# Separable VPA and Trends in the Fishing Mortality, Population Abundance and Spawning Stock Biomass for the Northwest Atlantic Mackerel (*Scomber scombrus* L.) Between 1968 and 2008

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## ABSTRACT

Catch at age of Atlantic mackerel (*Scomber scombrus* L.) of the Northwest Atlantic was analyzed using a separable VPA and a traditional VPA. Several models were tested and the results suggest that the fishing mortality has been increasing since the early 2000s and that some of the values are similar to those calculated in the 1970s when hundreds of thousands of tons were caught by fleets of foreign vessels. The results also indicate that the spawning stock biomass in recent years is among the lowest in the whole historical series. According to the reference points $F_{msy}$ and $SSB_{msy}$, the status of Atlantic mackerel in 2008 would be associated to the "*overfishing/overfished*" zone of the strategic management framework used by the Northeast Fisheries Science Center. Trends measured in this study are probably real. However, absolute values do not appear realistic, which suggests that abundance and spawning stock biomass were underestimated.

## RÉSUMÉ

La capture à l'âge du maquereau bleu (*Scomber scombrus* L.) du Nord-Ouest de l'Atlantique a été analysée à l'aide d'une VPA séparable et d'une VPA traditionnelle. Plusieurs modèles ont été testés et les résultats retenus suggèrent que la mortalité par la pêche est à la hausse depuis le début des années 2000 et que certaines des valeurs seraient du même ordre de grandeur que celles des années 1970 où des centaines de milliers de tonnes avaient été capturées par des flottes de navires étrangers. Les résultats indiquent aussi que les biomasses reproductrices des dernières années seraient parmi les plus basses de toute la série historique. Selon les points de référence $F_{msy}$ et $SSB_{msy}$, le statut du maquereau bleu en 2008 serait associé à la zone "*overfishing/overfished*" du cadre stratégique de gestion employé par le Northeast Fisheries Science Center. Les tendances mesurées au cours de la présente étude sont probablement réelles. Cependant, les valeurs absolues ne semblent pas être réalistes ce qui porte à croire que les abondances et les biomasses reproductrices ont été sous-évaluées.

# INTRODUCTION

Atlantic mackerel (*Scomber scombrus* L.) of the Northwest Atlantic was designated to be evaluated by the Transboundary Resources Assessment Committee (TRAC) at a meeting held in 2007 at the St. Andrews Biological Station in New Brunswick (Gabriel and Gavaris 2007). At this meeting it was agreed to develop and coordinate a work plan for a joint US-Canada abundance assessment and to stimulate research initiatives. A first meeting (video conference) took place in the fall of 2009 to discuss the data and models to use in the abundance assessment.

The abundance assessment took place during the first week of March 2010 at the laboratory of the Northeast Fisheries Science Center of Woods Hole (Mass.). Different analytical models were presented as well as various formulations of the same model. A first model, the separable VPA (Pope and Shepherd 1982), was applied only on the catch at age data. A second model, the traditional VPA (Darby and Flatman 1994), was applied using as input data the abundance and fishing mortality (instantaneous rate) produced by the separable VPA.

The objective of this document is to describe and compare the results from these two analytical models that were used without an abundance index.

# MATERIAL AND METHODS

## Source of Data

Catch at Age

The American and Canadian catches at age were updated so that they now cover the 1968-2008 period. The American catch at age includes discards for the 1989-2008 period and recreational catches for the 2005-2008 period. The Canadian catch at age only concerns the commercial fishery as the catches used for bait or from the recreational fishery are not recorded. The total catch at age for the entire Northwest Atlantic is the sum of American and Canadian catches at age.

Weight at Age

Total weight (kg) at age corresponds to the weighted averages (by the corresponding catches) of the American and Canadian weight (kg) at age. Total weight (kg) at age was used to convert abundance at age, from the traditional VPA, into biomass at age. Total weight (kg) at age was also used with catch at age to calculate total annual catch biomasses. These biomasses were compared with commercial landings in order to detect possible errors in catch at age calculations. Weight (kg) at age was examined by age group and averages were calculated for 10-year periods.

Maturity at Age

The proportions of maturity at age and length were calculated from biological data collected in Canadian waters since 1974. The proportions of maturity at length data were fitted using the SAS LOGISTIC procedure (SAS Institute1989). Mean proportions of maturity at age and length were calculated for 10-year periods.

**Description of the Data**

Log Catch Ratio

Logarithmic values (moving average of three years) of catch at age were compared between adjacent age groups (i.e. ages 1-2, ages 2-3, etc…) to describe the annual changes in mortality. An increase in logarithmic values between adjacent age groups is interpreted as an increase in fishing mortality (F). In older age groups, these values correspond to total mortality (Z).

Strong Year-Classes

Total catch at age, expressed in numbers at age, was transformed in percentage at age to describe the strong year-classes. For each of these year-classes, cumulative catch biomass was calculated until the age of nine. This age represents the last "*true*" age group because the $10^+$ group is composed of fish aged 10 and older. The annual catch biomass was described for the 1967 and 1999 year-classes.

Catch Curves

Total mortality (Z) in strong year-classes was calculated using the Ricker catch curve method (1975). The shape of a catch curve is related to selectivity changes at age. Moreover, the slope corresponding to age groups fully recruited to the fishery is associated with total mortality.

**Separable VPA**

The separable VPA (SVPA) model proposed by Pope and Shepherd (1982) assumes that fishing mortality can be separated into an annual component common to all ages of a same year, and into a component at age common to many years. According to this model, fishing mortality in year i and age j, or f (i,j) is defined as follows:

$$f(i,j) = F(i) \times S(j)$$

where F(i) represents fishing mortality for year i and S(j) the exploitation pattern or selectivity at age j.

Different methods have been developed to determine the best estimates for F(i) and S(j). Pope and Shepherd (1982) suggest minimizing a function whose input parameters are terminal fishing mortality F(t) at a reference age A(r) representing full recruitment and terminal selectivity S(t) associated with the same age.

A first SVPA series was conducted using a combination of the following values:

(1) F(t) = 0.10, 0.20, 0.30, 0.40, and 0.50
(2) S(t) = 0.75, 1.00, and 1.25.

The SVPA also requires as input parameters catch at age, natural mortality (set at 0.2 for all years and all age groups) and a reference age A(r). The latter is not critical and it is generally recommended to select only the median value from an age series (Darby 2003). However, in the context of this study, several values were used, namely:

(3) A(r) = 3, 4, 5, 6, 7, and 8

Several SVPA models (90) were tested using the VPA software, version 3.2 (Darby and Flatman 1994). Each model generated abundance and fishing mortalities at age as well as residuals at age. Residuals were calculated from the ratio between catches at age (logarithmic values) observed and predicted by the model. The residuals were examined in order to detect possible adjustment errors in the model. The chosen SVPA model was the one presenting no abnormalities in the residual pattern and having the smallest sum of squared residuals (Darby and Flatman 1994).

**Traditional VPA**

As suggested by Darby and Flatman (1994), abundance and fishing mortalities at age produced by the chosen SVPA model were used as input data to a traditional VPA. The main results of the VPA were presented as follows: (1) recruits (age one), including three recruitment levels (low, medium and high), (2) fishing mortalities at age, (3) partial recruitment calculated from fishing mortalities, (4) abundance at age, and (5) spawning stock biomass at age. The recruitment rates (recruits/SSB) were also calculated as well as the relationships between the spawning stock biomass, recruitment (age one) and fishing mortalities (ages 3-5, averages weighted by the corresponding abundances). Retrospective analysis was conducted for recruits (age one), abundances and fishing mortalities for the 2004-2007 period. The Mohn statistic (Mohn 1999, Legault 2009) was calculated for each analysis.

In order to validate the approach proposed by Darby and Flatman (1994), a traditional VPA from the results of an SVPA was also produced for six New England groundfish/flatfish stocks, including: Georges Bank haddock (*Melanogrammus aeglefinus*) (NFSC 2008a, 2008b), Georges Bank cod (*Gadus morhua*) (NFSC 2008a, 2008b), Georges Bank yellowtail flounder (*Limanda ferruginea*) (NFSC 2008a, 2008b), Gulf of Maine cod (Mayo et al. 2009), southern New England and Maine yellowtail flounder (NFSC 2008a, 2008b) and Gulf of Maine and Cape Cod yellowtail flounder (NFSC 2008a, 2008b). Abundance and fishing mortalities produced by these VPA were compared with those from current analytical assessments for which one or several abundance indices were used.

**Fishing Mortality**

Two calculation methods, the iterative cohort (J.-J. Maguire, pers. comm.) and the Sinclair Z (Sinclair 1998), were applied to determine if the terminal fishing mortality F(t) range used in the first SVPA series could be extended to higher values.

Iterative Cohort

This method assumes that fishing mortality in the last year equals the average mortality from the three previous years. Once convergence is reached, this method also assumes that fishing mortality in the last age group is equal to the average of certain ages (3-5) in the same year. The iterative cohort generates abundance and fishing mortality at age and, as with the SVPA, no abundance index is used. The input data are catches, weight (kg) at age and maturity at age (Canadian data) as well as natural mortality set at 0.2 for all years and all age groups.

Sinclair Z

Total mortalities (Z) were calculated using the Sinclair method (Sinclair 1998) from the U.S. abundance index expressed in average numbers per set at age (Dr. Jonathan Deroba, NOAA Fisheries, pers. comm.). Z was calculated for 4-year blocks and for age groups 2-6, 3-7 and 4-8.

Assuming constant natural mortality, the Z obtained using this method represents approximate fishing mortalities.

**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, 2009a). The input data for this analysis are the annual average (2004-2008) from the following parameters: (1) partial recruitment at age calculated from fishing mortalities (ages 3-5, averages weighted by the corresponding abundances) from the selected VPA model, (2) natural mortality set at 0.2 for all years and all age groups, (3) weight (kg) at age of catch, (4) weight (kg) at age of the population calculated according to the Rivard method (NOAA Fisheries Toolbox, 2009b), and (5) maturity at age (Canadian data). Reference points calculated by this analysis are $F_{0.1}$, $F_{max}$ and F at 40%, the latter considered by the Northeast Fisheries Science Center as a proxy of $F_{msy}$. For each of these reference points, the yield per recruit analysis calculated the ratio between spawning stock biomass and recruitment (SSB/R).

Deterministic Calculations of MSY and $SSB_{msy}$

The maximum sustainable yield, or MSY, was obtained analytically from the product of yield per recruit (Y/R) obtained at $F_{msy}$ (F at 40%) and recruitment (average historical level) from the selected VPA model. 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 stock assessed by the VPA for 2008 was described by 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 $SSB_{msy}$

Stochastic estimates of MSY and $SSB_{msy}$ were 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 selected VPA model. AGEPRO offers 19 relationship models between recruitment and spawning stock biomass. The final choice focused on empirical cumulative distribution (ECD) (Model 14) 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, the annual $SSB_{msy}$ and MSY values stabilized after some years. The selected values represent the averages for the 2020-2108 period.

**RESULTS**

**Description of the Data**

Total Catch

Northwest Atlantic mackerel catches reached a historical peak in the early 1970s (Figure 1). This was caused by the presence of a large number of foreign vessels fishing in U.S. and Canadian waters. The arrival of the 200 nautical miles exclusive economic zone (EEZ) in 1977 led to a rapid and significant decrease of this fishing effort. Catches increased again in the mid-1980s and early 2000s, but did not reach the 1970 level. Each of these periods is associated with the presence of one or more strong year-class (Tables 1-4).

After some adjustments, no significant difference was observed between the annual catch biomass (the product of the catch and weight at age) and the landings from the commercial and recreational fisheries, suggesting the absence of significant errors in calculating catch at age (Table 5, Figure 1).

Log Catch Ratio

The log values of catch at age ratio between adjacent age groups suggest a fishing mortality lower for fish aged one, two and three years (Figure 2). For all age groups, fishing mortalities increased from the late 1960s to the mid-1970s, which is the period of intensive fishing by foreign vessels. Mortalities declined in the late 1970s and for older age groups ($4^+$ years), they fluctuated slightly until the early 2000s. Mortalities then increased and in 2005 reached values as high as the mid-1970s. For age groups one and two, mortalities have shown a clear upward trend since 1987.

Strong Year-Classes

Since the late 1960s, the age structure of Northwest Atlantic mackerel has been characterized by the periodic presence of strong year-classes (Figure 3). Some of these year-classes were only present for a few years while others were observed over a longer period of time. In terms of landings, the two strongest year-classes were those of 1967 and 1982 (Figure 4). Catches totalling nearly 800,000 t were only associated with the 1967 year-class between 1968 and 1976 compared to nearly 300,000 t for the 1982 year-class between 1983 and 1991. Nearly 40% or more of the annual landings made between 1969 and 1972 was associated with the 1967 year-class (Figure 5A). The 1982 year-class was followed closely by the 1999 year-class with catches totalling nearly 250,000 t between 2000 and 2008 (Figure 4). Nearly 50% or more of the annual landings made between 2001 and 2004 was associated with this single year-class (Figure 5B). Among the strong year-classes, the catch at age curves indicate that the highest total mortalities (Z) were calculated for the 1974 (Z=0.46) and 1967 (Z=0.40) year-classes, and the lowest for the 1982 (Z=0.06) and 1999 (0.28) year-classes (Figure 6).

Weight and Maturity at Age

Mean weight (kg) at age has varied little over the years except during the 1980s when higher values were measured (Figure 7A). For each age group, weight began increasing in 1976 to reach maximum values in the early 1980s (Figure 7B). Weight at age rapidly declined thereafter and returned to levels similar to those of the 1970s.

The proportion of maturity at age for the first five age groups (0 to 4 years) appears to have slightly increased in the 2000s compared to the 1970s (1974-1979), 1980s and 1990s (Figure 8). This increase is more noticeable in maturity at length (Figure 9).

In the absence of data and to obtain same size matrices for weight (kg) and maturity at age, – a prerequisite for using the VPA software – maturity at age measured in 1974 was applied to the 1968-1973 period (Table 6). However, this period was excluded from annual average calculations.

**First SVPA Models**

The lowest sum of squared residuals was obtained for the SVPA model with a terminal fishing mortality F(t) of 0.50 and a terminal selectivity S(t) of 1.25 (Table 7). The selected reference age was four years. Simulations showed that the sums of squared residuals were always lower for this age regardless of the value assigned to terminal selectivity S(t). For the period covered by the model, the residual pattern presents high and opposite values between the youngest and oldest age groups (Figure 10A).

According to this model, fishing mortalities increased during the 1970s and then dropped sharply in 1977 (the arrival of the EEZ) (Figure 10B). Fishing mortalities have been on the rise since the early 1990s and 2000s. At ages $4^+$ and $6^+$, they reached values above 0.5 between 1996 and 1999 and between 2001 and 2008, and values above 1.0 for $6^+$ in 2005, 2006 and 2007. The highest abundances were observed in the late 1960s and early 1970s (Figure 10C). They dropped rapidly thereafter but increased in the mid-1980s and early 2000s before decreasing again.

New England Stocks

The sum of squared residuals from the SVPA models for the New England stocks are presented in Table 8. The selected reference age was four except for the Georges Bank and Gulf of Maine cod stocks for which age five was assigned. The fishing mortality values associated with the selected VPA-SVPA models (based on the lowest sum of squared residuals) were very close to those from current assessments with the exception of the South of New England and Maine and Gulf of Maine Cape Cod yellowtail flounder stocks, which presented similar trends (Figure 11).

Very few differences were observed in terms of abundance except for the last three years for the Gulf of Maine cod stock and the last two years for the Georges Bank yellowtail flounder stock (Figure 12). In the first case, the difference could be explained by the very few commercial catches of the 2005 and 2006 year-classes compared with corresponding high abundance index values (Mayo et al. 2009). It should be noted that these two stocks have significant retrospective patterns that tend to over-evaluate their actual abundances (NFSC 2008a).

Following these results, it was decided that this approach – VPA calculation using results from an SVPA – would be applied to Northwest Atlantic mackerel.

**First VPA Model**

Recruits, Mortality and Partial Recruitment

According to the selected VPA model, two distinct productivity periods are associated with the Atlantic mackerel recruitment. The first, between 1967 and 1974, is characterized by the

consecutive presence of several strong year-classes (Table 9, Figure 13A), whereas the second is characterized by only two strong year-classes; 1982 and 1999.

The fishing mortalities pattern produced by this VPA (Figure 13B) is similar to that of the corresponding SVPA (Figure 10B). For age groups 3-5, a fishing mortality of 0.20 was calculated in 2002 compared to 0.74 (the second highest value) in 2007 (Table 9). Partial recruitment has changed little over the years with a full recruitment occurring at about age four (Figure 13C).

Abundance, Biomass and Fishing Mortality

Three periods of high abundance were observed over the years, in the 1970s, the mid-1980s and early 2000s (Figures 14A, 14B). Spawning stock biomass has declined steadily since 2002 from 342,691 t to 133,957 t in 2008 (Table 9). The highest recruitment rates were observed in 1982 and 1999 (Figure 14C). Since the early 2000s, the two strongest year-classes were those of 2003 and 2007 (Figure 13A). The 2003 year-class was slightly higher than 2007, but both were far weaker than the strong 1999 year-class (Table 9).

Stock/Fishing Mortality-Recruitment

Except for the 1999 and 1982 year-classes, all the other strong year-classes appeared when the spawning stock biomass was high and above 600,000 t (Figure 15A). Fishing mortalities increased between 1972 and 1976 and were associated with a decrease in biomass (Figure 15B). They were relatively low thereafter except in the late 1990s and mid-2000s.

Retrospective Pattern

Recruits (age one) do not show any retrospective pattern (Figure 16A). In terms of differences (Figure 16B) and relative differences (Figure 16C), positive deviations were recorded in 2004 and 2005 compared to negative deviations in 2006 and 2007 resulting in positive values in Mohn's statistic (average and total) (Table 10). As with recruits, abundances do not show any retrospective pattern (Figure 17A). Positive deviations were measured for differences (Figure 17B) and relative differences (Figure 17C) and positive values were obtained in Mohn's statistic (Table 10). Fishing mortalities show a slight retrospective pattern for 2006 and 2007 (Figure 18A). For these two years, negative deviations were measured for differences (Figure 18B) and relative differences (Figure 18C) resulting in negative values for Mohn's statistic (Table 10).

Reference Points

The MSY and $SSB_{msy}$ reference points obtained by projections totalled 84,025 t and 384,258 t respectively (Figures 19A, 19B) relative to a total biomass of 537,984 t (Figure 19C). Reference points associated with fishing mortality, calculated by yield per recruit analysis (input data, Table 11) were estimated at 0.259 for $F_{0.1}$, 0.812 for $F_{max}$ and 0.215 for $F_{msy}$ (F at 40%) (Table 12, Figure 20). MSY and $SSB_{msy}$ reference points obtained analytically were 92,232 t and 421,830 t respectively (Table 13).

Stock Status for 2008

The ratio between fishing mortality (ages 3-5) in the last year (2008) of the VPA and $F_{msy}$ was estimated at 2.10 (Table 13). The ratio between spawning stock biomass in 2008 and $SSB_{msy}$ was estimated at 0.318 for the analytical assessment and at 0.349 for the stochastic

assessment. According to these ratios, the status of the Northwest Atlantic mackerel in 2008 would be associated to the "*overfishing/overfished*" zone of the strategic management framework used by the Northeast Fisheries Science Center (Figure 21).

**Final SVPA and VPA Models**

Sinclair Z

Total mortality calculated by the Sinclair method is very high and in many cases greater than the unit (Figures 22A, 22B and 22C). These results suggest that terminal mortalities would be higher than those used previously. A second series of SVPA was therefore used with terminal mortality values ranging from 0.6 to 1.0. The lowest squared residuals were obtained for terminal mortalities of 0.80, 0.90 and 1.00 and a terminal selectivity of 1.25 (Table 14).

The new SVPA do not show any significant pattern differences in terms of residuals (Figures 23A, 23B, 23C), fishing mortalities (Figures 24A, 24B, 24C) and abundance (Figures 25A, 25B, 25C). The increase in terminal mortality from 0.80 to 1.00 causes a decrease in recruits and spawning stock biomass and an increase in fishing mortalities (Table 15).

Iterative Cohort

Fishing mortalities produced by the iterative cohort are on the rise since the mid-1990s and early 2000s with values above 0.8 since 2006 (Figure 26A). Fishing mortalities and spawning stock biomass produced by this analysis are similar to those calculated by VPA-SVPA models with terminal mortalities above 0.8 (Figures 26A, 26B).

Based on the results from these two approaches, it was decided to run a final VPA from an SVPA with a terminal mortality of 0.90 and a terminal selectivity of 1.25.

Recruits, Mortality and Partial Recruitment

Recruits obtained at a terminal mortality of 0.90 and a terminal selectivity of 1.25 (Figure 27A) show annual patterns similar to those produced at Ft=0.50 and St=1.25 (Figure 13A). Fishing mortalities do not show any significant differences except for those in 2007 and 2008 when higher values were obtained at 0.90 (Figures 13B, 27B). No significant difference was observed for partial recruitment (Figures 13C, 27C).

Abundance, Biomass and Fishing Mortality

The patterns for annual abundance (Figure 28A), spawning stock biomass (Figure 28B) and recruitment rates (Figure 28C) show no major differences than those produces with a Ft = 0.50 and St=1.25 (Figures 14A, 14B, 14C). At a terminal mortality of 0.90, abundance and spawning stock biomass were slightly higher than those obtained at 0.50 for the 1968-1999 period, and lower in subsequent years.

Stock/Fishing Mortality-Recruitment

Relationships between recruitment (Figure 29A), fishing mortality (Figure 29B) and spawning stock biomass also present identical patterns than those at Ft = 0.50 and St=1.25 (Figures 15A, 15B). Except for 1999 and 1982, all the strong year-classes appeared when spawning stock biomass was high and above 600,000 t. Fishing mortalities increased between 1972 and 1976. Subsequently, they were relatively low except in the late 1990s and mid-2000s.

Retrospective Pattern

There was no retrospective pattern for recruits (Figure 30A) and abundance (Figure 31A), and a slight pattern was observed for fishing mortalities (Figure 32A). For the recruits and abundance, negative deviations were measured for the difference and relative differences (Figures 30B, 30C, 31B, 31C) and positive and negative deviations for fishing mortalities (Figures 32B, 32C). The corresponding Mohn statistics presented negative values for recruits and abundance and positive values for fishing mortalities (Table 16). Opposite values were obtained at a terminal mortality of 0.50 (Table 10).

Reference Points

MSY and $SSB_{msy}$ reference points obtained by projections totalled 82,520 t and 378,629 t respectively (Table 19, Figures 33A and 33B) and the corresponding total biomass was 529,785 t (Figure 33C). These values are slightly lower than those obtained at a terminal mortality of 0.50 (Figures 19A, 19B and 19C). The fishing mortality reference points calculated by yield per recruit analysis (input data, Table 17) were estimated at 0.258 for $F_{0.1}$, 0.787 for $F_{max}$ and 0.213 for $F_{msy}$ (F at 40%) (Table 18, Figure 34). MSY and $SSB_{msy}$ reference points obtained analytically totalled 90,734 t and 416,346 t (Table 19). These values are slightly lower than those obtained at a terminal mortality of 0.50 (Table 13).

Stock Status for 2008

The ratio between fishing mortality (ages 3-5) in the last year (2008) of the VPA and $F_{msy}$ was estimated at 3.379 (Table 19). The ratio between spawning stock biomass in 2008 and $SSB_{msy}$ was estimated at 0.207 for the analytical assessment and at 0.228 for the stochastic assessment.

According to these values, the status of the Northwest Atlantic mackerel would be associated to the "*overfishing/overfished*" zone of the strategic management framework used by the Northeast Fisheries Science Center (Figure 35).

**CONCLUSION**

Results from all the VPA-SVPA models indicate that fishing mortality in Northwest Atlantic mackerel increased rapidly during the 2000s reaching levels above those recorded in the 1970s. In addition to this increase in fishing mortality, there has been a decrease in abundance and spawning stock biomass. These trends are probably real given the similarities that were obtained from the New England stocks between the VPA-SVPA approach and current analytical assessments (identical results were also obtained from nine European stocks; F. Grégoire, unpublished data). However, absolute values do not appear to be realistic which suggests that abundance and spawning stock biomass were underestimated. In this sense, the 2008 landings were estimated at 51,043 t compared with a spawning stock biomass of 86,204 t calculated from a terminal mortality of 0.90 and a terminal selectivity of 1.25.

This underestimation of abundance could be the result of a catch at age that doesn't reflect all the landings. This problem is quite significant on the Canadian side where catches from recreational and bait fishing are not recorded (DFO 2008). Natural mortality should be reassessed because it has probably changed over the years. Moreover, it is likely not the same for all age groups.

