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58th Northeast Regional Stock Assessment Workshop (58th SAW)

Assessment Report

by the Northeast Fisheries Science Center

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NOAA Fisheries, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts
May 2014

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Foreword

The Northeast Regional Stock Assessment Workshop (SAW) process has three parts: preparation of stock assessments by the SAW Working Groups and/or by ASMFC Technical Committees / Assessment Committees; peer review of the assessments by a panel of outside experts who judge the adequacy of the assessment as a basis for providing scientific advice to managers; and a presentation of the results and reports to the Region's fishery management bodies.
Starting with SAW-39 (June 2004), the process was revised in two fundamental ways. First, the Stock Assessment Review Committee (SARC) became smaller panel with panelists provided by the Independent System for Peer Review (Center of Independent Experts, CIE). Second, the SARC provides little management advice. Instead, Council and Commission teams (e.g., Plan Development Teams, Monitoring and Technical Committees, Science and Statistical Committee) formulate management advice, after an assessment has been accepted by the SARC. Starting with SAW-45 (June 2007) the SARC chairs were from external agencies, but not from the CIE. Starting with SAW-48 (June 2009), SARC chairs are from the Fishery Management Council's Science and Statistical Committee (SSC), and not from the CIE. Also at this time, some assessment Terms of Reference were revised to provide additional science support to the SSCs, as the SSC's are required to make annual ABC recommendations to the fishery management councils.

Reports that are produced following SAW/SARC meetings include: An *Assessment Summary Report* - a summary of the assessment results in a format useful to managers; an *Assessment Report* – a detailed account of the assessments for each stock; and the SARC panelist reports – a summary of the reviewer's opinions and recommendations as well as individual reports from each panelist. SAW/SARC assessment reports are available online at

http://www.nefsc.noaa.gov/nefsc/publications/series/crdlist.htm. The CIE review reports and assessment reports can be found at *http://www.nefsc.noaa.gov/nefsc/saw/*".
The 58th SARC was convened in Woods Hole at the Northeast Fisheries Science Center, January 27-31, 2014 to review benchmark stock assessments of: butterfish (*Peprilus triacanthus*), golden tilefish (*Lopholatilus chamaeleonticeps*), and northern shrimp (*Pandalus borealis*). CIE reviews for SARC58 were based on detailed reports produced by NEFSC Assessment Working Groups. This Introduction contains a brief summary of the SARC comments, a list of SARC panelists, the meeting agenda, and a list of attendees (Tables 1 – 3). Maps of the Atlantic coast of the USA and Canada are also provided (Figures 1 - 5).

Outcome of Stock Assessment Review Meeting:

Text in this section is based on SARC-58 Review Panel reports (available at http://www.nefsc.noaa.gov/nefsc/saw/ under the heading "SARC-58 Panelist Reports").

For **butterfish** nearly all of the assessment Terms of Reference (ToRs) were fully met and the assessment results can be used as a basis for management. The Panel suggested that additional work could be done on consumptive removals of butterfish by predators and integration of results into the assessment. The SARC Panel felt that the work on habitat and oceanography was innovative, but the supporting document could have been clearer. The final accepted ASAP assessment model included an average measure of availability, which is a function of habitat suitability. But a temporally varying (by year) availability index was not included in the final model. In 2012, overfishing was not occurring, and the stock was not overfished. The stock is considered rebuilt.

For **golden tilefish** nearly all of the assessment ToRs were fully met and assessment results from the ASAP model can be used as a basis for management. The SARC Panel felt that the analysis of tilefish distribution in relation to temperature could be expanded by analyzing the relationship between commercial LPUE and environmental and climate variables. The Panel expressed some reservations about assuming a dome-shaped selectivity function, but noted that there appeared to be reasonable support for that assumption. In 2012, overfishing was not occurring, and the stock was not overfished. The stock is considered rebuilt.

For **northern shrimp** some key assessment ToRs were not met, and the results of the analytical assessment models should not be used as a basis for management. Three independent assessment models were presented but each model had problems. Model performance was partially related to the addition of new data, which created technical problems within the models. In lieu of an accepted assessment model, the SARC Panel recommended basing northern shrimp management on observed patterns in the northern shrimp catches, survey indices, and potentially on commercial CPUE.

Table 1. 58th Stock Assessment Review Committee Panel.

SARC Chairman (MAFMC SSC):

Dr. Robert Latour
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SARC Panelists (CIE):

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Table 2. Agenda, 58th Stock Assessment Review Committee Meeting.

January 27 – 31, 2014

Stephen H. Clark Conference Room – Northeast Fisheries Science Center
Woods Hole, Massachusetts

AGENDA* (version: 24 Jan. 2014)

TOPIC		PRESENTER(S)	SARC LEADER	RAPPORTEUR
Monday, Jan. 27				
10 – 10:30 AM				
Welcome		**James Weinberg**, SAW Chair		
Introduction		**Robert Latour**, SARC Chair		
Agenda				
Conduct of Meeting				
10:30 – 12:30	Assessment Presentation (A. Butterfish)	**Charles Adams** **John Manderson** **Tim Miller**	--	**Michelle Traver**
12:30 – 1:30 PM	Lunch			
1:30 – 3:00	Assesssment Presentation (A. Butterfish)	**Charles Adams** **John Manderson** **Tim Miller**	--	**Toni Chute**
3:00 – 3:15	Break			
3:15 – 5:15	SARC Discussion w/ Presenters (A. Butterfish)	**Robert Latour,** SARC Chair		**Toni Chute**
5:15 – 5:45	Public Comments (A. Butterfish)			**Toni Chute**
Tuesday, Jan.28				
8:45 – 11 AM	Assessment Presentation (B. Tilefish)	**Paul Nitschke**	--	**Brian Linton**
11 - 11:15	Break			
11:15 – 12:15	SARC Discussion w/presenters (B. Tilefish)	**Robert Latour,** SARC Chair		**Brian Linton**
12:15 – 12 :30	Public Comments (B. Tilefish)		**Brian Linton**	
12:30 – 1:45 PM	Lunch			
1:45 – 4:15	Assessment Presentation (C. Northern shrimp)	**Kelly Whitmore** **Anne Richards**	--	**Christine Lipsky**
4:15 - 4:30	Break			
4:30 – 5:45	SARC Discussion w/presenters (C. Northern shrimp)	**Robert Latour,** SARC Chair		**Christine Lipsky**
5:45 – 6	Public Comments (C. Northern shrimp)			**Christine Lipsky**

TOPIC	PRESENTER(S)	SARC LEADER	RAPPORTEUR

Wed. Jan. 29

9 – 11:15 AM Revisit with presenters (A. Butterfish)
Robert Latour, SARC Chair **Toni Chute**

11:15 – 11:30 Break

11:30 – 12:30 Revisit with presenters (B. Tilefish)
Robert Latour, SARC Chair **Brian Linton**

12:30 – 1:30 PM Lunch

1:30 -2:30 (cont) Revisit with presenters (B. Tilefish)
Robert Latour, SARC Chair **Brian Linton**

2:30 – 2:45 Break

2:45 – 5:15 Revisit with presenters (C. Northern shrimp)
Robert Latour, SARC Chair **Christine Lipsky**

Thur. Jan. 30

8:30 – 11:30 Review/edit Assessment Summary Report (A. Butterfish)
Robert Latour, SARC Chair **Dan Hennen**

11:30 – 12:30 PM Lunch

12:30 – 2:45 Review/edit Assessment Summary Report (B. Tilefish)
Robert Latour, SARC Chair **Brian Linton**

2:45 – 3 Break

3 - 5:30 Review/edit Assessment Summary Report (C. Northern shrimp)
Robert Latour, SARC Chair **Christine Lipsky**

Friday, Jan.31

9 AM – 5 PM SARC Report writing. (closed meeting)

*All times are approximate, and may be changed at the discretion of the SARC chair. The meeting is open to the public, except where noted.

Table 3. 58th SAW/SARC, List of Attendees

Name	Affiliation	Email
Chang Jui-Han	NEFSC	jui-han.chang@noaa.gov
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Wilcox Steve	MA DMF – New Bedford	steve.wilcox@state.ma.us
Wood Tony	NEFSC	anthony.wood@noaa.gov

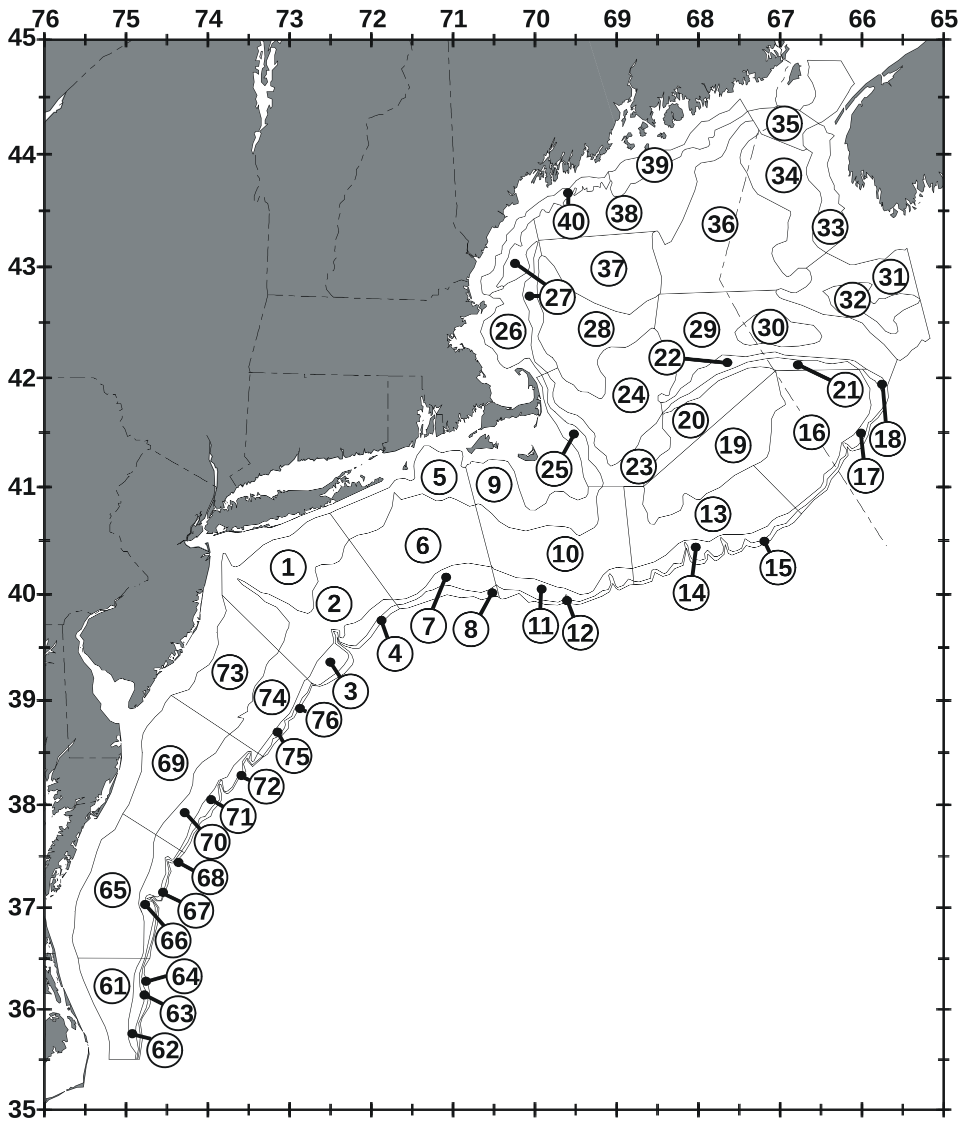

Figure 1. Offshore depth strata that have been sampled during Northeast Fisheries Science Center bottom trawl research surveys. Some of these may not be sampled presently.

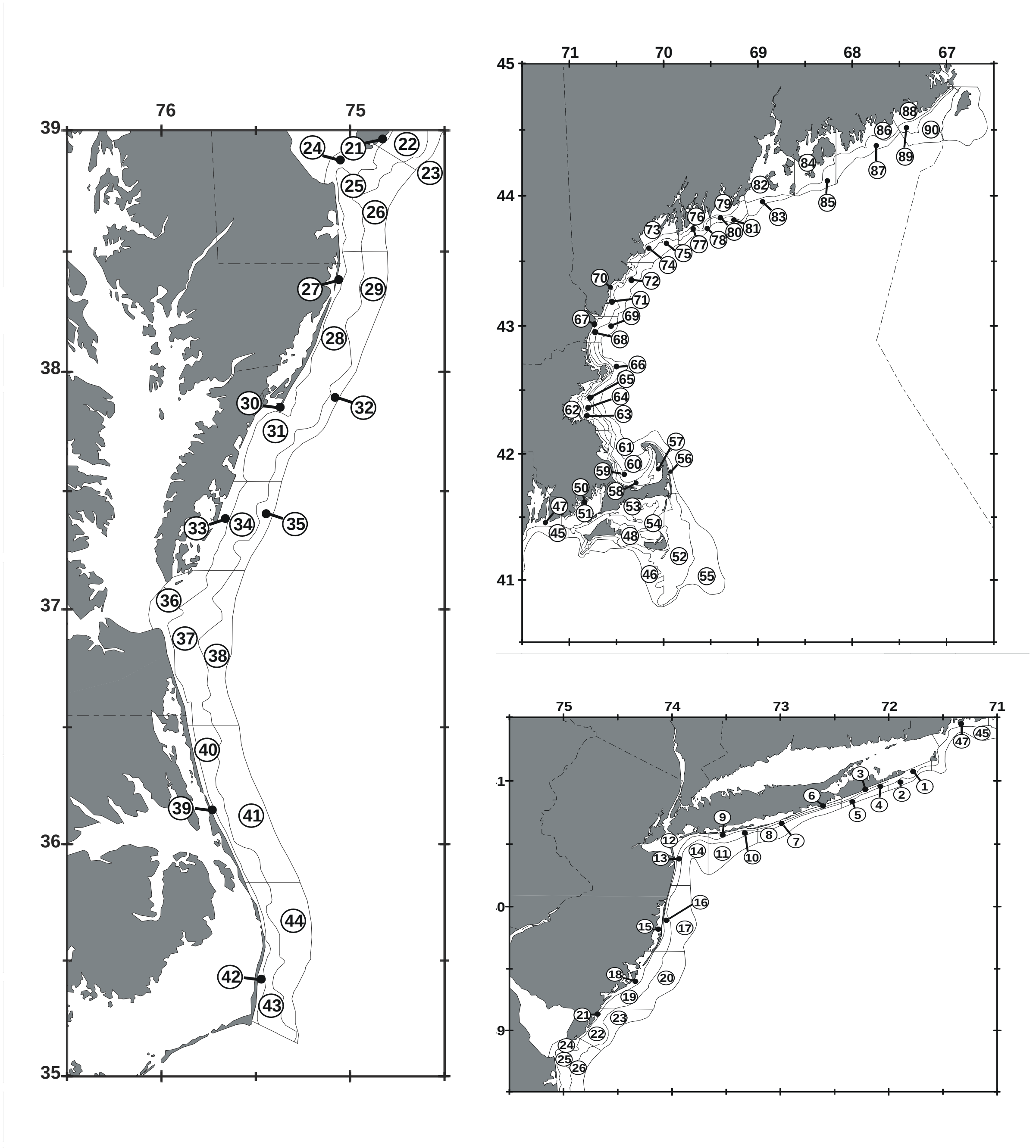

Figure 2. Inshore depth strata that have been sampled during Northeast Fisheries Science Center bottom trawl research surveys. Some of these may not be sampled presently.

