B. Butterfish Assessment Report

Executive Summary

Term of Reference 1:

Landings were largest in the 1970s and have been below 1000 mt since 2002. Revised discard estimates were made and included in total catch. From 1989-2008 discard estimates are made using the Standardized Bycatch Reporting Methodology (Wigley et al. 2006) and a hind-casting method was used to estimates discarding prior to 1989. The discard estimates were highly uncertain and comprise more than half of the total catch on average over the last 20 years. Recreational catches were negligible.

Term of Reference 2:

NEFSC spring, fall and winter survey data were used in the assessment. Fall and spring indices exhibited opposite trends in recent years, but the working group felt that the fall survey indices likely represent the trend in biomass more appropriately because they have better precision on average and the stock is more available to the survey during the fall. State survey data were not used due to low coverage of the stock area, and inability to form biomass indices of age 0 and 1+ fish required for the assessment model. Some state survey indices had no associated estimates of uncertainty and only two years of NEAMAP survey indices for the fall and spring are available which will not yet inform the assessment model.

Term of Reference 3:

Fishing mortality and biomass estimates are highly uncertain and also reliant on a prior distribution for the catchability of the NEFSC fall 1+ indices. While the scale of the estimates should be more appropriate than the previous assessment due to more realistic efficiency of the survey, there is still considerable uncertainty. Estimates of current (2008) fishing mortality, recruitment and spawning biomass are 0.02, 38,800 mt, and 45,000 mt, respectively.

Estimates of total mortality from survey age composition were much higher than the sum of the assumed natural mortality rate (0.8) and estimates of fishing mortality from the model. Furthermore, it appears that fishing mortality is negligible relative to natural mortality because there did not appear to be any correlation of total mortality estimates with total catch estimates.

Term of Reference 4:

The previous reference points were based on fitting a Fox surplus production model to the recruitment and biomass estimates from the assessment model (F_{MSY} = 0.38, MSY = 12,200 mt, B_{MSY} = 22,800). The working group determined that it would be beneficial to change the reference point methodology to one that uses recruitment estimates from the final model in stochastic projections under a specified fishing mortality to obtain distributions of equilibrium yield and spawning biomass. The working group proposed $F_{0.1}$= $F_{20\%}$=1.04 as an F_{MSY} proxy. Other candidate proxies included $F_{30\%}$=0.72 and $F_{40\%}$=0.52. Median equilibrium yield at $F_{0.1}$ is 36,608 mt and the median equilibrium spawning biomass is $SSB_{0.1}$ = 16,262 mt. Median equilibrium yield at $F_{30\%}$ is 33,108 mt and the median equilibrium spawning biomass is $SSB_{40\%}$ = 25,226 mt. Median equilibrium yield at $F_{40\%}$=0.52 is 29,166 mt and the median equilibrium spawning biomass is $SSB_{30\%}$ = 34,191 mt. F_{MAX} is undefined for this stock. The SARC did not accept any such equilibrium-based reference points (including those from the previous assessment) at this time for butterfish because the stock does not appear to be in equilibrium and, as such, these reference points would be inappropriate. Recruitment and spawning biomass appear to be in decline even though fishing mortality has been very low relative to natural mortality for more than 20 years.

Term of reference 5:

The estimate of current (2008) spawning biomass is 45,000 mt. The estimate of current total biomass is 88,800 mt. The current estimate of fishing mortality is 0.02. Because estimated fishing mortality has been negligible relative to natural mortality, the assessment concludes that overfishing is not likely to be occurring. The stock is in decline although this does not appear to be due to fishing mortality and the status is undefined because of uncertainty in the stock size and lack of an equilibrium-based biomass reference point.

Term of reference 6:

Total consumption of butterfish is on the same order of magnitude as estimates of butterfish stock landings. Total consumption of butterfish exhibits similar trends as landings estimates, until recent years. Instead of increasing uncertainty, incorporating information on consumption of butterfish may actually help to better inform and improve model fitting. It is feasible to calculate M in this context. Ignoring some form of dynamic M may provide misleading biological reference points, or at least result in incorrectly scaled model results (estimates of biomass, F, etc.).

Term of reference 7:

A projection methodology was proposed, but not acceptable because of the evidence that the stock was not in equilibrium. The proposed projection methodology is generally the same as that used for determining proposed reference points.

Term of Reference 8:

Several of the recommendations from the previous SARC were completed for this assessment.

Terms of Reference

1. Characterize the commercial catch including landings, effort and discards by fishery (i.e., *Loligo* fishery vs other fisheries). Characterize recreational landings. Describe the uncertainty in these sources of data. Evaluate the precision of the bycatch data with respect to achieving temporal management objectives throughout the year.
2. Characterize the survey data that are being used in the assessment (e.g., indices of abundance including RV Bigelow data, NEAMAP and state surveys, age-length data, etc.). Describe the uncertainty in these sources of data.

3. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and characterize the uncertainty of those estimates.
4. Update or redefine biological reference points (BRPs; estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, and F_{MSY}; and estimates of their uncertainty). Comment on the scientific adequacy of existing and redefined BRPs.
5. Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 4).
6. Evaluate the magnitude, trends and uncertainty of predator consumptive removals on butterfish and associated predation mortality estimates and, if feasible, incorporate said mortality predation estimates into models of population dynamics.
7. Develop and apply analytical approaches and data that can be used for conducting single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs).

   a. Provide numerical short-term projections (1-5years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. In carrying out projections, consider a range of assumptions about the most important uncertainties in the assessment.
   b. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.
   c. For a range of candidate ABC scenarios, compute the probabilities of rebuilding the stock by January 1, 2015.
   d. Describe this stock's vulnerability to having overfished status (consider mean generation time), and how this could affect the choice of ABC.

8. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

Introduction

Butterfish (*Peprilus triacanthus*) are distributed from the Florida to Nova Scotia, occasionally straying as far north as the Gulf of St Lawrence (Bigelow and Schroeder 2002). Butterfish is a fast growing species that schools by size, makes seasonal inshore and offshore movements, and seldom attains an age greater than 3 years. Butterfish mature at age 1, spawn during the summer months (June-August), and begin schooling at about 60 mm (Bigelow and Schroeder 2002). They exhibit a planktivorous diet, feeding mainly on zooplankton, ctenophores, chaetognaths, euphasids and other organisms. Butterfish are preyed upon by a large number of medium predatory fishes such as bluefish, weakfish, and spiny dogfish, marine mammals including pilot whales and common dolphins, seabirds such as greater shearwaters and northern gannets, large pelagic fish including swordfish, and invertebrates such as squid.

The last assessment for this stock was completed in 2003 (SARC 38, NEFSC 2004). The reference points from the assessment were fishing mortality at maximum sustainable yield, F_{MSY}=0.38, MSY = 12,200 mt and total biomass at MSY, B_{MSY}=22,800 mt.

Term of Reference 1: Commercial Catch

Characterize the commercial catch including landings, effort and discards by fishery (i.e., *Loligo* fishery vs other fisheries). Characterize recreational landings. Describe the uncertainty in these sources of data. Evaluate the precision of the bycatch data with respect to achieving temporal management objectives throughout the year.

The Fishery

A variety of data sources were used to derive the catch time series. Landings prior to 1963 were obtained from Murawski *et al*. (1978). Landings during 1963-2008 were obtained from the Commercial Fisheries Database System of the Northeast Fisheries Science Center. Butterfish catch data for the foreign fleets during 1963-1982 and 1983-1986 were obtained from previous stock assessment documents, Waring and Anderson (1983) and NEFSC (1990), respectively.

Landings

During the late 1800's through 1928, butterfish harvested from nearshore weirs and traps located along the coast between Cape Cod and Virginia ranged between 150 and 2,800 mt annually (Murawski *et al*. 1978). Landings increased during 1929-1962, ranging between 1,000 and 7,800 mt and averaging 4,300 mt (

Figure B1). During 1949-1958, trawlers based primarily in Point Judith and New Bedford landed butterfish in mixed-species food and industrial fisheries that occurred primarily in the coastal waters of southern New England (Edwards and Lawday 1960). During 1963-1986, foreign fleets targeting squid in offshore areas, primarily *Loligo pealeii*, reported landings of butterfish. Total catches of butterfish were dominated by the foreign fleets during 1969-1976, with most of the catch occurring in the Japanese *Loligo*/butterfish fishery (Lange and Sissenwine 1980; Murawski and Waring 1979). Catches by the foreign fleets averaged 15,400 mt during 1969-1976, with a peak catch of 31,700 mt in 1973 (Figure B2,). Butterfish landings averaged 1,976 mt during 1965-1979 without any trend. During 1980-1989 landings increased sharply to over 9,000 mt in 1982, declined, and then increased to over 11,000 mt in 1984. This rapid increase in the 1980s occurred due to heavy demand for butterfish in the Japanese market. Since 1987, butterfish catches have been solely from domestic fisheries. During 1987-2001, butterfish landings ranged between 1,400 and 4,600 mt but landings gradually tapered off and there has been no directed fishery since 2001. Since 2002, butterfish have been landed as bycatch, primarily in the small-mesh (codend mesh size = 50 mm) bottom trawl fishery for *Loligo* (MAFMC 2009), and landings ranged between 400 and 900 mt during 2002-2008. In 2008 landings were 451 mt. Preliminary butterfish landings through October of 2009 are 356 mt (Table B1) However, butterfish catches by the foreign fleets are likely underestimated because Spain and Italy did not report their butterfish bycatch from the squid fisheries during 1970-1976 and there was no US observer coverage of the fisheries until 1977 (Murawski and Waring 1979; Lange and Sissenwine 1980).

Commercial landings by the United States have remained below about 5,000 mt from 1960-2002 except for a period during the mid 1980s when landings increased to 8,837 mt in 1982 and over 11,000 mt in 1984 (Figure B2; Table B1)

Discard Estimates

Catch data between 1976 and 1986 as presented in historic assessment documents included some estimates of butterfish discards combined with landings between 1976 and 1986 (Waring and Anderson 1983, NEFSC 1990). We determined the portion of the annual total catches in these records attributable to discards by subtracting the landings obtained from the Commercial Fisheries Database System (Table B1) From descriptions of their discard estimation it appears that these discard estimates only account for discarding behavior of the directed butterfish fisheries until 1986. Because there is discarding of butterfish in other fisheries using trawl gear, it is likely that there is substantial discard not included in the reported catches.

Since the previous assessment, a Standardized Bycatch Reporting Methodology (SBRM) has been produced (Wigley *et al.* 2006) that combines landings, vessel trip report and observer sampling data to provide estimates of discard rates and total discards for specified stocks. We apply the SBRM to develop butterfish discard estimates using the “combined” ratio estimator (D2 in Wigley *et al.* 2006). Strata are defined here by quarter, gear type, and region (New England or Mid-Atlantic waters). The gear types we used in making discard estimates include “fish,” “scallop,” and “shrimp” bottom trawls (gear codes 50, 52, and 58), beach seines (gear code 70), gillnets (gear codes 100 and 110), and mid-water trawls (gear codes 170 and 370). We also stratified the data from fish bottom trawl fishing into effort using less than or greater than 4 inch mesh. Almost all estimated discards are attributable to tows where “fish” bottom trawls are used.

Annual discards between 1965 and 1988 were estimated by multiplying the regional (New England = NE or Mid-Atlantic = MA waters) average of annual discard rate estimates for “fish” bottom trawl gear using small mesh (less than 4 inches) between 1989 and 1999 and the total landings by gear type 50 in the corresponding year and region. Specifically, the estimated discard in year $y \in \{1965,\ldots,1988\}$ is

$$\hat{D}_y = \bar{\hat{R}}_{MA,SM} L_{MA,y} + \bar{\hat{R}}_{NE,SM} L_{NE,y}$$

where $\bar{\hat{R}}_{MA,SM} = \frac{1}{11}\sum_{y=1989}^{1999} \hat{R}_{MA,SM,y}$ and $\bar{\hat{R}}_{NE,SM} = \frac{1}{11}\sum_{y=1989}^{1999} \hat{R}_{NE,SM,y}$ are the average of estimated discard rates for the small mesh fish bottom trawl in the respective regions and $L_{MA,y}$ and $L_{NE,y}$ are the landings by fish bottom trawl gear in the respective region in year y. An approximate variance estimate was obtained as

$$\hat{V}\left(\hat{D}_y\right) = \hat{V}\left(\bar{\hat{R}}_{MA,SM}\right) L_{MA,y}^2 + \hat{V}\left(\bar{\hat{R}}_{NE,SM}\right) L_{NE,y}^2$$

where

$$\hat{V}\left(\bar{\hat{R}}_{MA,SM}\right) = \frac{\sum_{y=1989}^{1999}\left(\hat{R}_{MA,SM,y} - \bar{\hat{R}}_{MA,SM}\right)^2}{10}$$

and

$$\hat{V}\left(\bar{\hat{R}}_{NE,SM}\right) = \frac{\sum_{y=1989}^{1999}\left(\hat{R}_{NE,SM,y} - \bar{\hat{R}}_{NE,SM}\right)^2}{10}.$$

Only the landings by gear type 50 were estimated for this period because the other gear sectors had negligible butterfish discards observed (see Table B2 to Table B10). The

discard rate estimates for the small mesh portion of the fish bottom trawl gear type were applied to all landings previous to 1989 because it was thought by the working group that smaller mesh was used by this fleet in these early years. The discard rates from 1989 to 1999 were used because of changes in regulations for *Loligo* fishery in 2000 that the working group thought would change butterfish discarding behavior.
During the 1989-2008 period the total discard estimates varied from just over 240 mt in 2007 to as high as 8927 mt in 1999, but precision of these estimates is generally poor (Table B1). In only three years is the estimated coefficient of variation as low as 0.3. The estimated discards previous to 1989 are consistently greater than 5000 mt and reach more than 10,000 mt in 1965, 1982 and 1983, but these estimates have even poorer precision because variance estimation for these discards accounts for the indirect nature of their estimation.

Loligo landings-based discard estimates

To meet this term of reference for this SARC, we also made estimates of discard rates and total discards using landed *Loligo* from sampled and unsampled trips for expansion. Since bycatch of butterfish is almost entirely obtained from fisheries using gear classified as "fish" bottom trawl gear, we restrict attention to corresponding samples and landings (Table B11). The working group thought it better to use the discard estimates with discard ratios based on all kept species because precision of those estimates was better on average and and it would not be appropriate to use *Loligo* based discard rates for discard estimation in years prior to observer coverage.

Total Catch

Total catches of butterfish increased from 14,500 mt in 1965 to a peak of 39,300 mt in 1973 and were dominated by catches from the offshore foreign fleets. Total catches then declined to 11,200 mt in 1977, as effort in the foreign fisheries was reduced. Catches increased to a second peak of 21,600 mt in 1984, with the development of a domestic trawl fishery for butterfish, but then declined to 2,800 mt in 1990 as the Japanese market demand waned. During 1991-2001, catches ranged between 3,800 mt and 12,200 mt. Catches declined during 2002-2008 due to the lack of a directed fishery and ranged between 900 mt and 3,200 mt. Similar to the foreign fishery for *Loligo*, discarding of butterfish occurs primarily in the US *Loligo* fishery (Figure B3), but discarding also occurs to a lesser extent in the small-mesh fisheries for *Illex* and silver hake. Discards comprise a majority of the total butterfish catch, averaging 59% during 1987-2001 and 63% during 2002-2008 and poor precision of discard estimates results in poor precision of total catch estimates (Figure B4). Since 2002, butterfish have been landed as bycatch, primarily in the small-mesh (codend mesh size = 50 mm) bottom trawl fishery for *Loligo* (MAFMC 2009).

Recreational Catch

Recreational catch was investigated, but it was insignificant as measured by the Marine Recreational Fishery Statistics Survey (MRFSS).

Commercial Length Composition

Size composition from commercial samples of butterfish generally ranged 12-25 cm during 1995-2008 with a modal length at 16-17 cm (Figure B5 and Figure B6) The number of commercial samples and fish measured was highest in 1997 and 2007 at over 6000, but the number of length samples has been greater than 1000 annually (Table B12).

Size Composition of Discards

Data from observed trips were assembled to examine the size composition of the discarded and kept fraction of trips where butterfish were caught. The size composition of discarded butterfish ranged form 4-24 cm depending on the year and the fishery, but most discarded fish were less than 16 cm (

Figure B7and Figure B8). The length in kept fraction of trips was generally greater than 10 cm and usually had a modal length from 16-18 cm.

Term of Reference 2: Survey data

Characterize the survey data that are being used in the assessment (e.g., indices of abundance including RV Bigelow data, NEAMAP and state surveys, age-length data, etc.). Describe the uncertainty in these sources of data.

Research Survey Indices

Research survey abundance and biomass indices are available from several sources for assessing the status of the butterfish resource. In the last assessment, survey indices from NMFS bottom trawl surveys for the winter in 1992-2002, for the spring in 1968-2002, and fall in 1968-2002 were used (NEFSC 2004). In this assessment the working group chose to use the same surveys. The spring indices used only offshore strata 1-14, 16, 19, 20, 23, 25, and 61-76 (Figure B9). The fall strata were expanded to include inshore strata 1-92, but the time period of this series of indices now starts in 1975 because inshore strata were not consistently covered prior (Figure B10). The winter strata were reduced to offshore strata 1-14 because other previously included strata were not consistently covered (Figure B11).

For spring surveys conducted during years 1973 through 1981 there was usage of a Yankee 41 trawl as well as the usual Yankee 36. Sissenwine and Bowman (1978) found that the Yankee 41 trawl caught on average 35% more biomass per tow, but found no evidence of differences in numbers per tow between the two gears. Our estimates of average biomass per tow for the spring surveys are expanded by this percentage when the Yankee 41 trawl was used. In the previous assessment there was no conversion of catches made using the Yankee 41 gear, but different catchability parameters were estimated in the assessment model. Byrne and Forrester (1991) analyzed differences in expected catches of species when different doors were used on the survey in 1985, but found no evidence for differences in catchability for butterfish. As such, we assume the same catchability of butterfish for both types of doors.

Indices are also available for several state survey programs, notably Massachusetts Division of Marine Fisheries (MADMF), Rhode Island Division of Fish and Wildlife, Connecticut Department of Environmental Protection, New Jersey Bureau of Marine Fisheries, and Virginia Institute of Marine Science (VIMS). The annual coverage for these surveys spans the period from 1978-2002 although some do not start until after 1978. In the short time available for this assessment, only data for the MA and CT surveys were readily obtained, so only these surveys will be presented. All of the MADMF survey strata were included to form indices. The VIMS survey collects abundance indices (number/tow), but biomass indices are required for the current butterfish assessment model.

The Northeast Area Monitoring and Assessment Program (NEAMAP) survey covers inshore waters from Cape Hatteras to Rhode Island and has been performed with consistent strata coverage from fall 2007. As such, only two years of survey indices for the fall and spring are available which will not yet inform the assessment model (Table B13).

NEFSC Surveys

The spring survey abundance indices (stratified mean number per tow) ranged from a low of 9.9 to a high of 228 during 1968-1979, from 13.4-66.2 during 1980-1989, 8.9-112.9 during 1990-1999 and 36.8-141.4 for 2000-2008 (Table B14, Figure B12). Spring biomass indices (stratified mean wt/tow in kg) were generally highest in the early 1970s and early to mid 1980s (Table B14; Figure B13). Spring biomass indices increased slightly in the late 1990s and exhibit a slight increasing trend in the last few years.

Fall survey abundance indices were generally much higher than the winter and spring indices because of the presence of the age 0 fish in the autumn. Abundance indices were moderately high but fluctuating during 1975-1978 and very high from 1979-1990 (Table B15, Figure B12). Abundance indices exhibit declining trend since 1991. Fall biomass indices exhibit the same pattern over time as the abundance indices (Table B15; Figure B13).

The NEFSC winter survey covers 1992-2007 with abundance indices ranging from 22-186 and biomass indices range from 0.9-6.9 (Table B16, Figure B12 and Figure B13). The winter abundance indices reached highest values in 1994 and 2004 and biomass indices reached highest values in 1994 and 2000.

The estimated precision of annual survey biomass indices is poorest (average CV was 0.44) for the spring series (Table B14 to Table B16, Figure B14). The fall and winter biomass indices have similar precision with average CVs of 0.25 and 0.34, respectively.

Aged NEFSC Survey Indices

Spring survey abundance at age indices show that this survey generally catches age groups 1-3 and usually some fish from age group 4 (Table B17, Figure B15). Abundance at age indices for the fall during 1982-2008 show that this survey generally catches age groups 0-3 with the age 0 catch dominating the total catch (Table B18, Figure B16 to Figure B19).

The delay-difference biomass model (KLAMZ, see Appendix A of NEFSC 2004) used for this assessment approximates an age structured model and utilizes biomass per tow indices for two age groups (age 0 and age 1+). Aged butterfish data from NEFSC spring and fall surveys are available from 1982-2008. Because the NEFSC spring and winter surveys occur after January 1 (the assigned birth date) and prior to spawning (which occurs in the summer), all butterfish are assumed to have a nominal age greater than 0 and so these biomass indices reflect 1+ individuals only.

To obtain biomass indices for 0 and 1+ butterfish in the fall survey between 1982 and 2008, the weight at age from the fitted Schnute growth model (described below) was applied to the numbers at age in Table B18 and the 1+ biomass indices were the sum of the biomass/tow at individual ages. Indices for 1975-1981 were calculated from the relative proportions of biomass/tow of age 0 and 1+ butterfish in the respective year. The numbers at age/tow in Table E5 from SARC 17 assessment (NEFSC 1993) were multiplied by the weight/fish at age from the Schnute growth model and the proportion of biomass/tow at ages 1-4 was multiplied by the biomass/tow indices in Table B15 to get the biomass of 1+ butterfish per tow. The remainder is the annual biomass/tow index of age 0 butterfish (Table B19). The weight per fish at age for the entire series accounted for the time of year of the fall survey by adding to the nominal age the fraction of the year at which the midpoint of the survey occurred.

MADMF Survey

Numbers and biomass per tow in the MADMF spring survey were low relative to the NEFSC spring survey indices and precision of annual biomass indices was even poorer on average with CVs as high as 0.8-1.0. (Table B20; Figure B20 to Figure B22). The fall abundance index varied greatly from year to year. Large fluctuations were observed between 1987 and 1989 and rapid increases and decreases in the late 1990s and early 2000s (Table B20 and Figure B20). The fall biomass indices had similar large fluctuations (Figure B21). The precision of the fall biomass indices was much better than the spring with CVs generally between 0.2 and 0.4 (Table B20 and Figure B22). Survey catch rates from the MADMF fall survey are similar to those of the NEFSC fall survey. Unfortunately, there are no age data for the MADMF fall survey, so age 0 and age 1+ indices required for the assessment model are not available.

CTDEP Survey

The CTDEP bottom trawl survey carried out in the Long Island Sound (LIS) has abundance indices starting in 1982 in the fall and 1984 in the spring. Biomass indices begin in 1992 for both seasons. However, estimates of precision are not available for any of the series of indices. Similar to the MADMF spring survey, the abundance and biomass indices for the spring LIS are low relative to the spring NEFSC indices (Table B20 and Figure B23). The fall abundance index fluctuated greatly in the 1990s but then stabilized before dropping to its lowest levels in the last two years. The fall biomass index similarly fluctuated in the 1990s, but is showing a slight increasing trend in recent years (Table B20 and Figure B24). Together, the recent trend in both the abundance and biomass indices would suggest an increase in average size of individuals available to the LIS survey in the fall. As with the MADMF fall survey, there are no age data for the LIS survey which prohibits forming age 0 and 1+ indices.

Term of Reference 3: Stock biomass and fishing mortality

Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and characterize the uncertainty of those estimates.

As in the last assessment, the KLAMZ model (see Appendix A of NEFSC 2004) is used as the assessment model. The KLAMZ model is an implementation of the delay-difference model (Deriso 1980 and Schnute 1985) developed by Dr. Larry Jacobson at the NEFSC. In short, the KLAMZ model approximates an age structured model by tracking recruiting (to the fishery) and biomass of older fish that have previously recruited through growth and mortality by specified parameters. The model assumes all individuals to be fully selected to the fishery. Survey indices supply information on trend of the two components of the population and annual catches allow estimation of fishing mortality. We found scale of the population to be difficult to estimate without auxiliary information on the catchability of butterfish for one or more of the survey indices.

Biological data and analysis

Growth

Butterfish spawn during June-August and are assigned ages based on calendar years. Young-of-year butterfish born in the second half of 1983, for example, reach *nominal* age 1 on January 1, 1984 at a *biological* age of no more than 6 months. Butterfish grow rapidly and significant numbers are taken in commercial fisheries at nominal age zero as bycatch primarily during the second half of the year. Age data given in this report are nominal ages (as assigned by readers) unless otherwise specified.

Parameters of Schnute's (1985) growth model are required for the population dynamics model (KLAMZ) used to assess butterfish. The growth model is a reparameterization of the von Bertalanffy growth model for the delay-difference model and it is the same as Schnute and Fournier's (1980) length-based growth model,

$$w_a = v + \left(V - v\right)\frac{1-\rho^{1+a-k}}{1-\rho}$$

where k is the age at recruitment, w_a is weight at age $a \geq k$, v is the weight at age k-1, V is the weight at age k, and $\rho=e^{-K}$ where K is the parameter for von Bertalanffy growth. The assessment model, uses estimates of ρ and $J=v/V$ made external to the model. Note that this growth model treats change in weight with age identically to length with age in the von Bertalanffy growth model whereas other approaches account for variable rates of change in weight with length through a length-weight relationship (e.g., Quinn and Deriso 1999, pp.139-141).

Records of age 0 butterfish from winter and spring surveys were omitted because age 0 butterfish should not be available until after June. Ages used in fitting growth models were adjusted by increasing the nominal age by the average time of year of the survey where the age sample was taken. The average time of year of a given NEFSC survey (e.g. fall) changes slightly from one year to the next (Figure B25). Data from a total of 17,920 butterfish ages (0.59-5.26) and corresponding weights (0.0001 - 0.27 kg) collected between 1992 and 2009 were used to estimate the growth curve (Table B21; Figure B26).

Modeling butterfish growth in the KLAMZ model is complicated by the differences between nominal age (based on calendar years used in the model) and biological age, and because recruitment occurs at age zero and growth is rapid. As shown above, the growth parameter v should be a positive number that estimates body weight at age k-1 one year prior to recruitment. In theory, the parameter v for butterfish would be body size at age k-1 = –1 during the January of the year before spawning occurs. Moreover v for butterfish is negative when k = 0.

To obtain useful growth parameters for modeling butterfish, we estimated growth parameters in Schnute's model by nonlinear least squares assuming k=1.5 in nominal years (k=1 in biological years). Growth parameters used in the KLAMZ model for butterfish were ρ=0.81211 and J=v/V=0.13312 (Table B21)

Due to the disparity between the true and assumed age at recruitment, large variability in weight at age and apparent lack of asymptotic growth among observed ages, future assessments may wish to consider whether this growth model is adequate.

Our approach to estimating growth parameters may underestimate the growth rate and biological productivity of age zero butterfish in the FPA model. Nevertheless, the parameter J=0.13312 implies that body weight of young-of-year butterfish increases quickly by about 1/J=7.5 times per year during the first year of life. In addition, predicted weights for age zero butterfish during the second half of the year (when age zero butterfish tend to be taken by the fishery) and weight at age for all subsequent ages appears reasonable (Figure B26).

Natural mortality

Natural mortality rates for butterfish were investigated in Murawski and Waring (1979). The best estimate from this study was M=0.8, and this value was also used in the present stock assessment. Other supporting evidence suggests that natural mortality rates for this species may be high. Overholtz *et al.* (2000) studied consumption of pelagic fishes and squids in the Northeast shelf ecosystem. This study suggested that butterfish were not only important in the diets of predatory fish in the region in general, but that during 1977-1997 butterfish may have been very important to predators during years when herring and mackerel biomass was low. Consumption by predators as a group and as individual species was certainly important during this time. Appendix B1 also provides updated estimates of consumption of butterfish by groundfish.

Some idea of the true instantaneous natural mortality rate can be gained from the relationship of natural mortality rate and instantaneous growth rate parameter K in the von Bertalanffy growth model of length (Gulland 1983, pp. 116-117, Jensen 1996). The intrinsic growth rate parameter estimated by fitting a von Bertalanffy growth model of length at age using the same data used to fit the Schnute growth model above (Table B22), is less than the assumed natural mortality rate, but is somewhat greater than 0.6-0.67 of M, suggested by Jensen (1996).

Estimates of mortality and stock size

Because of the poor precision of the discard estimates prior to observer coverage (start in 1989) and the short generation time for butterfish, the working group thought it beneficial to begin the assessment model as close as possible to 1989. However, the previous assessment used 1965 as the starting year. The working group thought the fall survey to be the best indicator of trend in butterfish biomass because of evidence of low and perhaps inconsistent availability of butterfish to the spring and winter surveys. From survey data and observed commercial fishing tows, there appears to be far less butterfish density inshore and on the shelf during winter and spring months (Figure B27 to Figure B30). The fall indices in this assessment begin in 1975 because of the inclusion of inshore strata so poor survey information would be available to the model in the early years with a 1965 start year. There was also a concern to capture the largest scale of exploitation which occurred in the early 1970s. Furthermore, there were effects of the starting year on proposed equilibrium-based reference points. The largest recruitments were observed prior to 1989 and so average recruitment was highest during the early period which in turn affects estimates of equilibrium yield and spawning biomass at a given fishing mortality. The working group decided to compromise between the need to include these large recruitments (between 1965 and 1988) for reference point determination and the large catches in the 1970s and the reluctance to include uncertain total catches prior to 1989 by using the 1973 model start year.

The KLAMZ model for butterfish was set up on a calendar year basis using nominal ages. In the model, new recruits are age 0 butterfish that recruit to the stock on January 1. Estimates of total biomass (ages 0+) on January 1 from the KLAMZ model for butterfish include the amount of age 0 biomass necessary (considering growth and mortality) to explain subsequent catch data and survey trend data.

Growth

Growth in weight is modeled as a von Bertalanffy process (Schnute parameterization) with parameter estimates as described above, $\rho = 0.81211$, and $J = v / V = 0.13312$ for 1973-2008.

Maturity

Maturity was assumed to be 0 at age 0 and 1 for age 1+ butterfish. The model only allows two age groups and the range of potential assumptions for maturity is therefore limited. In future assessments, exploration of the sensitivity of results to this assumption would be useful particularly if other models are explored.

Natural Mortality

Natural mortality was assumed to be 0.8 as in previous assessments. The model program allows for the estimation of annual changes in M by modeling it as deviations from a mean value, but this feature was not used in the current approach due to focusing on other aspects of the assessment.

Recruitment

Recruitment can be modeled in 4 ways in the assessment model. Options include a Beverton-Holt or Ricker stock-recruitment model, random walk in recruitment and freely varying recruitment over time (independent recruitment events). The latter option was used in this and the previous assessment. The Beverton-Holt assumption was explored but not used.

Catch

The total estimated catch (Table B1 and Figure B1) from 1973-2008 including components for landings and discards was used in the assessment model. The variance of the discard estimates was assumed as the variance of the catches which were used as weights on each of the annual catches. However, this was complicated by the required specification of a CV applied to the entire catch series. This was set to 0.1 as in the last assessment. Ultimately, this matters little because there is little if any error in the predicted catches.

Research Surveys for Trend

Four sets of NMFS surveys indices were used in the butterfish KLAMZ model. These surveys included a winter 1+ (adult) survey, a spring 1+ (adult) survey, a fall age 0 (recruit) survey, and a fall 1+ (adult) survey. The winter and spring aggregate biomass indices were assumed to be sampling adult individuals because the nominal age of fish available to the surveys at these times of the year is at least 1. Massachusetts and Connecticut state surveys were evaluated, but these surveys cover a very small portion of the entire range of the stock and there is no ability to partition fall indices into 0 and 1+ series without strong assumptions. These surveys were not included in the analysis, however, their use in future butterfish assessments should be considered.

For initial fit of the final model, the CV estimates for each of the annual survey indices were used to weight these data. For the winter and spring indices, only 1+ fish are observed so the variance estimate based on the stratified design is an appropriate weight for these indices. However, the fall biomass indices are partitioned into 0 and 1+ biomass indices based on the estimated age composition. The uncertainty in the resulting indices is unknown, but we applied the variance estimates for the aggregate biomass indices to the partitioned indices. For example, the CV of the fall biomass index in 1999 was assumed for the 0 and 1+ indices in 1999. The CV of each of the yearly 0 or 1+ indices is probably higher because of sub-sampling for ages, but the correct weighting of one year relative to another within a series is likely to be retained. The final model has each of the series CVs rescaled to ensure that each of the surveys were informing the model.

Swept area biomass and estimating catchability

Throughout the model development process there was difficulty in determining scale for the butterfish population. As such, we decided to use an approach used in the longfin squid assessment at SARC 34 (NEFSC 2002) that allows for uncertainty in the relationship between the index and butterfish population biomass, but also includes information about the efficiency of the survey vessel. The KLAMZ model allows for a prior distribution to be specified for any of the survey catchability parameters. We chose to consider priors for the NEFSC fall 1+ index since it covers the largest portion of the stock area and is more precise than the NEFSC spring series.

We start from first principles of the relationship between biomass and the index. Following Paloheimo and Dickey (1964) , the linear mean relationship of index and biomass is through the "catchability" parameter Q which can be broken into the efficiency of the survey δ_S, the swept area of a single tow a_S, the covered survey area A_S, and the ratio of survey area to stock area ρ,

$$I_t = QB = \delta_S \frac{a_S}{A_S} \rho C B_t .$$

The constant $C = 10^6$ is a change of units as necessary between those for the index (kg) and those for the biomass (10^3 mt). When the survey is completely efficient ($\delta_S = 1$) and the survey area is equal to the stock area ($\rho = 1$),

$$I_t = \frac{a_S}{A_S} C B_t .$$

From a calibration study completed this year (Miller *et al.* 2009), we have an estimate of the efficiency of the survey vessel and gear used to collect data used in the butterfish assessment (*Albatross IV*) relative to that of the new research vessel (*Henry B. Bigelow*). This study actually estimated calibration factors for abundance and biomass indices that reflect the relative efficiency of the *Henry B. Bigelow* relative to the *Albatross IV*. To make use of this information, we can rewrite the equation in terms of two efficiency parameters,

$$I_t = \delta_{A|B}\delta_B \frac{a_S}{A_S}\rho C B_t$$

where $\delta_{A|B}$ is the efficiency of the *Albatross IV* relative to the *Henry B. Bigelow* and δ_B is the efficiency of the *Henry B. Bigelow*. Note that $\delta_{A|B}$ is the inverse of the calibration factor (say $\delta_{B|A}$) estimated by Miller *et al.* (2009). In their study, the calibration factor for biomass indices was parameterized as the product of the calibration factor for abundance and a calibration factor for average weight per fish, so

$$\delta_{A|B} = \frac{1}{\delta_{B|A}} = \frac{1}{\delta_{B|A,N}\delta_{B|A,\bar{w}}}.$$

The study fitted models where calibration factors (abundance and average weight per fish) were constant across seasons and where they differed by season. For butterfish, the best beta-binomial model based on likelihood ratio tests or AIC had abundance calibrations factor constant across season ($\delta_{B|A,N} = 1.7936$, SE = 0.1367). The best gamma model for average weight per fish had separate calibration factors for fall and spring. The estimated factor for average weight per fish in the fall was $\delta_{B|A,\bar{w}} = 0.9342$ (SE = 0.0574). The inverse of the product of these two calibration factors is the estimated relative efficiency of the *Albatross IV* for biomass in the fall $\delta_{A|B} = 0.5968$ (SE = 0.0978). The variance of the relative efficiency parameter was obtained by the delta method.

We do not know the efficiency of the *Henry B. Bigelow*, nor the ratio of the survey area to stock area, so we used a composite prior approach (NEFSC 2002) where we assumed a beta distribution for the product $\delta_{A|B}\delta_B\rho$ which was parameterized by the mean and variance of the product of each treated as independent random variables. We assumed uniform distributions for δ_B and ρ and a beta distribution for $\delta_{A|B}$ and bounds on the range of plausible values for these parameters. The bounds determined by consensus of the working group were $0.05 < \delta_{A|B} < 1$, $0.1 < \delta_B < 0.9$ and $0.5 < \rho < 0.9$, but we explored the sensitivity of the results to the maxima of the uniform distributions on ρ and δ_B using values of 0.85 and 0.95. The above ranges imply that we are certain that the efficiency of the *Albatross IV* relative to the *Henry B. Bigelow* is between 5 and 100%, the efficiency of the *Henry B. Bigelow* is between 10 and 90%, and that the survey area is anywhere between half and 90% of the stock area. The sensitivities consider the effect of assuming the efficiency of the *Henry B. Bigelow* and the ratio of survey to stock area being at most 85% or 95%. The actual ranges of the beta distribution for $\delta_{A|B}$ are not as important because the standard error of the estimates from the calibration study induce negligible probability at the limits. We assume the mean and variance of the beta distribution for $\delta_{A|B}$ are the estimates from the calibration study. The approximate area covered by the fall survey is 46,388 nm and the approximate area swept by the average tow is 0.0112 nm, thus the product of the change of units constant and the ratio of tow area to survey area is

$$\frac{a_S}{A_S}C = 0.2414 .$$

The resulting distribution of the catchability parameter as a product of random variables and scalars, $Q = \delta_{A|B}\delta_B \frac{a_S}{A_S}\rho C$, has nearly all of the probability of values at the lower end of range (Figure B31). The mean of the swept area catchability distribution (top axis of Figure B31) is 0.21 when the maxima on the uniform distributions is 0.9. Our prior on the catchability parameter implies that the expected efficiency of the *Albatross IV* is about 20%.

Assessment Model Run Results

Sensitivity Analysis Results

Various sensitivity runs were completed to narrow model choices to a few candidates for a final model; the 1973-1986 discards, the prior distribution for catchability, and the natural mortality rate were the inputs the model that we explored.

1973-1986 Discards

Because the discard estimates in early assessments (e.g., NEFSC 1990) for years previous to observer coverage were much smaller than those we estimated we fit model where total catch included either the new discard estimates previous to 1987 or the discard estimates from the early assessments (Figure B32). As might be expected, the spawning and recruitment biomass estimates are lower when the early discard estimates are used because the size of the population is well defined by the prior on the fall 1+ catchability parameter and if there were fewer fish caught, then there were fewer fish alive (Figure B33 to Figure B34). Likewise, the fishing mortality estimates are lower during the period prior to 1987 because the catches were not as great using the early discard estimates (Figure B35). The later fishing mortality estimates are higher because the biomass levels are lower during this period but the catches are the same.

Prior distributions for catchability

As mentioned above, the working group thought it useful to compare model results at different assumed values for the maxima of the uniform distributions used as priors for the efficiency of the Bigelow and the ratio of the survey to stock area. When the maxima of the two uniform distributions are decreased to 0.85, the expected value of the prior distribution on the catchability parameter will also decrease. Likewise the expected value of the prior distribution will increase when the maxima are set at 0.95. As expected, when the lower maxima are used, the spawning and recruitment biomass estimates are higher because the expectation of the prior and estimated catchability are lower (Figure B36 to Figure B37). Similarly, the biomass estimates are lower when the higher maxima are used. The inverse relationship occurs for the fishing mortality rate estimates because the catches are constant (Figure B38). With larger biomasses, the same catch is obtained with lower fishing mortality and vice versa.

Both the spring and winter indices are better fit with higher maxima on the uniform distributions (Table B23). However, the fall indices are better fit with lower maxima. The total maximized objective function value decreases with increased maxima, but the prior on the catchability parameter is included.

Natural Mortality

The final model assumes the natural mortality rate is 0.8 as in previous assessments. We fit alternative models where the natural mortality rate was 0.6, 0.7, 0.9 and 1.0. Based on the maximized total objective function value, the higher values of natural mortality provide better fit (Table B24). The spring and winter survey data are fit slightly better at higher values of natural mortality, but both the fall 0 and 1+ survey data are fit better at lower values of natural mortality. The catch data are fit slightly better at higher natural mortality values, but these data are fit almost exactly in all cases. The resulting spawning biomass estimates did not trend in a constant direction upward with increased natural mortality (Figure B39), but the recruitment biomass estimates did (Figure B40). Fishing mortality estimates generally decreased at higher natural mortality (Figure B41).

Retrospective analysis

We also fit models to discover whether retrospective patterns in biomass and fishing mortality exist. We fit models to data with terminal years of 2003 to 2008. From these fits there is not consistent pattern in terminal year spawning biomass, recruitment biomass or fishing mortality estimates and the annual estimates do not change dramatically as subsequent years of data are made available (Figure B42 to Figure B44).

Final Model

The final model uses the new discard estimates, natural mortality rate of 0.8, and the base case prior distribution on the catchability parameter for the NEFSC fall 1+ indices.

Biomass

The spawning biomass estimates are substantially greater than those estimated at the last assessment due to the use of the prior distribution on the fall 1+ catchability (Table B25 and Figure B45). The catchability estimate for the fall 1+ indices from the last assessment implies that the efficiency of the survey is greater than 100%. From the final model, the highest spawning biomass estimate was around 200,000 mt in 1975, but the current spawning biomass estimate (2008) is 45,000 mt. Recruitment estimates are also substantially higher than those estimated in the last assessment on average and are highly variable (Table B25 and Figure B46). The largest estimated recruitment was around 185,000 mt in 1974 and dropped to around 16,000 mt in the following year. Both spawning and recruitment biomass estimates have been in decline on average over the period of the analysis.

As a check of the plausibility of the biomass estimates from the model, an heuristic method described in Appendix B that takes fishing mortalities and survey efficiencies as inputs with catches and fall biomass indices was used to create an "envelope" or range of independent plausible annual biomass values over time. This analyses concludes that the annual biomass estimates from the KLAMZ model were generally within the envelope of independent plausible values.

Fishing Mortality

The estimated fishing mortality rates were much lower than the previous assessment (Table B25 and Figure B47). This again is a result of the use of the prior on the fall 1+ catchability parameter. Since the total catches have not changed dramatically from the previous assessment, but the biomass available to fishing has increased substantially, a lower fishing mortality is required to obtain the same catch. The highest estimated fishing mortality (0.21) occurred in the year with the greatest catch (1973) and fishing mortality generally remained greater than 0.1 until 1978. Since then, fishing mortality has generally stayed below 0.1 and current (2008) estimated fishing mortality is 0.02.

Stock Recruitment

As determined in the last assessment, meaningful estimation of a stock-recruitment relationship for butterfish is not feasible due to highly variable recruitment over the range of estimated spawning biomasses (Figure B48). Furthermore, these relationships are likely to be estimated with non-negligible bias in most cases due to usage of estimates of spawning biomass rather than true values (e.g., Walters and Ludwig 1981, Ludwig and Walters 1981).
Recruitment biomass has been highly variable for the butterfish stock over a range of about 40,000-200,000 mt of spawning biomass. Average recruitment during 1974-2008 was around 65,000 mt. Average recruitment in the last 10 years (1999-2008) is around 40,500 mt.

Both spawning biomass and recruitment estimates have been declining over time and the trajectory of the stock-recruitment relationship for butterfish reveals that these declines do not appear to be related to either fishing mortality (Figure B49) or known sources of predation. The equilibrium replacement lines corresponding to $F_{0.1} = 1.04$ (See TOR 4) and F=0 suggest that population would be declining even in the absence of fishing mortality. The $F_{0.1}$ replacement line exceeds all historical values, suggesting that fishing mortality rates this high would accelerate population decline. Results further support the notion that either natural mortality is much greater than the assumed M=0.8 or that an increasing trend in natural mortality has occurred.

Precision of Estimates

The KLAMZ model output includes variance estimates for fishing mortality and total biomass but not separately for recruitment biomass and spawning biomass (Table B26 and Table B27). There is generally large uncertainty (CV>0.5) in both the total biomass and fishing mortality indices.

Model Diagnostics

Residuals for the winter and fall age 0 surveys show no real trend over time, but the residuals for the spring indices show an increasing trend and fall age 1+ show a slight decreasing trend in the last 10 years (Table B28 to Table B31 and Figure B50). These trends in residuals occur because the fall 1+ and spring 1+ indices have opposite trend over this period (Figure B51). The residuals of the fall age 0 indices are generally small in absolute value relative to the other surveys because they are fit very well in the model. This was due to difficulty in determining the appropriate scaling factors to apply to the CVs of each of the surveys to obtain appropriately scaled residuals for all surveys simultaneously. The catches are predicted extremely accurately by the model (Figure B52).

Total Mortality Estimates from Survey Age Composition

We made annual estimates of total mortality by age from fall and spring survey age composition estimates (Table B17 and Table B18) as

$$\hat{Z}_{a,y} = \ln\left(\hat{N}_{a,y}\right) - \ln\left(\hat{N}_{a+1,y+1}\right).$$

We made mortality estimates for ages 0, 1 and 2 from fall age composition estimates and ages 0 and 1 from spring age composition estimates. Total mortality estimates varied greatly across years for a given age when estimated from either survey (Figure B53 and Figure B54). The average of mortality estimates for age 1 butterfish was approximately 1.5 when estimated from fall age composition and closer to 2.0 when estimated from spring age composition. Age 2 mortality estimates average near 2.0 and 3.0 from spring and fall age composition, respectively. Mortality estimates for age 0 from the fall age composition also average near 2.0. For all ages and surveys, there does not appear to be any trend in total mortality over time despite changes in total catch estimates over the same period. This may imply that fishing mortality is a small component of total mortality.

Summary

The biomass estimates are substantially larger and the fishing mortality estimates substantially smaller than the corresponding estimates from the last assessment (NEFSC 2004). This is primarily due to the use of a prior distribution for the NEFSC fall 1+ catchability parameter. If the catches of butterfish have not decreased due to abundance, the low estimates of fishing mortality rate are not unreasonable. Furthermore, to have fishing mortality estimates similar to those in the last assessment requires a catchability for the fall 1+ indices that is near or greater than 100%.

The magnitude of assumed natural mortality relative to estimated annual fishing mortality corresponds to the lack of trend in total mortality estimates from the survey age composition. Nevertheless, the total mortality estimates tend to be substantially larger than the sum of assumed natural mortality and estimated fishing mortality from the final KLAMZ model which may imply true natural mortality is higher than that assumed in the final model.