The recent increase in fishing mortality is alarming as well as the disappearance of older fish in commercial catches. This disappearance could be the result of an overly high fishing pressure and/or the presence of a distinct spatial distribution between the various age groups. For example, younger individuals may be found primarily in coastal waters - where most fishing activities take place - unlike older individuals that can be found in offshore waters. However, there is no data, at least from the Canadian side, to verify this hypothesis. Such data does exist however for the European mackerel fishery which is both coastal and offshore.

The decrease in spawning stock biomass measured by the different VPA-SVPA models since the mid-1990s corresponds to a certain extent to that observed in the Canadian egg survey (DFO 2008). In addition to a real abundance decrease, it might be associated with the presence of new distribution patterns caused by changes in water temperature. In fact, colder waters were measured in the southern Gulf of St. Lawrence in the 1990s. These migration route changes could also be the reason for the increased presence of mackerel in Newfoundland, where the majority of Canadian mackerel catches now occur.

The status of Northwest Atlantic mackerel as defined by the strategic management framework used by the Northeast Fisheries Science Center must be viewed with some caution given the uncertainty associated with the absolute values of fishing mortality and abundance. However, as demonstrated by the results obtained with U.S. stocks, the trends are probably close to reality.

Results obtained in this study incite a greater use of the separable VPA, at least for exploratory purposes, for stocks without any abundance index.

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***Table 1.*** *Total catch at age (thousands of fish) for the Northwest Atlantic mackerel in NAFO Subareas 2-6, 1968-2008[1].*

| YEAR | AGE (yr) | | | | | | | | | |
|------|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10+ |
| 1968 | 161 471 | 64 836 | 64 121 | 41 546 | 15 614 | 7 229 | 1 036 | 1 773 | 10 959 | 145 |
| 1969 | 8 743 | 269 708 | 165 912 | 66 385 | 5 968 | 3 247 | 2 317 | 3 227 | 2 333 | 11 087 |
| 1970 | 198 612 | 55 421 | 530 567 | 164 929 | 28 229 | 7 114 | 5 407 | 10 298 | 10 415 | 7 693 |
| 1971 | 77 391 | 297 082 | 128 064 | 572 914 | 206 472 | 35 284 | 9 759 | 4 195 | 5 033 | 17 452 |
| 1972 | 22 100 | 85 737 | 257 402 | 184 113 | 397 180 | 88 659 | 25 433 | 4 221 | 8 349 | 11 266 |
| 1973 | 165 837 | 292 274 | 289 345 | 237 706 | 198 547 | 207 008 | 34 859 | 12 219 | 4 468 | 6 105 |
| 1974 | 101 295 | 257 437 | 281 116 | 110 641 | 122 184 | 119 573 | 117 926 | 28 237 | 7 473 | 4 395 |
| 1975 | 382 600 | 447 003 | 121 875 | 108 090 | 63 018 | 72 515 | 55 318 | 52 954 | 13 017 | 3 664 |
| 1976 | 13 383 | 364 589 | 286 700 | 91 452 | 56 454 | 29 326 | 43 078 | 36 683 | 24 236 | 15 410 |
| 1977 | 2 093 | 27 893 | 103 824 | 55 417 | 12 461 | 10 222 | 5 701 | 6 481 | 3 912 | 4 415 |
| 1978 | 100 | 200 | 4 700 | 17 400 | 13 300 | 8 400 | 4 700 | 2 200 | 4 500 | 7 300 |
| 1979 | 400 | 600 | 1 300 | 7 100 | 18 600 | 13 100 | 6 200 | 2 600 | 2 200 | 6 500 |
| 1980 | 1 200 | 10 900 | 3 312 | 1 926 | 6 900 | 13 800 | 7 596 | 3 384 | 2 208 | 5 200 |
| 1981 | 16 100 | 7 100 | 9 200 | 1 400 | 2 000 | 6 100 | 11 700 | 4 900 | 2 500 | 3 500 |
| 1982 | 3 700 | 11 800 | 2 700 | 9 100 | 1 200 | 1 900 | 3 400 | 8 400 | 2 900 | 5 100 |
| 1983 | 2 200 | 15 300 | 6 500 | 1 900 | 7 000 | 700 | 1 200 | 5 500 | 10 200 | 6 500 |
| 1984 | 500 | 40 400 | 27 200 | 3 200 | 1 200 | 4 600 | 600 | 700 | 3 400 | 14 000 |
| 1985 | 3 105 | 1 558 | 122 995 | 32 539 | 2 900 | 955 | 3 952 | 420 | 737 | 14 871 |
| 1986 | 1 289 | 12 715 | 6 708 | 100 901 | 25 394 | 2 104 | 696 | 3 184 | 215 | 6 088 |
| 1987 | 4 168 | 14 588 | 14 622 | 7 705 | 110 118 | 17 794 | 2 511 | 363 | 2 107 | 3 531 |
| 1988 | 1 005 | 13 009 | 10 274 | 9 955 | 11 680 | 106 775 | 23 039 | 2 628 | 1 189 | 5 552 |
| 1989 | 3 932 | 17 163 | 11 033 | 7 320 | 7 077 | 2 352 | 88 629 | 4 977 | 925 | 2 252 |
| 1990 | 1 950 | 20 881 | 32 129 | 7 952 | 6 422 | 4 318 | 800 | 54 213 | 2 604 | 1 200 |
| 1991 | 1 413 | 14 610 | 56 390 | 24 626 | 6 460 | 3 900 | 3 300 | 1 000 | 27 300 | 1 200 |
| 1992 | 733 | 6 751 | 5 292 | 25 694 | 15 380 | 2 070 | 1 554 | 1 269 | 1 339 | 16 748 |
| 1993 | 1 519 | 9 205 | 11 311 | 6 171 | 16 535 | 8 949 | 1 918 | 814 | 1 116 | 8 442 |
| 1994 | 1 991 | 1 778 | 12 711 | 14 415 | 5 489 | 19 728 | 6 687 | 1 084 | 307 | 4 106 |
| 1995 | 18 516 | 20 653 | 2 732 | 9 544 | 8 203 | 3 231 | 10 261 | 3 226 | 307 | 921 |
| 1996 | 7 685 | 34 972 | 25 797 | 1 945 | 12 745 | 9 866 | 2 553 | 10 219 | 2 309 | 1 484 |
| 1997 | 6 902 | 21 987 | 23 401 | 11 115 | 1 076 | 8 523 | 6 801 | 2 781 | 7 227 | 1 872 |
| 1998 | 2 308 | 29 849 | 19 107 | 16 691 | 8 719 | 1 155 | 5 881 | 4 141 | 985 | 2 405 |
| 1999 | 1 738 | 6 715 | 23 877 | 14 191 | 9 205 | 4 805 | 1 450 | 2 908 | 2 023 | 1 274 |
| 2000 | 26 104 | 9 592 | 6 178 | 10 302 | 4 373 | 3 303 | 702 | 54 | 229 | 376 |
| 2001 | 9 084 | 76 911 | 23 792 | 7 512 | 9 859 | 2 384 | 2 068 | 716 | 168 | 331 |
| 2002 | 9 945 | 12 354 | 120 036 | 14 246 | 5 259 | 9 714 | 3 107 | 808 | 187 | 78 |
| 2003 | 10 212 | 23 947 | 26 542 | 121 931 | 13 985 | 5 018 | 4 861 | 261 | 5 | 0 |
| 2004 | 37 551 | 77 904 | 22 340 | 25 202 | 121 086 | 9 058 | 2 828 | 881 | 225 | 0 |
| 2005 | 18 652 | 101 050 | 63 245 | 12 859 | 9 410 | 70 156 | 2 164 | 3 243 | 80 | 45 |
| 2006 | 24 721 | 22 212 | 129 188 | 44 706 | 10 632 | 8 499 | 39 205 | 1 007 | 142 | 43 |
| 2007 | 2 186 | 52 804 | 39 401 | 64 204 | 13 947 | 2 167 | 1 668 | 6 531 | 151 | 6 |
| 2008 | 18 346 | 19 611 | 54 873 | 13 883 | 18 530 | 2 874 | 522 | 334 | 1 245 | 27 |

[1] US data include commercial discards for 1989-2008 and recreational landings for 2005-2008; Canadian data do not include discards and recreational landings; bold and underlined numbers represent strong year-classes

***Table 2.*** *Total catch at age (%) for the Northwest Atlantic mackerel in NAFO Subareas 2-6, 1968-2008[1].*

| YEAR | AGE (yr) |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10+ |
| 1968 | 43.79 | 17.58 | 17.39 | 11.27 | 4.23 | 1.96 | 0.28 | 0.48 | 2.97 | 0.04 |
| 1969 | 1.62 | 50.05 | 30.79 | 12.32 | 1.11 | 0.60 | 0.43 | 0.60 | 0.43 | 2.06 |
| 1970 | 19.50 | 5.44 | 52.08 | 16.19 | 2.77 | 0.70 | 0.53 | 1.01 | 1.02 | 0.76 |
| 1971 | 5.72 | 21.95 | 9.46 | 42.32 | 15.25 | 2.61 | 0.72 | 0.31 | 0.37 | 1.29 |
| 1972 | 2.04 | 7.91 | 23.74 | 16.98 | 36.62 | 8.18 | 2.35 | 0.39 | 0.77 | 1.04 |
| 1973 | 11.45 | 20.18 | 19.98 | 16.41 | 13.71 | 14.29 | 2.41 | 0.84 | 0.31 | 0.42 |
| 1974 | 8.81 | 22.38 | 24.44 | 9.62 | 10.62 | 10.40 | 10.25 | 2.45 | 0.65 | 0.38 |
| 1975 | 28.98 | 33.86 | 9.23 | 8.19 | 4.77 | 5.49 | 4.19 | 4.01 | 0.99 | 0.28 |
| 1976 | 1.39 | 37.93 | 29.82 | 9.51 | 5.87 | 3.05 | 4.48 | 3.82 | 2.52 | 1.60 |
| 1977 | 0.90 | 12.00 | 44.67 | 23.84 | 5.36 | 4.40 | 2.45 | 2.79 | 1.68 | 1.90 |
| 1978 | 0.16 | 0.32 | 7.48 | 27.71 | 21.18 | 13.38 | 7.48 | 3.50 | 7.17 | 11.62 |
| 1979 | 0.68 | 1.02 | 2.22 | 12.12 | 31.74 | 22.35 | 10.58 | 4.44 | 3.75 | 11.09 |
| 1980 | 2.13 | 19.32 | 5.87 | 3.41 | 12.23 | 24.46 | 13.46 | 6.00 | 3.91 | 9.22 |
| 1981 | 24.96 | 11.01 | 14.26 | 2.17 | 3.10 | 9.46 | 18.14 | 7.60 | 3.88 | 5.43 |
| 1982 | 7.37 | 23.51 | 5.38 | 18.13 | 2.39 | 3.78 | 6.77 | 16.73 | 5.78 | 10.16 |
| 1983 | 3.86 | 26.84 | 11.40 | 3.33 | 12.28 | 1.23 | 2.11 | 9.65 | 17.89 | 11.40 |
| 1984 | 0.52 | 42.17 | 28.39 | 3.34 | 1.25 | 4.80 | 0.63 | 0.73 | 3.55 | 14.61 |
| 1985 | 1.69 | 0.85 | 66.83 | 17.68 | 1.58 | 0.52 | 2.15 | 0.23 | 0.40 | 8.08 |
| 1986 | 0.81 | 7.98 | 4.21 | 63.34 | 15.94 | 1.32 | 0.44 | 2.00 | 0.13 | 3.82 |
| 1987 | 2.35 | 8.22 | 8.24 | 4.34 | 62.04 | 10.02 | 1.41 | 0.20 | 1.19 | 1.99 |
| 1988 | 0.54 | 7.03 | 5.55 | 5.38 | 6.31 | 57.68 | 12.45 | 1.42 | 0.64 | 3.00 |
| 1989 | 2.70 | 11.78 | 7.57 | 5.03 | 4.86 | 1.61 | 60.85 | 3.42 | 0.64 | 1.55 |
| 1990 | 1.47 | 15.76 | 24.25 | 6.00 | 4.85 | 3.26 | 0.60 | 40.93 | 1.97 | 0.91 |
| 1991 | 1.01 | 10.42 | 40.22 | 17.56 | 4.61 | 2.78 | 2.35 | 0.71 | 19.47 | 0.86 |
| 1992 | 0.95 | 8.79 | 6.89 | 33.44 | 20.02 | 2.69 | 2.02 | 1.65 | 1.74 | 21.80 |
| 1993 | 2.30 | 13.95 | 17.14 | 9.35 | 25.06 | 13.56 | 2.91 | 1.23 | 1.69 | 12.79 |
| 1994 | 2.92 | 2.60 | 18.61 | 21.11 | 8.04 | 28.89 | 9.79 | 1.59 | 0.45 | 6.01 |
| 1995 | 23.86 | 26.62 | 3.52 | 12.30 | 10.57 | 4.16 | 13.22 | 4.16 | 0.40 | 1.19 |
| 1996 | 7.01 | 31.92 | 23.54 | 1.78 | 11.63 | 9.00 | 2.33 | 9.33 | 2.11 | 1.35 |
| 1997 | 7.53 | 23.98 | 25.52 | 12.12 | 1.17 | 9.30 | 7.42 | 3.03 | 7.88 | 2.04 |
| 1998 | 2.53 | 32.71 | 20.94 | 18.29 | 9.56 | 1.27 | 6.45 | 4.54 | 1.08 | 2.64 |
| 1999 | 2.55 | 9.85 | 35.02 | 20.81 | 13.50 | 7.05 | 2.13 | 4.26 | 2.97 | 1.87 |
| 2000 | 42.64 | 15.67 | 10.09 | 16.83 | 7.14 | 5.40 | 1.15 | 0.09 | 0.37 | 0.61 |
| 2001 | 6.84 | 57.90 | 17.91 | 5.66 | 7.42 | 1.80 | 1.56 | 0.54 | 0.13 | 0.25 |
| 2002 | 5.66 | 7.03 | 68.31 | 8.11 | 2.99 | 5.53 | 1.77 | 0.46 | 0.11 | 0.04 |
| 2003 | 4.94 | 11.58 | 12.84 | 58.97 | 6.76 | 2.43 | 2.35 | 0.13 | 0.00 | 0.00 |
| 2004 | 12.64 | 26.22 | 7.52 | 8.48 | 40.76 | 3.05 | 0.95 | 0.30 | 0.08 | 0.00 |
| 2005 | 6.64 | 35.97 | 22.51 | 4.58 | 3.35 | 24.98 | 0.77 | 1.15 | 0.03 | 0.02 |
| 2006 | 8.82 | 7.92 | 46.08 | 15.95 | 3.79 | 3.03 | 13.98 | 0.36 | 0.05 | 0.02 |
| 2007 | 1.19 | 28.84 | 21.52 | 35.07 | 7.62 | 1.18 | 0.91 | 3.57 | 0.08 | 0.00 |
| 2008 | 14.09 | 15.06 | 42.13 | 10.66 | 14.23 | 2.21 | 0.40 | 0.26 | 0.96 | 0.02 |

[1] US data include commercial discards for 1989-2008 and recreational landings for 2005-2008; Canadian data do not include discards and recreational landings; bold and underlined numbers represent strong year-classes

***Table 3.*** *Mean weight at age (kg) for the Northwest Atlantic mackerel in NAFO Subareas 2-6, 1968-2008[1].*

| YEAR | AGE (yr) | | | | | | | | | |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|      | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10+ |
| 1968 | 0.148 | 0.241 | 0.335 | 0.425 | 0.506 | 0.576 | 0.634 | 0.683 | 0.722 | 0.753 |
| 1969 | 0.131 | 0.214 | 0.300 | 0.382 | 0.456 | 0.520 | 0.574 | 0.618 | 0.654 | 0.683 |
| 1970 | 0.107 | 0.179 | 0.253 | 0.324 | 0.389 | 0.444 | 0.491 | 0.530 | 0.562 | 0.595 |
| 1971 | 0.110 | 0.181 | 0.256 | 0.327 | 0.391 | 0.446 | 0.494 | 0.532 | 0.564 | 0.598 |
| 1972 | 0.123 | 0.210 | 0.300 | 0.386 | 0.464 | 0.533 | 0.590 | 0.638 | 0.677 | 0.725 |
| 1973 | 0.113 | 0.189 | 0.269 | 0.345 | 0.414 | 0.473 | 0.524 | 0.565 | 0.600 | 0.634 |
| 1974 | 0.111 | 0.190 | 0.273 | 0.352 | 0.425 | 0.487 | 0.541 | 0.585 | 0.621 | 0.654 |
| 1975 | 0.104 | 0.176 | 0.252 | 0.326 | 0.393 | 0.451 | 0.500 | 0.540 | 0.573 | 0.605 |
| 1976 | 0.097 | 0.168 | 0.244 | 0.316 | 0.382 | 0.440 | 0.489 | 0.530 | 0.563 | 0.592 |
| 1977 | 0.114 | 0.198 | 0.288 | 0.375 | 0.454 | 0.524 | 0.582 | 0.631 | 0.671 | 0.707 |
| 1978 | 0.192 | 0.285 | 0.425 | 0.463 | 0.509 | 0.582 | 0.625 | 0.659 | 0.673 | 0.713 |
| 1979 | 0.190 | 0.272 | 0.531 | 0.567 | 0.579 | 0.603 | 0.652 | 0.714 | 0.752 | 0.803 |
| 1980 | 0.146 | 0.376 | 0.541 | 0.600 | 0.617 | 0.635 | 0.670 | 0.706 | 0.769 | 0.777 |
| 1981 | 0.114 | 0.315 | 0.523 | 0.577 | 0.643 | 0.660 | 0.674 | 0.707 | 0.723 | 0.768 |
| 1982 | 0.152 | 0.340 | 0.541 | 0.606 | 0.666 | 0.743 | 0.737 | 0.722 | 0.719 | 0.775 |
| 1983 | 0.098 | 0.257 | 0.479 | 0.593 | 0.628 | 0.659 | 0.712 | 0.709 | 0.705 | 0.730 |
| 1984 | 0.098 | 0.162 | 0.338 | 0.525 | 0.625 | 0.657 | 0.696 | 0.715 | 0.705 | 0.716 |
| 1985 | 0.122 | 0.304 | 0.301 | 0.451 | 0.577 | 0.711 | 0.727 | 0.743 | 0.814 | 0.791 |
| 1986 | 0.103 | 0.258 | 0.391 | 0.394 | 0.483 | 0.621 | 0.740 | 0.743 | 0.820 | 0.770 |
| 1987 | 0.140 | 0.231 | 0.336 | 0.427 | 0.434 | 0.535 | 0.520 | 0.746 | 0.753 | 0.792 |
| 1988 | 0.112 | 0.232 | 0.355 | 0.426 | 0.473 | 0.506 | 0.601 | 0.697 | 0.759 | 0.775 |
| 1989 | 0.142 | 0.282 | 0.384 | 0.431 | 0.506 | 0.536 | 0.560 | 0.697 | 0.776 | 0.839 |
| 1990 | 0.133 | 0.222 | 0.334 | 0.449 | 0.487 | 0.527 | 0.609 | 0.570 | 0.644 | 0.774 |
| 1991 | 0.186 | 0.287 | 0.399 | 0.462 | 0.543 | 0.596 | 0.616 | 0.688 | 0.686 | 0.793 |
| 1992 | 0.180 | 0.269 | 0.375 | 0.419 | 0.476 | 0.520 | 0.575 | 0.627 | 0.640 | 0.653 |
| 1993 | 0.185 | 0.269 | 0.350 | 0.435 | 0.477 | 0.534 | 0.594 | 0.643 | 0.682 | 0.706 |
| 1994 | 0.158 | 0.231 | 0.315 | 0.396 | 0.486 | 0.519 | 0.591 | 0.643 | 0.701 | 0.675 |
| 1995 | 0.158 | 0.262 | 0.339 | 0.415 | 0.469 | 0.539 | 0.556 | 0.612 | 0.689 | 0.718 |
| 1996 | 0.191 | 0.246 | 0.352 | 0.474 | 0.481 | 0.550 | 0.585 | 0.644 | 0.690 | 0.770 |
| 1997 | 0.199 | 0.301 | 0.382 | 0.451 | 0.546 | 0.532 | 0.570 | 0.609 | 0.658 | 0.709 |
| 1998 | 0.147 | 0.250 | 0.373 | 0.482 | 0.535 | 0.560 | 0.592 | 0.604 | 0.656 | 0.684 |
| 1999 | 0.166 | 0.263 | 0.391 | 0.459 | 0.529 | 0.581 | 0.611 | 0.618 | 0.681 | 0.705 |
| 2000 | 0.199 | 0.230 | 0.321 | 0.442 | 0.530 | 0.585 | 0.614 | 0.674 | 0.693 | 0.747 |
| 2001 | 0.135 | 0.261 | 0.359 | 0.401 | 0.506 | 0.580 | 0.649 | 0.628 | 0.662 | 0.616 |
| 2002 | 0.138 | 0.220 | 0.344 | 0.430 | 0.471 | 0.563 | 0.599 | 0.645 | 0.708 | 0.693 |
| 2003 | 0.126 | 0.229 | 0.308 | 0.435 | 0.517 | 0.573 | 0.635 | 0.642 | 0.626 | 0.679 |
| 2004 | 0.171 | 0.224 | 0.341 | 0.387 | 0.479 | 0.500 | 0.606 | 0.695 | 0.545 | 0.679 |
| 2005 | 0.110 | 0.235 | 0.338 | 0.394 | 0.446 | 0.547 | 0.614 | 0.636 | 0.708 | 0.665 |
| 2006 | 0.181 | 0.249 | 0.304 | 0.387 | 0.419 | 0.451 | 0.537 | 0.567 | 0.465 | 0.521 |
| 2007 | 0.133 | 0.248 | 0.356 | 0.427 | 0.509 | 0.564 | 0.576 | 0.644 | 0.641 | 0.695 |
| 2008 | 0.140 | 0.227 | 0.346 | 0.418 | 0.481 | 0.500 | 0.613 | 0.526 | 0.662 | 0.689 |