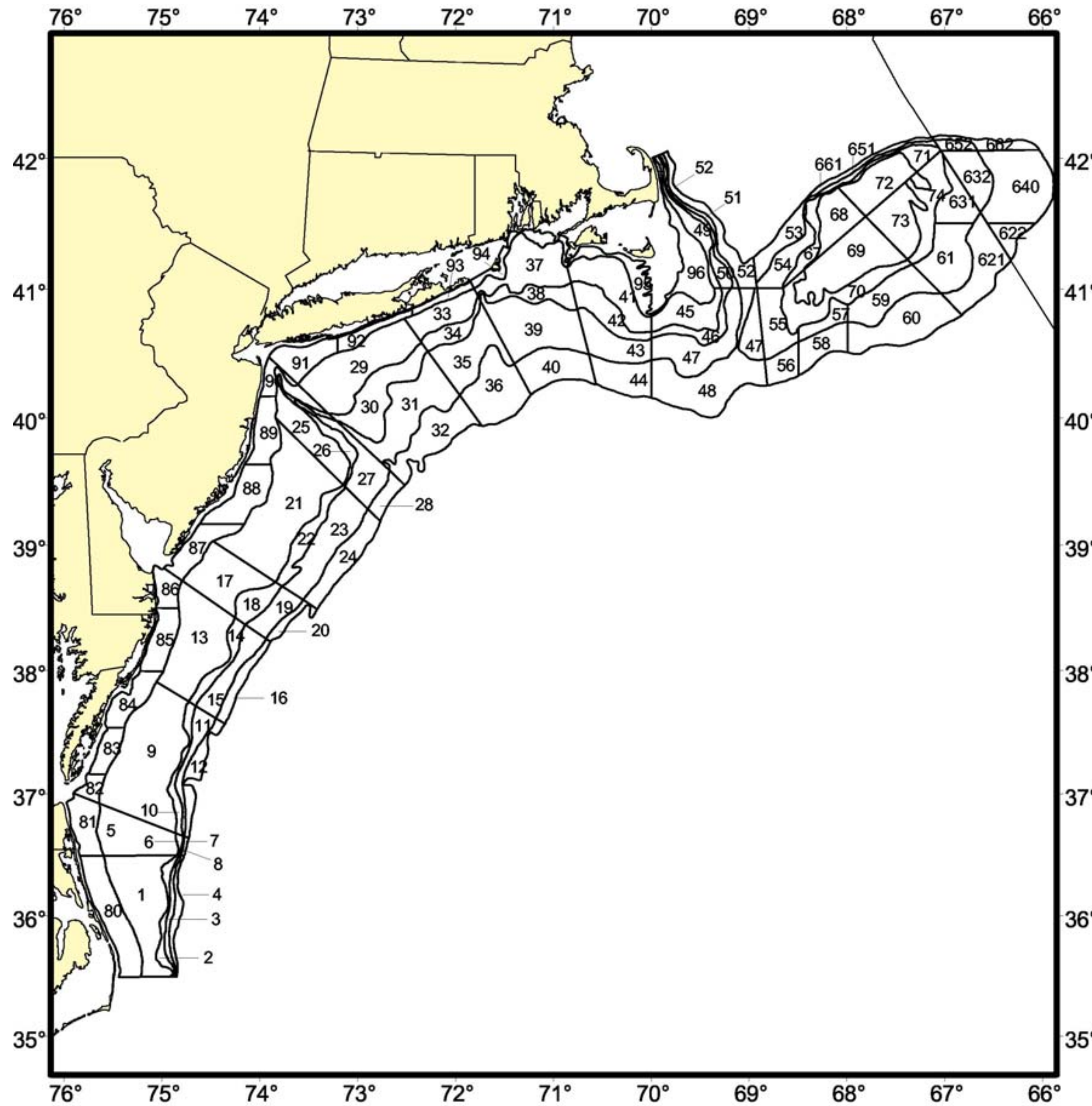

Figure 3. Depth strata sampled during Northeast Fisheries Science Center clam dredge research surveys.

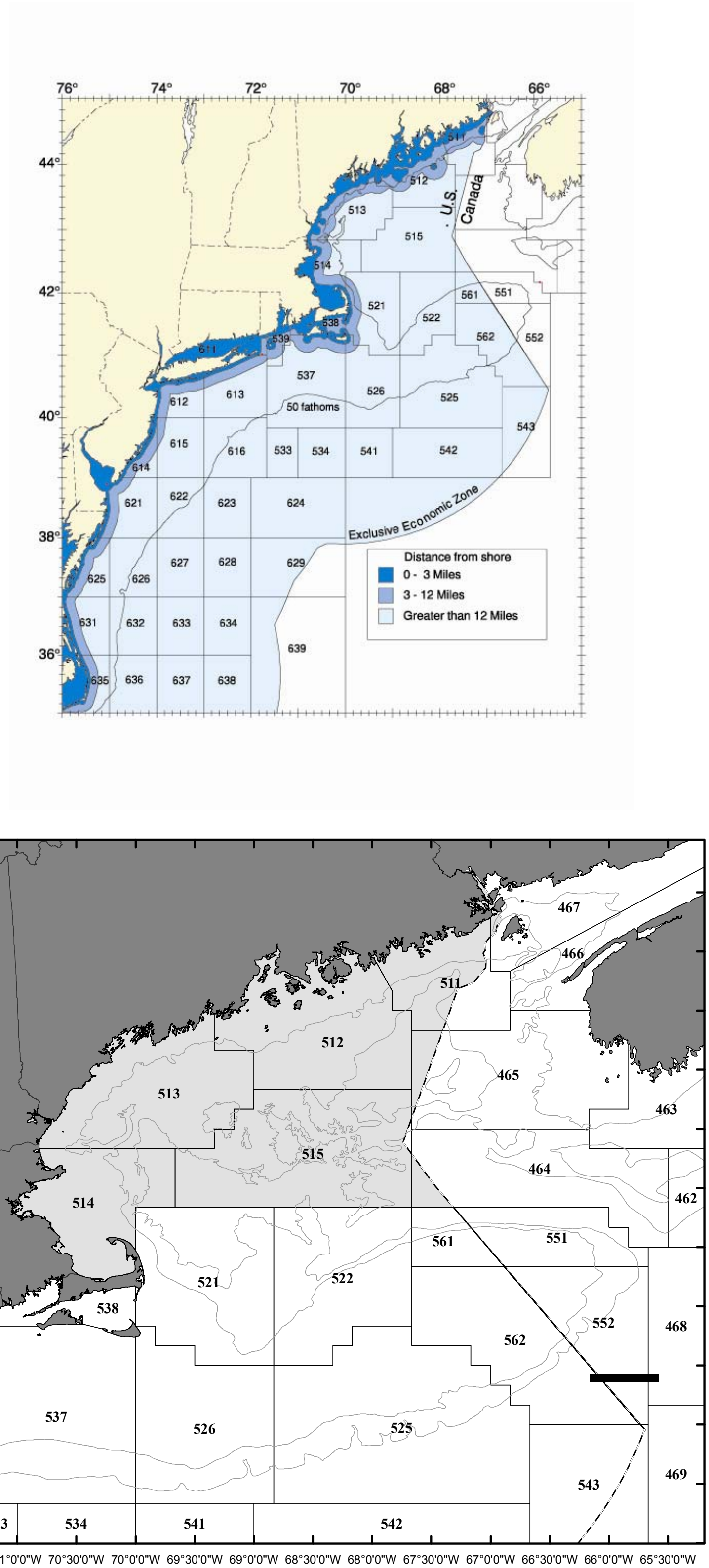

Figure 4. Statistical areas used for reporting commercial catches.

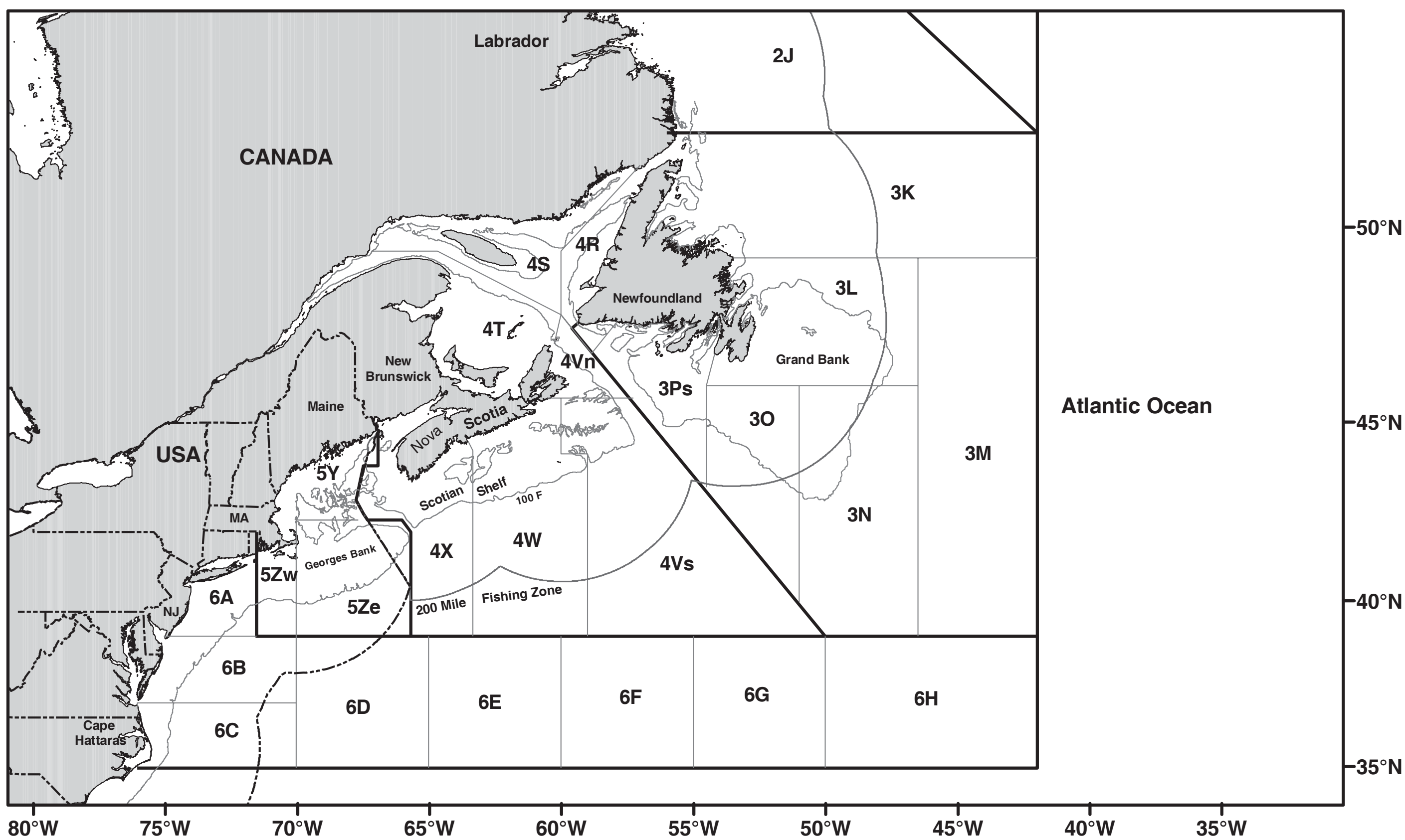

Figure 5. Catch reporting areas of the Northwest Atlantic Fisheries Organization (NAFO) for Subareas 3-6.

A. BUTTERFISH STOCK ASSESSMENT FOR 2014

by: Coastal/Pelagic Working Group

Data Meeting: August 26-28, 2013
Model Meeting: December 18-21, 2013
Woods Hole, MA

Dr. Charles Adams - NEFSC - co-lead assessment scientist
Dr. Timothy Miller - NEFSC - co-lead assessment scientist
Dr. John Manderson - NEFSC
Dr. David Richardson - NEFSC
Brian Smith - NEFSC
Dr. Chris Legault - NEFSC
Dr. Josh Kohut – Rutgers University
Dr. Jon Hare - NEFSC
Laura Palamara - Rutgers University
Gary Shepherd - NEFSC – chair Coastal/Pelagic SAW WG
Katherine Sosebee - NEFSC
Dr. Mark Terceiro - NEFSC
Dr. Olaf Jensen - Rutgers University
Jason Didden - MAFMC
Rich Seagraves - MAFMC
Greg DiDomenico - Garden State Seafood Association
Michele Traver - NEFSC
Alicia Miller - NEFSC
Dr. Kiersten Curti - NEFSC
Dr. Jon Deroba - NEFSC
Michael Palmer - NEFSC

Executive Summary

Major findings for TOR 1 – Characterize the commercial catch including landings, effort and discards by gear type. Describe the magnitude of uncertainty in these sources of data.

