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An Assessment of the Northwest Atlantic Mackerel (*Scomber scombrus* L.) with XSA (Extended Survivors Analysis)

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ABSTRACT

The abundance of Northwest Atlantic mackerel (*Scomber scombrus* L.) was evaluated using extended survivors analysis (XSA). The selected formulations have all presented adjustment problems that could be explained by a conflict between the catch at age and abundance index data. Despite these problems, the results were similar to those produced by analysis methods that do not require an abundance index. All these results suggest that current data describing the demographic structure and measuring the Atlantic mackerel abundance are not consistent with traditional methods of analytical assessment.

RÉSUMÉ

L’abondance du maquereau bleu (*Scomber scombrus* L.) du Nord-Ouest de l’Atlantique a été évaluée à l’aide de l’analyse étendue des survivants (XSA). Les formulations retenues ont toutes présenté des problèmes d’ajustement qui pourraient s’expliquer par un conflit entre les données de la capture à l’âge et celles de l’indice d’abondance. Malgré ces problèmes, les résultats obtenus se sont avérés semblables à ceux produits par des méthodes d’analyse n’utilisant pas d’indice d’abondance. Tous ces résultats portent à croire que les données actuelles décrivant la structure démographique et mesurant l’abondance du maquereau bleu ne se prêtent pas bien aux méthodes traditionnelles d’évaluation analytique.

INTRODUCTION

The abundance of Northwest Atlantic mackerel (*Scomber scombrus* L.) was evaluated in March 2010 by the Transboundary Resources Assessment Committee (TRAC). Various analytical models were presented during this assessment as well as different formulations of the same model. A first model, the separable VPA (Pope and Shepherd 1982), was carried out using only the catch at age. A second model, the traditional VPA (Darby and Flatman 1994), was run with abundance and fishing mortalities data from the separable VPA. The results of these models were described and compared in Grégoire and Maguire (2011).

The objective of this document is to present the results of an assessment conducted using a third analytical model, the extended survivors analysis (XSA). Unlike the separable VPA, XSA requires the input of one or several abundance indices.

MATERIAL AND METHODS

XSA

The extended survivors analysis (Shepherd 1992, 1999) is an extension of the survival analysis developed by Doubleday (1976, 1981). Compared to the latter, XSA allows the use of several abundance indices from scientific surveys and/or catch per unit effort from the commercial fishery. XSA is widely used by ICES for groundfish assessments. As part of this study, different formulations were tested using the VPA software, version 3.2 (Darby and Flatman 1994).

Data Input

The assessment by XSA covered the period 1962-2008. For each formulation tested, the input data were: (1) catch ('000) at age, (2) catch weight (kg) at age, (3) population weight (kg) at age based on the Rivard method (NOAA Fisheries Toolbox 2009a), and (4) maturity at age (Canadian data). Natural mortality was set at 0.2 for all years and ages, and the proportions of natural and fishing mortality before spawning at 0.5.

Index of Abundance

XSA was calibrated using an index of abundance from a spring bottom trawl survey (Dr. Gary Shepherd and Dr. Jon Deroba, NOAA Fisheries, pers. com.). Mean catch per set in numbers and weight were presented as well as mean numbers per set at age. The year-classes were described as the proportion of young age groups (ages 1-3 and ages 1-4). The follow-up of the year-classes in the survey was realized by comparing the abundance of adjacent age groups (i.e. ages 1-2, ages 2-3, etc...).

The instantaneous rates of total mortality (Z) were calculated from the relationship between the catches per set from several age groups for consecutive years. For example, the Z estimate for 2007 for the age groups 4^+ and 5^+ was calculated as follows:

$$\ln\left(\sum \text{age } 4^+ \text{ for } 2007 \Big/ \sum \text{age } 5^+ \text{ for } 2008\right)$$

The instantaneous rates of total mortality were also calculated based on the Sinclair (1998) method for blocks of 4 and 5 years and for age groups 2-6, 3-7 and 4-8. Supposing a constant natural mortality, the Z obtained with this method represent an estimate of fishing mortalities.

XSA Runs

Exploratory

Several formulations were tested by varying the study period, the total number of years and type of relationships used to weight the older data, the selected age groups ($1\text{-}6^{+}$, $1\text{-}7^{+}$, etc), the abundance index used overall or split, and ages at which catchability is considered fixed and independent of population size.

Final

The final formulations were selected based on the examination of residuals, the residual means squared (the smallest value) and the standard errors of catchability estimates. For a given age, a standard error greater than 0.5 (log scale) indicates a problem in the quality of the corresponding index (Darby and Flatman 1994). The regression slopes used to calculate catchability were tested to see if they were significantly different from the unit. In the event of a significant difference, the corresponding catchabilities were considered as proportional to abundance (Darby and Flatman 1994).

The final choice fell on two formulations (Run 1 and Run 2) producing identical results and diagnoses. What differs from these formulations involve the characteristics attributed to catchability, namely: (1) the age groups for which catchability is independent of abundance, and (2) the age groups from which catchability is constant.

By comparison, a third formulation (Run 3) was chosen, taking into account that age groups one to six, the latter being a "*real*" age group rather than a 6^{+} made up of all fish of age six and over.

Constant Catchability

The first formulation (Run 1) chosen was used to test the hypothesis that catchability coefficients have not changed over the years. To do this, and as proposed by Mohn (1999), several XSA models were produced for different periods of years.

References Points

Yield Per Recruit Analysis

The reference points associated with fishing mortality were calculated using a yield per recruit analysis (YPR) (NOAA Fisheries Toolbox 2009b). The input data for this analysis are the averages (2004-2008) of the following parameters: (1) partial recruitment at age (selectivity) calculated from fishing mortalities (ages 3-5, weighted by the corresponding abundances) from the second model chosen (Run 2), (2) natural mortality set at 0.2 for all years and all age groups, (3) catch weight (kg) at age, (4) population weight (kg) at age based on the Rivard method (NOAA Fisheries Toolbox 2009a), and (5) maturity at age (Canadian data). The reference points calculated by this analysis are $F_{0.1}$, F_{max}, and F at 40%, the latter being considered by the Northeast Fisheries Science Center as a proxy of F_{msy}. This analysis also calculated the ratio between spawning stock biomass and recruitment (SSB/R).

Deterministic Calculations of MSY and SSB_{msy}

For the second formulation chosen (Run 2), in which the residual mean squared was slightly lower than the first formulation (Run 1), the maximum sustainable yield, or MSY, was obtained analytically from the product of yield per recruit (Y/R) at F_{msy} (F at 40%) and recruitment (average historical level). Spawning stock biomass at maximum sustainable yield or SSB_{msy} was obtained by the product between the value of SSB/R at F_{msy} and recruitment (average historical level). The status of the population for 2008 was described with the following ratios: (1) fishing mortality (ages 3-5, averages weighted by the corresponding abundances) in 2008 and F_{msy}, and (2) spawning stock biomass in 2008 and SSB_{msy}.

Stochastic Calculations of MSY and SSB_{msy}

The MSY and SSB_{msy} reference points were also calculated using the AGEPRO procedure (NOAA Fisheries Toolbox 2009c). In addition to the parameters used in the yield per recruit analysis, AGEPRO requires as input recruits (age one) and abundance at age from the XSA results. The empirical cumulative distribution (ECD) (Model 14) was selected as the model describing the recruitment and spawning stock biomass relationship rather than a model whose form is already predetermined such as the Beverton-Holt (Model 5) and Ricker models (model 6). The ECD model generates recruitment values, assuming that their distribution is stationary and independent of stock size.

Projections were calculated with a 100-year outlook with F_{msy} as the annual harvest strategy. After a rapid increase, SSB_{msy} and MSY values stabilized after some years. The selected values represent the averages for the 2020-2108 period.

RESULTS

Abundance Index

Beginning in the late 1980s, mean numbers and weight per set gradually increased to peak in the 2000s (Table 1, Figure 1). Some of the strong year-classes observed in the commercial fishery over several years (Grégoire and Maguire 2011), such as 1967 and 1999, almost disappeared from the survey after only a few years (Table 2, Figure 2). At age one, the strong year-classes of 1974, 1982, 1988 and 1996 were virtually absent from the survey (Figure 3A) as was 1967, 1974, 1982, 1988, 1996 and 2003 at age two (Figure 3B). The late 1990s and the 2000s were mainly characterized by the presence of younger age groups (Figure 2). In fact, over 95% of catches in the survey since 1997 were composed of individuals of age 4 or younger (Figure 4A), and over 90% of age 3 or younger (Figure 4B).

Several year-classes have not been regularly monitored by the survey. For example, the 2003 year-class which was abundant at age one was almost completely absent from the survey at age two (Figure 5). The same can be mentioned for the 1999 year-class between ages four and five, and the 1982 year-class which increased significantly between these same age groups. However, the importance of this year-class declined rapidly between ages six and seven.

Instantaneous rates of total mortality do not really show any trend for the groups 1^+ and 2^+ (Figure 6A). However, higher values were measured in the mid 1970s and the beginning and the end of the 1980s for age groups 2^+ and older (Figures 6B, 6C, 6D and 6E). For these same age groups, the instantaneous rates of total mortality have been increasing since the mid-1990s, as with the Sinclair Z that have reached, since 2000, values greater than the unit for ages 4-8 and blocks of four years (except 2005) (Figure 7A) and blocks of five years (Figure 8A). Slightly lower values are observed for ages 3-7 (Figures 7B, 8B) and ages 2-6 (Figures 7C, 8C).

XSA: Formulations and Diagnostics

Run 1

The first formulation used had the following characteristics: (1) catchability at age seven is assigned to ages eight and nine, and (2) catchability independent of abundance for all age groups (Table 3). This formulation presented high and negative residuals for 1989, 1990 and 2004 (Figures 9A, 9B). No age effect was observed (Figure 9C) but the standard errors of catchability were all above 0.5 (Table 3) indicating a problem in the quality of the index. A slope significantly different from the unit was measured for age five (Table 3).

Run 2

For the second formulation, catchability was considered to be dependent on abundance for age groups one and two, and the value measured at age seven was assigned to ages eight and nine (Table 4). Adjustment problems were also observed for 1989, 1990 and 2004 (Figures 10A, 10B). There was no year effect (Figure 10C) but all the standard errors were greater than 0.5 (Table 4). A slope significantly different from the unit was measured for age seven.

These two formulations were selected given the similarity of their diagnoses. However, retrospective analysis and reference point calculations were carried out only with the second formulation for which the residual mean squared (log) was slightly lower. Because of adjustment problems, the results of these two formulations are presented for illustrative purposes only.

XSA: Run 1

Recruits, Mortality and Partial Recruitment

According to the recruits pattern (age one), two distinct productivity periods characterize Northwest Atlantic mackerel. The first period, between 1966 and 1974, is characterized by the presence of several consecutive strong year-classes (Table 5, Figure 11A), whereas only two strong year-classes (1982 and 1999) have been observed in the second period since 1975. Fishing mortalities gradually increased from the mid 1960s to mid 1970s (Figure 11B). Following a sharp drop in 1977, they increased in the late 1980s to stabilize between 1990 and 1995. Fishing mortalities increased very rapidly in the late 1990s and reached historic highs in the 2000s. For age groups 3-5, a fishing mortality of 0.22 was calculated in 2000 compared to a maximum of 0.92 in 2007 (Table 5). Partial recruitment has not been constant over the years (Figure 11C).

Abundance, Biomass and Fishing Mortality

Three periods of higher abundances were observed over the years; in the 1970s, the mid 1980s and early 2000s (Figures 12A, 12B). These periods are associated with the presence of strong year-classes. Spawning stock biomass has declined steadily since 2002, from 346,236 t to a historic low of 102,457 t in 2008 (Table 5). The highest recruitment rates were observed in 1967, 1982 and 1999 (Figure 12C).

<u>Stock/Fishing Mortality-Recruitment</u>

With the exception of the 1966, 1982 and 1999 year-classes, all other strong year-classes appeared when the spawning stock biomass was high and above 700,000 t (Figure 13A). Associated with a decrease in biomass, fishing mortalities increased between 1972 and 1976 (Figure 13B). They were relatively low thereafter except in the late 1990s and 2000s.

XSA: Run 2

<u>Recruits, Mortality and Partial Recruitment</u>

Recruits are generally similar to those produced by the first formulation (Table 5, Figures 11A, 14A). Both formulations produced similar results with regard to fishing mortalities (Figures 11B, 14B) and partial recruitment (Figures 11C, 14C).

<u>Abundance, Biomass and Fishing Mortality</u>

Annual abundance patterns (Figure 15A), spawning stock biomass (Figure 15B) and recruitment rates (Figure 15C) are all similar to those obtained with the first formulation.

<u>Stock/Fishing Mortality-Recruitment</u>

The relationships between recruitment (Figure 16A), fishing mortality (Figure 16B) and spawning stock biomass are also similar to those produced by the first formulation. Every strong year-class, except for 1966, 1982 and 1999, appeared when the spawning stock biomass was high and above 700,000 t. Fishing mortalities increased between 1972 and 1976 and they were relatively low thereafter except in the late 1990s and mid 2000s.

<u>Retrospective Pattern</u>

Recruits (age one) do not show any retrospective pattern (Figure 17A). In terms of differences, positive deviations were measured in 2004, 2005 and 2006 (Figure 17B) and a negative deviation for the relative differences in 2007 (Figure 17C) which resulted in a positive value of the Mohn statistic (average and total values) (Table 6). There is no retrospective pattern for abundance (1^+) (Figure 18A) and positive deviations were measured for the differences between 2004 and 2007 (Figure 18B) and negative deviations for the relative differences between 2000 and 2003 (Figure 18C) for a negative value of the Mohn statistic (Table 6). Fishing mortalities show a slight retrospective pattern (Figure 19A) with negative deviations for the differences between 2004 and 2007 (Figure 18B) and positive deviations for the relative differences in 2000 and 2002 (Figure 18C) which resulted in a negative value of the Mohn statistic (Table 6).

<u>Reference Points</u>

The MSY and SSB_{msy} reference points obtained stochastically totalled 94,553 t and 431,020 t respectively (Figures 20A, 20B) and the corresponding total biomass was 603,726 t (Figure 20C). Reference points associated with fishing mortality, calculated by yield per recruit analysis (input data, Table 7) were estimated at 0.258 for $F_{0.1}$, 0.819 for F_{max} and 0.217 for F at 40% (Table 8, Figure 21). MSY and SSB_{msy} reference points obtained analytically were 96,517 t and 440,021 t respectively (Table 9).

Stock Status for 2008

The relationship between fishing mortality (age 3-5) in the last year (2008) and F_{msy} was estimated at 3.284 (Table 9). The relationship between spawning stock biomass in 2008 and SSB_{msy} was estimated at 0.235 for the analytical assessment and at 0.240 for the stochastic assessment.