[1] Bold and underlined numbers represent strong year-classes

***Table 4.*** *Catch biomass at age (metric tons) for the Northwest Atlantic mackerel in NAFO Subareas 2-6, 1968-2008[1].*

| YEAR | AGE (yr) | | | | | | | | | |
|------|------|------|------|------|------|------|------|------|------|------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10+ |
| 1968 | 23 898 | 15 625 | 21 480 | 17 657 | 7 901 | 4 164 | 657 | 1 211 | 7 912 | 109 |
| 1969 | 1 145 | 57 718 | 49 774 | 25 359 | 2 721 | 1 688 | 1 330 | 1 994 | 1 526 | 7 572 |
| 1970 | 21 252 | 9 920 | 134 234 | 53 437 | 10 981 | 3 158 | 2 655 | 5 458 | 5 853 | 4 575 |
| 1971 | 8 513 | 53 772 | 32 784 | 187 343 | 80 731 | 15 736 | 4 821 | 2 232 | 2 838 | 10 432 |
| 1972 | 2 718 | 18 005 | 77 221 | 71 068 | 184 292 | 47 255 | 15 006 | 2 693 | 5 652 | 8 164 |
| 1973 | 18 740 | 55 240 | 77 834 | 82 009 | 82 199 | 97 915 | 18 266 | 6 904 | 2 681 | 3 872 |
| 1974 | 11 244 | 48 913 | 76 745 | 38 945 | 51 928 | 58 232 | 63 798 | 16 519 | 4 641 | 2 872 |
| 1975 | 39 790 | 78 672 | 30 713 | 35 237 | 24 766 | 32 704 | 27 659 | 28 595 | 7 459 | 2 218 |
| 1976 | 1 298 | 61 251 | 69 955 | 28 899 | 21 566 | 12 903 | 21 065 | 19 442 | 13 645 | 9 122 |
| 1977 | 239 | 5 523 | 29 901 | 20 781 | 5 657 | 5 356 | 3 318 | 4 089 | 2 625 | 3 121 |
| 1978 | 19 | 57 | 1 998 | 8 056 | 6 770 | 4 889 | 2 938 | 1 450 | 3 029 | 5 205 |
| 1979 | 76 | 163 | 690 | 4 026 | 10 769 | 7 899 | 4 042 | 1 856 | 1 654 | 5 220 |
| 1980 | 175 | 4 098 | 1 791 | 1 156 | 4 257 | 8 763 | 5 091 | 2 390 | 1 698 | 4 040 |
| 1981 | 1 835 | 2 237 | 4 812 | 808 | 1 286 | 4 026 | 7 886 | 3 464 | 1 808 | 2 688 |
| 1982 | 562 | 4 012 | 1 461 | 5 515 | 799 | 1 412 | 2 506 | 6 065 | 2 085 | 3 953 |
| 1983 | 216 | 3 932 | 3 114 | 1 127 | 4 396 | 461 | 854 | 3 900 | 7 191 | 4 745 |
| 1984 | 49 | 6 545 | 9 194 | 1 680 | 750 | 3 022 | 418 | 501 | 2 397 | 10 024 |
| 1985 | 377 | 473 | 36 972 | 14 680 | 1 672 | 679 | 2 874 | 312 | 600 | 11 770 |
| 1986 | 132 | 3 284 | 2 621 | 39 789 | 12 262 | 1 306 | 516 | 2 366 | 176 | 4 691 |
| 1987 | 584 | 3 372 | 4 920 | 3 294 | 47 836 | 9 521 | 1 306 | 271 | 1 586 | 2 796 |
| 1988 | 113 | 3 012 | 3 652 | 4 243 | 5 529 | 54 032 | 13 841 | 1 833 | 903 | 4 304 |
| 1989 | 559 | 4 833 | 4 233 | 3 153 | 3 578 | 1 260 | 49 630 | 3 469 | 718 | 1 888 |
| 1990 | 259 | 4 630 | 10 730 | 3 569 | 3 127 | 2 275 | 487 | 30 896 | 1 677 | 929 |
| 1991 | 264 | 4 199 | 22 479 | 11 369 | 3 506 | 2 324 | 2 033 | 688 | 18 728 | 952 |
| 1992 | 132 | 1 818 | 1 987 | 10 761 | 7 316 | 1 075 | 894 | 795 | 857 | 10 940 |
| 1993 | 281 | 2 480 | 3 956 | 2 682 | 7 881 | 4 775 | 1 140 | 523 | 761 | 5 961 |
| 1994 | 315 | 410 | 4 005 | 5 711 | 2 670 | 10 239 | 3 951 | 697 | 216 | 2 773 |
| 1995 | 2 933 | 5 403 | 926 | 3 962 | 3 846 | 1 741 | 5 706 | 1 974 | 211 | 661 |
| 1996 | 1 470 | 8 591 | 9 083 | 921 | 6 129 | 5 427 | 1 494 | 6 580 | 1 593 | 1 142 |
| 1997 | 1 375 | 6 610 | 8 930 | 5 013 | 588 | 4 534 | 3 880 | 1 694 | 4 756 | 1 327 |
| 1998 | 338 | 7 452 | 7 134 | 8 045 | 4 667 | 647 | 3 480 | 2 503 | 647 | 1 646 |
| 1999 | 289 | 1 768 | 9 340 | 6 510 | 4 866 | 2 792 | 886 | 1 798 | 1 377 | 898 |
| 2000 | 5 202 | 2 206 | 1 985 | 4 558 | 2 320 | 1 934 | 431 | 37 | 159 | 281 |
| 2001 | 1 228 | 20 074 | 8 530 | 3 014 | 4 987 | 1 382 | 1 342 | 450 | 111 | 204 |
| 2002 | 1 374 | 2 723 | 41 274 | 6 122 | 2 476 | 5 467 | 1 861 | 522 | 133 | 54 |
| 2003 | 1 289 | 5 477 | 8 162 | 53 003 | 7 229 | 2 873 | 3 089 | 167 | 3 | 0 |
| 2004 | 6 433 | 17 475 | 7 623 | 9 750 | 58 030 | 4 531 | 1 714 | 612 | 122 | 0 |
| 2005 | 2 050 | 23 750 | 21 396 | 5 063 | 4 198 | 38 357 | 1 328 | 2 062 | 57 | 30 |
| 2006 | 4 481 | 5 540 | 39 315 | 17 301 | 4 452 | 3 831 | 21 054 | 571 | 66 | 22 |
| 2007 | 291 | 13 087 | 14 014 | 27 420 | 7 100 | 1 222 | 960 | 4 205 | 97 | 4 |
| 2008 | 2 570 | 4 444 | 18 989 | 5 803 | 8 906 | 1 437 | 320 | 176 | 824 | 19 |

[1] Bold and underlined numbers represent strong year-classes

**Table 5.** *Total catch biomass[1] (metric tons) and total catch (metric tons) by country for the Northwest Atlantic mackerel in NAFO Subareas 2-6, 1968-2008.*

| YEAR | CATCH BIOMASS (metric tons) | CATCH (metric tons) | | | |
|------|------|------|------|------|------|
| | | Canada | US[2] | Foreign (US waters) | TOTAL |
| 1968 | 100 614 | 20 819 | 3 929 | 65 747 | 90 495 |
| 1969 | 150 828 | 17 364 | 4 364 | 114 189 | 135 917 |
| 1970 | 251 523 | 19 959 | 4 049 | 210 864 | 234 872 |
| 1971 | 399 202 | 24 496 | 2 406 | 355 892 | 382 794 |
| 1972 | 432 073 | 22 360 | 2 006 | 391 464 | 415 830 |
| 1973 | 445 659 | 38 514 | 1 336 | 396 759 | 436 609 |
| 1974 | 373 836 | 44 655 | 1 042 | 321 837 | 367 534 |
| 1975 | 307 814 | 36 258 | 1 974 | 271 719 | 309 951 |
| 1976 | 259 146 | 33 065 | 2 712 | 223 275 | 259 052 |
| 1977 | 80 611 | 22 765 | 1 377 | 56 067 | 80 209 |
| 1978 | 34 409 | 25 899 | 1 605 | 841 | 28 345 |
| 1979 | 36 397 | 30 612 | 1 990 | 440 | 33 042 |
| 1980 | 33 460 | 22 296 | 2 683 | 566 | 25 545 |
| 1981 | 30 849 | 19 294 | 6 151 | 5 361 | 30 806 |
| 1982 | 28 369 | 16 380 | 4 521 | 6 647 | 27 548 |
| 1983 | 29 935 | 19 797 | 6 807 | 5 955 | 32 559 |
| 1984 | 34 579 | 17 320 | 8 273 | 15 045 | 40 638 |
| 1985 | 70 409 | 29 855 | 9 345 | 32 409 | 71 609 |
| 1986 | 67 143 | 30 325 | 13 860 | 26 507 | 70 692 |
| 1987 | 75 485 | 27 488 | 16 342 | 36 564 | 80 394 |
| 1988 | 91 461 | 24 060 | 15 574 | 42 858 | 82 492 |
| 1989 | 73 321 | 20 795 | 16 503 | 36 823 | 74 121 |
| 1990 | 58 578 | 19 190 | 33 955 | 30 678 | 83 823 |
| 1991 | 66 542 | 24 914 | 30 625 | 15 714 | 71 253 |
| 1992 | 36 575 | 24 307 | 13 216 | 0 | 37 523 |
| 1993 | 30 440 | 26 158 | 5 601 | 0 | 31 759 |
| 1994 | 30 987 | 20 564 | 11 341 | 0 | 31 905 |
| 1995 | 27 363 | 17 706 | 9 748 | 0 | 27 454 |
| 1996 | 42 430 | 20 394 | 19 487 | 0 | 39 881 |
| 1997 | 38 707 | 21 309 | 17 196 | 0 | 38 505 |
| 1998 | 36 558 | 19 334 | 15 268 | 0 | 34 602 |
| 1999 | 30 525 | 16 561 | 13 615 | 0 | 30 176 |
| 2000 | 19 111 | 13 383 | 7 208 | 0 | 20 591 |
| 2001 | 41 322 | 23 950 | 14 546 | 0 | 38 497 |
| 2002 | 62 005 | 34 309 | 27 860 | 0 | 62 169 |
| 2003 | 81 291 | 44 475 | 35 243 | 0 | 79 718 |
| 2004 | 106 290 | 53 365 | 57 020 | 0 | 110 385 |
| 2005 | 98 291 | 54 279 | 43 774 | 0 | 98 053 |
| 2006 | 96 632 | 53 649 | 58 359 | 0 | 112 008 |
| 2007 | 68 402 | 53 016 | 26 518 | 0 | 79 534 |
| 2008 | 43 487 | 28 245 | 22 798 | 0 | 51 043 |

[1] From Table 4
[2] Commercial discards and recreational landings included

***Table 6.*** *Mean proportion of maturity at age for the Northwest Atlantic mackerel in NAFO Subareas 3-4, 1968-2008[1].*

| YEAR | AGE (yr) | | | | | | | | | |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|      | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10+ |
| 1968 | 0.288 | 0.495 | 0.705 | 0.853 | 0.934 | 0.972 | 0.988 | 0.995 | 0.998 | 0.999 |
| 1969 | 0.288 | 0.495 | 0.705 | 0.853 | 0.934 | 0.972 | 0.988 | 0.995 | 0.998 | 0.999 |
| 1970 | 0.288 | 0.495 | 0.705 | 0.853 | 0.934 | 0.972 | 0.988 | 0.995 | 0.998 | 0.999 |
| 1971 | 0.288 | 0.495 | 0.705 | 0.853 | 0.934 | 0.972 | 0.988 | 0.995 | 0.998 | 0.999 |
| 1972 | 0.288 | 0.495 | 0.705 | 0.853 | 0.934 | 0.972 | 0.988 | 0.995 | 0.998 | 0.999 |
| 1973 | 0.288 | 0.495 | 0.705 | 0.853 | 0.934 | 0.972 | 0.988 | 0.995 | 0.998 | 0.999 |
| 1974 | 0.288 | 0.495 | 0.705 | 0.853 | 0.934 | 0.972 | 0.988 | 0.995 | 0.998 | 0.999 |
| 1975 | 0.163 | 0.857 | 0.995 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1976 | 0.204 | 0.785 | 0.981 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1977 | 0.049 | 0.841 | 0.998 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1978 | 0.429 | 0.907 | 0.992 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1979 | 0.368 | 0.593 | 0.785 | 0.902 | 0.958 | 0.983 | 0.993 | 0.997 | 0.999 | 1.000 |
| 1980 | 0.231 | 0.972 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1981 | 0.123 | 0.984 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1982 | 0.015 | 0.995 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1983 | 0.378 | 0.654 | 0.854 | 0.948 | 0.983 | 0.994 | 0.998 | 0.999 | 1.000 | 1.000 |
| 1984 | 0.010 | 0.503 | 0.990 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1985 | 0.402 | 0.879 | 0.988 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1986 | 0.422 | 0.847 | 0.974 | 0.996 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1987 | 0.442 | 0.815 | 0.961 | 0.993 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1988 | 0.395 | 0.904 | 0.980 | 0.996 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1989 | 0.349 | 0.992 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1990 | 0.283 | 0.937 | 0.998 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1991 | 0.216 | 0.881 | 0.995 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1992 | 0.229 | 0.807 | 0.977 | 0.997 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1993 | 0.212 | 0.771 | 0.973 | 0.997 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1994 | 0.172 | 0.801 | 0.979 | 0.998 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1995 | 0.242 | 0.733 | 0.959 | 0.995 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1996 | 0.195 | 0.736 | 0.970 | 0.997 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1997 | 0.132 | 0.830 | 0.985 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1998 | 0.068 | 0.925 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1999 | 0.117 | 0.766 | 0.988 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2000 | 0.459 | 0.908 | 0.991 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2001 | 0.430 | 0.929 | 0.996 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2002 | 0.306 | 0.949 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2003 | 0.241 | 0.953 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2004 | 0.138 | 0.855 | 0.995 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2005 | 0.088 | 0.624 | 0.966 | 0.998 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2006 | 0.251 | 0.845 | 0.989 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2007 | 0.081 | 0.922 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2008 | 0.209 | 0.790 | 0.982 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

[1] From Canadian samples collected in June and July; 1974 data used for 1968-1973

**Table 7.** *Separable VPA (SVPA) for the Northwest Atlantic mackerel: Sum of squared residuals (SSQ) for different terminal fishing mortality (Ft) and selectivity (St) values.*

| TERMINAL FISHING MORTALITY (Ft) | TERMINAL SELECTIVITY (St) | | |
|---|---|---|---|
| | 0.75 | 1.00 | 1.25 |
| 0.10 | 166.38 | 164.54 | 163.11 |
| 0.20 | 160.61 | 157.25 | 154.69 |
| 0.30 | 157.91 | 153.85 | 150.81 |
| 0.40 | 156.30 | 151.82 | 148.49 |
| 0.50 | 155.24 | 150.46 | 146.95* |

\* Lowest value: outputs from this SVPA were used to start
a traditional VPA

**Table 8.** *Separable VPA (SVPA) for six New England groundfish/flatfish stocks: Sum of squared residuals (SSQ) for different terminal fishing mortality (Ft) and selectivity (St) values.*

Georges Bank Haddock

| Ft | St | | |
|---|---|---|---|
| | 0.75 | 1 | 1.25 |
| 0.10 | 809.0 | 806.1 | 805.98* |
| 0.20 | 817.0 | 814.4 | 814.1 |
| 0.30 | 824.3 | 821.8 | 821.1 |
| 0.40 | 830.9 | 828.2 | 827.3 |
| 0.50 | 836.7 | 834.0 | 832.8 |

Georges Bank Cod

| Ft | St | | |
|---|---|---|---|
| | 0.75 | 1 | 1.25 |
| 0.10 | 85.3 | 89.0 | 92.4 |
| 0.20 | 76.5 | 78.8 | 80.7 |
| 0.30 | 72.1 | 73.6 | 74.9 |
| 0.40 | 69.3 | 70.3 | 71.2 |
| 0.50 | 67.27* | 68.0 | 68.6 |

Gulf of Maine Cod

| Ft | St | | |
|---|---|---|---|
| | 0.75 | 1 | 1.25 |
| 0.10 | 1096.4 | 1119.2 | 1135.3 |
| 0.20 | 1042.8 | 1056.9 | 1066.4 |
| 0.30 | 1007.8 | 1017.8 | 1024.5 |
| 0.40 | 982.0 | 989.7 | 994.9 |
| 0.50 | 961.9* | 968.1 | 972.2 |

Georges Bank YTF

| Ft | St | | |
|---|---|---|---|
| | 0.75 | 1 | 1.25 |
| 0.10 | 100.2 | 117.9 | 125.7 |
| 0.20 | 99.9 | 107.3 | 112.9 |
| 0.30 | 96.1 | 102.1 | 106.4 |
| 0.40 | 93.6 | 98.7 | 102.4 |
| 0.50 | 91.83* | 96.4 | 99.6 |

SNEMA YTF[1]

| Ft | St | | |
|---|---|---|---|
| | 0.75 | 1 | 1.25 |
| 0.10 | 184.4 | 199.1 | 208.5 |
| 0.20 | 178.9 | 190.3 | 197.5 |
| 0.30 | 176.0 | 185.8 | 191.9 |
| 0.40 | 174.0 | 183.0 | 188.4 |
| 0.50 | 172.68* | 181.0 | 185.9 |

GOMCC YTF[2]

| Ft | St | | |
|---|---|---|---|
| | 0.75 | 1 | 1.25 |
| 0.10 | 73.1 | 77.4 | 80.7 |
| 0.20 | 68.1 | 71.4 | 73.6 |
| 0.30 | 65.5 | 68.4 | 70.1 |
| 0.40 | 64.0 | 66.4 | 68.0 |
| 0.50 | 62.87* | 65.0 | 66.5 |

\* Lowest values; outputs from these SVPA were used to start traditional VPAs

[1] South New England and Maine yellowtail flounder

[2] Gulf of Maine and Cape Cod yellowtail flounder

***Table 9.*** *Traditional VPA: Recruits at age 1 (thousands of fish), fishing mortality (average ages 3-5) and spawning stock biomass (metric tons) calculated from the outputs of a Separable VPA (SVPA) for **Ft=0.50** and **St=1.25**.*

| | 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) |
|---|---|---|---|
| 1968 | 4 964 383 | 0.259 | 651 327 |
| 1969 | 1 893 608 | 0.195 | 931 000 |
| 1970 | 2 261 357 | 0.226 | 1 077 340 |
| 1971 | 1 199 317 | 0.330 | 1 235 249 |
| 1972 | 1 336 130 | 0.363 | 1 315 682 |
| 1973 | 1 064 366 | 0.545 | 998 062 |
| 1974 | 1 514 764 | 0.605 | 762 317 |
| 1975 | 1 461 885 | 0.559 | 626 858 |
| 1976 | 201 302 | 0.832 | 463 295 |
| 1977 | 38 778 | 0.356 | 290 210 |
| 1978 | 24 638 | 0.099 | 271 422 |
| 1979 | 148 469 | 0.122 | 248 086 |
| 1980 | 41 448 | 0.158 | 244 954 |
| 1981 | 101 595 | 0.131 | 199 289 |
| 1982 | 417 340 | 0.168 | 191 801 |
| 1983 | 1 916 736 | 0.176 | 246 900 |
| 1984 | 85 387 | 0.121 | 304 133 |
| 1985 | 129 435 | 0.128 | 557 060 |
| 1986 | 97 699 | 0.145 | 519 437 |
| 1987 | 98 244 | 0.211 | 413 843 |
| 1988 | 256 695 | 0.348 | 343 998 |
| 1989 | 418 017 | 0.284 | 303 511 |
| 1990 | 96 307 | 0.283 | 252 305 |
| 1991 | 165 360 | 0.296 | 244 934 |
| 1992 | 147 725 | 0.212 | 184 510 |
| 1993 | 25 406 | 0.164 | 173 467 |
| 1994 | 138 247 | 0.211 | 145 755 |
| 1995 | 181 819 | 0.199 | 124 358 |
| 1996 | 129 339 | 0.443 | 124 588 |
| 1997 | 182 612 | 0.398 | 113 561 |
| 1998 | 90 237 | 0.509 | 105 652 |
| 1999 | 156 374 | 0.462 | 89 915 |
| 2000 | 1 254 978 | 0.216 | 196 928 |
| 2001 | 176 344 | 0.318 | 327 978 |
| 2002 | 140 739 | 0.204 | 342 691 |
| 2003 | 361 323 | 0.328 | 316 383 |
| 2004 | 621 930 | 0.561 | 274 434 |
| 2005 | 187 967 | 0.542 | 232 800 |
| 2006 | 360 159 | 0.732 | 207 527 |
| 2007 | 95 755 | 0.744 | 173 349 |
| 2008 | 494 404 | 0.451 | 133 957 |

***Table 10.*** *Traditional VPA: Mohn's Rho statistic for recruits (age 1), population abundance, and fishing mortality (average ages 3-5) calculated from the outputs of a Separable VPA (SVPA) for **Ft=0.50** and **St=1.25**.*

| TERMINAL YEAR | RECRUITS AGE 1 | POPULATION ABUNDANCE | FISHING MORTALITY (3-5) |
|---|---|---|---|
| 2003 | -0.370 | -0.261 | 0.374 |
| 2004 | 0.703 | 0.422 | -0.084 |
| 2005 | 0.874 | 0.265 | -0.146 |
| 2006 | -0.050 | 0.135 | -0.443 |
| 2007 | -0.535 | 0.141 | -0.396 |
| AVERAGE: | 0.125 | 0.140 | -0.139 |
| TOTAL | 0.623 | 0.701 | -0.695 |

***Table 11.*** *Input data for the yield per recruit (YPR) and projection (AGEPRO[1]) analyses. Recruits at age 1 for all year-classes (n=41) and selectivity data (partial recruitment) are from a traditional VPA started with the outputs of a Separable VPA (SVPA) for **Ft=0.50** and **St=1.25**.*

| AGE | SELECTIVITY [2] | NATURAL MORTALITY[3] | STOCK WEIGHT [4] | CATCH WEIGHT [5] | SPAWNING STOCK WEIGHT | FRACTION MATURE [6] |
|---|---|---|---|---|---|---|
| 1 | 0.1142 | 1 | 0.118 | 0.147 | 0.118 | 0.154 |
| 2 | 0.4893 | 1 | 0.184 | 0.237 | 0.184 | 0.807 |
| 3 | 0.8968 | 1 | 0.283 | 0.337 | 0.283 | 0.986 |
| 4 | 1.0000 | 1 | 0.364 | 0.403 | 0.364 | 0.999 |
| 5 | 0.9935 | 1 | 0.435 | 0.467 | 0.435 | 1.000 |
| 6 | 1.0000 | 1 | 0.492 | 0.512 | 0.492 | 1.000 |
| 7 | 0.9822 | 1 | 0.557 | 0.589 | 0.557 | 1.000 |
| 8 | 1.0000 | 1 | 0.603 | 0.613 | 0.603 | 1.000 |
| 9 | 0.9646 | 1 | 0.619 | 0.604 | 0.619 | 1.000 |
| 10 | 0.9646 | 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] A factor of 1 is applied on M=0.2

[4] Rivard's method (NOAA Fisheries Toolbox 2009b), average 2004-2008

[5] Average 2004-2008

[6] Canadian data, average 2004-2008

**Table 12.** *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 a traditional VPA started with the outputs of a Separable VPA (SVPA) for **Ft=0.50** and **St=1.25**.*

| | 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 | 0.259 | 0.162 | 0.616 | 0.892 | 2.994 | 4.725 | 1.567 |
| F-Max | 0.812 | 0.187 | 0.232 | 0.473 | 2.028 | 3.083 | 0.699 |
| F at 40% | 0.215 | 0.153 | 0.701 | 0.982 | 3.194 | 5.035 | 1.724 |

**Table 13.** *Biological reference points: MSY and $SSB_{msy}$ 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 a traditional VPA started with the outputs of a Separable VPA (SVPA) for **Ft=0.50** and **St=1.25**.*

| RECRUITS | Analytical | | Stochastic | | F (3-5) $_{2008}$ / $F_{msy}$ | SSB $_{2008}$ / $B_{msy}$ | |
|---|---|---|---|---|---|---|---|
| (average 1968-2008) | MSY (t) | $SSB_{msy}$ (t) | MSY (t) | $SSB_{msy}$ (t) | Analytical | Analytical | Stochastic |
| 601 918 | 92 232 | 421 830 | 84 025 | 384 258 | 2.100 | 0.318 | 0.349 |

**Table 14.** *Additional Separable VPAs (SVPA) runs for the Northwest Atlantic mackerel: Sum of squared residuals (SSQ) for different terminal fishing mortality (Ft) and selectivity (St) values.*

| TERMINAL FISHING MORTALITY (Ft) | TERMINAL SELECTIVITY (St) | | |
|---|---|---|---|
| | 0.75 | 1.00 | 1.25 |
| 0.60 | 154.49 | 149.49 | 145.85 |
| 0.70 | 153.94 | 148.77 | 145.03 |
| 0.80 | 153.52 | 148.21 | 144.39* |
| 0.90 | 153.20 | 147.78 | 143.89* |
| 1.00 | 152.96 | 147.43 | 143.13* |

\* Lowest values; outputs from these SVPAs were used to start
  traditional VPAs

**Table 15.** *Traditional VPAs: Recruits at age 1 (thousands of fish), fishing mortality (average ages 3-5) and spawning stock biomass (metric tons) calculated from the outputs of three Separable VPAs (SVPA) for **Ft=0.80, 0.90**, and **1.00** and **St=1.25**.*