Landings were largest in the 1970s, when catch was dominated by foreign fleets targeting longfin squid (*Doryteuthis pealeii*) in offshore areas. Foreign landings were completely phased out by 1987. Landings during 1988-2001 averaged 2,797 mt (6.2 million lb). From 2002-2012 there was no directed fishery, and landings, primarily as bycatch in the small mesh (< 4 in = 10.2 cm) bottom trawl longfin squid fishery, have been below 900 mt (2.0 million lb). A directed fishery was re-established in January 2013, and preliminary landings have been 1,070 mt (2.4 million lb) to date.

Discards were estimated for the period 1989-2012 using the Standardized Bycatch Reporting Methodology (Wigley et al., 2007). Discards comprised a majority of the total butterfish catch, averaging 58% during 1989-2001 and 67% during 2002-2012. Total catch estimates were highly variable and imprecise, with CVs ranging from 0.07 – 1.43 due to the uncertain discard estimates. Recreational catches were negligible.

Major findings for TOR 2 – Characterize the survey data that are being used in the assessment. Describe the magnitude of uncertainty in these sources of data.

Northeast Fisheries Science Center (NEFSC) fall survey data were used in the assessment. In spring 2009 the FSV *Henry B. Bigelow* replaced the FRV *Albatross IV*. Due to the larger size of the FSV *Henry B. Bigelow* the two innermost inshore strata have not been surveyed since 2008. Thus, data for each survey were divided into an offshore series, which included the offshore strata and the outermost inshore strata; and an inshore series, which included the two innermost inshore strata.

The Northeast Area Monitoring and Assessment Program (NEAMAP) fall survey data were also used in the assessment. NEAMAP has surveyed inshore waters from Cape Cod to Cape Hatteras since fall 2007. These strata are approximately the same as the NEFSC inshore strata.

Precision of the NEFSC indices are generally best for the fall offshore series, and it is considered the most reliable abundance index. Most of the population is thought to be within the survey domain and CVs were generally acceptable (0.13 – 0.47). The CVs for NEAMAP abundance indices were ≤ 0.21 with the exception of one outlier. State data were not used as tuning indices in the assessment model.

Major findings for TOR 3 – Characterize oceanographic and habitat data as it pertains to butterfish distribution and availability. If possible, integrate the results into the stock assessment (TOR-5).

Work on oceanographic and habitat effects focused on development of methods to estimate the availability of the butterfish stock to fishery independent surveys. With low landings, the assessment is largely driven by fishery independent surveys and there is concern that recent changes in ocean temperatures may have caused shifts in species range and migration dynamics that could affect survey catchability. Availability is here defined as the proportion of the stock falling within the space-time frame of a fishery independent survey.

A thermal niche model for butterfish was developed and coupled to debiased bottom water temperatures estimated from a numerical ocean model to make daily hindcasts of thermal habitat suitability for butterfish in the northwest Atlantic during the fall and spring from 1973-2012. Evaluation of the coupled model indicated that patterns of occupancy for butterfish in samples from fishery independent surveys throughout the region were well explained by hindcasts of thermal habitat suitability.

The coupled model thermal habitat suitability models was used with the locations and dates of sampling to compute the availability of the butterfish stock to surveys as the proportion of thermal habitat suitability sampled within the space-time frame of the survey.

Based on the coupled model offshore NEFSC stations sampled between 62% and 75% of the estimated thermal habitat suitability was available to butterfish during the fall, while 53% to 59% of thermal habitat suitability was sampled during the spring. Inshore NEAMAP stations sampled between 10 and 12% of the thermal habitat suitability available in the fall while NEFSC inshore stations sampled <11% of available thermal habitat. Estimates of availability from the coupled model for 2008-12 during the fall fell within the narrow range of empirical estimates developed from Richardson's (2014) analysis of simultaneous but non-overlapping fishery independent surveys and day: night differences in detectability of butterfish.

Model based estimates of availability were combined with Richardson's empirical calculations of detectability of butterfish (=proportion of fish within the footprint of an average trawl tow captured in the net) to parameterize catchability in the base ASAP model.

Major findings for TOR 4 – Evaluate consumptive removals of butterfish by its predators. If possible, integrate results into the stock assessment (TOR-5).

The principle predators of butterfish were identified from food habit data collected during the NEFSC bottom trawl survey. The six predators were smooth dogfish, spiny dogfish, silver hake, summer flounder, bluefish and goosefish. Total consumption was estimated as ranging between 1,000 and 8,000 mt per year. A time series analysis of the consumption results supported the use of a constant natural mortality in the assessment model.

Major findings for TOR 5 – Use assessment models to estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Include a comparison with previous assessment results and previous projections.

Note: Refer to Appendix 4 for final details regarding TOR 5.

Atlantic butterfish was last assessed in 2009 using a type of delay-difference model (KLAMZ), but the scale of the population was not accepted by the SARC (NEFSC, 2010). The current assessment is based on an augmented version of a peer-reviewed age-structured assessment program (ASAP) software (Legault and Restrepo, 1999), which models the butterfish stock between 1989 and 2012. The model relies on abundance indices and age composition from the Northeast Fisheries Science Center fall survey and the Northeast Area Monitoring and Assessment Program fall survey; US landings and discard estimates, and commercial mean weights at age. The augmentations to the ASAP model also allowed estimation of natural mortality and inclusion of thermal-habitat-based measures of availability of the stock to the area surveyed by the NEFSC fall survey, measures of maximum efficiency of the survey based on analyses of day-night differences in NEFSC fall survey catches, and length-based relative catch efficiency of the FRV *Albatross IV* and FSV *Henry B. Bigelow* vessels used for the NEFSC surveys. Simulations indicated that the statistical behavior of the augmented ASAP was appropriate.

The results of the model imply that fishing mortality has declined over the timespan of the model, but it has always been low relative to natural mortality which was estimated to be much higher than assumed in prior assessments. Stock size has varied over the time span of the model, but has increased in recent years. No strong trend in recruitment was indicated over the time span.

Major findings for TOR 6 – State the existing stock status definitions for "overfished" and "overfishing". Given that the stock status is currently unknown, update or redefine biological reference points (BRPs; point estimates for B_{MSY}, $B_{THRESHOLD}$, F_{MSY} and MSY, or their proxies) and provide estimates of their uncertainty. Consider effects of environmental factors on stability of reference points and implications for stock status.

Note: Refer to Appendix 4 for final details regarding TOR 6.

Based on Patterson (1992), the proposed overfishing reference point is F = 2M/3 = 2 ×1.22/3 = 0.81 CV = 0.05. The current fishing mortality (F_{2012} = 0.02) is well below the accepted overfishing reference point. The accepted biomass reference point SSB_{MSY} proxy is 45,616 mt (100.6 million lb); CV = 0.25. $SSB_{threshold}$ is one half the SSB_{MSY} proxy, or 22,808 mt (50.3 million lb). SSB_{2012} is estimated to be 79,451 mt (175.2 million lb), which is well above the $SSB_{threshold}$. Overfishing is not occurring and the stock is not overfished.

Bottom temperature during the NEFSC fall offshore survey was used to estimate availability of the butterfish stock to the survey. Thus, annual estimates of recruitment were informed by these estimates of availability, and these recruitment estimates were used in long-term projections to establish the biological reference points.

Major findings for TOR 7 – Evaluate stock status with respect to a newly proposed model and with respect to "new" BRPs and their estimates (from TOR-6). Evaluate whether the stock is rebuilt.

Note: Refer to Appendix 4 for final details regarding TOR 7.

Fishing mortality was estimated to be 0.02 in 2012, which is well below the proposed overfishing reference point F_{MSY} proxy = 0.81. There is a < 1% chance the estimated fishing mortality is above the F_{MSY} proxy.

SSB in 2012 was estimated to be 79,451 mt (199.9 million lb), which is well above the accepted biomass reference point SSB_{MSY} proxy = 45,616 mt (100.6 million lb). $SSB_{threshold}$ is one half the SSB_{MSY} proxy, or 22,808 mt (50.3 million lb). There is a < 1% chance the estimated SSB_{2012} is below $SSB_{threshold}$.

The butterfish stock was not overfished and the overfishing was not occurring in 2012 relative to the new biological reference points.

Major findings for TOR 8 – Develop approaches and apply them to conduct stock projections and to compute the statistical distribution (e.g., probability density function) of the OFL (overfishing level) and candidate ABCs (Acceptable Biological Catch; see Appendix to the SAW TORs).

a) *Provide numerical annual projections (2 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which* *a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment). Comment on which projections seem most realistic.*

b) *Describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming overfished, and how this could affect the choice of ABC.*

Note: Refer to Appendix 4 for final details regarding TOR 8.

If preliminary butterfish catch (landings plus discards) for 2013 (2,489 mt; 5.5 million lb) is used, the median projection of SSB in 2013 is 51,746 mt (114.1 million lb), with 5% and 95% confidence limits of 32,489 mt (71.6 million lb) and 81,073 mt (178.7 million lb), respectively. Because the catch is fixed at 2,489 mt, the median projected total catch is 2,489 mt, with 5% and 95% confidence limits of 2,489 mt and 2,489 mt, respectively.

If the 2014 butterfish ABC (9,100 mt; 20.1 million lb) is assumed for 2014 catch, the median projection of SSB in 2014 is 53,580 mt (118.1 million lb), with 5% and 95% confidence limits of 38,365 mt (84.6 million lb) and 73,885 mt (162.9 million lb), respectively. Because the catch is fixed at 9,100 mt, the median projected total catch is 9,100 mt, with 5% and 95% confidence limits of 9,100 mt and 9,100 mt, respectively.

Major findings for TOR 9 – Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in most recent SARC reviewed assessment and review panel reports. Identify new research recommendations.

The SARC 38 made 8 research recommendations of which 6 have been examined and/or incorporated into the current assessment. The WG for SARC 58 made 4 new recommendations including that no additional assessments be conducted until such time as the fishery has developed to the point that it could influence the total stock biomass.

A. BUTTERFISH

TERMS OF REFERENCE

1). Characterize the commercial catch including landings, effort and discards by gear type. Describe the magnitude of uncertainty in these sources of data.

2). Characterize the survey data that are being used in the assessment. Describe the magnitude of uncertainty in these sources of data.

3). Characterize oceanographic and habitat data as it pertains to butterfish distribution and availability. If possible, integrate the results into the stock assessment (TOR-5).

4). Evaluate consumptive removals of butterfish by its predators. If possible, integrate results into the stock assessment (TOR-5).

5). Use assessment models to estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Include a comparison with previous assessment results and previous projections.

6). State the existing stock status definitions for “overfished” and “overfishing”. Given that the stock status is currently unknown, update or redefine biological reference points (BRPs; point estimates for B_{MSY}, $B_{THRESHOLD}$, F_{MSY} and MSY, or their proxies) and provide estimates of their uncertainty. Consider effects of environmental factors on stability of reference points and implications for stock status.

7). Evaluate stock status with respect to a newly proposed model and with respect to “new” BRPs and their estimates (from TOR-6). Evaluate whether the stock is rebuilt.

8). Develop approaches and apply them to conduct stock projections and to compute the statistical distribution (e.g., probability density function) of the OFL (overfishing level) and candidate ABCs (Acceptable Biological Catch; see Appendix to the SAW TORs).

a. Provide numerical annual projections (2 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment). Comment on which projections seem most realistic.

b. Describe this stock’s vulnerability (see “Appendix to the SAW TORs”) to becoming overfished, and how this could affect the choice of ABC.

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

Introduction

Butterfish (*Peprilus triacanthus*) are distributed from Florida to Nova Scotia, occasionally straying as far north as Newfoundland, but are primarily found from Cape Hatteras to the Gulf of Maine, where the population is considered to be a unit stock (Collette and Klein-MacPhee, 2002). Butterfish are a fast growing species, overwintering offshore, and then moving inshore and northwards in the summer. Butterfish mature during their second summer (age 1), spawn primarily during June-July, and begin schooling around 60 mm. The diet consists primarily of urochordates (Larvacea, Ascidacea, Thaliacea),ctenophores and thecosome mollusks (*Clione*). They are preyed upon by a number of commercially important fishes such as haddock, silver hake, swordfish, bluefish, weakfish, summer flounder, goosefish, and hammerhead shark. Although it is generally thought that butterfish comprise a large part of the diet of longfin squid, recent stable isotope and fatty acid work suggests this is not the case (Jensen et al., 2013).

The last assessment for this stock was completed in 2009 (SARC 49, NEFSC 2010). The review panel accepted the trends in F and SSB provided by the assessment but recommended that actual point estimates of biomass and F be interpreted with caution. In addition, the panel did not accept the redefined biological reference points or the reference points generated in the 2004 assessment. Subsequent management advice was based on an "envelope analysis" which provided a bounded estimate of catch based on an empirical analysis of NEFSC survey and total catch. The results provide a likely range of historic stock size and fishing mortality rates under a range of assumptions for survey catchability (0.1 and 1) and natural mortality (0.8 and 1.1). Survey data were expanded to total swept area biomasses for assumed catchabilities. For each combination of the catchabilities and natural mortality rates, historic fishing mortality and January 1 biomasses were obtained by coupling with catch data.

TOR 1. Characterize the commercial catch including landings, effort and discards by gear type. Describe the magnitude of uncertainty in these sources of data.

Data

A variety of data sources were used to derive the catch time series. Landings prior to 1965 were obtained from Lyles (1967) as compiled by Murawski et al. (1978). Landings from 1965-1989 were obtained from the Northeast Fisheries Science Center (NEFSC) commercial fisheries state canvas data table, while landings from 1990-2012 were obtained from the NEFSC commercial fisheries detail species data tables. Butterfish catch data for foreign fleets during 1963-1982 and 1983-1986 were obtained from Waring and Anderson (1983) and NEFSC (1990), respectively.

Two additional sources of data were used to estimate discards: the Northeast Regional Office Vessel Tracking and Reporting System; and the NEFSC Observer Database System. The latter database begins in 1989. Thus, the working group decided to start the catch time series in 1989. Additional reasons for this approach include: uncertainty in foreign discards; differences between foreign and US discard proportions; differences in foreign discard estimates in the 1970s; and the possibility of industrial fishing with no discards included.