According to these values, the status of Northwest Atlantic mackerel in 2008 was in the "*overfishing/overfished*" zone of the strategic management framework used by the Northeast Fisheries Science Center (Figure 22).

Catchability

Catchability at age has increased over the years (Figures 23A, 23B). The most significant increase was measured for age groups 1 and 2.

CONCLUSION

Given the adjustment problems encountered with XSA, the absolute values of recruitment, abundance, spawning stock biomass and fishing mortality must be interpreted with caution. These problems could be explained by a conflict between the survey data and those from the commercial fishery. Catch at age was very likely underestimated, at least on the Canadian side where catches from recreational and bait fishing are not recorded. The survey abundance index shows changes in catchability. Catches in recent years have been made up essentially of younger fish, which could be the result of an actual decline in the abundance of older fish and/or the presence of these older fish in areas not sampled by the survey.

The results obtained by XSA are quite similar to those by separable VPA, traditional VPA and iterative cohort (Grégoire and Maguire 2011). Among these methods, there is very little difference in the estimates of recruits (Figure 24A), fishing mortality (Figure 24B), abundance (Figure 24C) and spawning stock biomass (Figure 24D). This similarity is difficult to explain given that all these methods, unlike XSA, were produced without the use of an abundance index. Moreover, contrary to expectation, when the older fish are excluded from XSA (Table 10), higher abundances occurred (Tables 5, 11). All these results suggest that we should explore other methods of calculation and/or use of new abundance indices.

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Table 1. *Standardized stratified mean catch per set in numbers and weight (kg) for Atlantic mackerel in the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008*.*

	SPRING SURVEY BACKTRANSFORMED GEOMETRIC MEAN	
YEAR	**No/Set**	**Wt/Set**
1968	17.921	1.831
1969	0.190	0.033
1970	2.908	0.972
1971	3.154	1.023
1972	2.566	0.657
1973	3.490	0.885
1974	3.444	0.866
1975	1.200	0.232
1976	1.353	0.345
1977	0.535	0.209
1978	1.068	0.482
1979	0.405	0.231
1980	0.797	0.368
1981	4.606	1.978
1982	1.112	0.396
1983	0.611	0.121
1984	2.819	0.971
1985	3.036	1.005
1986	1.334	0.484
1987	14.006	3.676
1988	7.095	2.469
1989	4.321	0.713
1990	4.104	0.883
1991	6.577	1.477
1992	12.719	2.267
1993	9.767	2.674
1994	15.604	3.045
1995	15.668	2.865
1996	15.555	2.669
1997	6.679	1.248
1998	13.389	1.736
1999	24.723	3.723
2000	30.193	3.446
2001	59.106	6.022
2002	11.387	2.615
2003	44.151	5.177
2004	32.741	3.063
2005	7.761	1.611
2006	38.982	4.917
2007	15.602	2.606
2008	9.166	1.893

* Data from G. Shepherd and J. Deroba, NEFSC, Woods Hole, pers. comm.

Table 2. *Standardized stratified mean catch per set at age (numbers) of Atlantic mackerel in the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008*.*

	AGE (yr)									
YEAR	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**
1968	**12.94****	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

* Data from G. Shepherd and J. Deroba, NEFSC, Woods Hole, pers. comm.

** Bold and underlined figures represent the strong year-classes seen in the catch at age

Table 3. *Extended Survivors Analysis (XSA) formulation for* ***Run 1****: Catchability independent of stock size for all ages and independent of age for ages ≥ 7; last true age in the catch at age is 9 (10^+ is present).*

FLEET	FIRST YEAR	LAST YEAR	FIRST AGE	LAST AGE	Alpha	Beta
Spring Survey:	1968	2008	1	9	0.333	0.417

Time series weights : Tapered time weighting applied
Power = 3 over 20 years

Catchability analysis : Catchability independent of stock size for **all ages**
Catchability independent of age for ages >= 7

Terminal population estimation : Survivor estimates shrunk towards the mean F
of the final 5 years or the 5 oldest ages

S.E. of the mean to which the estimates are shrunk = .500

Minimum standard error for population
estimates derived from each fleet = .300

Prior weighting not applied
Tuning converged after 11 iterations

Mean log catchability and standard error of ages with catchability independent of year class strength and constant w.r.t. time

Run 1:	Age	**1**	**2**	**3**	**4**	**5**	**6**
	Mean Log q	-15.267	-15.014	-15.585	-16.052	-16.218	-16.431
	S.E(Log q)	0.641	0.733	0.657	0.628	0.959	0.894
	Age	**7**	**8**	**9**			
	Mean Log q	-16.228	-16.228	-16.228			
	S.E(Log q)	1.257	0.759	1.122			

Regression statistics :
Ages with q independent of year class strength and constant w.r.t. time.

Run 1:	Age	Slope	t-value	Intercept	RSquare	No Pts	Reg s.e
	1	1.22	-0.709	15.93	0.50	20	0.80
	2	1.73	-1.667	17.22	0.34	20	1.18
	3	1.27	-0.859	16.64	0.51	20	0.84
	4	1.14	-0.544	16.77	0.60	20	0.74
	5	3.54	-2.843*	31.24	0.11	20	2.65
	6	1.23	-0.668	17.98	0.49	19	1.13
	7	1.56	-0.966	20.38	0.25	18	1.97
	8	1.15	-0.509	17.20	0.65	15	0.89
	9	1.43	-1.593	18.94	0.72	15	0.98

Residual mean squared (log) : **1.13**
*** p< 0.05**

Table 4. *Extended Survivors Analysis (XSA) formulation for **Run 2**: Catchability dependent on stock size for ages < 3 and independent of age for ages ≥ 7; last true age in the catch at age is 9 (10^+ is present).*

FLEET	FIRST YEAR	LAST YEAR	FIRST AGE	LAST AGE	Alpha	Beta
Spring Survey:	1968	2008	1	9	0.333	0.417

Time series weights :
Tapered time weighting applied
Power = 3 over 20 years

Catchability analysis :
Catchability dependent on stock size for ages < 3
Regression type = P
Minimum of 5 points used for regression
Survivor estimates not shrunk to the population mean
Catchability independent of age for ages >= 7

Terminal population estimation :
Survivor estimates shrunk towards the mean F
of the final 5 years or the 5 oldest ages

S.E. of the mean to which the estimates are shrunk = .500

Minimum standard error for population
estimates derived from each fleet = .300

Prior weighting not applied
Tuning converged after 11 iterations

Mean log catchability and standard error of ages with catchability independent of year class strength and constant w.r.t. time

Run 2:	Age	3	4	5	6	7	8	9
	Mean Log q	-15.582	-16.052	-16.217	-16.431	-16.228	-16.228	-16.228
	S.E(Log q)	0.657	0.629	0.959	0.894	1.256	0.758	1.122

Regression statistics :
Ages with q dependent on year class strength

Run 2:	Age	Slope	t-value	Intercept	RSquare	No Pts	Reg s.e
	1	0.60	-2.10	14.08	0.49	20	0.56
	2	0.57	-1.67	13.73	0.33	20	0.69
Ages with q independent of year class strength and constant w.r.t. time.							
	3	0.64	-1.788	14.17	0.51	20	0.60
	4	0.68	-1.817	14.42	0.60	20	0.57
	5	0.39	-1.741	12.62	0.11	20	0.88
	6	0.60	-1.958	13.70	0.49	19	0.79
	7	0.38	-2.753*	11.68	0.25	18	0.98
	8	0.75	-1.149	14.09	0.65	15	0.72
	9	1.03	0.115	15.72	0.72	15	0.83

Residual mean squared (log): **1.09**
*** p< 0.05**

Table 5. *Extended Survivors Analysis (XSA): Recruits at age 1 (thousands of fish), fishing mortality (weighted average ages 3-5) and spawning stock biomass (metric tons) calculated from the outputs of XSA* ***Run 1*** *and* ***Run 2****.*

NORTHWEST ATLANTIC MACKEREL
- NAFO Subareas 2-6 -

YEAR	RECRUITS AGE 1 (thousands of fish)		FISHING MORTALITY (average ages 3-5)		SPAWNING STOCK BIOMASS (metric tons)	
	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2
1962	371 131	371 131	0.038	0.038	175 878	175 878
1963	198 465	198 465	0.066	0.066	207 482	207 482
1964	264 301	264 301	0.047	0.047	238 059	238 059
1965	301 995	301 995	0.034	0.034	272 654	272 654
1966	727 223	727 223	0.034	0.034	321 062	321 062
1967	1 896 746	1 896 746	0.078	0.078	393 760	393 760
1968	5 127 975	5 127 975	0.223	0.223	779 768	779 768
1969	1 998 853	1 998 853	0.182	0.182	1 097 396	1 097 396
1970	2 458 808	2 458 809	0.217	0.217	1 195 723	1 195 723
1971	1 281 043	1 281 043	0.312	0.312	1 346 896	1 346 897
1972	1 415 964	1 415 965	0.334	0.334	1 455 240	1 455 240
1973	1 126 161	1 126 162	0.484	0.484	1 116 250	1 116 250
1974	1 550 555	1 550 556	0.517	0.517	881 642	881 643
1975	1 690 570	1 690 573	0.472	0.472	743 107	743 107
1976	291 108	291 109	0.747	0.747	588 300	588 301
1977	52 029	52 030	0.268	0.268	438 063	438 064
1978	25 925	25 925	0.068	0.068	460 508	460 510
1979	171 974	171 975	0.075	0.075	403 059	403 060
1980	47 299	47 300	0.102	0.102	380 430	380 432
1981	105 347	105 348	0.109	0.109	301 717	301 719
1982	411 831	411 833	0.141	0.141	273 569	273 572
1983	2 115 758	2 115 782	0.152	0.152	332 700	332 703
1984	102 984	102 987	0.121	0.121	392 369	392 371
1985	137 199	137 201	0.117	0.117	651 264	651 271
1986	96 351	96 352	0.130	0.130	578 250	578 258
1987	99 604	99 605	0.184	0.184	467 850	467 857
1988	277 166	277 177	0.310	0.310	391 047	391 054
1989	461 951	462 011	0.276	0.276	348 538	348 549
1990	99 823	99 834	0.266	0.266	294 096	294 115
1991	169 352	169 362	0.265	0.265	294 005	294 030
1992	149 678	149 681	0.186	0.186	231 132	231 158
1993	26 116	26 121	0.149	0.149	196 845	196 867
1994	138 003	138 003	0.207	0.207	155 592	155 615
1995	183 692	183 692	0.195	0.195	136 760	136 779
1996	130 739	130 740	0.445	0.445	137 836	137 855
1997	183 906	183 906	0.399	0.399	122 572	122 587
1998	90 877	90 877	0.511	0.511	108 376	108 386
1999	158 032	158 031	0.461	0.461	91 323	91 327
2000	1 268 238	1 268 220	0.215	0.215	198 983	198 984
2001	177 888	177 888	0.317	0.317	331 448	331 446
2002	141 433	141 434	0.203	0.203	346 236	346 232
2003	358668	358 658	0.326	0.326	319928	319924
2004	600679	599 932	0.559	0.559	276187	276163
2005	172297	172 347	0.557	0.557	230803	230708
2006	300370	296 083	0.800	0.802	197265	196923
2007	100503	114 376	0.915	0.918	151046	150226
2008	241682	246 575	0.651	0.665	102457	103504

Table 6. *Extended Survivors Analysis (XSA): Mohn's Rho statistic for recruits (age 1), population abundance, and fishing mortality (average ages 3-5) calculated from the outputs of XSA **Run 2**.*

TERMINAL YEAR	RECRUITS AGE 1	POPULATION ABUNDANCE	FISHING MORTALITY (3-5)
2000	-0.697	-0.651	0.323
2001	0.278	-0.458	0.076
2002	0.601	-0.267	0.372
2003	-0.112	-0.091	0.009
2004	0.804	0.505	-0.155
2005	0.811	0.250	-0.195
2006	0.262	0.392	-0.540
2007	-0.563	0.108	-0.425
AVERAGE:	0.173	-0.026	-0.067
TOTAL	1.383	-0.212	-0.537

Table 7. *Input data for the yield per recruit (YPR) and projection (AGEPRO[1]) analyses. Recruits at age 1 for all year-classes (n=47) and selectivity data (partial recruitment) are from the outputs of XSA **Run 2**.*

AGE	SELECTIVITY [2]	NATURAL MORTALITY	STOCK WEIGHT [3]	CATCH WEIGHT [4]	SPAWNING STOCK WEIGHT	FRACTION MATURE [5]
1	0.1260	1	0.118	0.147	0.118	0.154
2	0.4329	1	0.184	0.237	0.184	0.807
3	0.8941	1	0.283	0.337	0.283	0.986
4	0.9973	1	0.364	0.403	0.364	0.999
5	0.9887	1	0.435	0.467	0.435	1.000
6	1.0000	1	0.492	0.512	0.492	1.000
7	0.9827	1	0.557	0.589	0.557	1.000
8	1.0000	1	0.603	0.613	0.603	1.000
9	1.0000	1	0.619	0.604	0.619	1.000
10	1.0000	1	0.650	0.650	0.650	1.000

[1] Recruit model = empirical CDF; harvest strategy = F at 40%
[2] From Fs (3-5), average 2004-2008
[3] Rivard's method (NOAA Fisheries Toolbox 2009a), average 2004-2008
[4] Average 2004-2008
[5] Canadian data, average 2004-2008

Table 8. *Yield per recruit analysis (YPR) results (F at 40% as a proxy of F_{msy}). Selectivity data (partial recruitment) used in this analysis are from the outputs of XSA **Run 2**.*

	PARAMETERS						
	F	**Y/R**	**SSB/R**	**TB/R**	**Mean Age**	**Mean Gen. Time**	**Expected Spawnings**
F-0	0	0	1.752	2.067	5.517	8.146	3.075
F-0.1	0.258	0.162	0.624	0.901	3.006	4.731	1.589
F-Max	0.819	0.187	0.236	0.478	2.040	3.095	0.716
F at 40%	0.217	0.154	0.701	0.982	3.185	5.009	1.731

Table 9. *Biological reference points: MSY and B_{msy} as deterministic points estimated by the YPR analysis; MSY and B_{msy} were also estimated from stochastic bootstrapped projections (AGEPRO). Recruits and selectivity data (partial recruitment) used in YPR and AGEPRO are from the outputs of XSA **Run 2**.*

RECRUITS	**Analytical**		**Stochastic**		**F (3-5) $_{2008}$ / F_{msy}**	**SSB $_{2008}$ / B_{msy}**	
(average 1961-2008)	**MSY (t)**	**B_{msy} (t)**	**MSY (t)**	**B_{msy} (t)**	Analytical	Analytical	Stochastic
627 919	96 517	440 021	94 553	431 020	3.284	0.235	0.240

Table 10. *Extended Survivors Analysis (XSA) formulation for **Run 3**: Catchability independent of stock size for all ages and independent of age for ages ≥ 5; last age in the catch at age is 6 (no 7^+).*

FLEET	**FIRST YEAR**	**LAST YEAR**	**FIRST AGE**	**LAST AGE**	**Alpha**	**Beta**
Spring Survey	1968	2008	1	**6**	0.333	0.417

Time series weights : Tapered time weighting applied
Power = 3 over 20 years

Catchability analysis : Catchability independent of stock size for **all ages**
Catchability independent of age for ages >= 5

Terminal population estimation : Survivor estimates shrunk towards the mean F of the final 5 years or the 5 oldest ages

S.E. of the mean to which the estimates are shrunk = .500

Minimum standard error for population estimates derived from each fleet = .300

Prior weighting not applied
Tuning converged after 25 iterations

Mean log catchability and standard error of ages with catchability independent of year class strength and constant w.r.t. time

Run 3:	Age	**1**	**2**	**3**	**4**	**5**	**6**
	Mean Log q	-15.428	-15.2129	-15.8634	-16.4715	-16.8652	-16.8652
	S.E(Log q)	0.613	0.7456	0.6255	0.5928	0.8557	0.9987

Regression statistics :
Ages with q independent of year class strength and constant w.r.t. time.

