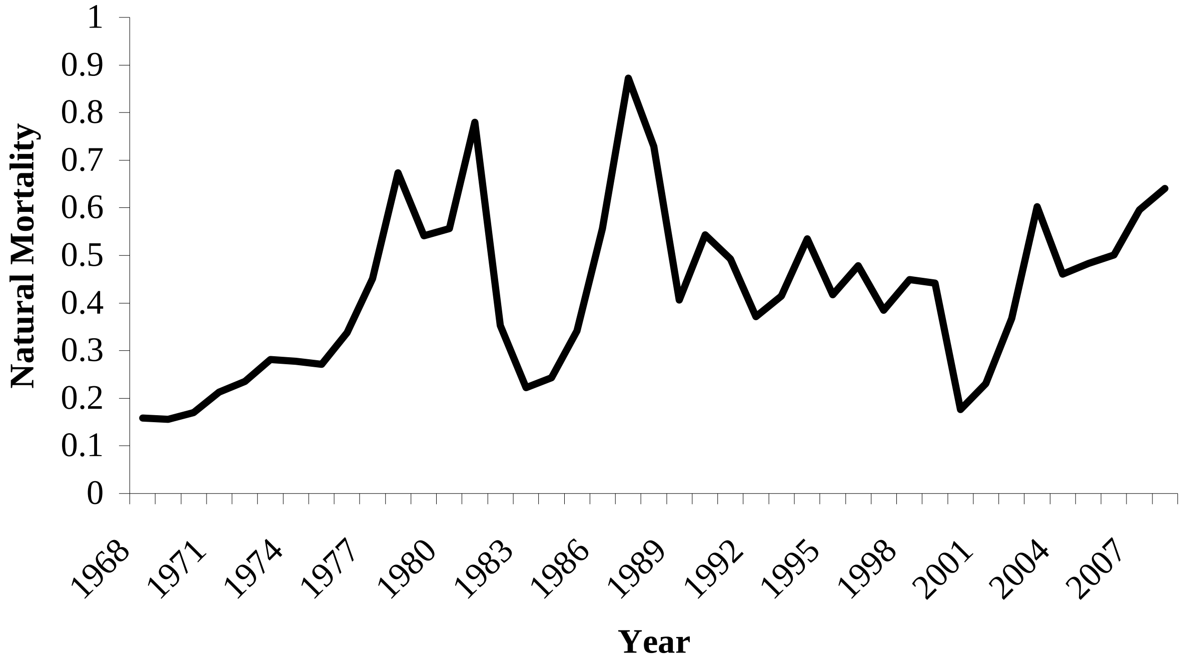
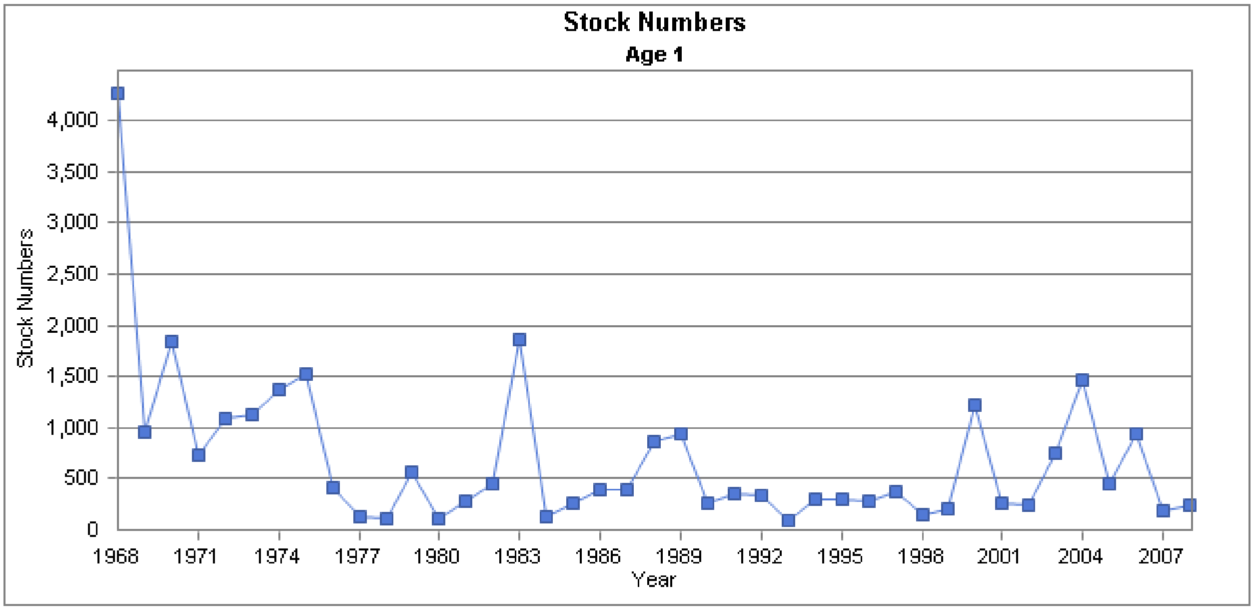
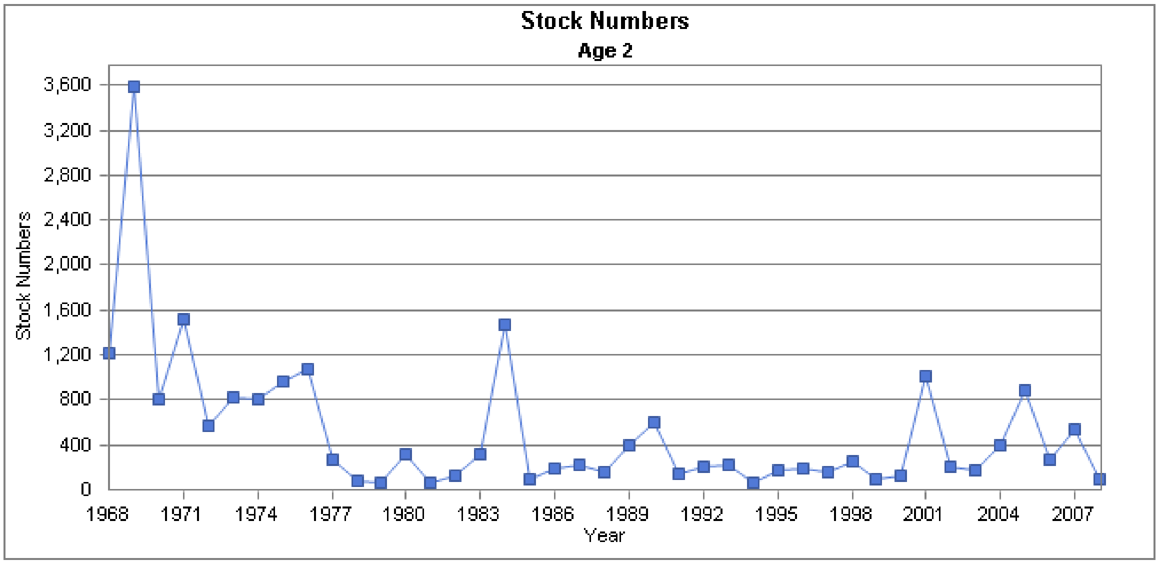


Figure C7. Estimates of mackerel abundance at age (millions) from ASAP model with predation .