### 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) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ft=0.80 | Ft=0.90 | Ft=1.00 | Ft=0.80 | Ft=0.90 | Ft=1.00 | Ft=0.80 | Ft=0.90 | Ft=1.00 |
| 1968 | 4 969 971 | 4 971 415 | 4 972 711 | 0.324 | 0.323 | 0.323 | 654 756 | 655 593 | 656 329 |
| 1969 | 1 895 906 | 1 896 505 | 1 897 044 | 0.197 | 0.197 | 0.196 | 934 498 | 935 357 | 936 118 |
| 1970 | 2 266 454 | 2 267 768 | 2 268 945 | 0.226 | 0.225 | 0.225 | 1 080 090 | 1 080 780 | 1 081 394 |
| 1971 | 1 203 092 | 1 204 050 | 1 204 904 | 0.369 | 0.369 | 0.369 | 1 239 126 | 1 240 099 | 1 240 965 |
| 1972 | 1 341 345 | 1 342 661 | 1 343 832 | 0.356 | 0.356 | 0.356 | 1 320 080 | 1 321 198 | 1 322 195 |
| 1973 | 1 070 721 | 1 072 323 | 1 073 750 | 0.540 | 0.540 | 0.539 | 1 002 449 | 1 003 568 | 1 004 565 |
| 1974 | 1 526 555 | 1 529 521 | 1 532 160 | 0.574 | 0.572 | 0.571 | 767 530 | 768 859 | 770 047 |
| 1975 | 1 477 844 | 1 481 849 | 1 485 407 | 0.583 | 0.581 | 0.579 | 633 611 | 635 326 | 636 857 |
| 1976 | 205 616 | 206 695 | 207 651 | 0.790 | 0.784 | 0.780 | 471 611 | 473 719 | 475 599 |
| 1977 | 39 679 | 39 904 | 40 103 | 0.312 | 0.309 | 0.307 | 300 529 | 303 137 | 305 460 |
| 1978 | 25 189 | 25 326 | 25 447 | 0.096 | 0.095 | 0.094 | 284 225 | 287 457 | 290 334 |
| 1979 | 151 431 | 152 166 | 152 817 | 0.098 | 0.097 | 0.097 | 260 692 | 263 865 | 266 687 |
| 1980 | 42 077 | 42 234 | 42 373 | 0.169 | 0.168 | 0.167 | 257 313 | 260 418 | 263 176 |
| 1981 | 102 933 | 103 266 | 103 562 | 0.150 | 0.149 | 0.148 | 209 460 | 212 013 | 214 281 |
| 1982 | 422 816 | 424 178 | 425 383 | 0.173 | 0.172 | 0.171 | 202 420 | 205 082 | 207 450 |
| 1983 | 1 934 432 | 1 938 821 | 1 942 703 | 0.167 | 0.166 | 0.165 | 254 491 | 256 386 | 258 069 |
| 1984 | 86 076 | 86 247 | 86 398 | 0.124 | 0.123 | 0.123 | 311 261 | 313 036 | 314 608 |
| 1985 | 130 590 | 130 875 | 131 127 | 0.155 | 0.154 | 0.153 | 566 443 | 568 775 | 570 840 |
| 1986 | 98 389 | 98 559 | 98 709 | 0.171 | 0.170 | 0.170 | 528 343 | 530 553 | 532 510 |
| 1987 | 98 890 | 99 049 | 99 189 | 0.229 | 0.228 | 0.228 | 420 487 | 422 135 | 423 593 |
| 1988 | 258 075 | 258 414 | 258 712 | 0.399 | 0.398 | 0.396 | 349 808 | 351 248 | 352 524 |
| 1989 | 419 885 | 420 344 | 420 747 | 0.283 | 0.282 | 0.281 | 309 308 | 310 745 | 312 015 |
| 1990 | 96 637 | 96 719 | 96 791 | 0.329 | 0.328 | 0.327 | 257 164 | 258 368 | 259 432 |
| 1991 | 165 743 | 165 838 | 165 921 | 0.349 | 0.348 | 0.347 | 249 044 | 250 062 | 250 960 |
| 1992 | 148 044 | 148 122 | 148 191 | 0.217 | 0.216 | 0.216 | 187 023 | 187 643 | 188 190 |
| 1993 | 25 460 | 25 473 | 25 485 | 0.172 | 0.172 | 0.172 | 175 971 | 176 588 | 177 132 |
| 1994 | 138 413 | 138 454 | 138 490 | 0.231 | 0.231 | 0.230 | 148 026 | 148 585 | 149 079 |
| 1995 | 181 819 | 181 819 | 181 819 | 0.208 | 0.208 | 0.208 | 125 498 | 125 777 | 126 024 |
| 1996 | 129 338 | 129 338 | 129 338 | 0.383 | 0.383 | 0.383 | 125 466 | 125 681 | 125 871 |
| 1997 | 182 606 | 182 606 | 182 607 | 0.346 | 0.346 | 0.346 | 114 106 | 114 241 | 114 359 |
| 1998 | 90 180 | 90 170 | 90 163 | 0.548 | 0.547 | 0.547 | 105 966 | 106 043 | 106 113 |
| 1999 | 156 262 | 156 242 | 156 226 | 0.569 | 0.569 | 0.569 | 90 079 | 90 121 | 90 158 |
| 2000 | 1 252 712 | 1 252 331 | 1 252 039 | 0.262 | 0.262 | 0.262 | 196 842 | 196 841 | 196 844 |
| 2001 | 175 817 | 175 734 | 175 672 | 0.318 | 0.319 | 0.319 | 327 501 | 327 425 | 327 368 |
| 2002 | 139 791 | 139 629 | 139 504 | 0.265 | 0.265 | 0.265 | 342 032 | 341 924 | 341 843 |
| 2003 | 355 007 | 353 895 | 353 032 | 0.422 | 0.422 | 0.422 | 315 335 | 315 157 | 315 022 |
| 2004 | 591 574 | 586 065 | 581 725 | 0.561 | 0.562 | 0.563 | 271 880 | 271 434 | 271 087 |
| 2005 | 166 780 | 162 876 | 159 777 | 0.549 | 0.552 | 0.553 | 226 780 | 225 706 | 224 866 |
| 2006 | 284 173 | 270 074 | 258 818 | 1.031 | 1.045 | 1.055 | 192 317 | 189 550 | 187 363 |
| 2007 | 68 034 | 62 975 | 58 940 | 0.992 | 1.039 | 1.080 | 144 704 | 139 452 | 135 286 |
| 2008 | 281 411 | 245 198 | 217 071 | 0.755 | 0.846 | 0.937 | 93 531 | 86 204 | 80 404 |

**Table 16.**  *Traditional VPA: Mohn's Rho statistic for recruits (age 1), population abundance, and fishing mortality (average ages 3-5) calculated from the outputs of a Separable VPA (SVPA) for Ft=0.90 and St=1.25.*

| TERMINAL YEAR | RECRUITS AGE 1 | POPULATION ABUNDANCE | FISHING MORTALITY (3-5) |
|---|---|---|---|
| 2003 | -0.691 | -0.544 | 1.303 |
| 2004 | -0.128 | -0.179 | 0.554 |
| 2005 | 0.064 | -0.196 | 0.476 |
| 2006 | -0.362 | -0.183 | -0.120 |
| 2007 | -0.652 | -0.061 | -0.192 |
| AVERAGE | -0.354 | -0.233 | 0.404 |
| TOTAL | -1.769 | -1.163 | 2.021 |

**Table 17.**  *Input data for the yield per recruit (YPR) and projection (AGEPRO[1]) analyses. Recruits at age 1 for all year-classes (n=41) and selectivity data (partial recruitment) are from a traditional VPA started with the outputs of a Separable VPA (SVPA) for Ft=0.90 and St=1.25.*

| AGE | SELECTIVITY [2] | NATURAL MORTALITY[3] | STOCK WEIGHT [4] | CATCH WEIGHT [5] | SPAWNING STOCK WEIGHT | FRACTION MATURE [6] |
|---|---|---|---|---|---|---|
| 1 | 0.1297 | 1 | 0.118 | 0.147 | 0.118 | 0.154 |
| 2 | 0.5017 | 1 | 0.184 | 0.237 | 0.184 | 0.807 |
| 3 | 0.9013 | 1 | 0.283 | 0.337 | 0.283 | 0.986 |
| 4 | 0.9981 | 1 | 0.364 | 0.403 | 0.364 | 0.999 |
| 5 | 0.9895 | 1 | 0.435 | 0.467 | 0.435 | 1.000 |
| 6 | 1.0000 | 1 | 0.492 | 0.512 | 0.492 | 1.000 |
| 7 | 0.9816 | 1 | 0.557 | 0.589 | 0.557 | 1.000 |
| 8 | 1.0000 | 1 | 0.603 | 0.613 | 0.603 | 1.000 |
| 9 | 0.9598 | 1 | 0.619 | 0.604 | 0.619 | 1.000 |
| 10 | 0.9598 | 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]  A factor of 1 is applied on M=0.2

[4]  Rivard's method (NOAA Fisheries Toolbox 2009b), average 2004-2008

[5]  Average 2004-2008

[6]  Canadian data, average 2004-2008

**Table 18.** *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 a traditional VPA started with the outputs of a Separable VPA (SVPA) for **Ft=0.90** and **St=1.25**.*

| | F | Y/R | SSB/R | TB/R | Mean Age | Mean Gen. Time | Expected Spawnings |
|---|---|---|---|---|---|---|---|
| | | | | PARAMETERS | | | |
| F-0 | 0 | 0 | 1.752 | 2.067 | 5.517 | 8.146 | 3.075 |
| F-0.1 | 0.258 | 0.162 | 0.613 | 0.888 | 2.994 | 4.734 | 1.559 |
| F-Max | 0.787 | 0.186 | 0.233 | 0.474 | 2.036 | 3.110 | 0.701 |
| F at 40% | 0.213 | 0.153 | 0.701 | 0.981 | 3.200 | 5.052 | 1.720 |

**Table 19.** *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 a traditional VPA started with the outputs of a Separable VPA (SVPA) for **Ft=0.90** and **St=1.25**.*

| RECRUITS (average 1968-2008) | Analytical MSY (t) | Analytical $B_{msy}$ (t) | Stochastic MSY (t) | Stochastic $B_{msy}$ (t) | F (3-5) $_{2008}$/ Fmsy Analytical | SSB $_{2008}$/ Bmsy Analytical | SSB $_{2008}$/ Bmsy Stochastic |
|---|---|---|---|---|---|---|---|
| 594 042 | 90 734 | 416 346 | 82 520 | 378 629 | 3.979 | 0.207 | 0.228 |

NORTHWEST ATLANTIC MACKEREL
- NAFO Subareas 2-6 -
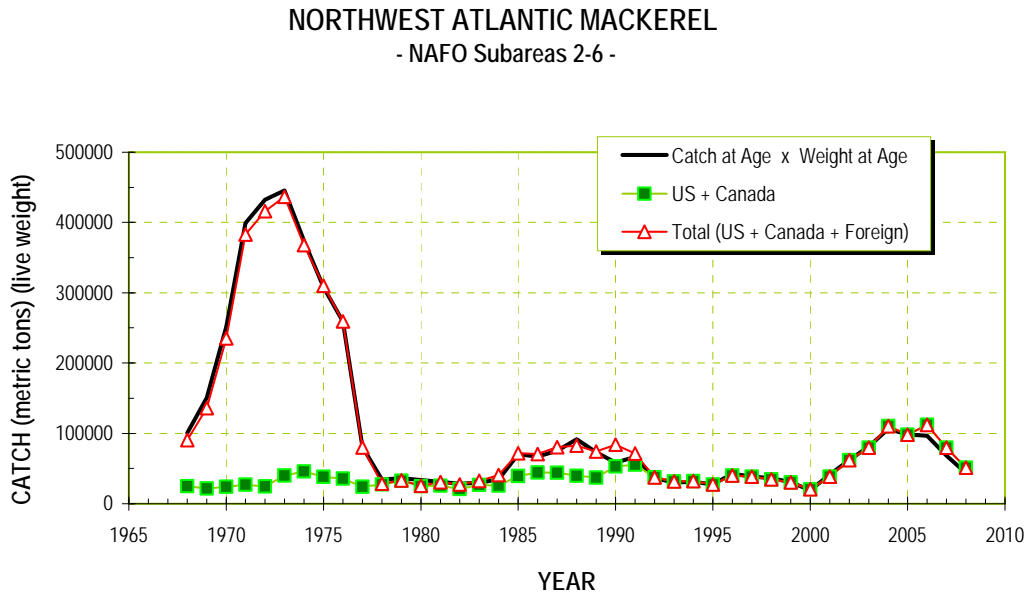


**Figure 1.**    *Total catch (metric tons) of Atlantic mackerel in NAFO Subareas 2-6, 1968-2008.*

NORTHWEST ATLANTIC MACKEREL
- NAFO Subareas 2-6 -
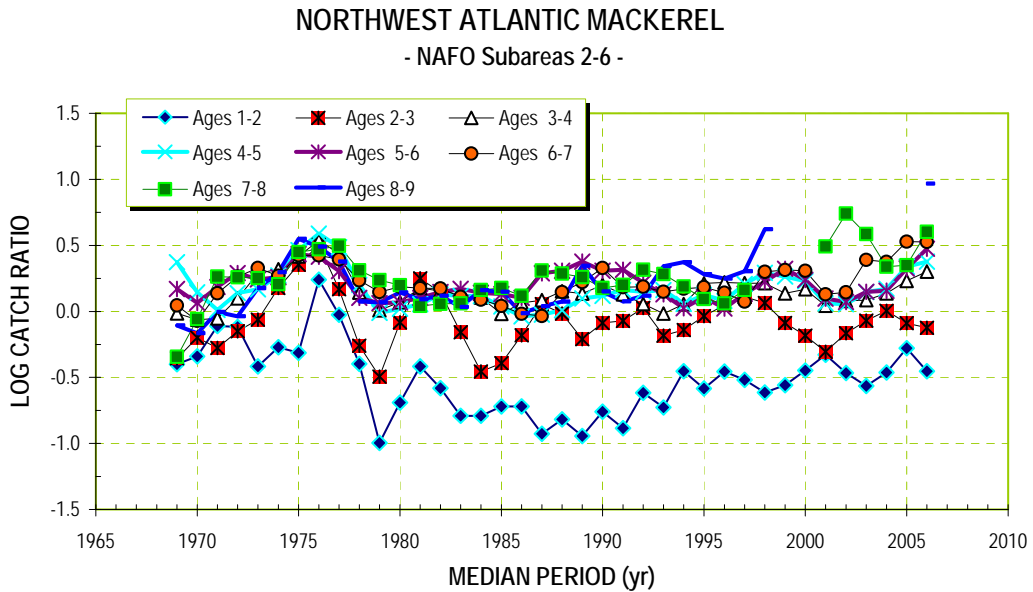


**Figure 2**.    *Mortality signal in the catch data: Log of catch ratio (3 year running average) between successive age groups.*

NORTHWEST ATLANTIC MACKEREL
-NAFO Subareas 2-6-
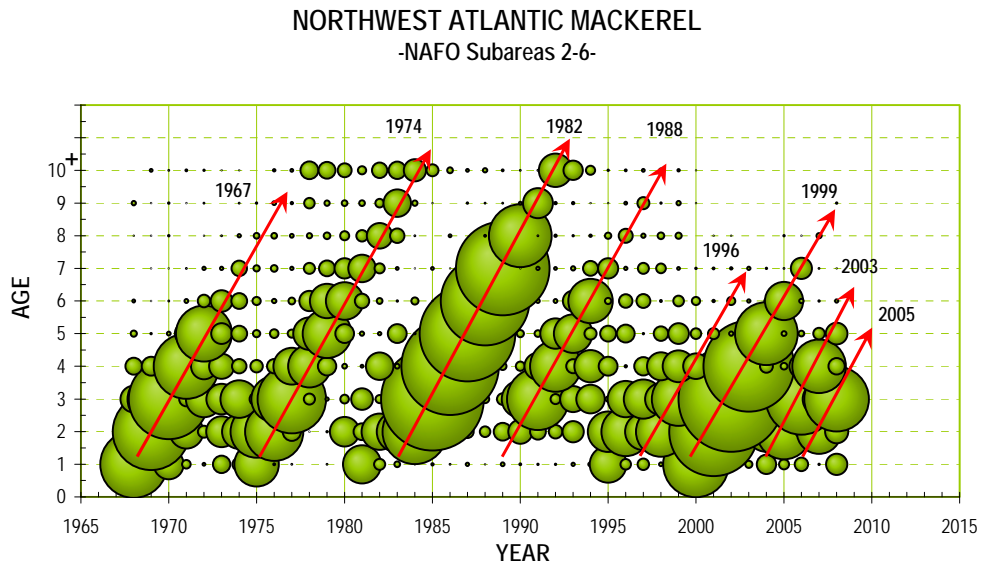
**Figure 3.** *Catch at age (%) for the 1968-2008 period (size represents width of bubbles; the strong year-classes that have dominated the fishery are indicated; the 10+ age group represents all fish older than 10 years old).*

NORTHWEST ATLANTIC MACKEREL
- NAFO Subareas 2-6 -
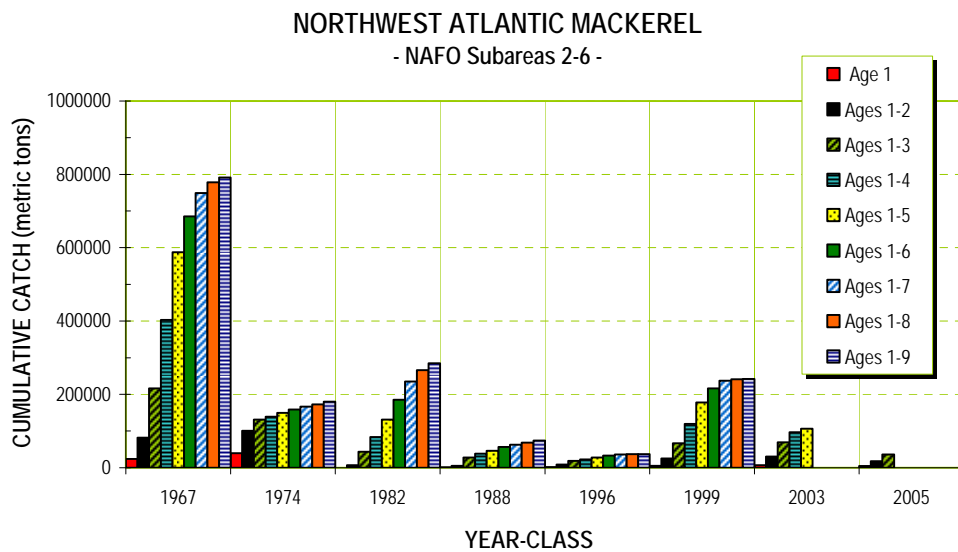
**Figure 4.** *Cumulative catch biomass at age (metric tons) for the strong year-classes that have dominated the fishery since the end of the 1960s.*
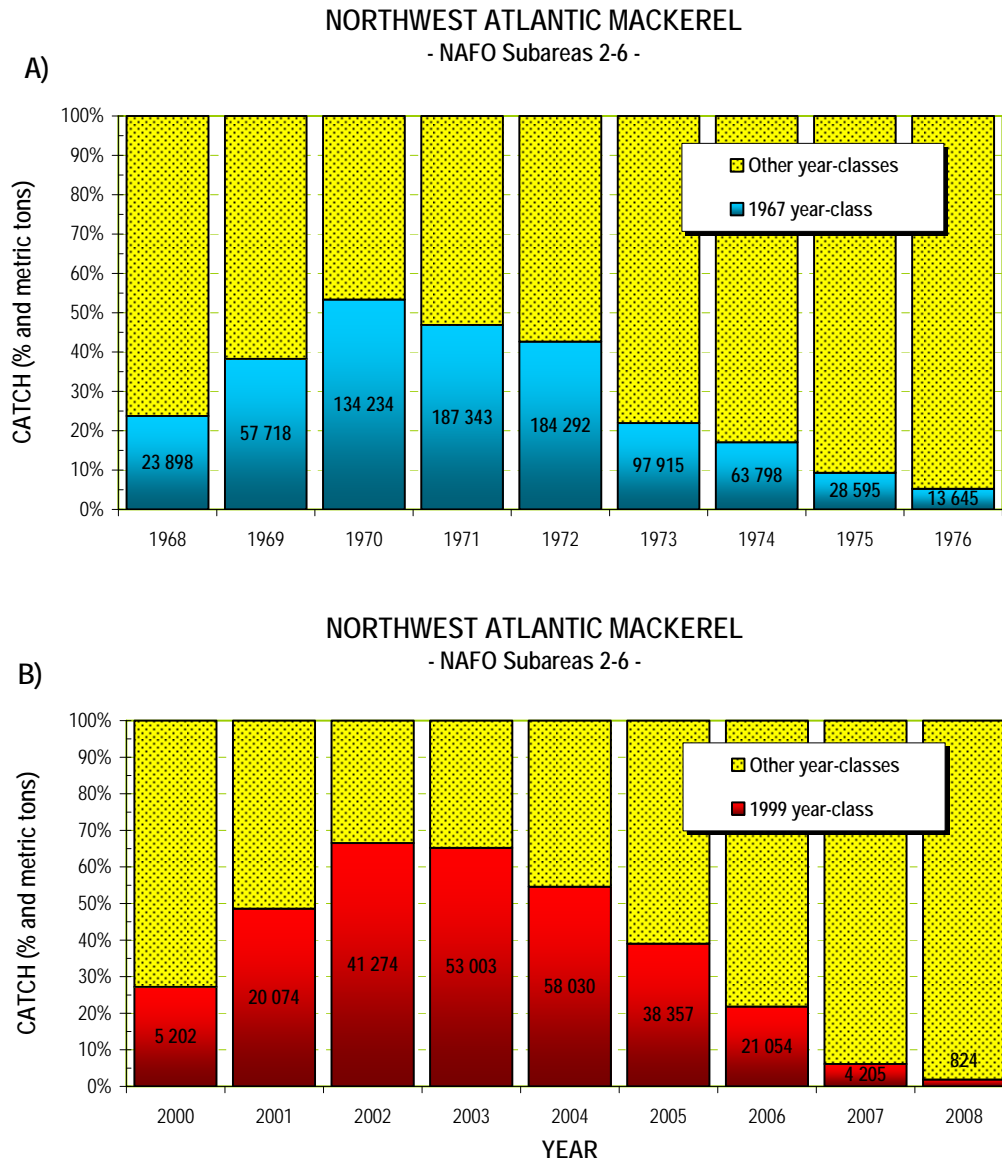
**Figure 5.** Annual catch biomass (% and metric tons) attributed to the strong 1967 (A) and 1999 (B) year-classes between 1968 and 1976 and 2000 and 2008, respectively.
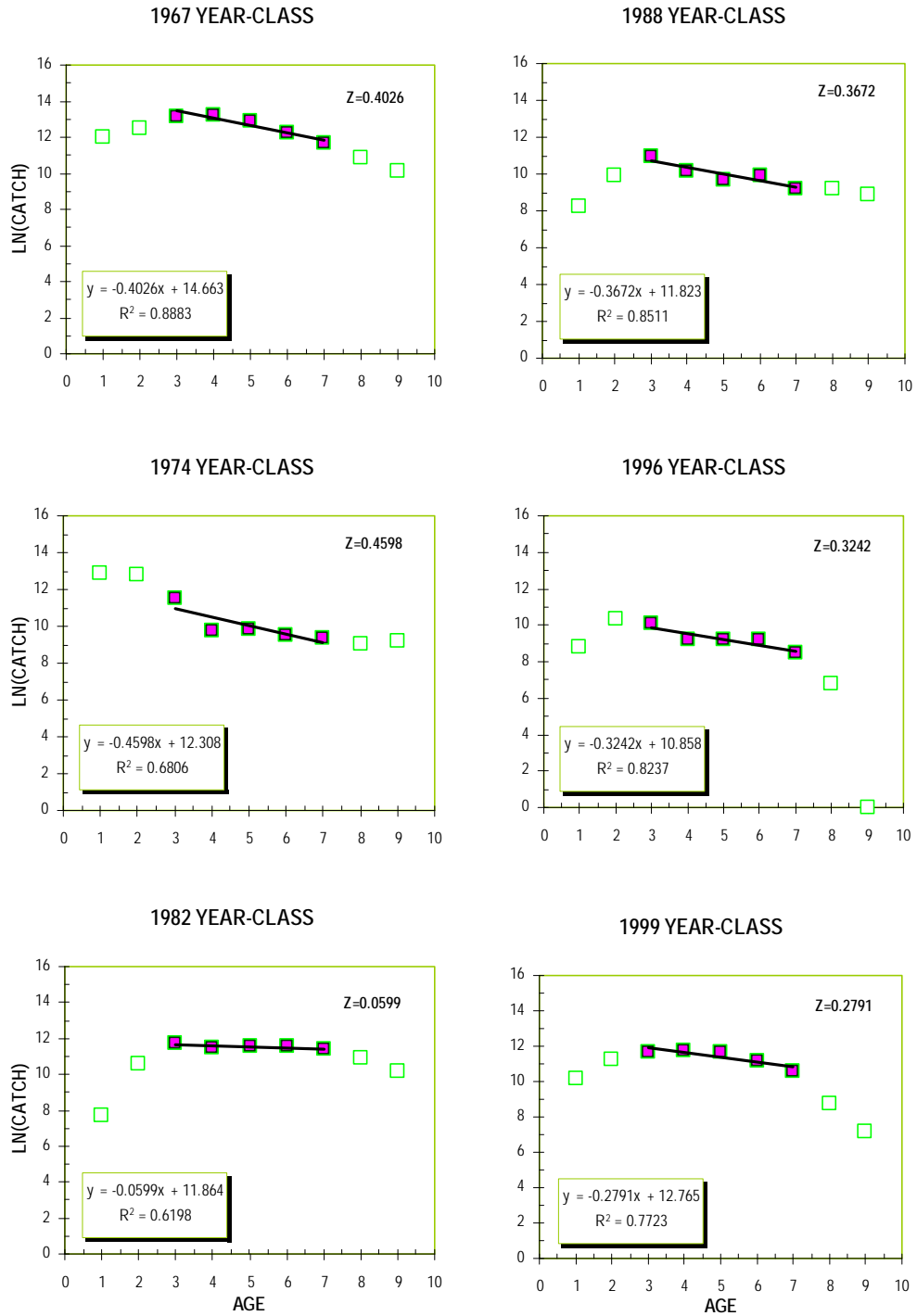
**Figure 6.** *Catch at age curves for the Northwest Atlantic mackerel year-classes that have dominated the fishery since the end of the 1960s.*
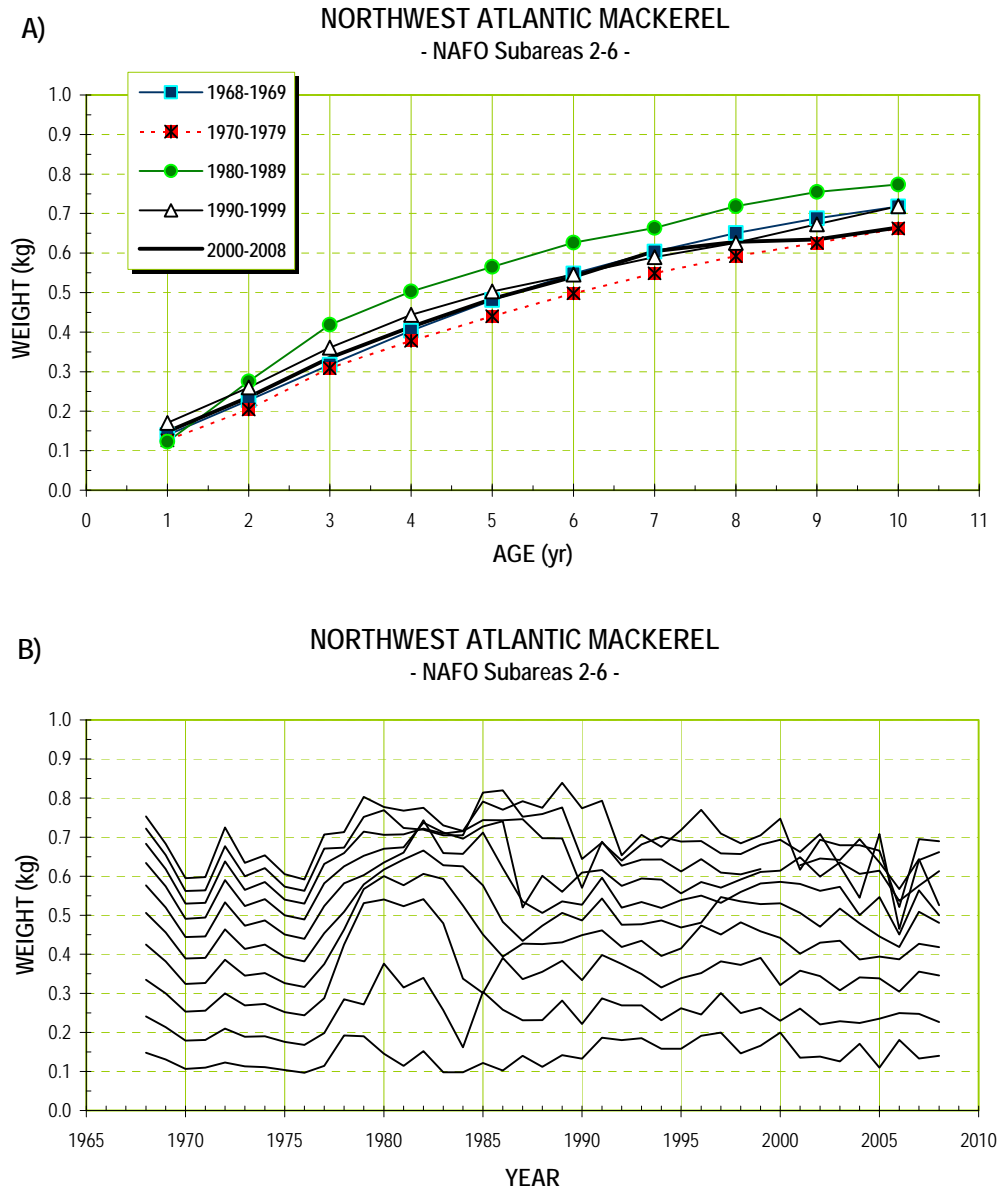
Figure 7. Mean weight (kg) at age of the Northwest Atlantic mackerel by group of years (A) and age group (1 to 10$^+$) (B).
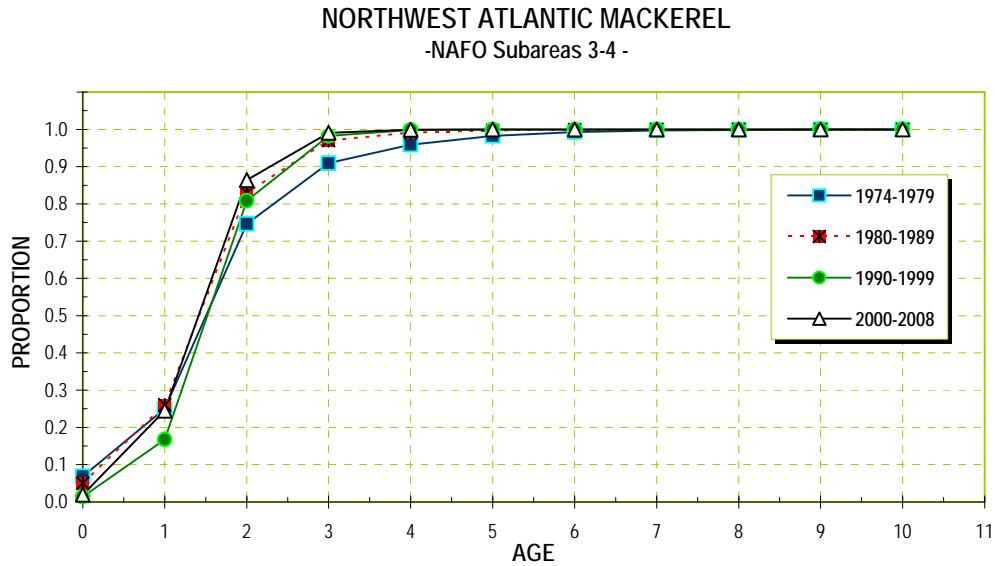
**Figure 8.** *Mean proportion of maturity at age of the Northwest Atlantic mackerel by group of years (from Canadian samples collected in June and July; data not available before 1974).*
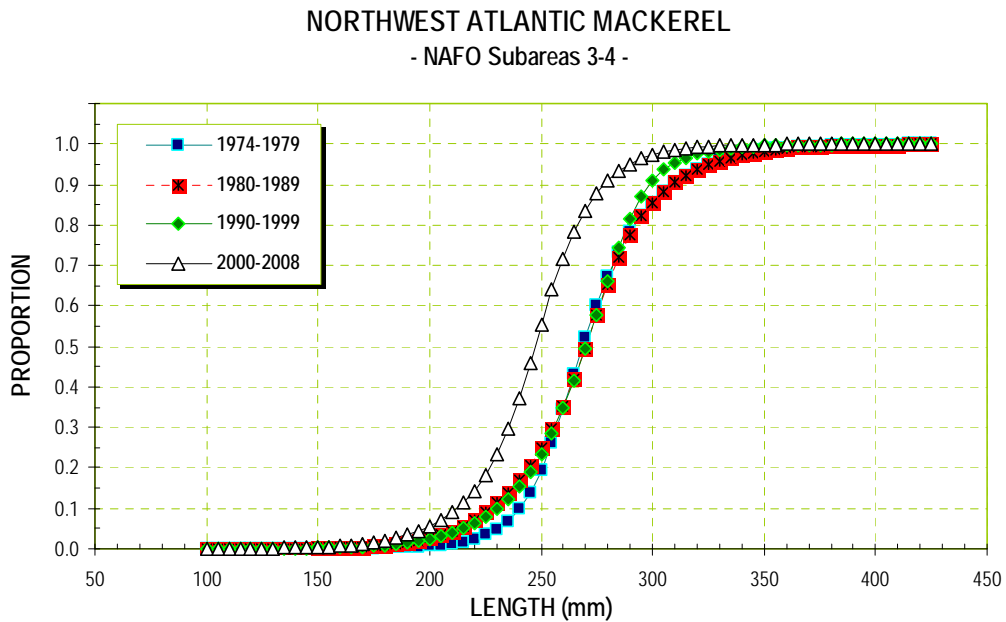