Commercial landings

During the late 1800s through 1928, butterfish harvested from nearshore weirs and traps between Cape Cod and Virginia ranged between 142 mt (0.3 million lb) and 2,794 mt (6.2 million lb) annually (Murawski et al. 1978). Landings increased during 1929-1962, ranging between 1,033 mt (2.3 million lb) and 7,758 mt (17.1 million lb), and averaging 4,315 mt (9.5 million lb; Figure A1.1). This was due to trawlers based primarily in Point Judith, RI and New Bedford, MA that landed butterfish in mixed-species food and industrial fisheries (e.g., Edwards and Lawday, 1960).

During 1963-1986 landings of butterfish were reported by foreign fleets targeting longfin squid (*Doryteuthis pealeii*) in offshore areas. In many cases the reported catch included discards; thus, foreign landings are described below in the Total Catch section. Domestic landings of butterfish averaged 1,976 mt (4.4 million lb) during 1965-1979 without any trend (Table A1.1; Figure A1.2). A domestic fishery was developed to supply the Japanese market, leading to peak landings of 11,715 mt (25.8 million lb) in 1984, but then declined to 2,298 mt (5.1 million lb) in 1990. During 1991-2001 landings ranged between 1,449 mt (3.2 million lb) and 4,608 mt (10.2 million lb). During 2002-2012 there was no directed fishery, and landings, primarily as bycatch in the small mesh (< 4 in = 10.2 cm) bottom trawl longfin squid fishery, ranged between 428 mt (0.9 million lb) and 872 mt (1.9 million lb). A directed fishery was re-established in January 2013, and preliminary landings have been 1,070 mt (2.4 million lb) to date.

Commercial size composition

Butterfish are sampled dockside as part of the National Marine Fisheries Service (NMFS) commercial sampling program. Samples are collected per market category, port and gear. Since 1989 an average of 28 butterfish samples per year have been collected averaging one sample per 91 mt of landings (ranging between 11 mt per sample to345 mt per sample). Each sample contains approximately 100 fish, resulting in an average of 2,864 lengths per year, ranging from 688 in 1995 to 6,431 in 2007 (Table A1.2). Size composition from commercial samples of butterfish ranged from 7-29 cm during 1989-2012 with modal lengths from 14-17 cm (Figures A1.5-A1.10).

Discard estimates

Catch data from 1976-1986 as presented in historic assessment documents include some estimates of butterfish discards combined with landings (Waring and Anderson, 1983; NEFSC, 1990). In the last assessment (NEFSC, 2010) the portion of the annual total catches in these records attributable to discards was determined by subtracting the landings obtained from the NEFSC Commercial Fisheries State Canvas Data Table. These values are reproduced here as "historic discards" in Table A1.1.

The Standardized Bycatch Reporting Methodology (SBRM; Wigley et al., 2007) combines landings, vessel trip report and observer sampling data to provide estimates of discard rates and total discards for specified stocks. Butterfish discard estimates for 1989-2012 were developed using the combined ratio estimator (method 2 in Wigley et al., 2007). Strata were defined by quarter, gear type, and region (New England or Mid-Atlantic waters). Total discard estimates varied from just under 239 mt (0.5 million lb) in 2007 to as high as 8,867 mt (19.5 million lb) in 1999, but the precision of these estimates is generally poor (Table A1.3). In only five years is the estimated coefficient of variation ≤ 0.30.

Almost all estimated discards are attributable to tows with bottom trawls, either in a single otter trawl configuration or a twin trawl configuration (Table A1.4). Details for these two gear types, with an additional stratification of mesh size < 4 inches vs. ≥ 4 inches (10.2 cm), are shown in Tables A1.5 and A1.6.

The number of observed trips for any stratum ranged from a low of 12 in 1994 for mesh size < 4 inches in the Mid-Atlantic (Table A1.5) to a high of 1,591 in 2011 for mesh size ≥ 4 inches in New England waters (Table A1.6). The average number of observed trips was greater in New England waters (116 for mesh size < 4 inches and 450 for mesh size ≥ 4 inches) relative to the Mid-Atlantic (88 for mesh size < 4 inches and 124 for mesh size ≥ 4 inches).

Discards are roughly an order of magnitude higher with small mesh (< 4 inches), averaging 1,151 mt (2.5 million lb) in New England waters and 1,291 mt (2.8 million lb) in the Mid-Atlantic; while large mesh discards averaged 259 mt (0.6 million lb) and 144 mt (0.3 million lb) in New England and Mid-Atlantic waters, respectively.

Discard size composition

Data from observed trips 1989-2012 were used to examine the size composition of the discarded and kept fraction of trips where butterfish were caught. The number of butterfish measured averaged 4,600, ranging from 1,176 in 1992 to 18,774 in 2011 (Figures A1.11-A1.13). The size composition of discarded butterfish ranged from 3-34 cm, with modal lengths from 8-15 cm. The size composition of kept butterfish also ranged from 3-36 cm, with modal lengths from 15-19 cm.

Total commercial catch

Total catches of butterfish increased from 15,167 mt (33.4 million lb) in 1965 to a peak of 39,896 mt (88.0 million lb) in 1973, and were dominated by catches from the offshore foreign fleets (Table A1.1; Figure A1.1). Total catches then declined to 11,863 mt (26.2 million lb) in 1977, following the implementation of the Fishery Conservation and Management Act of 1976. Foreign landings were completely phased out by 1987. Butterfish catches by foreign fleets are likely underestimated because Spain and Italy did not report their butterfish bycatch from the squid fisheries during 1972-1976 (Murawski and Waring 1979).

A domestic fishery was developed to supply the Japanese market, leading to a peak catch of 22,401 mt (49.4 million lb) in 1984, but then declined to 2,831 mt (6.2 million lb) in 1990 (Table A1.1; Figure A1.1). During 1991-2001, catches ranged between 3,928 mt (8.7 million lb) and 12,185 mt (26.9 million lb). Catches declined during 2002-2012 due to the lack of a directed fishery, ranging between 918 mt (2.0 million lb) and 4,593 mt (10.1 million lb). Discards comprised a majority of the total butterfish catch, averaging 58% during 1989-2001 and 67% during 2002-2012. Total catch estimates were highly variable and imprecise, with CVs ranging from 0.07 – 1.43 (Table A1.3; Figure A1.4) due to the uncertain discard estimates.

Almost all of the total catch (not including landings by pound net and unknown gear types) was with single or twin bottom trawls, averaging 99% during 1989-2001, and 96% during 2002-2012 (Table A1.4).

Commercial catch at age

Commercial landings were compromised primarily of age 1 and age 2 butterfish (Table A1.7), discards were comprised primarily of age 0 and age 1 fish (Table A1.8), and total catches were comprised primarily of age 1, age 0 and age 2 fish (Table A1.9; Figures A1.14 and A1.15). Commercial mean weights at age are presented in Tables A1.10 to A1.12.

Recreational catch

Recreational catch was insignificant as measured by the Marine Recreational Information Program (MRIP).

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Table A1.1. Butterfish USA landings (mt), historic USA discards (mt), estimated USA discards (mt), foreign catch (mt), and total catch (mt), 1965-2012. USA landings from 1976-1986 include discards, which were assumed by Waring and Anderson (1983) and SAW 10 (NEFSC, 1990) to be 10% of landings; these discards were estimated in SAW 49 (NEFSC, 2010) and are shown here as historic discards. Foreign catch includes discards, which were estimated by dividing longfin squid catch by survey ratios to account for butterfish discards of countries reporting only longfin (Murawski and Waring, 1979; NEFSC, 1990).

Year	USA Landings	Historic USA Discards	USA Discards	Foreign_Catch	Total catch
1965	2944		11474	749	15167
1966	2461		10997	3865	17323
1967	2245		10174	2316	14735
1968	1585		9856	5437	16878
1969	2198		9421	15378	26997
1970	1731		8760	12450	22941
1971	1566		7977	8913	18456
1972	704		6653	12221	19578
1973	1521		6696	31679	39896
1974	1778		6197	15465	23440
1975	1973		5658	12764	20395
1976	1376	152	6193	14437	22006
1977	1296	152	7255	3312	11863
1978	3615	61	8675	1699	13989
1979	2646	185	9193	1107	12946
1980	5172	184	9956	1392	16520
1981	4855	0	9531	1400	15786
1982	8837	68	11098	1578	21513
1983	4743	162	10911	630	16284
1984	11715	257	10257	429	22401
1985	4633	106	8328	804	13765
1986	4418		7936	164	12518
1987	4578		7351		11929
1988	2107		7352		9459
1989	3216		4480		7696
1990	2298		533		2831
1991	2189		4887		7076
1992	2754		5025		7779
1993	4608		7577		12185
1994	3634		6694		10328
1995	2067		6353		8420
1996	3555		1049		4604
1997	2794		1134		3928
1998	1966		6412		8378
1999	2110		8867		10977
2000	1449		7044		8493
2001	4404		4969		9373
2002	872		2350		3222
2003	536		2088		2624

Table A1.1 continued.

2004	497	1323	1820
2005	428	647	1075
2006	555	856	1411
2007	679	239	918
2008	452	1029	1481
2009	435	1079	1514
2010	576	4017	4593
2011	664	1612	2276
2012	671	1040	1711

Table A1.2. U.S. commercial butterfish samples and lengths collected, 1989-2012.

		Quarter				
		1	2	3	4	Total
1989	Total number of samples taken	11	4	8	5	28
	Total number of fish measured	1115	399	800	504	2818
1990	Total number of samples taken	8	6	11	9	34
	Total number of fish measured	812	589	1103	901	3405
1991	Total number of samples taken	9	4	10	7	30
	Total number of fish measured	901	402	1002	700	3005
1992	Total number of samples taken	8	6	7	5	26
	Total number of fish measured	803	600	710	513	2626
1993	Total number of samples taken	2	6	4	9	21
	Total number of fish measured	206	539	451	969	2165
1994	Total number of samples taken		3	4	7	14
	Total number of fish measured		142	419	724	1285
1995	Total number of samples taken	1	3	2		6
	Total number of fish measured	210	314	164		688
1996	Total number of samples taken	3	1	5	7	16
	Total number of fish measured	400	115	421	791	1727
1997	Total number of samples taken	14	4	2	11	31
	Total number of fish measured	1499	413	199	964	3075
1998	Total number of samples taken	9	7	4	5	25
	Total number of fish measured	893	618	383	467	2361
1999	Total number of samples taken	12	8	5	3	28
	Total number of fish measured	1239	728	521	237	2725
2000	Total number of samples taken	3	3	1	3	10
	Total number of fish measured	345	280	108	295	1028
2001	Total number of samples taken	6	14	7	1	28
	Total number of fish measured	637	1446	714	114	2911
2002	Total number of samples taken	6	1	2	3	12
	Total number of fish measured	617	98	215	313	1243
2003	Total number of samples taken	9	9	7	3	28
	Total number of fish measured	930	931	774	312	2947
2004	Total number of samples taken	5	12	17	7	41
	Total number of fish measured	540	1117	1755	682	4094
2005	Total number of samples taken	11	9	9	10	39
	Total number of fish measured	1124	924	903	975	3926
2006	Total number of samples taken	10	17	7	16	50
	Total number of fish measured	988	1795	731	1638	5152
2007	Total number of samples taken	13	10	23	17	63
	Total number of fish measured	1433	1005	2232	1761	6431
2008	Total number of samples taken	13	10	12	7	42
	Total number of fish measured	1374	1043	980	694	4091
2009	Total number of samples taken	7	7	3	8	25
	Total number of fish measured	694	614	325	818	2451

Table A1.2 continued.

2010	Total number of samples taken	5	11	9	7	32
	Total number of fish measured	563	1109	867	702	3241
2011	Total number of samples taken	13	4	1	6	24
	Total number of fish measured	1307	400	100	557	2364
2012	Total number of samples taken	11	5	2	4	22
	Total number of fish measured	1011	500	200	400	2111

Table A1.3. Estimated USA Butterfish discards (mt) and total catch (mt) from Table A1.1, and respective coefficients of variation (CV), 1989-2012.

Year	USA Discards	CV
1989	4480	0.85
1990	533	0.37
1991	4887	0.99
1992	5025	0.54
1993	7577	0.32
1994	6694	0.41
1995	6353	0.49
1996	1049	0.71
1997	1134	0.84
1998	6412	1.87
1999	8867	0.36
2000	7044	0.23
2001	4969	0.54
2002	2350	1.25
2003	2088	1.38
2004	1323	0.28
2005	647	0.21
2006	856	0.71
2007	239	0.60
2008	1029	0.64
2009	1079	0.30
2010	4017	0.33
2011	1612	0.15
2012	1040	0.35

Year	USA Catch	CV
1989	7696	0.49
1990	2831	0.07
1991	7076	0.68
1992	7779	0.35
1993	12185	0.20
1994	10328	0.26
1995	8420	0.37
1996	4604	0.16
1997	3928	0.24
1998	8378	1.43
1999	10977	0.29
2000	8493	0.19
2001	9373	0.29
2002	3222	0.91
2003	2624	1.10
2004	1820	0.20
2005	1075	0.13
2006	1411	0.43
2007	918	0.16
2008	1481	0.44
2009	1514	0.22
2010	4593	0.29
2011	2276	0.10
2012	1711	0.22

Table A1.4. Butterfish commercial catch (mt) by gear type, 1989-2012. Otter trawl/twin trawl and other gear types include discards. Pound net and unknown gear types are landings only.

Year	Otter trawl/twin trawl	Pound net	Other gear types	Unknown gear types	Total
1989	7545	86	52	0	7683
1990	2750	27	52	0	2830
1991	6996	12	66	0	7074
1992	7704	22	49	0	7775
1993	11969	131	84	0	12183
1994	10139	74	56	57	10326
1995	8236	57	52	71	8416
1996	4386	63	151	3	4603
1997	3680	67	172	11	3930
1998	8244	47	80	8	8378
1999	10844	66	66	0	10977
2000	8359	49	84	1	8493
2001	9242	43	87	0	9372
2002	3131	28	53	7	3219
2003	2563	16	41	0	2620
2004	1672	37	49	61	1819
2005	901	25	80	68	1074
2006	1276	0	62	72	1411
2007	742	7	74	94	917
2008	1344	2	45	84	1475
2009	1374	0	52	86	1512
2010	4427	0	76	118	4621
2011	2034	0	79	161	2274
2012	1462	0	108	140	1710

Table A1.5. Total kept of all species, number of observed trips, discard rate (estimated from observed trips), estimated butterfish discards, and coefficient of variation (CV) for bottom trawl (negear = 050 and 053) and mesh size < 4 inches in New England and Mid-Atlantic waters, 1989-2012. Note that the kept all for trips with unknown mesh size are also included.