Term of Reference 4: Updated or redefined biological reference points

Update or redefine biological reference points (BRPs; estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, and F_{MSY}; and estimates of their uncertainty). Comment on the scientific adequacy of existing and redefined BRPs.

The Mid Atlantic Fishery Management Council manages butterfish as part of the Atlantic Mackerel, Squid, and Butterfish (MSB) Fishery Management Plan. Overfishing for this species is defined as occurring when the fishing mortality rate at maximum sustainable yield (F_{MSY}) is exceeded. The current overfishing definition is based on an MSY of 12,175 mt and a fishing rate of F_{MSY}=0.38. The biomass target for this stock is defined as total biomass at equilibrium harvest of maximum sustainable yield (B_{MSY}=74,550 mt) and the minimum biomass threshold is defined as ½ B_{MSY}. ***But see below (in bold italics) for comments and decisions by the SARC-49 review panel regarding butterfish reference points (BRPs).***

Reference Point and Stock Status Methodology

The previous assessment used a Fox surplus production model (Fox 1970) to estimate reference points for the stock. There is an implicit density-dependence assumption in the Fox model, whereas the assessment model assumes no relationship between stock and recruitment nor does the projection methodology. To make reference points consistent with the assessment and projection models, we propose using deterministic projections to determine the equilibrium relationship between fishing mortality rate and resulting yield and spawning biomass per recruit. The SPROJDDIF program written in FORTRAN by Dr. Larry Jacobson at the NEFSC provides a means to make either deterministic or stochastic projections of the KLAMZ model (see Appendix A of NEFSC 2004). The SPROJDDIF program will use assumptions about recruitment that are consistent with the model used to fit the data. For butterfish we assume no relationship of spawning and recruitment biomass so SPROJDDIF will use the mean and variance of recruitment estimates provided by the KLAMZ model fit to make stochastic projections of recruitment and subsequent spawning biomass estimate under assumed constant fishing mortality rates or constant catch specifications.

Given a specified F_{MSY} proxy, the Working Group proposed to determine spawning biomass at MSY (SSB_{MSY}) and status of the stock by stochastic projections using SPROJDDIF. To do this, we completed 7,000 bootstraps for the final model using BOOTADM (see Appendix A of NEFSC 2004) and made 1 projection 50 years into the future for each bootstrap. SSB_{MSY} is the median spawning biomass in year 50 at the prescribed fishing mortality rate. Estimates of uncertainty and confidence intervals for SSB_{MSY} and stock status can also be obtained from the 7,000 projections. Stock status could either be based on the spawning biomass estimate in 2008 from fit of the final model or the median of the biomass estimates in year 0 of the projections.

To determine an F_{MSY} proxy, the Working Group performed deterministic projections for equilibrium fishing mortalities between 0 and 2. These projections provide the relationship of equilibrium fishing mortality to equilibrium yield per recruit, spawning biomass per recruit, and spawning potential ratio (Figure B55 to Figure B57). For these deterministic projections we used the same SPROJDDIF software above, but we used estimates from the final model rather than bootstraps. There was no defined F_{MAX} for butterfish due to the high rates of growth and natural mortality. $F_{0.1}$ = 1.04

resulted in a catch/recruit ratio of 0.76 and $F_{30\%}$ dropped the ratio 12% to 0.67 and $F_{40\%}$ droppped the ratio 24% to 0.58. The spawning potential ratio at $F_{0.1}$ was 20%. In lieu of an F_{MAX}, we proposed that $F_{0.1}$ = 1.04 is used as an F_{MSY} proxy ($F_{Threshold}$) and $F_{30\%}$=0.72 is used as an F_{Target}.

The Working Group performed stochastic projections for fishing mortalities at the F values corresponding to 20, 30 and 40% spawning potential ratios (Table B32). Median equilibrium yield at F_{MSY}=$F_{0.1}$=1.04 was 36,608 mt and the median equilibrium spawning biomass was 16,262 mt. Median equilibrium yield at $F_{30\%}$=0.72 was 33,108 mt and the median equilibrium spawning biomass was 25,226 mt. Median equilibrium yield at $F_{40\%}$=0.52 was 29,166 mt and the median equilibrium spawning biomass was 34,191 mt. There was large uncertainty in the equilibrium yield and spawning biomasses. Current (2008) spawning biomass was greater than the median equilibrium spawning biomass at each of the fishing mortalities and current fishing mortality was less than those fishing mortalities. The high equilibrium yields at low equilibrium spawning biomasses when F= $F_{0.1}$ or F= $F_{30\%}$ reflects the high growth rate and reproductive potential for butterfish. However, the high variability in recruitment coupled with high uncertainty in biomass and fishing mortality estimates resulted in large uncertainty in spawning biomass and yield in any given year.

When the stock is in equilibrium, this methodology is preferred for both reference determination and stock projection because it puts the determination of both current and future status of the stock within a consistent framework.

When the Fox surplus production model was fit to the biomass and surplus production estimates resulting from the final model, F_{MSY} = 0.233, MSY = 17,400 mt and B_{MSY} = 74,550 mt (Table B32). However, the fit was very poor and the B_{MSY} (and consequently F_{MSY}) estimates were very poorly defined (Figure B58). Note also that the biomass reference point was for total rather than spawning biomass.

Upon review at SARC 49, the stock was determined to not be in equilibrium because of declining biomass over the entire time series of the model in the absence of significant fishing mortality. Given the lack of equilibrium the use of equilibrium-based reference points was found to be unacceptable and the proposed reference points were rejected. The reference points from the previous assessment were also found to be unacceptable for the same reason as well as the unlikely scale of the estimates biomass and fishing mortality upon which the reference points were based.

Term of Reference 5: Stock status evaluation with respect to BRPs.

Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 4).

Current (2008) spawning biomass (45,000 mt) was greater than the median equilibrium spawning biomass at the proposed F_{MSY} proxy ($SSB_{0.1}$ = $SSB_{20\%}$ = 16,262 mt) as well as at the other considered fishing mortality reference points ($F_{30\%}$=0.72, $F_{40\%}$=0.52). Similarly, current F (0.02) was lower than the candidate F_{MSY} proxies. ***However, these reference points were not accepted by the SARC panel due to the determination by reviewers that the stock is not in equilibrium. Despite the rejection of the reference points, there was a consensus at SARC 49 that overfishing was not likely to be occurring.*** There are sizable corresponding uncertainty in estimates of current fishing mortality and biomass (Table B26 and Table B27) as well as the SSB_{MSY} (Table B32) (spawning biomass with F= F_{MSY}=$F_{0.1}$).

Term of Reference 6: Predator consumptive removals and predation.

Evaluate the magnitude, trends and uncertainty of predator consumptive removals on butterfish and associated predation mortality estimates and, if feasible, incorporate said mortality predation estimates into models of population dynamics.

See Appendix B2.

Term of Reference 7: Projections

Develop and apply analytical approaches and data that can be used for conducting single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs).

a. Provide numerical short-term projections (1-5years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. In carrying out projections, consider a range of assumptions about the most important uncertainties in the assessment.

b. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.

c. For a range of candidate ABC scenarios, compute the probabilities of rebuilding the stock by January 1, 2015.

d. Describe this stock's vulnerability to having overfished status (consider mean generation time), and how this could affect the choice of ABC.

Projection Methodology

If the stock needed to be rebuilt, the same stochastic projection methods describe above for TOR 5 could be used for short term projections. In fact, the same set of bootstraps used above for determining median equilibrium spawning biomass and yield can be used here. However, the working group suggested that recent recruitment (1999-2008) should be used for the short term projections because recruitment has been low relative to earlier in the time period. As the stock was estimated to be above the SSB at the candidate F_{MSY} proxies, projections carried out at each of the potential F_{MSY} proxies (not rebuilding fishing mortalities) with the full series of recruitments resulted in the expected probability of <0.5 of being overfished in the first few years and converge to 0.5 (Figure B59). Also as expected, the probability of being overfished increased to around 0.75 when recent recruitments (lower on average than the entire time series) were used and fishing was assumed tooccur at the F_{MSY} proxies (Figure B60). Note that the fishing mortalities used in these projections were substantially higher than the current (2008) fishing mortality (0.02). Continued fishing at the status quo with projections based on recruitment estimates for the last 10 years would result in a probability less the 0.01 of spawning biomass being below the proposed SSB_{MSY} (Figure B61). Fishing at F=0.52 resulted in 30% probability of the stock being below the proposed SSB_{MSY} whereas fishing at F=0.72 resulted in 50% probability of being below the proposed SSB_{MSY} when future recruitment was based on recent recruitment (Figure B61). Median spawning biomass climbed to 54,000 mt and yield increased to about 1400 mt when the current fishing mortality rate persists and future recruitment is based on recent recruitment (Figure B62).

The user can also specify in SPROJDDIF program constant catch to find probability of F exceeding candidate F_{MSY} proxies. When catch was assumed constant at 2008 levels fishing mortality remained at or below 0.03 whether recruitment was based on the full time series of recruitment estimates or those from the last 10 years (Table B33). If catch was assumed to double, fishing mortality remained below 0.05 in either case. When the swept area catchability for the fall 1+ indices was assumed to be 0.006 rather than 0.16 as estimated in the final model, fishing mortality rates were negligible whether catches are assumed the same as 2008 or twice the 2008 catch (Table B34). When the swept area catchability for the fall 1+ indices was assumed to be 0.49, fishing mortalities were still below 0.1 whether catches are the same or twice as large as those in 2008.

Term of Reference 8: Research Recommendations

Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

SARC 38 Research Recommendations

1) *A study of the characteristics of inshore and offshore components should be initiated. A study of growth, morphometrics, distribution and other factors related to inshore and offshore butterfish should be conducted.*
Examination of characteristics of the inshore and offshore components has not been conducted. Comparison of seasonal distribution was examined.
2) *Further work on potential information (for example the VTR database) for the estimation of discards of butterfish from all sources should be undertaken. Other methods and stratification and time averaging of the discard data for estimating discards should be explored.*
New methods for estimation of discards based on observer data was undertaken and adopted for use in the assessment.
3) A close examination of the NMFS Observer data from 2003 was warranted for its application in the next butterfish assessment. Observer coverage was transferred to only a few vessels in the Illex fishery and hence was greatly expanded because of the transfer of effort into the scallop fishery by large Mid-Atlantic trawlers.
New methods for estimation of discards based on observer data was undertaken and adopted for use in the assessment.
4) Explore alternative methods for estimating natural mortality.
The assessment examined sensitivity and likelihood values for a variety of M values but no alternative methods of estimation were made. Trends in consumption were examined as indicative of annual variation in M.
5) Explore using landings of target species as a denominator in the discard ratio, based on VTR matched trips (trips with reported landings of target species and butterfish discards).

New methods for estimation of discards based on observer data was undertaken and adopted for use in the assessment.
6) Explore the utility of incorporating into the assessment model ecological relationships, predation, and oceanic events that influence butterfish population size on the continental shelf and its availability to the resource survey.
Predation on butterfish was examined in detail although the results were not directly incorporated into the assessment model.
7) Explore the use of an age-based model for future assessments.
The recommendation was limited by the availability of age data from commercial fisheries.
8) Further investigate the estimation of suitable biological reference points. Stock status determination is currently based on an Fmsy proxy (F0.1=1.01, Bmsy has not been previously estimated). New biological reference points were estimated in the delay-difference model for butterfish. However, there is considerable uncertainty in these estimates and they are subject to change.
Biological reference points were updated and again based on the model results for consistency. Alternative methods were also explored.

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Tables

Table B1. Butterfish USA landings (MT), estimated USA discards (and coefficient of variation (CV), foreign landings, and total catch (using new discard estimates) during 1965-2008.

Year	US Landings	Foreign Landings	Historic Discards	New Discard Estimates	New Discard CV	Total Catch (Revised Discards)
1965	2944	749		10402.58	1.64	14095.58
1966	2461	3865		9978.09	1.63	16304.09
1967	2245	2316		9247.5	1.6	13808.5
1968	1585	5437		8941.83	1.63	15963.83
1969	2198	15378		8590.13	1.56	26166.13
1970	1731	12450		7968.76	1.59	22149.76
1971	1566	8913		7277.52	1.56	17756.52
1972	704	12221		6080.02	1.53	19005.02
1973	1521	31679		6105.67	1.56	39305.67
1974	1778	15465		5640.11	1.59	22883.11
1975	1973	12764		5147.79	1.59	19884.79
1976	1376	14437	152	5663.26	1.53	21476.26
1977	1296	3312	152	6598.97	1.59	11206.97
1978	3615	1699	61	7971.15	1.47	13285.15
1979	2646	1107	185	8443.37	1.47	12196.37
1980	5172	1392	184	9126.17	1.49	15690.17
1981	4855	1400	0	8743.93	1.48	14998.93
1982	8837	1578	68	10213.72	1.45	20628.72
1983	4743	630	162	10036.98	1.45	15409.98
1984	11715	429	257	9494.46	1.38	21638.46
1985	4633	804	106	7703.15	1.39	13140.15
1986	4418	164	0	7397.01	1.3	11979.01
1987	4578	0		6905.27	1.23	11483.27
1988	2107	0		6920.56	1.21	9027.56
1989	3216	0		4480.03	0.85	7696.03
1990	2298	0		532.93	0.37	2830.93
1991	2189	0		4886.71	0.99	7075.71
1992	2754	0		5025.15	0.54	7779.15
1993	4608	0		7577.07	0.32	12185.07
1994	3634	0		6300.37	0.36	9934.37
1995	2067	0		6465.52	0.5	8532.52
1996	3555	0		1047.48	0.72	4602.48
1997	2794	0		985.98	1.04	3779.98
1998	1966	0		6378.44	1.68	8344.44
1999	2110	0		8927.16	0.36	11037.16
2000	1449	0		7014.89	0.23	8463.89
2001	4404	0		4474.27	0.47	8878.27
2002	872	0		2348.41	1.25	3220.41
2003	536	0		2113.51	1.44	2649.51
2004	537	0		1246.16	0.3	1783.16
2005	437	0		642.13	0.21	1079.13
2006	554	0		845.47	0.72	1399.47
2007	674	0		241.31	0.61	915.31
2008	451	0		1178.39	0.56	1629.39

Table B2. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for "fish" bottom trawl (gear code = 50 and mesh size less than 4 inches) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic Ratio	Total Catch (mt)	Discards (mt)	CV	New England Ratio	Total Catch (mt)	Discards (mt)	CV
1989	0.022	14849.7	327.3	0.60	0.032	10677.4	343.0	0.32
1990	0.024	14410.8	349.2	0.44	0.005	11763.7	63.8	1.08
1991	0.036	17743.7	641.3	0.40	0.034	10473.0	351.3	0.32
1992	0.072	17247.7	1242.1	0.28	0.08	11279.6	902.0	0.51
1993	0.048	19523.1	938.7	0.74	0.006	13782.0	88.3	0.68
1994	0.074	17878.3	1321.9	1.04	0.279	13530.7	3776.1	0.36
1995	0.037	17463.3	640.9	1.31	0.004	11557.1	41.6	1.04
1996	0.031	23818.6	744.8	0.82	0.012	14609.0	169.5	1.45
1997	0.01	24601.2	248.4	2.21	0.009	11492.2	108.4	2.22
1998	0.003	28953.5	100.0	1.09	0.025	14607.2	370.4	0.80
1999	0.263	18145.5	4778.2	0.39	0.047	13303.6	628.7	0.63
2000	0.004	19357.9	73.9	1.36	0.117	9728.9	1140.4	0.69
2001	0.008	13368.2	106.4	4.18	0.035	12729.9	448.0	0.33
2002	0.143	12140.0	1732.3	0.90	0.016	8654.0	137.7	1.30
2003	0.14	12498.5	1752.0	1.66	0.016	9368.6	154.6	0.47
2004	0.02	31427.5	625.6	0.47	0.045	9016.0	404.0	0.43
2005	0.027	16922.9	450.7	0.28	0.014	7451.4	103.8	0.33
2006	0.011	37205.7	403.9	1.44	0.015	8666.9	128.8	0.40
2007	0.002	14935.8	29.3	3.46	0.009	11081.7	100.5	0.50
2008	0.014	20567.1	280.0	0.84	0.066	8831.0	583.8	0.76

Table B3. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for "fish" bottom trawl (gear code = 50 and mesh size greater than 4 inches) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic Ratio	Total Catch (mt)	Discards (mt)	CV	New England Ratio	Total Catch (mt)	Discards (mt)	CV
1989	0.003	1463.4	4.4	0.35	0	41411.8	5.9	0.55
1990	0.001	1699.2	1.6	0.64	0.002	55075.1	117.9	0.85
1991	0.005	2161.1	11.6	0.50	0.001	49171.0	51.1	0.53
1992	0.007	2194.5	15.0	0.87	0	39275.2	5.8	0.76
1993	0	2170.1	0.1	1.54	0	32234.4	0.6	1.29
1994	0	2683.8	0.2	0.77	0	25936.9	2.4	0.44
1995	0.005	5404.7	25.3	1.03	0	30538.5	4.9	0.86
1996	0	5838.5	2.8	1.41	0.001	36679.2	24.3	14.86
1997	0	5919.3	1.5	0.74	0.001	32028.2	31.9	0.83
1998	0	6866.9	2.5	0.29	0	33224.9	0.2	0.57
1999	0.001	7794.3	6.6	0.96	0	32605.6	0.6	1.37
2000	0.401	6389.7	2559.7	0.32	0.001	36877.8	28.1	0.68
2001	0.001	7285.3	5.6	0.71	0	44410.8	0.4	0.59
2002	0	7292.8	0.3	0.34	0	40569.8	0.7	0.70
2003	0	6940.8	0.7	0.45	0	42864.3	0.3	0.45
2004	0	9446.1	3.7	0.66	0	39100.5	0.7	0.26
2005	0.001	11538.0	7.3	0.44	0	34591.4	0.4	0.40
2006	0.001	9802.6	9.7	0.48	0	27821.9	0.6	0.27
2007	0.001	7413.9	5.8	0.56	0	28085.0	5.1	0.74
2008	0.001	8432.6	10.6	0.48	0	29980.6	0.4	0.26

Table B4. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for “fish” bottom trawl (gear code = 50 and unknown meshsize) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic Ratio	Total Catch (mt)	Discards (mt)	CV	New England Ratio	Total Catch (mt)	Discards (mt)	CV
1989	0.03	26329.4	790.9	1.82	0.08	39566.4	3008.5	1.17
1990	0	28129.7	0.0	NA	0	47038.3	0.0	NA
1991	0.08	36841.4	2931.3	1.63	0.02	49809.0	896.9	0.61
1992	0.05	43745.9	2095.1	1.21	0.02	47705.9	762.8	1.02
1993	0.02	34376.7	625.2	0.5	0.14	41446.0	5922.7	0.39
1994	0	35994.8	150.1	0.54	0.03	39843.3	1046.3	1.16
1995	0.01	22474.5	328.4	1.32	0.21	25371.5	5419.4	0.57
1996	0	20322.0	53.8	0.75	0	28555.7	47.4	0.66
1997	0	20763.2	69.1	11.78	0.02	25483.7	519.3	0.36
1998	0.18	23067.0	4196.2	2.48	0.06	28980.1	1708.4	1.55
1999	0.04	17120.7	760.9	2.92	0.11	25440.5	2751.1	0.51
2000	0.09	14275.5	1246.4	0.63	0.07	27110.0	1965.3	0.4
2001	0.11	9183.8	997.0	0.67	0.11	27071.5	2912.4	0.67
2002	0	8887.6	8.7	2.36	0.02	24054.4	468.3	5.28
2003	0	8604.3	20.8	43.51	0.01	23728.8	183.9	0.91
2004	0.01	13185.4	78.5	0.75	0	39950.2	131.8	1.15
2005	0.01	11739.1	60.0	0.58	0	22919.8	18.1	0.4
2006	0.02	13082.0	273.0	0.6	0	14146.8	28.2	0.46
2007	0	6850.9	29.9	2.07	0.01	13831.7	70.1	1.03
2008	0.03	6812.9	189.7	2.22	0.01	11686.4	96.0	0.92

Table B5. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for "scallop" bottom trawl (gear code = 52) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic Ratio	Total Catch (mt)	Discards (mt)	CV	New England Ratio	Total Catch (mt)	Discards (mt)	CV
1989	NA	133.4	NA	NA	NA	NA	NA	NA
1990	NA	158.8	NA	NA	NA	42.8	NA	NA
1991	NA	57.0	NA	NA	NA	NA	NA	NA
1992	NA	36.8	NA	NA	NA	NA	NA	NA
1993	NA	106.0	NA	NA	NA	34.0	NA	NA
1994	NA	120.1	NA	NA	NA	1.6	NA	NA
1995	NA	241.6	NA	NA	NA	7.8	NA	NA
1996	NA	90.2	NA	NA	NA	3.1	NA	NA
1997	NA	145.0	NA	NA	NA	0.4	NA	NA
1998	NA	706.9	NA	NA	NA	0.0	NA	NA
1999	NA	332.9	NA	NA	NA	1.1	NA	NA
2000	NA	688.6	NA	NA	NA	1.1	NA	NA
2001	NA	748.8	NA	NA	NA	0.8	NA	NA
2002	0	548.9	0	NA	NA	NA	NA	NA
2003	NA	1546.6	NA	NA	NA	1.5	NA	NA
2004	0	1104.1	0.5	0.649	NA	42.4	NA	NA
2005	0	3732.7	0.0	0.557	NA	3.4	NA	NA
2006	0	3088.9	0.5	0.532	NA	5.2	NA	NA
2007	0	1444.6	0.2	1.051	NA	40.0	NA	NA
2008	0	1619.0	0	NA	NA	89.5	NA	NA

Table B6. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for "shrimp" bottom trawl (gear code = 58) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic Ratio	Total Catch (mt)	Discards (mt)	CV	New England Ratio	Total Catch (mt)	Discards (mt)	CV
1989	NA	NA	NA	NA	0	4343.3	0.1	1.39
1990	NA	NA	NA	NA	0	5167.4	0.2	1.01
1991	NA	NA	NA	NA	0	3875.8	0.8	1.27
1992	NA	NA	NA	NA	0	3446.7	1.5	0.28
1993	NA	NA	NA	NA	0	2206.3	0.0	0.90
1994	NA	37.9	NA	NA	0	3349.1	0.2	0.51
1995	NA	62.6	NA	NA	0	5836.9	1.1	0.31
1996	NA	7.7	NA	NA	0	9025.6	3.7	0.65
1997	NA	1059.7	NA	NA	0.001	6089.7	6.0	0.45
1998	NA	208.3	NA	NA	NA	3306.0	NA	NA
1999	NA	239.3	NA	NA	NA	1456.0	NA	NA
2000	NA	352.9	NA	NA	NA	2134.8	NA	NA
2001	NA	91.6	NA	NA	0	825.6	0.0	1.07
2002	NA	264.7	NA	NA	0	307.5	0.0	NA
2003	NA	100.6	NA	NA	0.001	855.5	0.5	0.96
2004	NA	282.6	NA	NA	0	1114.3	0.0	1.05
2005	NA	123.2	NA	NA	0.001	875.3	0.5	0.63
2006	NA	341.9	NA	NA	0	1296.0	0.1	0.72
2007	NA	1645.0	NA	NA	0	2337.7	0.0	0.80
2008	NA	1911.7	NA	NA	0	2114.8	0.0	0.59

Table B7. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for seine fishing (gear code = 70) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic Ratio	Total Catch (mt)	Discards (mt)	CV	New England Ratio	Total Catch (mt)	Discards (mt)	CV
1989	NA	1080.8	NA	NA	NA	0.3	NA	NA
1990	NA	1017.1	NA	NA	NA	NA	NA	NA
1991	NA	898.7	NA	NA	NA	2.9	NA	NA
1992	NA	1110.8	NA	NA	NA	20.7	NA	NA
1993	NA	1414.4	NA	NA	NA	4.0	NA	NA
1994	NA	1728.0	NA	NA	NA	NA	NA	NA
1995	NA	1335.8	NA	NA	NA	0.6	NA	NA
1996	NA	1563.6	NA	NA	NA	140.8	NA	NA
1997	NA	2481.1	NA	NA	NA	175.1	NA	NA
1998	0	2064.9	0	NA	NA	247.5	NA	NA
1999	0	2527.6	0	NA	NA	NA	NA	NA
2000	0	1595.1	0.01	2.70	NA	NA	NA	NA
2001	0	1494.7	0	NA	NA	NA	NA	NA
2002	0	1605.5	0	NA	NA	0.6	NA	NA
2003	0	1908.3	0	NA	NA	NA	NA	NA
2004	0	1184.8	0	NA	NA	NA	NA	NA
2005	0	1369.9	0.1	0.19	NA	NA	NA	NA
2006	0	56.5	0	NA	NA	NA	NA	NA
2007	0	1293.1	0	NA	NA	NA	NA	NA
2008	0.007	755.4	5.0	1.41	NA	NA	NA	NA

Table B8. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for gillnet gear (gear code = 100 or 110) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic Ratio	Total Catch (mt)	Discards (mt)	CV	New England Ratio	Total Catch (mt)	Discards (mt)	CV
1989	NA	3892.2	NA	NA	0	21189.6	0	NA
1990	0	3777.0	0	NA	0	23185.0	0.3	0.56
1991	0	5969.3	0	NA	0	20998.0	0.2	0.29
1992	0	5936.0	0	NA	0	20374.9	0.2	0.26
1993	0	8759.8	0.2	7.65	0	23183.0	0.6	0.77
1994	0	8462.9	0.8	0.36	0	21887.4	0.1	0.92
1995	0	9150.8	0.3	0.34	0	24999.9	0.3	0.60
1996	0	15366.4	0.2	0.45	0	22279.7	0	NA
1997	0	18133.4	1.0	0.73	0	19223.1	0	NA
1998	0	20329.9	0.5	1.06	0	20930.8	0.0	1.01
1999	0	18592.3	1.1	0.70	0	16762.2	0.0	1.32
2000	0	16164.9	0.4	0.58	0	14826.5	0.1	0.94
2001	0	13570.2	3.1	1.30	0	14613.2	0	NA
2002	0	12544.3	0.2	0.77	0	14967.8	0.0	0.84
2003	0	13390.7	0	NA	0	16693.6	0.0	0.82
2004	0	11609.2	0.2	0.79	0	19119.5	0.1	0.51
2005	0	14193.5	0.7	0.70	0	13580.1	0.0	0.64
2006	0	7645.7	0.1	0.44	0	13725.5	0.0	0.76
2007	0	15363.8	0.1	1.02	0	15209.0	0.0	0.95
2008	0	10706.7	0	NA	0	17318.3	0.0	0.74

Table B9. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for scallop dredge gear (gear code = 132) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic Ratio	Total Catch (mt)	Discards (mt)	CV	New England Ratio	Total Catch (mt)	Discards (mt)	CV
1989	NA	240.4	NA	NA	NA	5483.3	NA	NA
1990	NA	268.5	NA	NA	NA	763.0	NA	NA
1991	NA	281.2	NA	NA	NA	733.4	NA	NA
1992	NA	265.5	NA	NA	NA	547.3	NA	NA
1993	NA	332.5	NA	NA	NA	445.4	NA	NA
1994	NA	1972.8	NA	NA	NA	1379.8	NA	NA
1995	NA	1272.5	NA	NA	NA	1721.4	NA	NA
1996	NA	2624.5	NA	NA	NA	1610.5	NA	NA
1997	0	2613.0	0	NA	NA	1914.9	NA	NA
1998	0	3087.5	0	NA	NA	1701.7	NA	NA
1999	0	3493.2	0	NA	NA	3608.5	NA	NA
2000	0	5141.2	0	NA	0	2456.9	0	NA
2001	NA	9242.8	NA	NA	NA	4275.2	NA	NA
2002	0	10085.4	0	NA	0	2747.1	0	NA
2003	0	11960.6	0.4	0.68	0	3404.9	0	NA
2004	0	12276.1	0	NA	0	3489.7	0.0	0.28
2005	0	13930.7	0	NA	0	6962.7	0	NA
2006	0	16721.0	0	NA	0	9749.4	0	NA
2007	0	20918.6	0	NA	0	7289.6	0	NA
2008	0	15863.9	0.0	0.66	0	4313.3	0	NA

Table B10. Annual ratio estimates, total catch of all species, discard estimates, and coefficient of variation for mid-water trawl gear (gear code = 170 or 370) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic Ratio	Total Catch (mt)	Discards (mt)	CV	New England Ratio	Total Catch (mt)	Discards (mt)	CV
1989	NA	NA	NA	NA	NA	322.5	NA	NA
1990	NA	2.1	NA	NA	NA	362.8	NA	NA
1991	0.004	549.2	2.1	0.43	0	1786.2	0	NA
1992	0	163.9	0	NA	NA	2349.5	NA	NA
1993	0	128.0	0	NA	0	4925.5	0	NA
1994	0	578.2	0.3	0.07	0	7313.0	0	NA
1995	0	3623.6	1.2	0.16	0	30980.4	0	NA
1996	NA	5492.9	NA	NA	NA	37856.3	NA	NA
1997	NA	7844.3	NA	NA	NA	36926.6	NA	NA
1998	NA	8525.5	NA	NA	NA	43337.6	NA	NA
1999	NA	5384.0	NA	NA	0	10827.6	0	NA
2000	0	6640.0	0	NA	0	2424.2	0	NA
2001	NA	10852.3	NA	NA	0	353.6	0	NA
2002	0	5612.9	0	NA	NA	3156.0	NA	NA
2003	0	16191.2	0	NA	0	16004.4	0	NA
2004	0	21948.4	0	NA	0	14158.9	0.5	0.71
2005	0	11052.6	0	NA	0	27318.3	0.5	0.61
2006	0	22138.1	0.3	0.95	0	24891.9	0.3	0.67
2007	0	4601.9	0.0	1.47	0	13386.7	0.1	1.07
2008	0	15863.9	0.0	0.66	0	4313.3	0	NA

Table B11. Annual ratio estimates (discarded butterfish to kept *Loligo* squid), total catch of *Loligo* squid, discard estimates, and coefficient of variation for "fish" bottom trawl (gear code = 50) in Mid-Atlantic and New England waters.

Year	Mid-Atlantic Ratio	Total Catch (mt)	Discards (mt)	CV	New England Ratio	Total Catch (mt)	Discards (mt)	CV
1989	0.058	12055.4	696.8	0.39	0.271	9718.3	2631.2	0.38
1990	0.081	7912.7	639.6	122.10	0.240	6419.3	1538.2	2.20
1991	0.185	11445.7	2119.8	0.67	0.385	7384.8	2844.5	0.87
1992	0.193	13491.9	2606.9	0.23	1.487	4419.2	6572.5	0.44
1993	0.109	16780.4	1834.9	4.76	1.499	5102.1	7649.1	0.29
1994	0.315	14649.3	4620.1	1.57	0.589	7656.5	4509.3	0.65
1995	0.260	10874.2	2826.4	0.97	0.616	5505.4	3393.3	0.74
1996	0.457	6781.0	3096.2	0.34	0.063	4806.0	300.8	1.17
1997	0.078	11585.8	902.4	1.15	0.065	3837.1	247.7	1.74
1998	0.170	10814.7	1835.2	0.68	0.080	7927.2	631.2	0.86
1999	0.727	11680.3	8487.1	1.04	0.196	7189.2	1405.6	0.46
2000	0.730	11931.3	8711.7	0.31	0.216	5164.9	1118.0	10.35
2001	0.143	8447.3	1205.1	0.29	0.404	4744.5	1915.9	8.44
2002	0.153	9868.3	1509.9	0.72	0.128	5256.2	670.5	3.27
2003	1.428	5520.7	7883.5	0.43	0.177	6303.6	1114.9	0.50
2004	0.067	8498.4	567.1	0.52	0.198	5062.6	1003.9	0.32
2005	0.047	8223.7	389.6	0.36	0.028	5295.5	150.2	0.94
2006	0.087	9505.5	826.5	0.79	0.047	4909.8	233.0	1.85
2007	0.091	4813.3	438.3	1.26	0.064	6694.4	429.6	10.69
2008	0.241	5930.4	1427.9	0.29	0.085	4880.0	414.4	5.65

Table B12. U.S. commercial butterfish samples and lengths collected, 1994-2008.

Year		Qtr 1	2	3	4	total
1994	Total Sum of samples		3	4	7	14
	Total Sum of lengths		142	419	724	1285
1995	Total Sum of samples		3	4	7	14
	Total Sum of lengths		142	419	724	1285
1996	Total Sum of samples	3	1	5	7	16
	Total Sum of lengths	400	115	421	791	1727
1997	Total Sum of samples	30	8	4	22	64
	Total Sum of lengths	2998	826	398	1928	6150
1998	Total Sum of samples	9	7	4	5	25
	Total Sum of lengths	893	618	383	467	2361
1999	Total Sum of samples	12	8	5	3	28
	Total Sum of lengths	1239	728	521	237	2725
2000	Total Sum of samples	3	3	1	3	10
	Total Sum of lengths	345	280	108	295	1028
2001	Total Sum of samples	6	14	7	1	28
	Total Sum of lengths	637	1446	714	114	2911
2002	Total Sum of samples	6	1	2	3	12
	Total Sum of lengths	617	98	215	313	1243
2003	Total Sum of samples	9	9	7	3	28
	Total Sum of lengths	930	931	774	312	2947
2004	Total Sum of samples	5	12	17	7	41
	Total Sum of lengths	540	1117	1755	682	4094
2005	Total Sum of samples	11	9	9	10	39
	Total Sum of lengths	1124	924	903	975	3926
2006	Total Sum of samples	10	17	7	16	50
	Total Sum of lengths	988	1795	731	1638	5152
2007	Total Sum of samples	13	10	23	17	63
	Total Sum of lengths	1433	1005	2232	1761	6431
2008	Total Sum of samples	13	10	12	7	42
	Total Sum of lengths	1374	1043	980	694	4091

Table B13. Abundance (number/tow) and biomass indices (kg/tow) provided by the Northeast Monitoring and Assessment Program for the fall and spring.

	Spring		Fall	
Year	Number/tow	Kg/tow	Number/tow	Kg/tow
2007			70.71	2.82
2008	44.53	2.29	207.34	4.71
2009	64.72	2.01		

Table B14. NEFSC spring abundance and biomass indices (number and weight per tow) and corresponding coefficients of variation (CV) for 1968-2008 from data collected in offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76).

Year	Number	CV	Weight	CV
1968	33.44	0.59	1.98	0.629
1969	30.77	0.803	3.08	0.831
1970	9.94	0.284	0.53	0.292
1971	21.72	0.563	0.77	0.407
1972	228.09	0.962	6.66	0.916
1973	68.70	0.33	5.35	0.404
1974	25.26	0.486	1.72	0.484
1975	121.07	0.197	4.00	0.192
1976	31.15	0.441	1.31	0.291
1977	7.01	0.345	0.56	0.331
1978	4.70	0.287	0.25	0.324
1979	12.86	0.368	1.05	0.426
1980	58.18	0.242	3.20	0.258
1981	43.81	0.212	2.47	0.301
1982	49.19	0.419	2.55	0.425
1983	64.74	0.421	3.90	0.676
1984	15.84	0.423	0.71	0.368
1985	37.84	0.447	1.60	0.404
1986	66.21	0.461	2.78	0.408
1987	15.62	0.398	0.57	0.31
1988	13.35	0.381	0.48	0.304
1989	32.31	0.806	0.76	0.666
1990	8.93	0.452	0.36	0.386
1991	27.84	0.712	1.01	0.588
1992	17.95	0.213	0.61	0.207
1993	26.68	0.401	0.81	0.317
1994	36.29	0.276	1.45	0.273
1995	42.11	0.593	2.21	0.774
1996	11.47	0.398	0.51	0.311
1997	112.87	0.382	3.41	0.398
1998	41.07	0.612	2.14	0.742
1999	76.23	0.594	2.46	0.655
2000	36.77	0.36	0.99	0.333
2001	61.21	0.37	1.89	0.156
2002	46.57	0.447	1.70	0.399
2003	47.70	0.601	1.39	0.731
2004	115.35	0.338	2.06	0.325
2005	37.46	0.388	1.26	0.361
2006	70.87	0.395	1.98	0.357
2007	141.41	0.537	4.77	0.505
2008	130.57	0.723	3.06	0.582

Table B15. NEFSC fall abundance and biomass indices (number and weight per tow) and corresponding coefficients of variation (CV) for 1975-2008 from data collected in inshore strata (1-92) and offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76).

Year	Number	CV	Weight	CV
1975	45.69	0.221	2.60	0.279
1976	139.58	0.221	5.80	0.214
1977	87.00	0.226	5.21	0.284
1978	154.51	0.249	4.62	0.165
1979	287.89	0.240	11.50	0.224
1980	325.19	0.275	14.69	0.483
1981	279.17	0.304	10.10	0.255
1982	108.83	0.238	4.50	0.255
1983	440.50	0.260	12.49	0.210
1984	347.75	0.308	11.35	0.265
1985	375.77	0.242	14.79	0.222
1986	182.21	0.195	6.78	0.175
1987	114.04	0.274	4.58	0.281
1988	309.07	0.161	7.14	0.174
1989	392.48	0.346	12.00	0.268
1990	358.52	0.223	8.74	0.222
1991	187.42	0.402	5.16	0.327
1992	237.21	0.256	4.38	0.245
1993	252.41	0.227	9.63	0.215
1994	495.19	0.444	12.51	0.327
1995	111.51	0.248	5.45	0.257
1996	85.13	0.190	2.65	0.255
1997	251.02	0.108	4.38	0.132
1998	207.41	0.313	6.34	0.373
1999	243.54	0.354	4.84	0.278
2000	211.74	0.247	7.09	0.236
2001	86.16	0.225	3.06	0.296
2002	102.37	0.188	2.40	0.186
2003	193.44	0.138	3.96	0.169
2004	92.04	0.234	3.02	0.289
2005	53.44	0.204	1.16	0.240
2006	181.00	0.221	4.87	0.201
2007	54.83	0.167	1.50	0.286
2008	131.91	0.212	2.70	0.206

Table B16. NEFSC winter abundance and biomass indices (number and weight per tow) and corresponding coefficients of variation (CV) for 1992-2007 from data collected in offshore strata (1-14 and 61-76).

Year	Number	CV	Weight	CV
1992	22.10	0.241	0.85	0.226
1993	117.86	0.461	2.62	0.399
1994	186.25	0.715	6.87	0.637
1995	151.57	0.558	3.82	0.512
1996	74.38	0.615	1.49	0.375
1997	40.91	0.209	1.94	0.253
1998	44.65	0.412	1.10	0.275
1999	46.44	0.213	1.55	0.228
2000	151.65	0.331	5.00	0.310
2001	75.01	0.401	3.66	0.391
2002	43.90	0.296	1.89	0.241
2003	50.62	0.360	1.38	0.356
2004	180.75	0.528	3.43	0.456
2005	25.19	0.251	1.19	0.279
2006	45.20	0.232	1.75	0.232
2007	116.85	0.322	2.86	0.333

Table B17. Abundance indices (number per tow) for NEFSC spring surveys in offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76) during 1982-2008 for ages 0-3 and 4+.

Year	0	1	2	3	4+
1982	0	36.10	10.31	2.31	0.48
1983	0	33.82	23.00	7.04	0.89
1984	0	10.88	3.90	0.99	0.07
1985	0	30.19	4.92	2.22	0.52
1986	0	53.05	12.05	1.01	0.10
1987	0	13.93	1.43	0.23	0.03
1988	0	11.29	1.88	0.18	0.01
1989	0	25.64	5.71	0.96	0.01
1990	0	7.22	1.36	0.31	0.04
1991	0.03	25.67	1.50	0.63	0.02
1992	0	16.10	1.61	0.23	0.01
1993	0	23.56	2.71	0.42	0
1994	0	29.56	5.65	1.04	0.044
1995	0	26.55	12.95	2.61	0
1996	0	7.73	2.41	1.28	0.05
1997	0	107.72	4.50	0.66	0
1998	0	18.32	21.54	1.21	0
1999	0	64.97	9.30	1.96	0
2000	0	34.71	1.70	0.33	0.04
2001	0	49.28	11.14	0.79	0
2002	0	38.19	6.03	2.12	0.24
2003	0	39.36	5.49	2.66	0.18
2004	0	114.07	1.18	0.08	0.02
2005	0	28.23	7.74	1.01	0.48
2006	0	66.26	3.15	1.08	0.39
2007	0	120.77	17.23	3.20	0.21
2008	0	120.53	9.26	0.69	0.08

Table B18. Abundance indices (number per tow) for NEFSC fall surveys in inshore strata (1-92) and offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76) during 1982-2008 for ages 0-3 and 4+.

Year	0	1	2	3	4+
1982	74.28	26.52	7.54	0.50	0
1983	341.34	83.41	13.43	2.29	0.03
1984	287.43	43.91	13.23	3.17	0.00
1985	281.25	80.31	11.85	2.28	0.09
1986	140.48	27.94	11.49	1.99	0.32
1987	77.32	29.95	6.54	0.22	0
1988	275.32	20.96	12.70	0.10	0
1989	329.46	47.26	14.85	0.92	0
1990	320.81	32.93	3.77	1.02	0
1991	163.50	19.94	3.65	0.34	0
1992	223.30	9.42	4.39	0.10	0
1993	192.53	49.56	9.49	0.83	0
1994	462.33	21.98	9.40	1.46	0.02
1995	45.63	41.67	24.13	0.08	0
1996	63.56	17.31	4.00	0.27	0
1997	231.46	16.92	2.51	0.14	0
1998	149.78	48.64	8.26	0.74	0
1999	226.15	15.28	2.09	0.03	0
2000	164.44	41.94	4.98	0.38	0
2001	62.60	14.81	8.53	0.22	0
2002	88.12	10.99	3.15	0.11	0
2003	178.35	12.78	1.68	0.40	0.21
2004	66.56	16.26	8.04	0.69	0.49
2005	45.68	5.23	1.71	0.81	0.02
2006	154.96	19.78	5.25	0.93	0.08
2007	39.12	13.76	1.94	0.02	0
2008	123.06	7.69	1.09	0.06	0

Table B19. Biomass per tow for 0 and 1+ butterfish in NEFSC fall surveys as estimated using growth parameter estimates and numbers at age during 1982-2008 in Table B18 and numbers at age for 1975-1981 from Table E5 in NEFSC (1994).

Year	Age 0	Age 1+
1975	0.803	1.793
1976	3.236	2.568
1977	1.470	3.741
1978	2.922	1.702
1979	5.588	5.910
1980	6.090	8.598
1981	5.374	4.726
1982	1.472	2.383
1983	6.699	6.605
1984	5.623	4.290
1985	5.572	6.289
1986	2.731	3.055
1987	1.489	2.448
1988	5.215	2.460
1989	6.281	4.347
1990	5.976	2.446
1991	3.005	1.570
1992	4.174	0.986
1993	3.550	3.944
1994	8.496	2.366
1995	0.836	4.741
1996	1.204	1.447
1997	4.326	1.264
1998	3.033	3.844
1999	4.551	1.133
2000	2.970	2.999
2001	1.139	1.701
2002	1.592	0.959
2003	3.311	0.999
2004	1.248	1.880
2005	0.862	0.575
2006	2.906	1.801
2007	0.763	1.017
2008	2.223	0.566

Table B20. Massachusetts spring (1982-2008) and fall (1982-2008) and Connecticut (Long Island Sound Survey) spring (1984-2008) and fall (1982-2008) abundance and biomass indices (number and weight per tow).

Year	MA Spring Number	MA Spring Weight	MA Fall Number	MA Fall Weight	CT Spring Number	CT Spring Weight	CT Fall Number	CT Fall Weight
1982	0.184	0.283	319.296	2.344			51.93	
1983	2.31	0.046	314.958	1.435			89.72	
1984	4.733	0.722	102.333	5.371	8.92		63.41	
1985	10.508	0.199	166.836	1.881	0.62		60.09	
1986	2.665	0.019	296.035	2.872	2.38		146.67	
1987	1.184	0.239	17.128	2.942	0.25		174.87	
1988	1.063	0.495	1387.95	1.914	0.46		154.65	
1989	0.261	0.619	181.665	1.464	0.8		170.59	
1990	15.551	0.218	231.682	4.615	1.6		301.72	
1991	28.526	0.086	366.505	0.697	2.17		87.73	
1992	0.933	0.104	1151.021	12.269	2.6	0.43	93.05	6.31
1993	1.86	0.023	1270.304	2.59	0.48	0.1	320.06	4.12
1994	4.999	0.897	608.334	2.685	1.71	0.31	173.74	3.4
1995	14.454	1.191	600.737	3.355	1.06	0.19	186.62	10.26
1996	4.568	0.061	550.701	9.257	3.22	0.73	355.49	9.3
1997	9.011	0.151	660.385	10.778	6.16	1.27	477.91	6.97
1998	5.299	0.334	1576.006	7.613	6.51	1.06	125.97	13.27
1999	1.019	0.427	649.108	5.66	1.9	0.52	142.89	15.43
2000	43.393	0.345	164.4	6.848	3.35	0.69	165.07	4.45
2001	19.373	0.385	118.074	8.318	2.94	0.79	112.86	7.8
2002	16.776	0.403	424.988	14.713	7.09	1.48	175.37	6.56
2003	14.173	0.042	1011.975	7.985	3.17	0.64	197.24	3.47
2004	4.395	1.706	184.228	3.284	2.1	0.41	140.23	6.24
2005	2.231	1.476	649.279	1.843	2.27	0.55	154.53	7.85
2006	13.246	0.875	199.643	3.973	18.67	2.3	181.71	7.73
2007	81.109	0.907	465.435	3.546	3.48	0.66	51.93	5.82
2008	10.544	0.33	878.692	2.881	4.64	1.06	89.72	8.97

Table B21. Growth parameter estimates based on age and weight data collected in surveys between 1992-2009. Schnute's (1985) parameterization was fitted by non-linear least squares.

Parameter	Estimate	SE
v	0.0067	0.00037
V	0.0502	0.00026
ρ	0.8121	0.01176

Table B22. Length at age growth von Bertalanffy parameter estimates based on age and length data collected in surveys between 1992-2009. Schnute's (1985) parameterization was fitted by non-linear least squares.

	Estimate	SE
Linf	19.189	0.1957
K	0.6771	0.0235
t0	-0.214	0.0224

Table B23. Maximized objective function components at assumed maxima on the uniform priors for the ratio of survey to stock area and efficiency of the Bigelow.