Run 3:	**Age**	**Slope**	**t-value**	**Intercept**	**RSquare**	**No Pts**	**Reg s.e**
	1	1.11	-0.383	15.77	0.53	20	0.71
	2	1.72	-1.489	17.41	0.30	20	1.22
	3	1.13	-0.437	16.38	0.53	20	0.73
	4	1.04	-0.164	16.67	0.63	20	0.65
	5	2.63	-2.498*	26.65	0.19	20	1.85
	6	1.01	-0.030	17.52	0.62	19	0.83

Residual mean squared (log) : **1.12**
* $p< 0.05$

Table 11. *Extended Survivors Analysis (XSA): Recruits at age 1 (thousands of fish), fishing mortality (weighted average ages 3-5) and spawning stock biomass (metric tons) calculated from the outputs of XSA **Run 3**.*

NORTHWEST ATLANTIC MACKEREL - NAFO Subareas 2-6 -			
YEAR	**RECRUITS AGE 1** (thousands of fish)	**FISHING MORTALITY** (average ages 3-5)	**SPAWNING STOCK BIOMASS** (metric tons)
1962	395 040	0.012	525 170
1963	185 480	0.019	583 896
1964	200 980	0.018	637 818
1965	374 380	0.022	641 503
1966	1 049 960	0.038	311 611
1967	2 980 910	0.076	354 999
1968	6 073 980	0.163	836 365
1969	2 738 520	0.110	1 250 403
1970	2 806 330	0.158	1 499 151
1971	1 503 070	0.211	1 754 294
1972	1 633 880	0.240	1 950 380
1973	2 336 340	0.345	1 436 061
1974	2 782 770	0.373	1 051 635
1975	2 030 590	0.192	1 071 041
1976	342 060	0.215	954 074
1977	114 630	0.089	954 345
1978	61 530	0.029	987 298
1979	451 280	0.048	693 084
1980	82 020	0.063	471 775
1981	161 430	0.038	284 549
1982	809 650	0.049	250 692
1983	3 666 390	0.058	425 725
1984	155 500	0.058	564 964
1985	247 170	0.063	991 505
1986	185 360	0.067	994 665
1987	182 470	0.092	866 675
1988	551 640	0.137	713 155
1989	845 890	0.110	304 645
1990	149 010	0.111	362 454
1991	266 270	0.119	433 976
1992	264 230	0.079	366 311
1993	37 700	0.073	351 918
1994	202 300	0.110	257 321
1995	255 100	0.098	162 798
1996	172 700	0.222	171 645
1997	290 770	0.210	161 758
1998	132 980	0.253	158 366
1999	196 620	0.216	159 899
2000	1 400 280	0.108	274 473
2001	202 120	0.190	407 185
2002	148 250	0.173	417 726
2003	373 890	0.272	371 131
2004	636 930	0.452	315 916
2005	186 050	0.486	266 398
2006	327 500	0.693	186 102
2007	110 990	0.717	165 059
2008	264 110	0.502	122 439

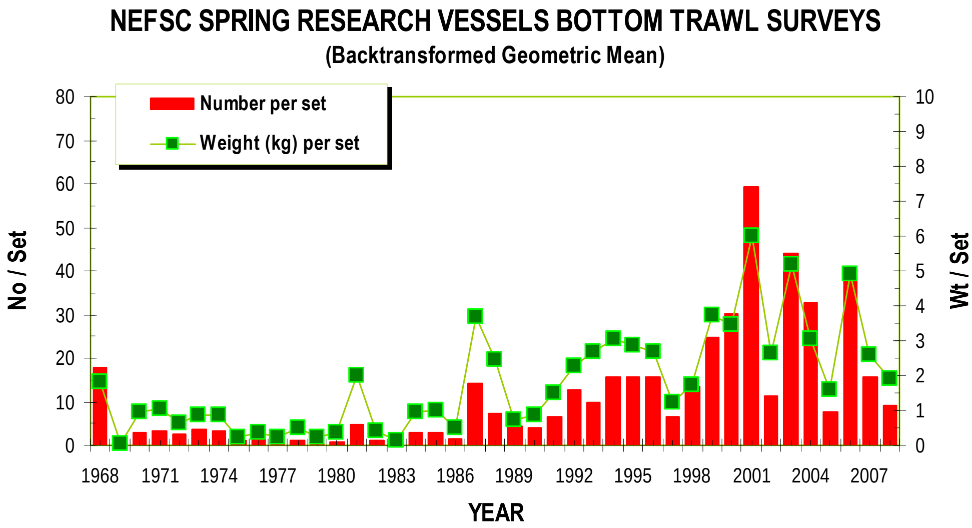


Figure 1. *Mean catch per set in numbers and weight (kg) for Atlantic mackerel in the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008.*

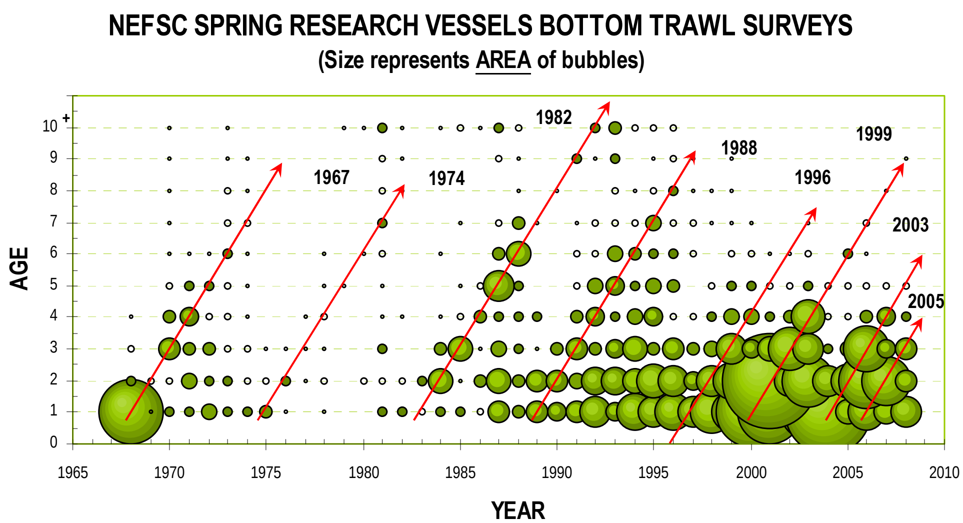
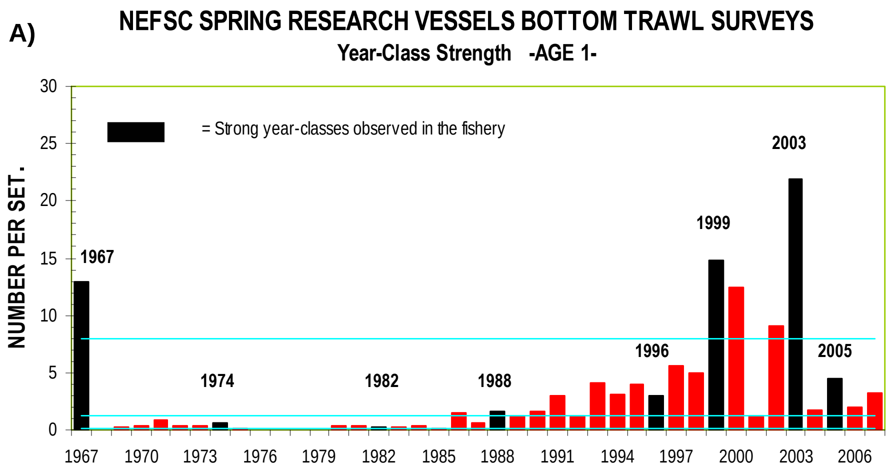


Figure 2. *Mean catch per set at age (numbers) of Atlantic mackerel in the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008 (the strong year-classes observed in the catch at age are indicated).*

A)



B)

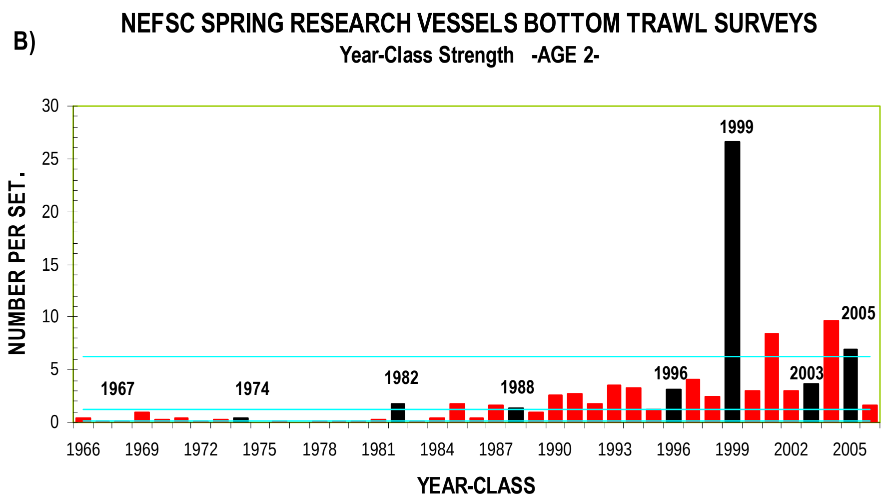


Figure 3. *Year-class strength of age 1 (A) and age 2 (B) of Atlantic mackerel in the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008. The horizontal lines represent three levels of abundance: low, average and high.*

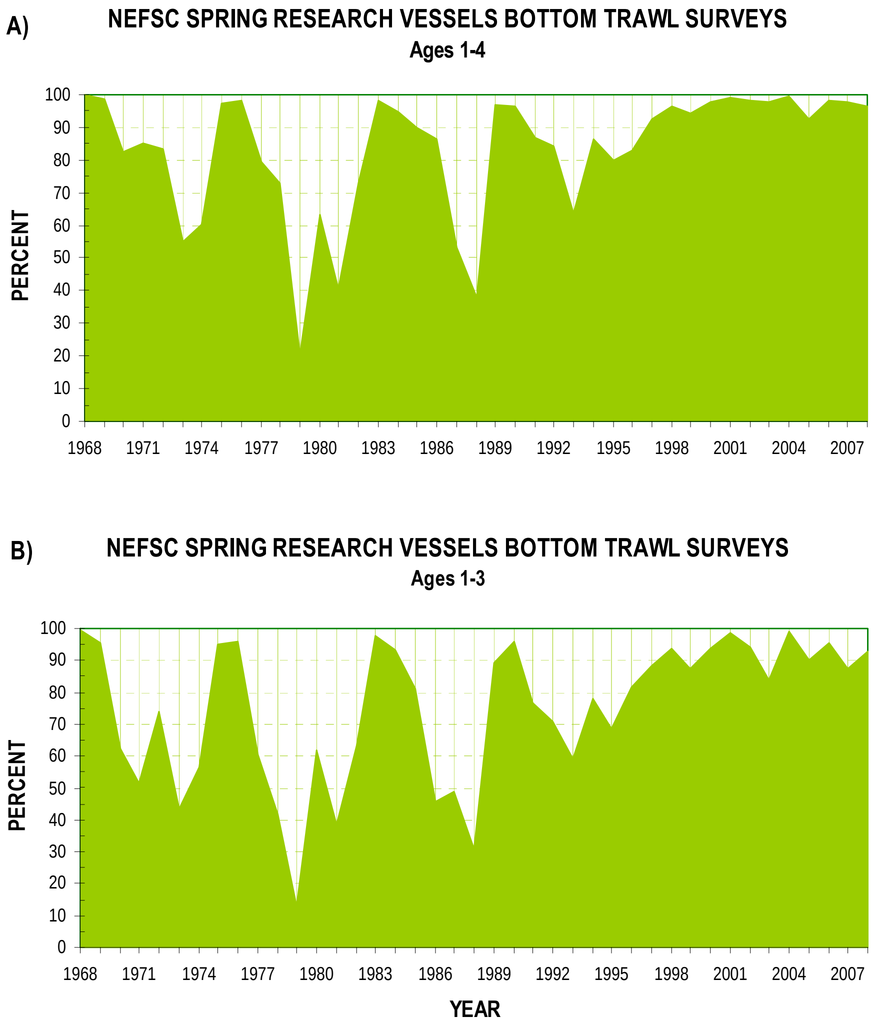


Figure 4. *Percentage at ages 1-4 (A) and ages 1-3 (B) of Atlantic mackerel in the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008.*