	New England					Mid-Atlantic				
Year	Kept all (mt)	Obs. trips	Ratio	Discards (mt)	CV	Kept all (mt)	Obs. trips	Ratio	Discards (mt)	CV
1989	50243.8	82	0.03061	1538.2	0.33	41179.1	32	0.02401	988.6	0.52
1990	58802.0	33	0.00544	320.0	1.68	42540.6	32	0.02589	1101.4	0.43
1991	60282.0	96	0.03191	1923.9	0.35	54585.1	70	0.03892	2124.4	0.37
1992	58985.4	61	0.07948	4688.2	0.56	60993.5	42	0.06455	3936.9	0.29
1993	55228.0	24	0.07214	3984.3	0.66	53899.8	31	0.02705	1457.9	0.71
1994	53374.0	37	0.05067	2704.3	0.89	53873.0	12	0.03075	1656.5	0.54
1995	36928.6	91	0.00546	201.8	0.91	39937.8	69	0.03398	1357.1	1.15
1996	43164.7	60	0.01053	454.3	0.72	44140.6	82	0.02427	1071.1	1.06
1997	36975.9	54	0.01564	578.4	0.68	45364.4	46	0.01060	480.7	2.11
1998	43587.3	18	0.01959	854.0	0.54	52020.5	36	0.00283	147.4	0.92
1999	38744.0	54	0.05833	2260.0	0.42	35266.2	45	0.10642	3753.1	0.82
2000	36838.8	62	0.07821	2881.0	0.41	33633.4	42	0.06130	2061.6	0.60
2001	39801.3	39	0.01316	523.7	3.24	22552.0	63	0.01137	256.4	1.68
2002	32708.4	111	0.00407	133.2	0.49	21027.5	33	0.04703	988.9	1.34
2003	33097.4	107	0.00970	320.9	0.59	21102.8	33	0.18842	3976.1	1.20
2004	48966.3	190	0.02269	1111.1	0.41	44612.8	150	0.01500	669.3	0.41
2005	30654.2	193	0.00587	179.8	0.32	28943.6	92	0.02360	683.2	0.32
2006	22857.4	91	0.00960	219.5	0.39	50379.5	117	0.01042	525.0	1.46
2007	24195.8	115	0.00421	101.8	0.43	21247.8	128	0.00243	51.6	3.26
2008	22415.0	92	0.03194	715.9	0.76	25240.4	98	0.01546	390.3	0.80
2009	25453.9	253	0.01980	504.1	0.31	29155.7	206	0.01830	533.5	0.60
2010	21369.0	341	0.04472	955.5	0.29	29775.9	219	0.02462	733.2	0.36
2011	15354.4	324	0.01186	182.1	0.25	30353.0	273	0.04526	1373.8	0.17
2012	16985.1	251	0.01651	280.5	0.24	26585.6	158	0.02547	677.0	0.49

Table A1.6. Total kept of all species, number of observed trips, discard rate (estimated from observed trips), estimated butterfish discards, and coefficient of variation (CV) for "fish" bottom trawl (negear = 050 and 053) and mesh size ≥ 4 inches in New England and Mid-Atlantic waters, 1989-2012.

	New England					Mid-Atlantic				
Year	Kept all (mt)	Obs. trips	Ratio	Discards (mt)	CV	Kept all (mt)	Obs. trips	Ratio	Discards (mt)	CV
1989	41411.8	68	0.00014	6.0	0.55	1463.4	21	0.00732	10.7	0.28
1990	55075.1	55	0.00214	117.7	0.85	1699.2	18	0.00092	1.6	0.64
1991	49171.0	91	0.00104	51.1	0.53	2161.1	22	0.00538	11.6	0.50
1992	39275.2	69	0.00015	5.8	0.76	2194.5	24	0.00683	15.0	0.87
1993	32234.4	54	0.06094	1964.3	0.48	2170.1	19	0.02464	53.5	0.45
1994	25936.9	40	0.00178	46.1	0.76	2683.8	29	0.00128	3.4	0.66
1995	30538.5	69	0.00535	163.3	1.07	5404.7	58	0.00469	25.4	1.02
1996	36679.1	45	0.00085	31.3	11.58	5838.5	27	0.00271	15.8	1.30
1997	32028.2	32	0.00130	41.6	0.58	5919.3	31	0.01428	84.5	0.78
1998	33224.9	28	0.02903	964.6	1.58	6866.9	17	0.12694	871.7	2.77
1999	32605.6	41	0.05569	1815.8	0.67	7794.3	43	0.12486	973.2	0.61
2000	36877.8	110	0.00354	130.4	0.84	6389.7	38	0.00061	3.9	0.55
2001	44410.8	168	0.01115	495.3	0.63	7285.3	63	0.14814	1079.2	0.81
2002	40569.8	246	0.00628	255.0	1.17	7292.8	111	0.00041	3.0	0.56
2003	42864.3	408	0.00075	32.3	0.93	6940.8	64	0.00006	0.4	0.66
2004	39100.5	605	0.00092	35.9	0.62	9446.1	249	0.00171	16.1	0.77
2005	34591.4	1497	0.00004	1.4	0.42	11538.0	194	0.00204	23.5	0.47
2006	27821.9	651	0.00015	4.1	0.79	9802.6	118	0.01690	165.7	0.20
2007	28541.1	638	0.00081	23.1	0.74	7327.9	273	0.00093	6.8	0.52
2008	30011.9	766	0.00024	7.1	1.07	6747.1	203	0.00335	22.6	0.93
2009	27999.5	893	0.00033	9.2	0.47	9523.5	265	0.00195	18.6	0.89
2010	26152.1	1053	0.00030	7.9	0.42	6300.2	438	0.00173	10.9	0.64
2011	32666.9	1591	0.00008	2.8	0.32	12875.6	385	0.00088	11.3	0.44
2012	35371.0	1573	0.00008	2.7	0.29	9463.0	269	0.00166	15.7	1.11

Table A1.7. Butterfish commercial landings at age (numbers, 000s), 1989-2012.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	519	14510	18229	7271	131
1990	1766	13052	10781	2953	261
1991	1139	10532	10133	3961	252
1992	298	13459	15746	3563	144
1993	5337	31738	17984	5391	0
1994	1359	11349	21275	8407	786
1995	374	7496	14411	2863	15
1996	2169	7205	21989	10732	956
1997	1139	18582	10847	2193	105
1998	209	6649	13783	2393	19
1999	815	6877	12115	3244	241
2000	539	5697	4469	1294	934
2001	959	9507	39195	3732	5
2002	1222	2714	3399	1998	251
2003	152	1118	1211	1812	743
2004	371	1710	2259	965	310
2005	259	751	1374	1603	802
2006	1569	3234	1822	802	302
2007	312	2670	3676	1211	123
2008	271	1332	2255	961	177
2009	672	1825	2293	877	178
2010	565	2496	2004	1580	180
2011	617	1868	2642	1387	1224
2012	511	3795	2553	1314	410

Table A1.8. Butterfish commercial discards at age (numbers, 000s), 1989-2012.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	43467	54831	22578	4748	109
1990	4892	6007	1404	241	27
1991	50316	64322	8207	2595	0
1992	38176	40354	24727	977	0
1993	30890	44222	25629	16008	0
1994	37253	74821	20033	4758	2159
1995	76725	78882	27475	3024	0
1996	6675	7890	6319	1572	25
1997	10713	14994	2102	173	0
1998	19040	68852	36428	1089	0
1999	48926	110810	24757	3444	2446
2000	105253	53089	22367	4353	2643
2001	57136	30651	22411	2160	728
2002	22996	21961	9224	1434	628
2003	15944	10468	5516	4899	816
2004	5939	14143	3532	1030	410
2005	1997	5120	4035	959	230
2006	7566	7931	1738	700	290
2007	654	2668	833	119	53
2008	10969	7409	4208	470	59
2009	7559	12156	3180	746	317
2010	23001	33742	16007	4800	326
2011	13229	15125	5905	1492	599
2012	3500	13248	3076	806	233

Table A1.9. Butterfish commercial catch at age (numbers, 000s), 1989-2012.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	43985	69341	40807	12020	240
1990	6658	19059	12185	3194	288
1991	51455	74854	18339	6557	252
1992	38474	53813	40473	4540	144
1993	36227	75960	43613	21399	0
1994	38612	86170	41308	13165	2945
1995	77100	86378	41886	5886	15
1996	8844	15095	28307	12303	981
1997	11853	11853	11853	11853	11853
1998	19249	75501	50211	3482	19
1999	49741	117687	36872	6688	2687
2000	105792	58786	26836	5647	3577
2001	58095	40158	61606	5892	732
2002	24218	24675	12623	3432	879
2003	16097	11586	6727	6711	1559
2004	6310	15853	5790	1995	720
2005	2256	5871	5409	2562	1032
2006	9135	11165	3560	1501	592
2007	967	5338	4509	1330	176
2008	11240	8741	6463	1431	237
2009	8232	13981	5474	1623	496
2010	23566	36238	18011	6380	506
2011	13846	16993	8548	2879	1822
2012	4011	17043	5629	2120	642

Table A1.10. Butterfish commercial landings mean weight at age (kg), 1989-2012.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0.050	0.072	0.082	0.099	0.211
1990	0.062	0.074	0.088	0.097	0.119
1991	0.061	0.072	0.090	0.109	0.166
1992	0.062	0.071	0.087	0.122	0.157
1993	0.058	0.073	0.085	0.104	0
1994	0.059	0.074	0.086	0.101	0.151
1995	0.065	0.073	0.086	0.096	0
1996	0.055	0.069	0.085	0.093	0.105
1997	0.060	0.082	0.088	0.112	0
1998	0.058	0.074	0.083	0.143	0
1999	0.072	0.074	0.095	0.112	0
2000	0.066	0.087	0.136	0.128	0.128
2001	0.067	0.074	0.082	0.115	0
2002	0.062	0.083	0.094	0.116	0.140
2003	0.074	0.085	0.098	0.113	0.152
2004	0.054	0.076	0.089	0.105	0.166
2005	0.061	0.070	0.082	0.102	0.113
2006	0.053	0.067	0.084	0.099	0.133
2007	0.061	0.075	0.085	0.116	0.147
2008	0.061	0.073	0.086	0.122	0.129
2009	0.050	0.066	0.083	0.095	0.094
2010	0.059	0.075	0.084	0.115	0.115
2011	0.061	0.073	0.084	0.101	0.115
2012	0.057	0.069	0.084	0.104	0.118

Table A1.11. Butterfish commercial discards mean weight at age (kg), 1989-2012.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0.025	0.034	0.050	0.077	0.204
1990	0.027	0.045	0.074	0.098	0.126
1991	0.032	0.037	0.081	0.095	0.000
1992	0.027	0.048	0.079	0.103	0.000
1993	0.037	0.050	0.090	0.120	0
1994	0.038	0.039	0.071	0.102	0.197
1995	0.023	0.035	0.049	0.078	0
1996	0.034	0.044	0.058	0.065	0.055
1997	0.025	0.047	0.069	0.090	0
1998	0.042	0.046	0.065	0.079	0
1999	0.033	0.041	0.066	0.071	0.019
2000	0.018	0.051	0.065	0.092	0.179
2001	0.025	0.033	0.085	0.150	0.352
2002	0.017	0.048	0.067	0.079	0.013
2003	0.037	0.050	0.075	0.095	0.113
2004	0.036	0.045	0.078	0.122	0.181
2005	0.044	0.041	0.057	0.087	0.164
2006	0.034	0.044	0.075	0.092	0.197
2007	0.039	0.048	0.071	0.110	0.281
2008	0.028	0.052	0.067	0.105	0.104
2009	0.034	0.039	0.065	0.094	0.217
2010	0.031	0.051	0.070	0.088	0.094
2011	0.029	0.042	0.067	0.081	0.112
2012	0.035	0.045	0.069	0.098	0.131

Table A1.12. Butterfish commercial catch mean weight at age (kg), 1989-2012.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0.025	0.042	0.064	0.090	0.208
1990	0.037	0.065	0.087	0.097	0.120
1991	0.032	0.042	0.086	0.103	0.166
1992	0.027	0.054	0.082	0.118	0.157
1993	0.040	0.059	0.088	0.116	0
1994	0.039	0.044	0.079	0.101	0.185
1995	0.023	0.035	0.072	0.110	0
1996	0.039	0.056	0.079	0.089	0.104
1997	0.028	0.066	0.085	0.111	0
1998	0.042	0.049	0.070	0.123	0
1999	0.034	0.042	0.075	0.091	0.036
2000	0.018	0.054	0.077	0.100	0.166
2001	0.026	0.043	0.083	0.128	0.350
2002	0.019	0.052	0.074	0.100	0.049
2003	0.038	0.054	0.079	0.100	0.131
2004	0.037	0.048	0.082	0.114	0.174
2005	0.046	0.044	0.063	0.096	0.124
2006	0.037	0.051	0.080	0.096	0.165
2007	0.046	0.061	0.082	0.116	0.187
2008	0.029	0.055	0.074	0.117	0.123
2009	0.035	0.043	0.073	0.094	0.173
2010	0.032	0.053	0.071	0.095	0.101
2011	0.031	0.046	0.073	0.091	0.114
2012	0.038	0.050	0.076	0.102	0.123