	0.85	0.9	0.95
Spring 1+	24.224	24.139	24.058
Winter 1+	5.496	5.489	5.483
Fall 0	2.973	2.997	3.019
Fall 1+	12.508	12.569	12.628
Catch	0.002	0.003	0.003
Total	48.772	48.641	48.512

Table B24. Maximized objective function components at assumed values of natural mortality (M) from 0.6-1.0 in the final model.

	0.6	0.7	0.8	0.9	1
Spring 1+	24.972	24.979	24.139	23.994	23.872
Winter 1+	5.990	5.731	5.489	5.308	5.154
Fall 0	2.884	2.910	2.997	3.051	3.126
Fall 1+	13.590	13.136	12.569	12.356	12.217
Catch	0.005	0.003	0.003	0.002	0.001
Total	50.904	50.222	48.641	48.152	47.810

Table B25. Estimated annual population parameter from the final model.

Year	Recruits (kmt)	Total Biomass (kmt)	Spawning Biomass (kmt)	Ave Biomass (kmt)	F	IGR (Recruits)	IGR (spawning biomass)	IGR (all)	Surplus Production (kmt)
1973	NA	245.71	NA	184.54	0.21	NA	NA	0.41	105.47
1974	184.78	319.26	134.48	253.56	0.09	0.53	0.24	0.41	-85.29
1975	15.56	215.13	199.57	157.51	0.13	0.53	0.25	0.27	-24.96
1976	63.59	175.15	111.56	128.08	0.17	0.53	0.18	0.31	-38
1977	28.71	120.4	91.69	88.69	0.13	0.53	0.2	0.28	13.82
1978	61.86	125.63	63.77	95.24	0.14	0.53	0.19	0.36	78.64
1979	122.38	193.63	71.25	155.31	0.08	0.53	0.22	0.42	86.18
1980	146.01	269.74	123.73	215.25	0.07	0.53	0.25	0.4	19.85
1981	106.42	276.74	170.32	216.29	0.07	0.53	0.24	0.35	-68.39
1982	29.31	196.36	167.05	142.71	0.14	0.53	0.22	0.27	37.82
1983	118.06	218.58	100.52	170.41	0.09	0.53	0.18	0.37	30.41
1984	104.62	236.52	131.9	181.54	0.12	0.53	0.23	0.36	12.91
1985	94.67	232.04	137.37	180.85	0.07	0.53	0.23	0.35	-34.59
1986	47.53	186.94	139.4	141.56	0.08	0.53	0.22	0.3	-45.71
1987	26.7	131.92	105.22	96.8	0.12	0.53	0.2	0.26	34.7
1988	88.66	157.88	69.22	124.51	0.07	0.53	0.18	0.38	29.74
1989	82.58	180.27	97.69	142.98	0.05	0.53	0.23	0.37	22.56
1990	84.13	196.61	112.47	157.69	0.02	0.53	0.23	0.36	-28.34
1991	40.28	165.99	125.71	127.31	0.06	0.53	0.22	0.3	11.31
1992	75.77	171.81	96.04	134.35	0.06	0.53	0.2	0.34	8.57
1993	69.91	174.16	104.25	134.21	0.09	0.53	0.22	0.34	57.48
1994	119.81	221.93	102.12	177.24	0.06	0.53	0.22	0.39	-58.57
1995	14.55	155.25	140.69	116.31	0.07	0.53	0.24	0.27	-41.94
1996	22.01	106.85	84.84	80.04	0.06	0.53	0.18	0.25	30.58
1997	75.15	133.95	58.8	107.3	0.04	0.53	0.17	0.37	7.8
1998	52.87	138.67	85.8	107.62	0.08	0.53	0.23	0.35	43.28
1999	92.81	175.3	82.49	138.28	0.08	0.53	0.22	0.39	-1.53
2000	56.58	164.78	108.2	128.01	0.07	0.53	0.24	0.34	-39.32
2001	20.57	118.74	98.17	88.04	0.1	0.53	0.21	0.27	-20.11
2002	28.24	91.88	63.64	70.43	0.05	0.53	0.18	0.29	26.31
2003	62.35	115.69	53.34	93.05	0.03	0.53	0.19	0.38	-16.1
2004	22.81	97.44	74.63	75.97	0.02	0.53	0.23	0.3	-21.29
2005	16.36	74.77	58.41	57.55	0.02	0.53	0.2	0.27	22.74
2006	53.03	96.68	43.65	78.08	0.02	0.53	0.18	0.37	-19.52
2007	13.05	76.02	62.97	58.97	0.02	0.53	0.23	0.28	8.49
2008	38.81	83.81	44.99	66.64	0.02	0.53	0.19	0.35	NA

Table B26. Estimated total biomass and standard errors for the final model.

Year	Total Biomass	SE
1973	245.71	239.78
1974	319.26	187.28
1975	215.13	130.4
1976	175.15	105.2
1977	120.4	77.49
1978	125.63	76.63
1979	193.63	116.28
1980	269.74	162.53
1981	276.74	165.19
1982	196.36	120.05
1983	218.58	134.15
1984	236.52	142.15
1985	232.04	143.06
1986	186.94	116.62
1987	131.92	84.37
1988	157.88	98.7
1989	180.27	112.98
1990	196.61	123.46
1991	165.99	103.19
1992	171.81	105.81
1993	174.16	104.98
1994	221.93	135.94
1995	155.25	98.33
1996	106.85	69.39
1997	133.95	82.81
1998	138.67	84.86
1999	175.3	105.66
2000	164.78	100.61
2001	118.74	74.3
2002	91.88	59.51
2003	115.69	72.04
2004	97.44	60.68
2005	74.77	46.49
2006	96.68	59.11
2007	76.02	46.67
2008	83.81	50.63

Table B27. Estimated annual fishing mortality rate and standard errors for the final model.

Year	F	SE
1973	0.213	0.219
1974	0.09	0.054
1975	0.126	0.081
1976	0.168	0.108
1977	0.126	0.086
1978	0.139	0.09
1979	0.078	0.049
1980	0.073	0.046
1981	0.069	0.043
1982	0.144	0.094
1983	0.09	0.058
1984	0.119	0.075
1985	0.073	0.046
1986	0.085	0.055
1987	0.119	0.08
1988	0.073	0.047
1989	0.054	0.035
1990	0.018	0.011
1991	0.056	0.036
1992	0.058	0.037
1993	0.091	0.057
1994	0.056	0.035
1995	0.073	0.048
1996	0.058	0.038
1997	0.035	0.022
1998	0.078	0.05
1999	0.08	0.05
2000	0.066	0.041
2001	0.101	0.066
2002	0.046	0.03
2003	0.028	0.018
2004	0.023	0.015
2005	0.019	0.012
2006	0.018	0.011
2007	0.016	0.01
2008	0.024	0.015

Table B28. Predicted values, residuals and estimated catchability (Q) for the NEFSC spring 1+ survey.

Year	Time	Index	Scaled CV	Predicted	Residual	Standardized Resid	Q
1973	1973.31	5.35	0.81	NA	NA	NA	NA
1974	1974.27	1.72	0.97	1.83	-0.06	-0.08	0.02
1975	1975.26	4	0.38	2.7	0.39	1.06	0.02
1976	1976.26	1.31	0.58	1.47	-0.12	-0.21	0.02
1977	1977.3	0.56	0.66	1.2	-0.76	-1.26	0.02
1978	1978.31	0.25	0.65	0.82	-1.17	-1.98	0.02
1979	1979.29	1.05	0.85	0.96	0.09	0.12	0.02
1980	1980.29	3.2	0.52	1.67	0.65	1.33	0.02
1981	1981.3	2.47	0.6	2.29	0.08	0.14	0.02
1982	1982.26	2.55	0.85	2.23	0.13	0.18	0.02
1983	1983.26	3.9	1.35	1.35	1.06	1.04	0.02
1984	1984.24	0.71	0.74	1.81	-0.93	-1.42	0.02
1985	1985.22	1.6	0.81	1.93	-0.19	-0.27	0.02
1986	1986.24	2.78	0.82	1.92	0.37	0.52	0.02
1987	1987.28	0.57	0.62	1.39	-0.88	-1.55	0.02
1988	1988.24	0.48	0.61	0.95	-0.68	-1.22	0.02
1989	1989.22	0.76	1.33	1.38	-0.6	-0.59	0.02
1990	1990.23	0.36	0.77	1.59	-1.48	-2.17	0.02
1991	1991.23	1.01	1.18	1.76	-0.56	-0.6	0.02
1992	1992.23	0.61	0.41	1.33	-0.79	-1.98	0.02
1993	1993.25	0.81	0.63	1.42	-0.57	-0.97	0.02
1994	1994.24	1.45	0.55	1.42	0.02	0.04	0.02
1995	1995.25	2.2	1.55	1.94	0.13	0.11	0.02
1996	1996.25	0.51	0.62	1.16	-0.81	-1.42	0.02
1997	1997.24	3.41	0.8	0.81	1.44	2.05	0.02
1998	1998.23	2.14	1.48	1.19	0.58	0.54	0.02
1999	1999.23	2.46	1.31	1.14	0.76	0.77	0.02
2000	2000.27	0.99	0.67	1.47	-0.4	-0.66	0.02
2001	2001.24	1.89	0.31	1.35	0.34	1.11	0.02
2002	2002.24	1.7	0.8	0.88	0.67	0.95	0.02
2003	2003.24	1.39	1.46	0.74	0.63	0.59	0.02
2004	2004.24	2.06	0.65	1.05	0.67	1.13	0.02
2005	2005.19	1.26	0.72	0.84	0.41	0.63	0.02
2006	2006.24	1.98	0.71	0.61	1.18	1.84	0.02
2007	2007.24	4.77	1.01	0.89	1.68	2.01	0.02
2008	2008.26	3.06	1.16	0.62	1.6	1.73	0.02

Table B29. Predicted values, residuals and estimated catchability (Q) for the NEFSC winter 1+ survey.

Year	Time	Index	Scaled CV	Predicted	Residual	Standardized Resid	Q
1992	1992.15	0.84	1.09	3.23	-1.34	-1.52	0.04
1993	1993.12	2.62	0.62	3.55	-0.3	-0.53	0.04
1994	1994.11	6.87	0.38	3.52	0.67	1.81	0.04
1995	1995.13	3.82	0.51	4.78	-0.23	-0.47	0.04
1996	1996.13	1.49	0.82	2.88	-0.66	-0.92	0.04
1997	1997.12	1.94	0.72	2.01	-0.04	-0.05	0.04
1998	1998.13	1.1	0.95	2.92	-0.97	-1.21	0.04
1999	1999.12	1.55	0.8	2.83	-0.6	-0.85	0.04
2000	2000.14	5	0.45	3.68	0.31	0.72	0.04
2001	2001.11	3.66	0.52	3.37	0.08	0.17	0.04
2002	2002.13	1.89	0.73	2.16	-0.14	-0.21	0.04
2003	2003.13	1.38	0.85	1.82	-0.28	-0.38	0.04
2004	2004.12	3.43	0.54	2.57	0.29	0.57	0.04
2005	2005.12	1.19	0.92	2.01	-0.52	-0.67	0.04
2006	2006.13	1.75	0.76	1.49	0.17	0.25	0.04
2007	2007.13	2.86	0.59	2.16	0.28	0.51	0.04

Table B30. Predicted values, residuals and estimated catchability (Q) for the NEFSC fall 0 survey.

Year	Time	Index	Scaled CV	Predicted	Residual	Standardized Resid	Q
1975	1975.82	0.8	0.28	0.8	0.01	0.03	0.07
1976	1976.82	3.24	0.21	3.15	0.03	0.13	0.07
1977	1977.83	1.47	0.28	1.47	0	0.01	0.07
1978	1978.78	2.92	0.17	3.18	-0.08	-0.52	0.07
1979	1979.79	5.59	0.22	6.59	-0.17	-0.75	0.07
1980	1980.8	6.09	0.48	7.87	-0.26	-0.56	0.07
1981	1981.78	5.37	0.26	5.78	-0.07	-0.29	0.07
1982	1982.71	1.47	0.26	1.55	-0.05	-0.2	0.07
1983	1983.72	6.7	0.21	6.45	0.04	0.19	0.07
1984	1984.72	5.62	0.27	5.61	0	0.01	0.07
1985	1985.74	5.57	0.22	5.21	0.07	0.3	0.07
1986	1986.71	2.73	0.18	2.62	0.04	0.24	0.07
1987	1987.71	1.49	0.28	1.44	0.03	0.12	0.07
1988	1988.72	5.21	0.17	4.92	0.06	0.34	0.07
1989	1989.69	6.28	0.27	4.68	0.3	1.12	0.07
1990	1990.71	5.98	0.22	4.87	0.21	0.94	0.07
1991	1991.71	3	0.33	2.27	0.28	0.89	0.07
1992	1992.7	4.17	0.25	4.26	-0.02	-0.09	0.07
1993	1993.7	3.55	0.21	3.85	-0.08	-0.38	0.07
1994	1994.69	8.5	0.33	6.77	0.23	0.71	0.07
1995	1995.69	0.84	0.26	0.81	0.03	0.11	0.07
1996	1996.71	1.2	0.25	1.24	-0.03	-0.11	0.07
1997	1997.71	4.33	0.13	4.29	0.01	0.05	0.07
1998	1998.7	3.03	0.37	2.94	0.03	0.09	0.07
1999	1999.7	4.55	0.28	5.15	-0.12	-0.45	0.07
2000	2000.7	2.97	0.24	3.17	-0.07	-0.28	0.07
2001	2001.71	1.14	0.3	1.12	0.02	0.05	0.07
2002	2002.71	1.59	0.19	1.6	0	-0.02	0.07
2003	2003.71	3.31	0.17	3.58	-0.08	-0.47	0.07
2004	2004.7	1.25	0.29	1.32	-0.05	-0.19	0.07
2005	2005.7	0.86	0.24	0.95	-0.09	-0.4	0.07
2006	2006.7	2.91	0.2	3.08	-0.06	-0.29	0.07
2007	2007.7	0.76	0.29	0.76	0.01	0.03	0.07
2008	2008.73	2.22	0.21	2.22	0	0	0.07

Table B31. Predicted values, residuals and estimated catchability (Q) for the NEFSC fall 1+ survey.

Year	Time	Index	Scaled CV	Predicted	Residual	Standardized Resid	Q
1975	1975.82	1.79	0.84	4.53	-0.93	-1.27	0.04
1976	1976.82	2.57	0.64	2.31	0.1	0.18	0.04
1977	1977.83	3.74	0.85	1.99	0.63	0.85	0.04
1978	1978.78	1.7	0.5	1.4	0.19	0.42	0.04
1979	1979.79	5.91	0.67	1.69	1.25	2.05	0.04
1980	1980.8	8.6	1.45	2.98	1.06	1	0.04
1981	1981.78	4.73	0.77	4.13	0.13	0.2	0.04
1982	1982.71	2.38	0.77	3.99	-0.52	-0.76	0.04
1983	1983.72	6.61	0.63	2.41	1.01	1.74	0.04
1984	1984.72	4.29	0.8	3.24	0.28	0.4	0.04
1985	1985.74	6.29	0.67	3.48	0.59	0.98	0.04
1986	1986.71	3.06	0.53	3.44	-0.12	-0.24	0.04
1987	1987.71	2.45	0.84	2.47	-0.01	-0.01	0.04
1988	1988.72	2.46	0.52	1.67	0.39	0.79	0.04
1989	1989.69	4.35	0.8	2.45	0.57	0.81	0.04
1990	1990.71	2.45	0.67	2.94	-0.18	-0.3	0.04
1991	1991.71	1.57	0.98	3.19	-0.71	-0.86	0.04
1992	1992.7	0.99	0.74	2.37	-0.88	-1.33	0.04
1993	1993.7	3.94	0.64	2.6	0.42	0.71	0.04
1994	1994.69	2.37	0.98	2.58	-0.09	-0.11	0.04
1995	1995.69	4.74	0.77	3.55	0.29	0.42	0.04
1996	1996.71	1.45	0.76	2.08	-0.36	-0.54	0.04
1997	1997.71	1.26	0.4	1.47	-0.15	-0.39	0.04
1998	1998.7	3.84	1.12	2.18	0.57	0.63	0.04
1999	1999.7	1.13	0.84	2.07	-0.6	-0.83	0.04
2000	2000.7	3	0.71	2.74	0.09	0.14	0.04
2001	2001.71	1.7	0.89	2.4	-0.34	-0.45	0.04
2002	2002.71	0.96	0.56	1.58	-0.5	-0.96	0.04
2003	2003.71	1	0.51	1.36	-0.31	-0.64	0.04
2004	2004.7	1.88	0.87	1.96	-0.04	-0.06	0.04
2005	2005.7	0.57	0.72	1.49	-0.95	-1.48	0.04
2006	2006.7	1.8	0.6	1.1	0.49	0.88	0.04
2007	2007.7	1.02	0.86	1.66	-0.49	-0.66	0.04
2008	2008.73	0.57	0.62	1.14	-0.7	-1.23	0.04

Table B32. Candidate F_{MSY} proxies and corresponding median equilibrium yields and biomasses (mt) based on 7000 bootstraps and projections. Fox-model-based reference points are estimated within the KLAMZ model. Previous reference points were also based on the Fox model.

F Reference point	F	Yield	95% CI	Spawning Biomass	95% CI	Total Biomass	95% CI
$F_{0.1}$ (= $F_{20\%}$)	1.04	36,608	10,912-139,261	16,262	4,828-61,600	65,306	19,546-243,587
$F_{30\%}$	0.72	33,108	10,561-117,116	25,226	8,069-90,387	75,752	24,534-263,642
$F_{40\%}$	0.52	29,166	9,779-99,358	34,191	11,570-116,722	85,810	29,178-286,435
F = 0	0	0	0	89,881	35,281-255,747	145,296	56,998-405,540
SARC 38	0.38	12,200				22,800	
F_{MSY} (Fox)	0.23	17,400				74,550	
F_{MAX} (Empirical)	NA	NA		NA			

Table B33. Estimates from the base model and median fishing mortality and spawning biomass in constant catch projections when recruitments from either the entire time series (1974-2008) or the last 10 years (1999-2008) are used to generate future recruitments. Medians are based on 7000 bootstraps and 1 projection for each bootstrap.

Fall 1+ Model Q	0.04
Fall 1+ Swept Area Q	0.16
SSB_{2008}	45,993 mt
R_{2008}	38,814 mt
B_{2008}	83,807 mt
F_{2008}	0.02

	1974-2008 Recruitment Catch = 0	Catch = 1630 mt	Catch = 3260 mt	1999-2008 Recruitment Catch = 0	Catch = 1630 mt	Catch = 3260 mt
F_{2009}	0	0.02	0.04	0	0.03	0.05
F_{2010}	0	0.02	0.04	0	0.03	0.05
F_{2011}	0	0.02	0.03	0	0.02	0.05
F_{2012}	0	0.02	0.03	0	0.02	0.05
F_{2013}	0	0.01	0.03	0	0.02	0.05
SSB_{2009}	43,904 mt	43,904 mt	43,904 mt	43,897 mt	43,897 mt	43,897 mt
SSB_{2010}	61,016 mt	59,376 mt	58,056 mt	48,863 mt	47,570 mt	46,268 mt
SSB_{2011}	74,811 mt	72,511 mt	70,457 mt	52,015 mt	49,985 mt	47,956 mt
SSB_{2012}	82,568 mt	80,220 mt	77,779 mt	54,495 mt	52,121 mt	49,695 mt
SSB_{2013}	85,596 mt	84,217 mt	81,607 mt	54,841 mt	52,264 mt	49,682 mt

Table B34. Estimates from the models where catchability of the fall1+ indices is assumed to be 0.001 or 0.12 and corresponding median fishing mortality and spawning biomass in constant catch projections when recruitments from the entire time series (1974-2008) are used to generate future recruitments. Medians are based on 100 bootstraps and 10 projection for each bootstrap.

Fall 1+ Model Q	0.001			0.12		
Fall 1+ Swept Area Q	0.006			0.49		
SSB_{2008}	1,108,000 mt			17,873 mt		
R_{2008}	899,274 mt			16,944 mt		
B_{2008}	2,007,280 mt			34,817 mt		
F_{2008}	0.001			0.06		

	Catch = 0	Catch = 1630 mt	Catch = 3260 mt	Catch = 0	Catch = 1630 mt	Catch = 3260 mt
F_{2009}	0	0.0010	0.0019	0	0.05	0.10
F_{2010}	0	0.0008	0.0015	0	0.04	0.08
F_{2011}	0	0.0007	0.0015	0	0.04	0.07
F_{2012}	0	0.0007	0.0014	0	0.03	0.07
F_{2013}	0	0.0007	0.0013	0	0.03	0.07
SSB_{2009}	1,077,099 mt	1,077,099 mt	1,077,099 mt	18,403 mt	18,403 mt	18,403 mt
SSB_{2010}	1,368,321 mt	1,367,019 mt	1,365,717 mt	26,871 mt	25,544 mt	24,222 mt
SSB_{2011}	1,694,726 mt	1,692,646 mt	1,690,565 mt	35,342 mt	33,271 mt	31,201 mt
SSB_{2012}	1,783,808 mt	1,781,382 mt	1,778,956 mt	39,422 mt	36,995 mt	34,550 mt
SSB_{2013}	1,894,167 mt	1,891,599 mt	1,889,028 mt	41,783 mt	39,176 mt	36,547 mt

Figures

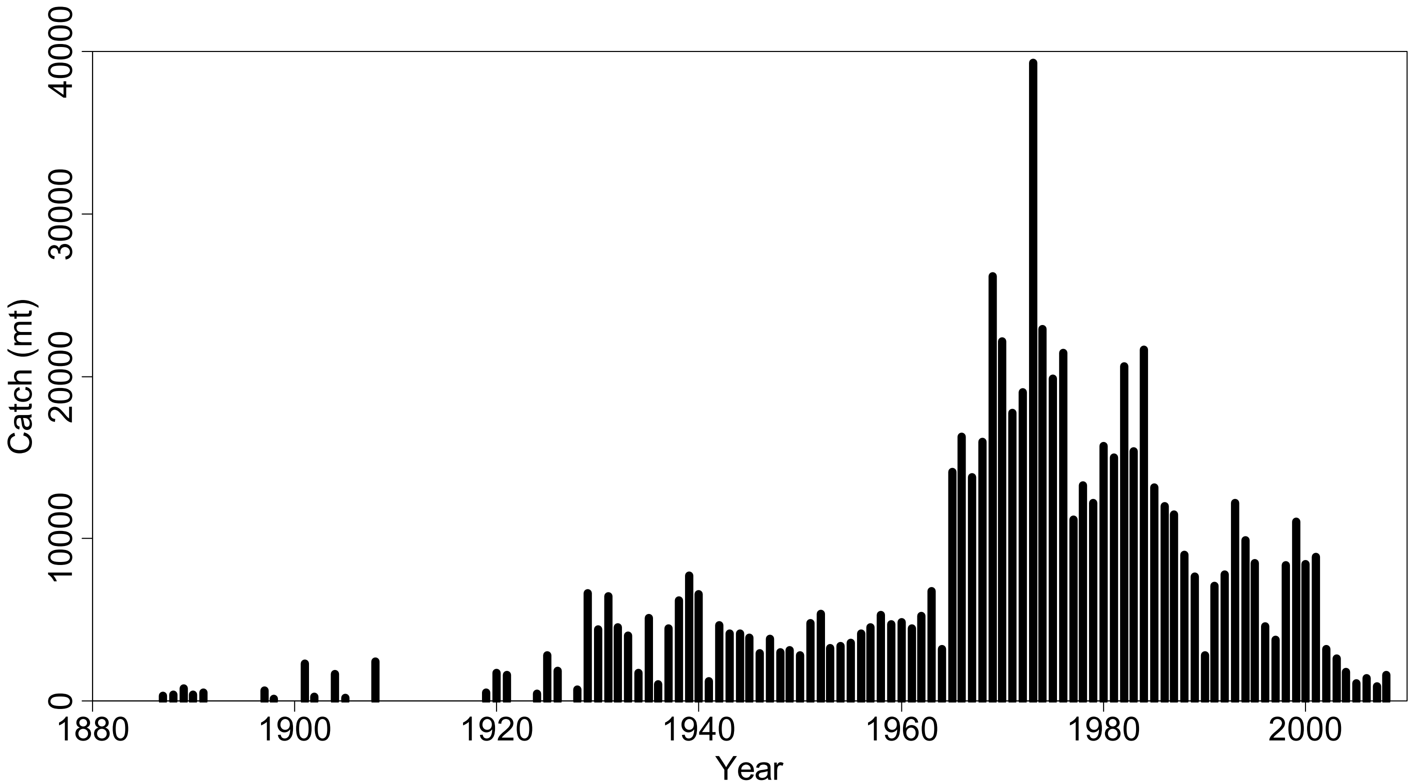

Figure B1. Total catch from from 1887 to 2008. Annual catch data are missing for some years prior to 1930 and total catch between 1965 and 1988 includes discards estimated by applying an average of discard rates for trawl gear estimated between 1989 and 1999 to annual landings of all species between 1965 and 1988 by trawl gear.

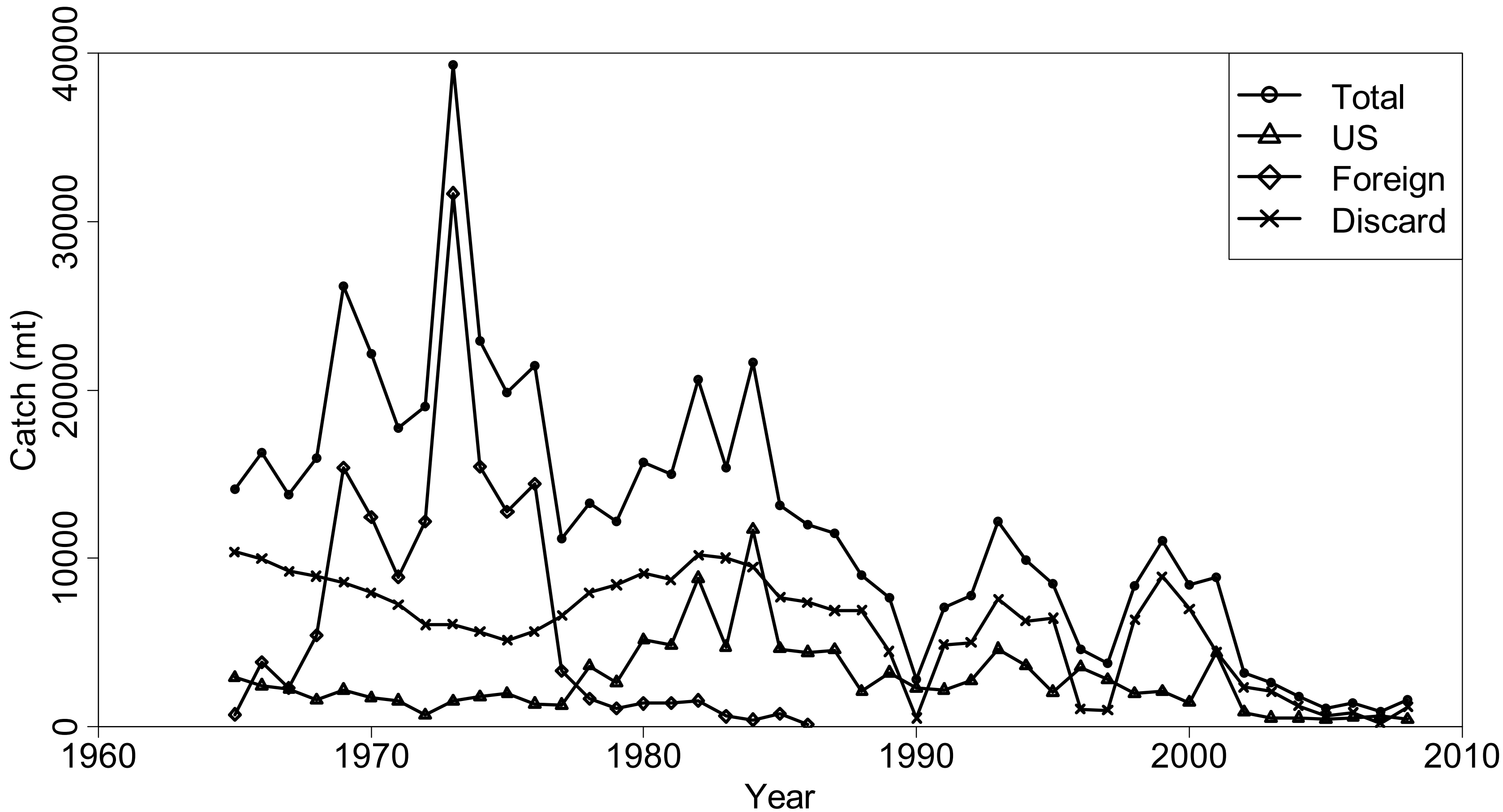

Figure B2. Total (circle), US (triangle), and foreign (diamond) landings and estimated discards (x) of butterfish between 1965 and 2008.

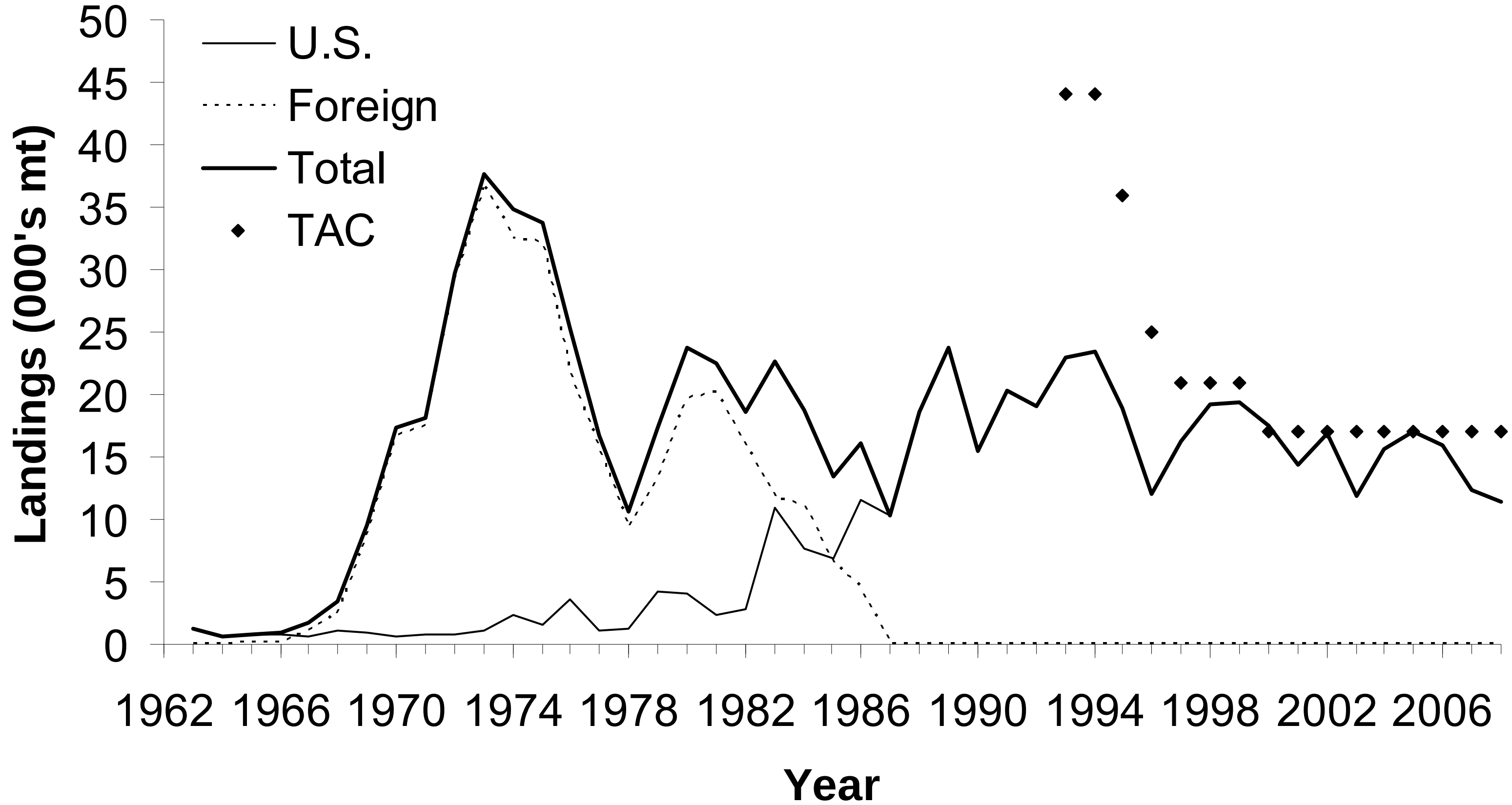

Figure B3. US, foreign, and total *Loligo* landings and total allowable catches (TACs).

Figure B4. Coefficient of variation of total catch estimates reflecting variance estimates associated with discard estimates.

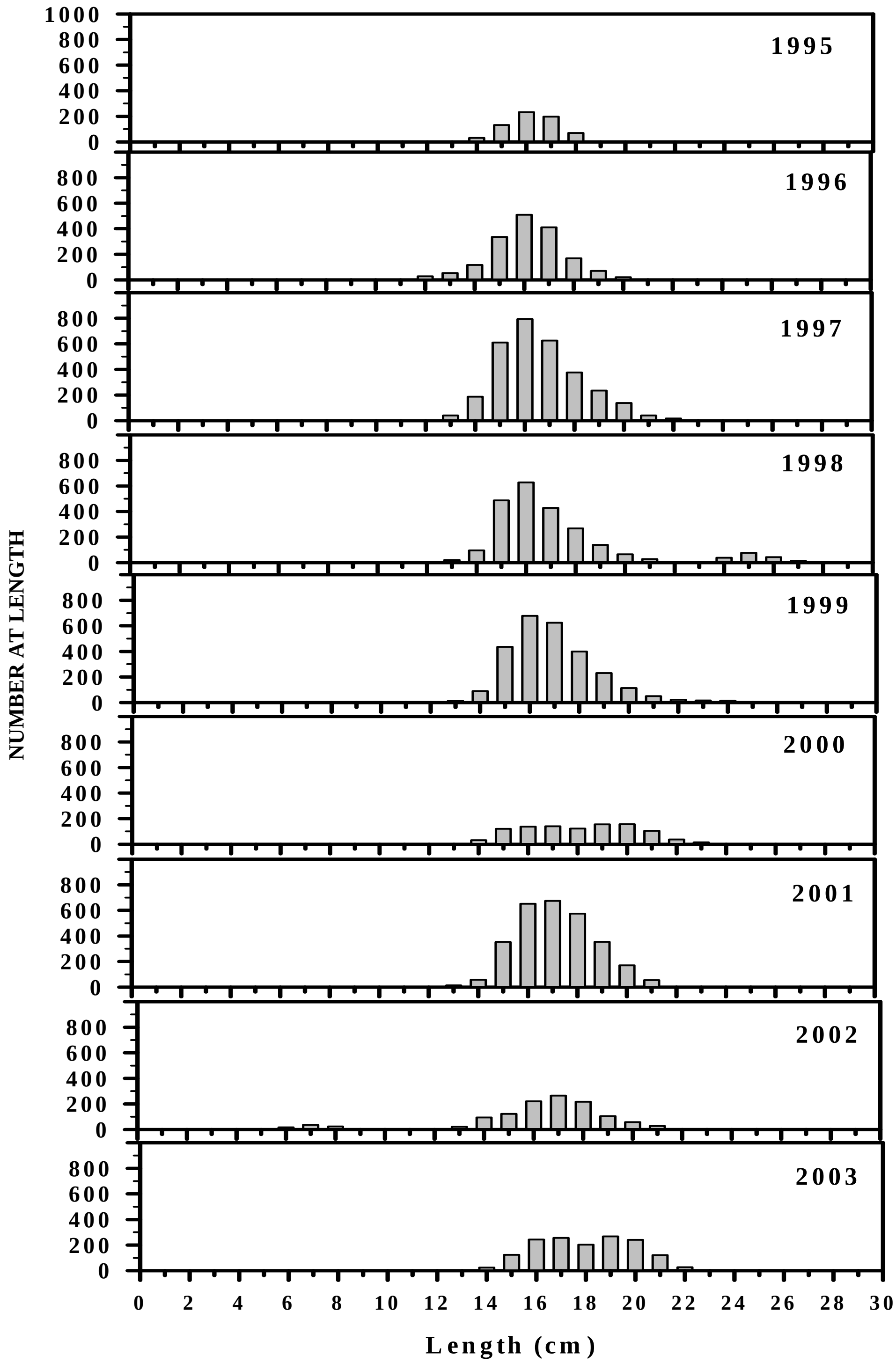

Figure B5. Size composition data from commercial landings of butterfish during 1995-2003.

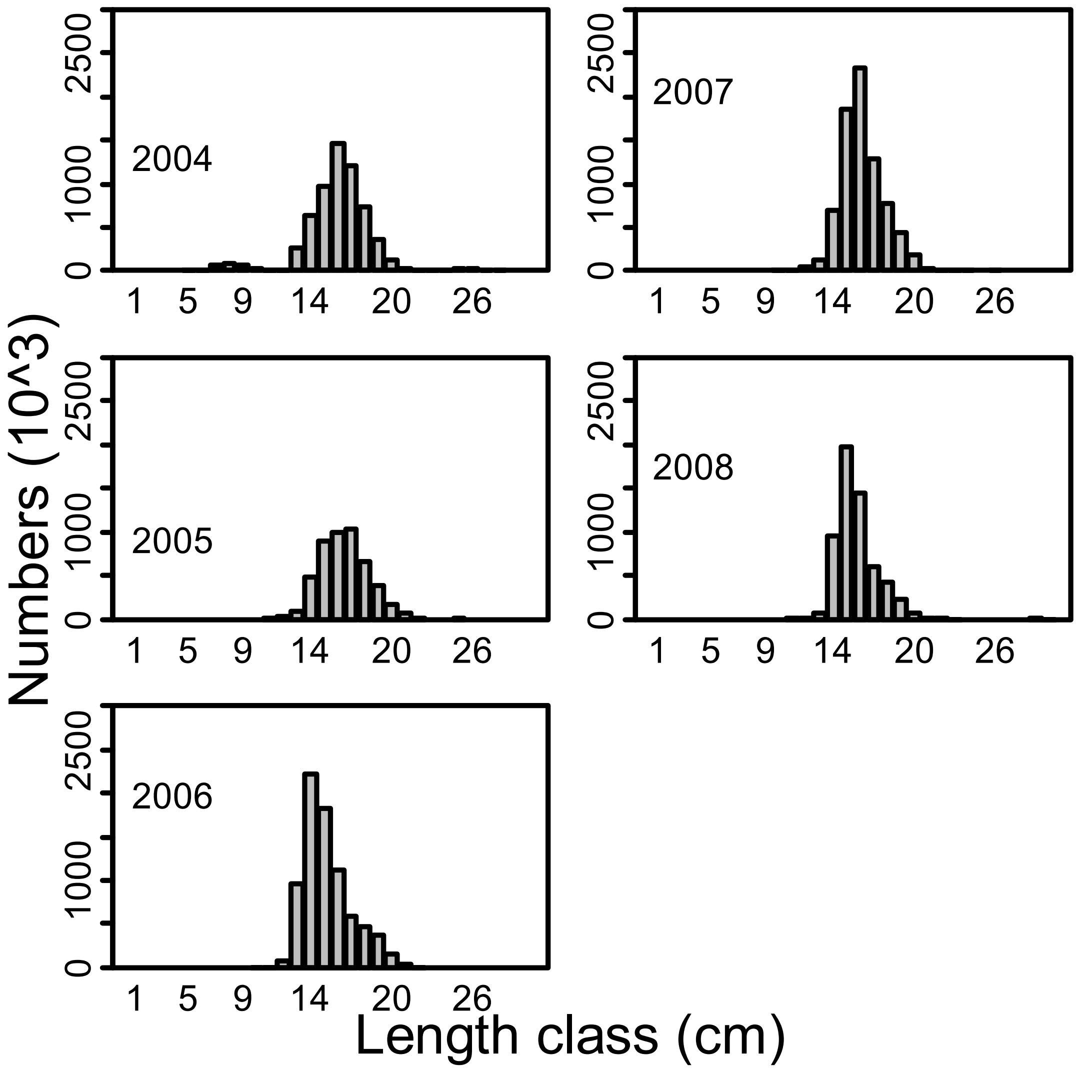

Figure B6. Size composition data from commercial landings of butterfish between 2004 and 2008 accounting for sampling by market category.

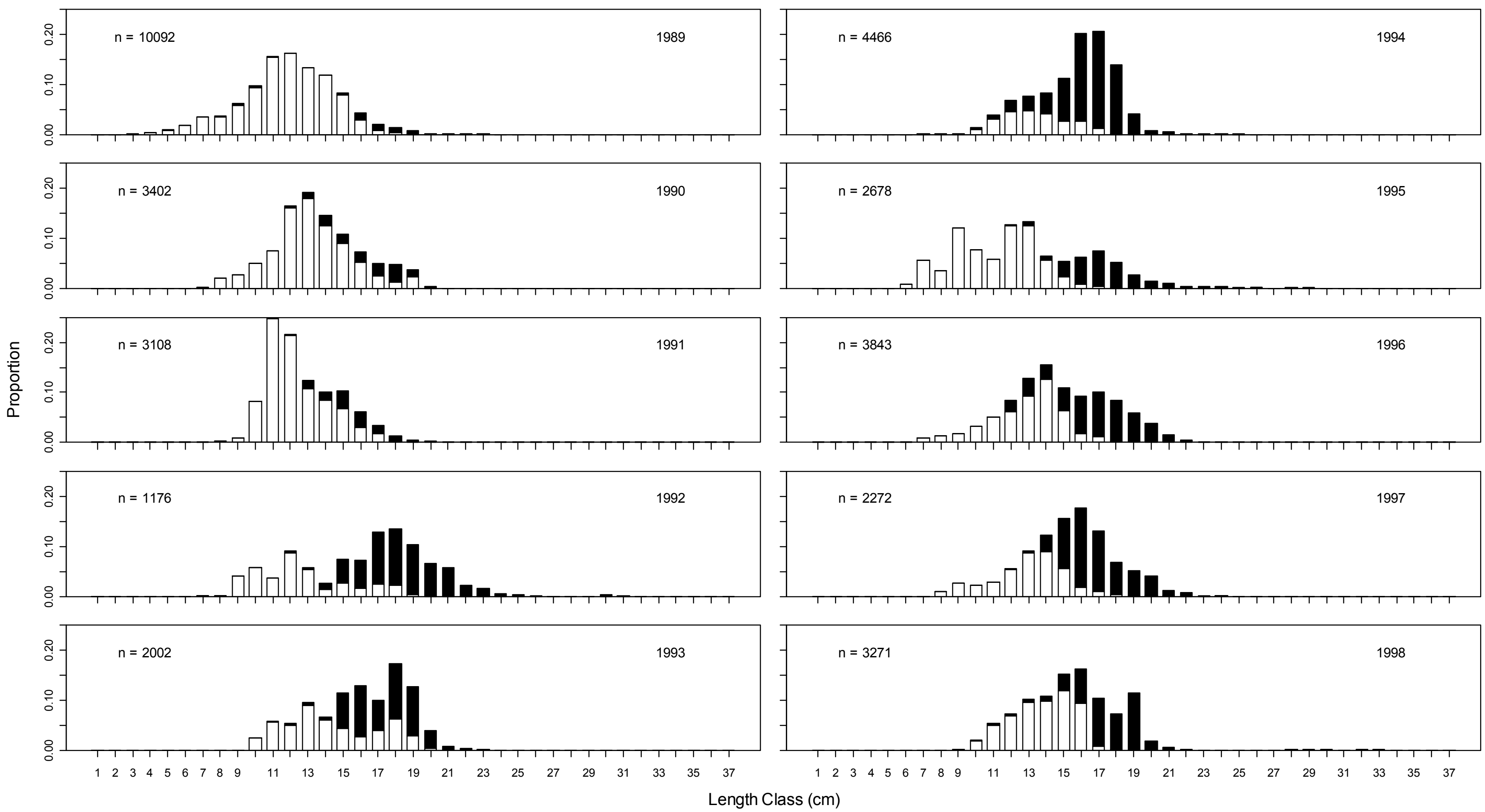

Figure B7. Length composition for NMFS Observer Program for butterfish between 1989 and 1998 with kept fish in black and discard in white. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

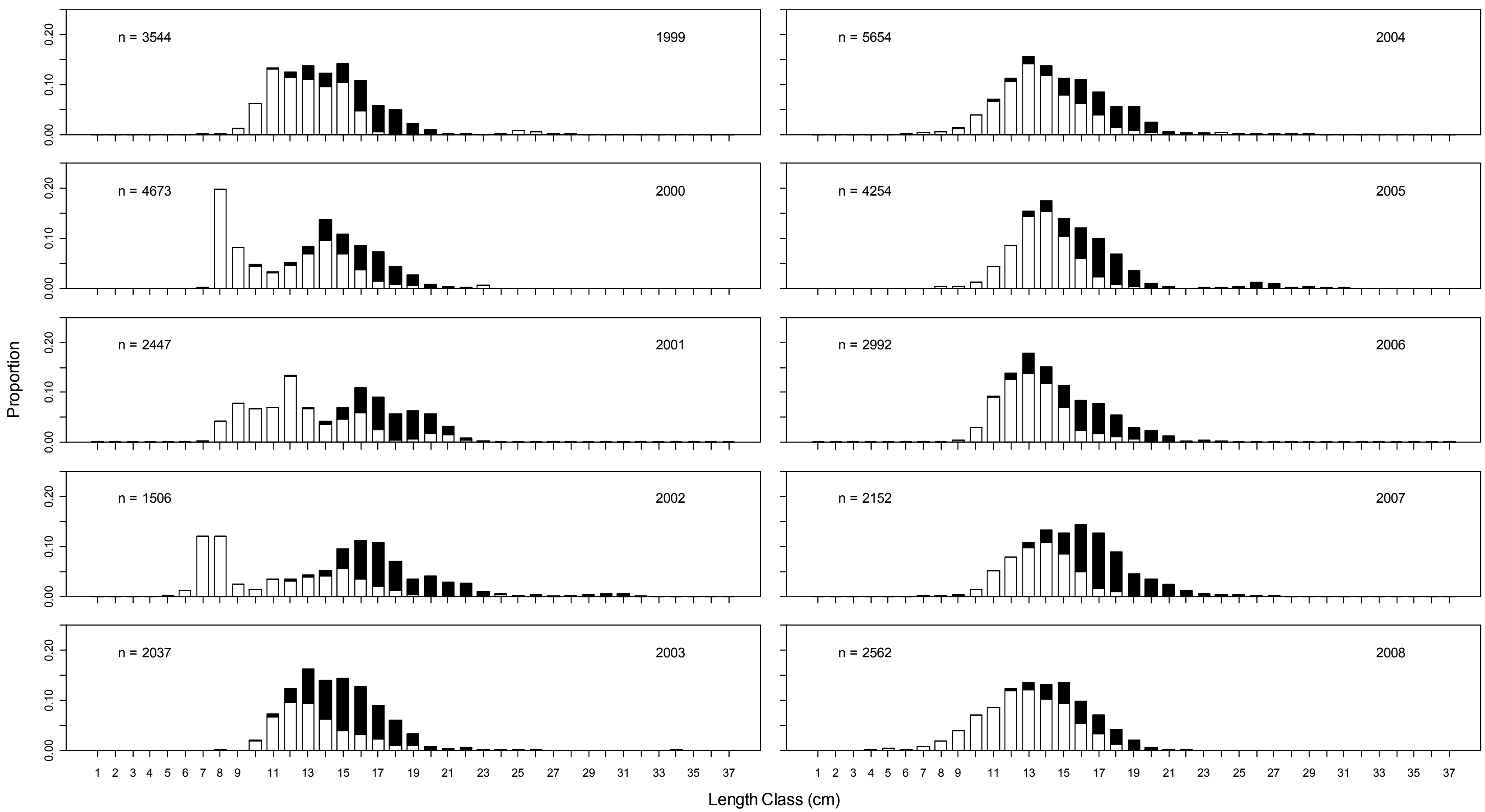

Figure B8. Length composition for NMFS Observer Program for butterfish between 1999 and 2008 with kept fish in black and discard in white. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

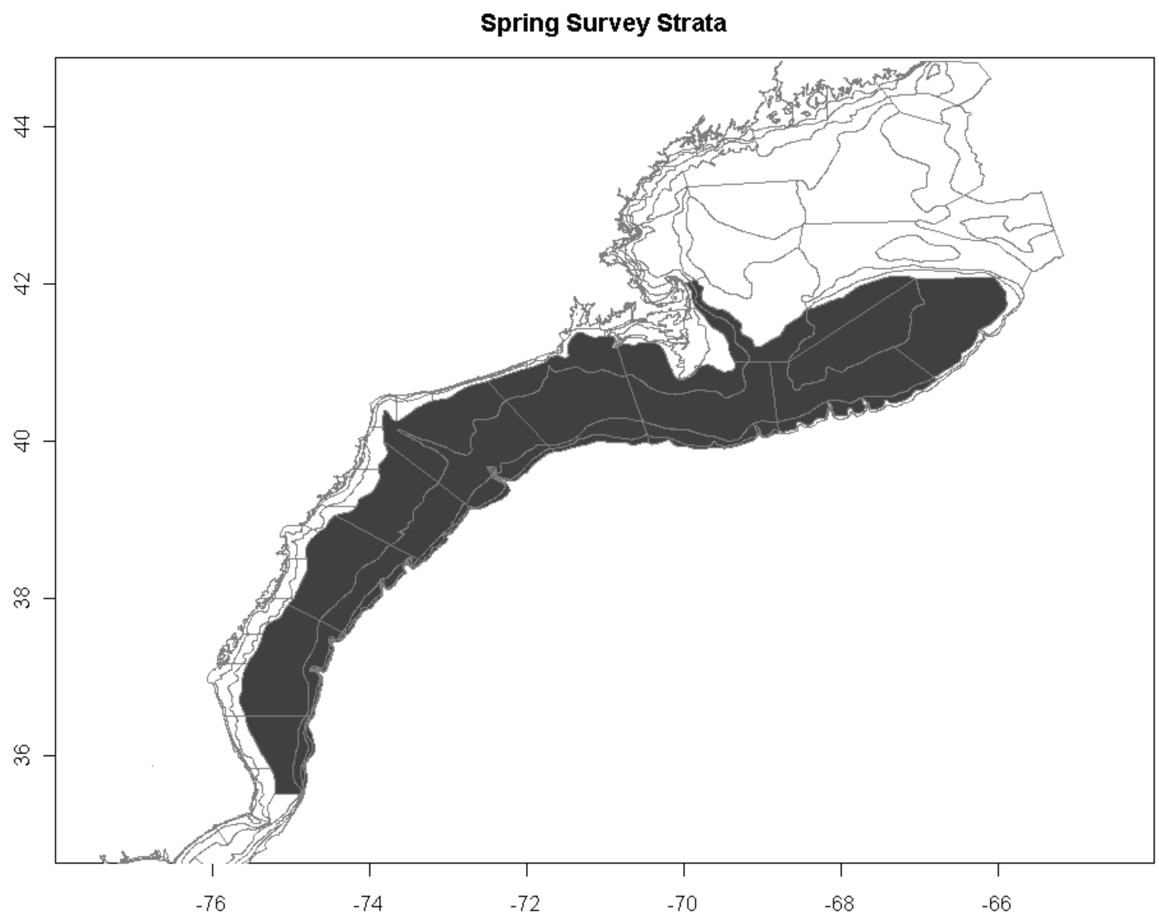

Figure B9. Strata used for NEFSC spring survey biomass indices.