**Figure 9.** *Mean proportion of maturity at length (mm) of the Northwest Atlantic mackerel by group of years (from Canadian samples collected in June and July; data not available before 1974).*
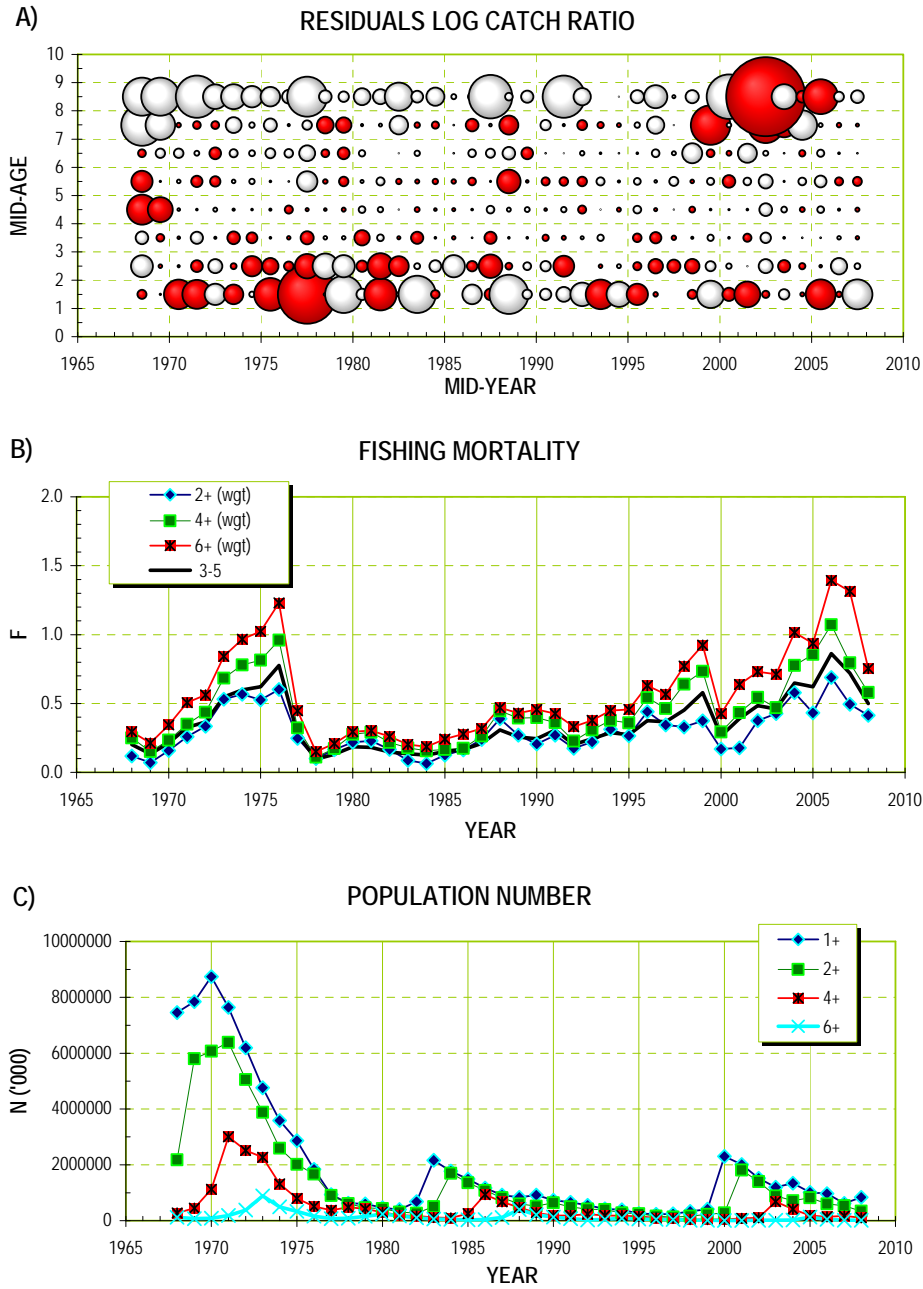
**Figure 10.** *Separable VPA (SVPA) analysis for **Ft=0.50** and **St=1.25**: A) log of catch ratio residuals; B) fishing mortality (F) (weighted by abundance); and C) population abundance (thousands of fish).*
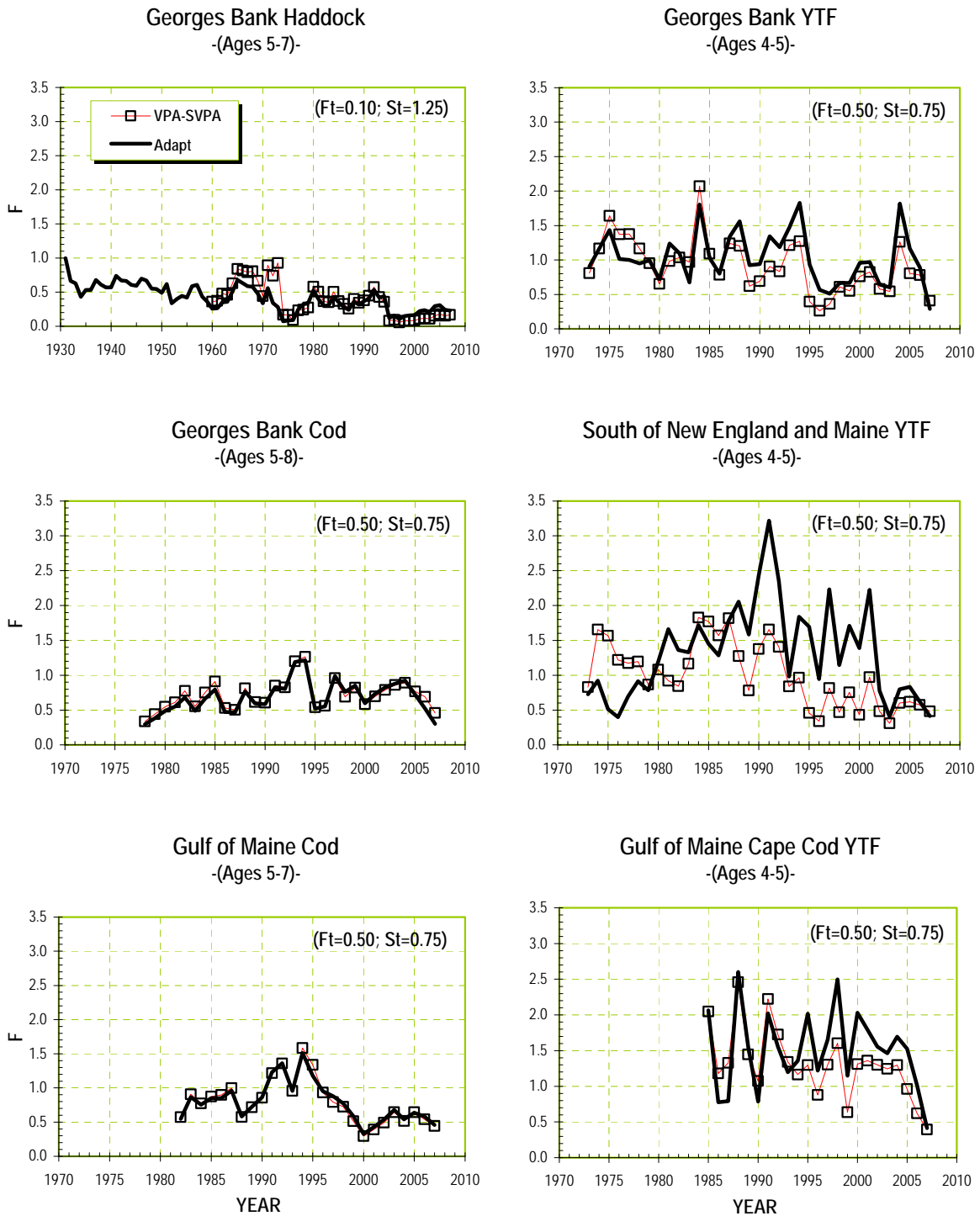
**Figure 11.** *Fishing mortalities calculated for six New England groundfish/flatfish stocks. **Adapt**: Current assessment (see references) conducted with at least one index of abundance. **VPA-SVPA**: Traditional VPA started with the outputs of a separable VPA (SVPA) (**Ft** and **St** were chosen based on the lowest sum of squared residuals).*
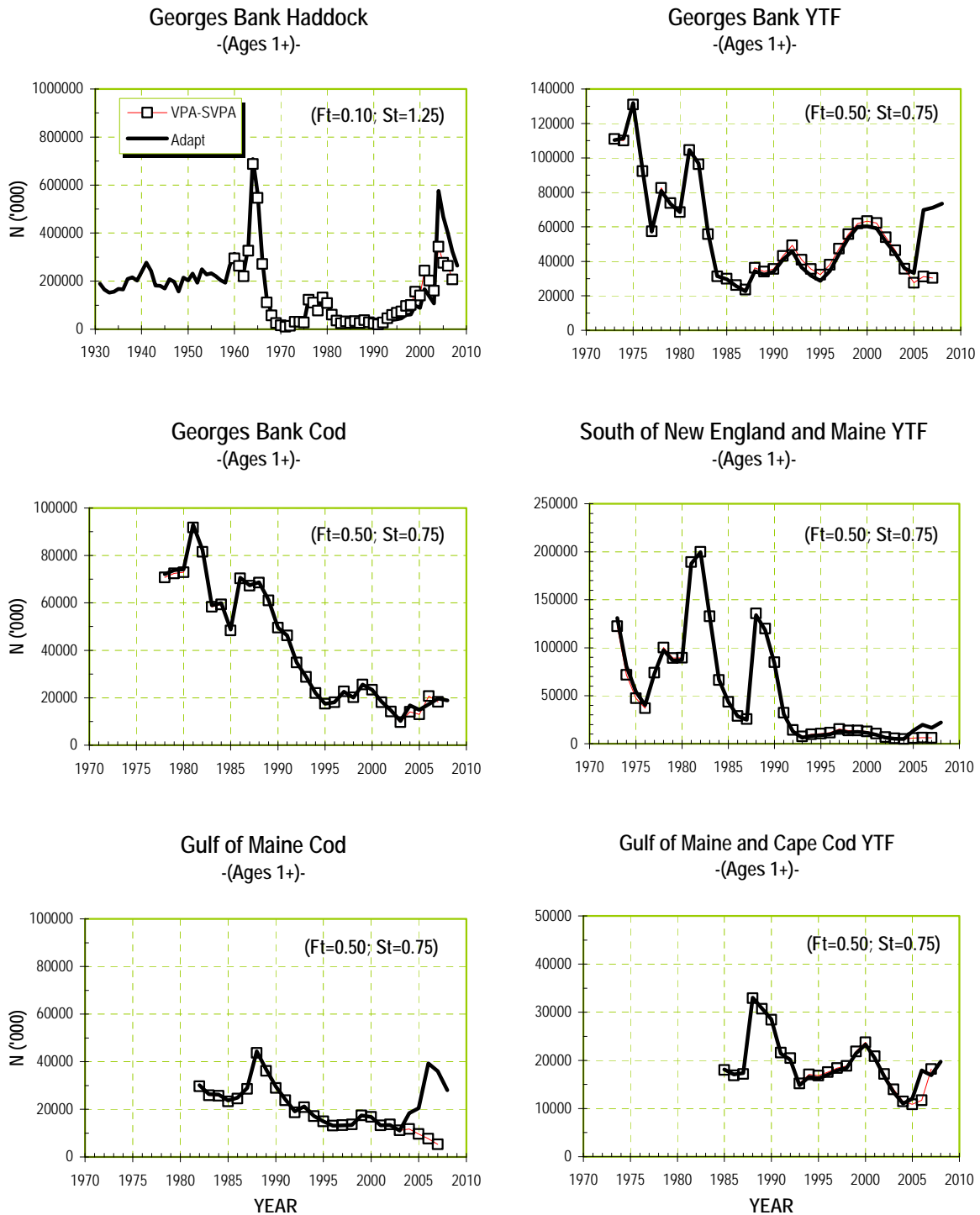
**Figure 12.** *Population number (thousands of fish) calculated for six New England groundfish/flatfish stocks.* **Adapt**: *Current assessment (see references) conducted with at least one index of abundance.* **VPA-SVPA**: *Traditional VPA started with the outputs of a Separable VPA (SVPA)* (**Ft** *and* **St** *were chosen based on the lowest sum of squared residuals).*
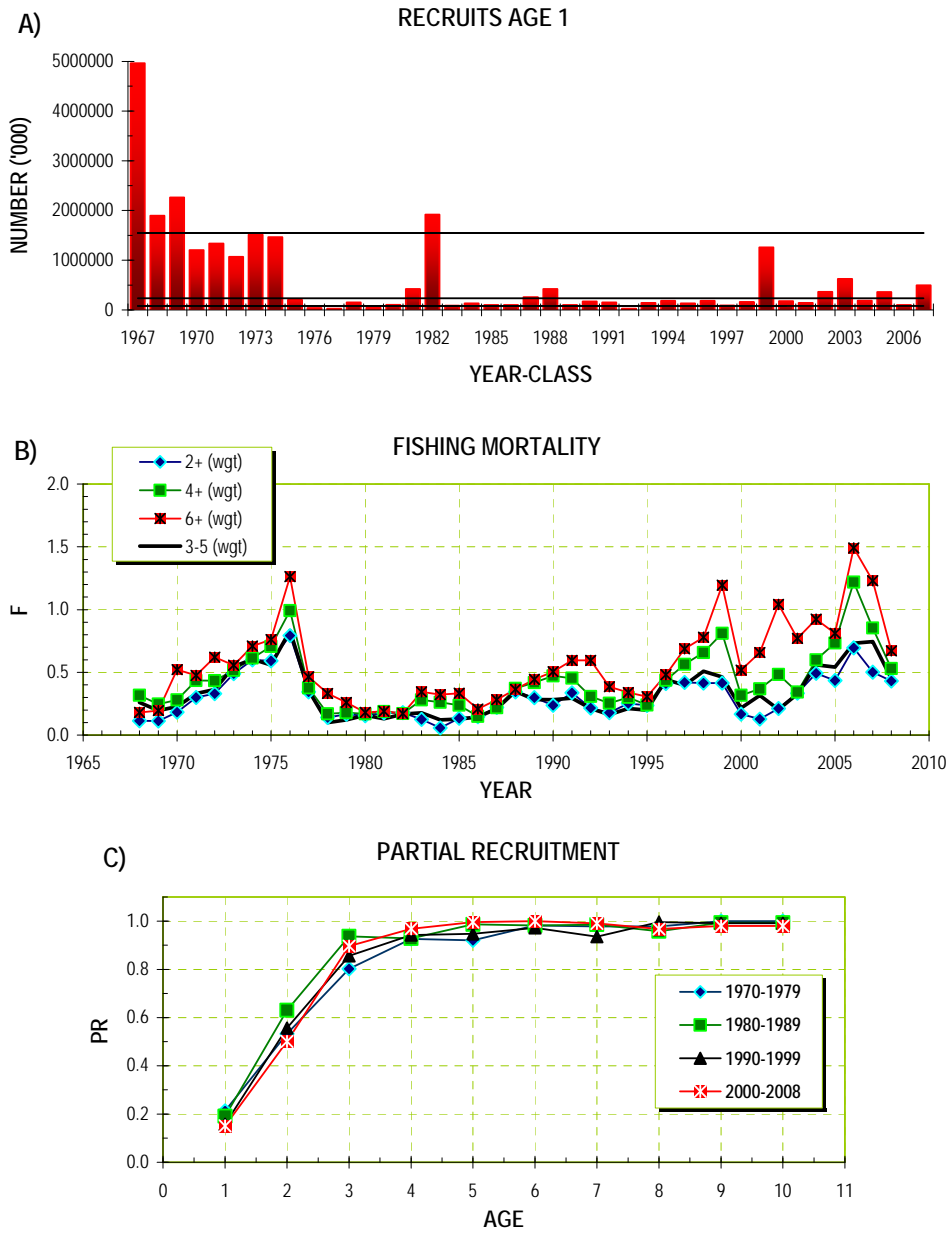
**Figure 13.** *Traditional VPA: A) Recruits at age 1 (thousands of fish); B) fishing mortality (weighted by abundance); and C) partial recruitment (from fishing mortalities) for the Northwest Atlantic mackerel. The horizontal lines in A) represent three levels of recruitment: low, average and high. The VPA was started from the outputs of a Separable VPA (SVPA) for **Ft=0.50** and **St=1.25**.*

A)



B)