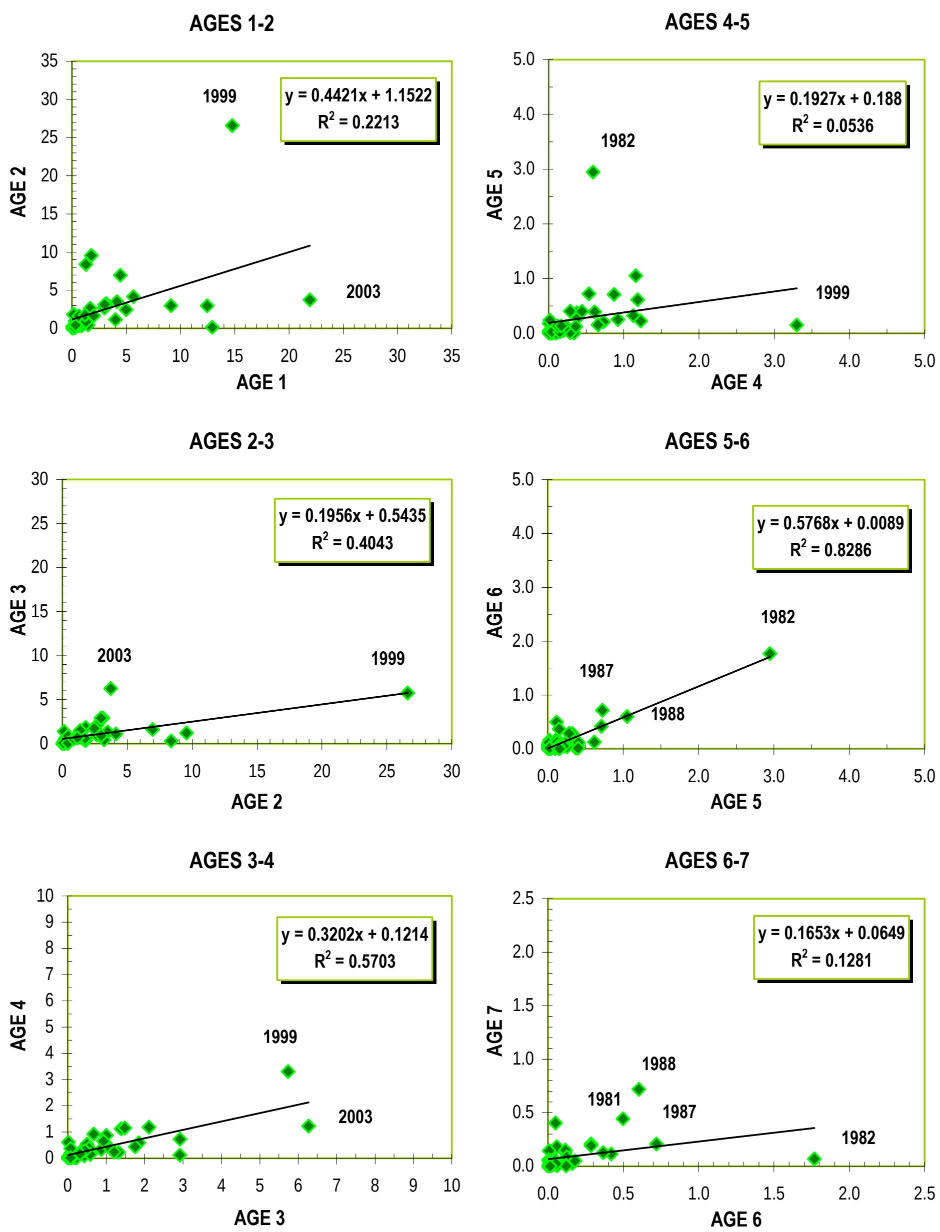


Figure 5. *Comparison between NEFSC spring research vessels bottom trawl surveys indices (shifted) at age and the indices of the same year-class one year later.*

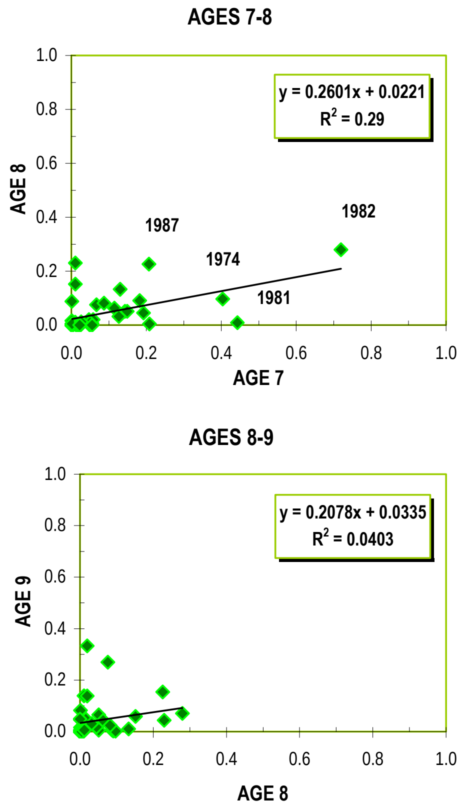


Figure 5. *(Continued).*

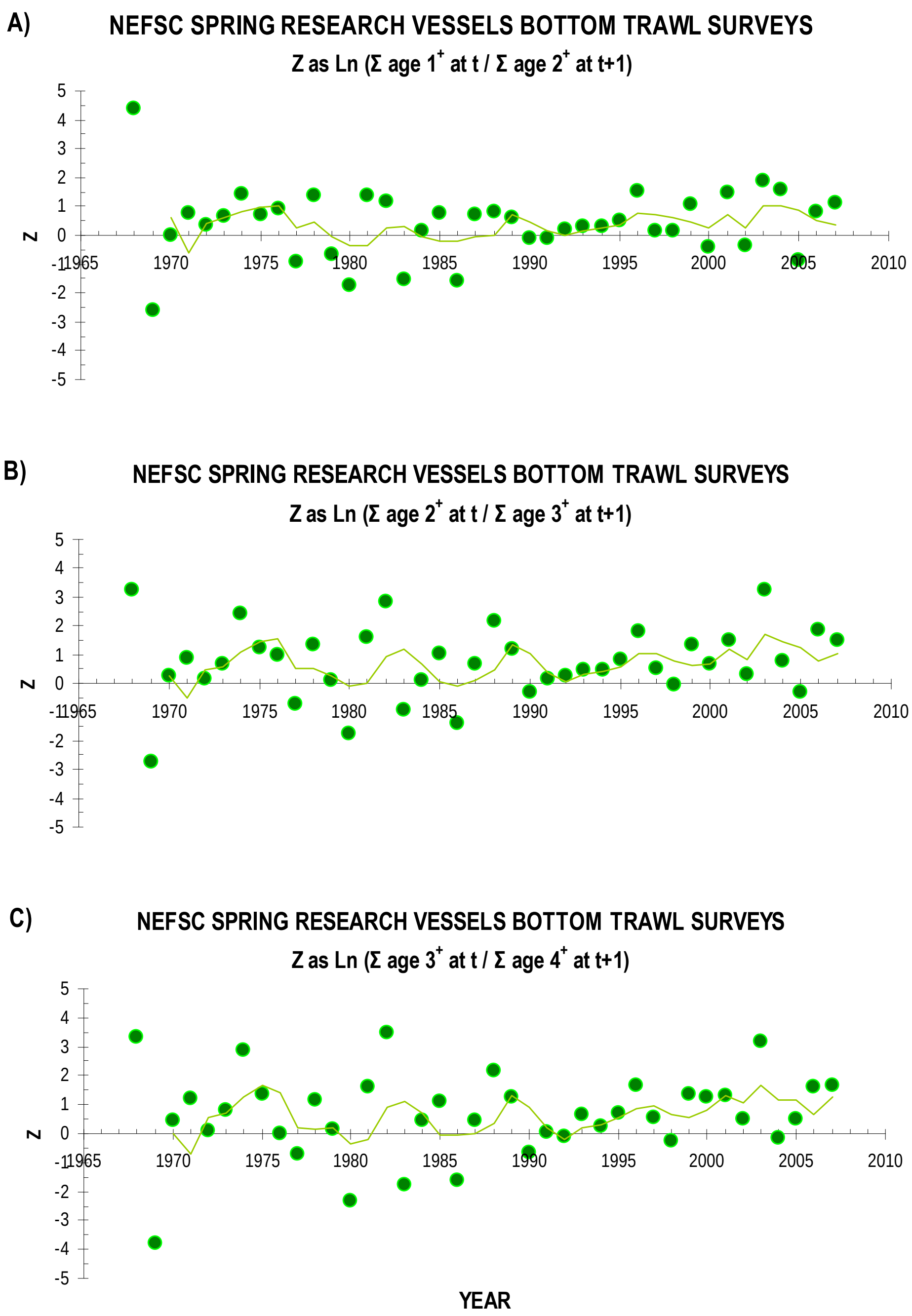


Figure 6. *Estimates of instantaneous rate of total mortality (Z) derived from the NEFSC spring research vessels bottom trawl surveys fit with a 3-year moving average over the time series and blocks of ages: A) ln(Σ age 1^+ at t / Σ age 2^+ at t+1); B) ln(Σ age 2^+ at t / Σ age 3^+ at t+1); C) ln(Σ age 3^+ at t / Σ age 4^+ at t+1); D) ln(Σ age 4^+ at t / Σ age 5^+ at t+1); and E) ln(Σ age 5^+ at t / Σ age 6^+ at t+1).*

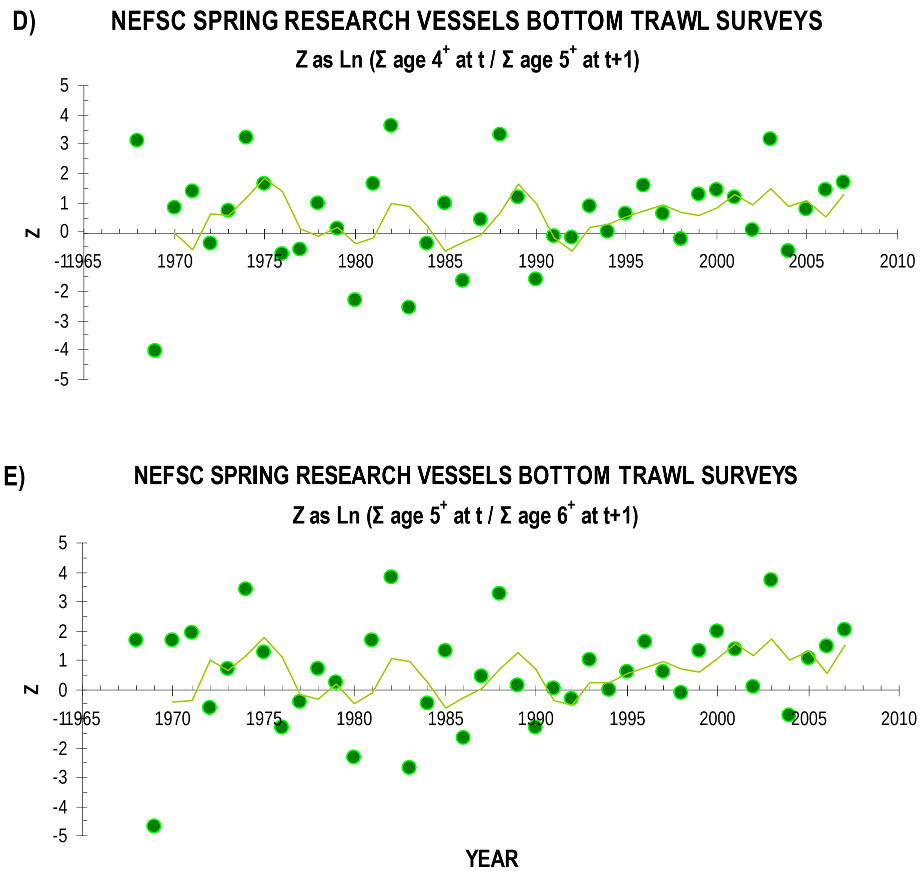


Figure 6. *(Continued).*

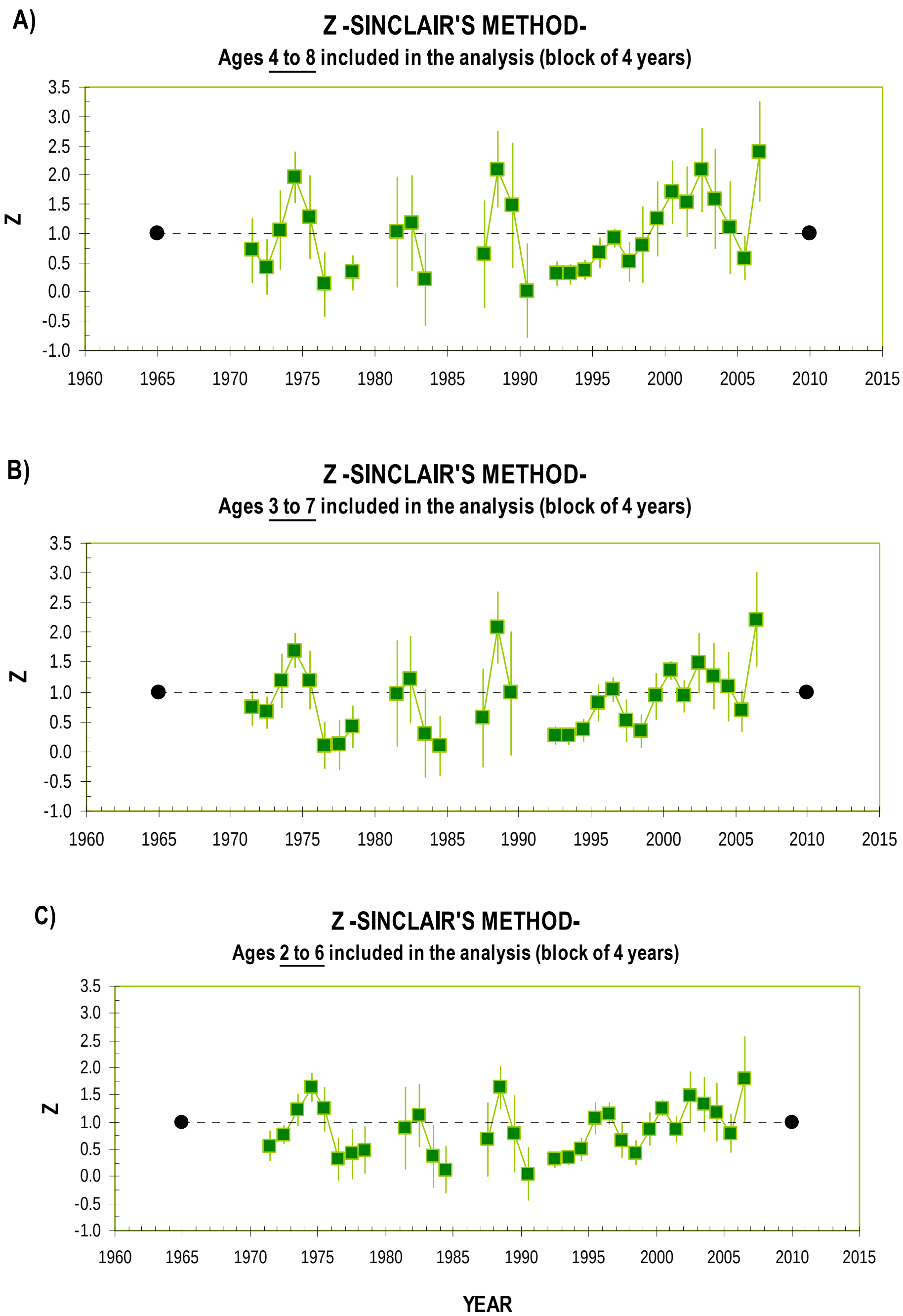


Figure 7. *Estimates of instantaneous rate of total mortality (Z) derived from the NEFSC spring research vessels bottom trawl surveys and fit according to the Sinclair's method (Sinclair 1998) for blocks of 4 years and different groups of ages: A) ages 4 to 8; B) ages 3 to 7; and C) ages 2 to 6. The horizontal lines represent Z=1.0.*