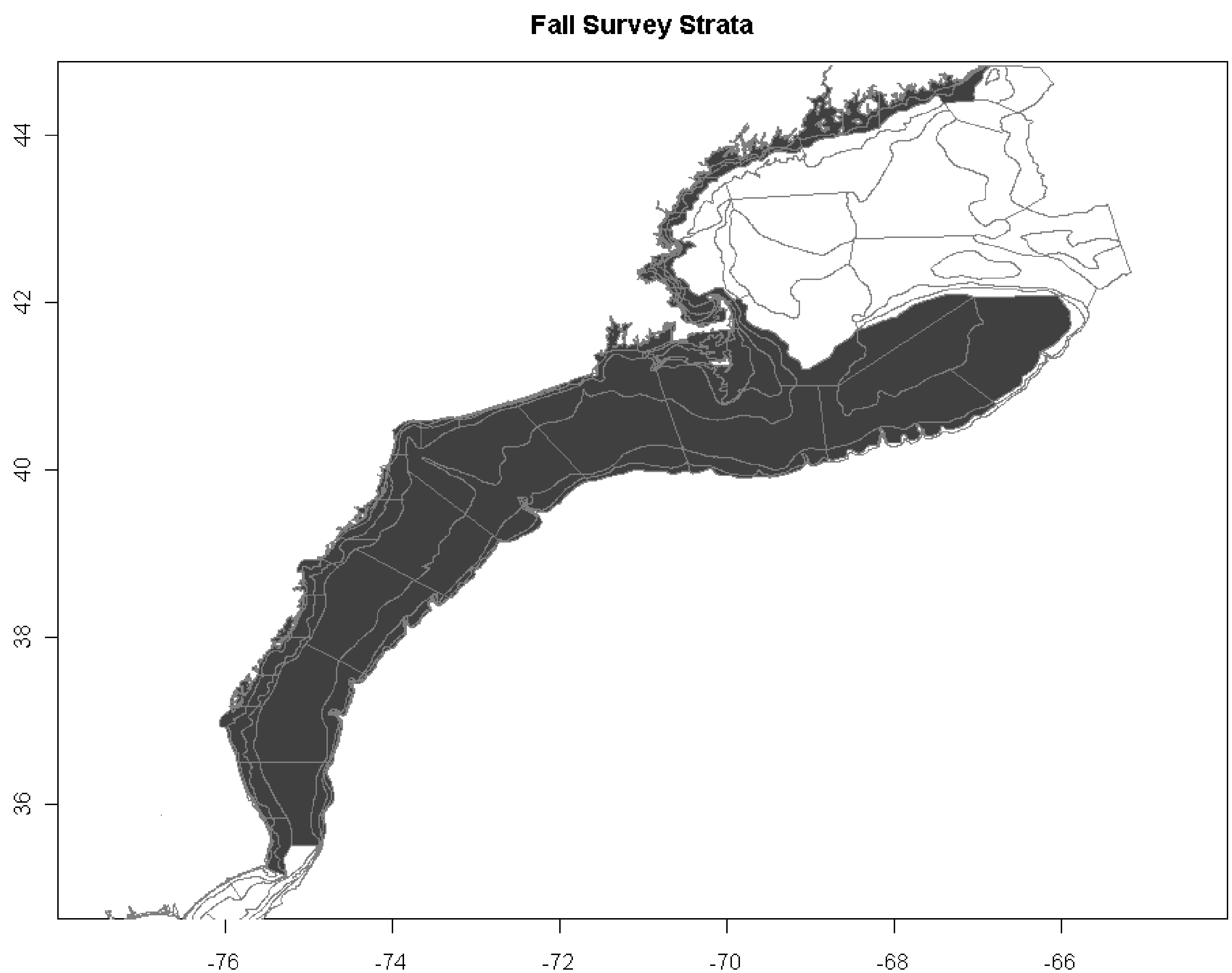

Figure B10. Strata used for NEFSC fall survey biomass indices.

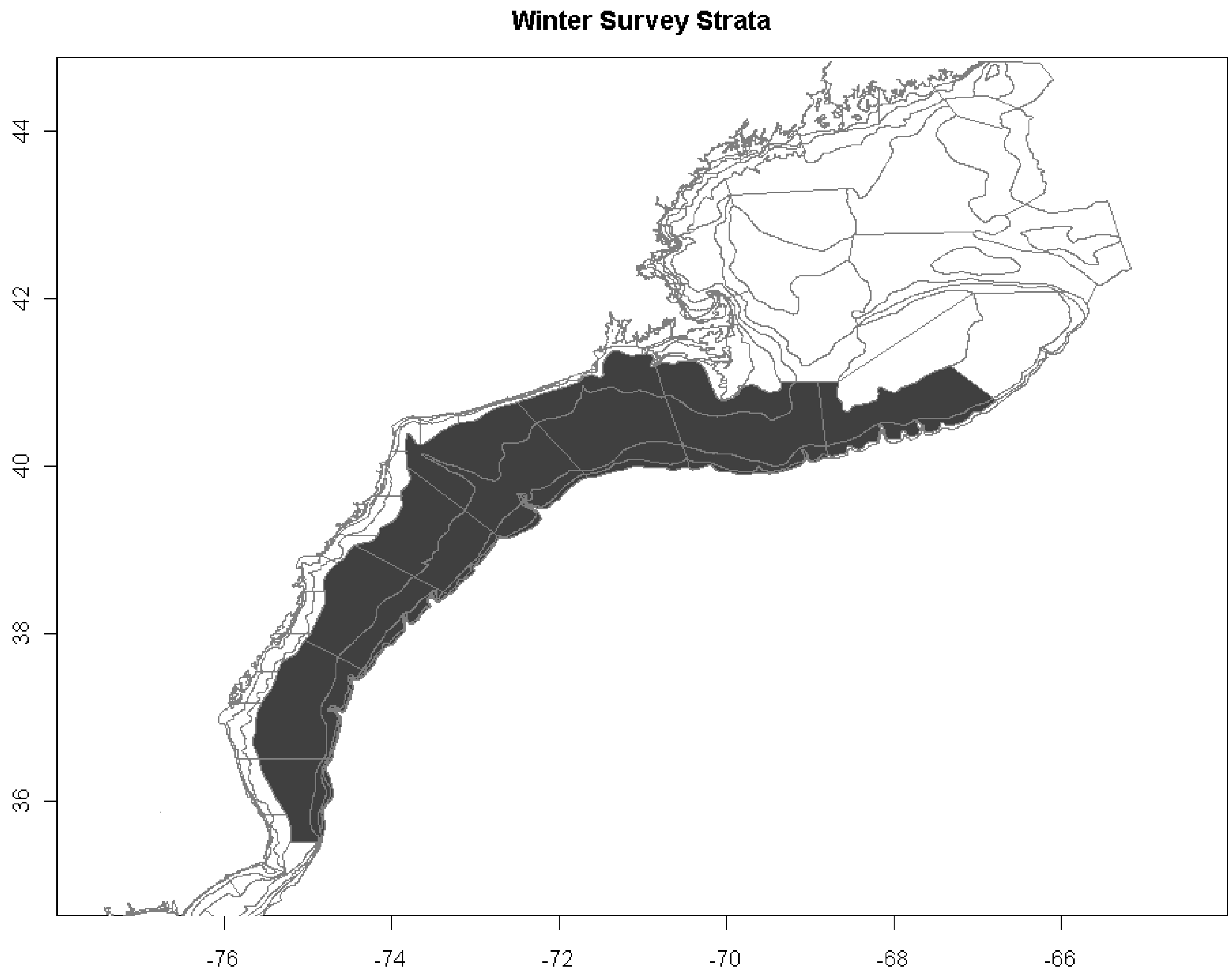

Figure B11. Strata used for NEFSC winter survey biomass indices.

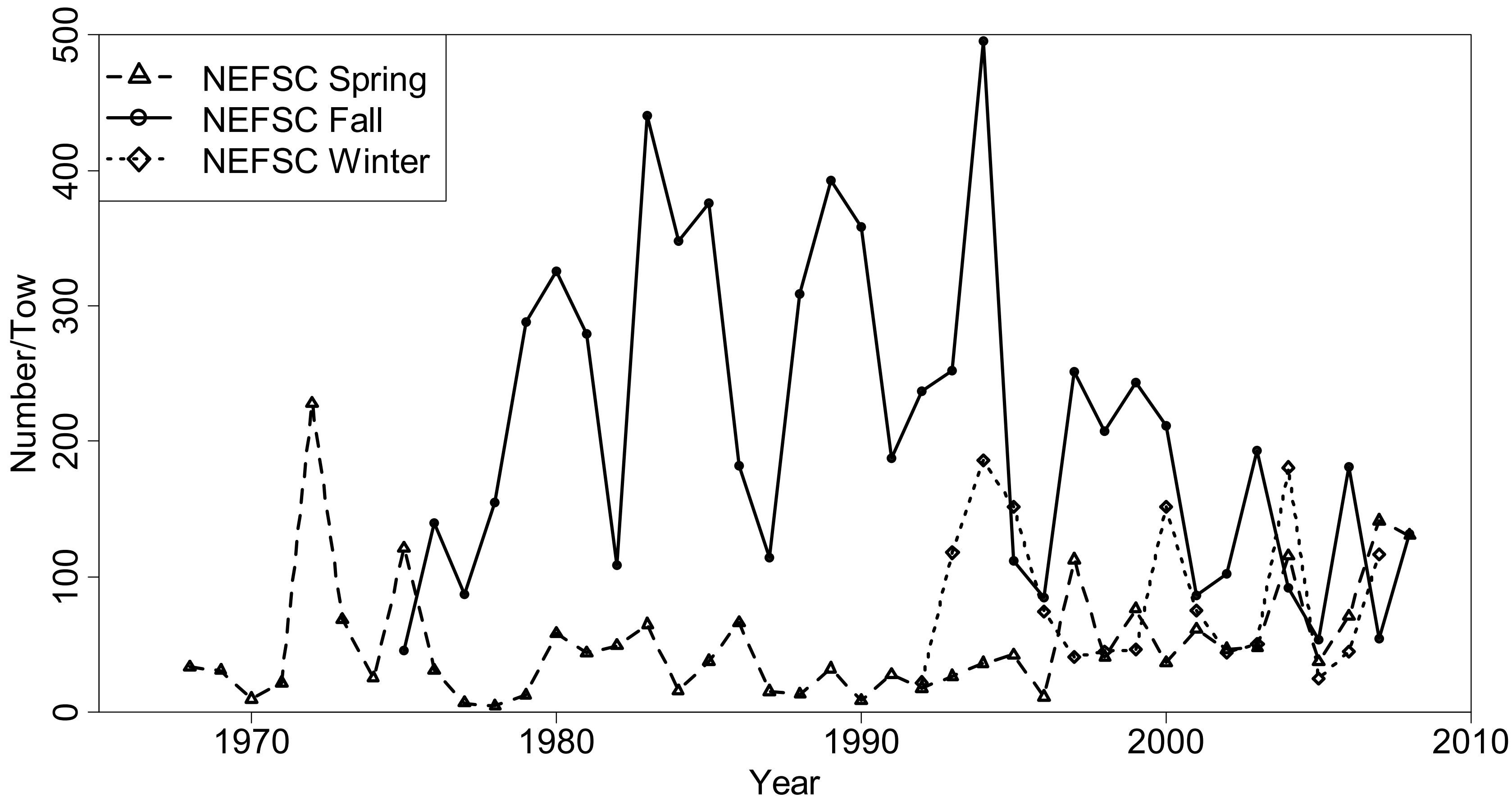

Figure B12. NEFSC spring (triangle), and autumn (circle) and winter (diamond) survey stratified mean number per tow for butterfish. Spring estimates include data from offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76), fall estimates include data from inshore (1-92) and offshore (1-14, 16, 19, 20, 23, 25, and 61-76) strata, and winter estimates include data from offshore strata(1-14 and 61-76).

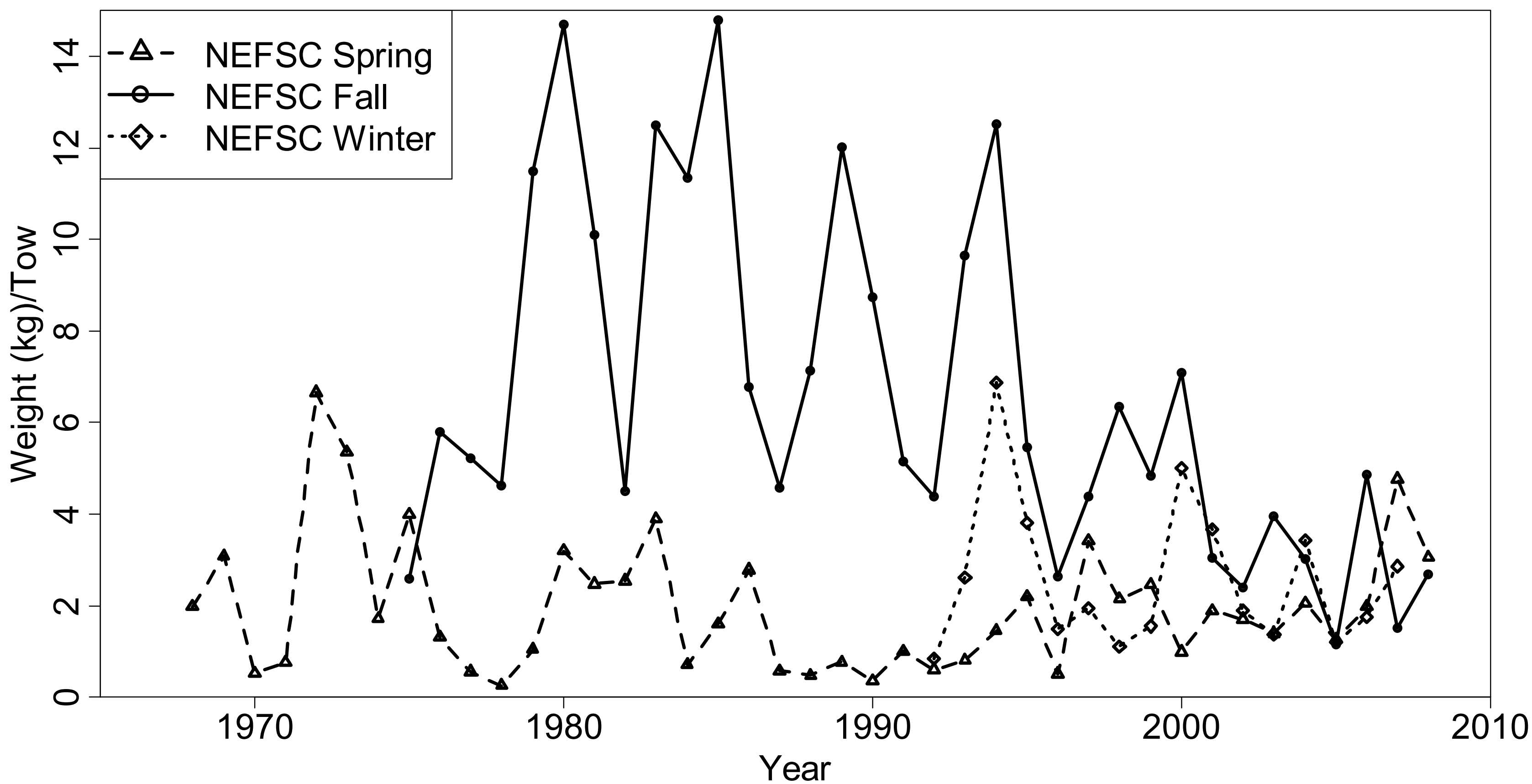

Figure B13. NEFSC spring (triangle), and autumn (circle) and winter (diamond) survey stratified mean weight per tow for butterfish. Spring estimates include data from offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76), fall estimates include data from inshore (1-92) and offshore (1-14, 16, 19, 20, 23, 25, and 61-76) strata, and winter estimates include data from offshore strata(1-14 and 61-76).

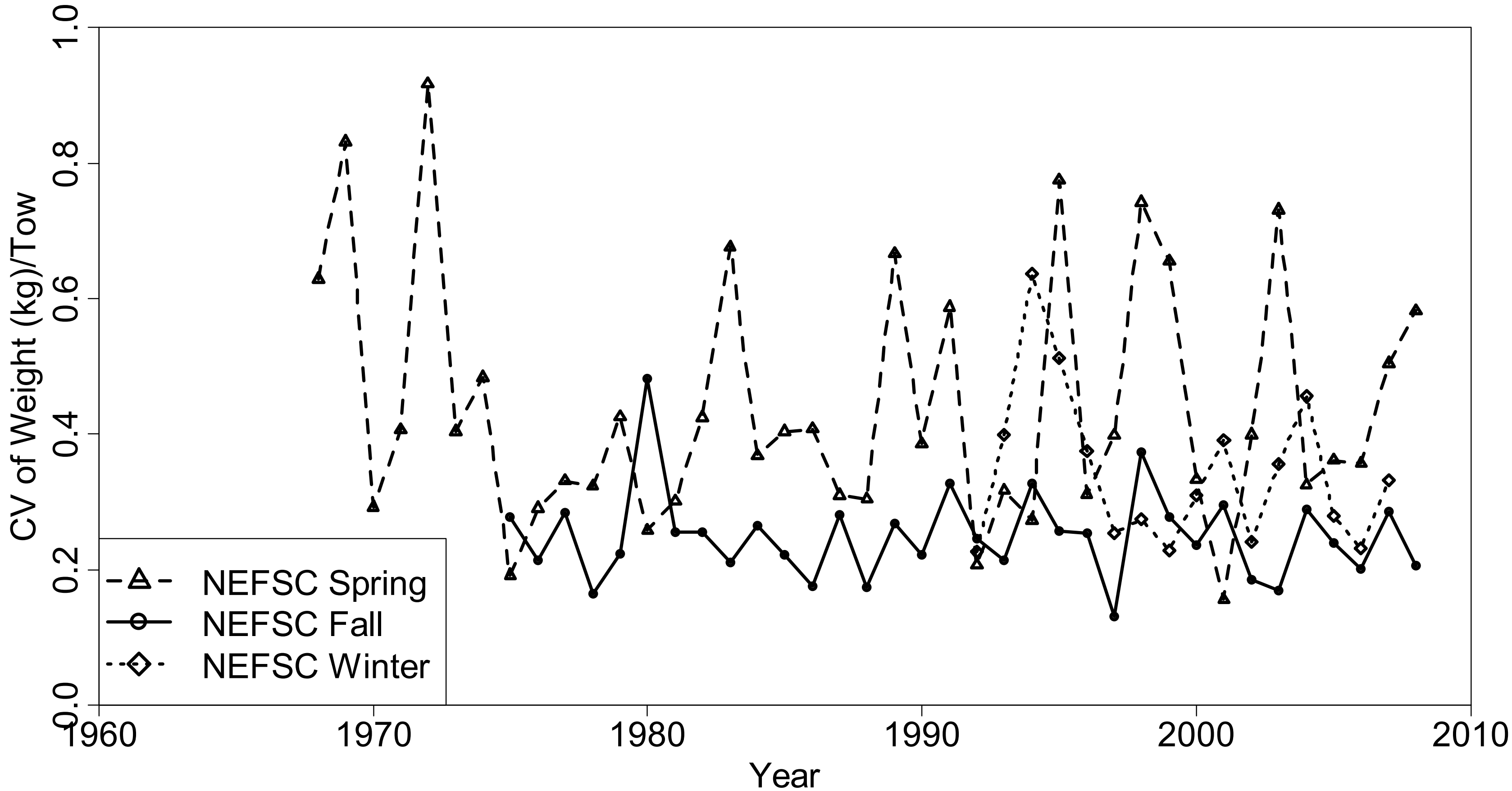

Figure B14. Coefficient of variation (CV) for NEFSC spring (triangle), and autumn (circle) and winter (diamond) survey stratified mean weight per tow for butterfish. Spring estimates include data from offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76), fall estimates include data from inshore (1-92) and offshore (1-14, 16, 19, 20, 23, 25, and 61-76) strata, and winter estimates include data from offshore strata(1-14 and 61-76).

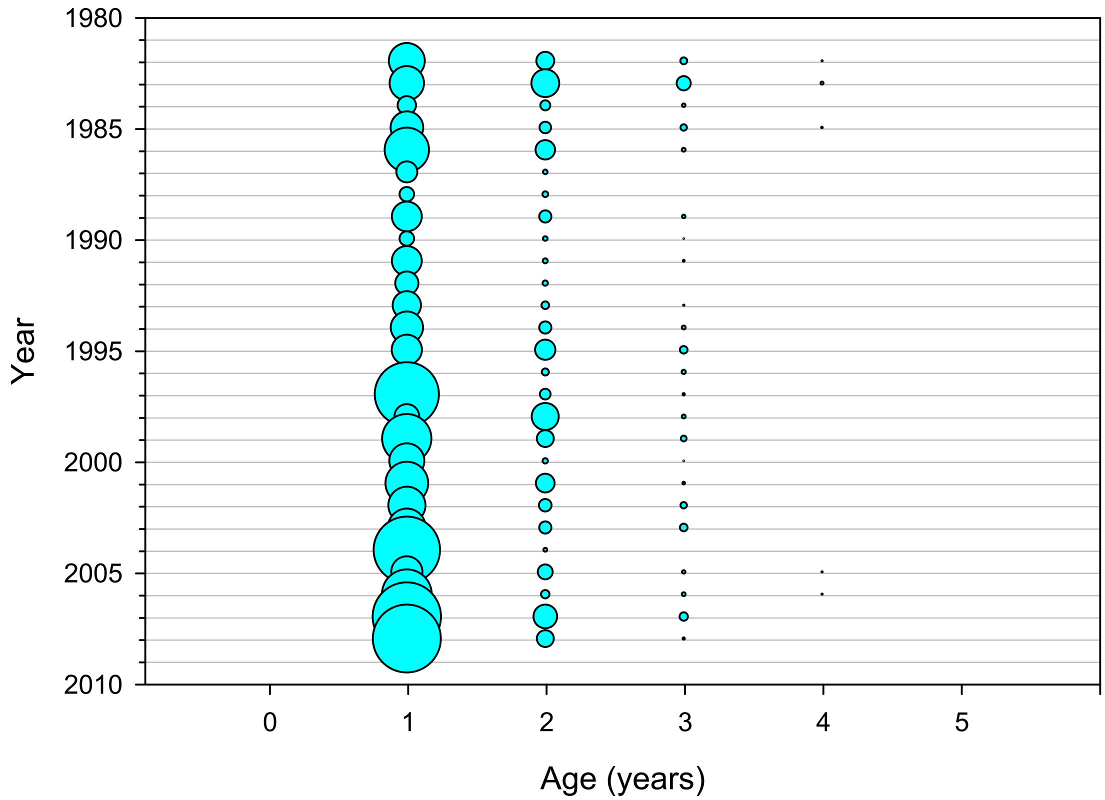

Figure B15. Age composition of butterfish in NEFSC spring bottom trawl surveys, 1982-2008.

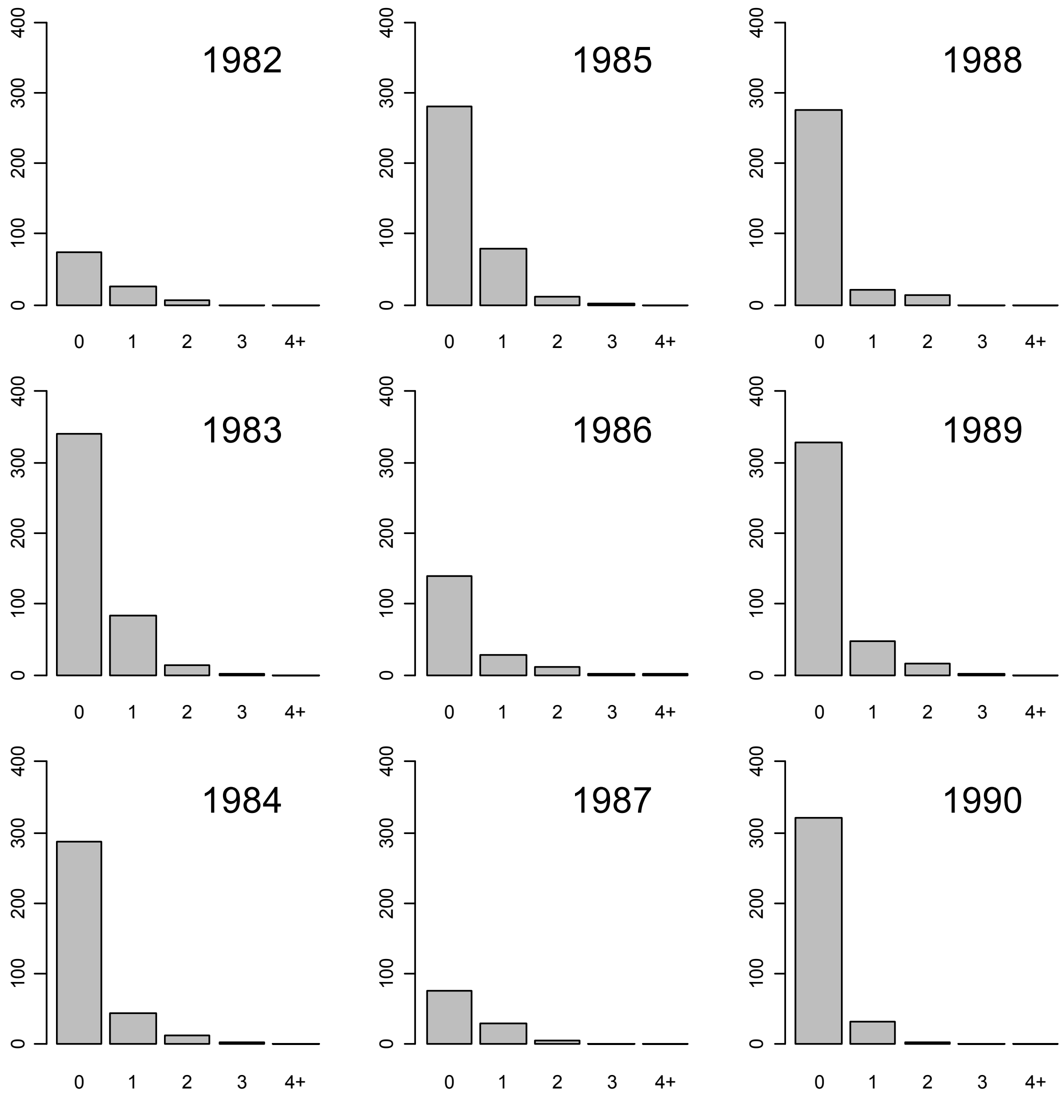

Figure B16. Annual (1982-1990) age composition (numbers/tow) for the NEFSC fall survey combining inshore and offshore strata.

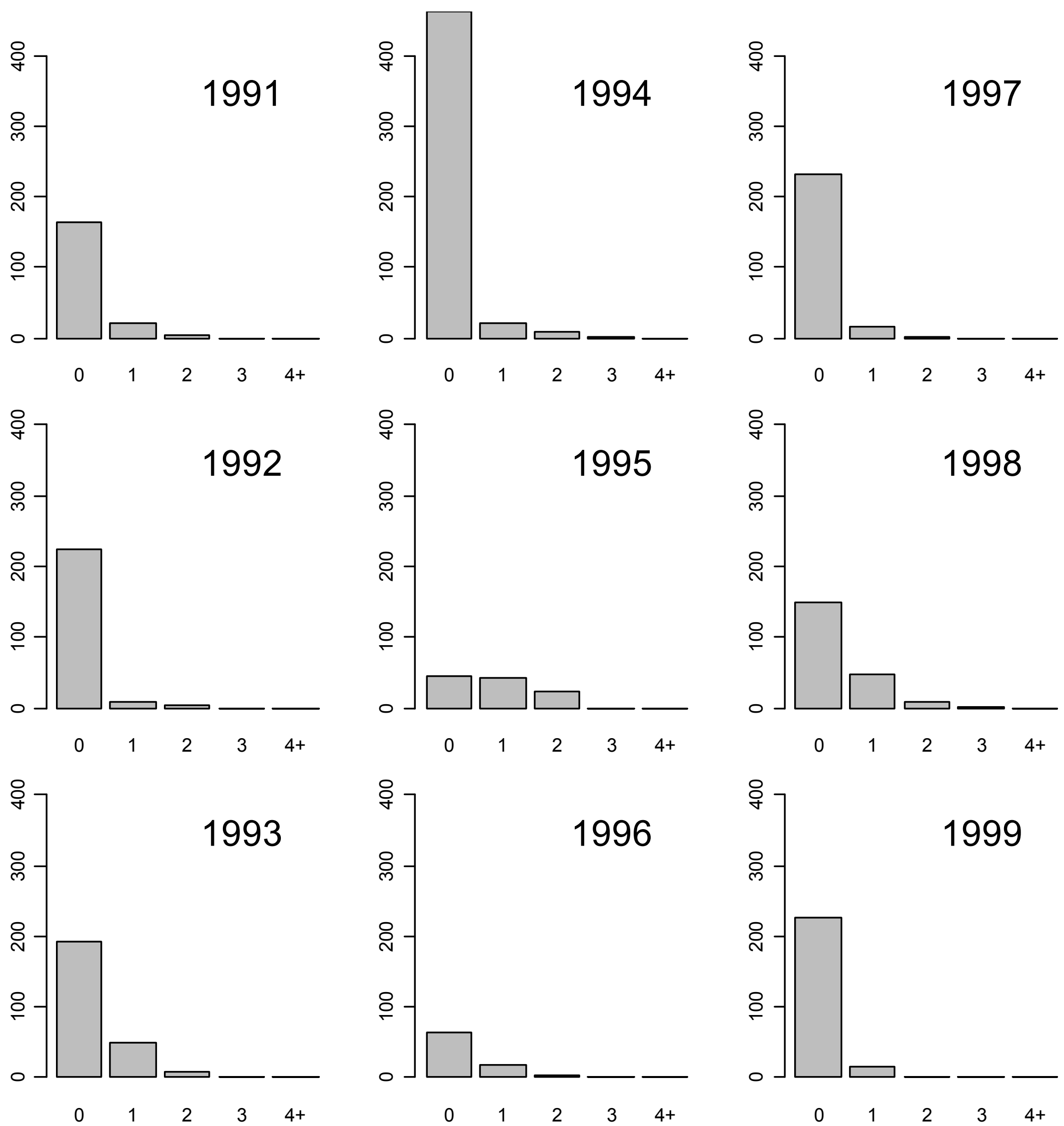

Figure B17. Annual (1991-1999) age composition (numbers/tow) for the NEFSC fall survey combining inshore and offshore strata.

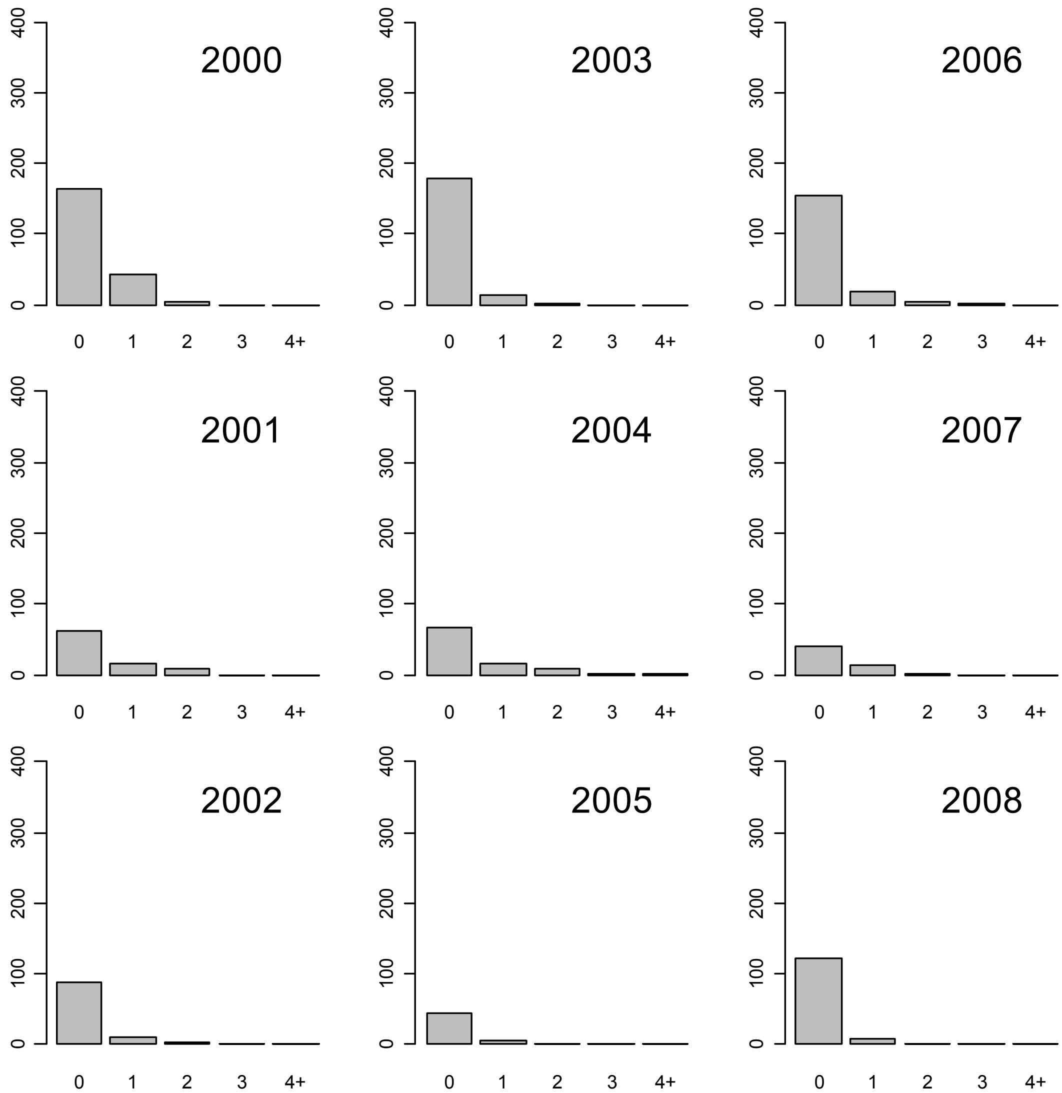

Figure B18. Annual (2000-2008) age composition (numbers/tow) for the NEFSC fall survey combining inshore and offshore strata.

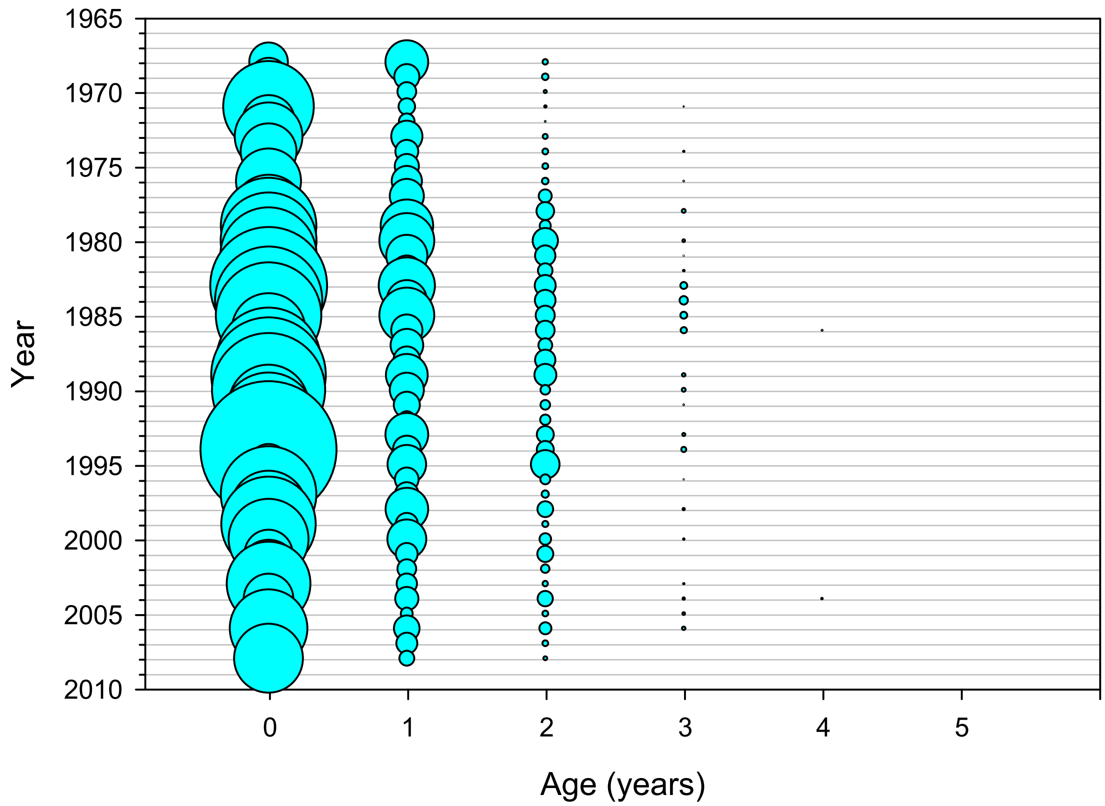

Figure B19. Age composition of butterfish in NEFSC fall bottom trawl surveys, 1968-2008.

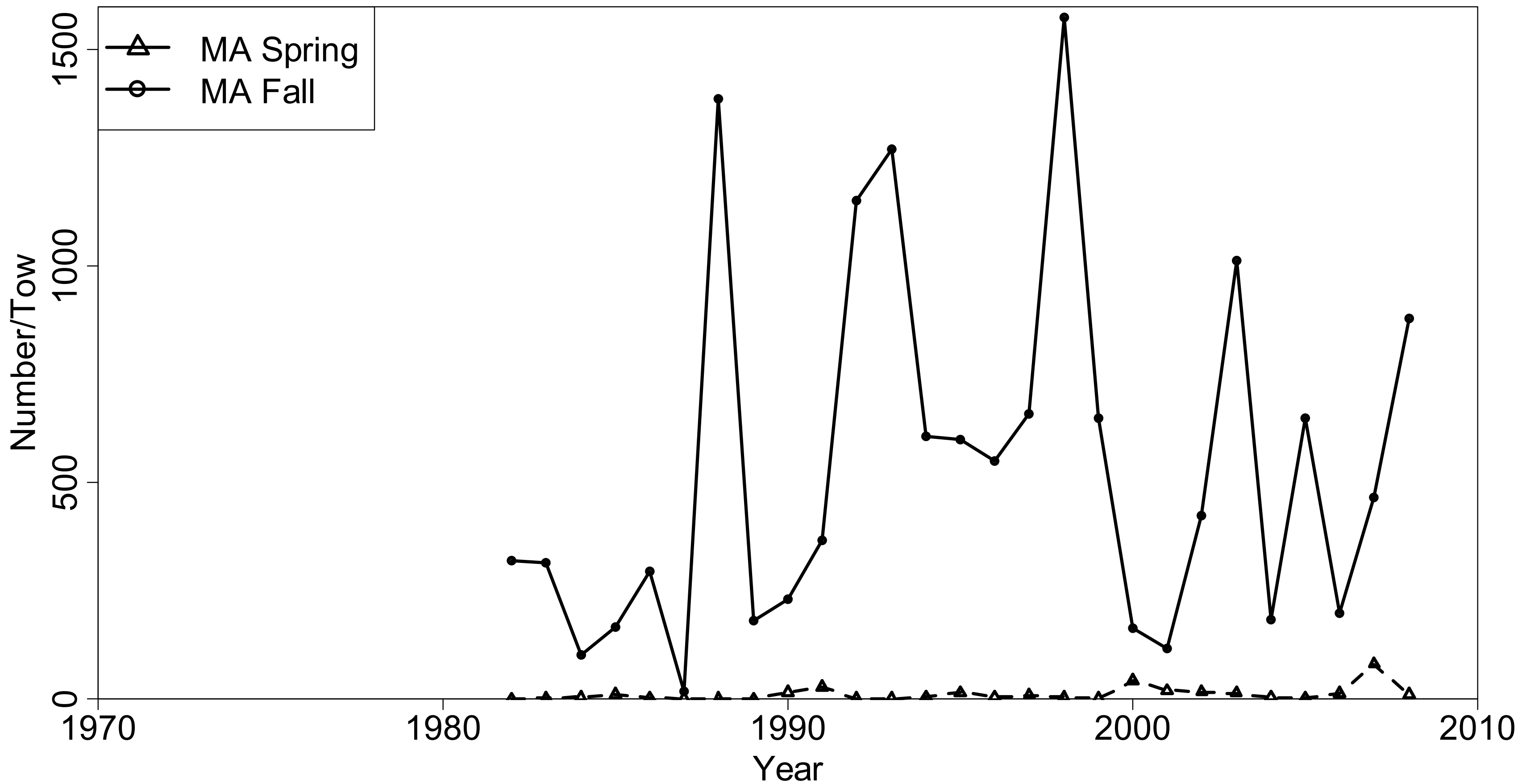

Figure B20. Massachusetts state survey stratified mean number per tow for butterfish in spring (triangle), and fall (circle).