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1995
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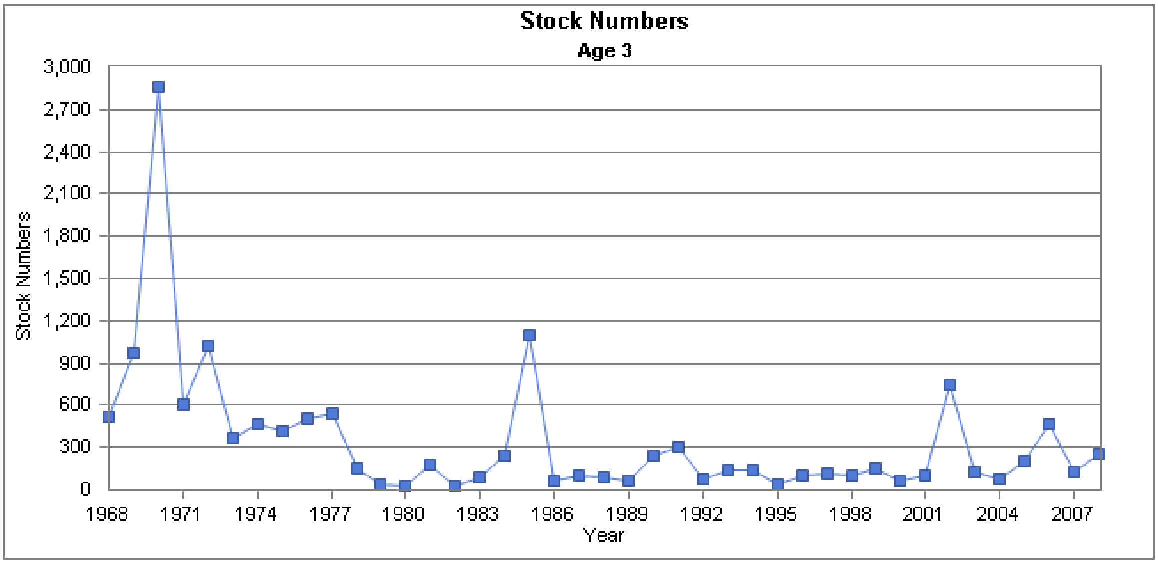
2001
2004
2007
Year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2001
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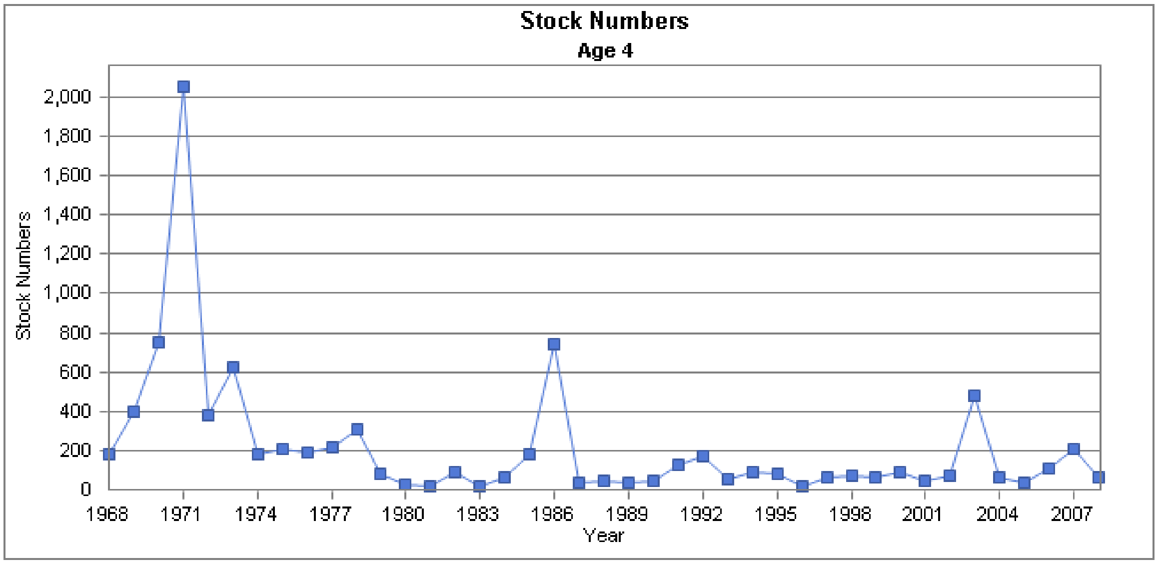
2007
Year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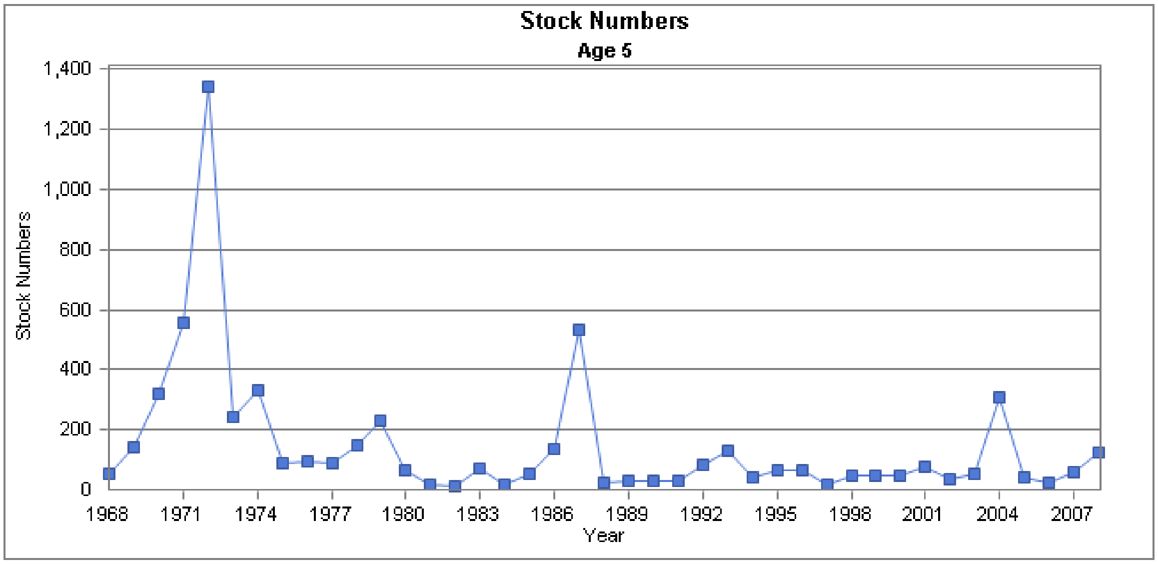