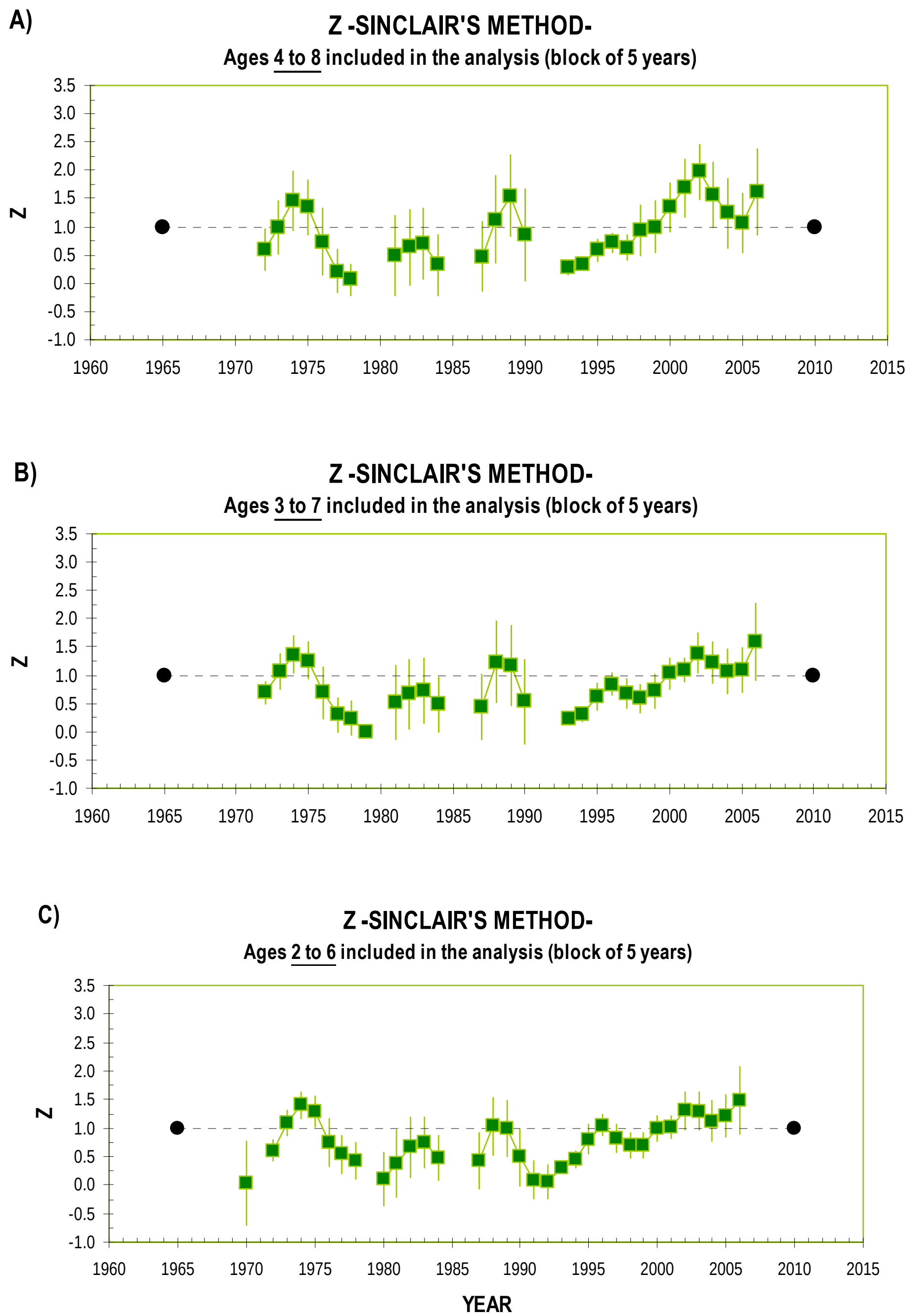


Figure 8. *Estimates of instantaneous rate of total mortality (Z) derived from the NEFSC spring research vessels bottom trawl surveys and fit according to the Sinclair's method (Sinclair 1998) for blocks of 5 years and different groups of ages: A) ages 4 to 8; B) ages 3 to 7; and C) ages 2 to 6. The horizontal lines represent Z=1.0.*

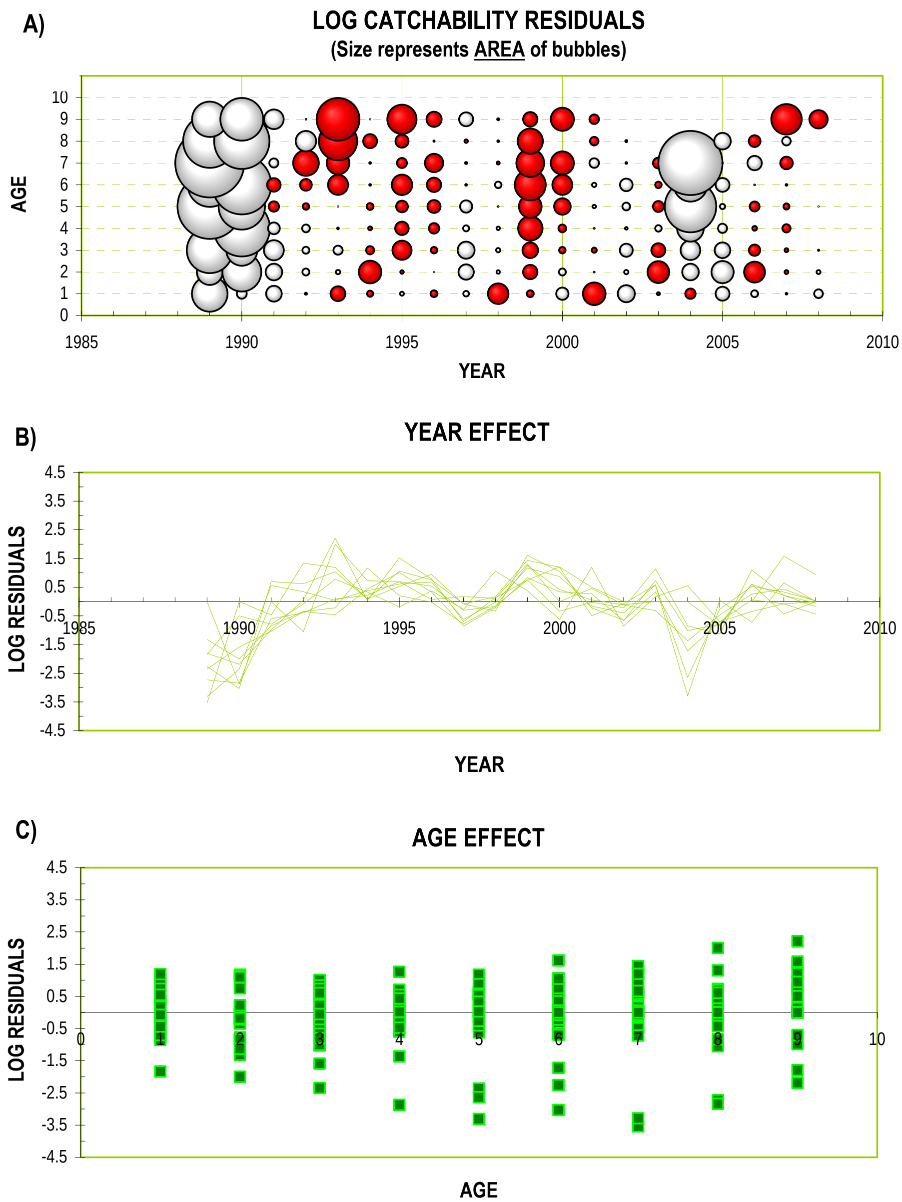


Figure 9. *Extended Survivors Analysis (XSA) diagnostics for* ***Run 1****: A) log of catchability residuals at year and age (negative values are in white); B) plotted against time (year effect); and C) plotted against age (age effect).*

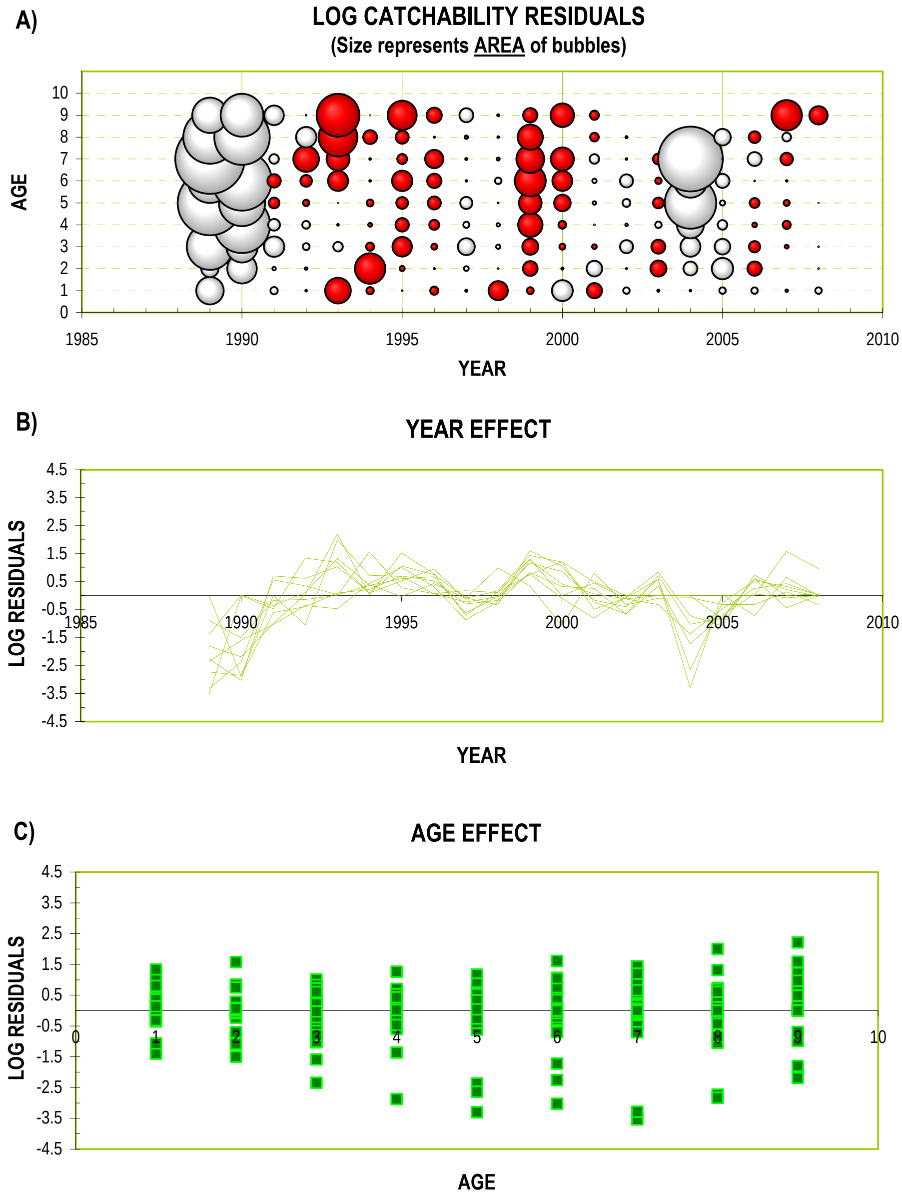


Figure 10. *Extended Survivors Analysis (XSA) diagnostics for **Run 2**: A) log of catchability residuals at year and age (negative values are in white); B) plotted against time (year effect); and C) plotted against age (age effect).*

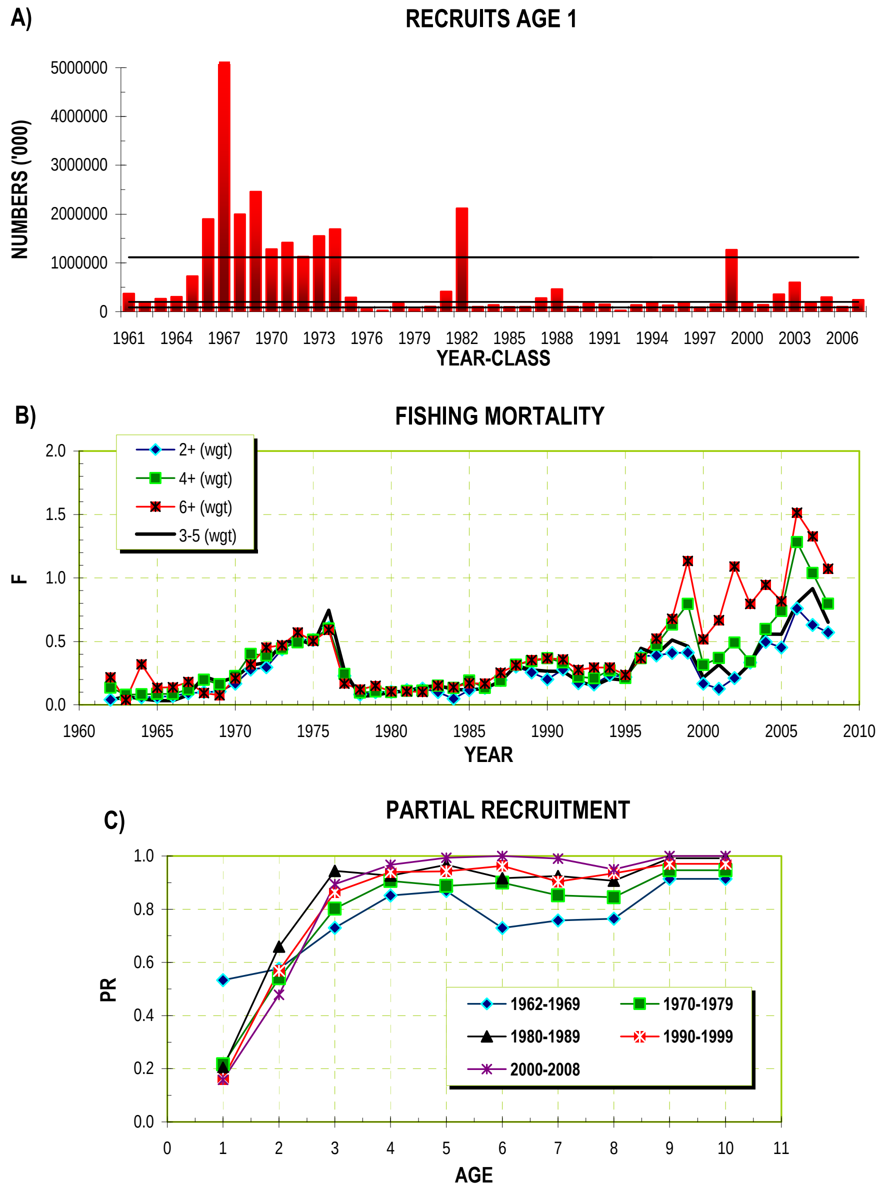


Figure 11. *Extended Survivors Analysis (XSA) results for* ***Run 1****: A) Recruits at age 1 (thousands of fish); B) fishing mortality (weighted by abundance); and C) partial recruitment (from fishing mortalities) for the Northwest Atlantic mackerel. The horizontal lines in A) represent three levels of recruitment: low, average and high.*