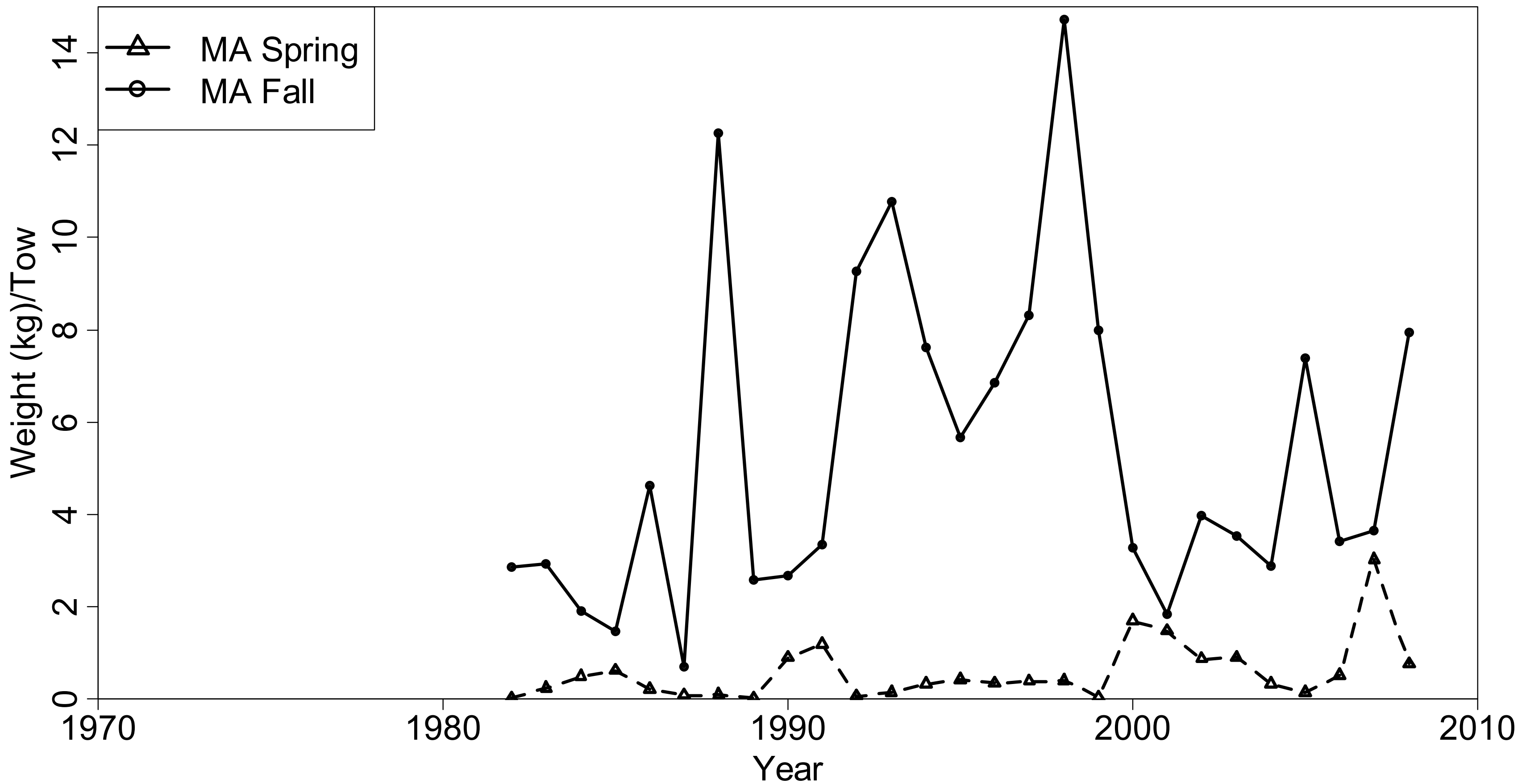

Figure B21. Massachusetts state survey stratified mean weight per tow for butterfish in spring (triangle), and fall (circle).

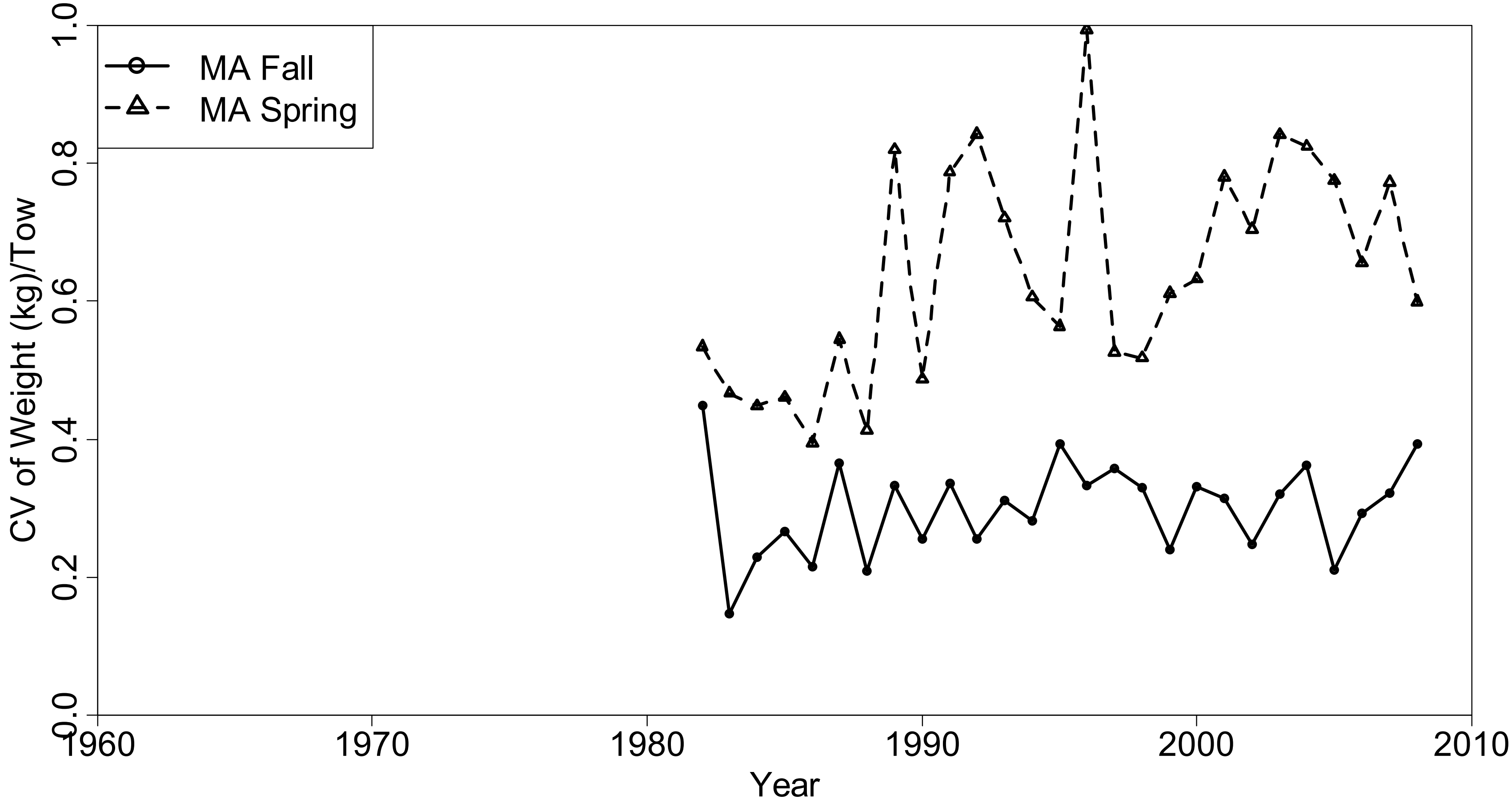

Figure B22. Coefficient of variation (CV) of Massachusetts state survey stratified mean weight per tow for butterfish in spring (triangle), and fall (circle).

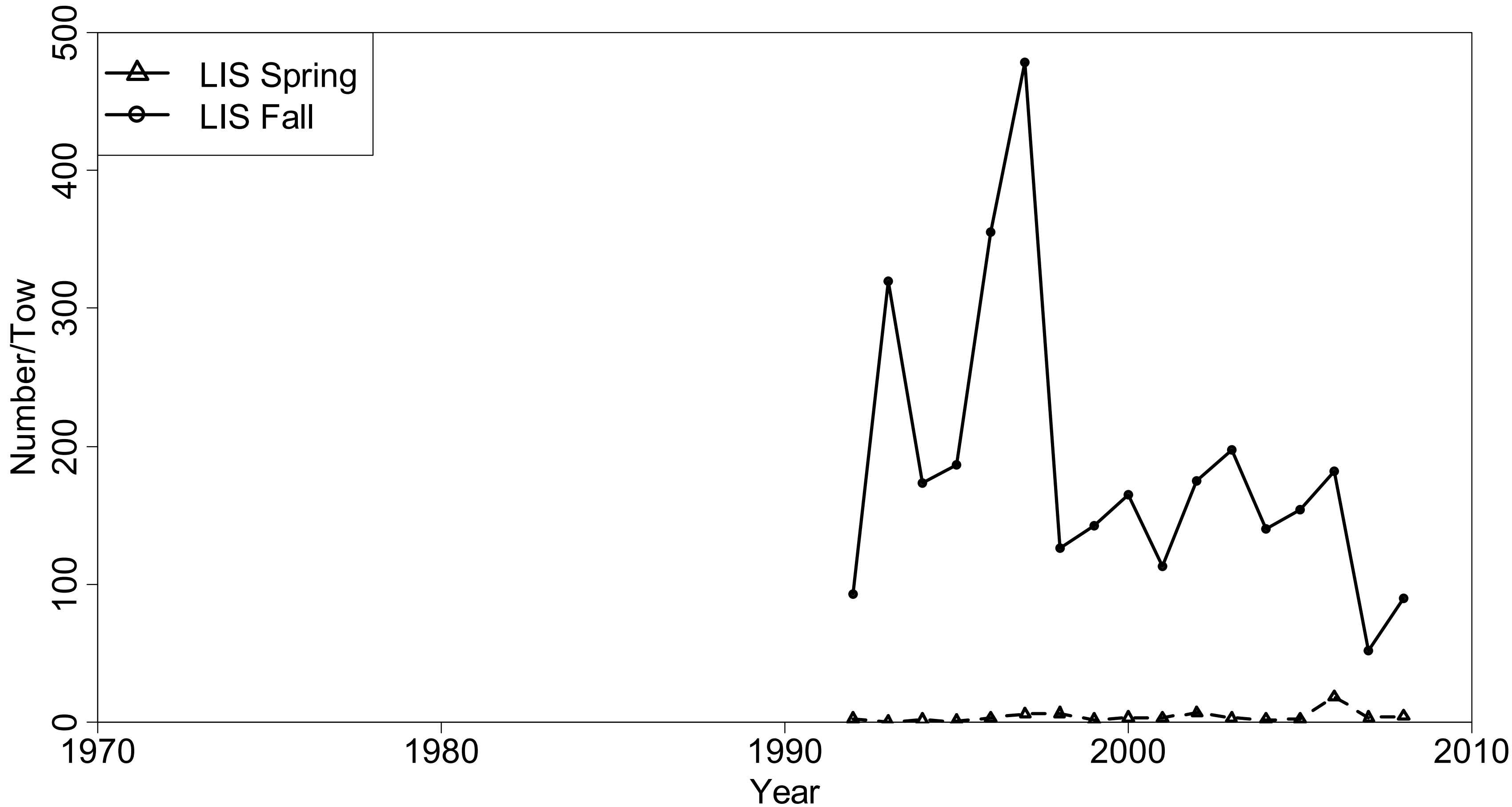

Figure B23. Connecticut state survey (Long Island Sound) number per tow for butterfish in spring (triangle), and autumn (circle).

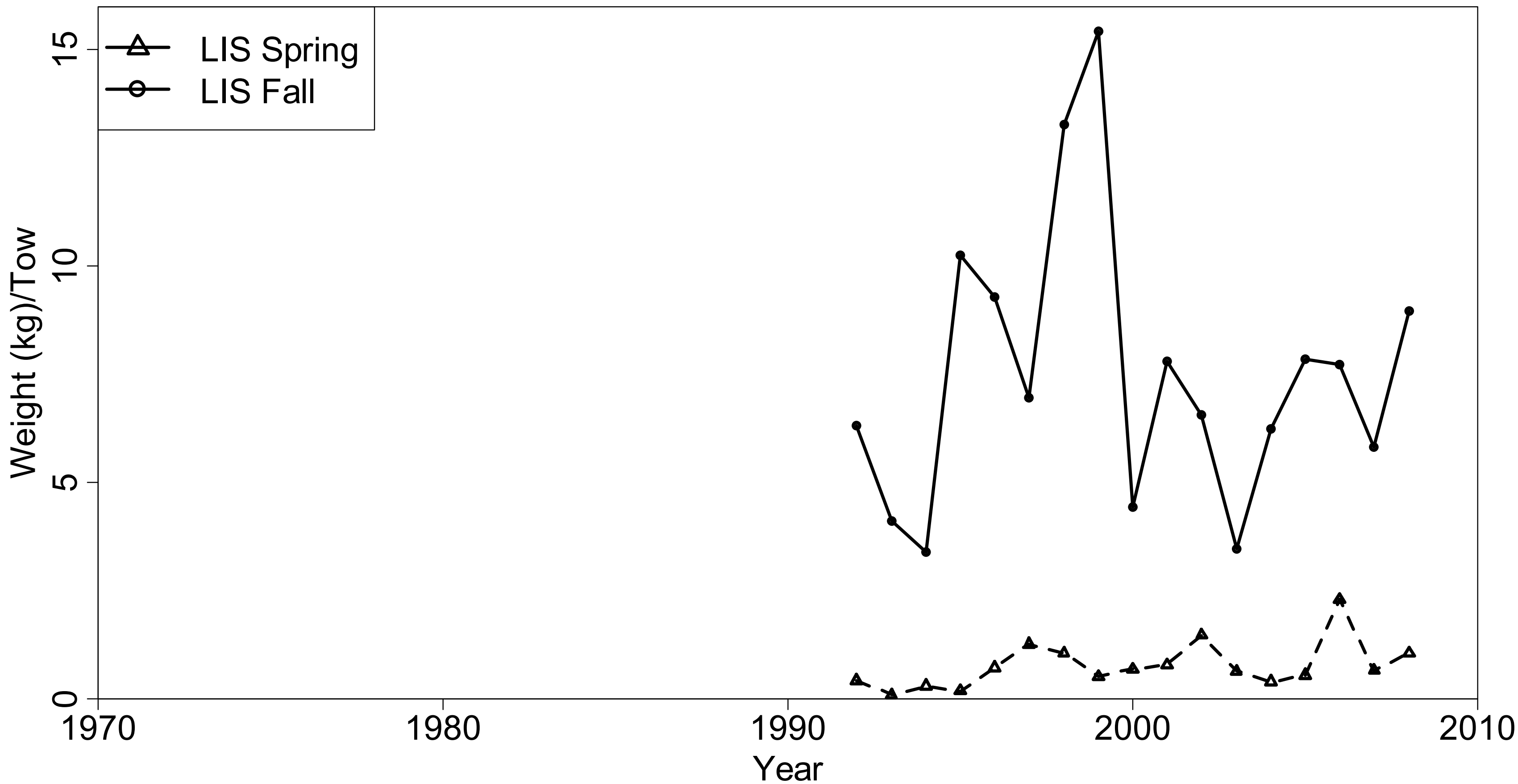

Figure B24. Connecticut state survey (Long Island Sound) weight per tow for butterfish in spring (triangle), and autumn (circle).

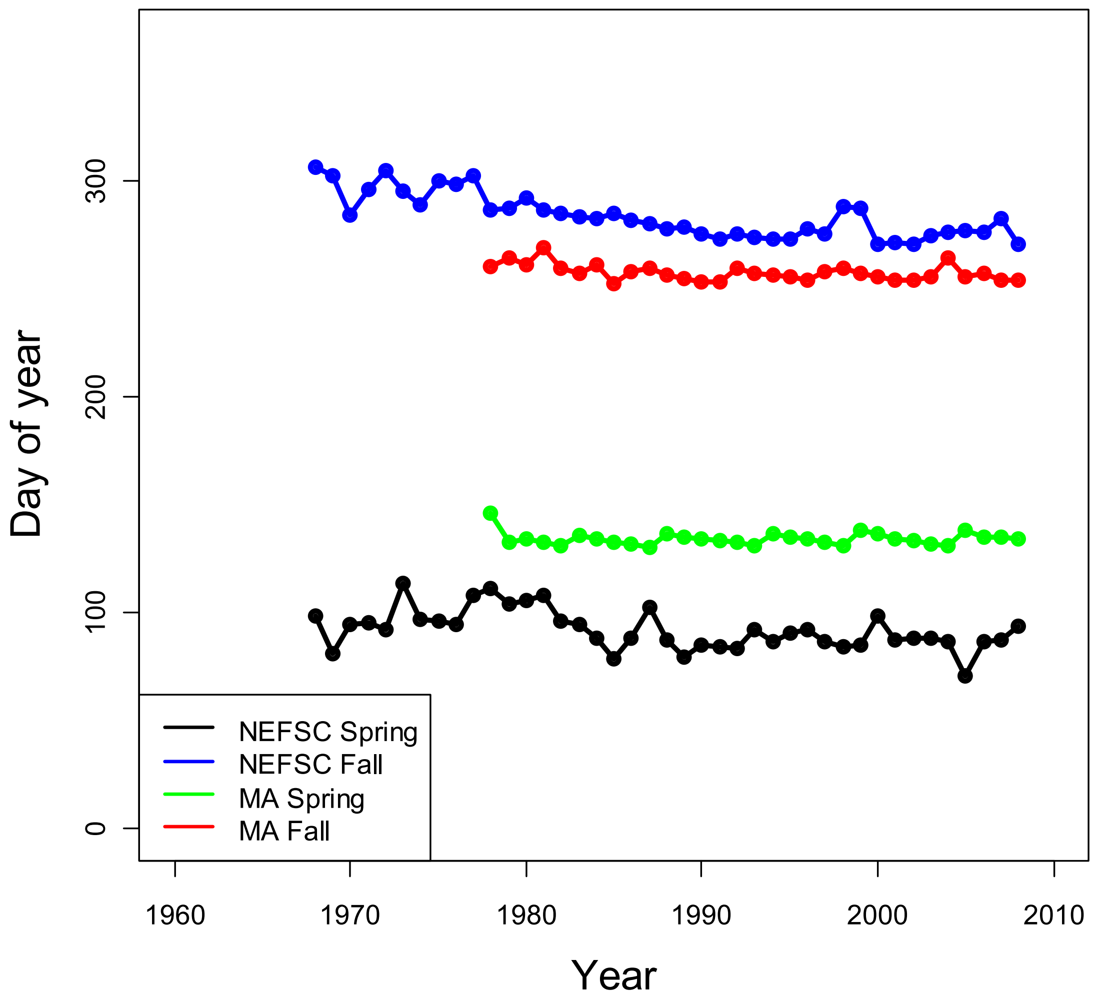

Figure B25. Average Julian day for NEFSC and Massachusetts state annual surveys.

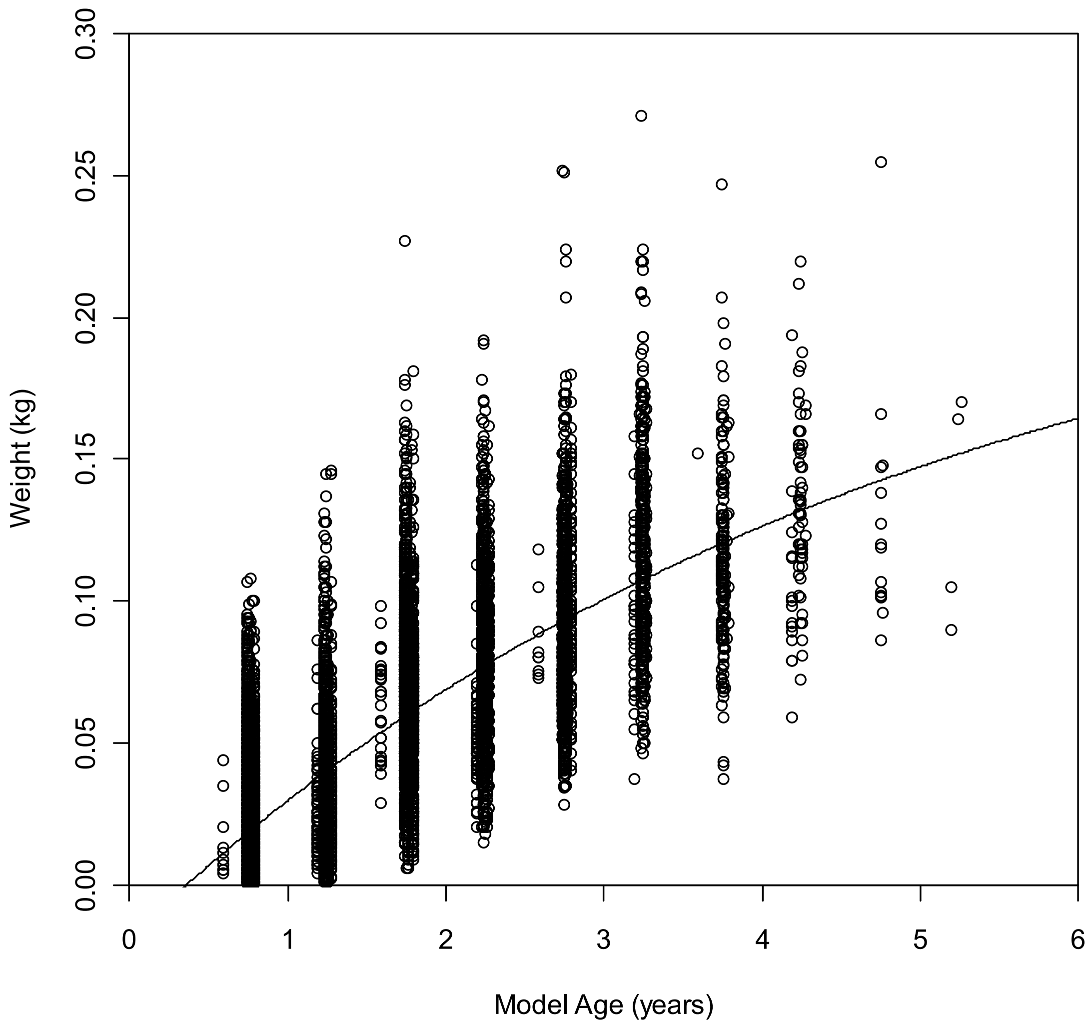

Figure B26. Attributed model age and weight and predicted weight at age from fitted Schnute (1985) growth model fit to NEFSC survey data from 1992-2009.

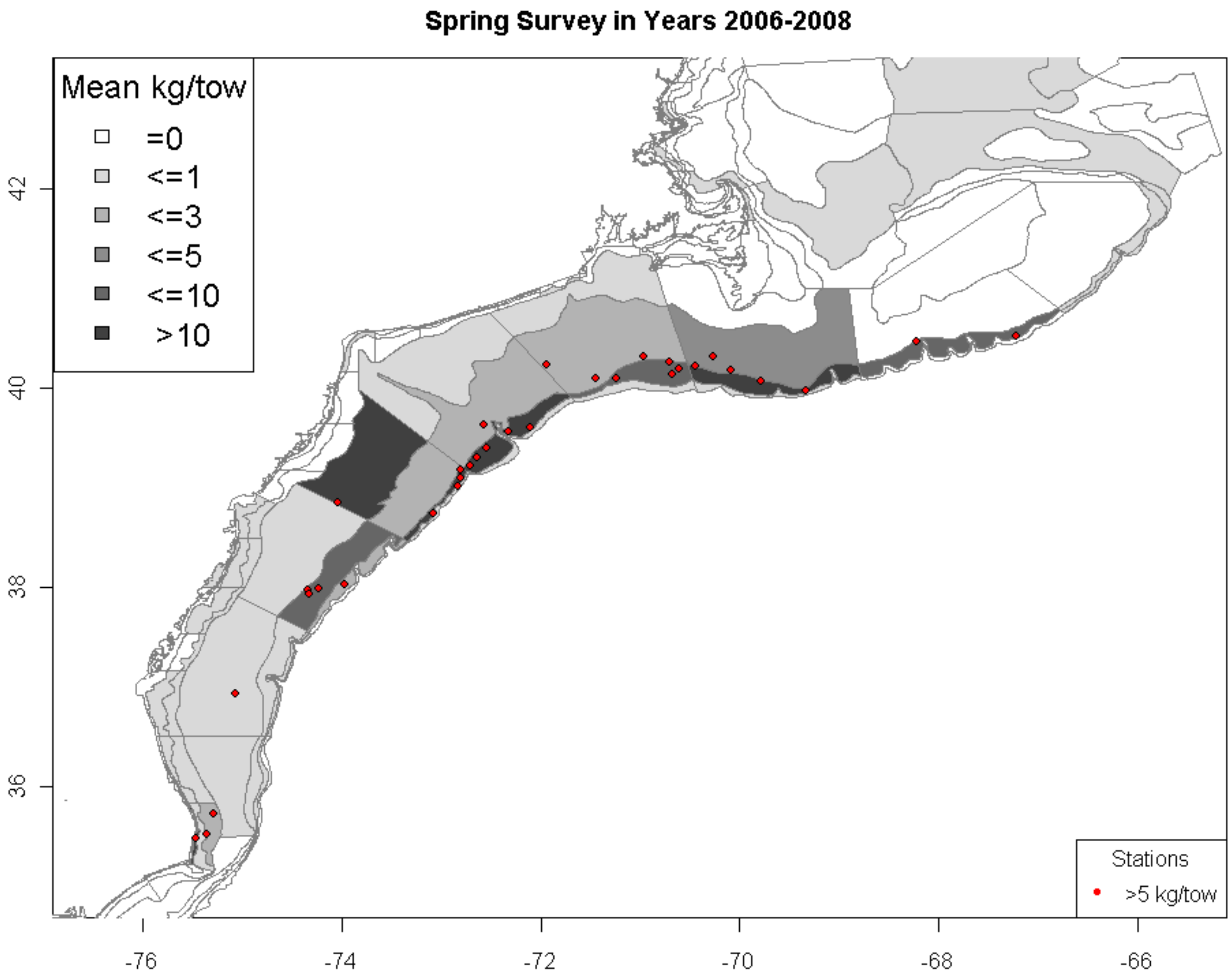

Figure B27. Mean butterfish catch (kg) per tow by stratum in the NEFSC spring survey for all sampled stations between 2006 and 2008 and location of stations where greater than 5 kg were observed.

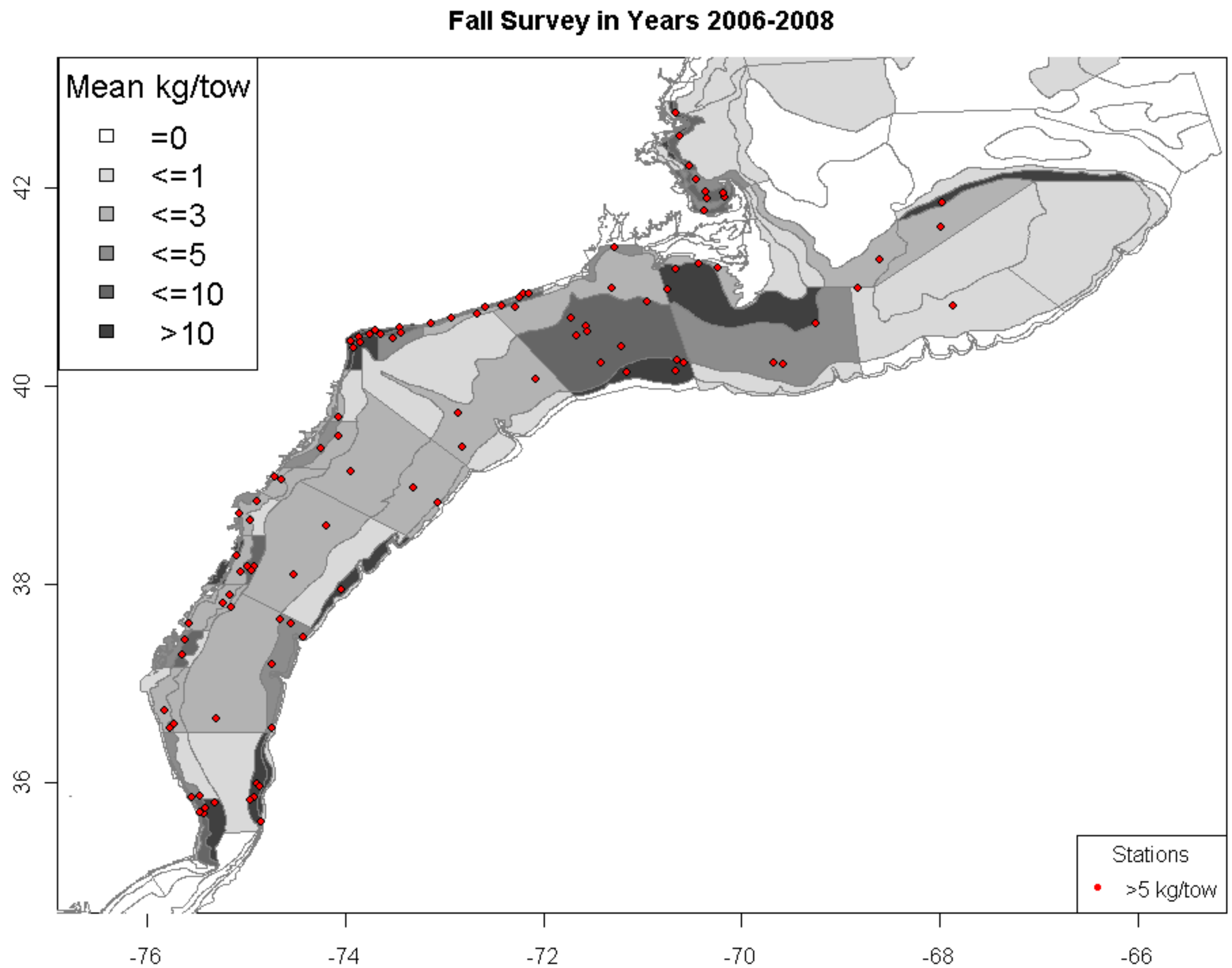

Figure B28. Mean butterfish catch (kg) per tow by stratum in the NEFSC fall survey for all sampled stations between 2006 and 2008 and location of stations where greater than 5 kg were observed.

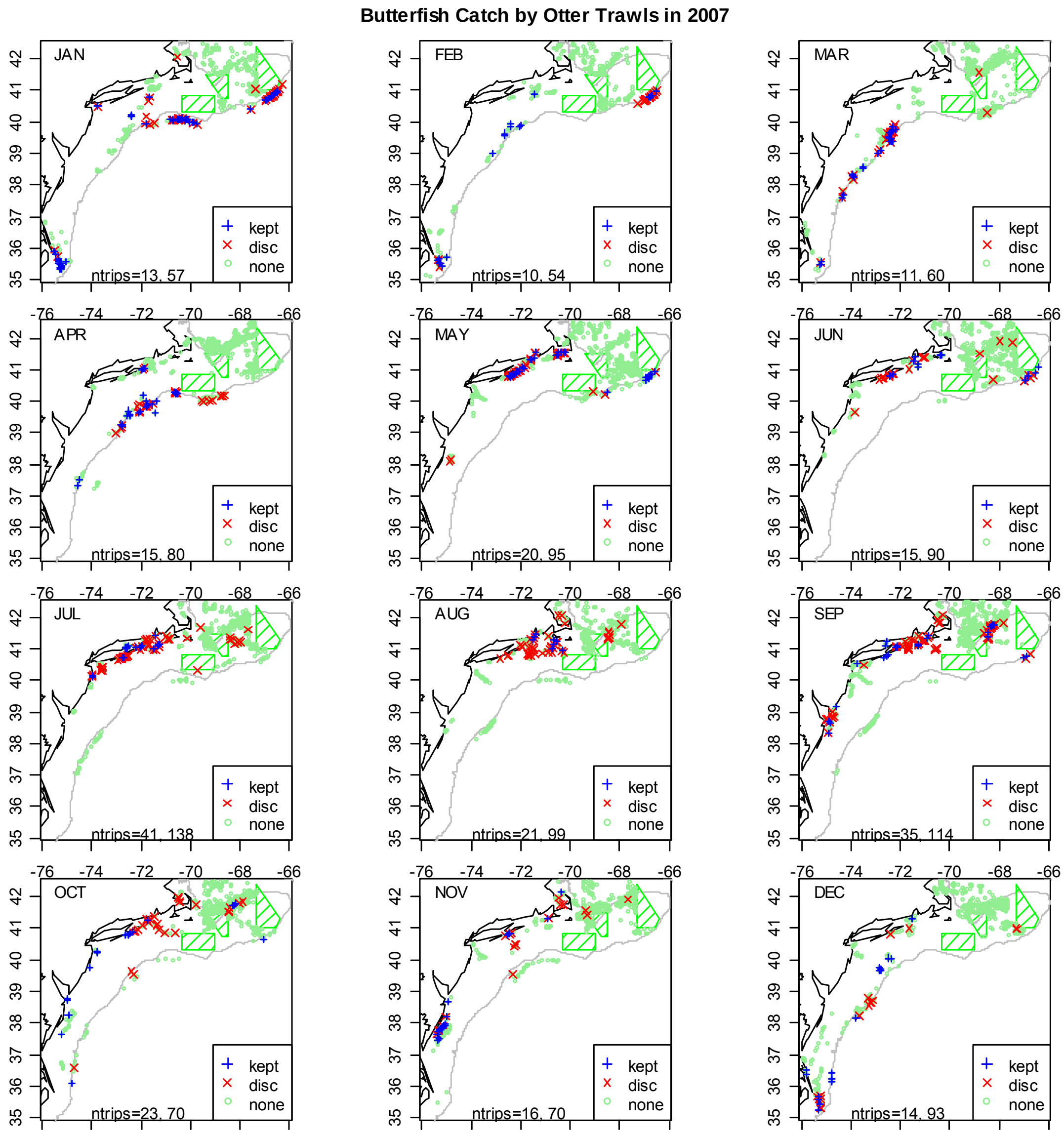

Figure B29. Observed commercial bottom trawl tows in 2007 where butterfish were absent (green circle), present and kept (blue +), and present and discarded (red x).

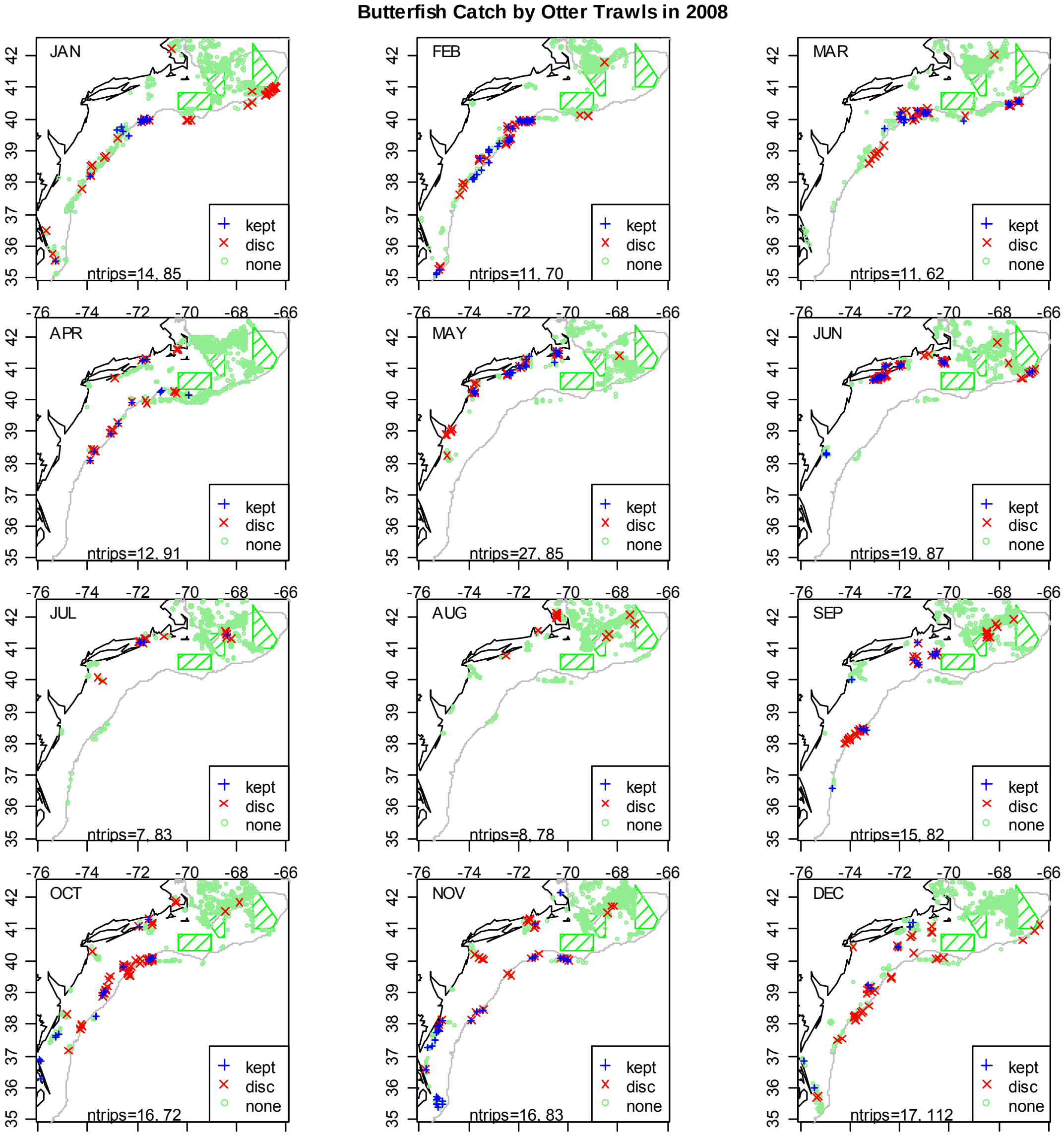

Figure B30. Observed commercial bottom trawl tows in 2008 where butterfish were absent (green circle), present and kept (blue +), and present and discarded (red x).

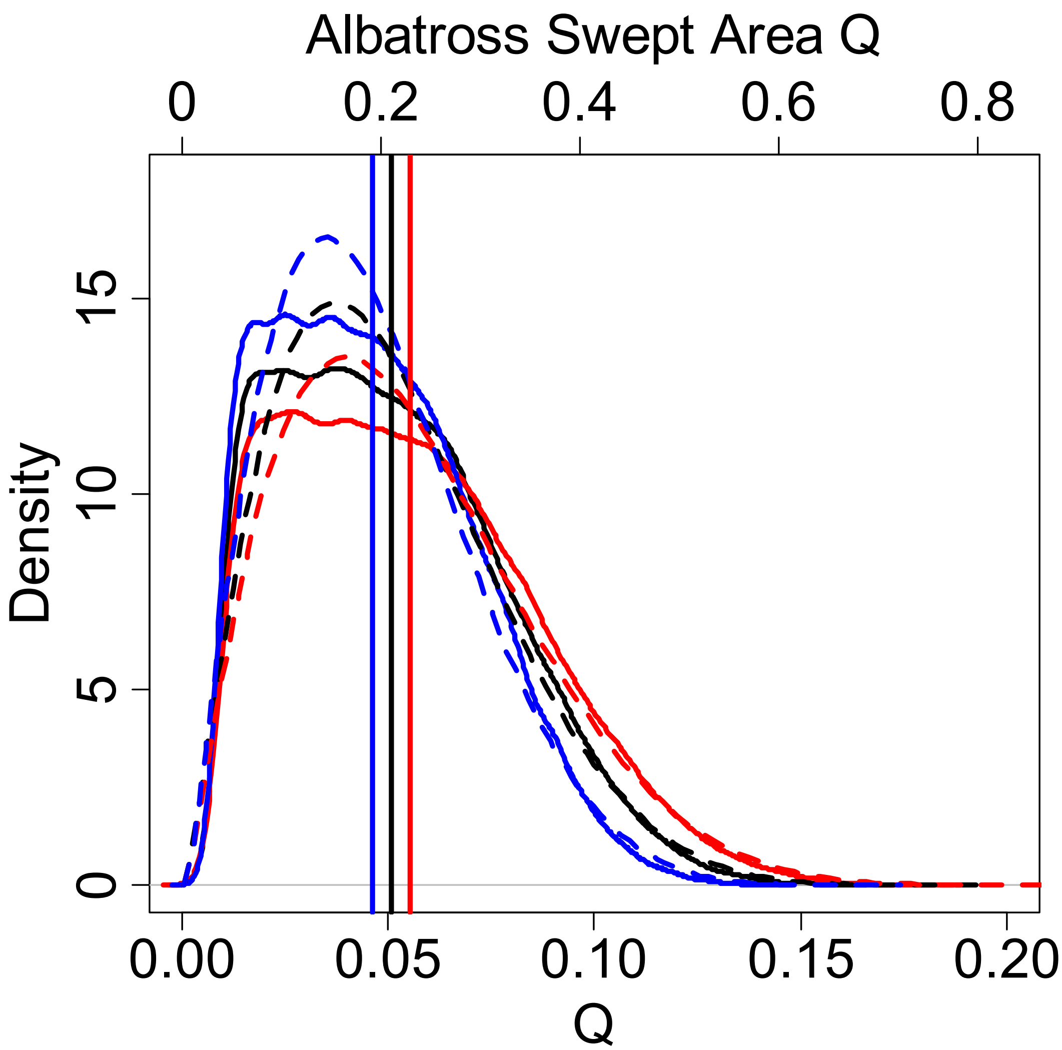

Figure B31. Empirical distribution (solid black) of the catchability parameter (swept area catchability on the top axis) for the NEFSC fall adult index as a product of known scalars and of random variables for unknown components and beta distribution (dashed black) with the same mean and variance used as a prior in the final model. Blue and red represent corresponding distributions when maxima for the ratio of survey and stock area and the efficiency of the Bigelow are 0.85 and 0.95. Vertical solid lines are the means of the distributions.

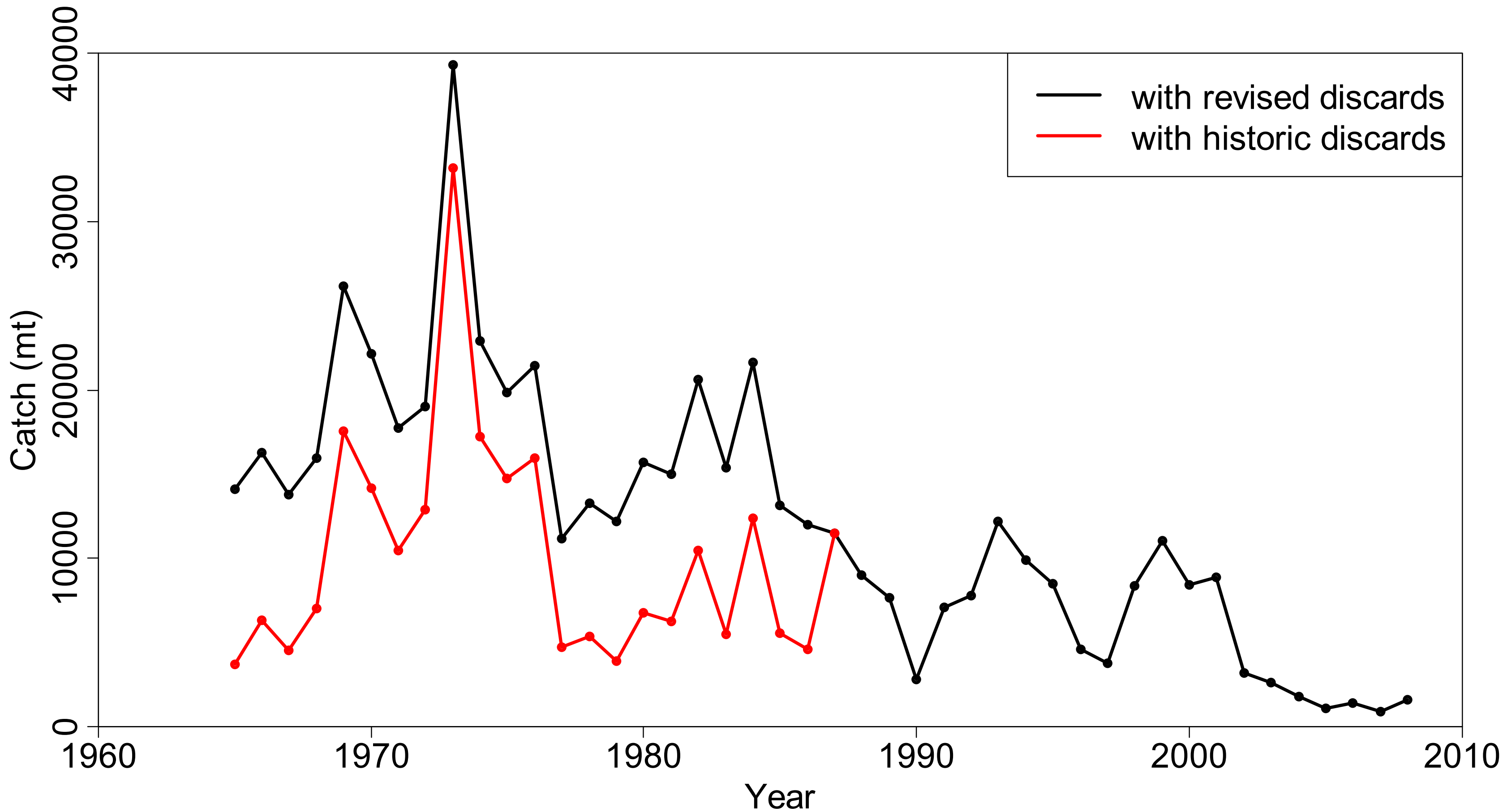

Figure B32. Total Catch including US landings, foreign catch and US new discard estimates (black) or US discards as reported by Waring and Anderson (1983) and NEFSC (1990) (red).