C)
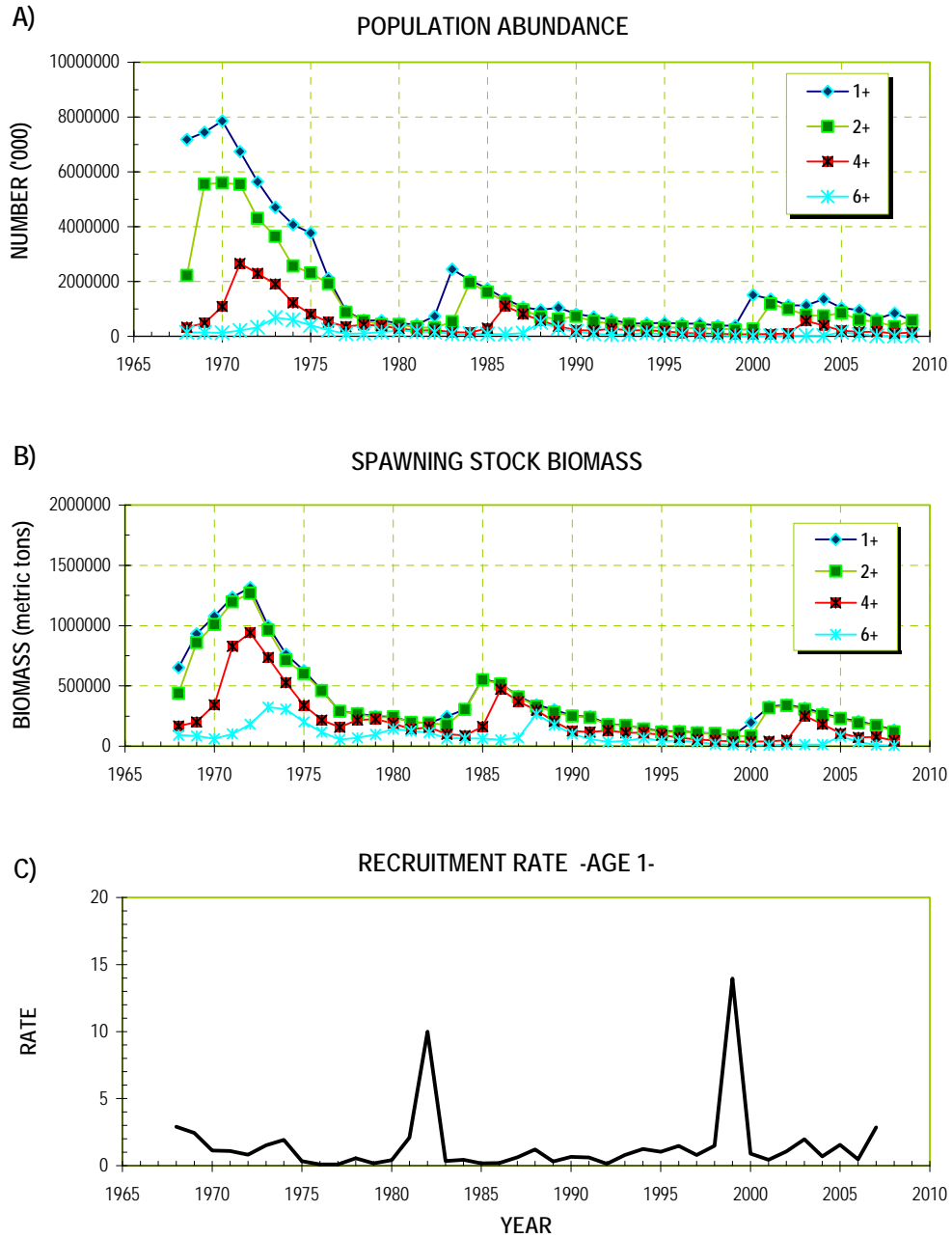


**Figure 14.** *Traditional VPA: A) Population abundance (thousands of fish); B) spawning stock biomass (metric tons); and C) recruitment rate at age 1 for the Northwest Atlantic mackerel. The VPA was started from the outputs of a Separable VPA (SVPA) for **Ft=0.50** and **St=1.25**.*

A)

## STOCK-RECRUITMENT RELATIONSHIP



B)

## STOCK-FISHING MORTALITY RELATIONSHIP
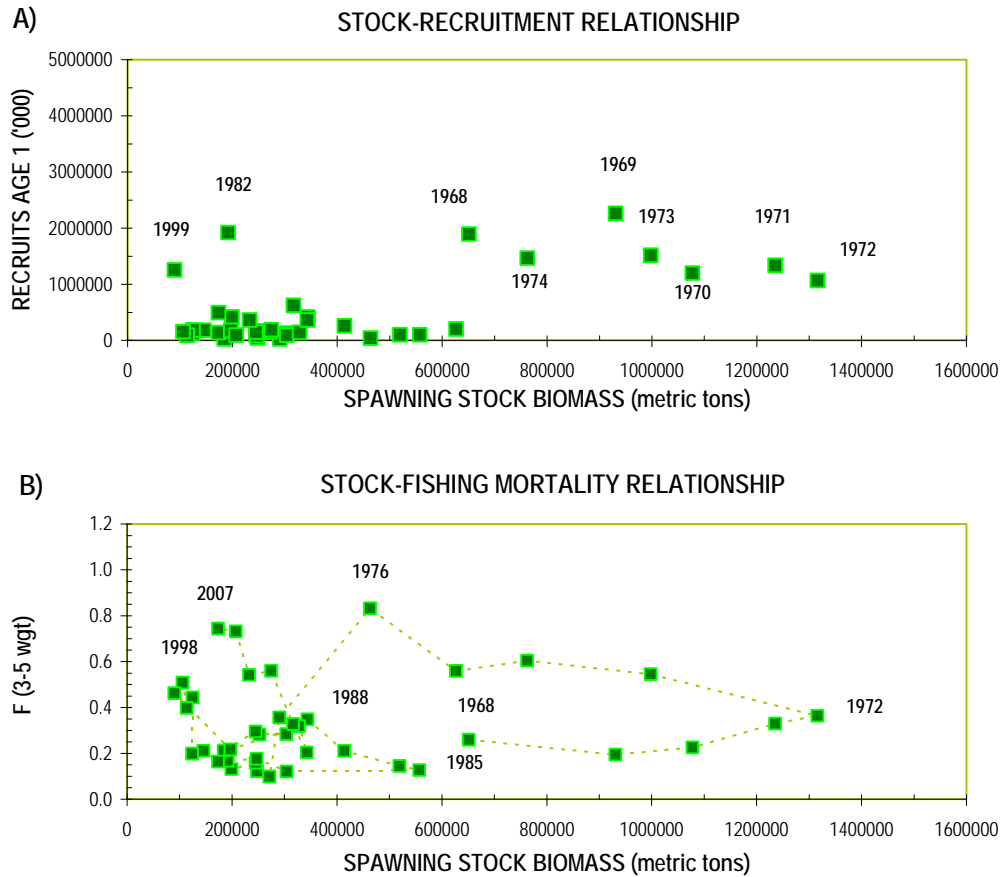


**Figure 15.** *Traditional VPA: A) Stock-recruitment relationship (some year-classes are indicated); and B) stock-fishing mortality (weighted average, ages 3-5) relationship for the Northwest Atlantic mackerel (some years are indicated). The VPA was started from the outputs of a Separable VPA (SVPA) for **Ft=0.50** and St=**1.25**.*

A)



B)



C)
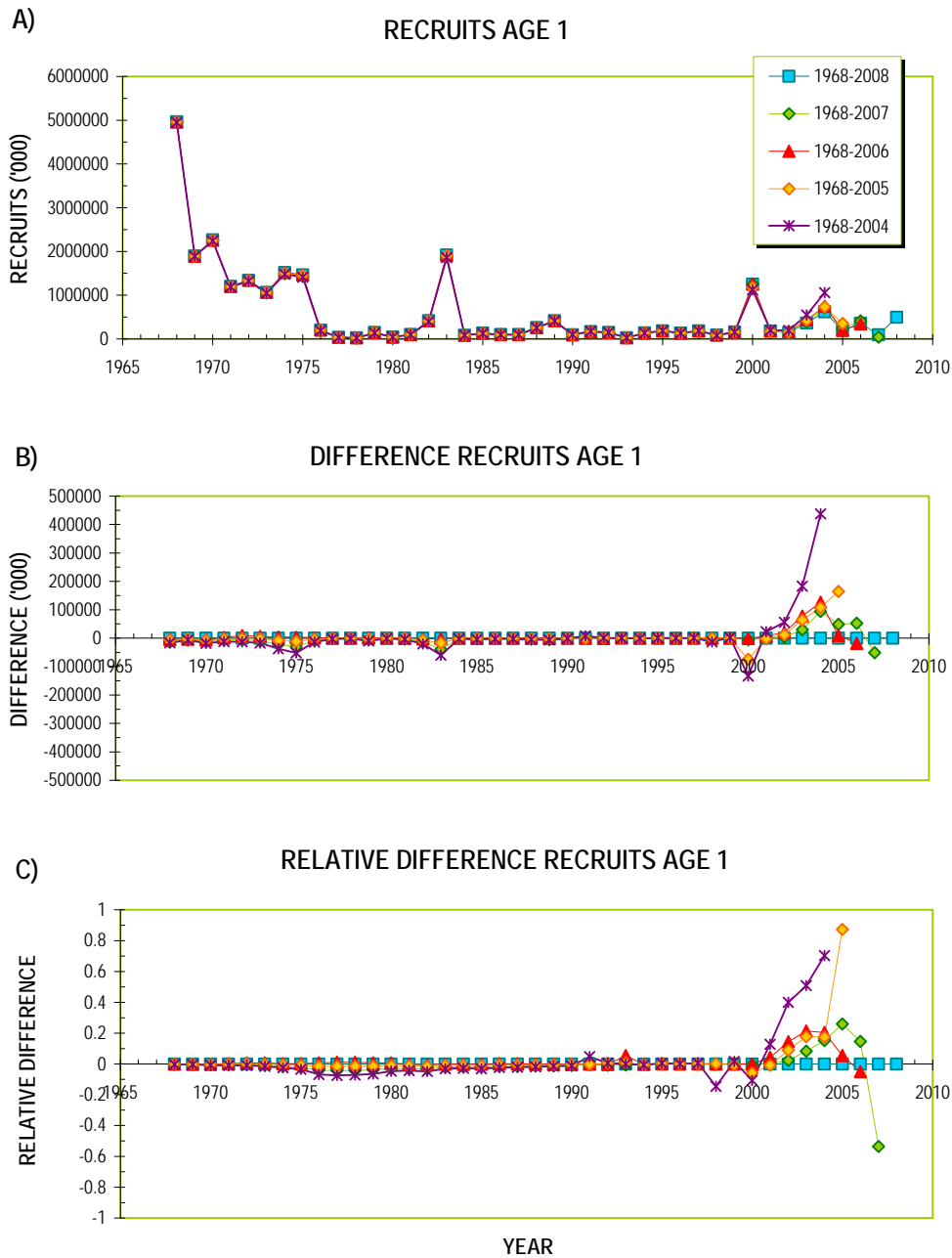


**Figure 16.** *Traditional VPA: A) Retrospective analysis of age 1 recruitment; B) difference; and (C) relative difference to the terminal year (Mohn's Rho statistic: Average = 0.125; total = 0.623). The VPA was started from the outputs of a Separable VPA (SVPA) for **Ft=0.50** and **St=1.25**.*

A)

POPULATION ABUNDANCE AGES 1+



B)

DIFFERENCE POPULATION ABUNDANCE AGES 1+



C)

RELATIVE DIFFERENCE POPULATION ABUNDANCE AGES 1+
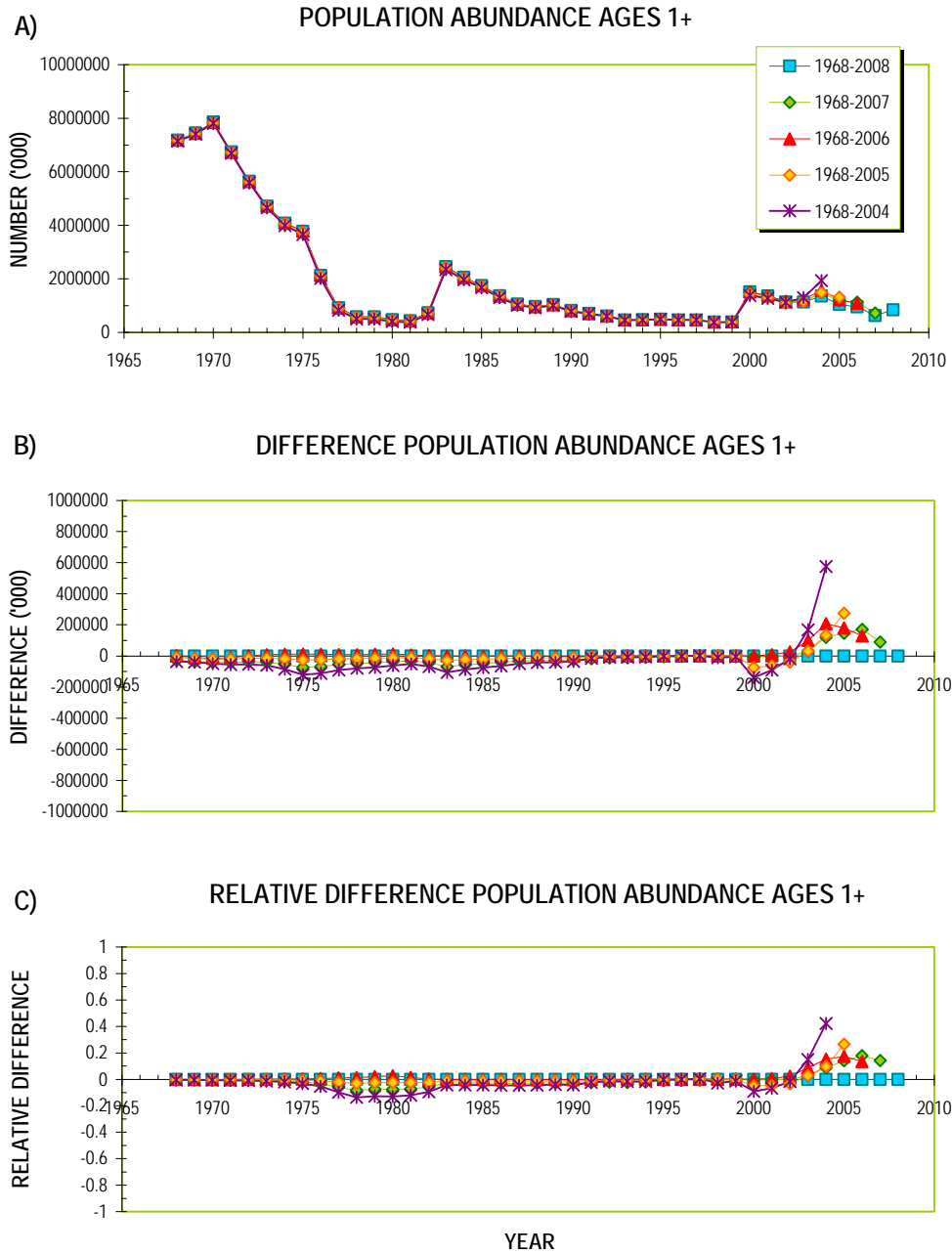


YEAR

**Figure 17.** *Traditional VPA: A) Retrospective analysis of population abundance ages 1⁺; B) difference; and C) relative difference to the terminal year (Mohn's Rho statistic: Average = 0.140; total = 0.701). The VPA was started from the outputs of a Separable VPA (SVPA) for **Ft=0.50** and **St=1.25**.*
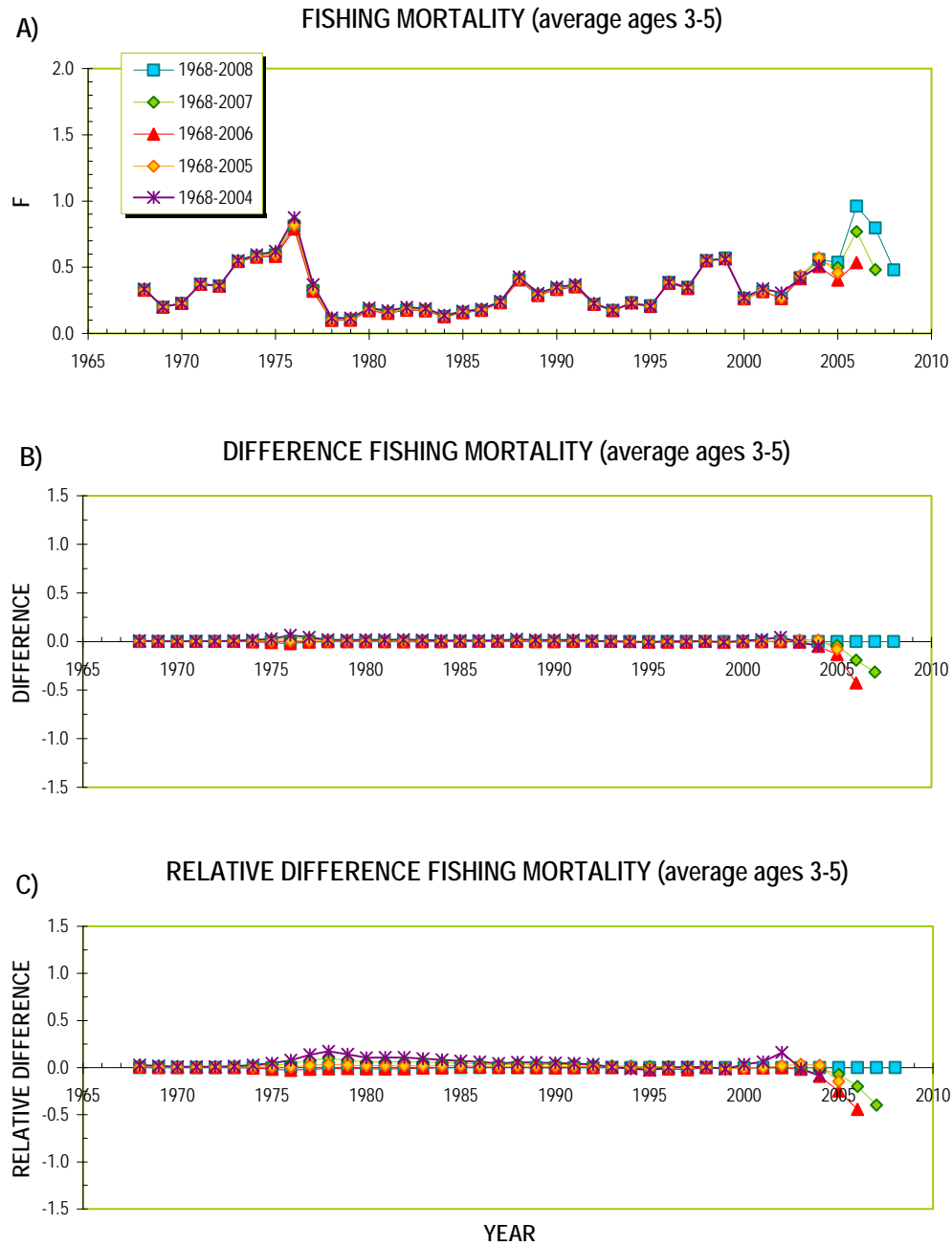
*Figure 18.* Traditional VPA: A) Retrospective analysis of fishing mortality (average ages 3-5); B) difference; and C) relative difference to the terminal year (Mohn's Rho statistic: Average = - 0.139; total = -0.695). The VPA was started from the outputs of a Separable VPA (SVPA) for **Ft=0.50** and **St=1.25**).
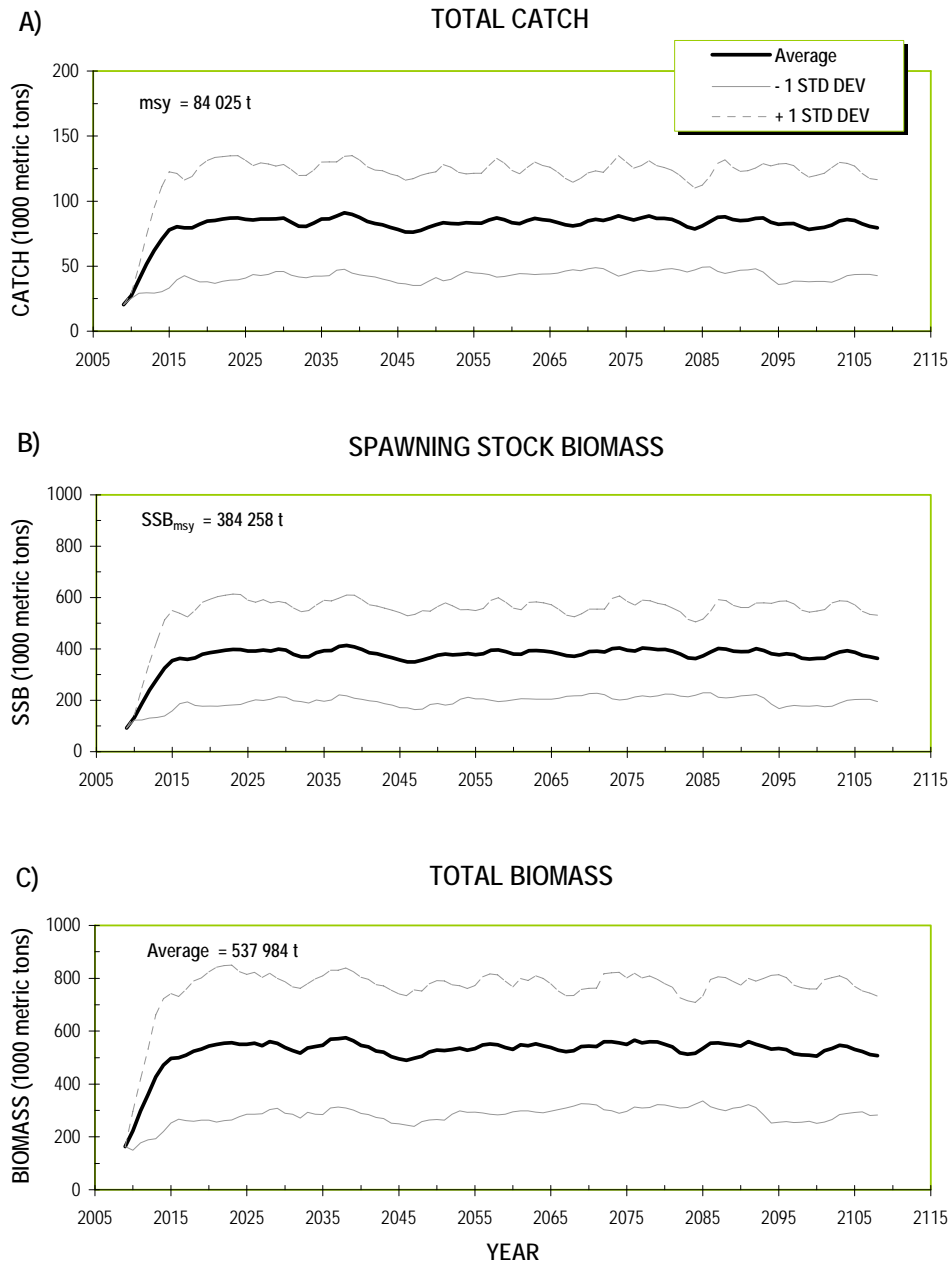
***Figure 19.*** *Stochastic bootstrapped projections (AGEPRO) of: A) total catch (thousands of metric tons); B) spawning stock biomass (thousands of metric tons); and C) total biomass (thousands of metric tons) with F at 40% as the harvest strategy. MSY and SSB$_{msy}$ in A) and B) are calculated as the averages of the 2020-2108 period. Data used in this analysis are from a traditional VPA started with the outputs of a Separable VPA (SVPA) for **Ft=0.50** and **St=1.25**.*
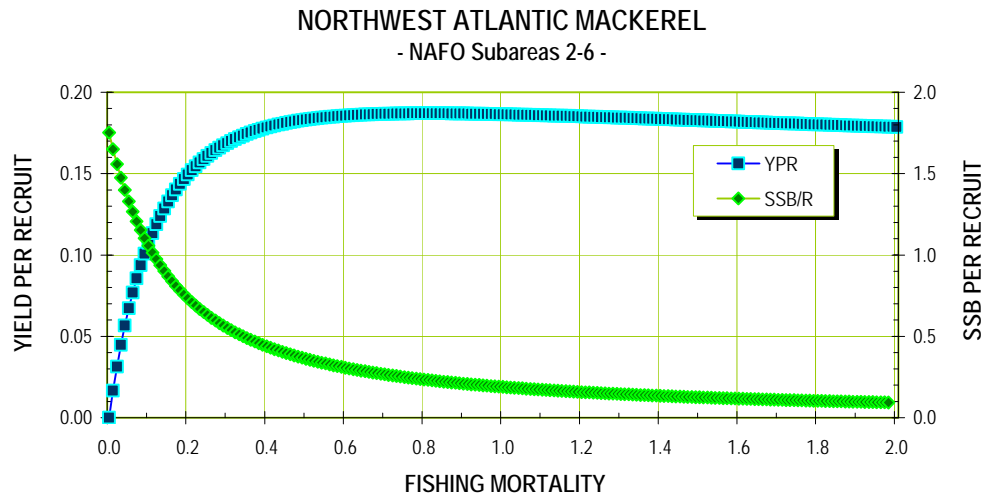
**Figure 20.** *Yield- and spawning stock biomass per-recruit analyses for the Northwest Atlantic mackerel ($F_{0.1}$ = 0.259, $F_{max}$ = 0.812 and F at 40% = 0.215). Data used in these analyses are from a traditional VPA started with the outputs of a Separable VPA (SVPA) for **Ft=0.50** and **St=1.25**.*
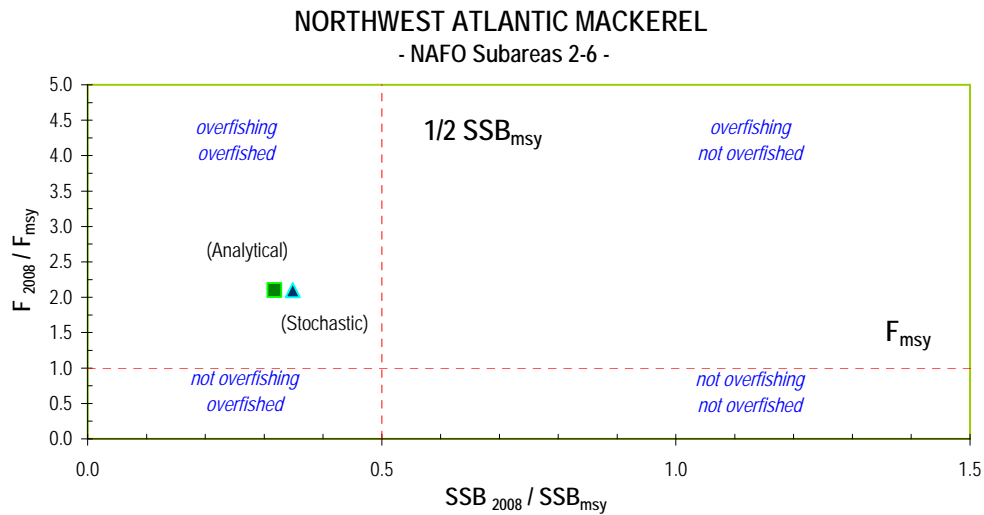