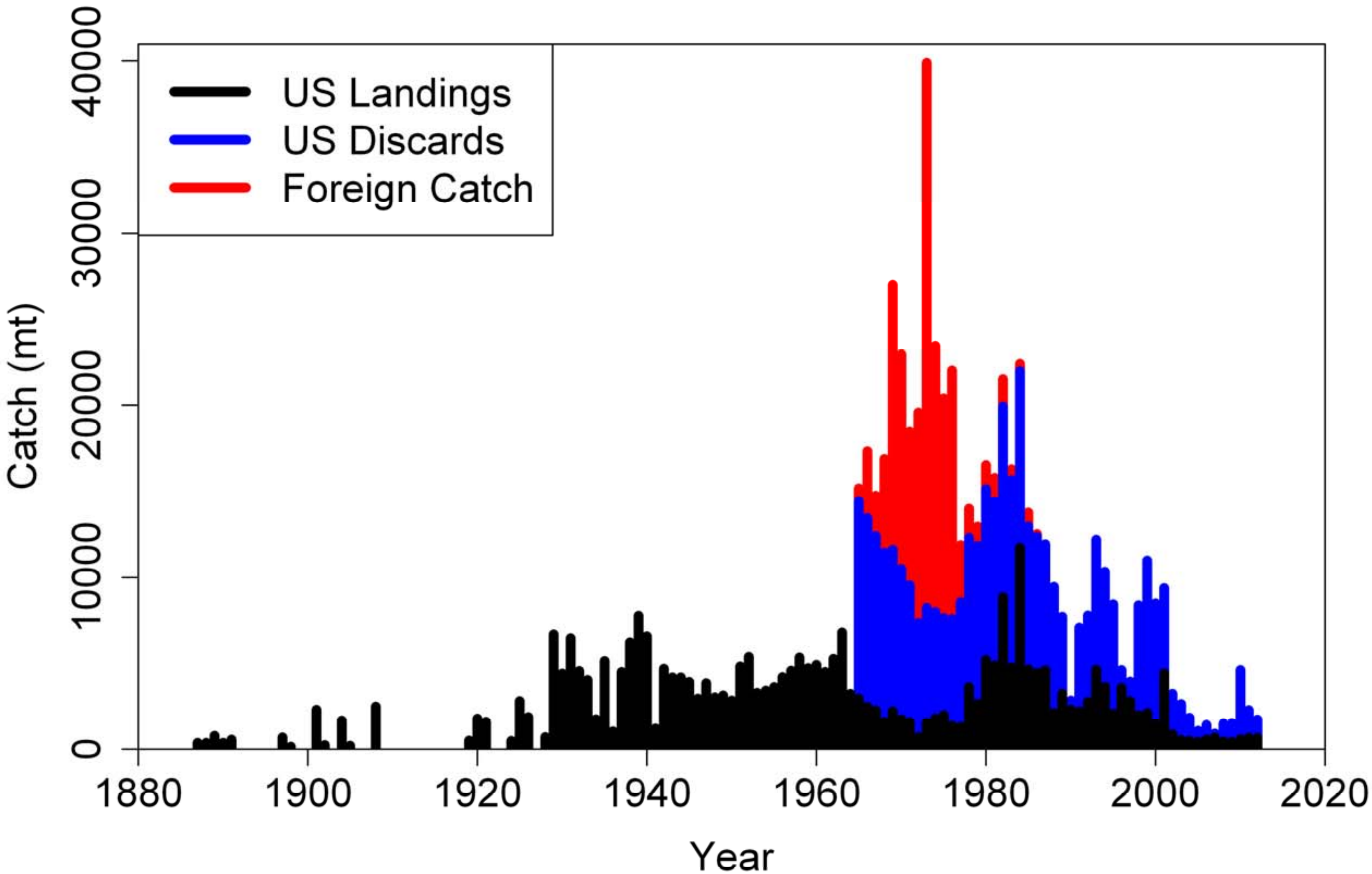

Figure A1.1. Butterfish total catch, 1887-2012. Annual catch data are missing for some years prior to 1930. Discards are unavailable prior to 1965. Total catch between 1965-1988 includes discards estimated by applying an average of discard rates for trawl gear from 1989-1999 to annual landings of all species between 1965-1988 by trawl gear.

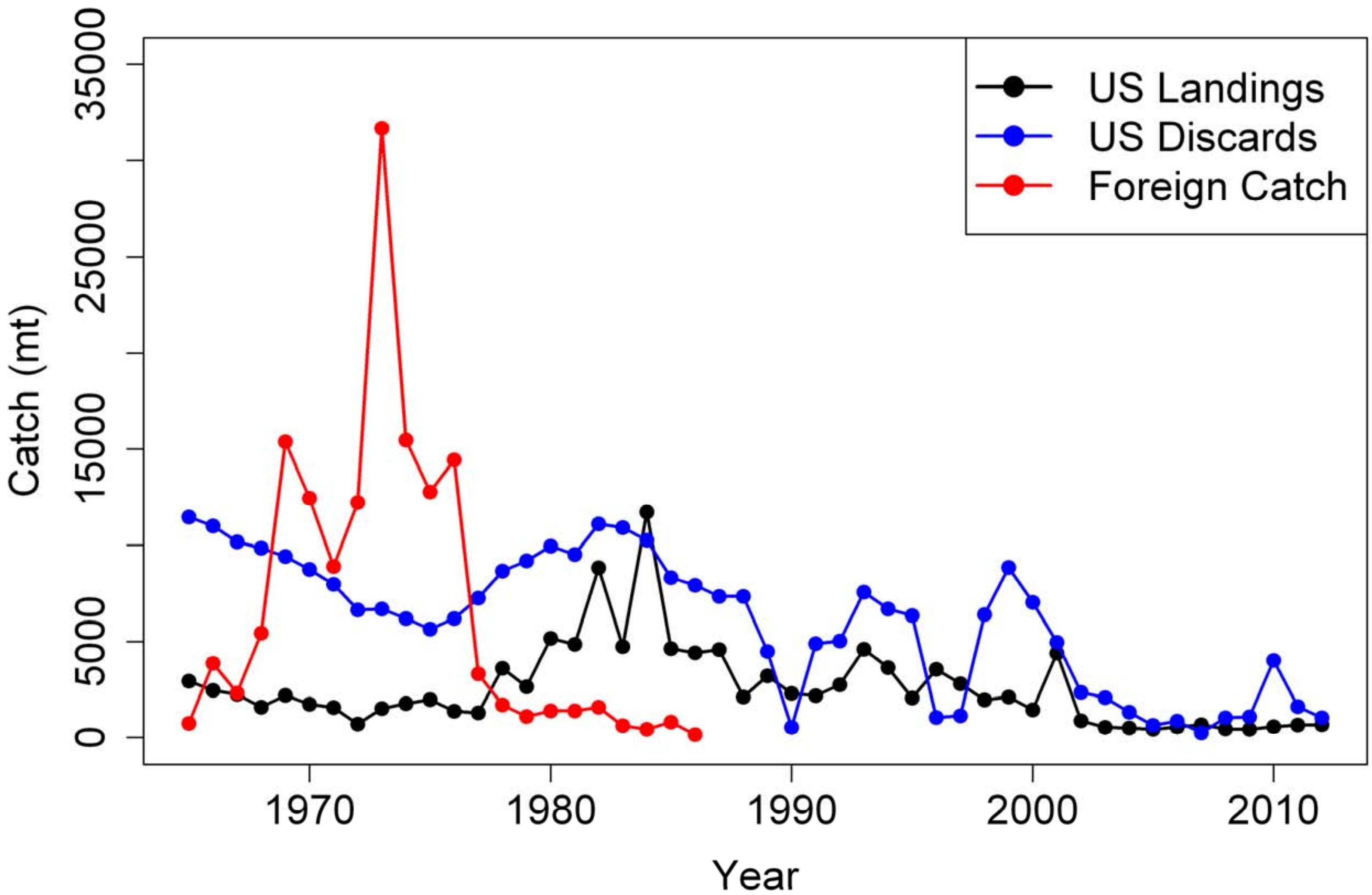

Figure A1.2. US landings, US discards, and foreign catch of butterfish, 1965-2012.

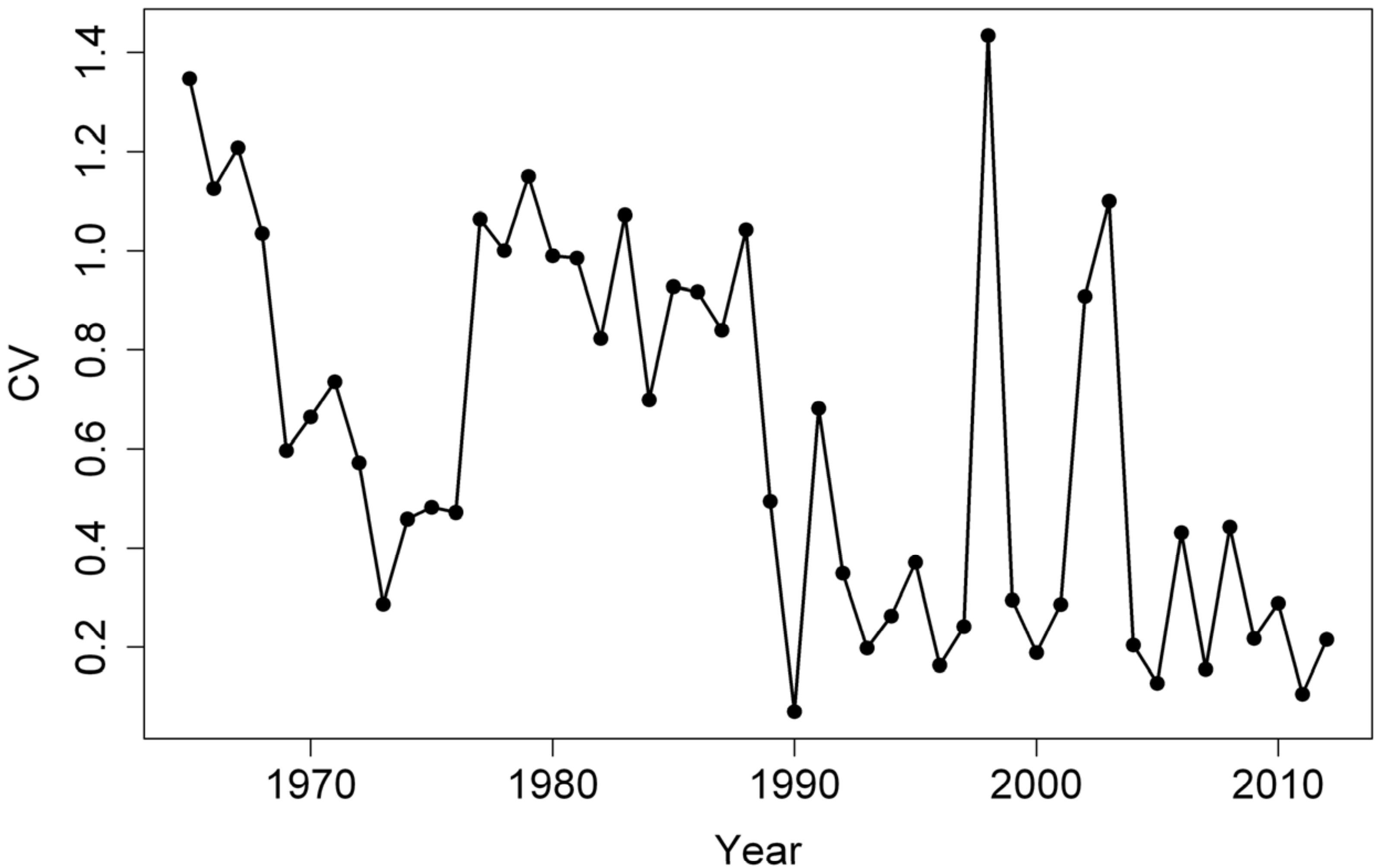

Figure A1.3. Coefficient of variation of butterfish total catch estimates reflecting variance estimates associated with discard estimates.

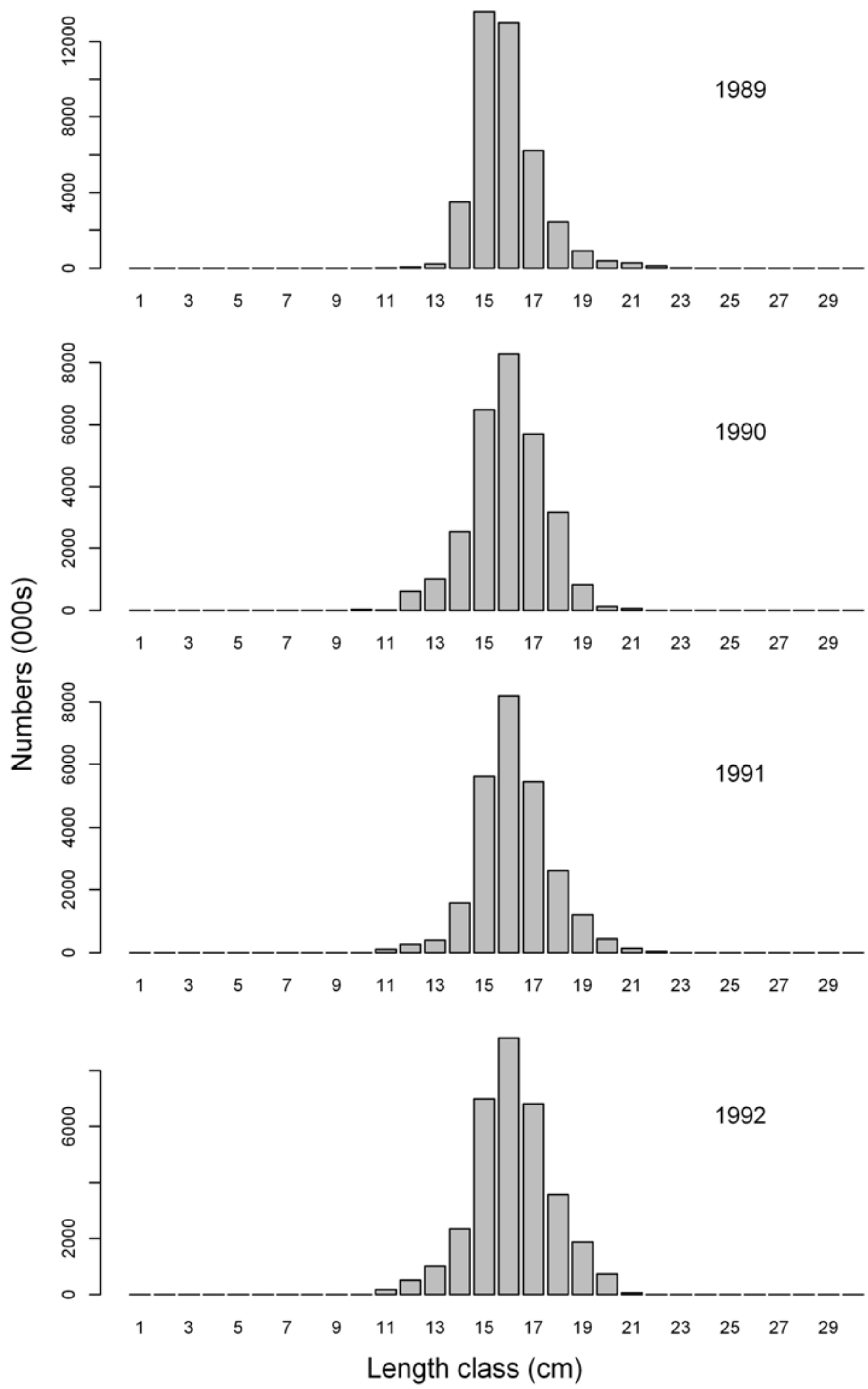

Figure A1.4. Size composition data from New England and Mid-Atlantic commercial landings of butterfish, 1989-1992. Note the Y-axis varies by year.