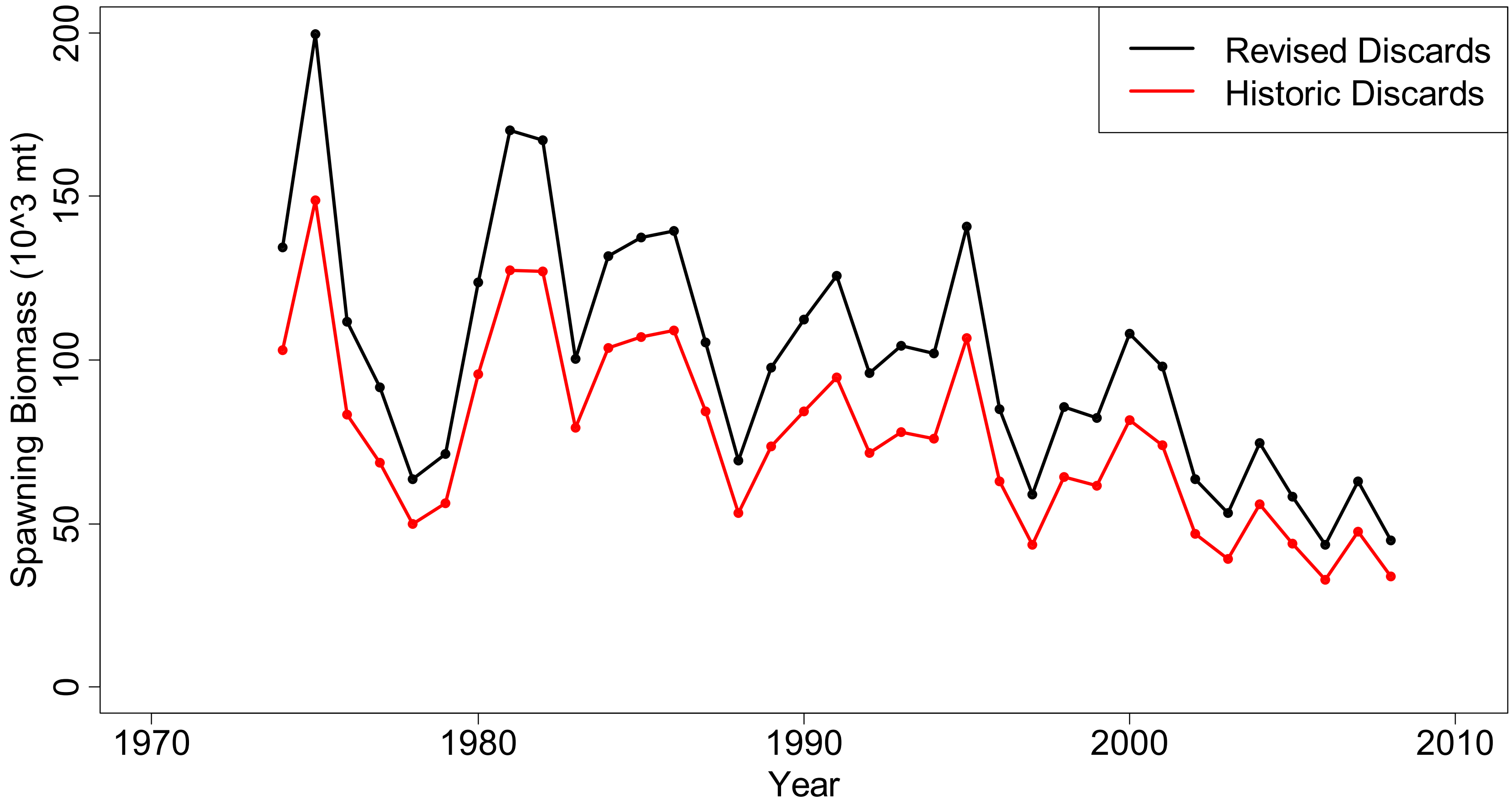

Figure B33. Estimates of spawning biomass from the final model when revised discard estimates between 1973 and 1986 are used in the total catch (black) (final model) or the discard estimates provided in early assessment documents are used in the total catch (red).

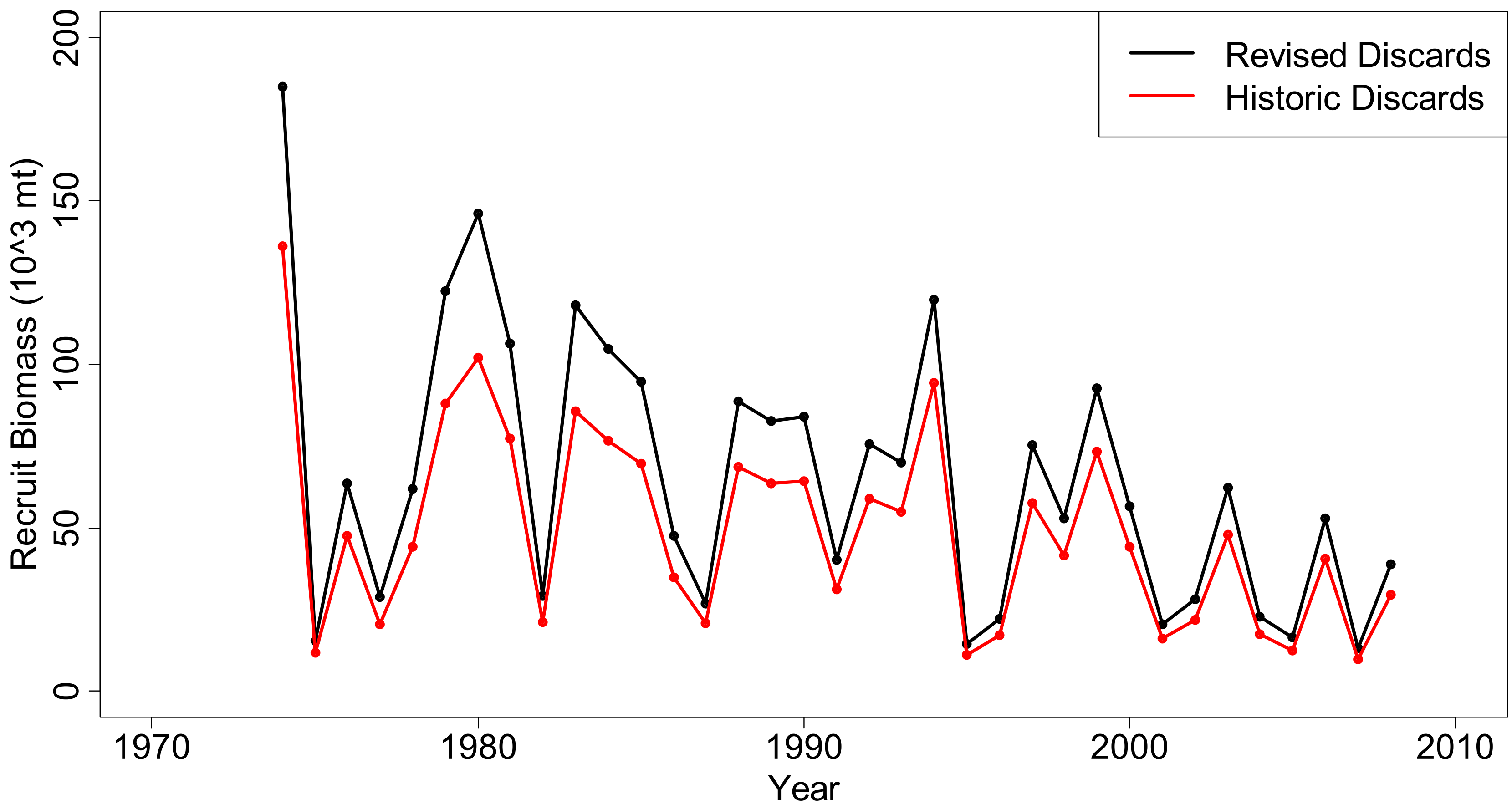

Figure B34. Estimates of recruit biomass from the final model when revised discard estimates between 1973 and 1986 are used in the total catch (black) (final model) or the discard estimates provided in early assessment documents are used in the total catch (red).

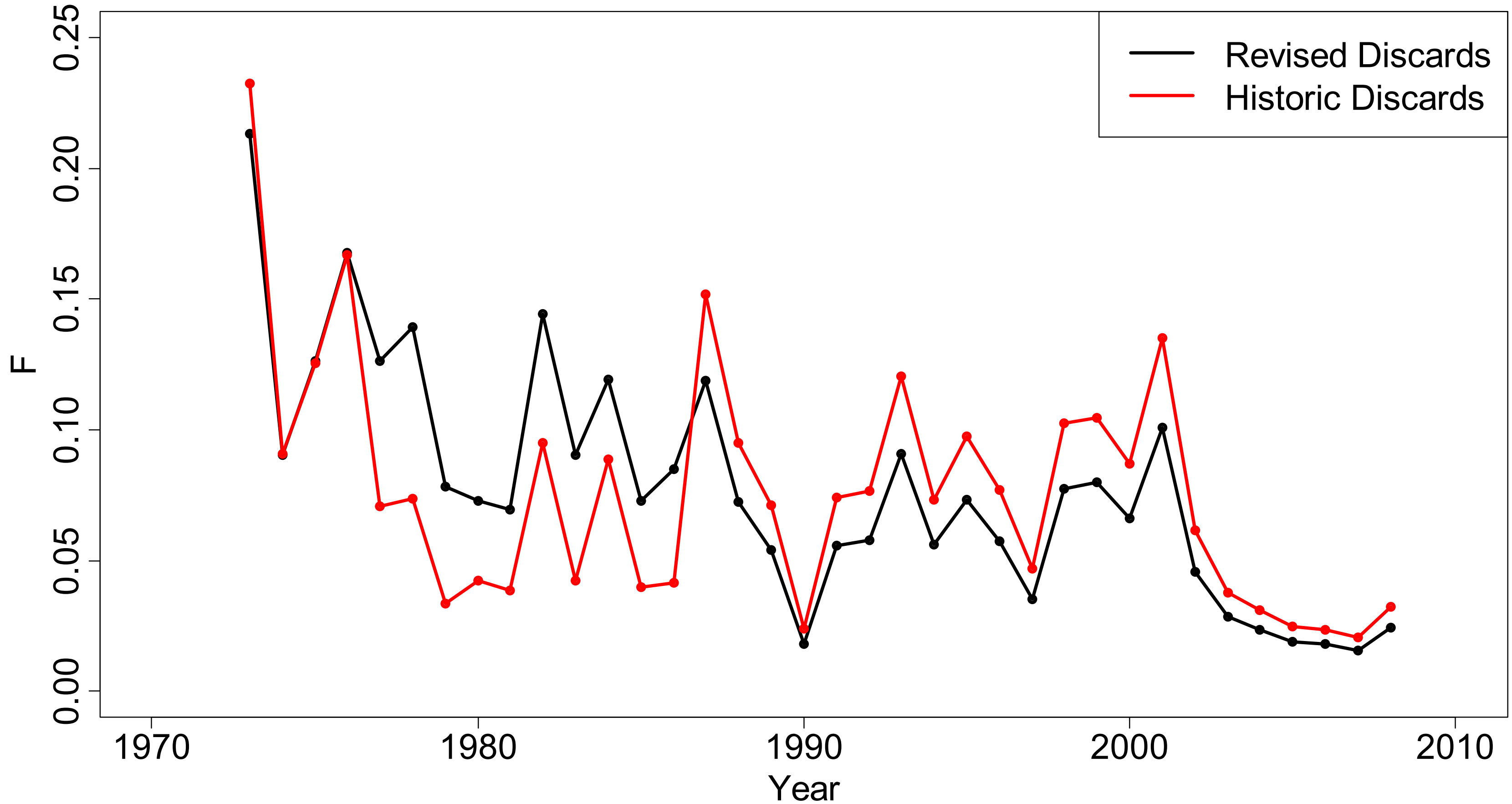

Figure B35. Estimates of fishing mortality from the final model when revised discard estimates between 1973 and 1986 are used in the total catch (black) (final model) or the discard estimates provided in early assessment documents are used in the total catch (red).

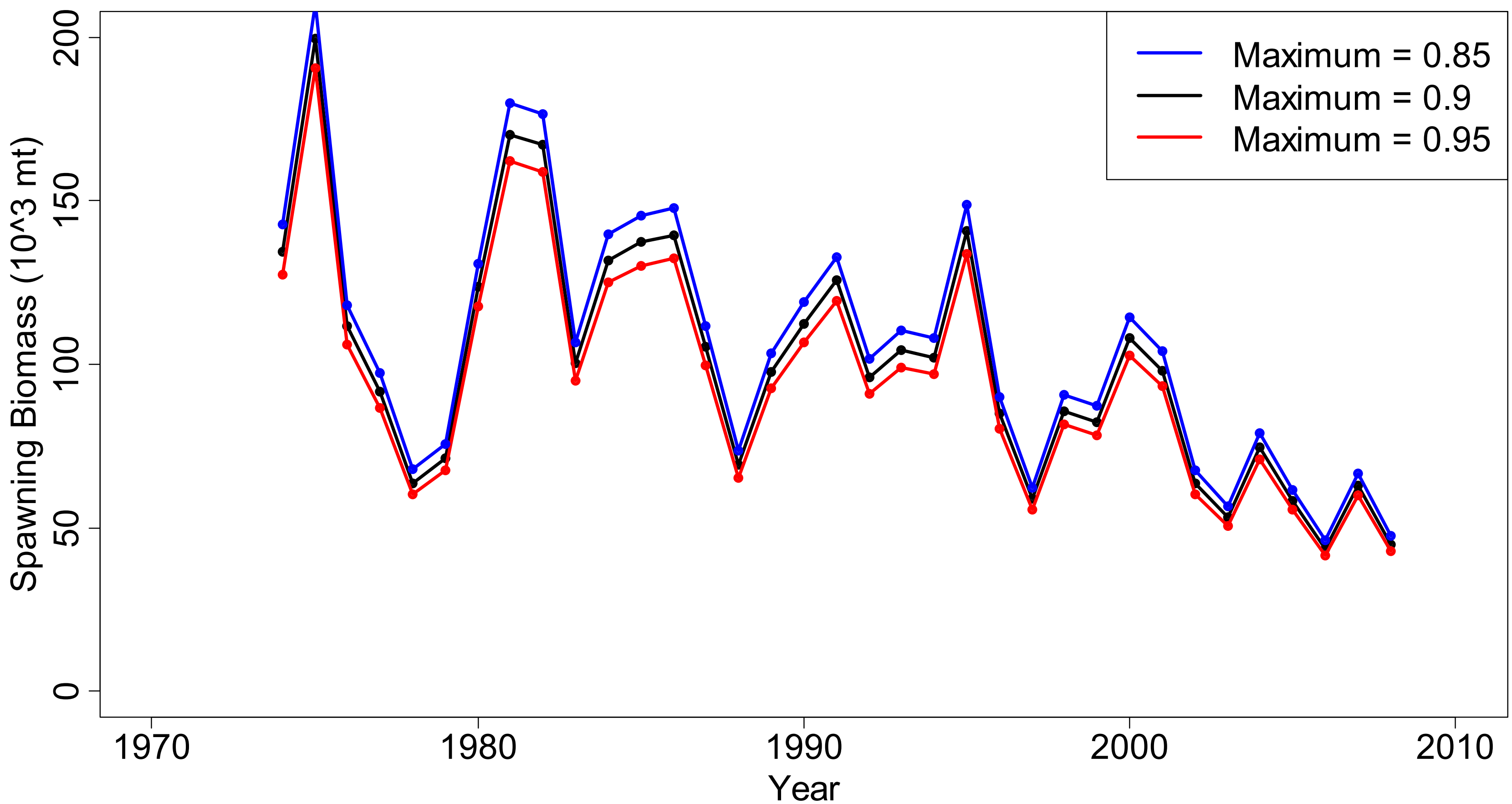

Figure B36. Estimates of spawning biomass from the final model under assumed maxima for the ratio of survey to stock area and the efficiency of the *Henry B. Bigelow*.

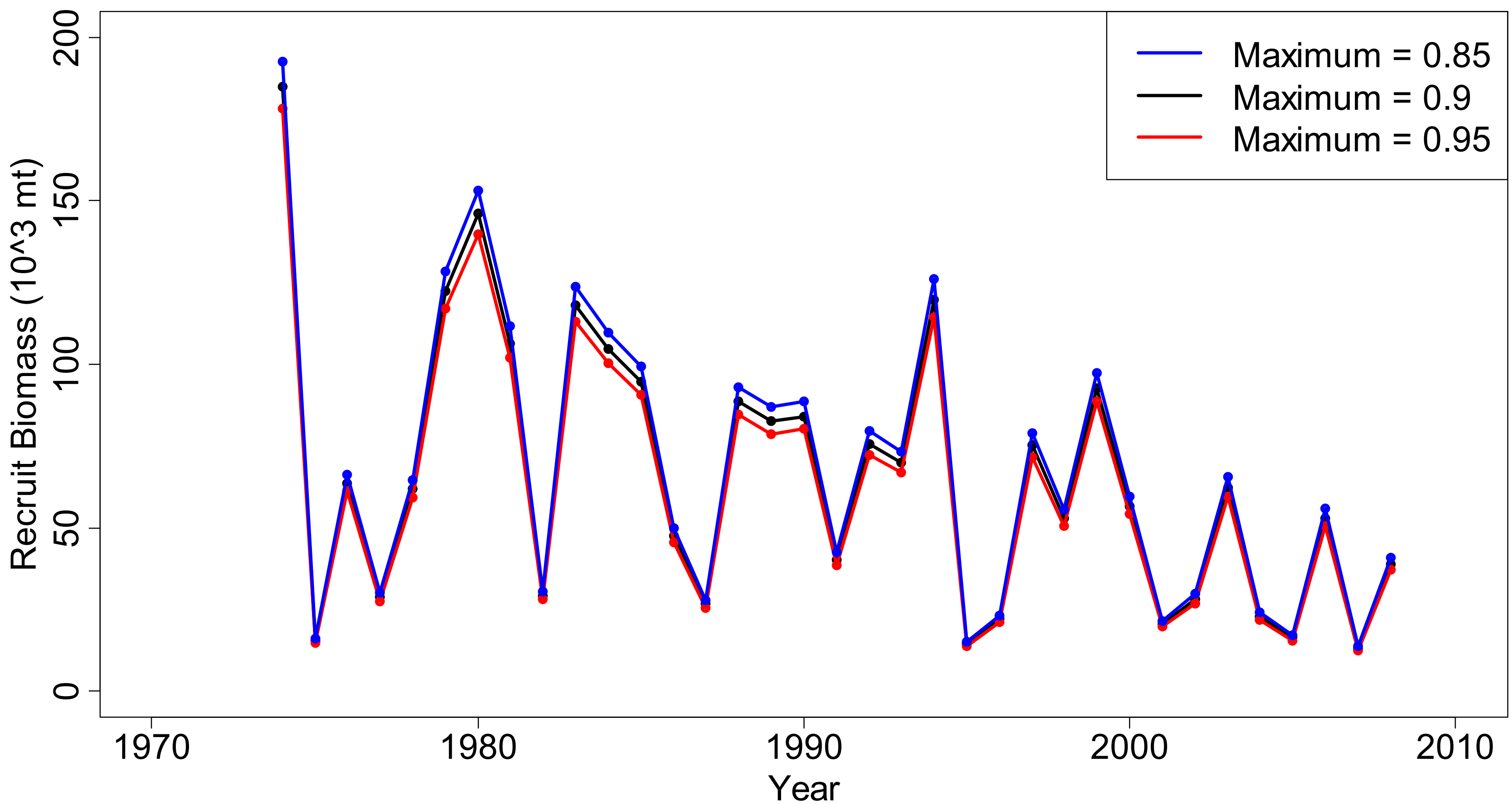

Figure B37. Estimates of recruitment biomass from the final model under assumed maxima for the ratio of survey to stock area and the efficiency of the *Henry B. Bigelow*.

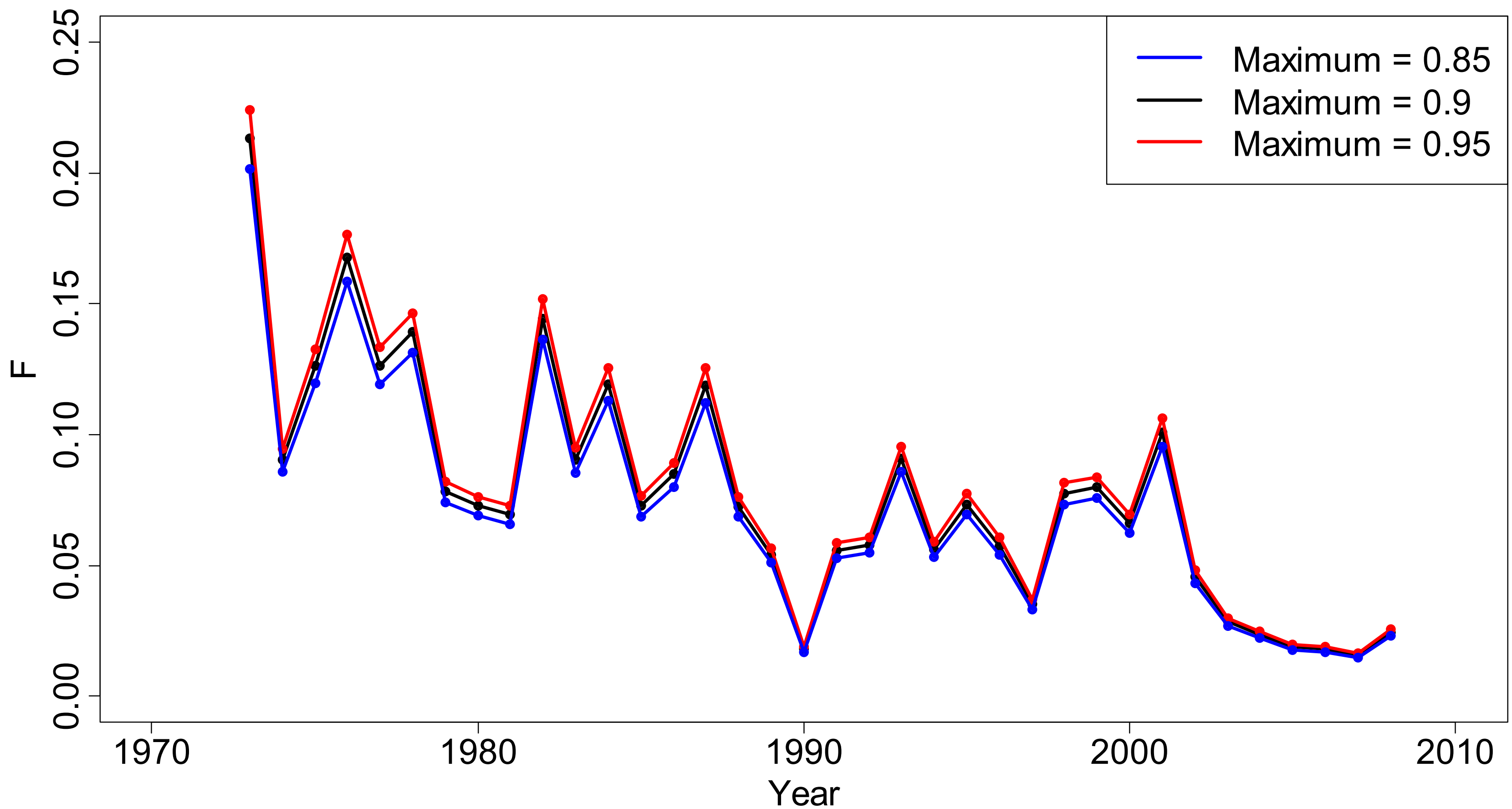

Figure B38. Estimates of spawning biomass from the final model under assumed maxima for the ratio of survey to stock area and the efficiency of the *Henry B. Bigelow*.

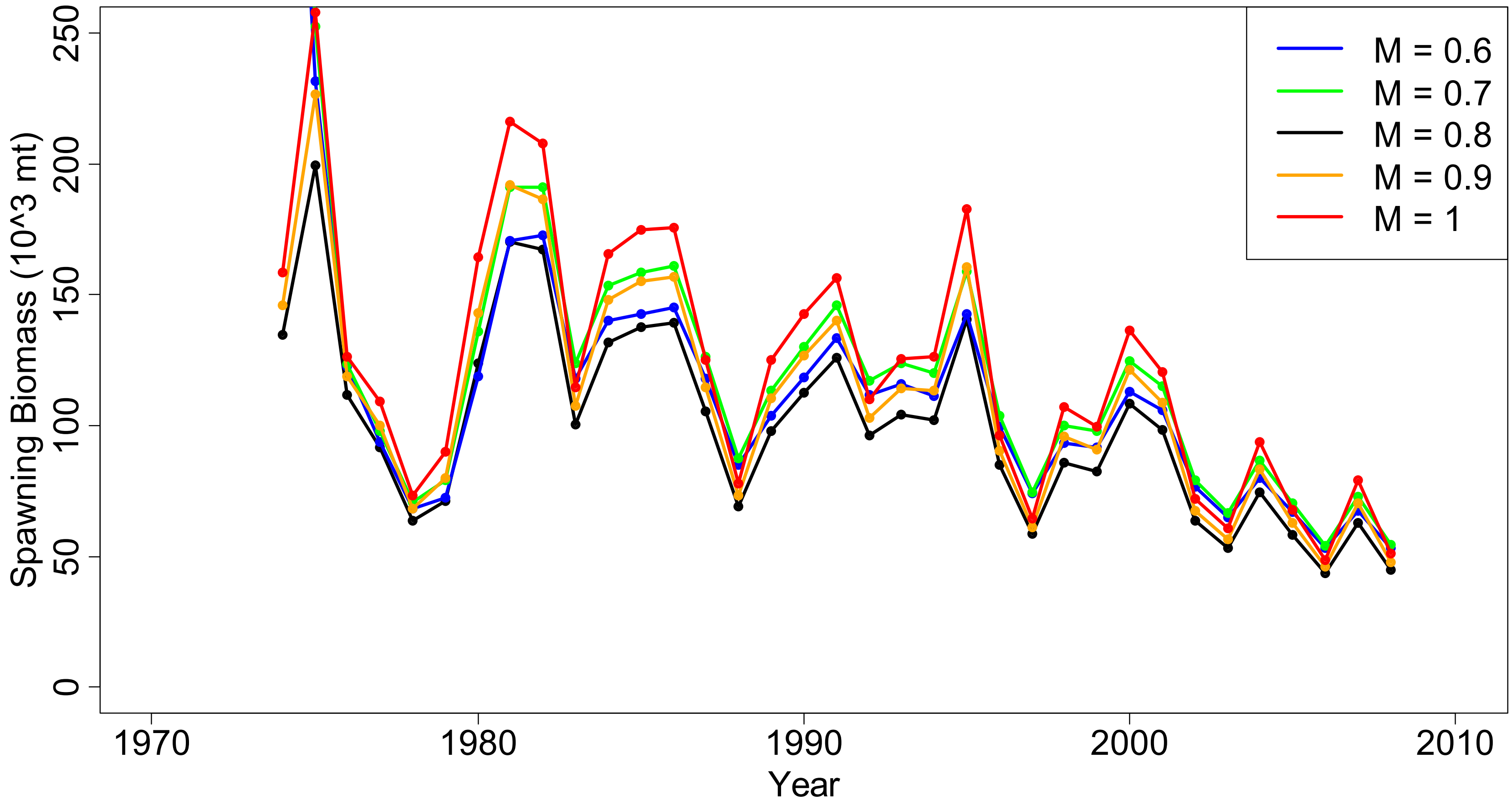

Figure B39. Estimates of spawning biomass from the final model under assumed natural mortality rates between 0.6 and 1.0.

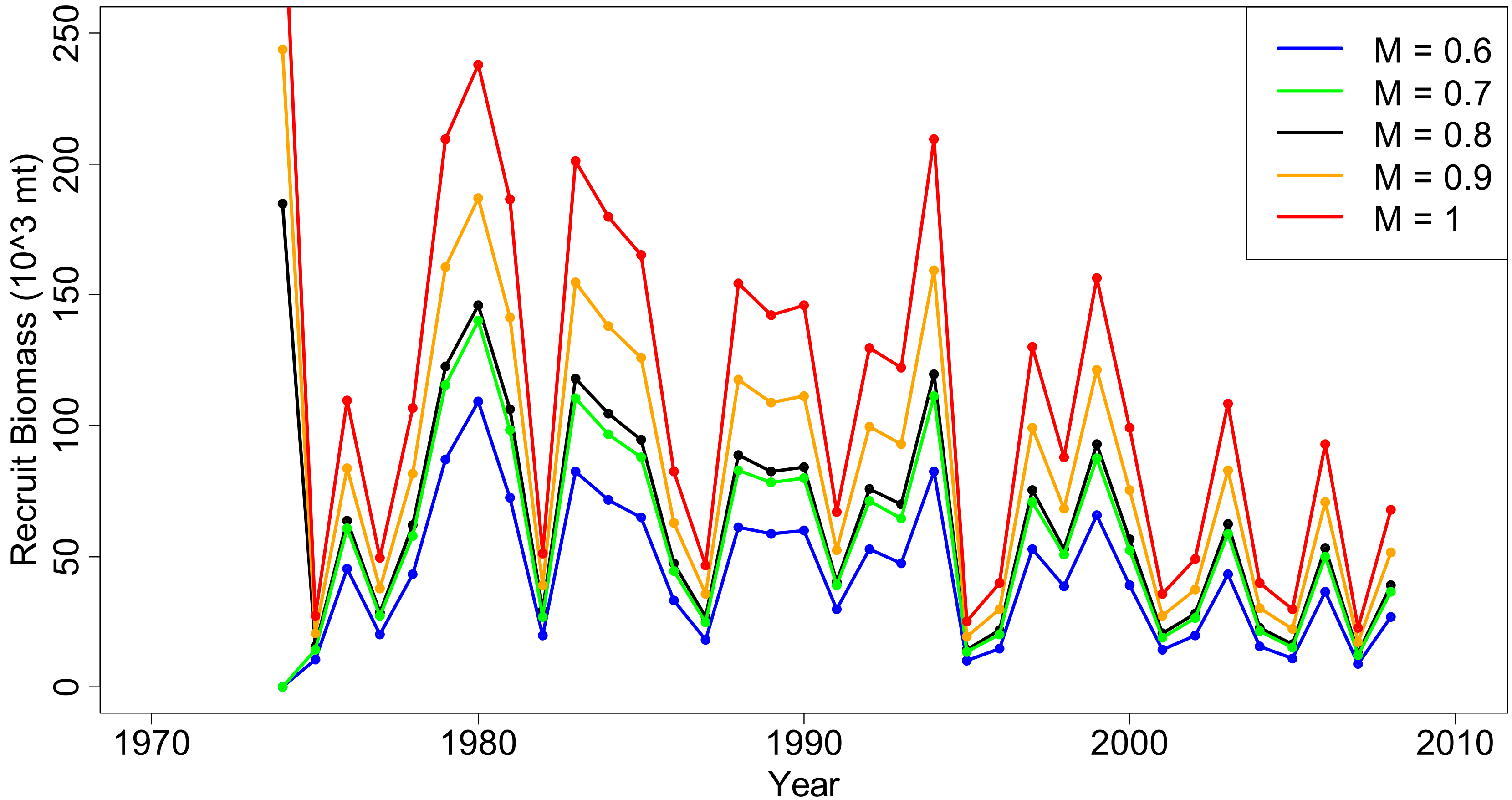

Figure B40. Estimates of recruitment biomass from the final model under assumed natural mortality rates between 0.6 and 1.0.

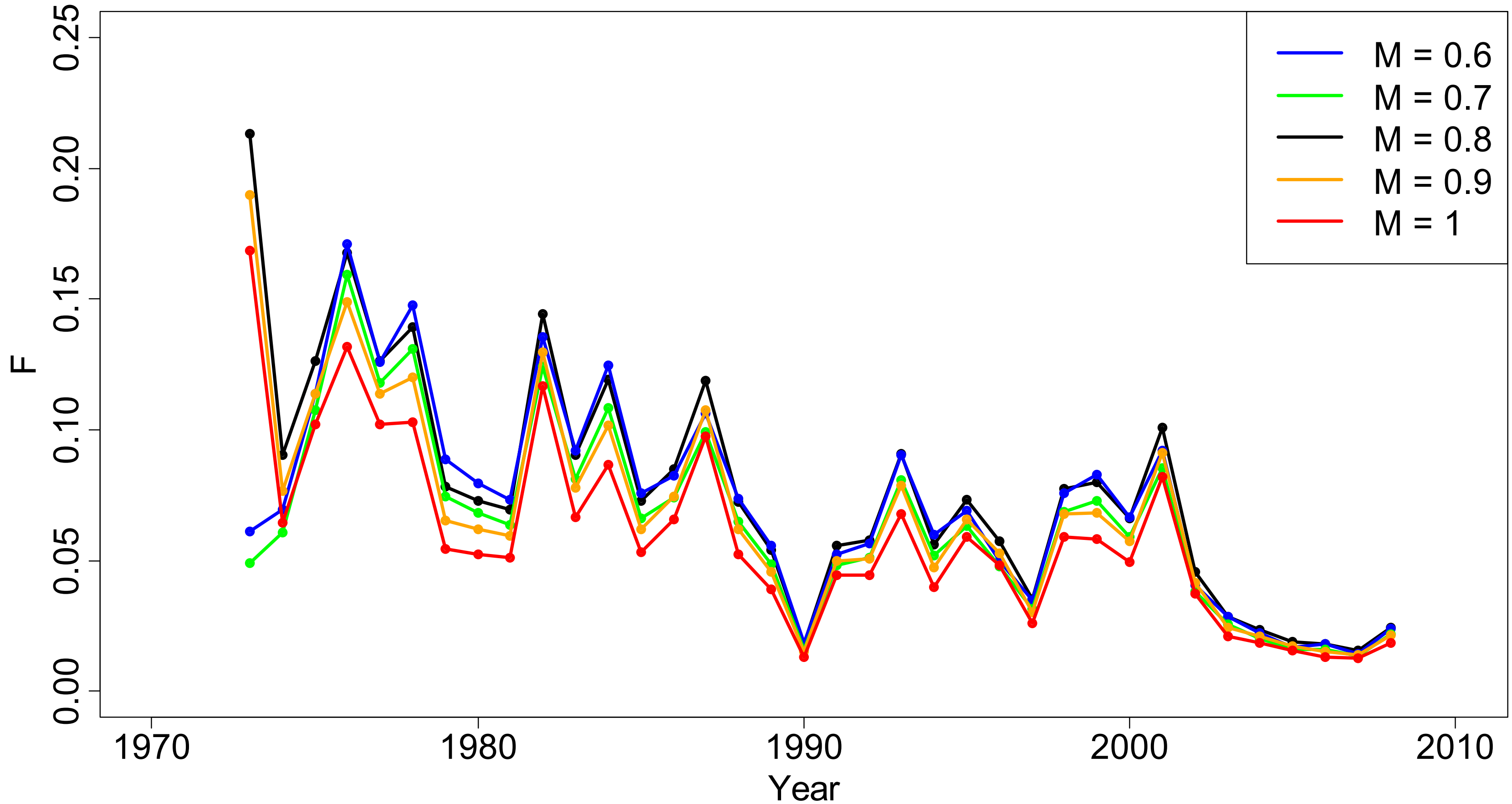

Figure B41. Estimates of fishing mortality from the final model under assumed natural mortality rates between 0.6 and 1.0.

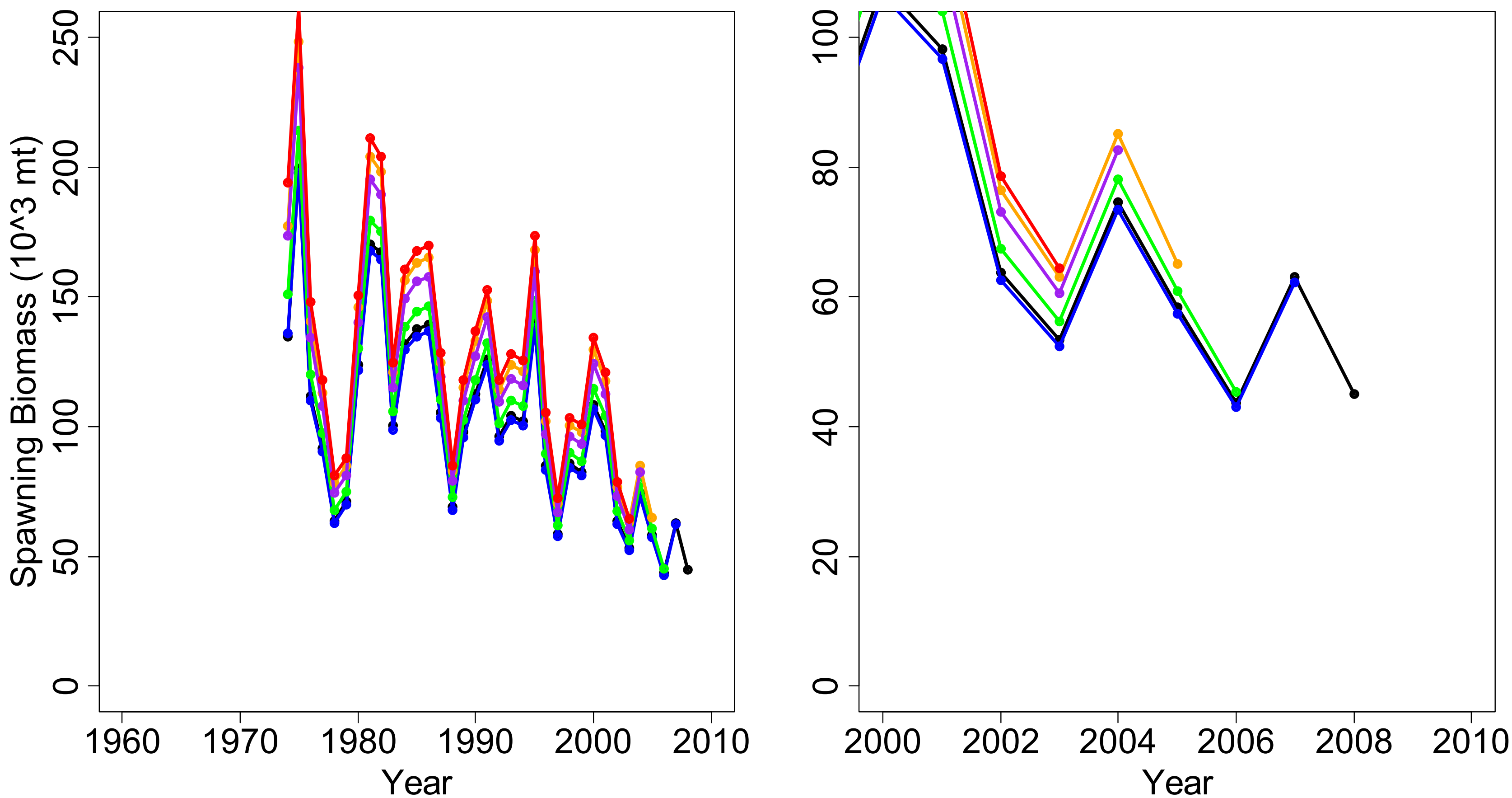

Figure B42. Retrospective behaviour of spawning biomass estimates from the final model.

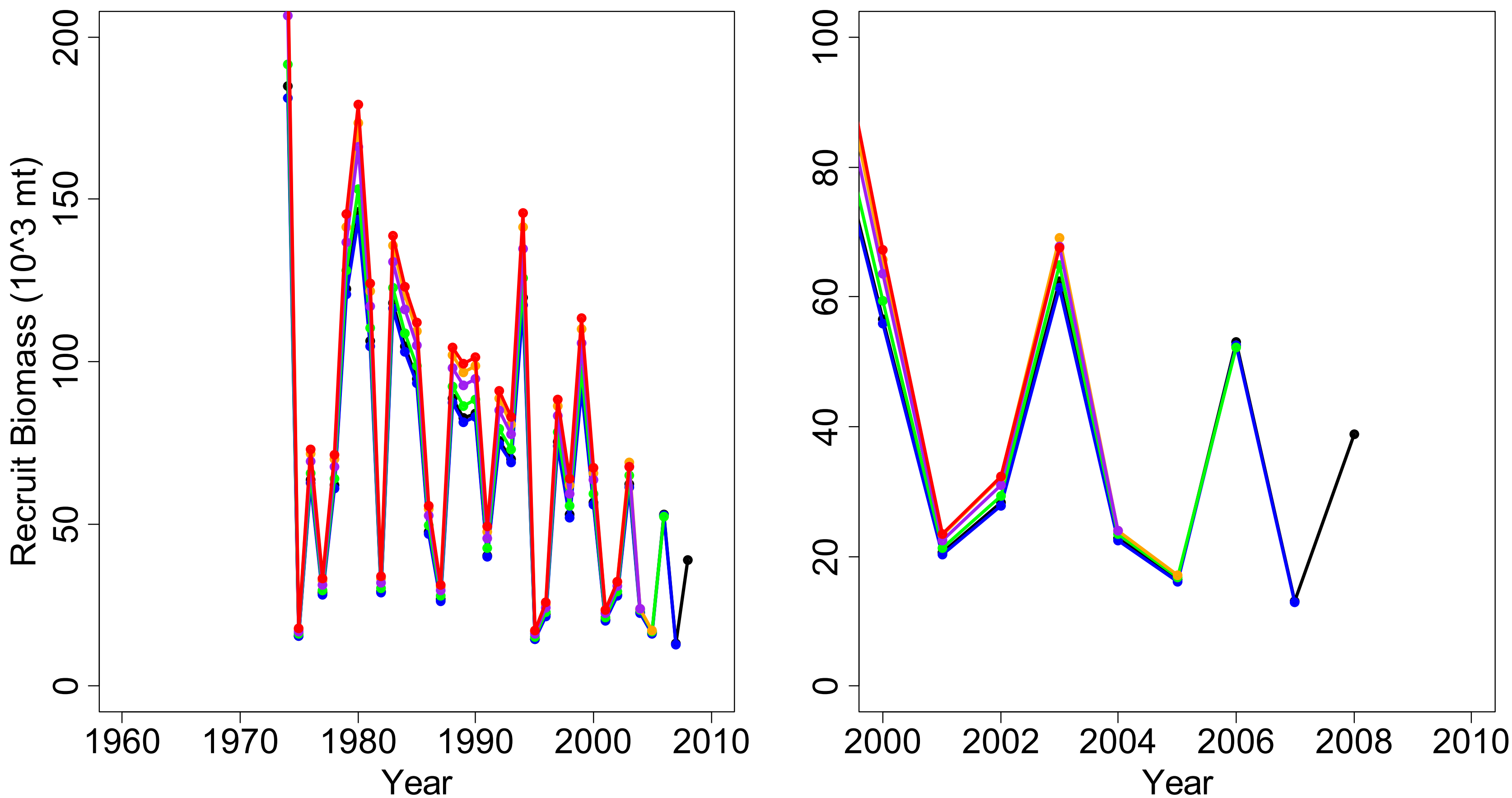

Figure B43. Retrospective behaviour of recruitment biomass estimates from the final model.

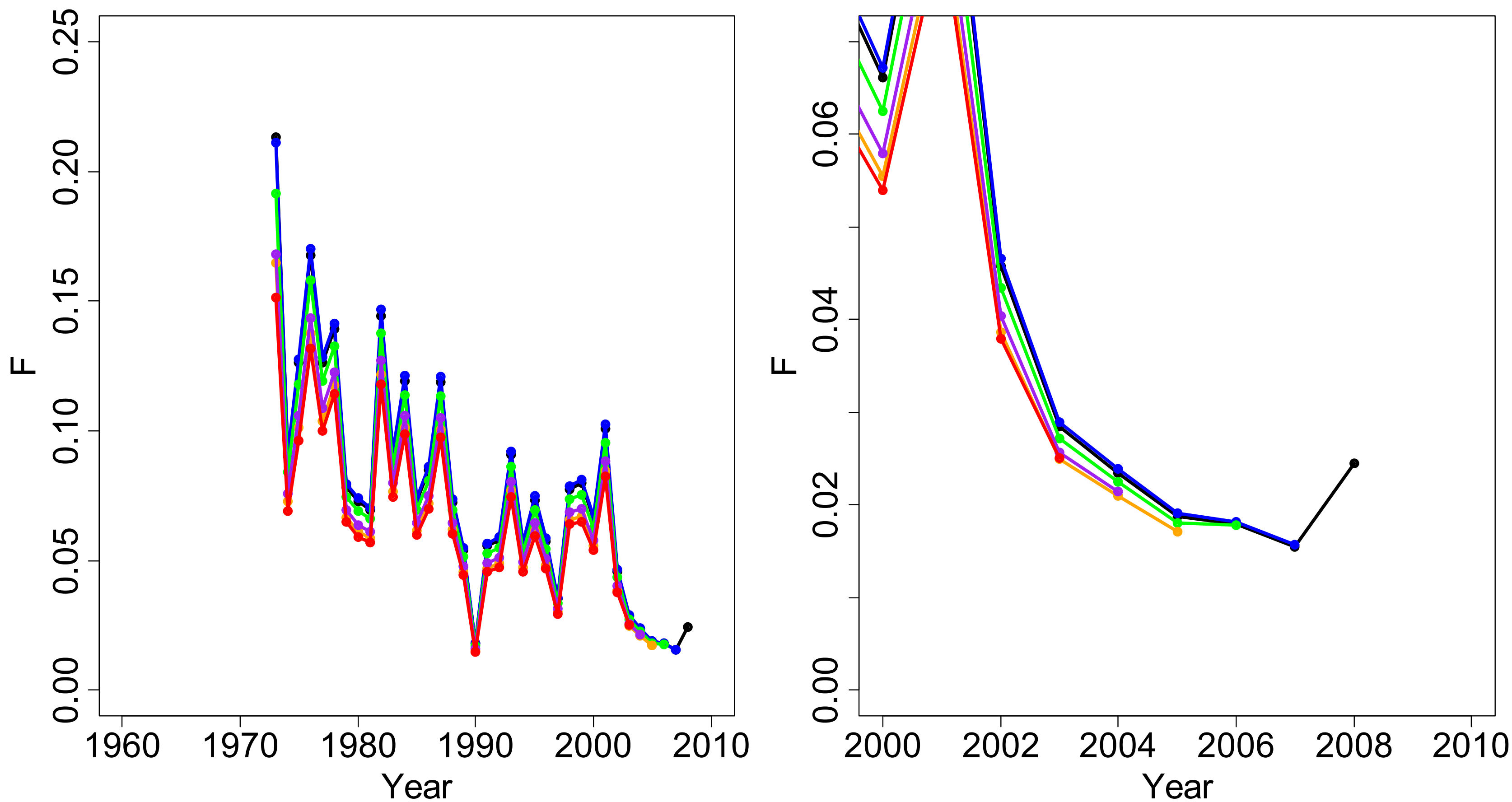

Figure B44. Retrospective behaviour of fishing mortality estimates from the final model.