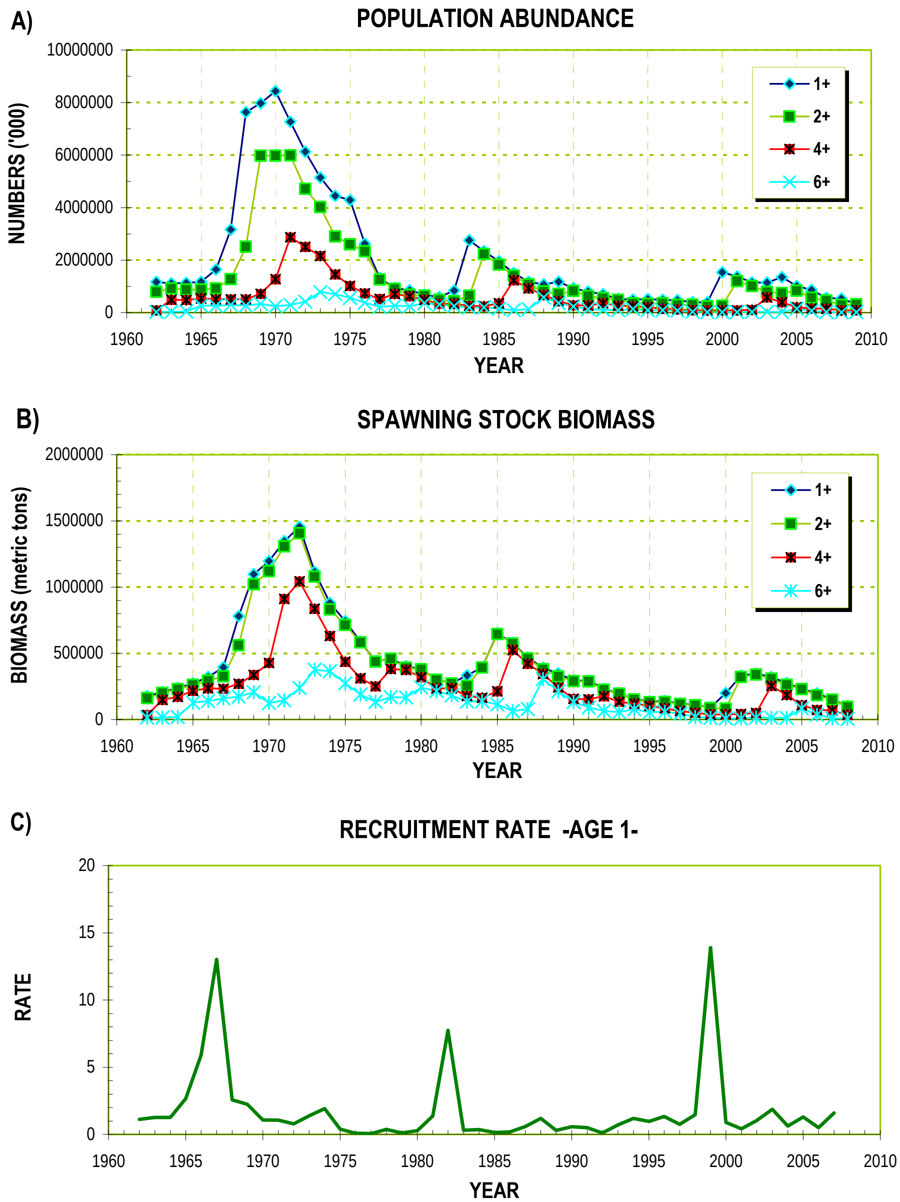


Figure 12. *Extended Survivors Analysis (XSA) results for **Run 1**: A) Population abundance (thousands of fish); B) spawning stock biomass (metric tons); and C) recruitment rate at age 1 for the Northwest Atlantic mackerel.*

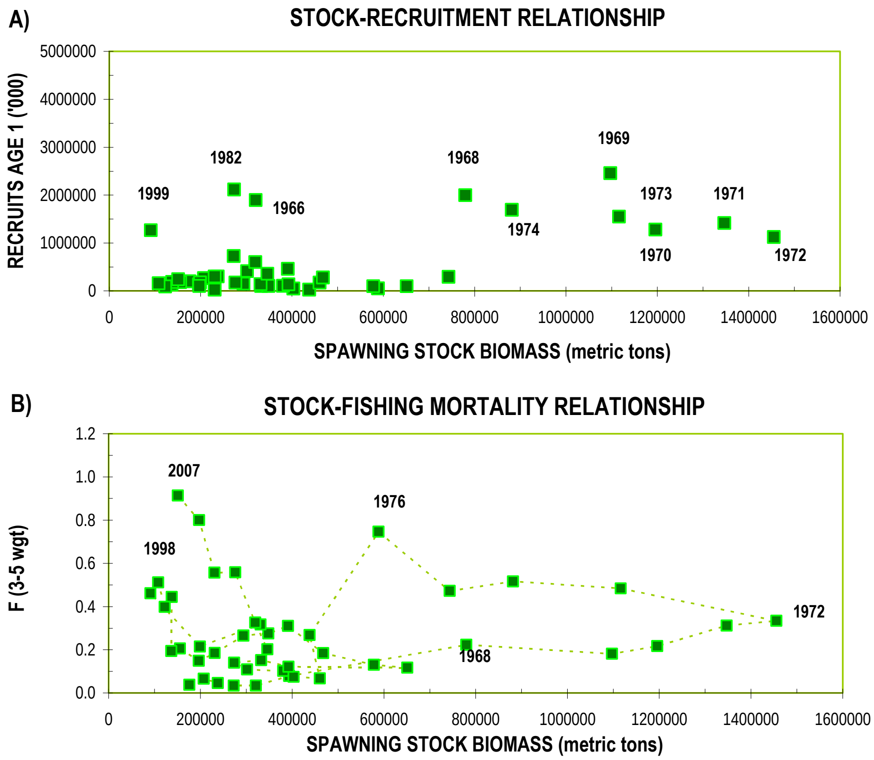


Figure 13. *Extended Survivors Analysis (XSA) results for **Run 1**: A) Stock-recruitment relationship (some year-classes are indicated); and B) stock-fishing mortality relationship for the Northwest Atlantic mackerel (some years are indicated).*

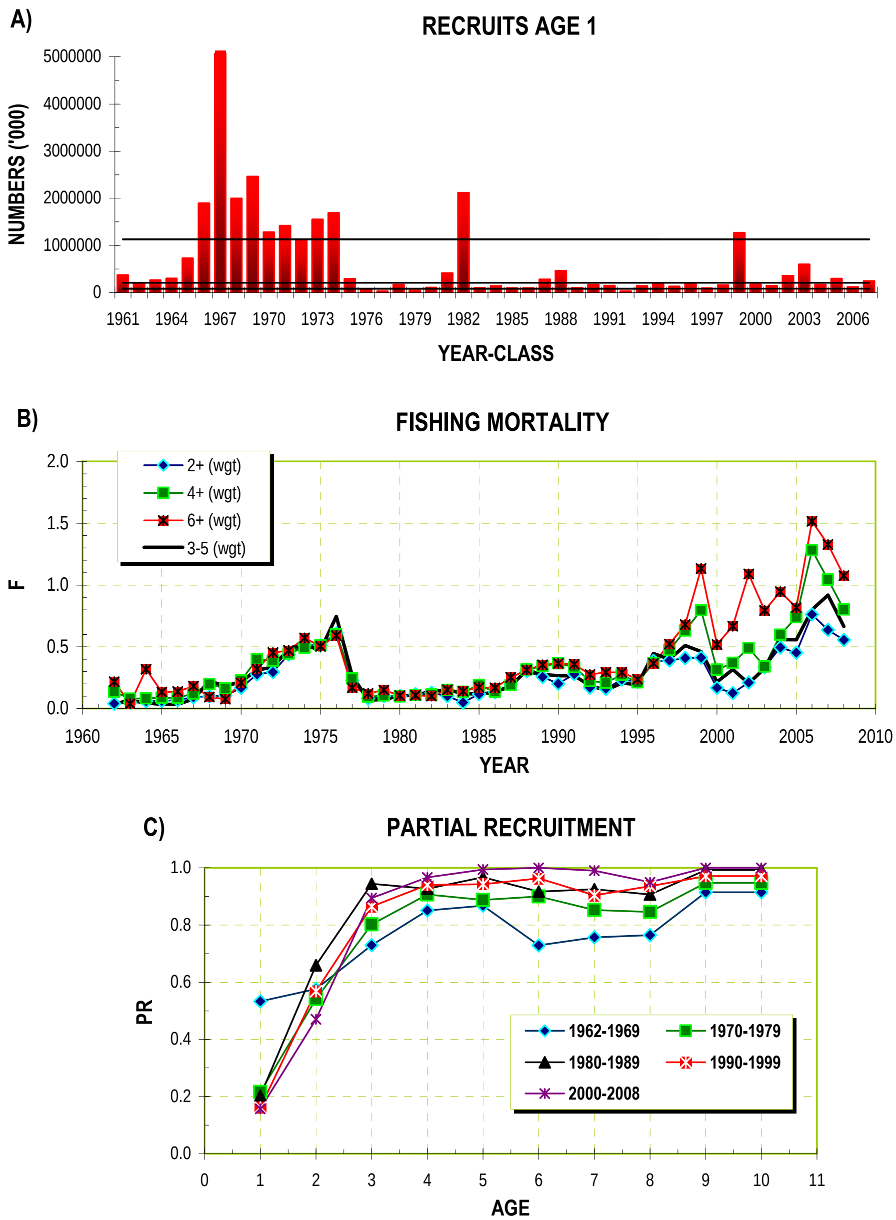


Figure 14. *Extended Survivors Analysis (XSA) results for* ***Run 2****: A) Recruits at age 1 (thousands of fish); B) fishing mortality (weighted by abundance); and C) partial recruitment (from fishing mortalities) for the Northwest Atlantic mackerel. The horizontal lines in A) represent three levels of recruitment: low, average and high.*

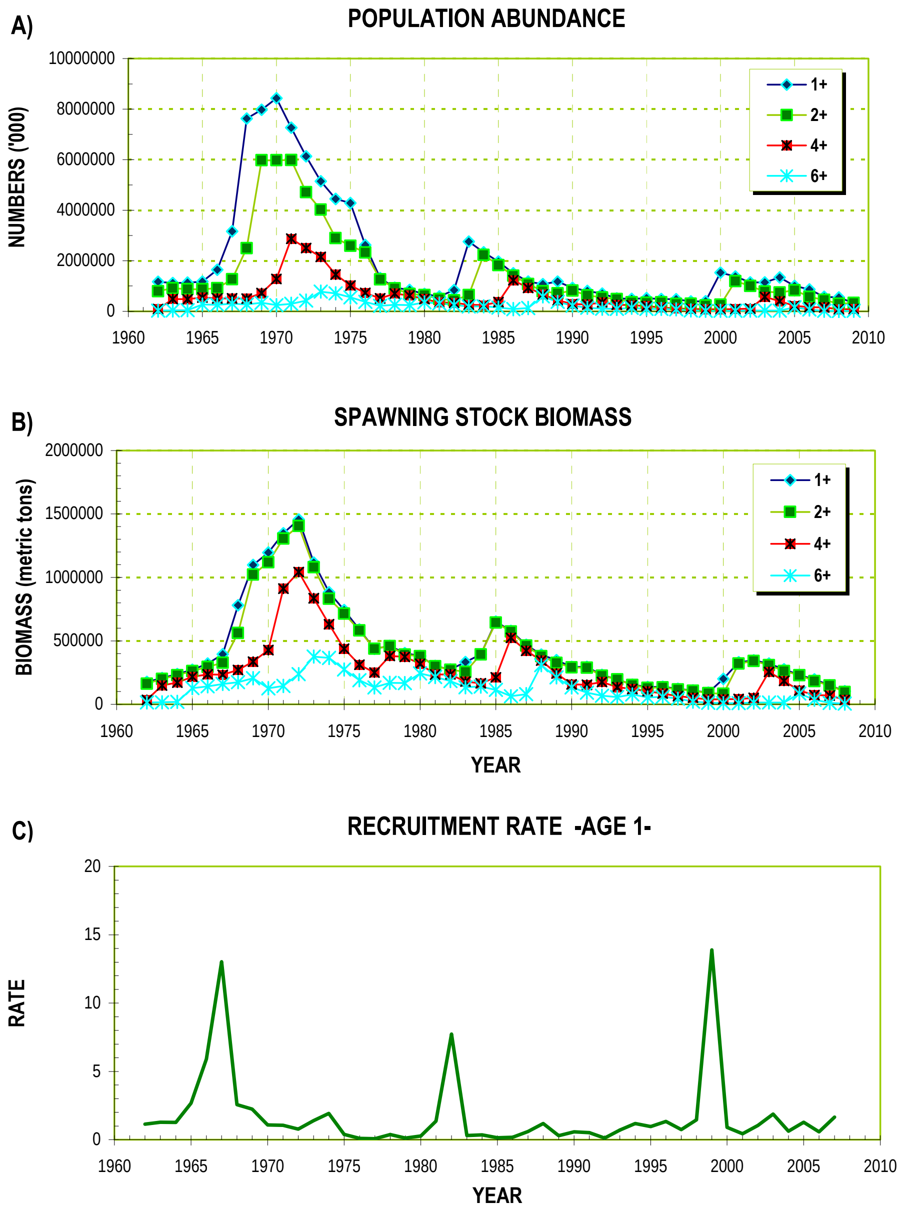


Figure 15. *Extended Survivors Analysis (XSA) results for **Run 2**: A) Population abundance (thousands of fish); B) spawning stock biomass (metric tons); and C) recruitment rate at age 1 for the Northwest Atlantic mackerel.*