**Figure 21.** *Status of 2008 fishing mortality (F) and spawning stock biomass (SSB) of the Northwest Atlantic mackerel to $F_{msy}$ and $SSB_{msy}$. Data used in this analysis are from a traditional VPA started with the outputs of a Separable VPA (SVPA) for **Ft=0.50** and **St=1.25**.*
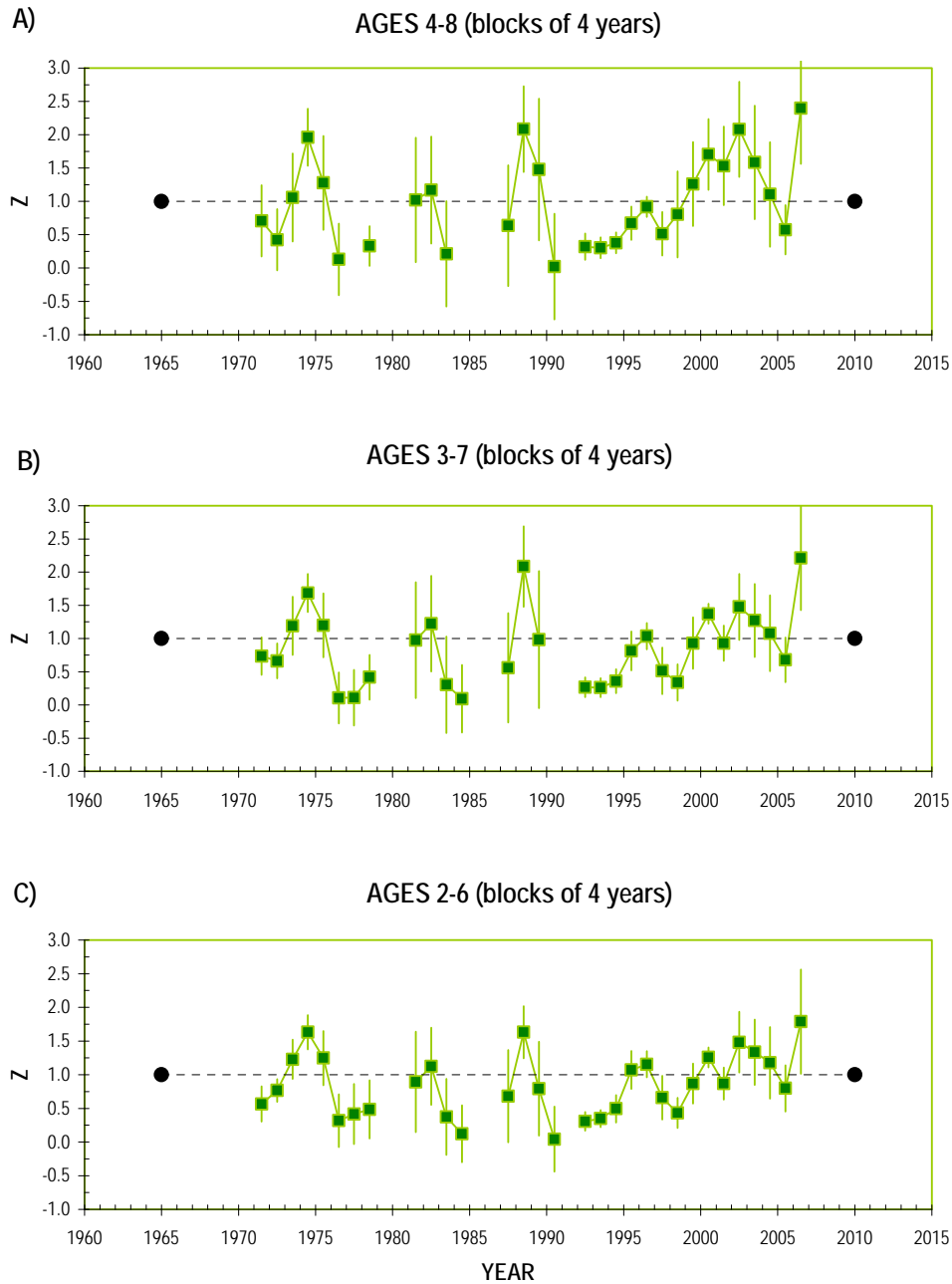
**Figure 22.** *Estimates of instantaneous rate of total mortality (Z) derived from the NEFSC spring research vessels bottom trawl surveys and fit according to the Sinclair's method (Sinclair 1998) for blocks of 4 years and different groups of ages: A) ages 4 to 8; B) ages 3 to 7; and C) ages 2 to 6. The horizontal lines represent Z = 1.0.*
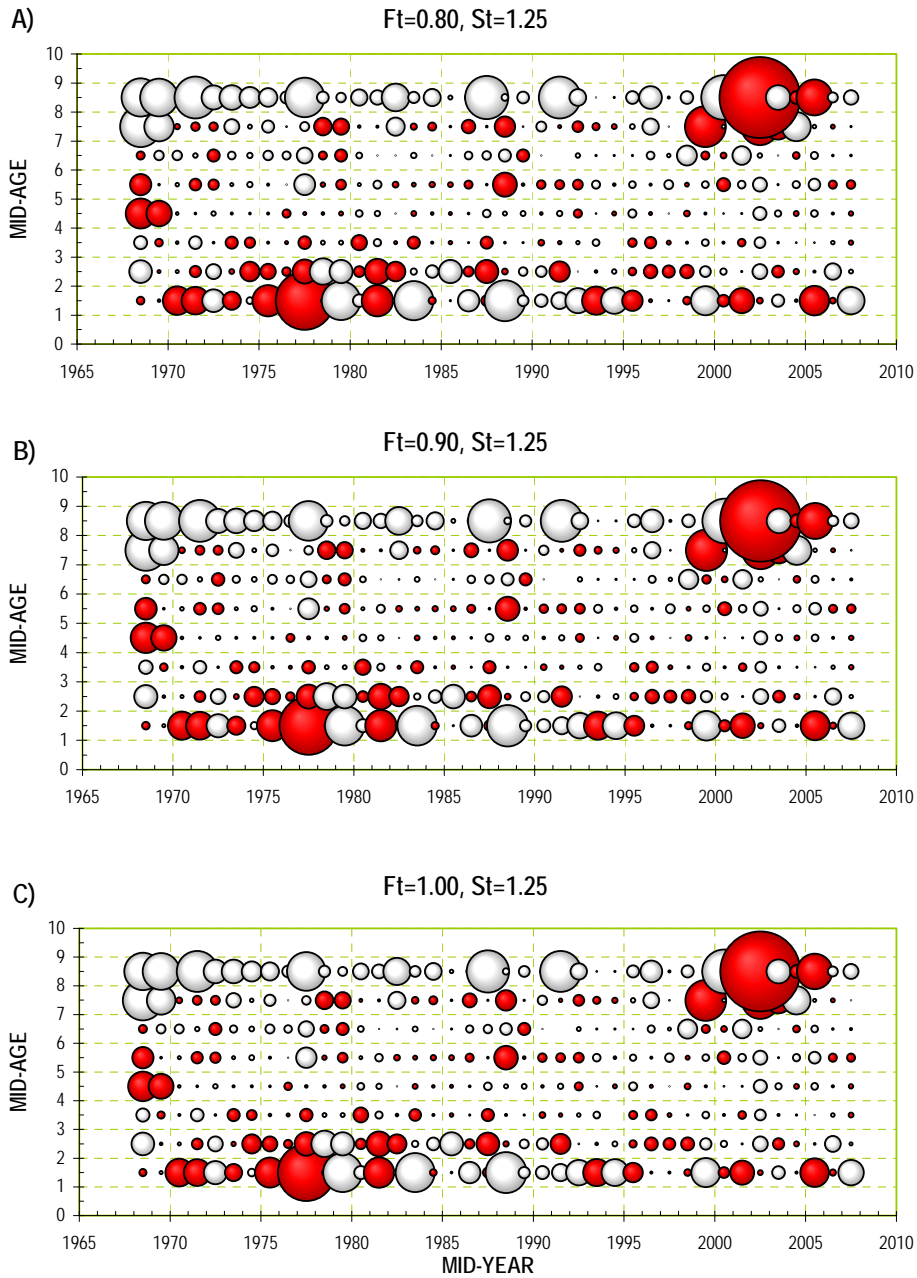
**Figure 23.** *Separable VPA (SVPA) analysis: Log of catch ratio residuals for **Ft=0.80, 0.90, and 1.00** and St=1.25.*
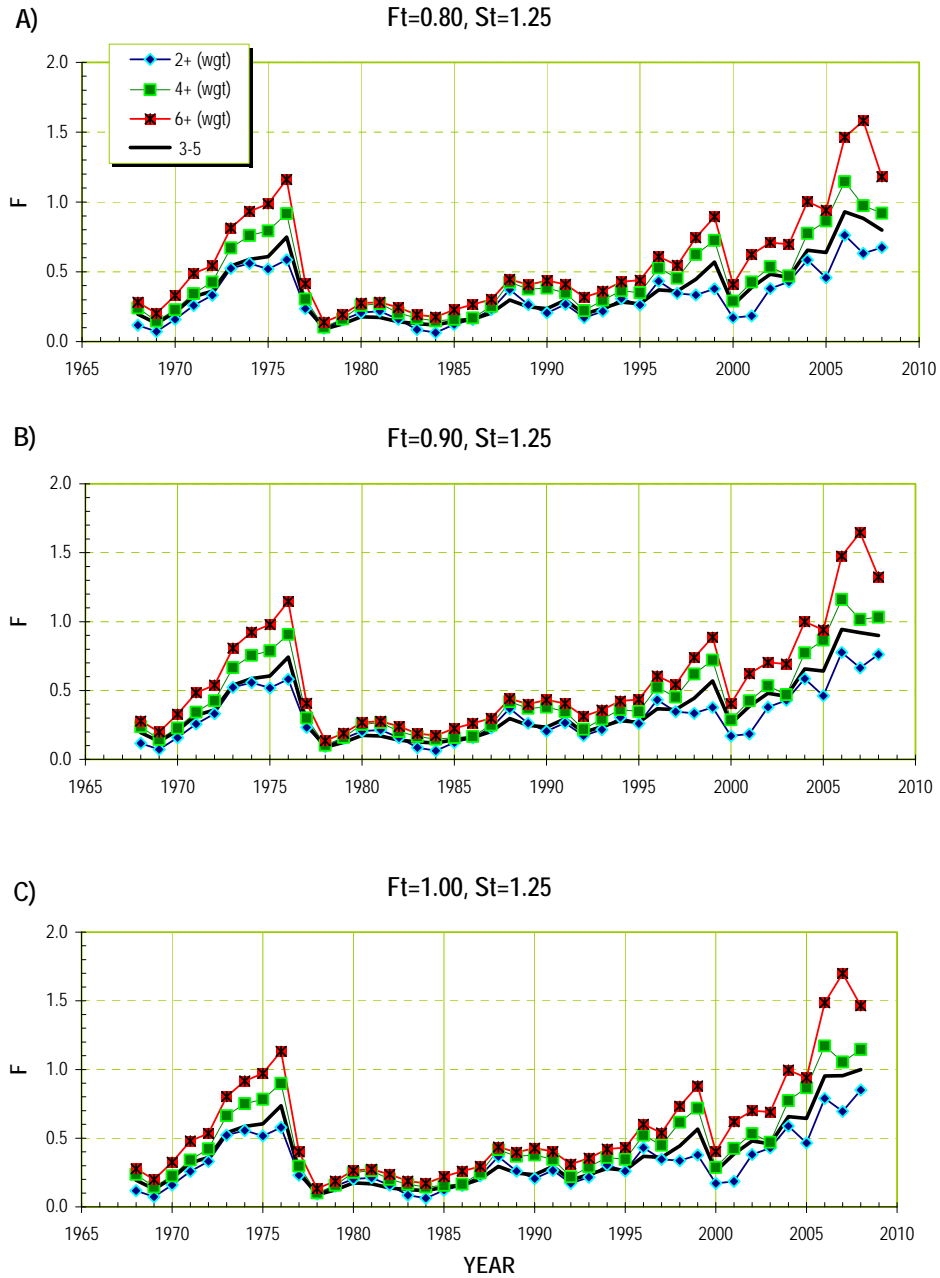
**Figure 24.** *Separable VPA (SVPA) analysis: Fishing mortality for **Ft=0.80, 0.90**, and **1.00** and **St=1.25**.*
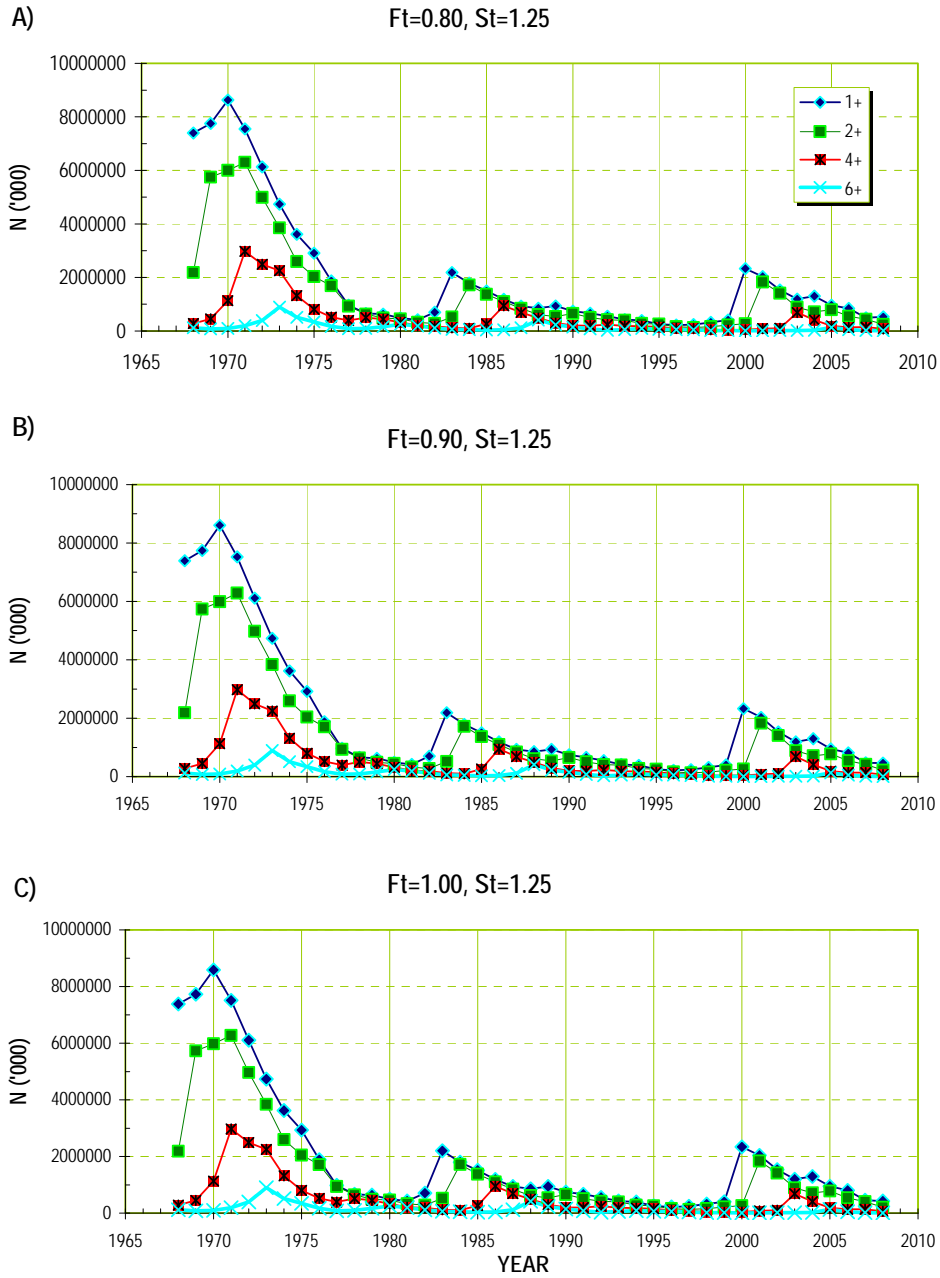
**Figure 25.** *Separable VPA (SVPA) analysis: Population abundance (thousands of fish) for **Ft=0.80**, **0.90**, and **1.00** and **St=1.25**.*
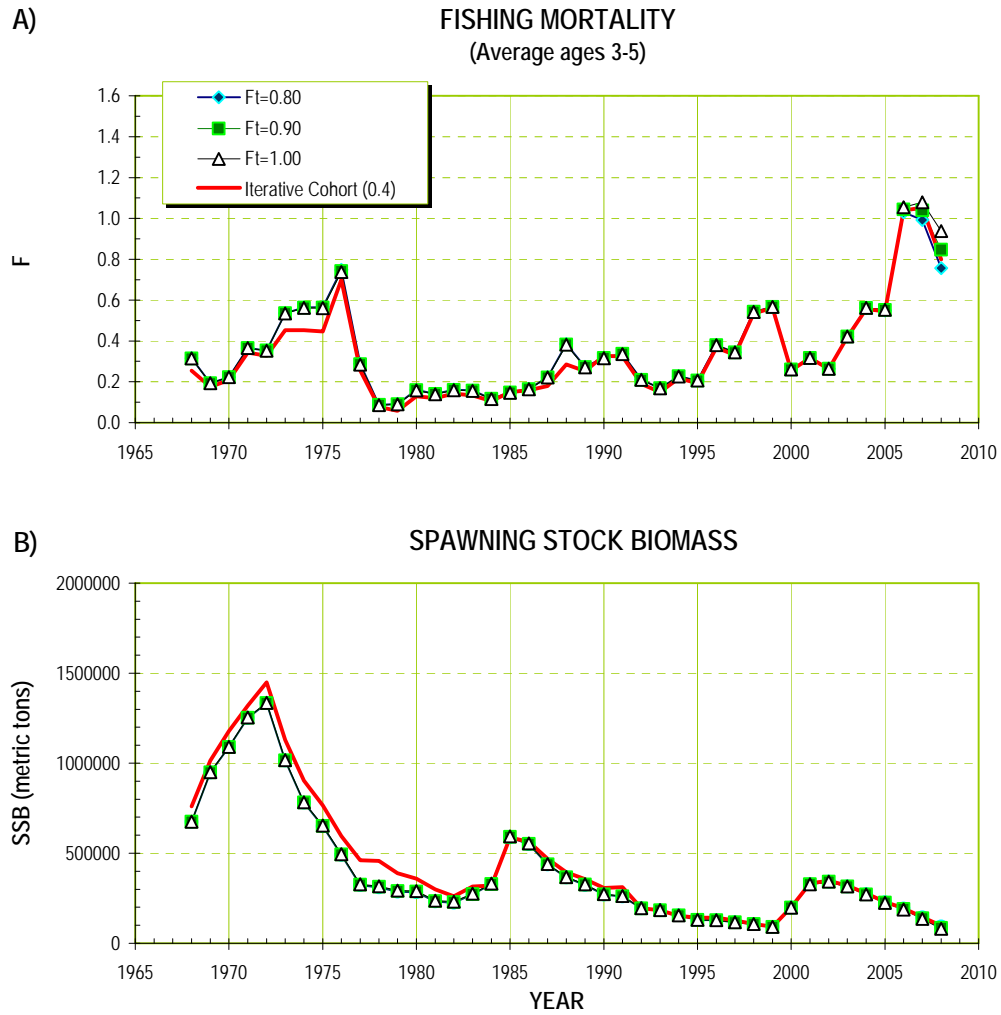
**Figure 26.** *Fishing mortality (weighted average, ages 3-5) (A) and spawning stock biomass (metric tons) (B) calculated from traditional VPA and iterative cohort (J.-J. Maguire, pers. comm.). Traditional VPA were started from the outputs of a Separable VPA (SVPA) for **Ft=0.80, 0.90, and 1.00** and **St=1.25**, and the iterative cohort with an initial **Ft** of **0.4**.*

**Figure 27.** *Traditional VPA: A) Recruits at age 1 (thousands of fish); B) fishing mortality (weighted by abundance); and partial recruitment (from fishing mortalities) for the Northwest Atlantic mackerel. The horizontal lines in A) represent three levels of recruitment: low, average and high. The VPA was started from the outputs of a Separable VPA (SVPA) for **Ft=0.90** and **St=1.25**.*

A) POPULATION ABUNDANCE



B) SPAWNING STOCK BIOMASS



C) RECRUITMENT RATE  -AGE 1-
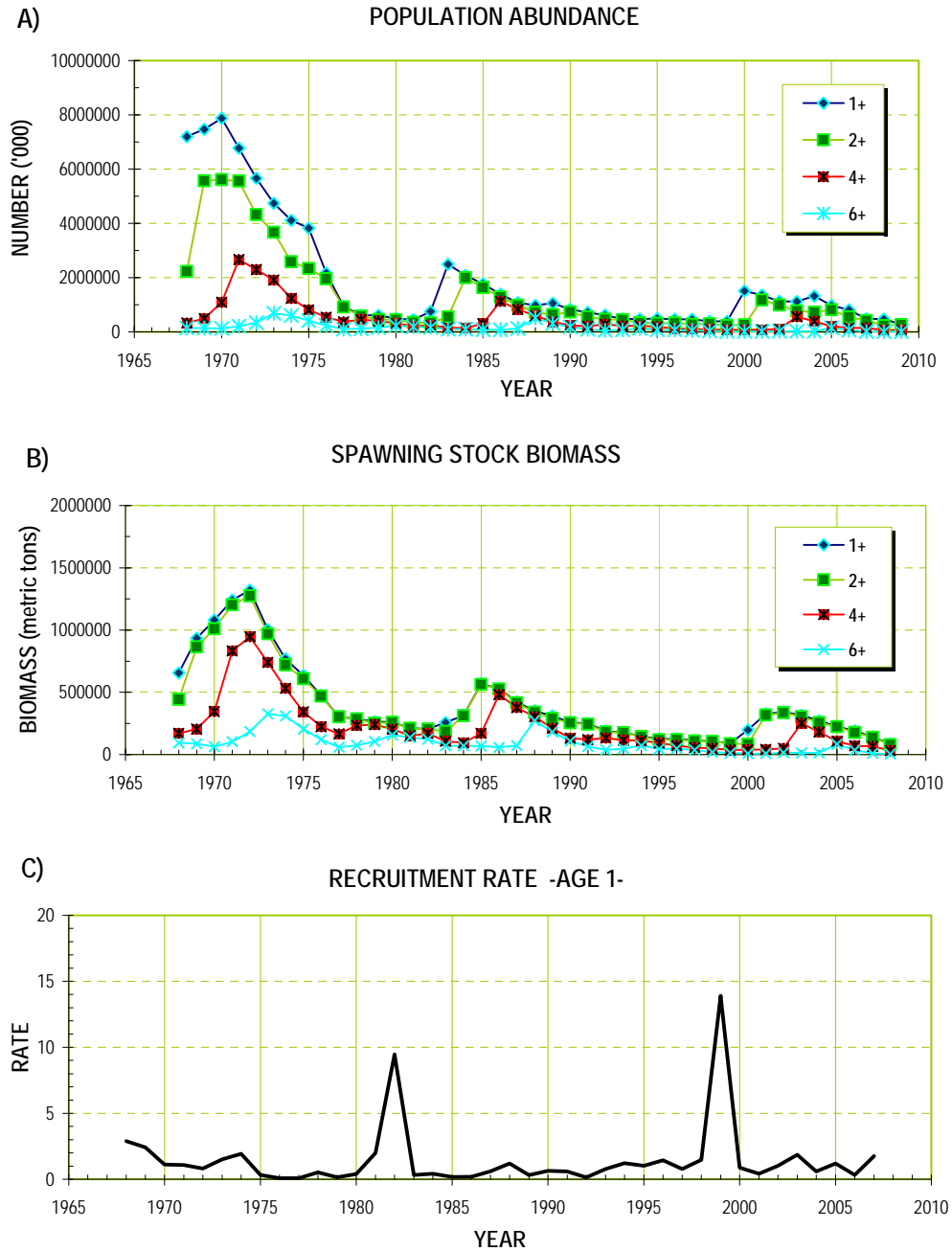


***Figure 28.*** *Traditional VPA: A) Population abundance (thousands of fish); B) spawning stock biomass (metric tons); and C) recruitment rate at age 1 for the Northwest Atlantic mackerel. The VPA was started from the outputs of a Separable VPA (SVPA) for **Ft=0.90** and **St=1.25**.*