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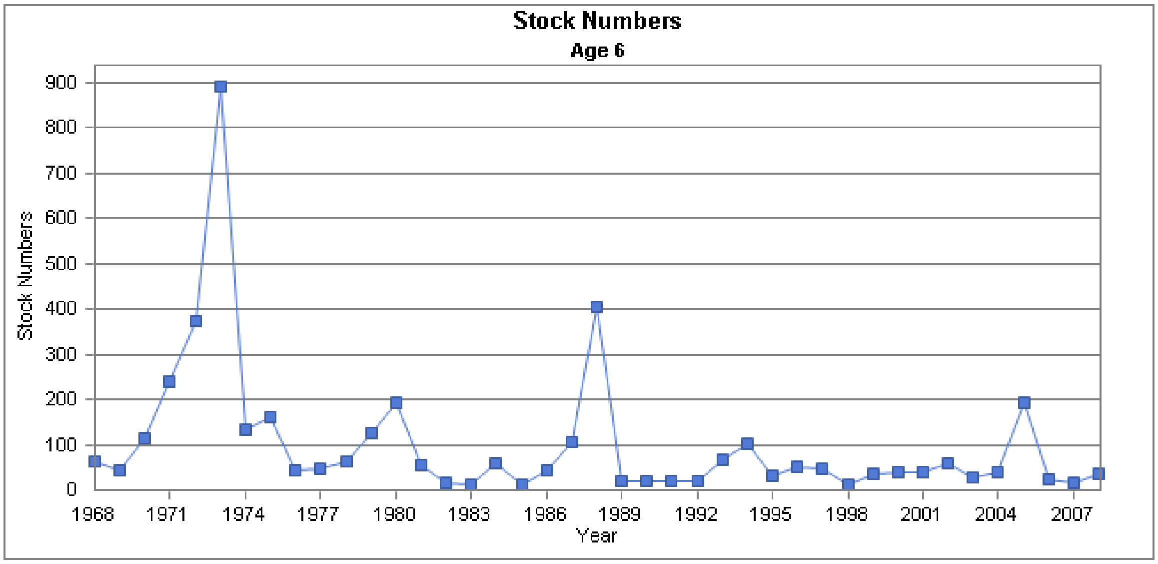
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Age 6
Stock Numbers
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300
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1971
1974
1977
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1983
1986
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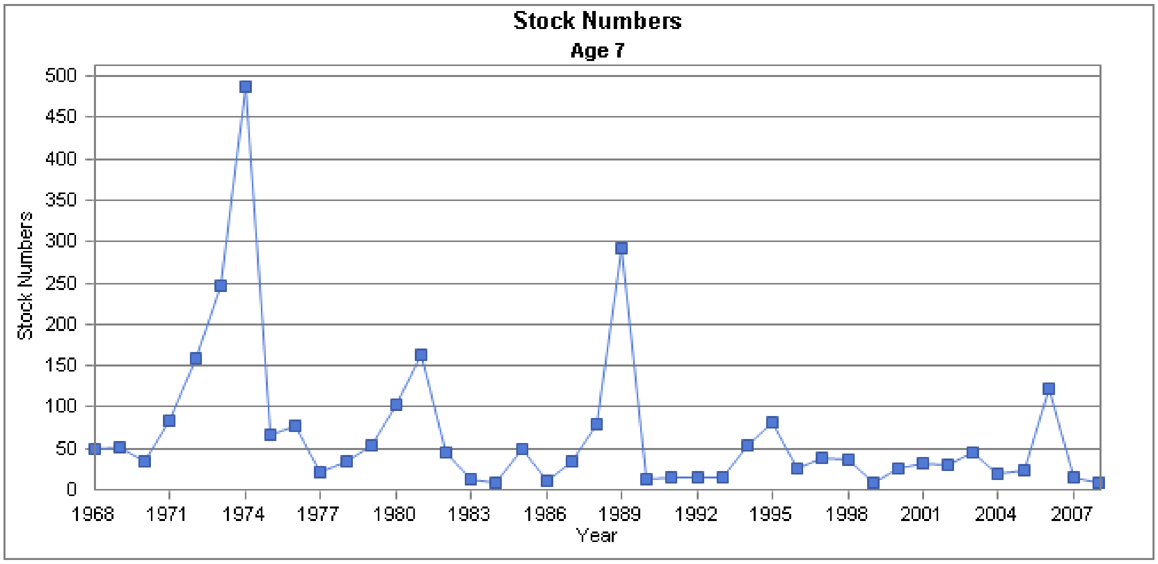
2001
2004
2007
Year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Age 7