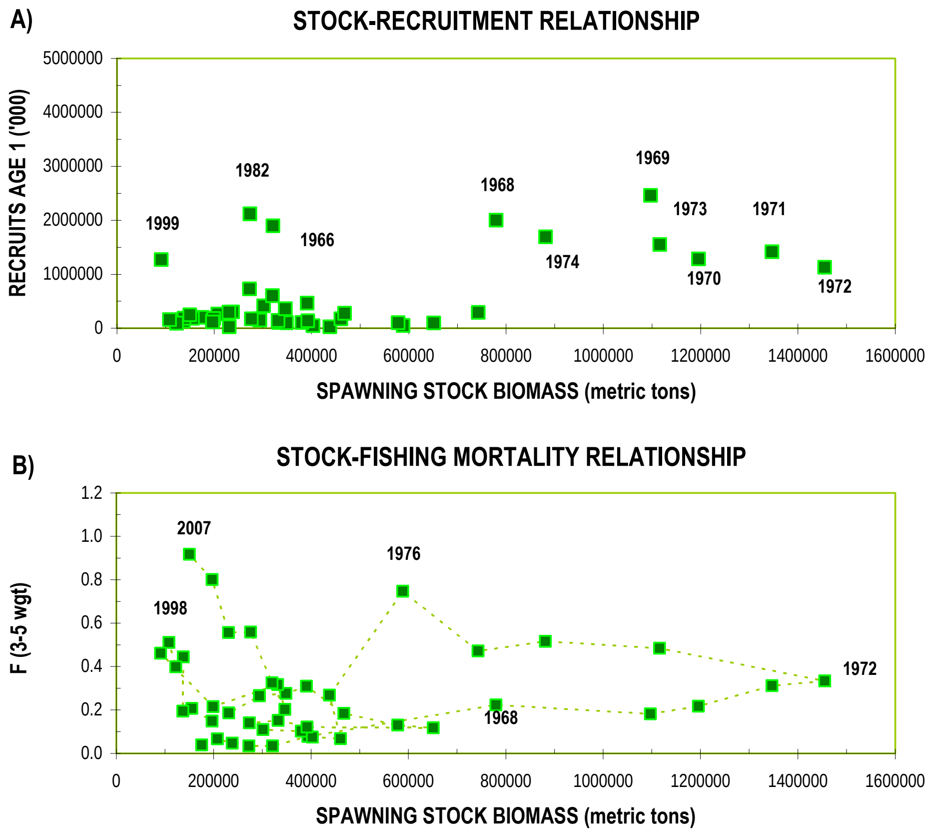


Figure 16. *Extended Survivors Analysis (XSA) results for* ***Run 2****: A) Stock-recruitment relationship (some year-classes are indicated); and B) stock-fishing mortality relationship for the Northwest Atlantic mackerel (some years are indicated).*

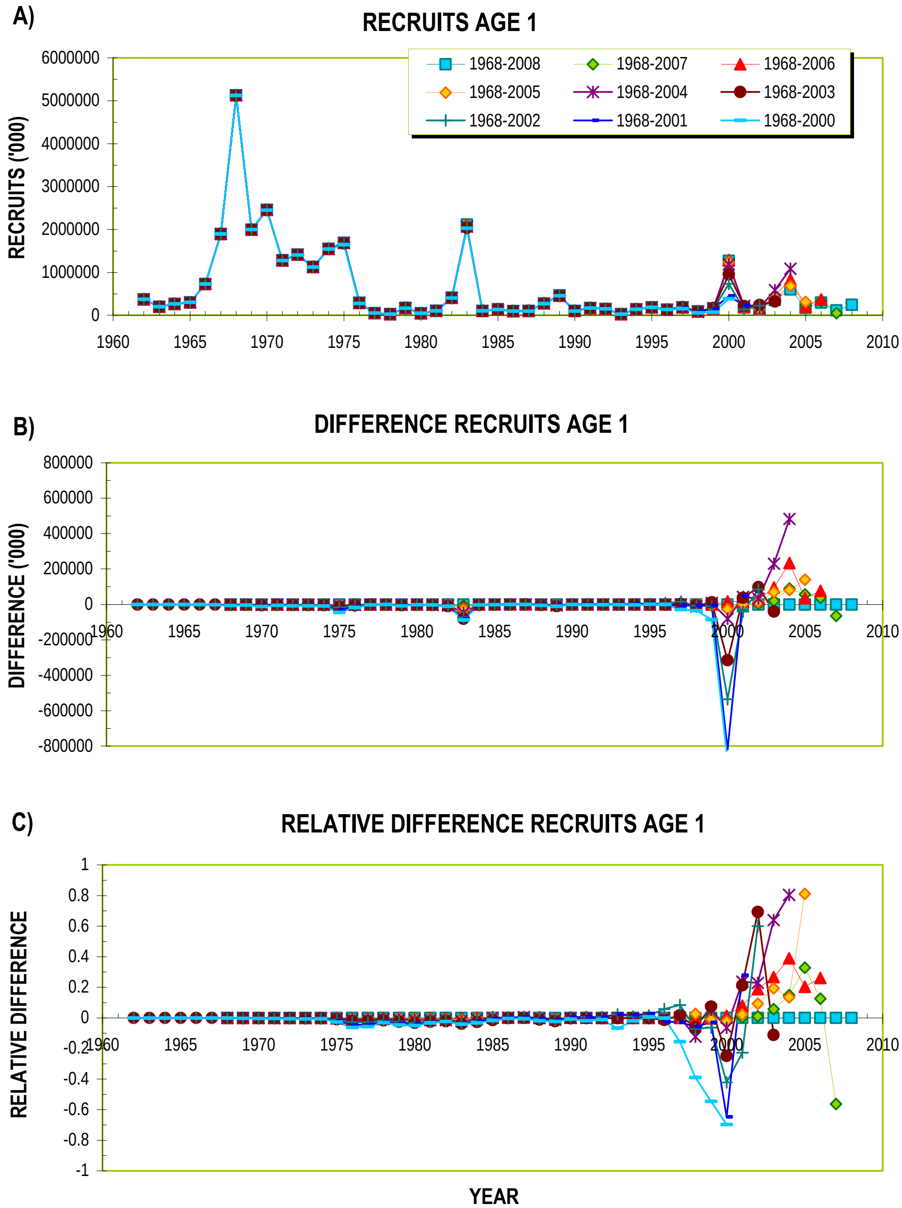


Figure 17. *Extended Survivors Analysis (XSA) results for **Run 2**: A) Retrospective analysis of age 1 recruitment; B) difference; and C) relative difference to the terminal year (Mohn's Rho statistic: Average = 0.173; total = 1.383).*

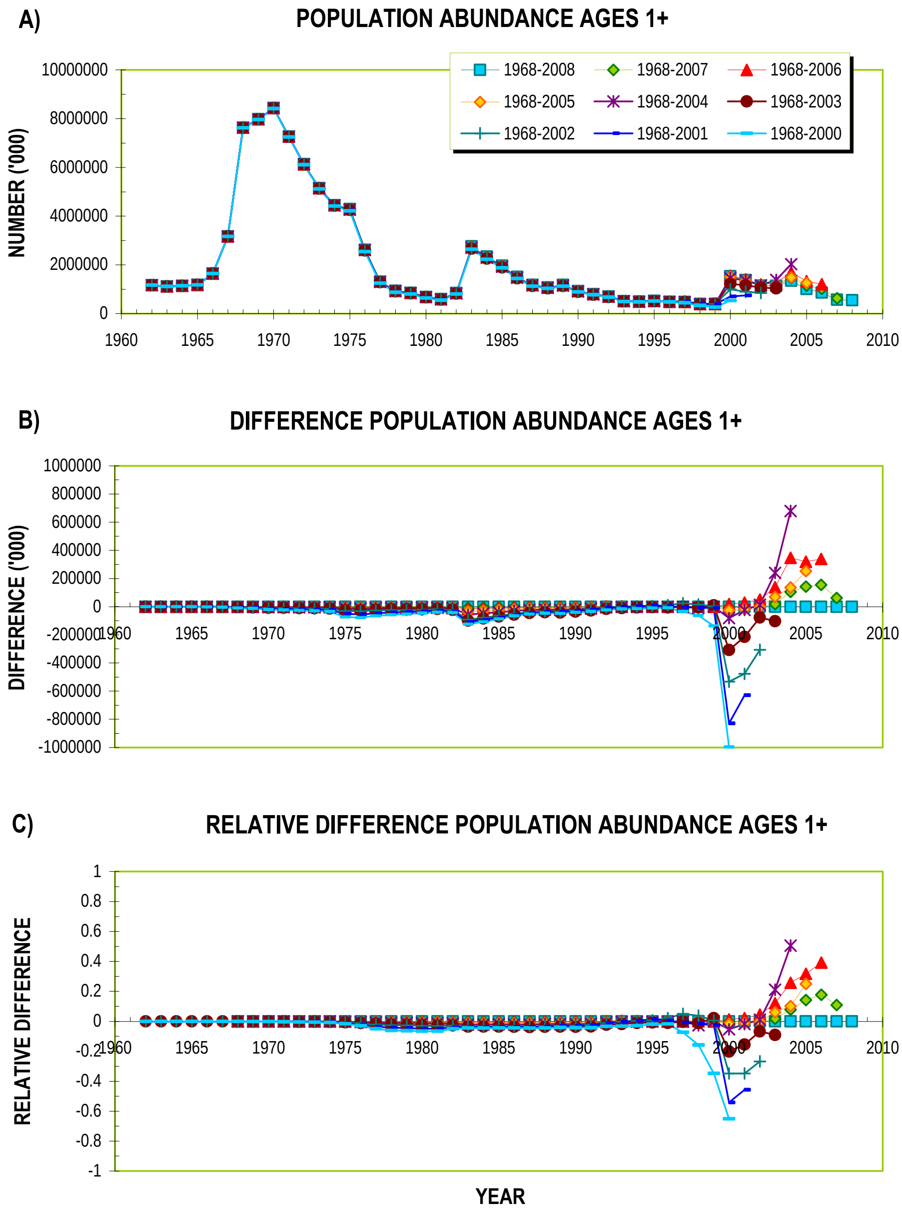


Figure 18. *Extended Survivors Analysis (XSA) results for **Run 2**: A) Retrospective analysis of population abundance ages 1^{+}; B) difference; and C) relative difference to the terminal year (Mohn's Rho statistic: Average = -0.026; total = -0.212).*

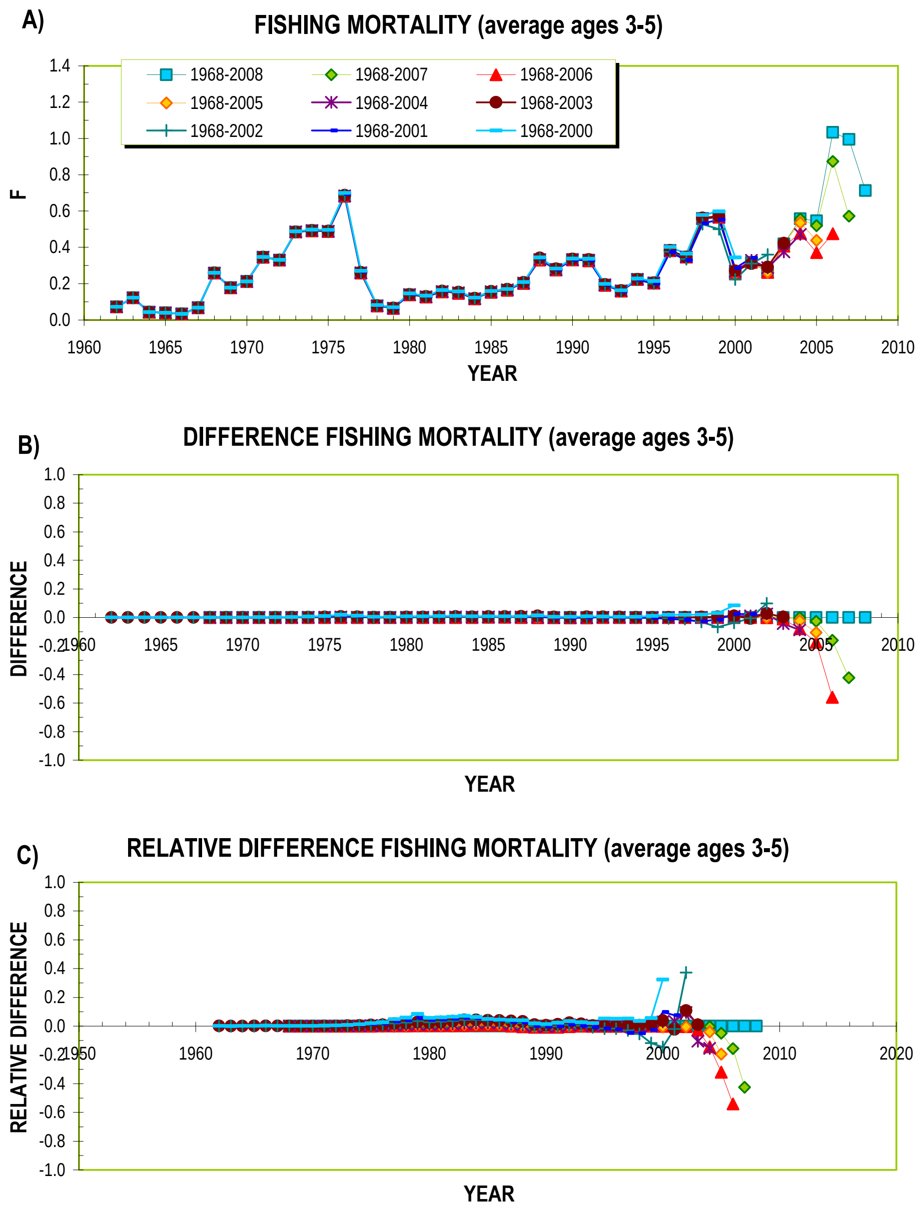


Figure 19. *Extended Survivors Analysis (XSA) results for **Run 2**: A) Retrospective analysis of fishing mortality (average ages 3-5); B) difference; and C) relative difference to the terminal year (Mohn's Rho: Average = -0.067; total = -0.537).*