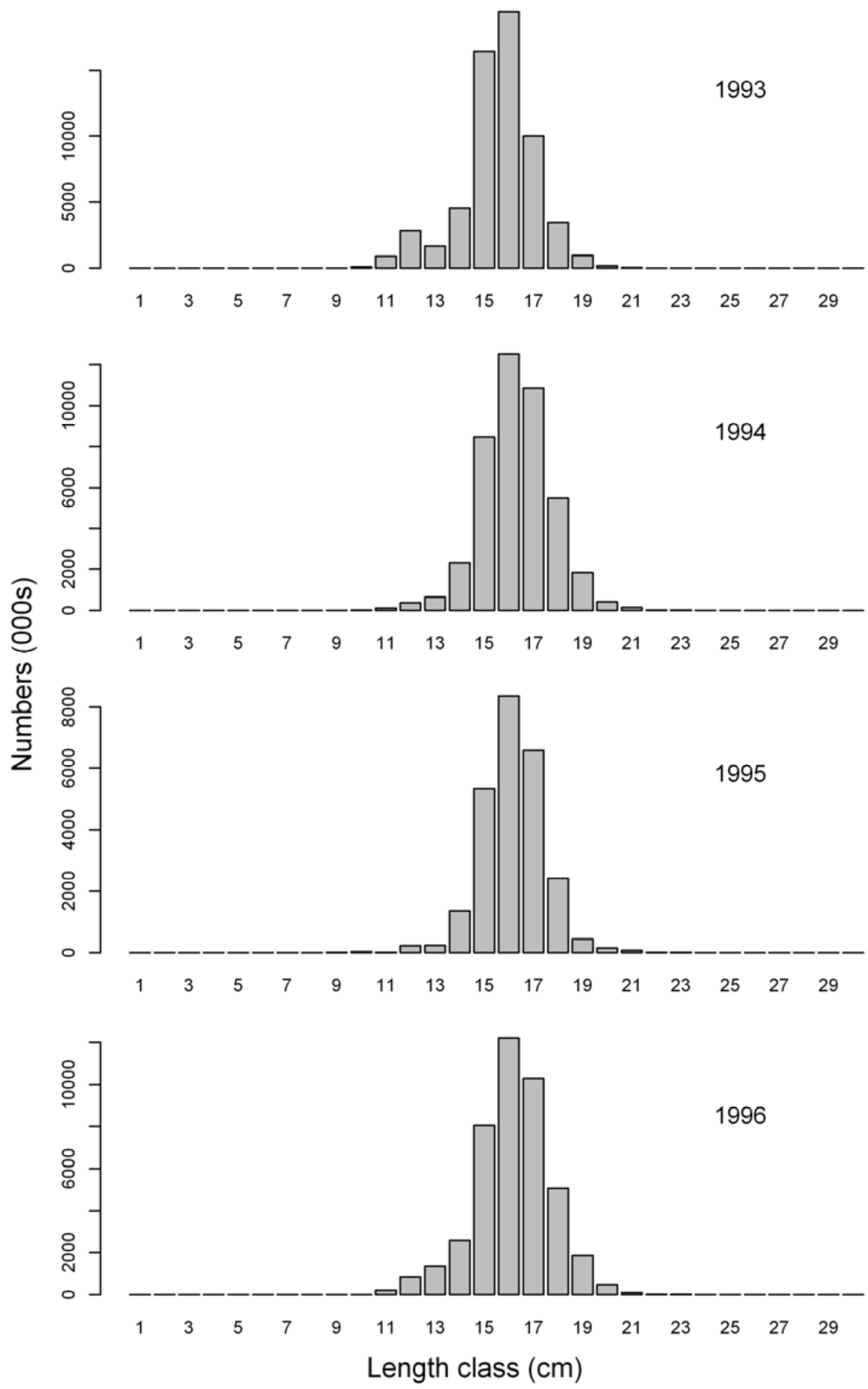

Figure A1.5. Size composition data from New England and Mid-Atlantic commercial landings of butterfish, 1993-1996. Note the Y-axis varies by year.

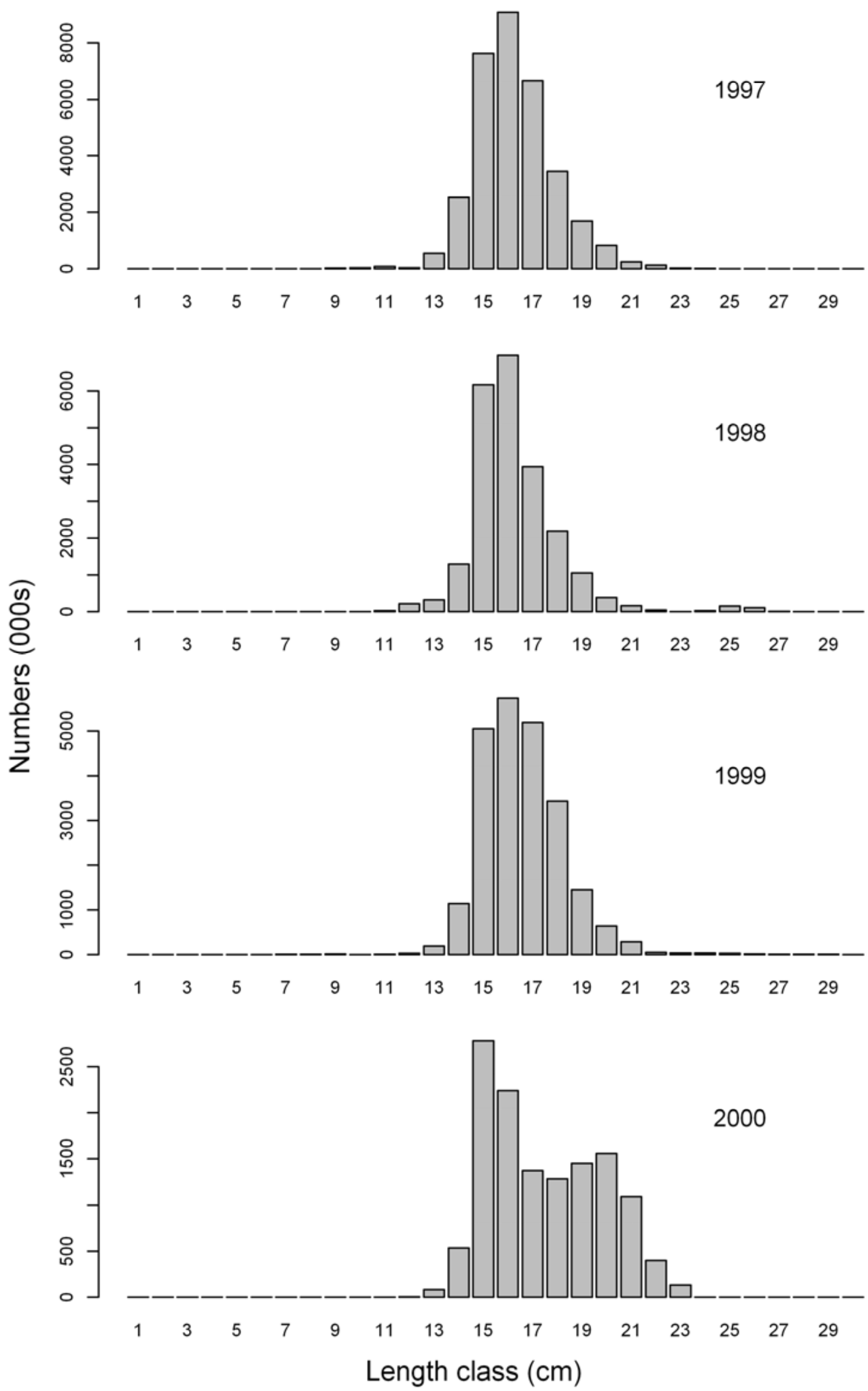

Figure A1.6. Size composition data from New England and Mid-Atlantic commercial landings of butterfish, 1997-2000. Note the Y-axis varies by year.

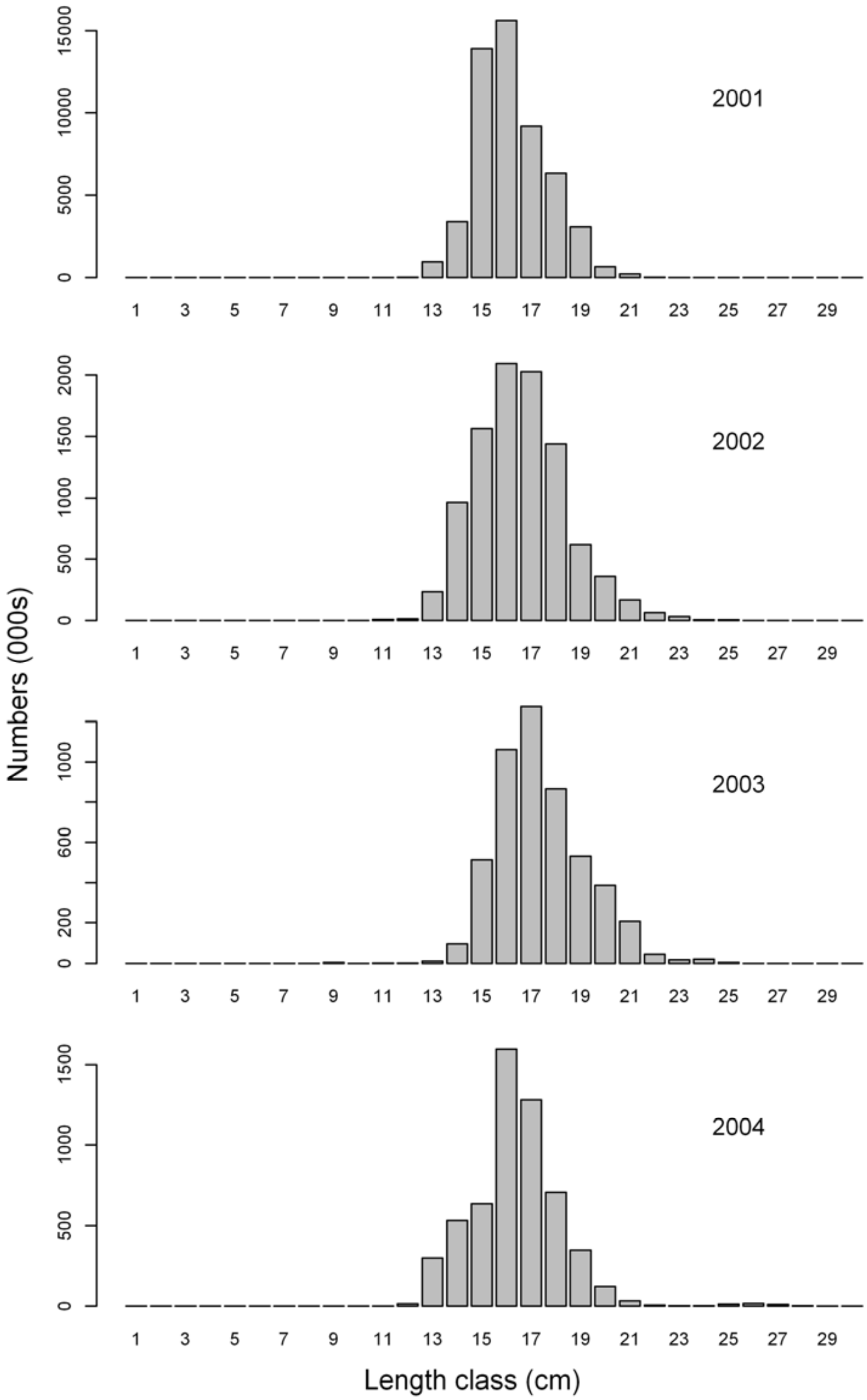

Figure A1.7. Size composition data from New England and Mid-Atlantic commercial landings of butterfish, 2001-2004. Note the Y-axis varies by year.