Stock Numbers
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400
350
300
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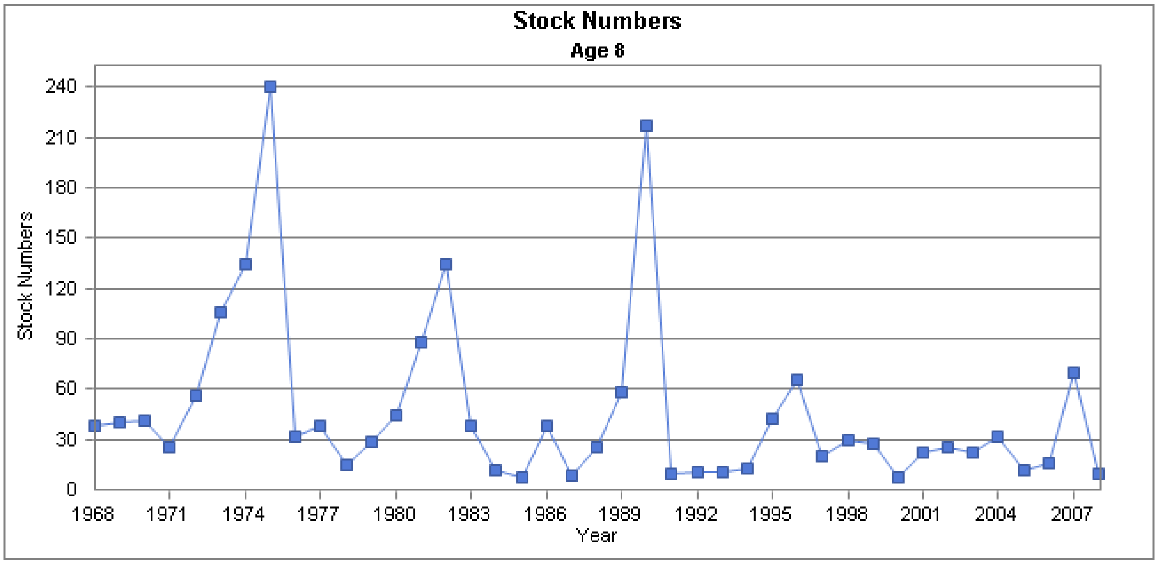
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year


Stock Numbers
Age 8
Stock Numbers
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180
150
120
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30
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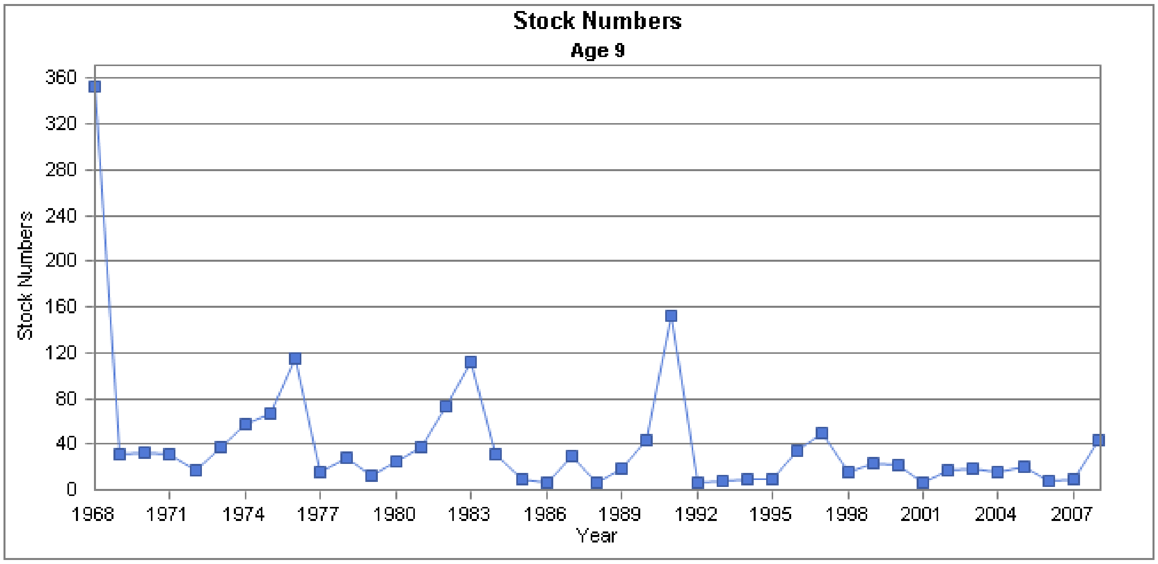