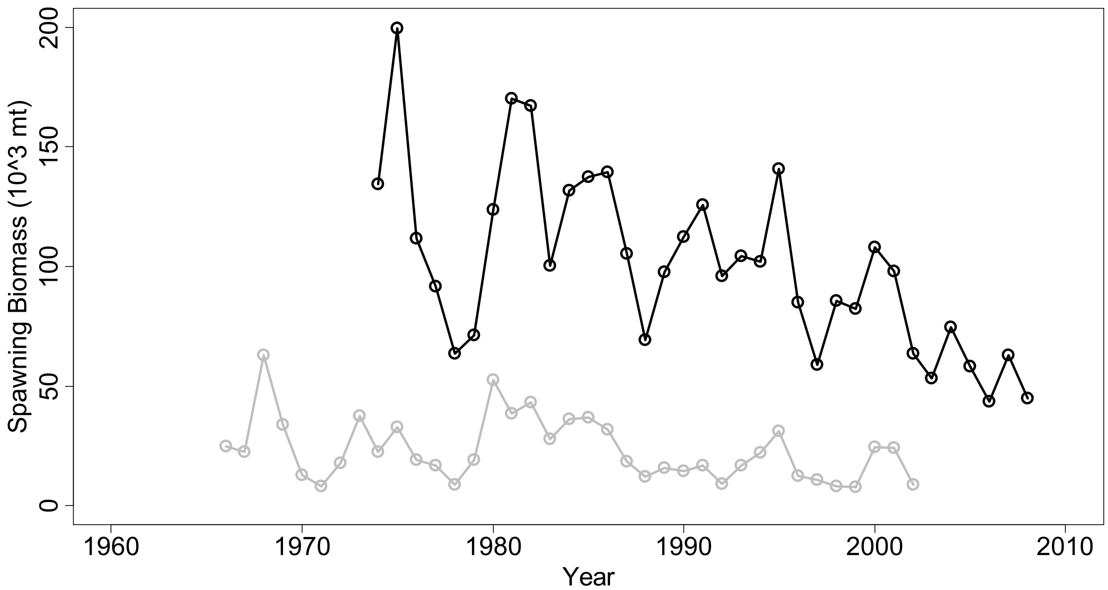

Figure B45. Estimated spawning biomasses from NEFSC (2004) (grey) and final model (black).

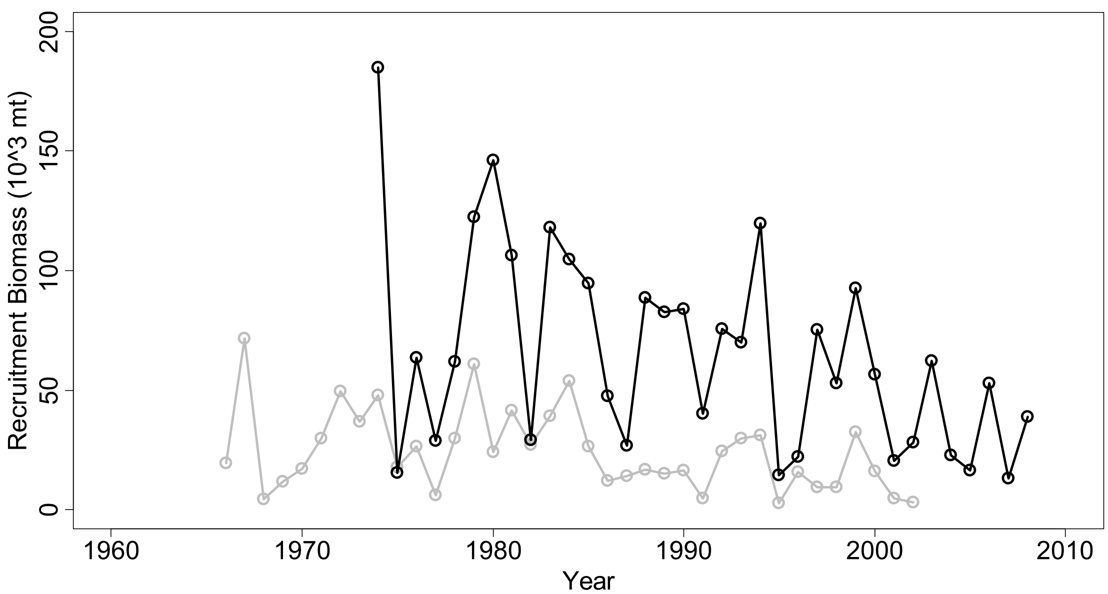

Figure B46. Estimated recruitment biomasses from NEFSC (2004) (grey) and final model (black).

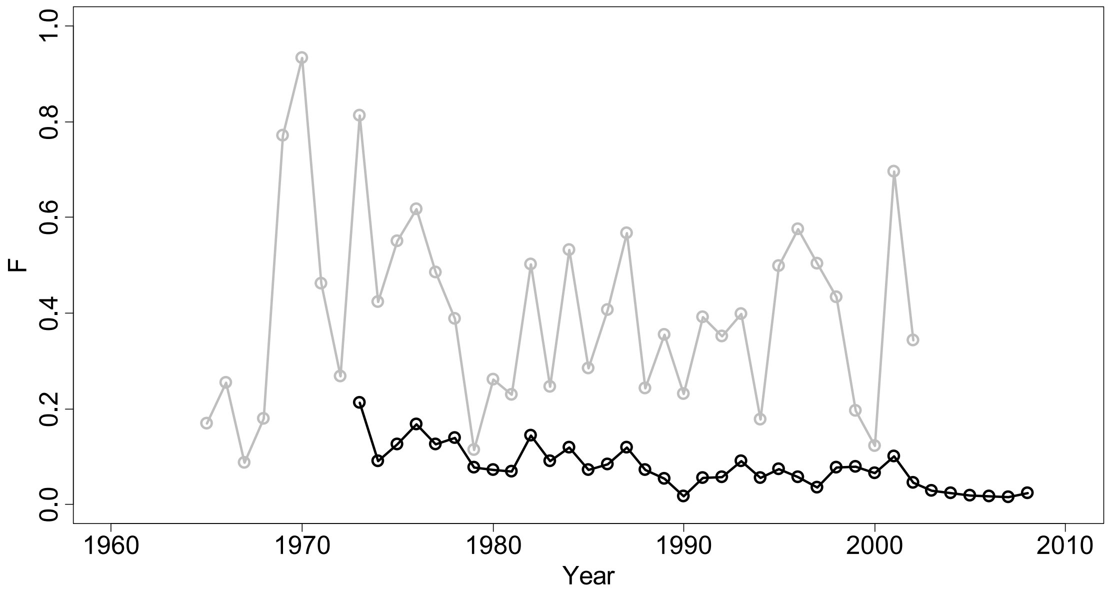

Figure B47. Estimated fishing mortality from NEFSC (2004) (grey) and final model (black).

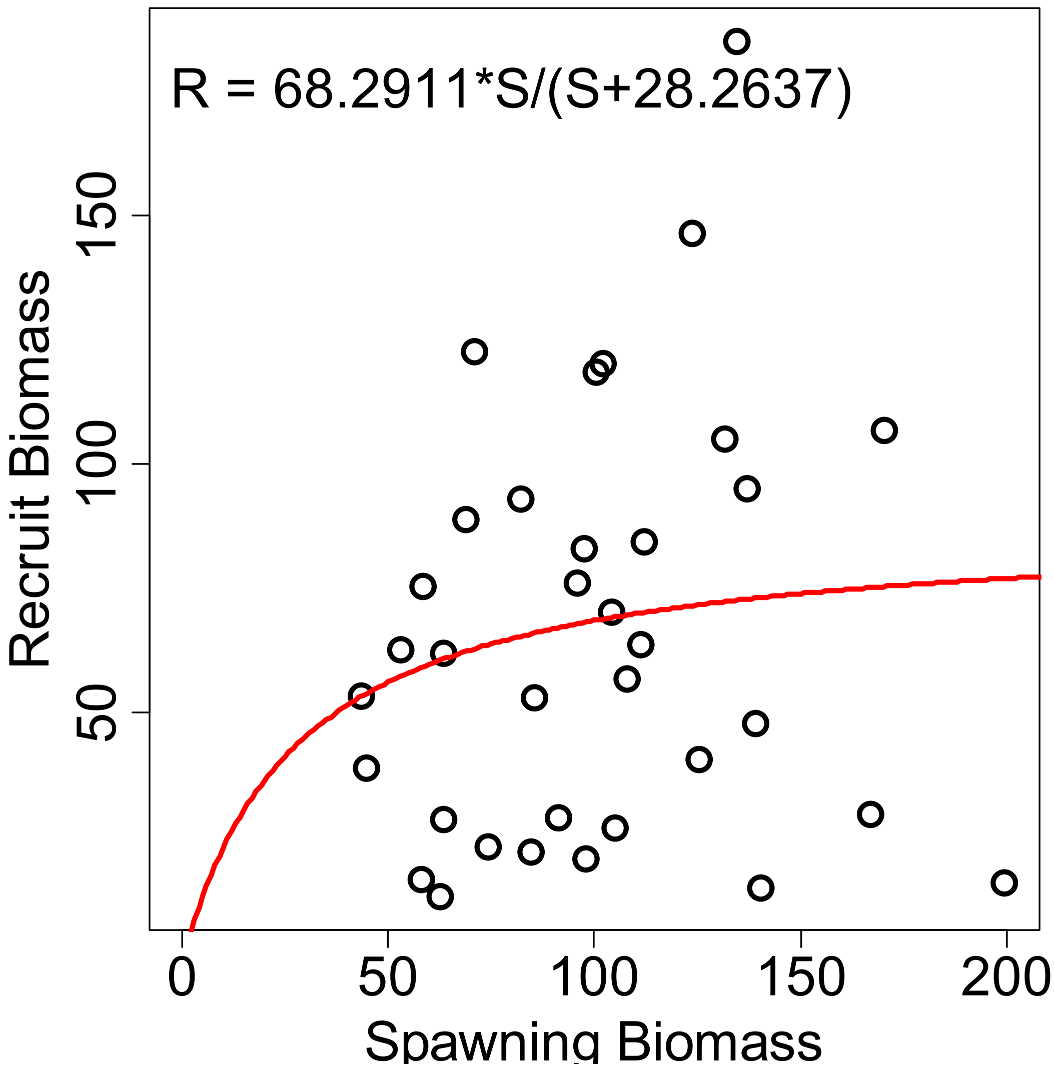

Figure B48. Recruitment and spawning biomass estimates from the final model. Red line represents bias corrected (1.29) estimated Beverton-Holt spawner-recruit curve.

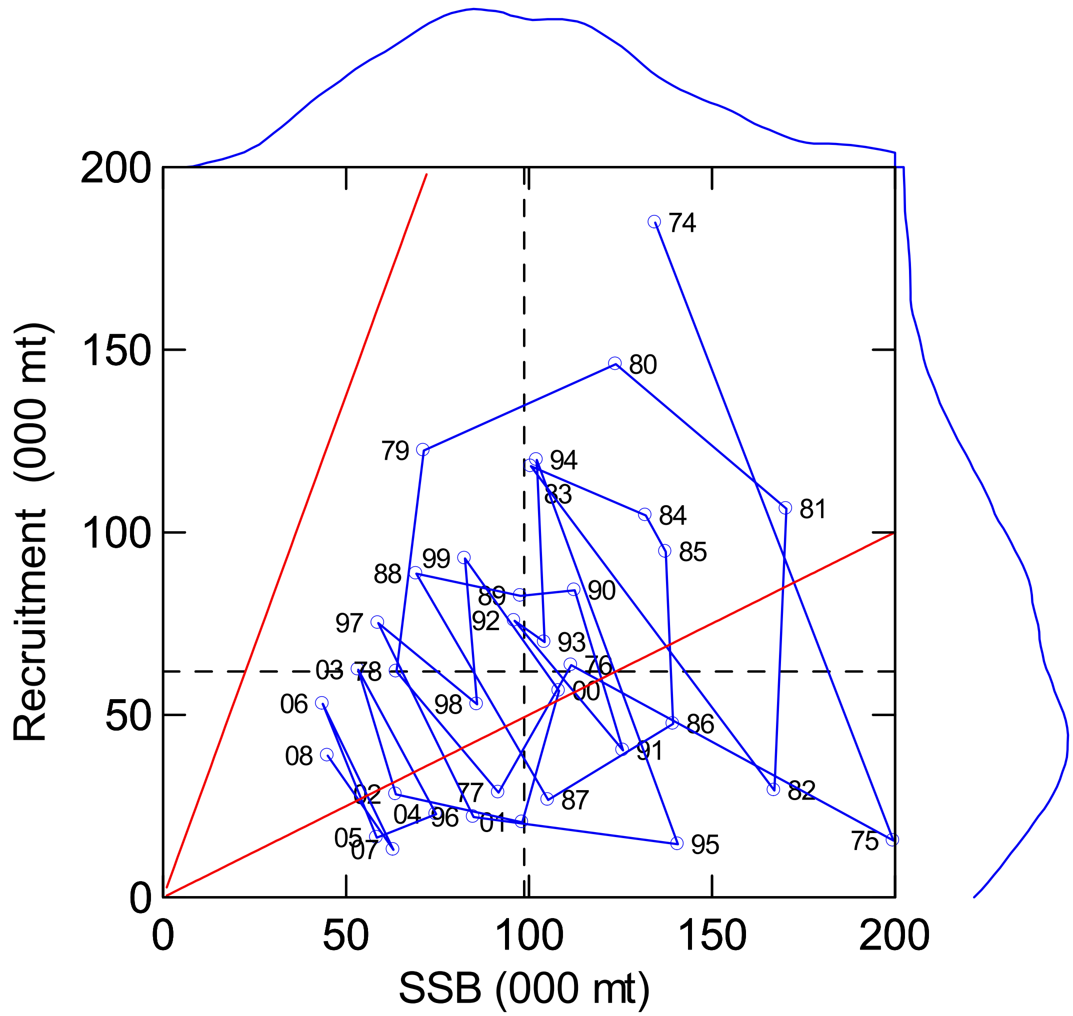

Figure B49. Relationship between recruitment vs spawning stock biomass (SSB) in year t for years 1974 to 2008. The point label refers to year of spawning. The nonparametric kernel distributions of R and SSB are depicted in the margins. Median R (61,860 mt) and SSB (98,700 mt) values are represented by dashed lines. The solid diagonal lines represent replacement lines for $F_{0.1}$=1.04 (steeper slope) and F=0 (shallow slope).

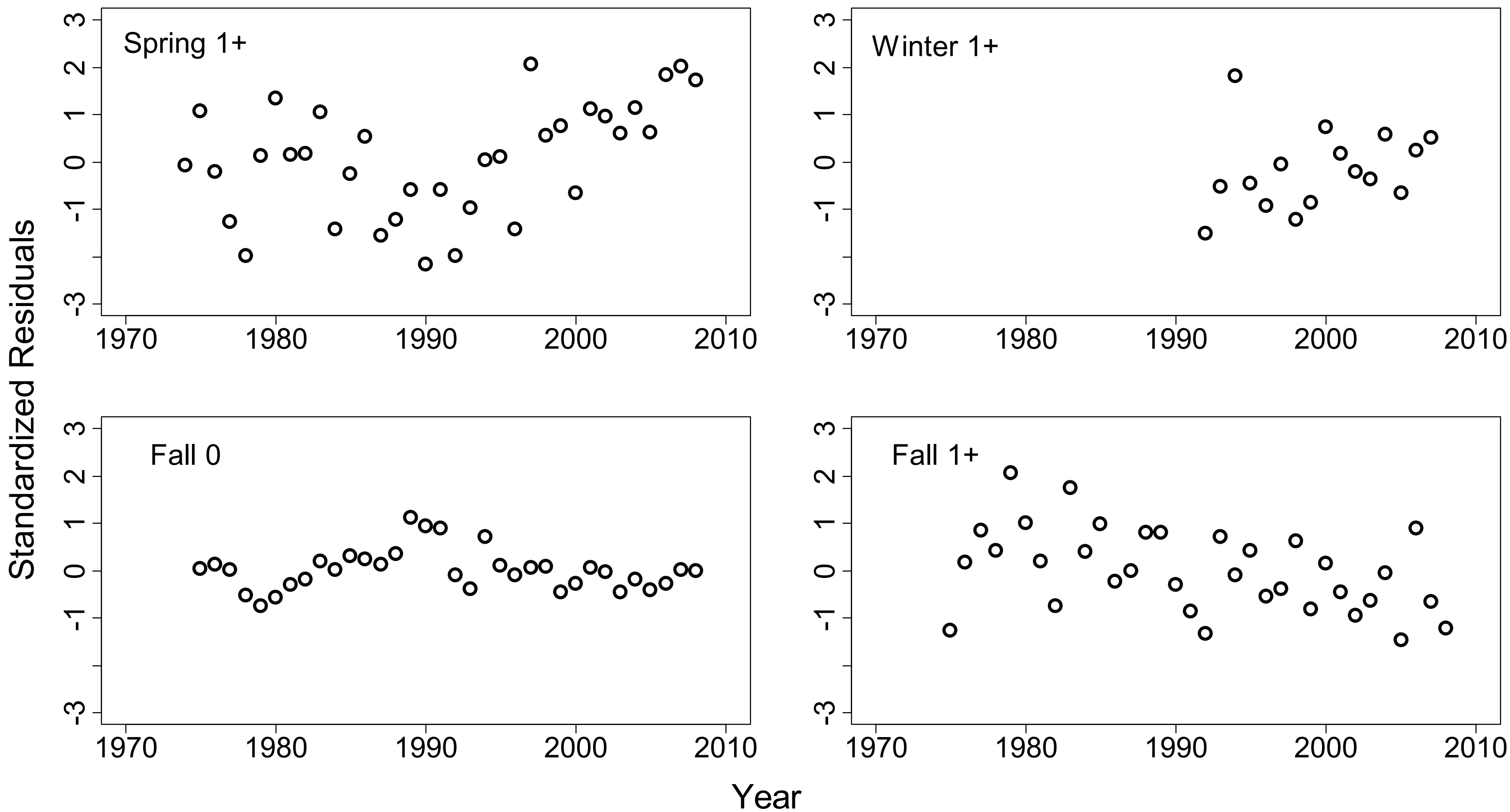

Figure B50. Standardized Residuals over time from final model for NEFSC survey indices.

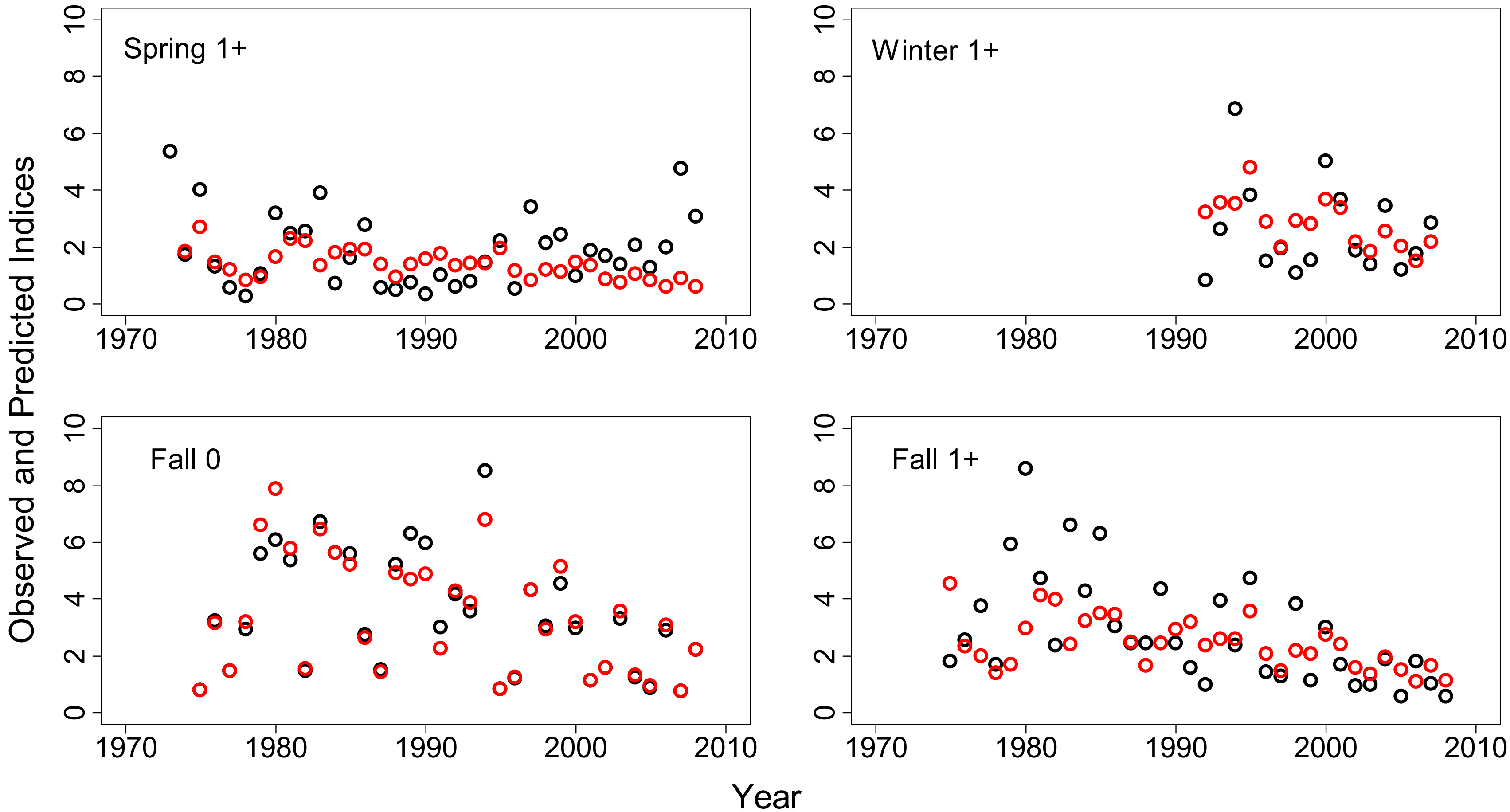

Figure B51. Observed NEFSC survey indices (black) and predicted values from the final model (red).

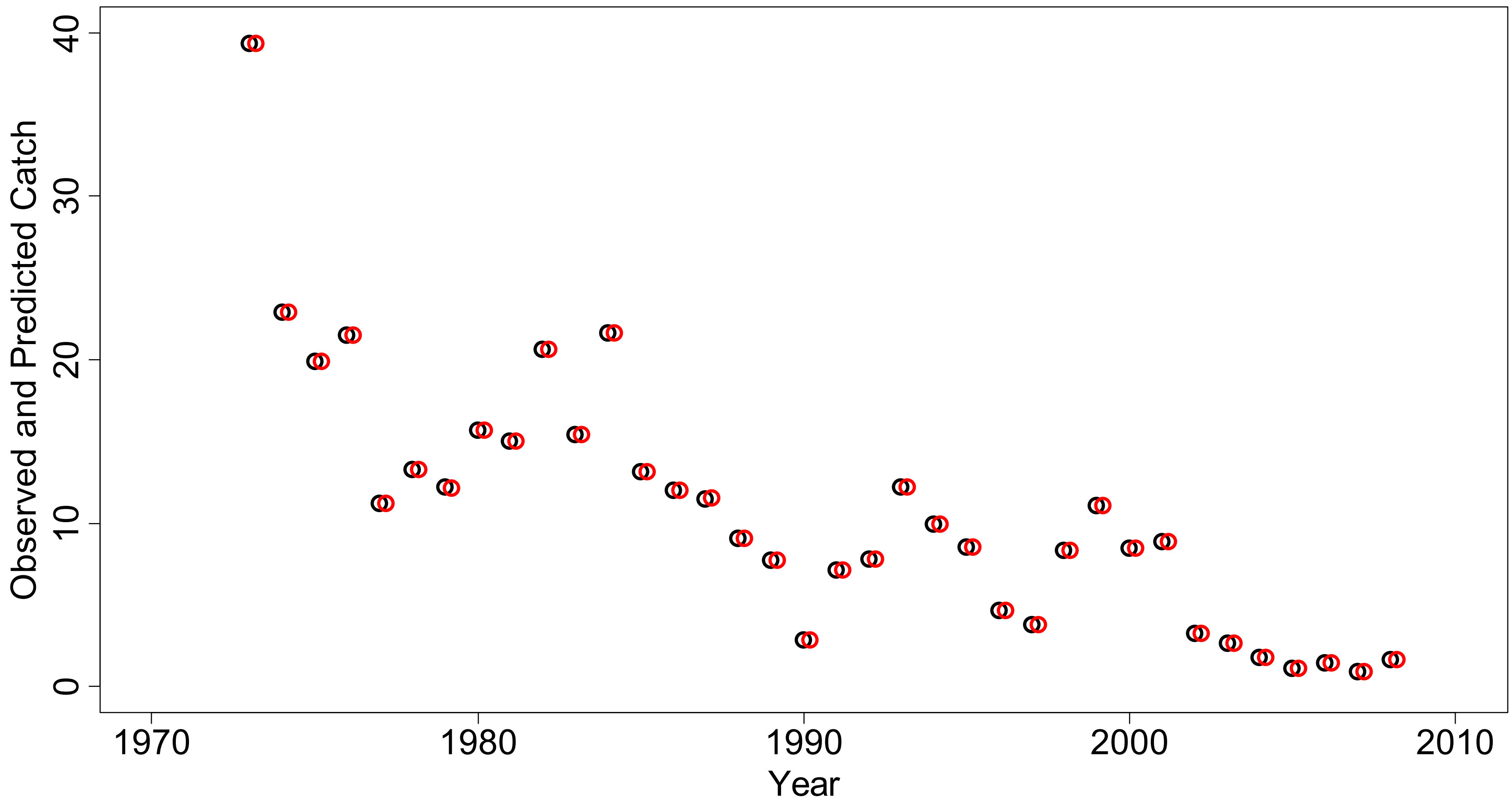

Figure B52. Observed Catches (kmt) (black) and predicted values from the final model (red).

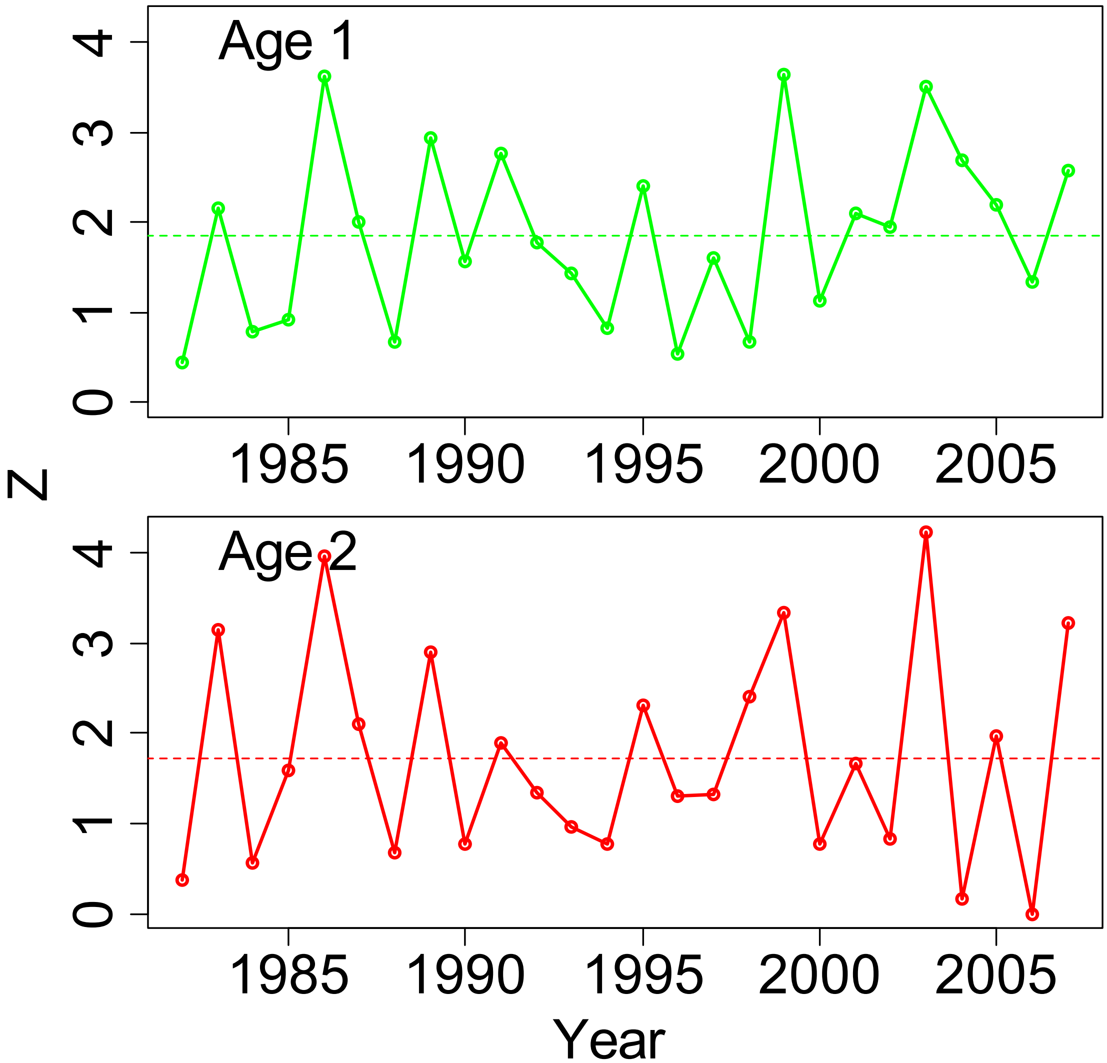

Figure B53. Annual estimates of total instantaneous mortality by year and age from spring survey age composition estimates (Table B17).

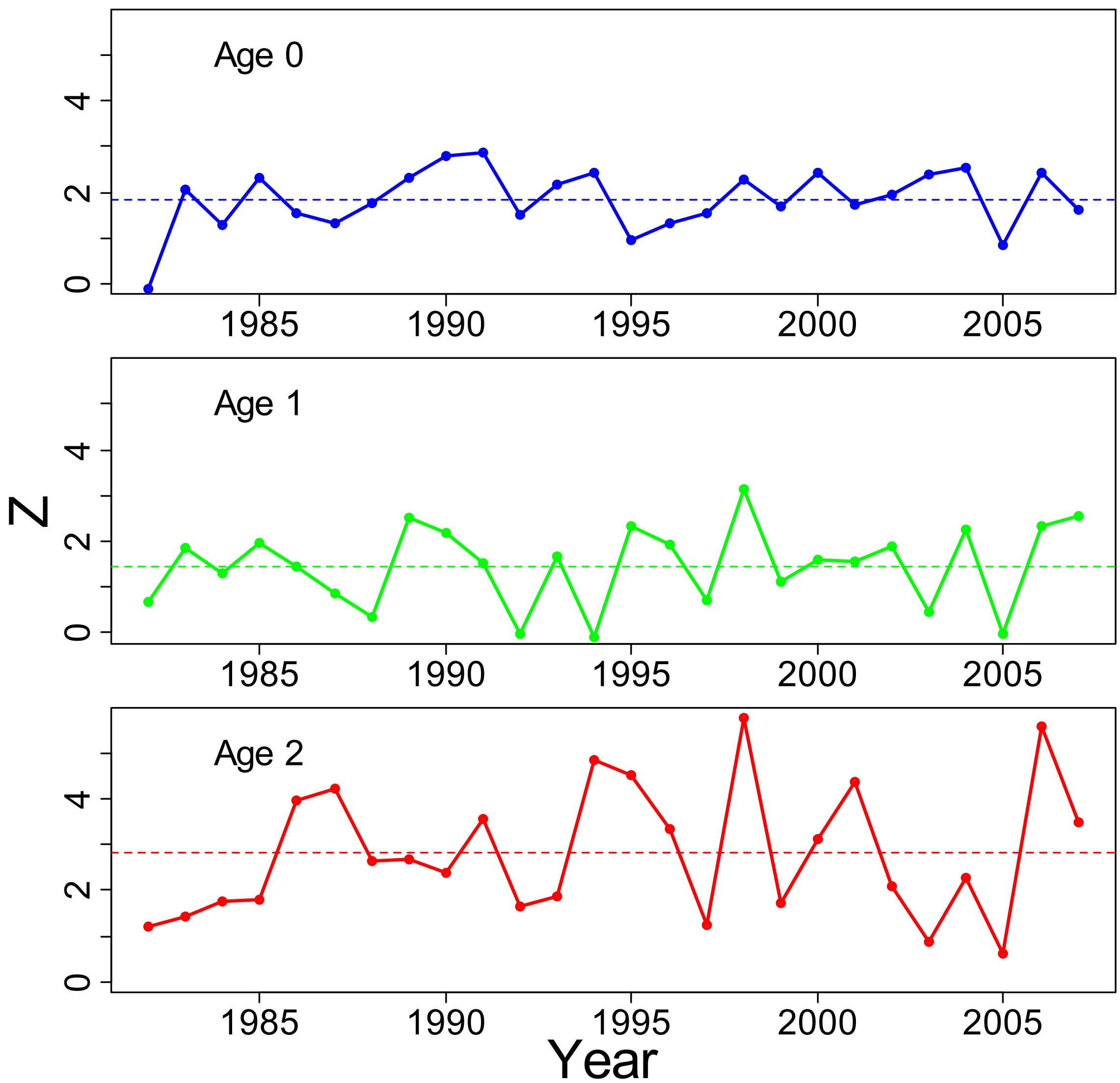

Figure B54. Annual estimates of total instantaneous mortality by year and age from fall survey age composition estimates (Table B18).

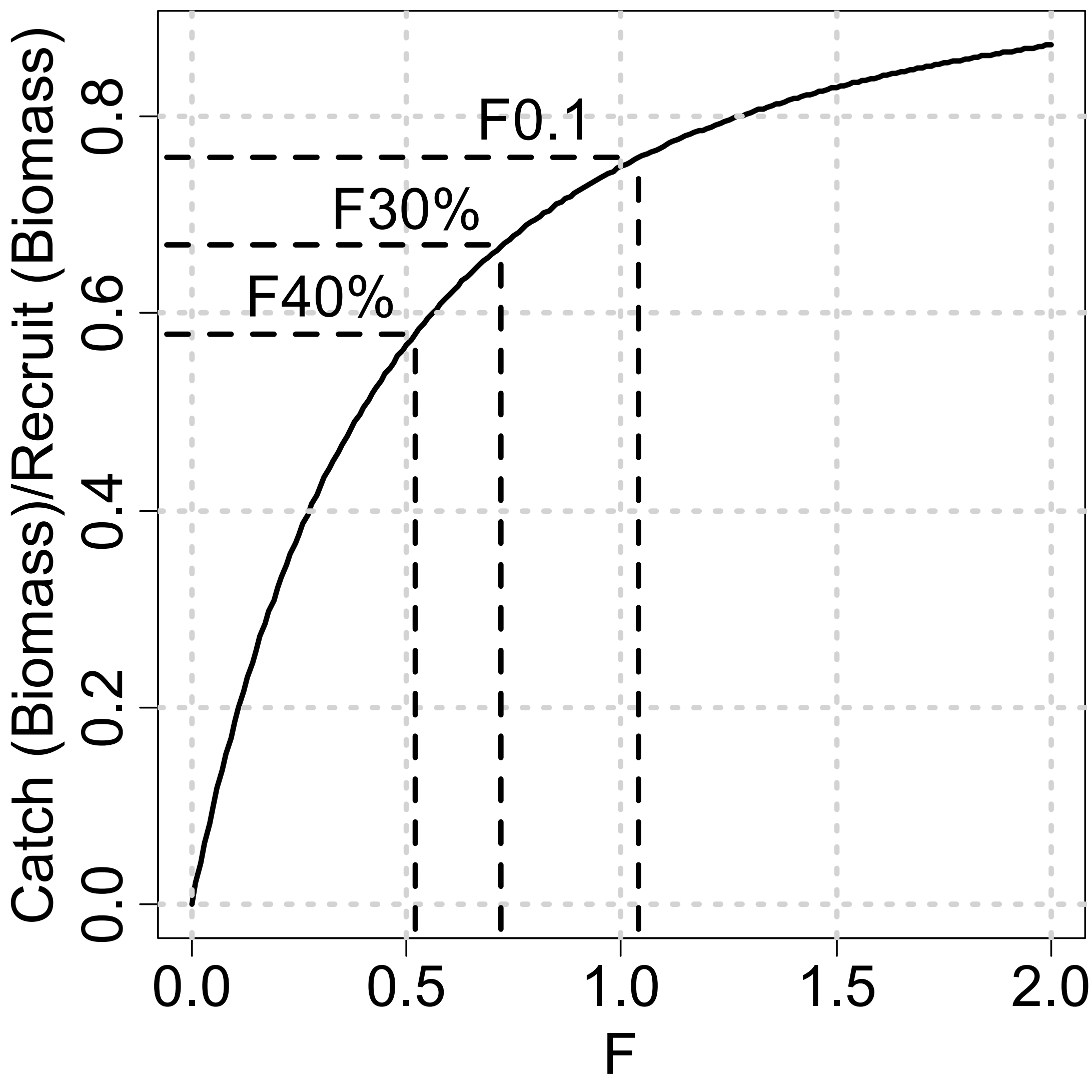

Figure B55. Equilibrium ratio of catch biomass to recruitment biomass with constant fishing mortality. Results are obtained by using the BOOTADM bootstrapping and SPROJDDIF projection software written for the KLAMZ model by Dr. Larry Jacobson. Non-stochastic projections were carried out 50 years into the future.

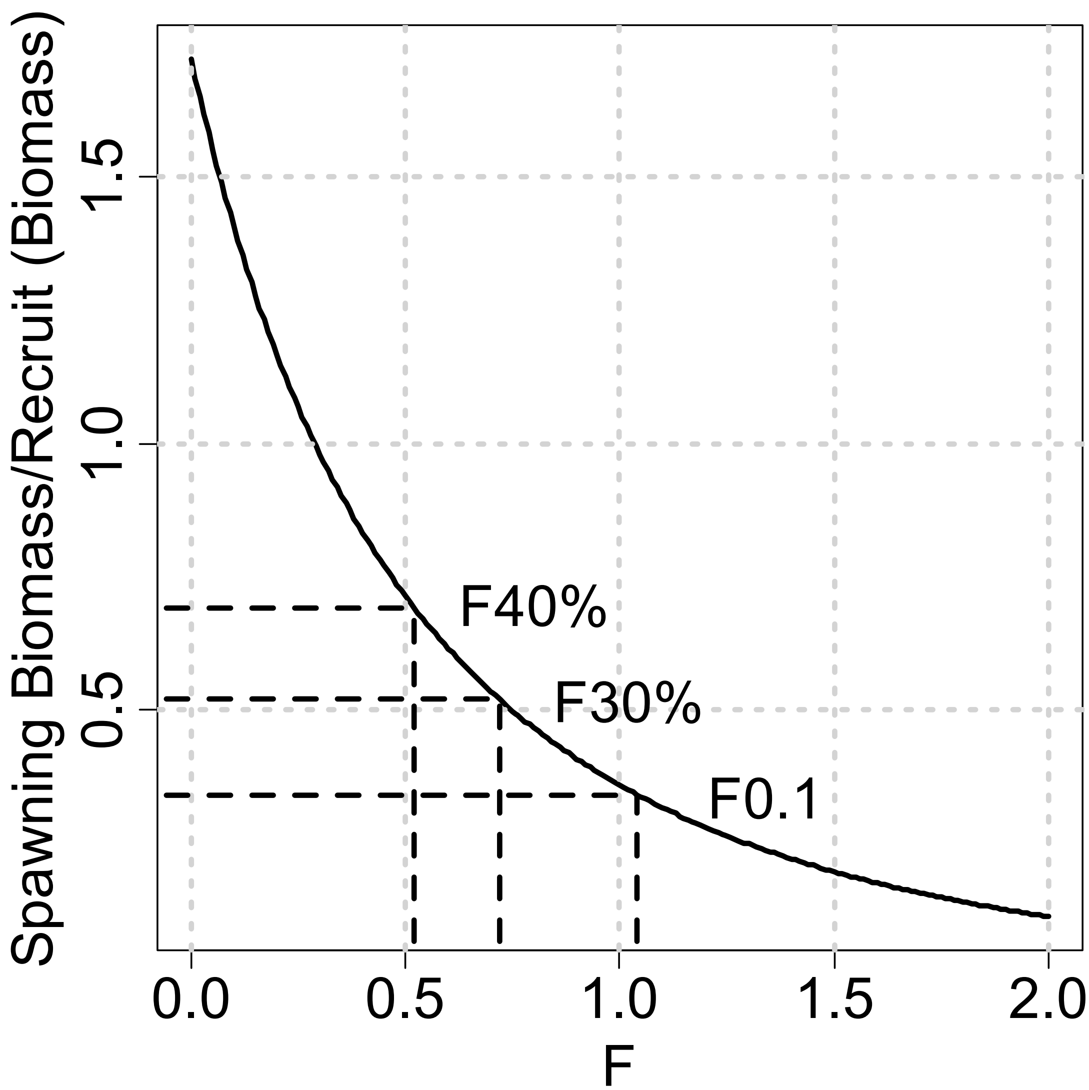

Figure B56. Equilibrium ratio of spawning biomass to recruitment biomass with constant fishing mortality. Results are obtained by using the BOOTADM bootstrapping and SPROJDDIF projection software written for the KLAMZ model by Dr. Larry Jacobson. Non-stochastic projections were carried out 50 years into the future.

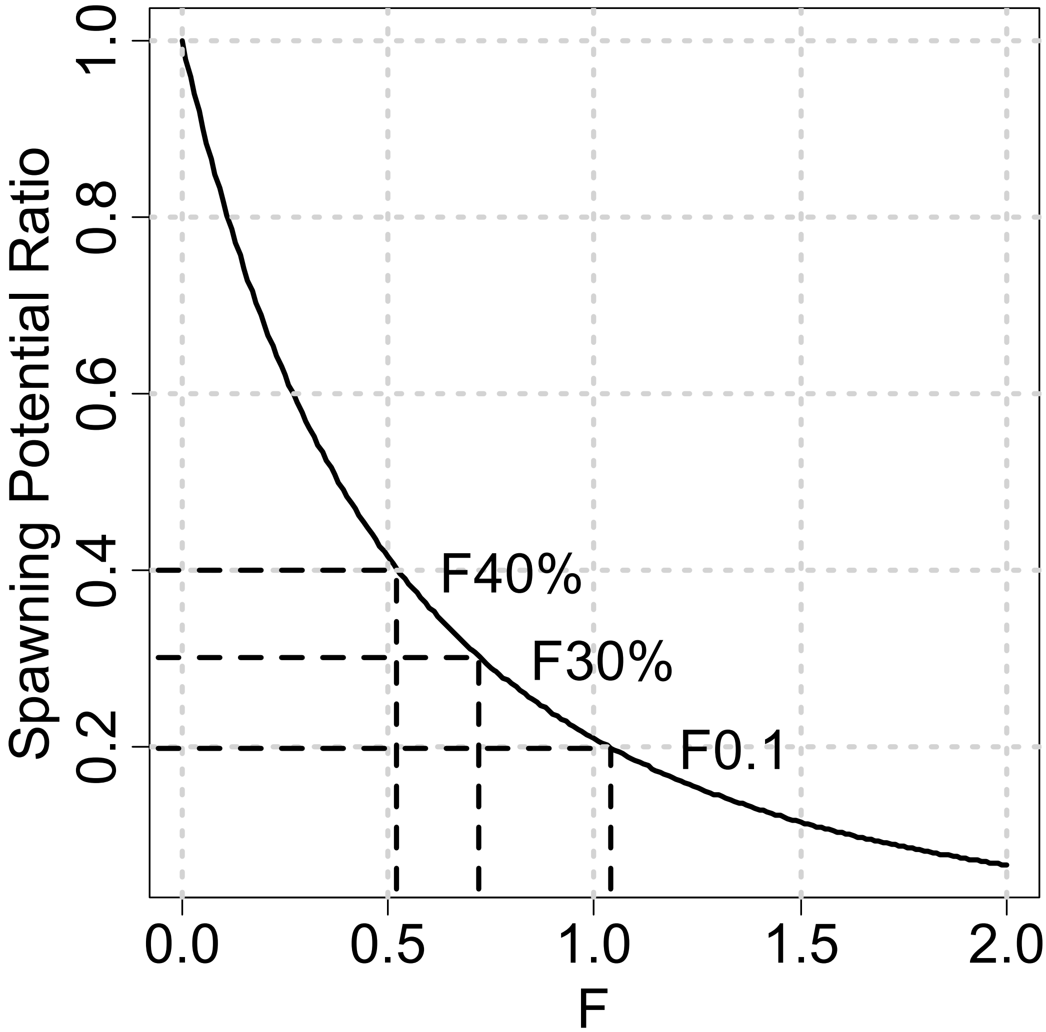

Figure B57. Equilibrium spawning potential ratio with constant fishing mortality. Results are obtained by using the BOOTADM bootstrapping and SPROJDDIF projection software written for the KLAMZ model by Dr. Larry Jacobson. Non-stochastic projections were carried out 50 years into the future.