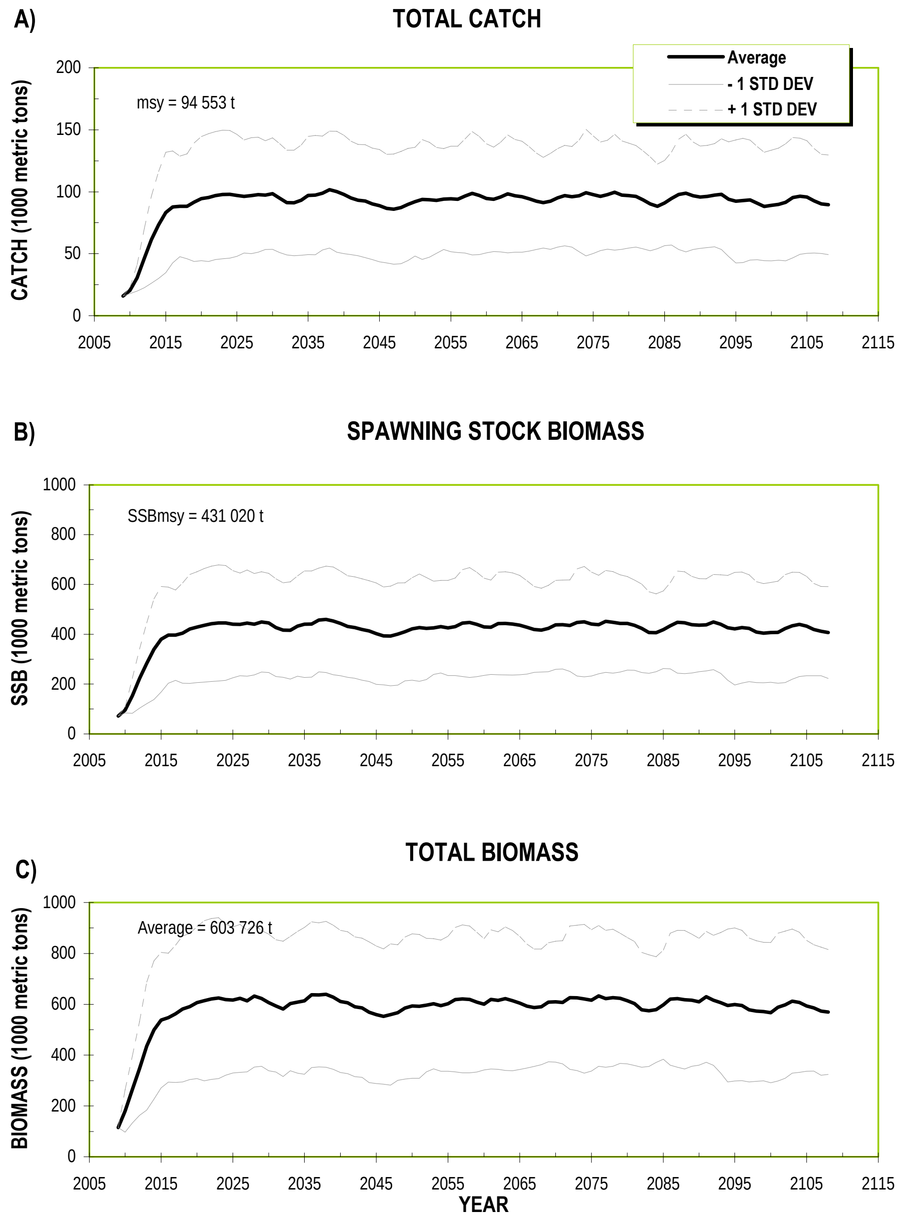


Figure 20. *Stochastic bootstrapped projections (AGEPRO) of: A) total catch (thousands of metric tons); B) spawning stock biomass (thousands of metric tons); and C) total biomass (thousands of metric tons) with F at 40% as the harvest strategy. MSY and B_{msy} in A) and B) are calculated as the averages of the 2020-2108 period. Data used in this analysis are from the outputs of XSA* ***Run 2****.*

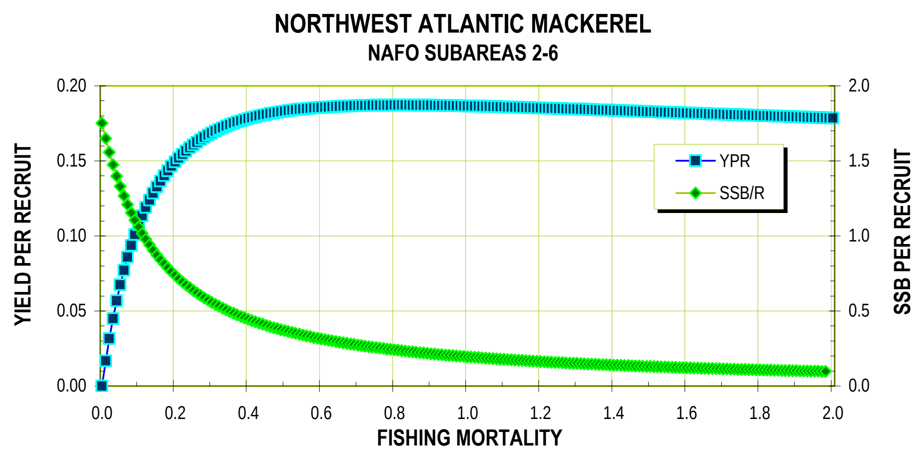


Figure 21. *Yield- and spawning stock biomass per-recruit analyses for the Northwest Atlantic mackerel ($F_{0.1}$ = 0.258, F_{max} = 0.819 and F at 40% = 0.217). Data used in these analyses are from the* outputs of XSA **Run 2**.

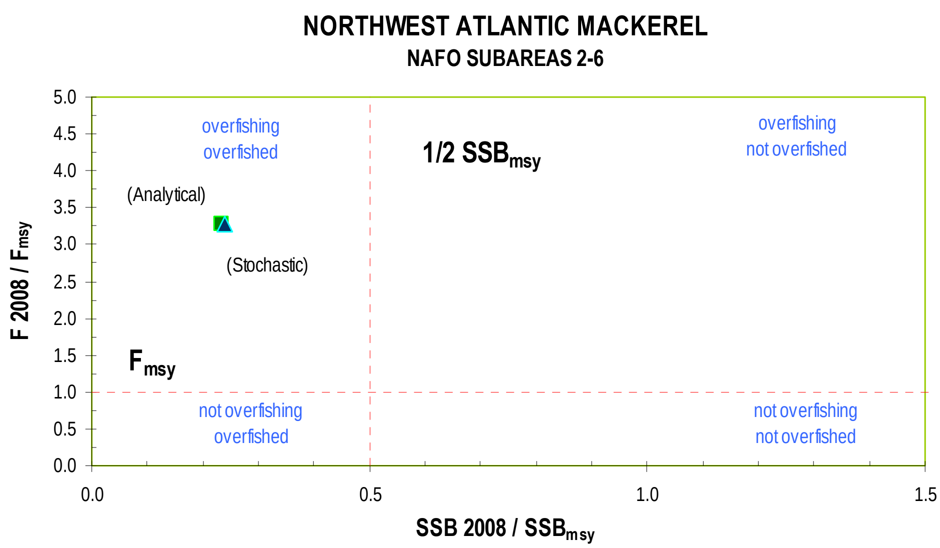


Figure 22. *Status of 2008 fishing mortality (F) and spawning stock biomass (SSB) of the Northwest Atlantic mackerel to F_{msy} and SSB_{msy}. Data used in this analysis are from the outputs of XSA* ***Run 2****.*

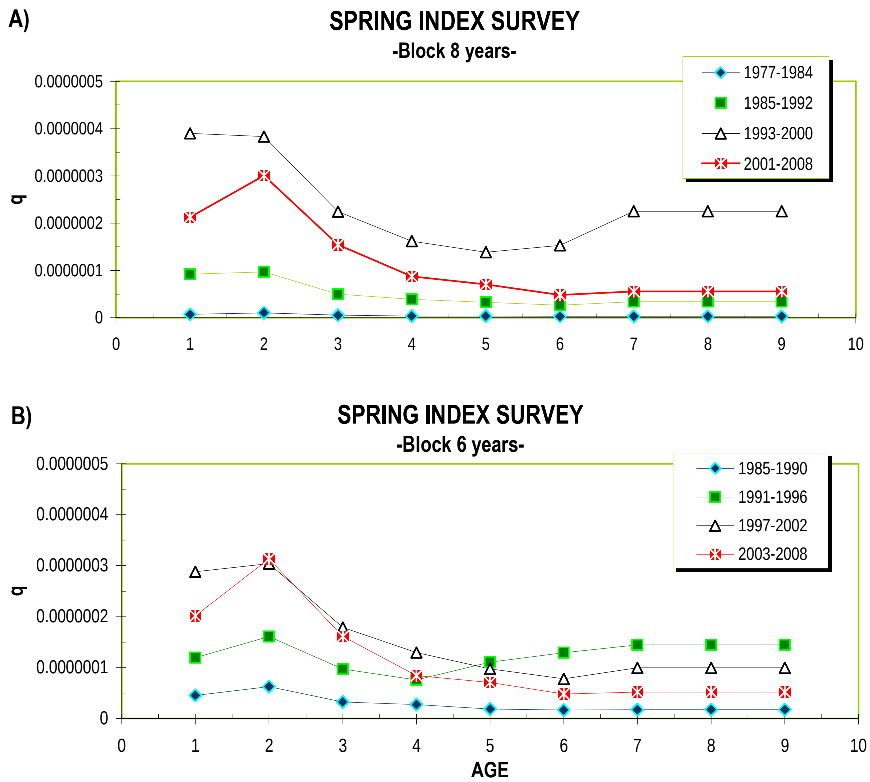


Figure 23. *Coefficients of catchability calculated for blocks of 8 (A) and 6 (B) years.*

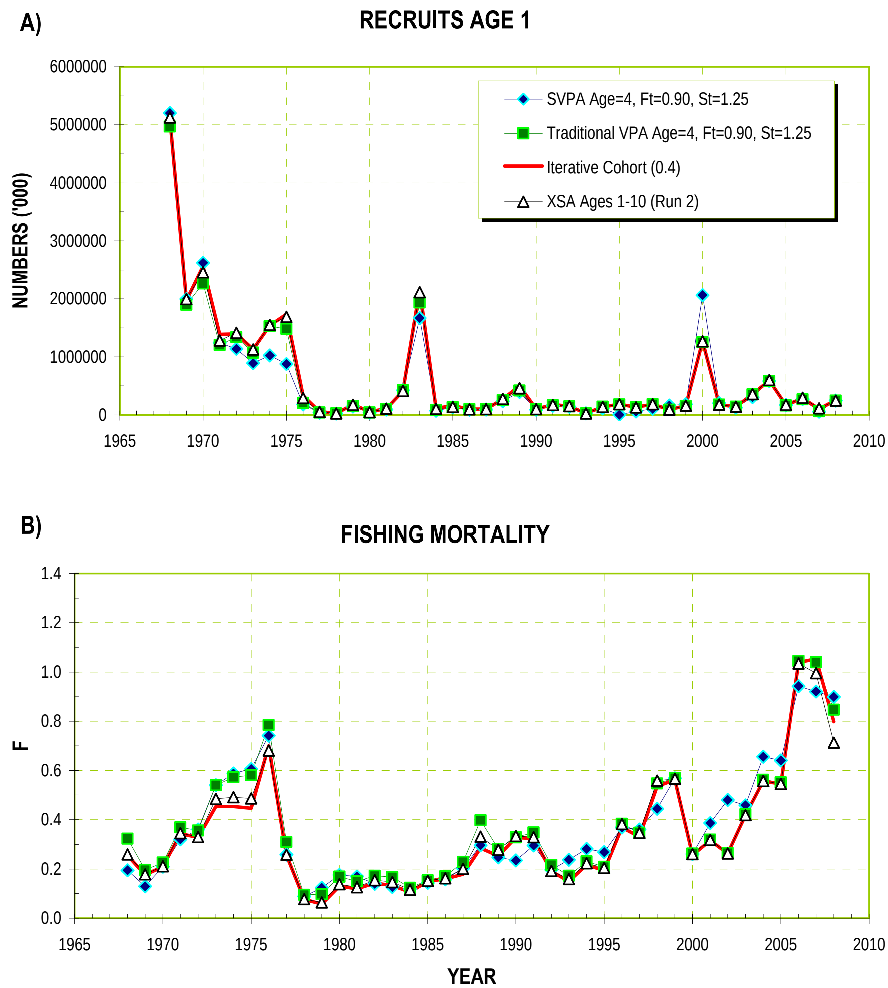


Figure 24. *Assessments of the Northwest Atlantic mackerel from Separable VPA (SVPA), traditional VPA, iterative cohort and Extended Survivors Analysis (XSA): A) recruits at age 1 (thousands of fish); B) fishing mortality (average ages 3-5); C) population abundance ages 1^+ (thousands of fish); and D) spawning stock biomass (metric tons) for the 1968-2008 period.*

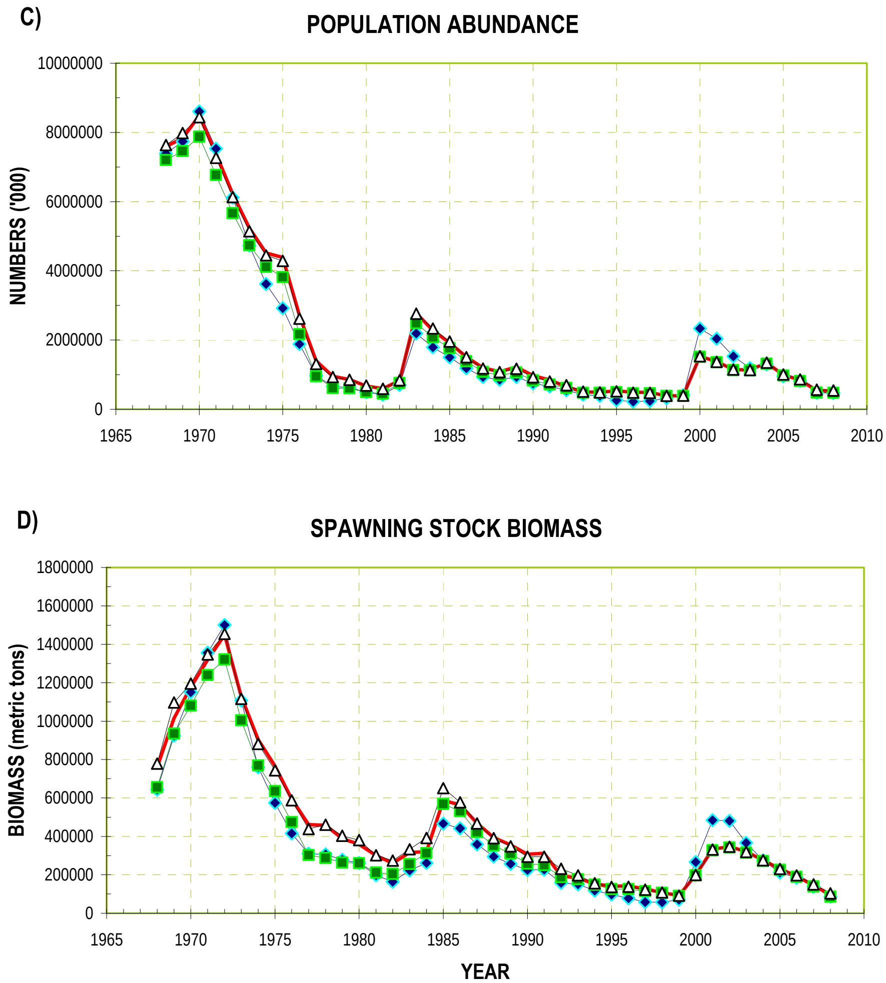


Figure 24. *(Continued).*