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year


Stock Numbers
Age 9
Stock Numbers
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240
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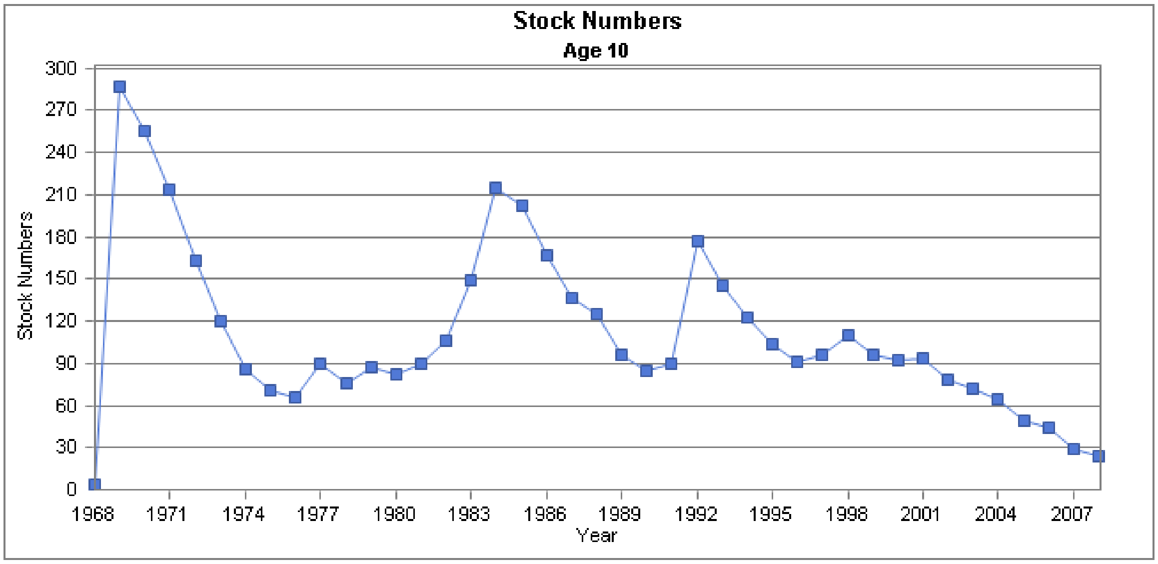
1986
1989
1992
1995
1998
2001
2004
2007
Year


Stock Numbers
Age 10
Stock Numbers
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180
150
120
90
60
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0