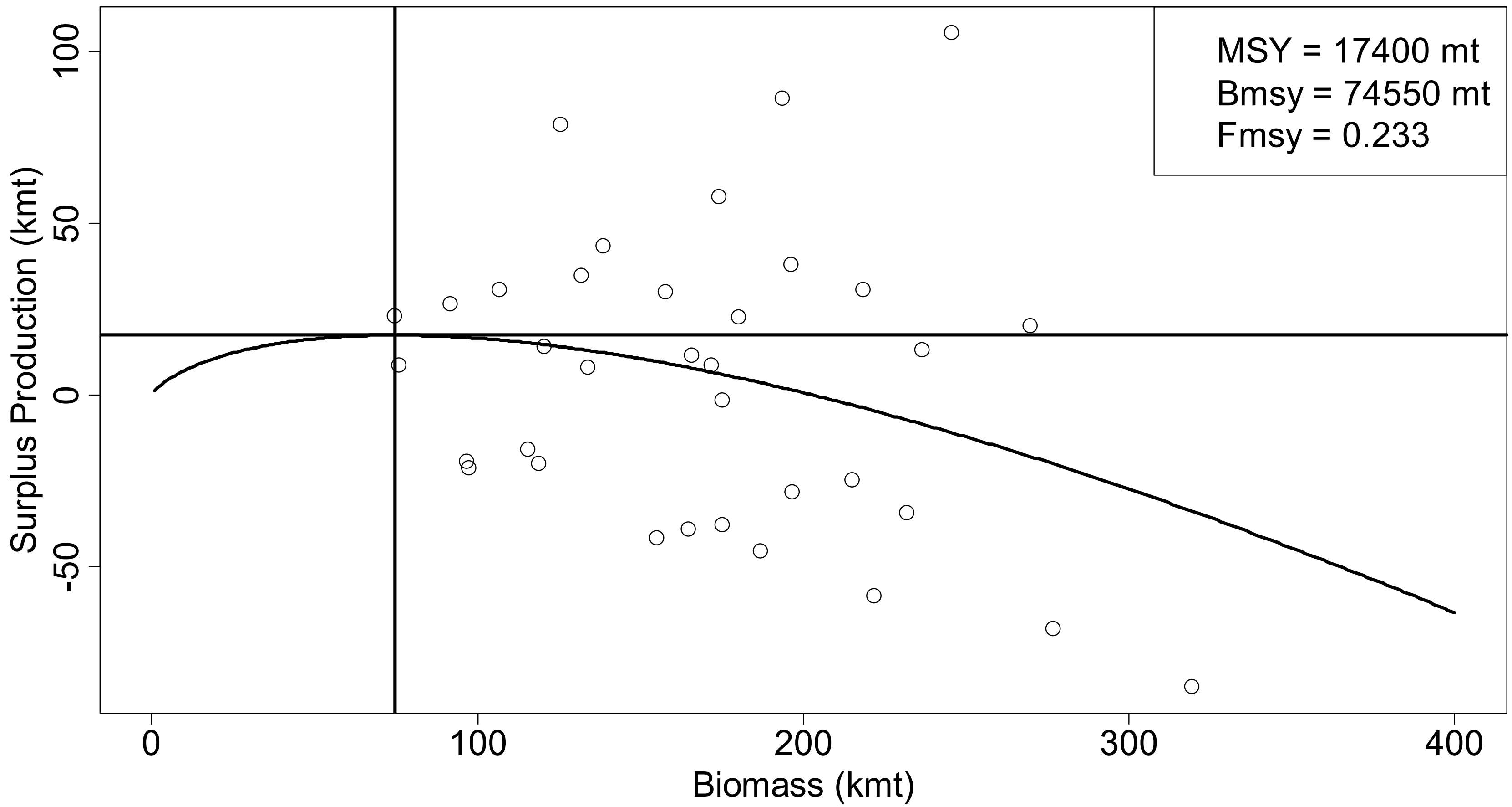

Figure B58. Fox surplus production curve as estimated internal to the final KLAMZ model.

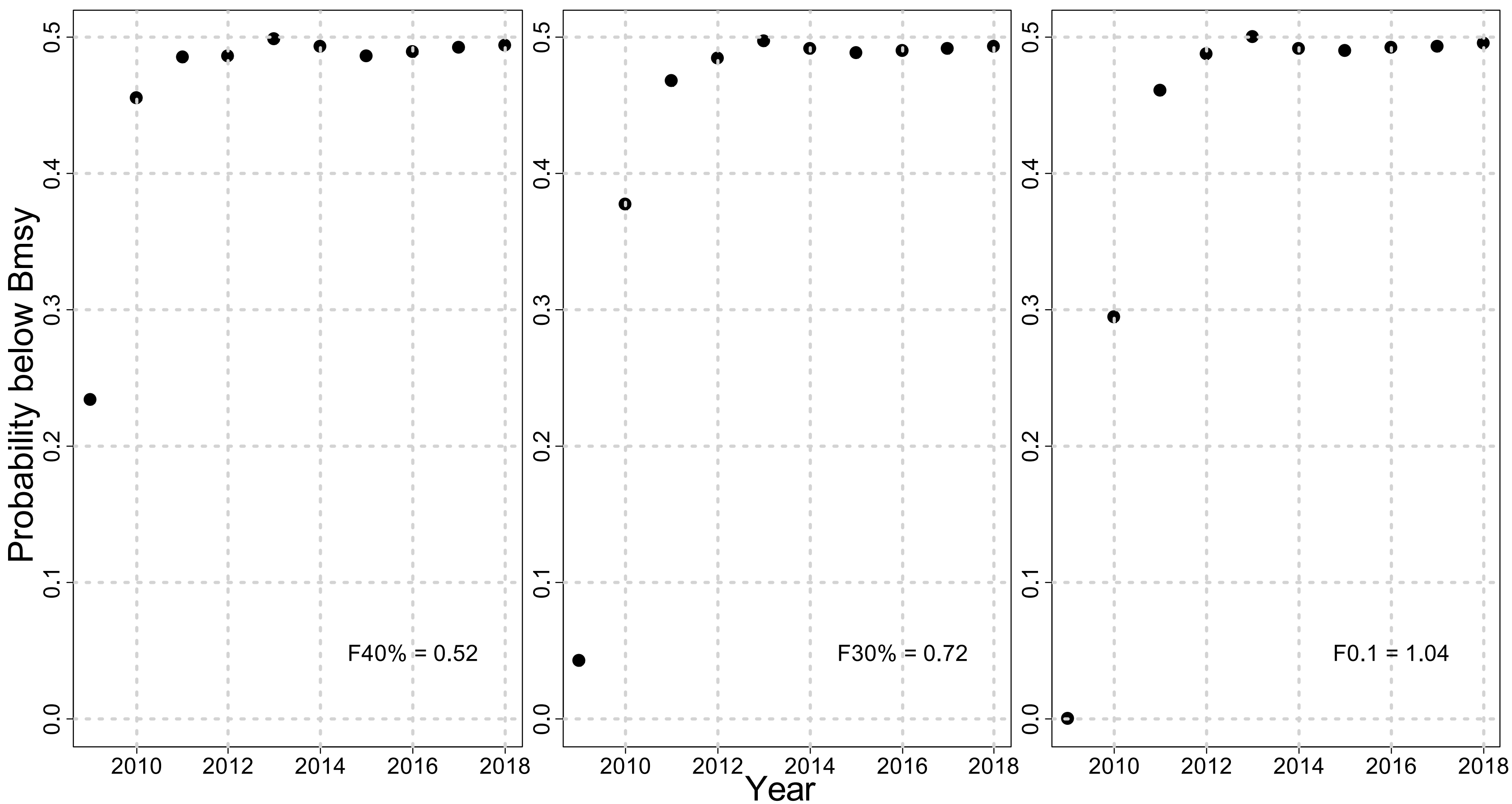

Figure B59. Probabilities of median biomass being below the corresponding candidate SSB_{MSY} proxies when fishing at candidate F_{MSY} proxies and the entire recruitment series is used.

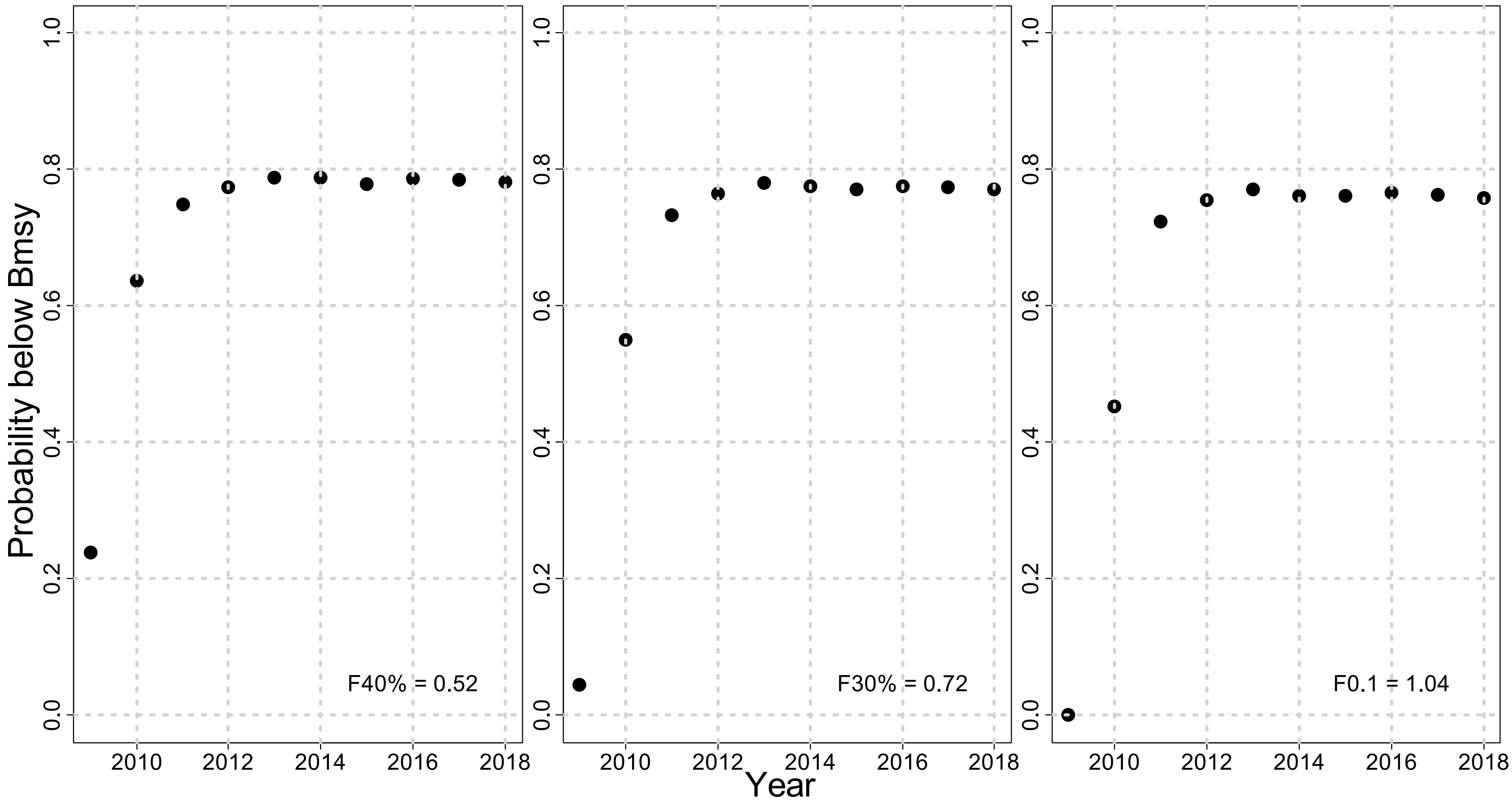

Figure B60. Probabilities of median spawning biomass being below the corresponding candidate SSB_{MSY} when fishing at candidate F_{MSY} proxies and recruitment is based on recruitment estimates for the last 10 years (1999-2008).

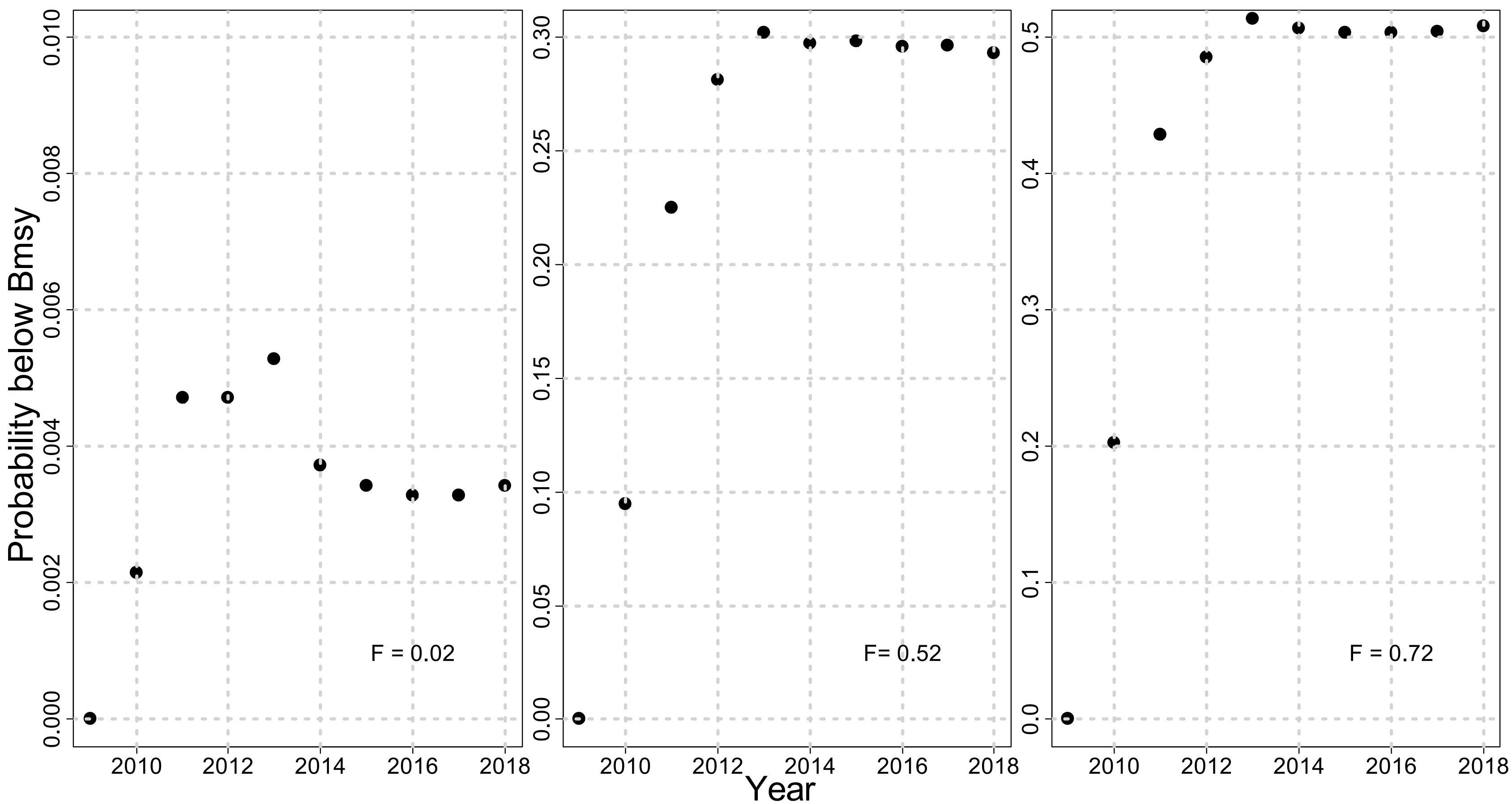

Figure B61. Probabilities of median spawning biomass being below the proposed SSB_{MSY} for potential constant fishing mortality rates ($F=F_{2008}$=0.02, F=0.52, and F=0.72) when recruitment is based on recruitment estimates for the last 10 years (1999-2008).

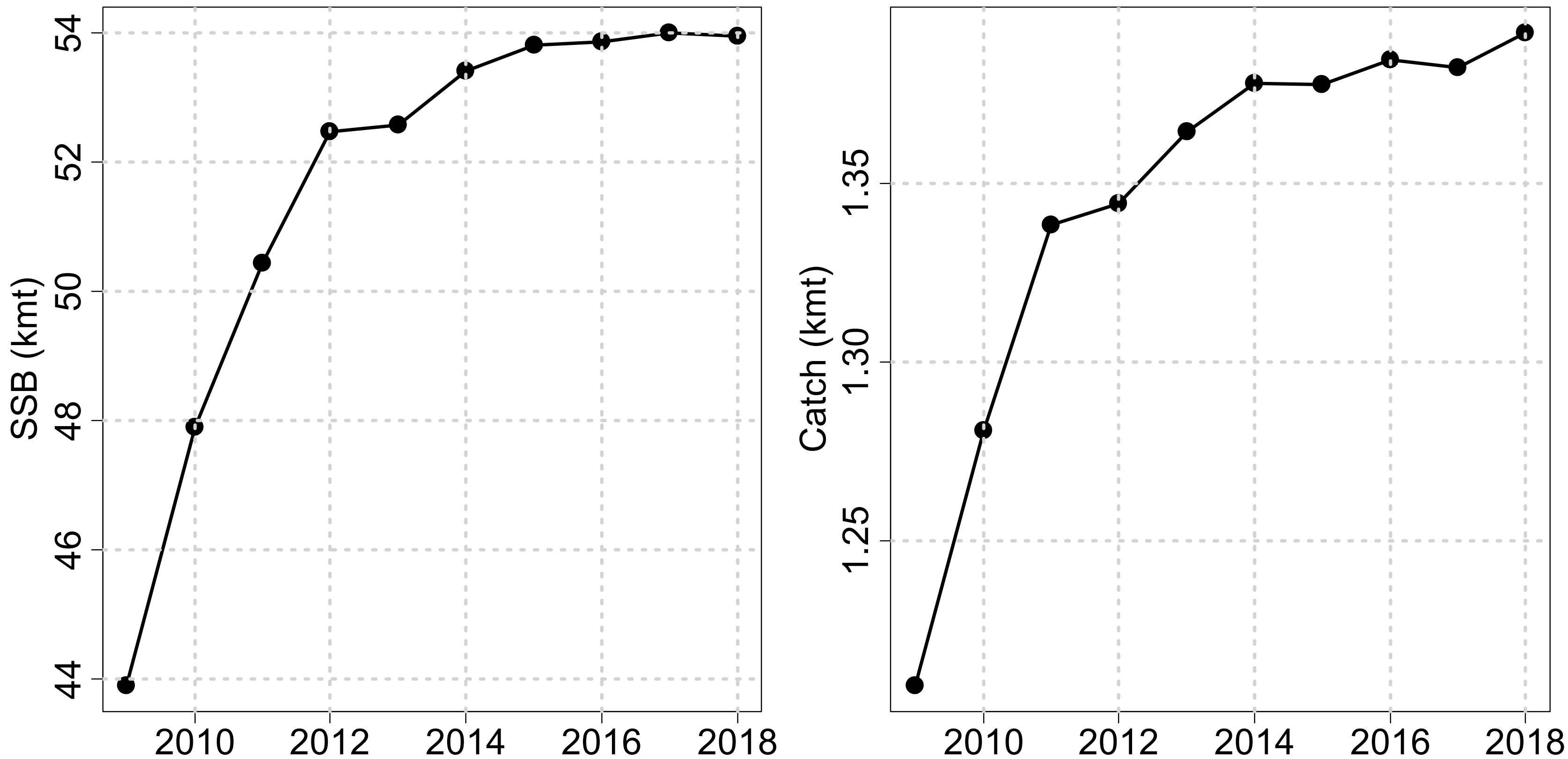

Figure B62. Median spawning biomass and catch for constant fishing at $F=F_{2008}=0.02$ when recruitment is based on recruitment estimates for the last 10 years (1999-2008).

Appendix B1: Term of Reference 6

Evaluate the magnitude, trends and uncertainty of predator consumptive removals on butterfish and associated predation mortality estimates and, if feasible, incorporate said mortality predation estimates into models of population dynamics.

Introduction

Food habits were evaluated for a wide range of butterfish predators. The total amount of food eaten and the type of food eaten were the primary food habits data examined. From these basic food habits data, diet composition of butterfish, per capita consumption, total consumption, and the amount of butterfish removed by these butterfish predators were calculated. Combined with abundance estimates of these predators, when summed the total amount of butterfish removed by predators was calculated. Contrasts to estimates of landings (see above) were conducted to place this source of mortality into context and to fully address the Term of Reference.

Methods

Every predator that contained butterfish was identified from the NEFSC Food Habits Database System (FHDBS). From that original list, a subset of predators was analyzed to elucidate which predators consistently ate butterfish with a diet composition of >1% for any five year block. The consistent butterfish predators are listed in Table B.6.1.

Estimates were calculated on a seasonal basis (two 6 month periods) for each predator species, summed for each annum. Although the food habits data collections started quantitatively in 1973, not all species of butterfish predators were sampled during the full extent of this sampling program. For more details on the food habits sampling protocols and approaches, see Link and Almeida (2000). This sampling program was a part of the NEFSC bottom trawl survey program; for background and context, further details of the survey program can be found in Azarovitz (1981) and NEFC (1988).

This approach followed previously established and described methods for estimating consumption, using an evacuation rate model methodology. For further details, see Durbin et al. (1983), Ursin et al. (1985), Pennington (1985), Overholtz et al. (1991, 1999, 2000, 2008), Tsou & Collie (2001a, 2001b), Link & Garrison (2002), Link et al. (2002, 2006, 2008, 2009), Methratta & Link (2006), Link & Sosebee (2008), Overholtz & Link (2006, 2007), Tyrrell et al. (2007, 2009), Link and Idoine (2009), Moustahfid et al. (2009a, 2009b), and NEFSC (2006, 2007a, 2007b, 2008). The main data inputs are mean stomach contents (S_i) for each butterfish predator i, diet composition (D_{ij}) where j is the specific prey butterfish, and T is the bottom temperature taken from the bottom trawl surveys (Taylor et al. 2005). Estimates of variance about all these variables (data inputs) were calculated. Further particulars of these estimators can be found in Link and Almeida (2000). Units for stomach estimates are in g.

As noted, to estimate per capita consumption, the gastric evacuation rate method was used (Eggers 1977, Elliott and Persson 1978). There has been copious experience in this region using these models (see references listed above). The two main parameters, α and β, were set to 0.004 and 0.11 respectively based upon prior studies and sensitivity analyses (NEFSC 2007a, 2007b). The exception is that α was set to 0.002 for elasmobranch predators to reflect their slightly lower metabolism than teleost fishes.

Once daily per capita consumption rates were estimated for each butterfish predator those estimates were then scaled up to a seasonal estimate by multiplying the number days in each half year, which were then multiplied by the diet composition D_{ij} that was butterfish, to estimate the seasonal per capita consumption of butterfish, which were then summed to provide an annual estimate, which were then scaled by the total stock abundance of each predator to estimate a total amount of butterfish *(j)* removed by any predator *i*, where either the swept area estimate of abundance or stock assessment value for each predator for each year were used, with a cutoff of 20 cm to exclude predators incapable of consuming butterfish. These predator species-specific consumptions were then summed across all *i* predators to estimate a total amount of butterfish removed by all consistent butterfish predators.

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Results

Total consumptive removals by all consistent butterfish predators exhibited two increasing trends, one in the early to mid 1980s and another more recently (Figure B.6.1.a). These estimates have averaged around 4-6 MT yr^{-1}. When examining only the amount of consumptive removals by age class, the same trends and patterns follow, with most of the consumption being on adults (~80%) (Figure B.6.1.a). For more explicit presentation of the step-by-step consumptive removal results, please contact the working group, as has been done in prior assessments (NEFSC 2007a, 2007b).

When comparing the total amount of butterfish consumed by all predators to landings (Figure B.6.1.b), landings dominated earlier in the time series (1970s), but some of the same patterns (or at least magnitudes) were seen in the 1980s for both estimates. Finally, since the early 2000s consumptive removals are a much larger source of removals than are landings.

Sources of Uncertainty

1. Minimum swept area estimates for some predator abundance does not account for q for all predators; these are likely lower estimates of predator abundance and thus these consumption estimates should be viewed as conservative estimates.
2. Size cutoffs to allocate between juvenile and adult butterfish assumed fixed and consistent sizes across predators and time; they may be more dynamic.
3. Is the α too low compared to literature? These too may be somewhat conservative, but are within the range of those generally reported.
4. Some fish predators that did not consistently eat butterfish (e.g. pollock) were dropped.
5. Also, these estimates did not include a wide range of other (non-fish) predators known to consume butterfish (e.g., seabirds, squids, marine mammals). Collectively this relatively limited set of predators thus may result in these being fairly conservative estimates of overall predatory removals of butterfish.
6. Spatio-temporal overlap considerations between predators and butterfish were not taken into account fully.
7. Diet compositions of butterfish in these predators amount to a relatively small amount. Thus these estimates may either be an underestimate of diet composition

contributed by butterfish or reflective of non-preference by predators for butterfish.

Summary

1. Total consumption of butterfish is on the same order of magnitude as estimates of butterfish stock landings.
2. Total consumption of butterfish exhibits similar trends as landings estimates, until recent years.
3. Butterfish were usually coincident with squid in the diets of these predators (not shown).
4. Variances about these estimates (available, not shown) have CVs on the order of 0.5 to 1, often much tighter than estimates of butterfish discard/bycatch (see above).
5. Instead of increasing uncertainty, incorporating information on consumption of butterfish may actually help to better inform and improve model fitting.
6. It is feasible to calculate M in this context
7. Ignoring some form of dynamic M may provide misleading BRPs, or least result in incorrectly scaled model results (estimates of B, F, etc.).

Recommendations

1. At the least, consumptive removals should be able to be used as a qualitative index in butterfish assessment, providing context.
2. These results provide further justification for modifying M (to be dynamic) in the assessment model, which should be modeled explicitly.
3. Consumptive removals may be able to be included as a covariate to a dynamically modeled M.
4. Even a simple ratio of Consumptive Removals/Biomass can be used to scale, inform and approximate M used in the model apart from a separate estimation procedure for M.
5. The Consumptive removals are able to be incorporated as a separate "fleet" a la Overholtz et al., Moustahfid et al., etc., and this should be done.
6. Incorporating Consumptive removals should help to stabilize, inform and otherwise improve the KLAMS model as an ESAM.
7. Partitioning total mortality into Z and M2 (with some minimal assumed M1) will have implications for projections and BRPs, but it is feasible.
8. Extant Multispecies models should also be considered to provide further context; although not shown, they confirm these general consumptive removal results.
9. Given the high co-occurrence of butterfish with squids-- in time, space, and the fishery-- future assessments should consider a joint assessment of these species using some form of MS model. Such models are extant and have been reviewed, albeit not for this particular application.

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Appendix B2: Coastal/Pelagic Working Group

Coastal/Pelagic Working Group
Meeting September 21-22,2009
Woods Hole, MA
November 4, 2009
Woods Hole, MA (conference call/Webex)

Dr. Timothy Miller – NEFSC – lead assessment scientist
Dr. Chris Legault – NEFSC
Lisa Hendrickson – NEFSC
Dr. Paul Rago – NEFSC- chief, Population Dynamics Branch
Katherine Sosebee – NEFSC
Dr. Mark Terceiro – NEFSC
Dr. Jason Link – NEFSC
Gary Shepherd – NEFSC – chair Coastal/Pelagic
Carrie Nordeen – NMFS RO
Dr. Olaf Jensen – Industry advisor
Dr. Vidar Wepstead –Industry advisor
Jason Didden – MAFMC
Greg DiDomenico – Garden State Seafood Association
Brad Sewell – Natural Resources Defense Council
Pamela Lyons Gromen – Natural Resources Defense Council

Appendix B3: Butterfish predators

Species of consistent butterfish predators.

Smooth Dogfish	*Mustelus canis*
Spiny Dogfish	*Squalus acanthias*
Silver Hake	*Merluccius bilinearis*
Summer Flounder	*Paralichthys dentatus*
Bluefish	*Pomatomus saltatrix*
Goosefish	*Lophius americanus*

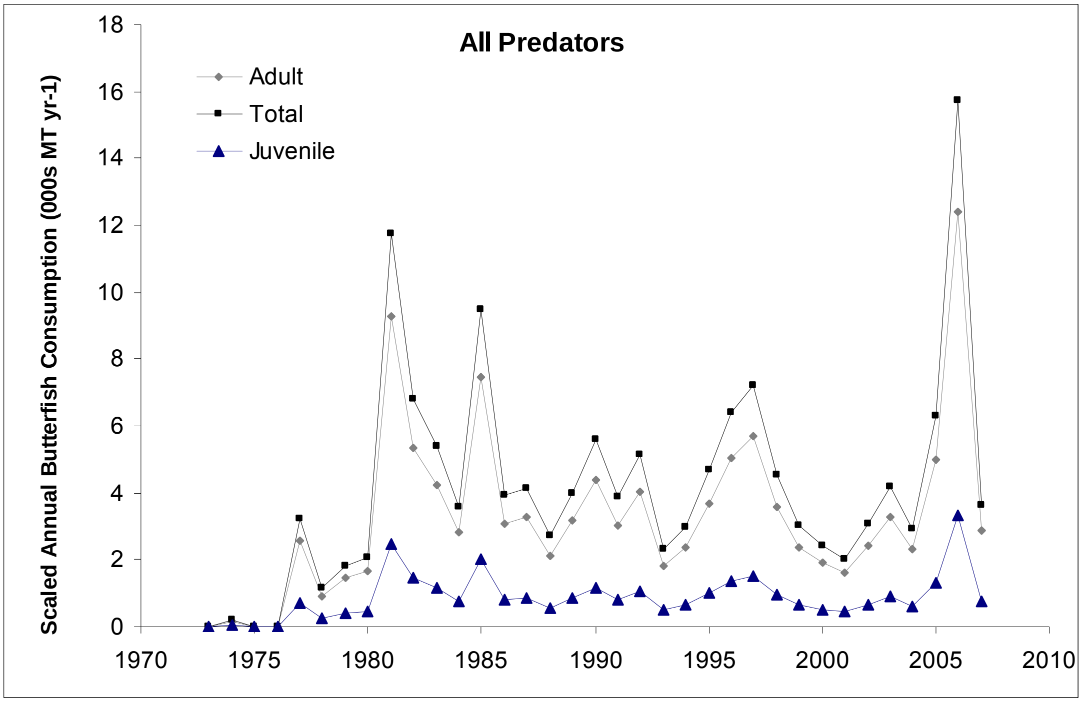


Figure B3.1.a. Total butterfish biomass consumed by all predators. The total is split into juvenile and adult butterfish consumed

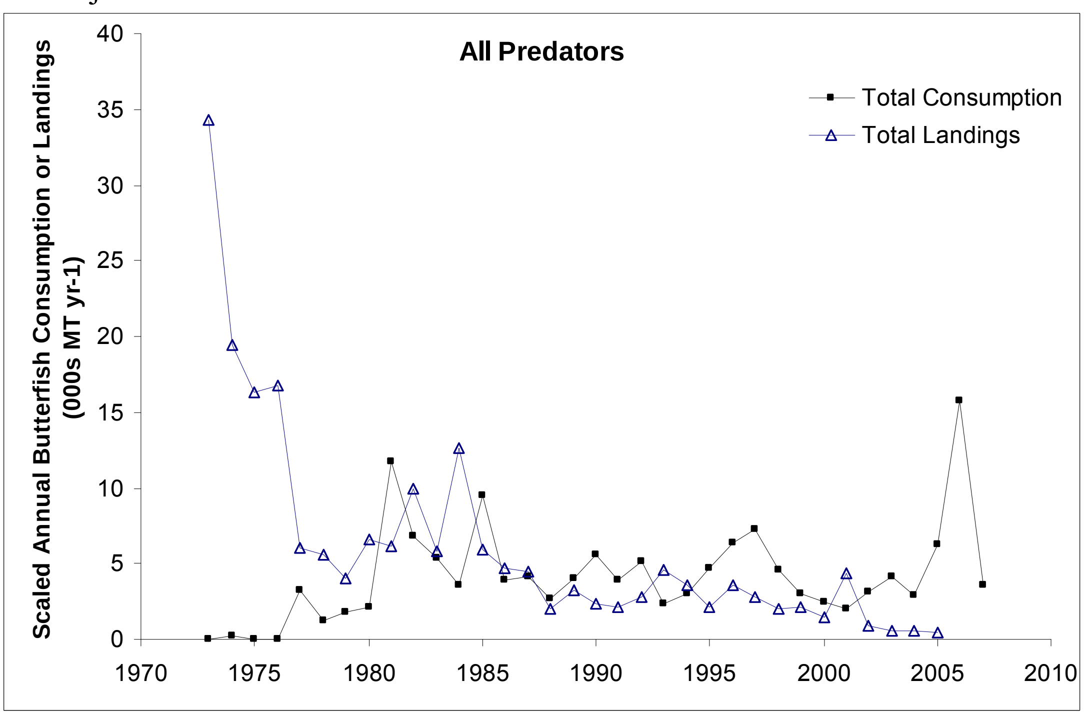


Figure B3.1.b. Total butterfish biomass consumed by all predators compared to butterfish landings.

Appendix B4: Envelope Method

Stock assessment models typically incorporate two primary sources of information: estimates of total catch (landings plus discards), and fishery-independent indices of abundance. The former quantities provide estimates of population scale, the latter quantities provide measures of trend. Total catch provides some insight into the scale of the population but without additional information it is impossible to determine if total catch is the result of a low fishing mortality rate applied to a large population or a high fishing mortality rate applied to a small population. Fishery independent stock size estimates from trawl surveys, expressed in terms of average catch per tow, approximate the true population size subject to an arbitrary scalar that reflects gear efficiency, availability, and the variability in the realization of the sampling design. Collectively these factors are called catchability and denoted as the parameter q.

The uncertainty in the interpretation of these two basic quantities is addressed explicitly in an assessment model but the underlying relationships can be obscured by complexity of the mathematics and tradeoffs among poorly estimated parameters. Here we propose a simple approach to reconcile these perspectives on stock size that provides a feasible range or "envelope" of population sizes. The purpose of this exercise is not to replace the delay-difference model used in this assessment. Instead the purpose is to demonstrate that the assessment model is consistent with the implications simpler measures of stock size.

Let I_t represent the observed index of biomass at time t and C_t represent the catch at time t. The estimated total biomass consistent with the index is

$$B_t = \frac{I_t}{q} \qquad (1)$$

where q is an assumed value. The biomass consistent with observed catch can be obtained from the catch equation as

$$B_t = \frac{C_t}{\frac{F}{F+M}\left(1-e^{-(F+M)}\right)} \qquad (2)$$

where F is unknown. Thus biomass can be written as a function of arbitrary scalars q and F. These equations can be generalized and written as

$$\begin{aligned}
\hat{B}_{1,t} &= B(I_t, q_{Low}) \\
\hat{B}_{2,t} &= B(I_t, q_{High}) \\
\hat{B}_{3,t} &= B'(C_t, F_{Low}, M) \\
\hat{B}_{4,t} &= B'(C_t, F_{High}, M)
\end{aligned} \qquad (3)$$

In theory the above measures of stock biomass should be consistent. Prior information on the suitable range for q can be obtained from analyses of relative survey catchability as detailed in the main body of the report. The suitable range of F values can obtained from analogy with other fisheries, or more simply by picking a wide range of values.

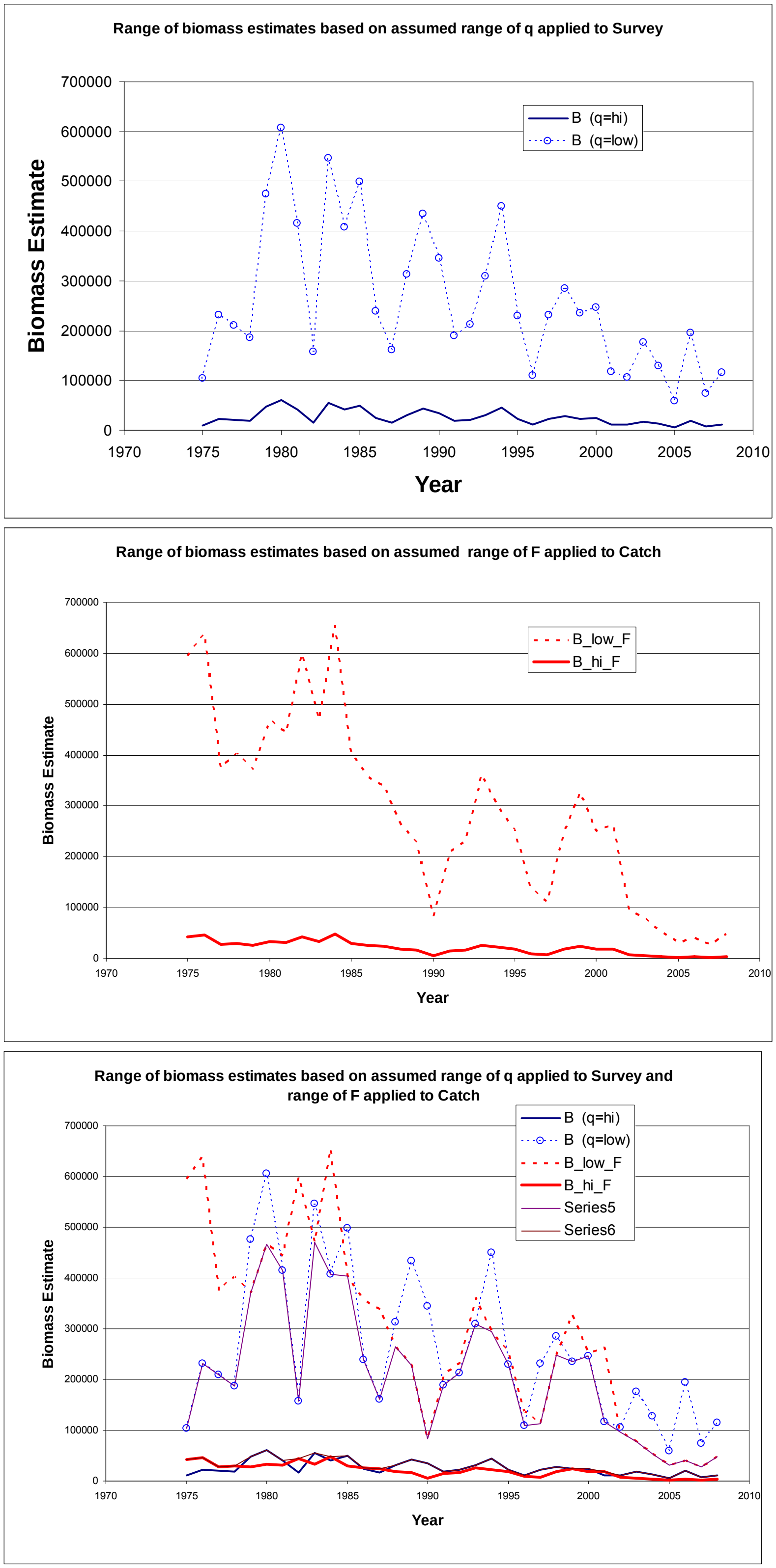
By inspection it is evident that $B_{1,t}$ and $B_{3,t}$ constitute an upper range, and $B_{2,t}$ and $B_{4,t}$ constitute a lower range. Upper and lower bounds consistent with these estimates are

$$\begin{aligned}\widehat{B}_{upper,t} &= \min(B_{1,t}, B_{3,t}) \\ \widehat{B}_{lower,t} &= \max(B_{2,t}, B_{4,t})\end{aligned} \qquad (4)$$

These bounds describe a set of feasible options that are consistent with the assumed ranges of q and F. In theory, a more sophisticated population model should lie within this feasible range.

Figure B.B1 illustrates the application of the envelope method using equations 1 to 4. Results suggest that biomasses necessary to support observed catches in the early 1980's were as high as 400,000 mt. Current population sizes since 2001 are likely to have been below 100,000 mt. The trend in minimum biomass estimates (high F, high q) is less pronounced but similar in relative trend. A comparison with biomass estimates from the final model run (Figure B.B2).

The envelope concept can also be extended to compute a range of feasible F values consistent with derived biomass estimates from Eq. 4. Assuming that $B_{1,t}$ and $B_{2,t}$ approximate average biomass at time t, then the ratio of C_t to $B_{1,t}$ or $B_{2,t}$ is a measure of biomass weighted F. These estimates can then be compared directly with the estimates of F from the KLAMZ model. Figure B.B3 suggests a comparable range of values except in 2003 to 2008. In these years the model-based estimate of F was about 0.03 which was lower than the lowest value of F (=0.05) used to construct the biomass series based on $B_{3,t}$.



A.

B.

C. Superposition of A and B with feasible set identified by Eq. 4.

Figure B4.1. Illustration of the envelope estimation method for the NEFSC fall survey index (A), and total catch (B). Panel C represents the feasible envelope of biomass estimates.

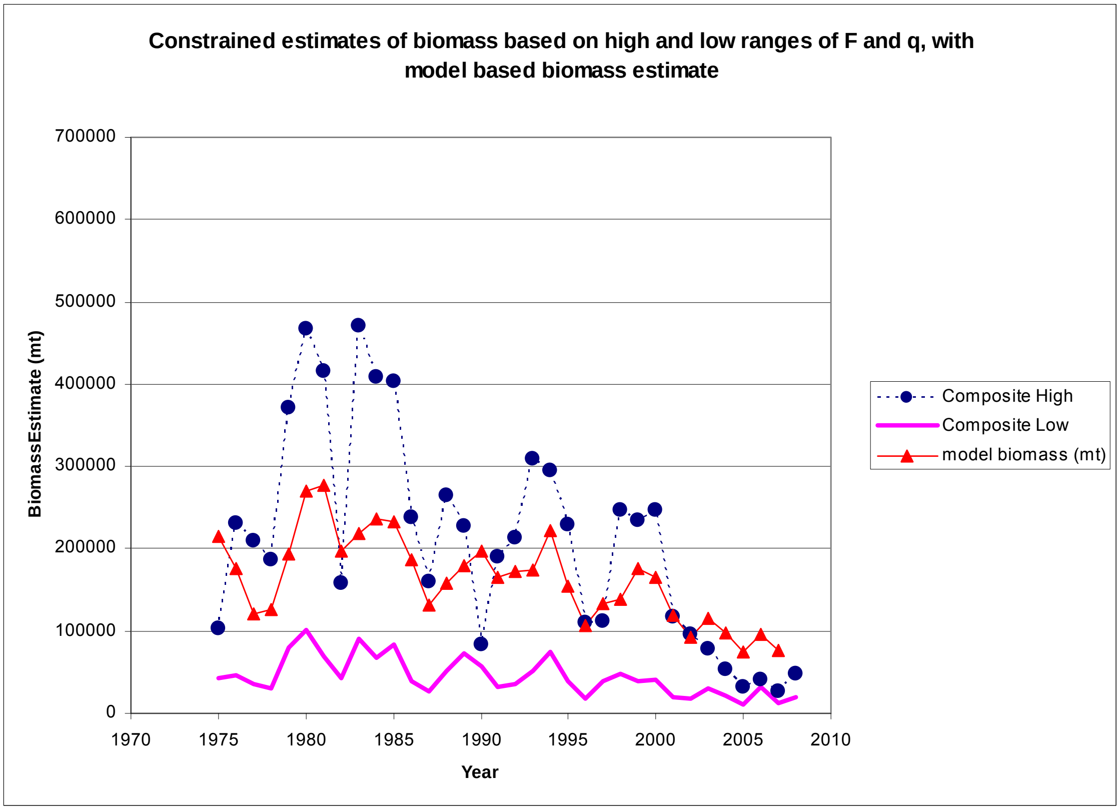


Figure B4.2. Comparison of the envelope measure of stock biomass with model based estimates.

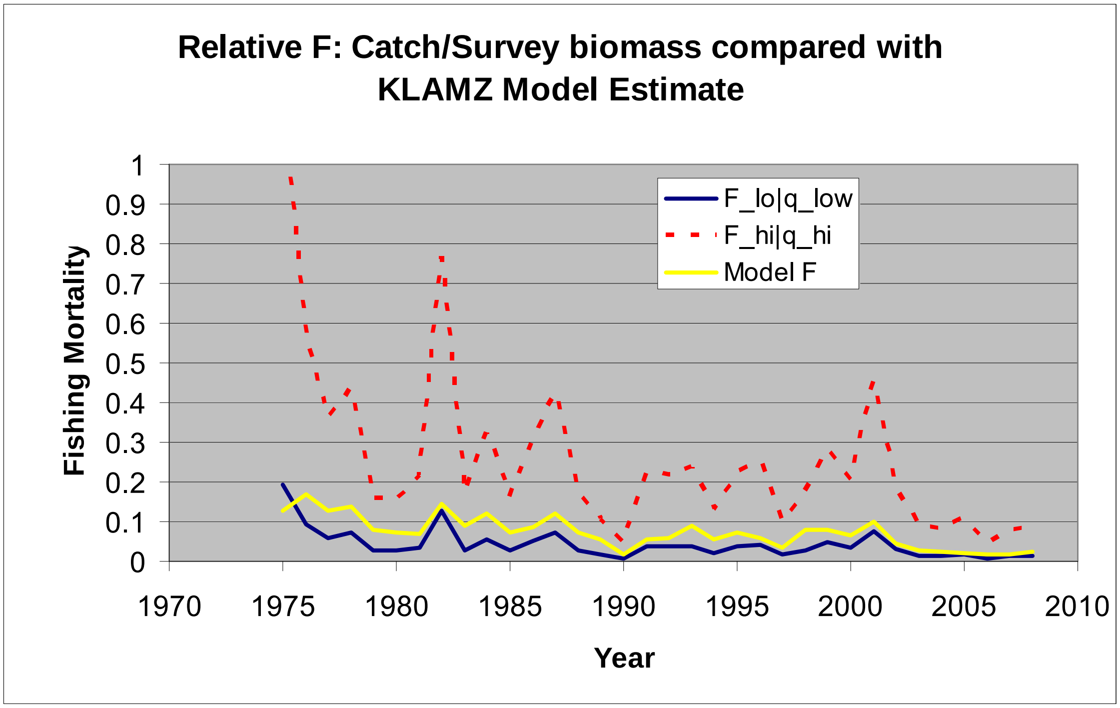


Figure B4.3. Comparison of KLAMZ estimate of fishing mortality with envelope derived from ratio of C_t to B_t derived from assumed range of q applied to survey indices.