A) STOCK-RECRUITMENT RELATIONSHIP-

B) STOCK-FISHING MORTALITY RELATIONSHIP
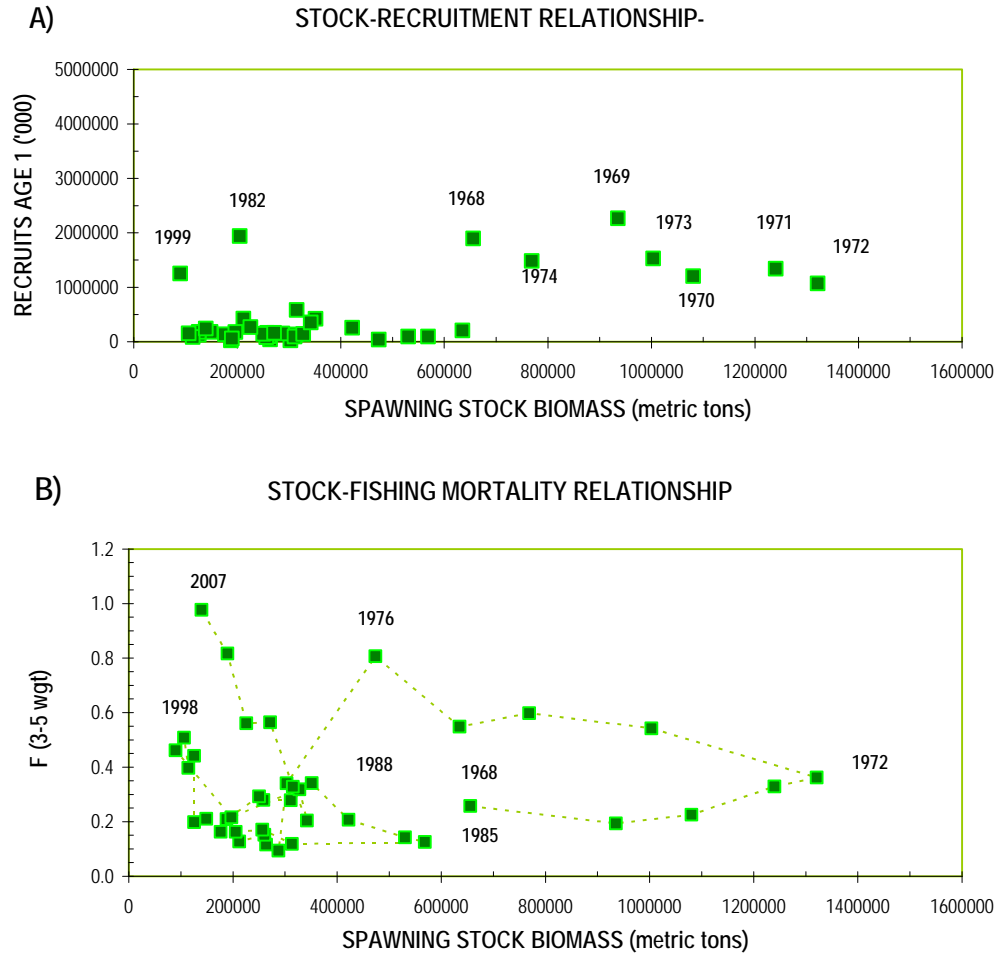
***Figure 29.*** *Traditional VPA: A) Stock-recruitment relationship (some year-classes are indicated); and B) and stock-fishing mortality relationship for the Northwest Atlantic mackerel (some years are indicated). The VPA was started from the outputs of a Separable VPA (SVPA) for **Ft=0.90** and St=**1.25**.*
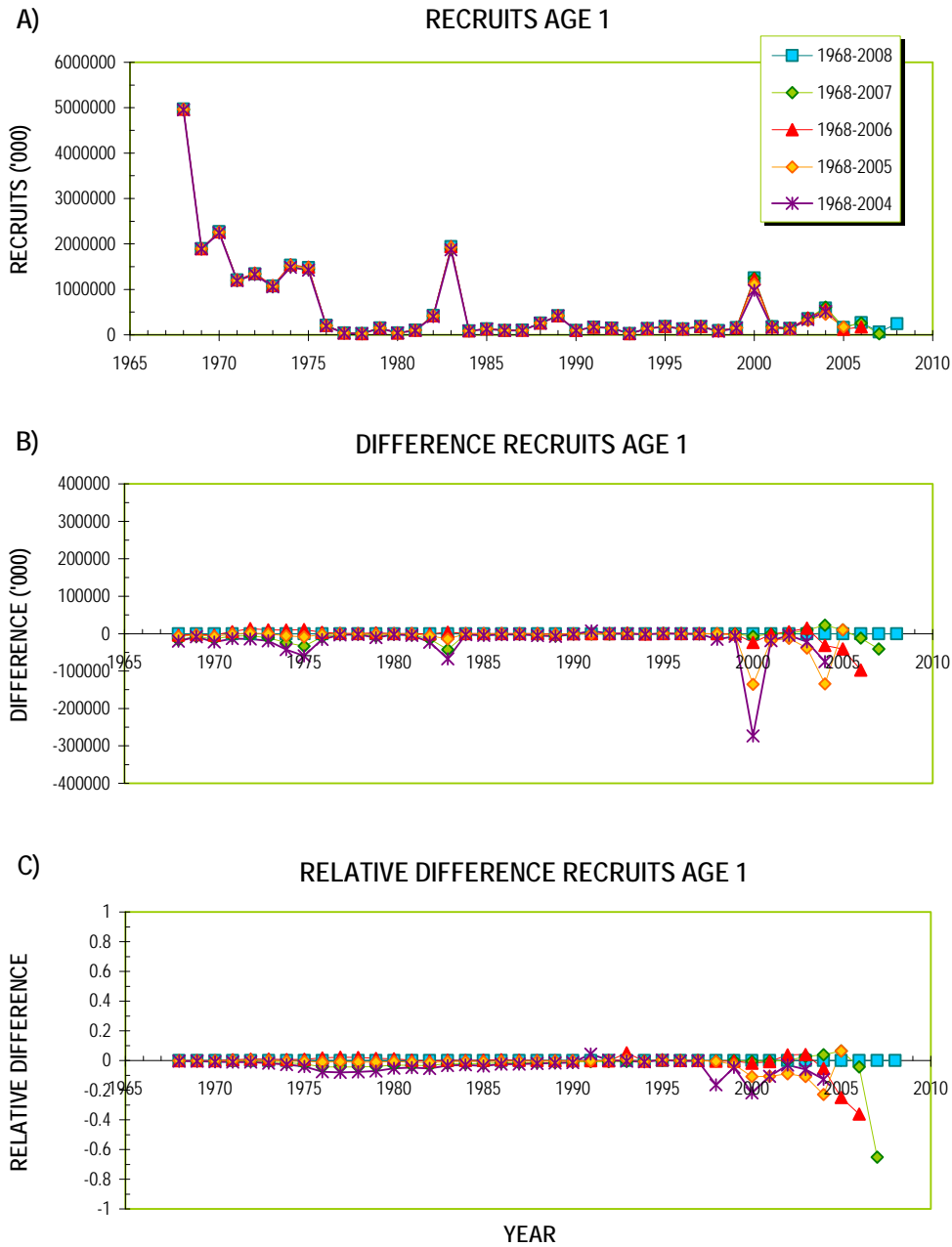
**Figure 30.** *Traditional VPA: A) Retrospective analysis of age 1 recruitment; B) difference; and (C) relative difference to the terminal year (Mohn's Rho statistic: Average = -0.354; total = -1.769). The VPA was started from the outputs of a Separable VPA (SVPA) with **Ft=0.90** and **St=1.25**.*
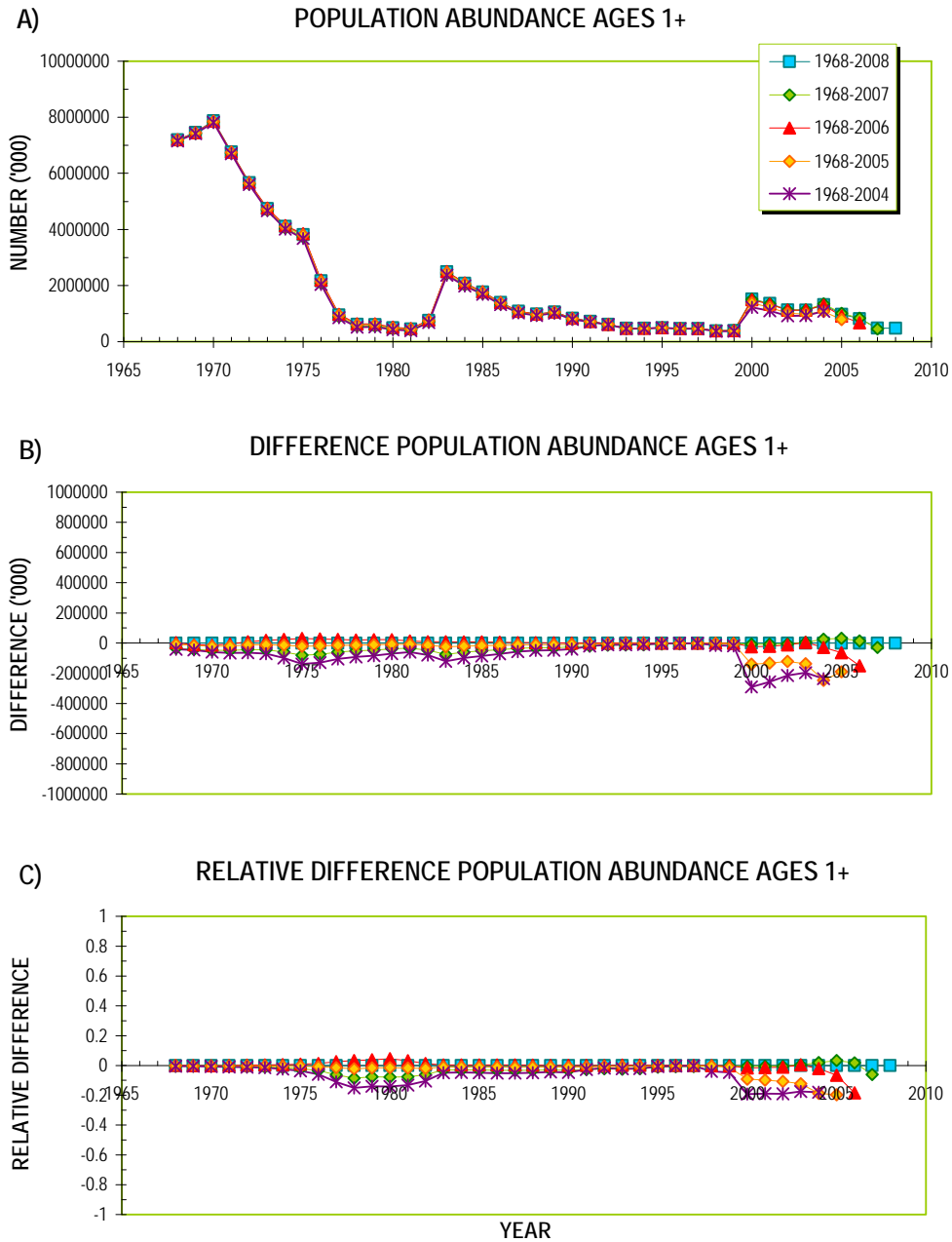
**Figure 31.** *Traditional VPA: A) Retrospective analysis of population abundance ages 1[+]; B) difference; and C) relative difference to the terminal year (Mohn's Rho statistic: Average = -0.233; total = -1.163). The VPA was started from the outputs of a Separable VPA (SVPA) for **Ft=0.90** and **St=1.25**.*
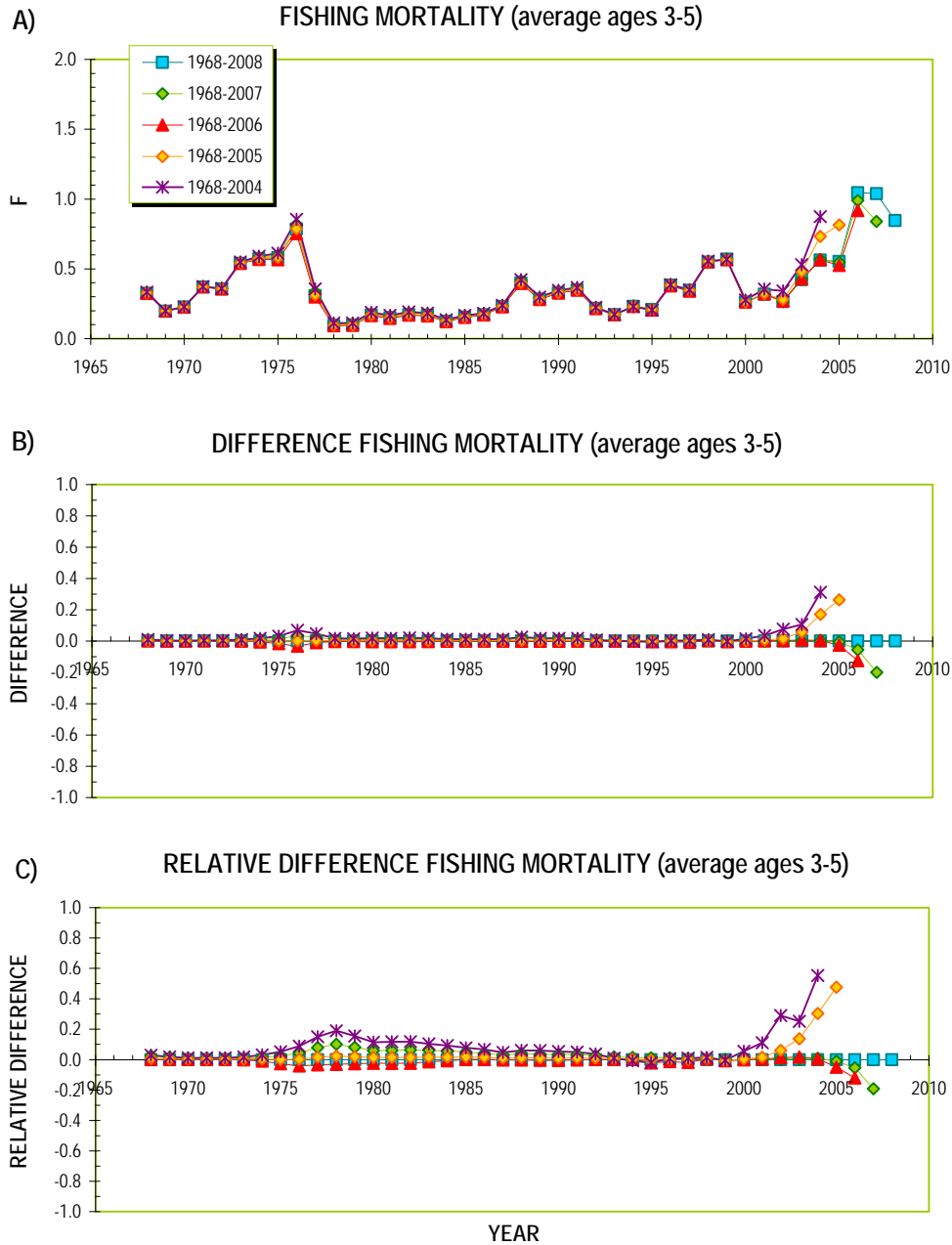
**Figure 32.** *Traditional VPA: A) Retrospective analysis of fishing mortality (average ages 3-5);
B) difference; and C) relative difference to the terminal year (Mohn's Rho statistic: Average =
0.404; total = 2.021). The VPA was started from the outputs of a Separable VPA (SVPA) for
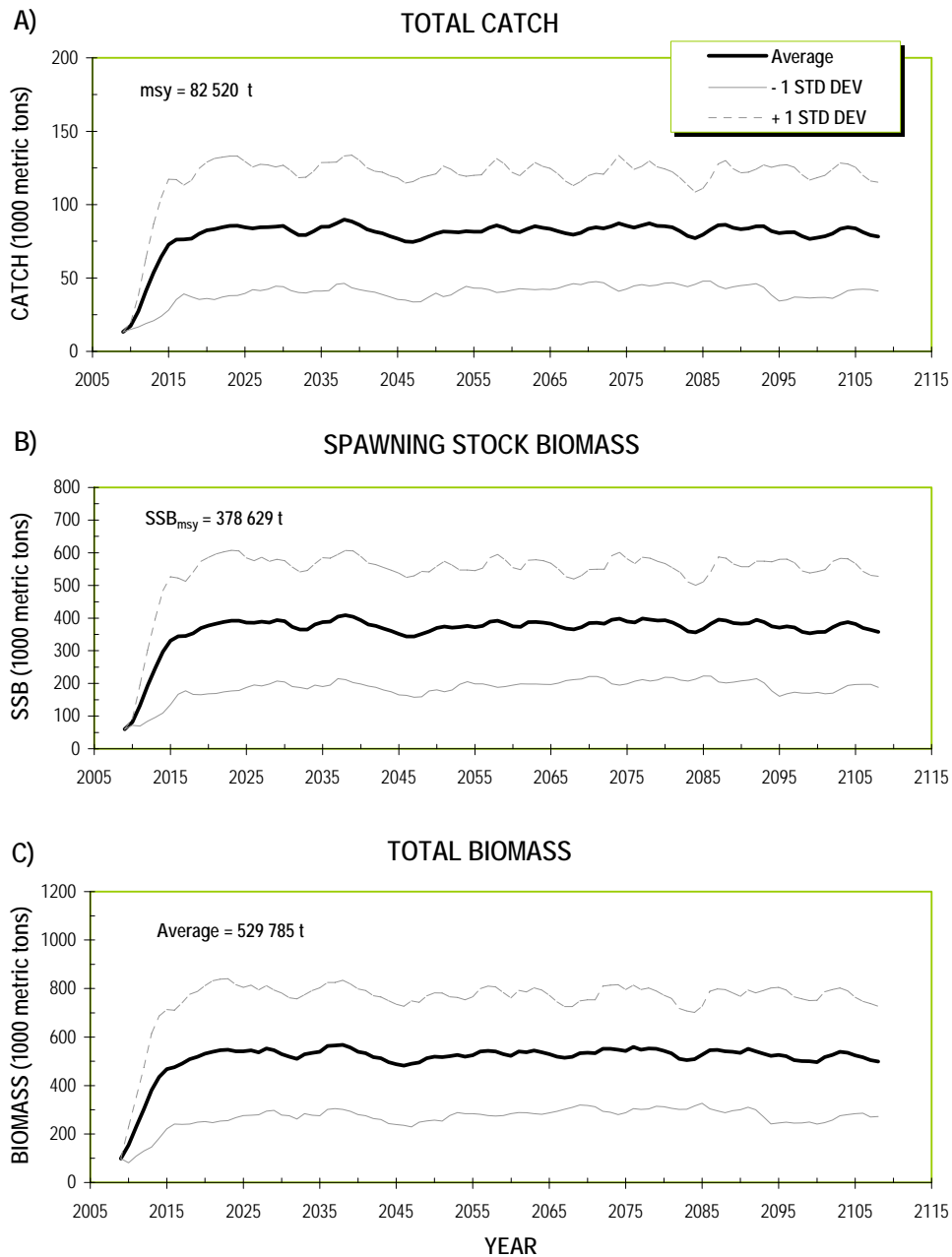**Ft=0.90** and **St=1.25**).*

A)



B)



C)



***Figure 33.*** *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 SSB$_{msy}$ in A) and B) are
calculated as the averages of the 2020-2108 period. Data used in this analysis are from the
outputs of a Separable VPA (SVPA) for **Ft=0.90** and **St=1.25**.*

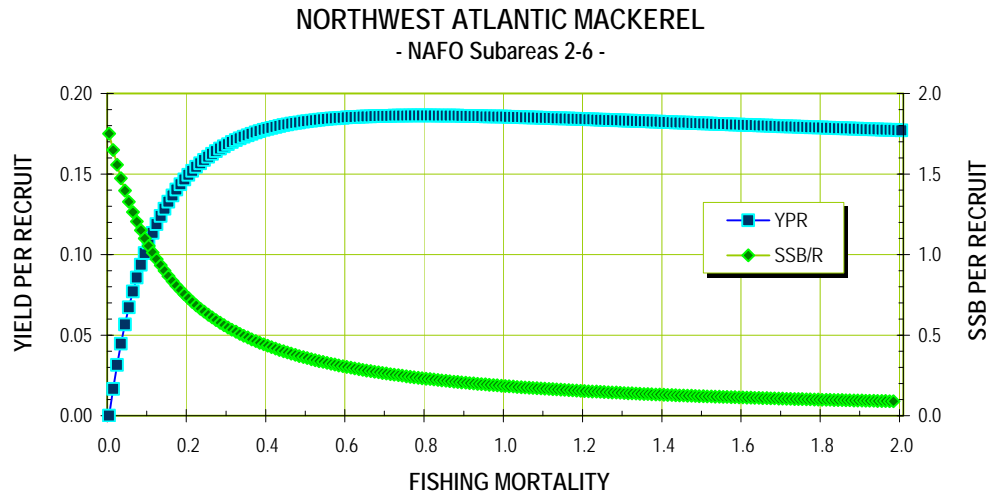NORTHWEST ATLANTIC MACKEREL
- NAFO Subareas 2-6 -

**Figure 34.** *Yield- and spawning stock biomass per-recruit analyses for the Northwest Atlantic mackerel ($F_{0.1}$ = 0.258, $F_{max}$ = 0.787 and F at 40% = 0.213). Data used in these analyses are from a traditional VPA started with the outputs of a Separable VPA (SVPA) for **Ft=0.90** and **St=1.25**.*
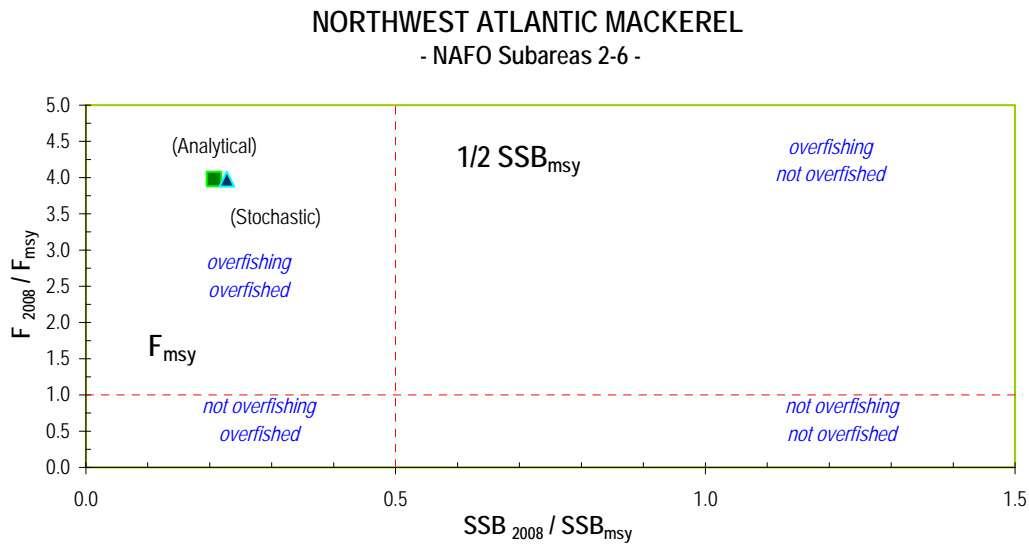


NORTHWEST ATLANTIC MACKEREL
- NAFO Subareas 2-6 -

**Figure 35.** *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 a traditional VPA started with the outputs of a Separable VPA (SVPA) for **Ft=0.90** and **St=1.25**.*