1968
1971
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1977
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1983
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1989
1992
1995
1998
2001
2004
2007
Year

Figure C8. Comparison of mackerel abundance from models with and without predation.

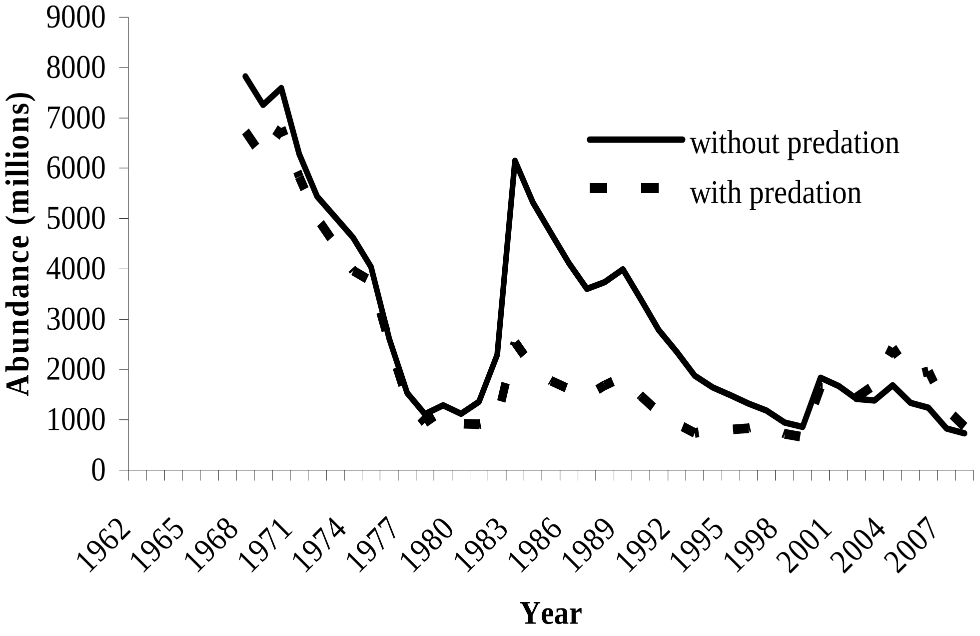

Figure C9.Comparison of mackerel fishing mortality from models with and without predation.

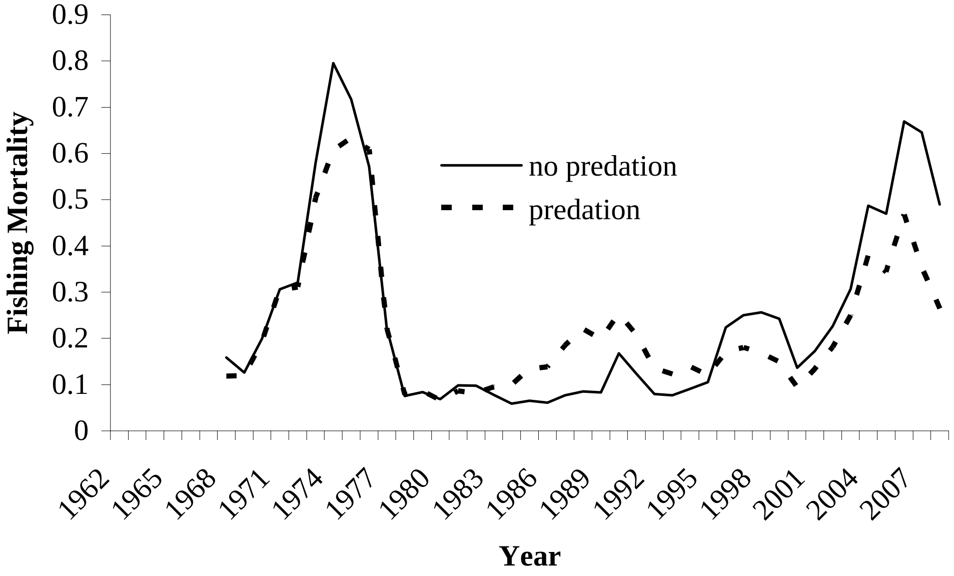

Figure C10. Comparison of mackerel spawning stock biomass (000s mt) from models with and without predation.

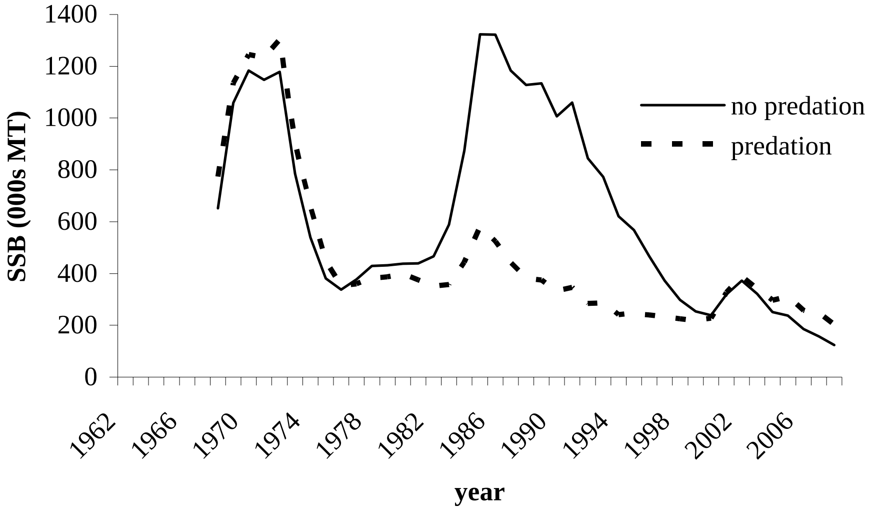

Figure C11. Comparison of mackerel age 1 recruitment (millions) from models with and without predation.