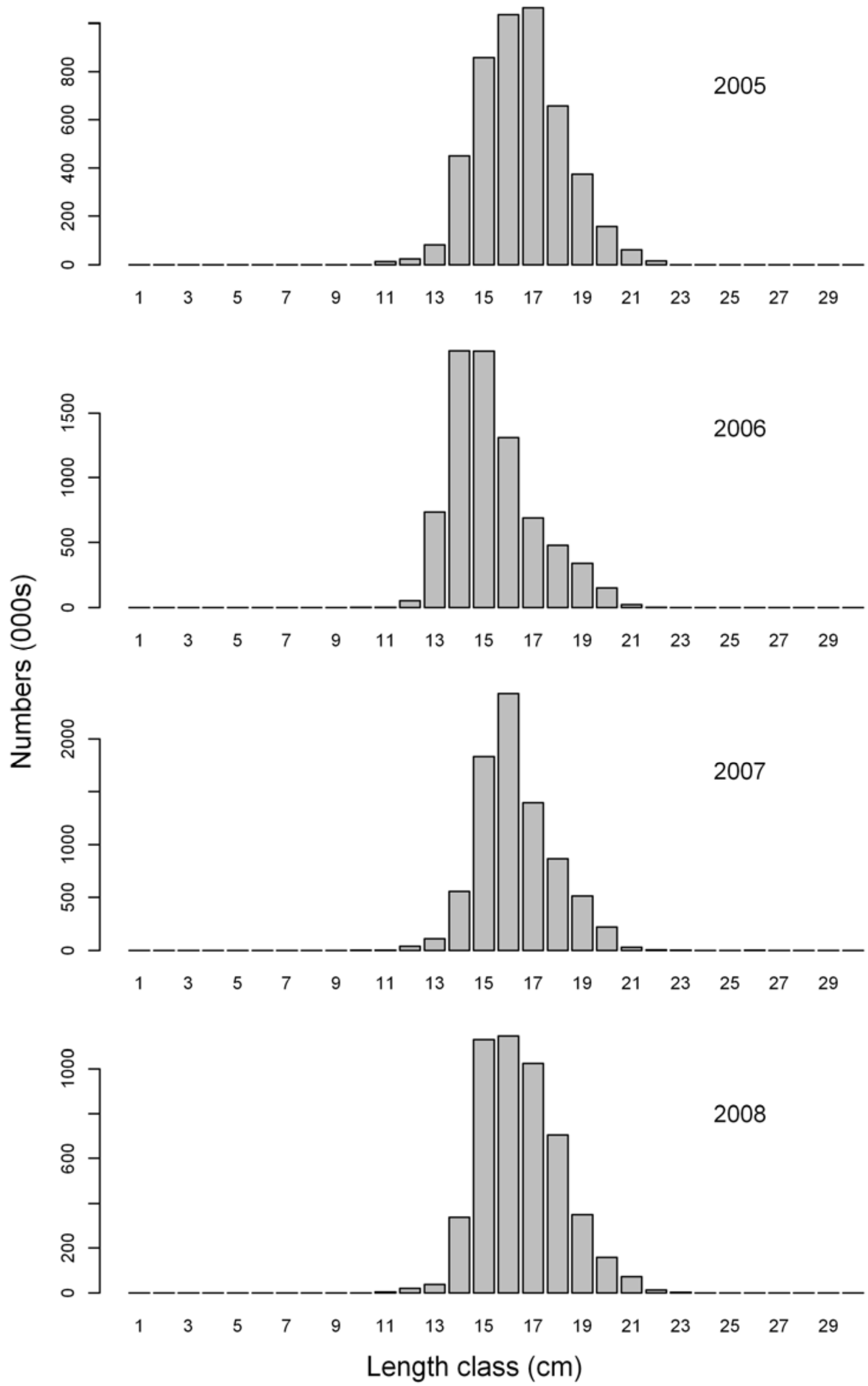

Figure A1.8. Size composition data from New England and Mid-Atlantic commercial landings of butterfish, 2005-2008. Note the Y-axis varies by year.

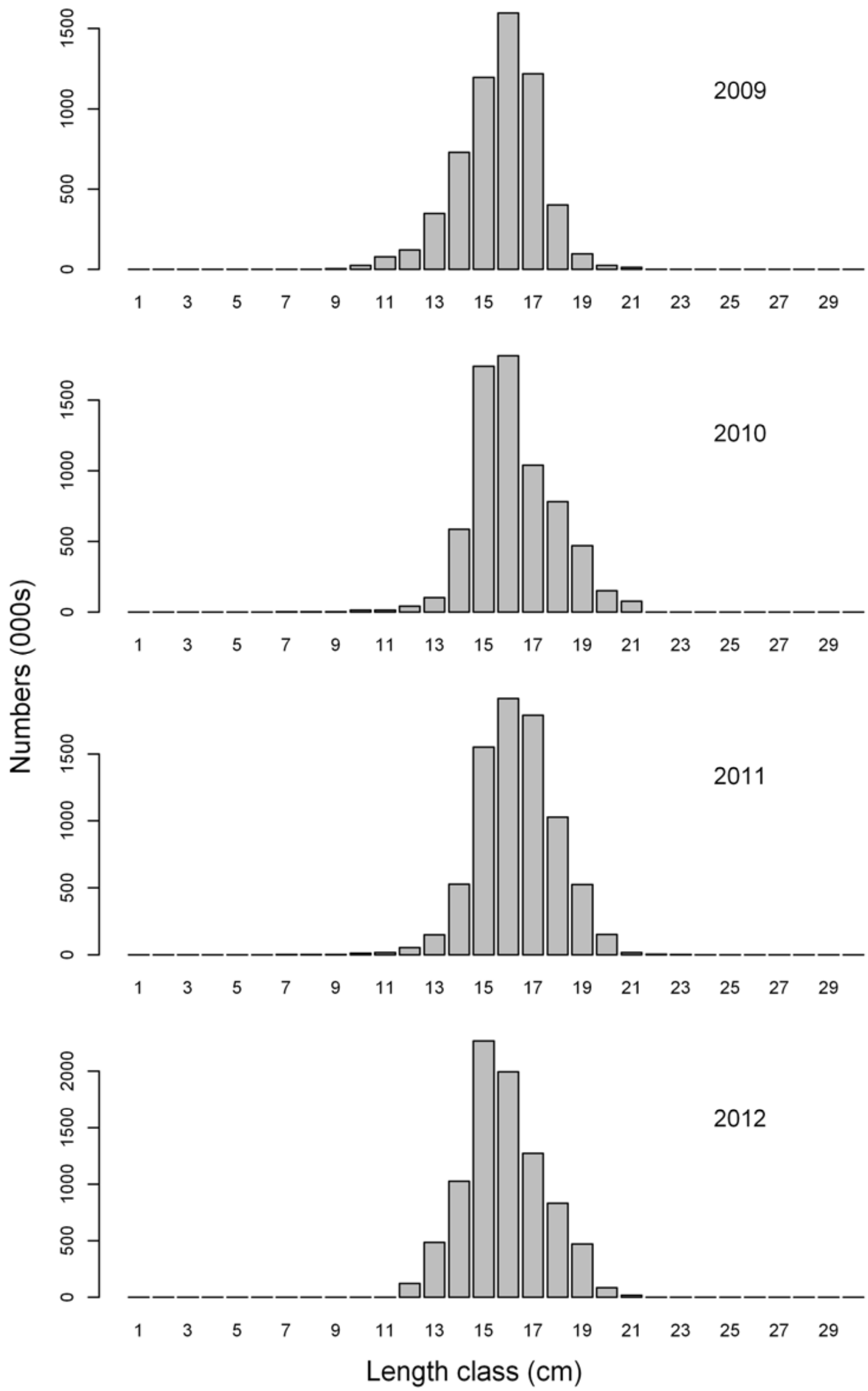

Figure A1.9. Size composition data from New England and Mid-Atlantic commercial landings of butterfish, 2009-2012. Note the Y-axis varies by year.

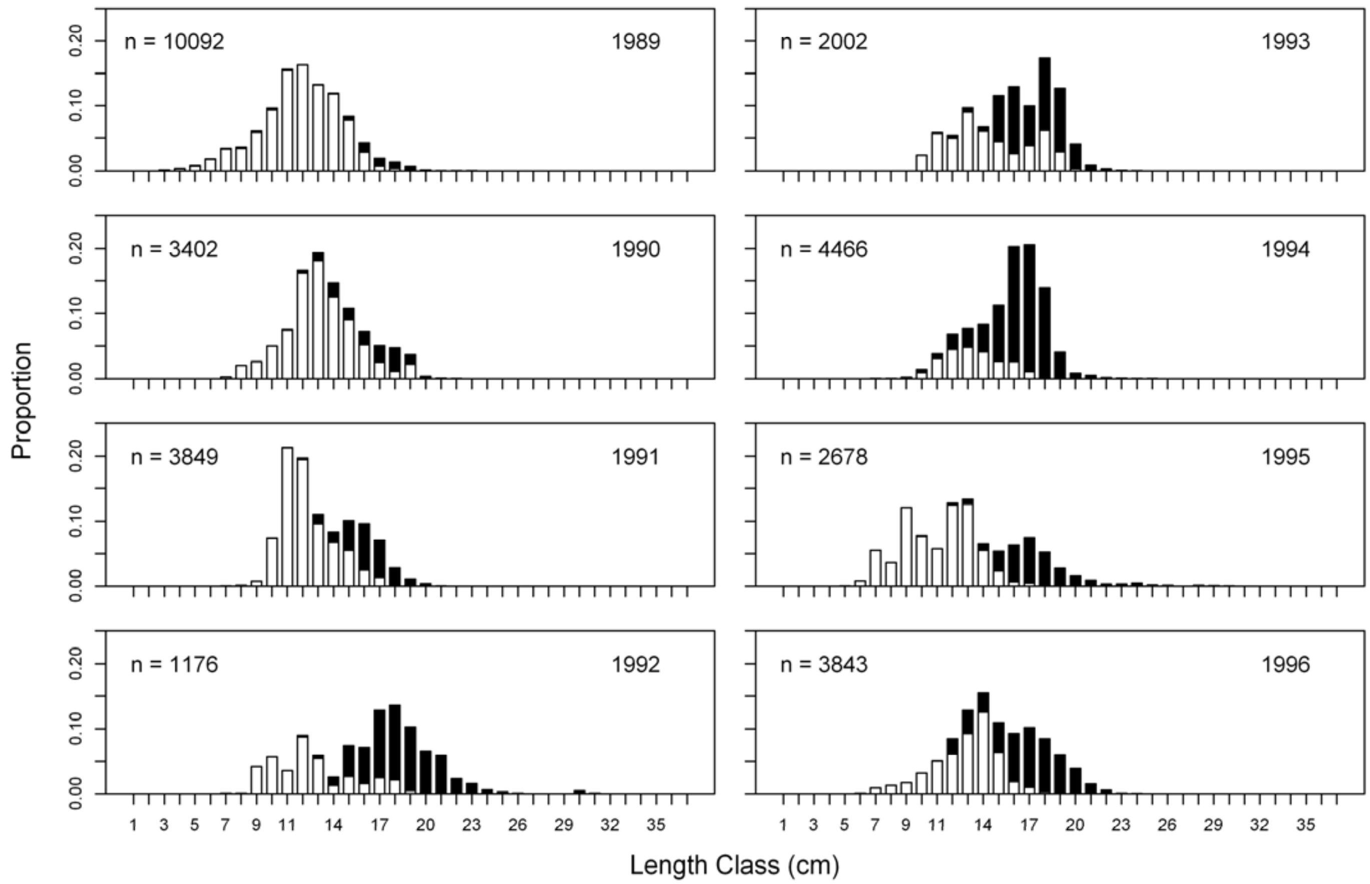

Figure A1.10. Length composition of butterfish from NMFS Observer Program, 1989-1996, with kept fish in black and discards in white. Bars are stacked. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

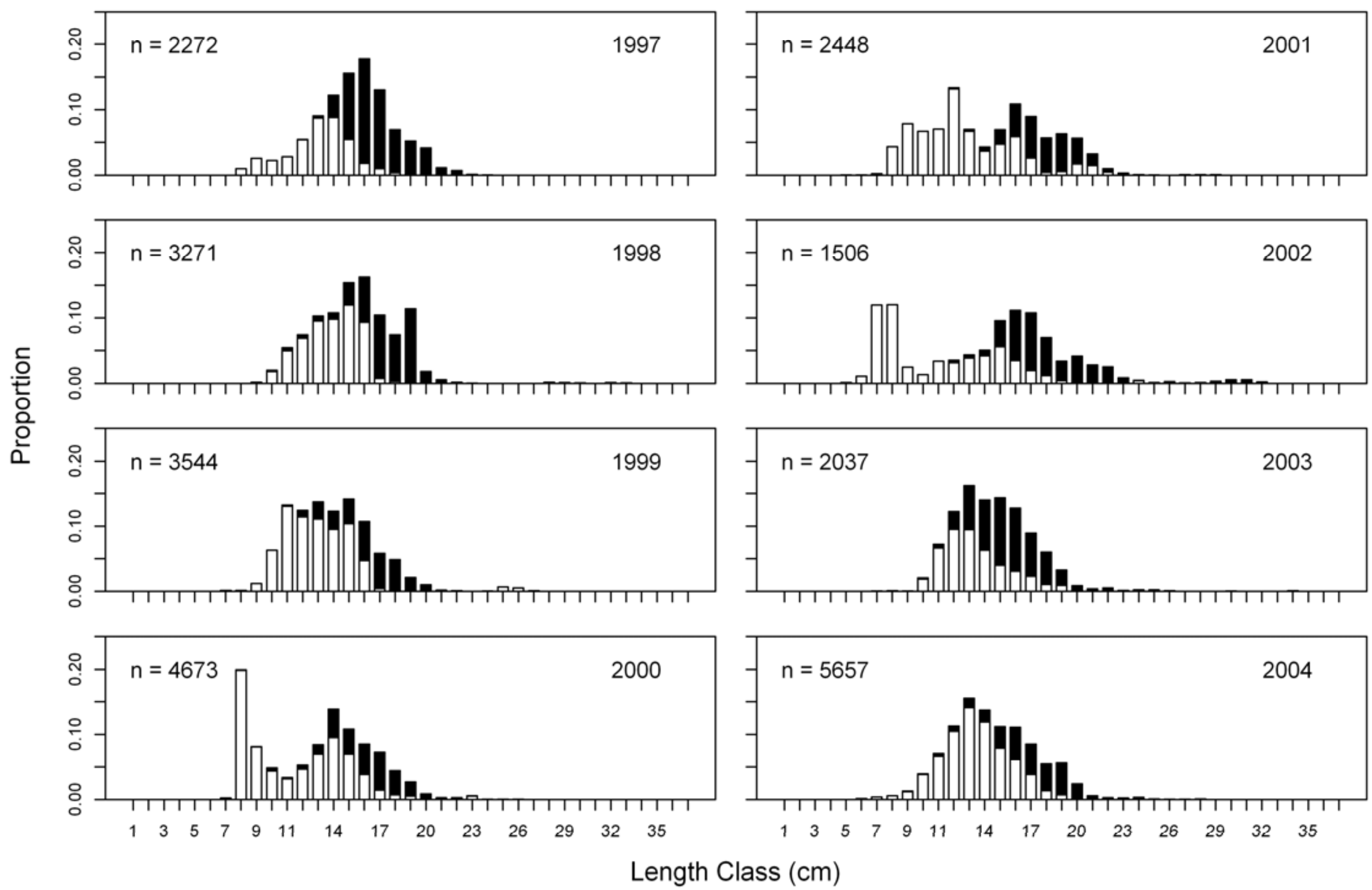

Figure A1.11. Length composition of butterfish from NMFS Observer Program, 1997-2004, with kept fish in black and discards in white. Bars are stacked. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

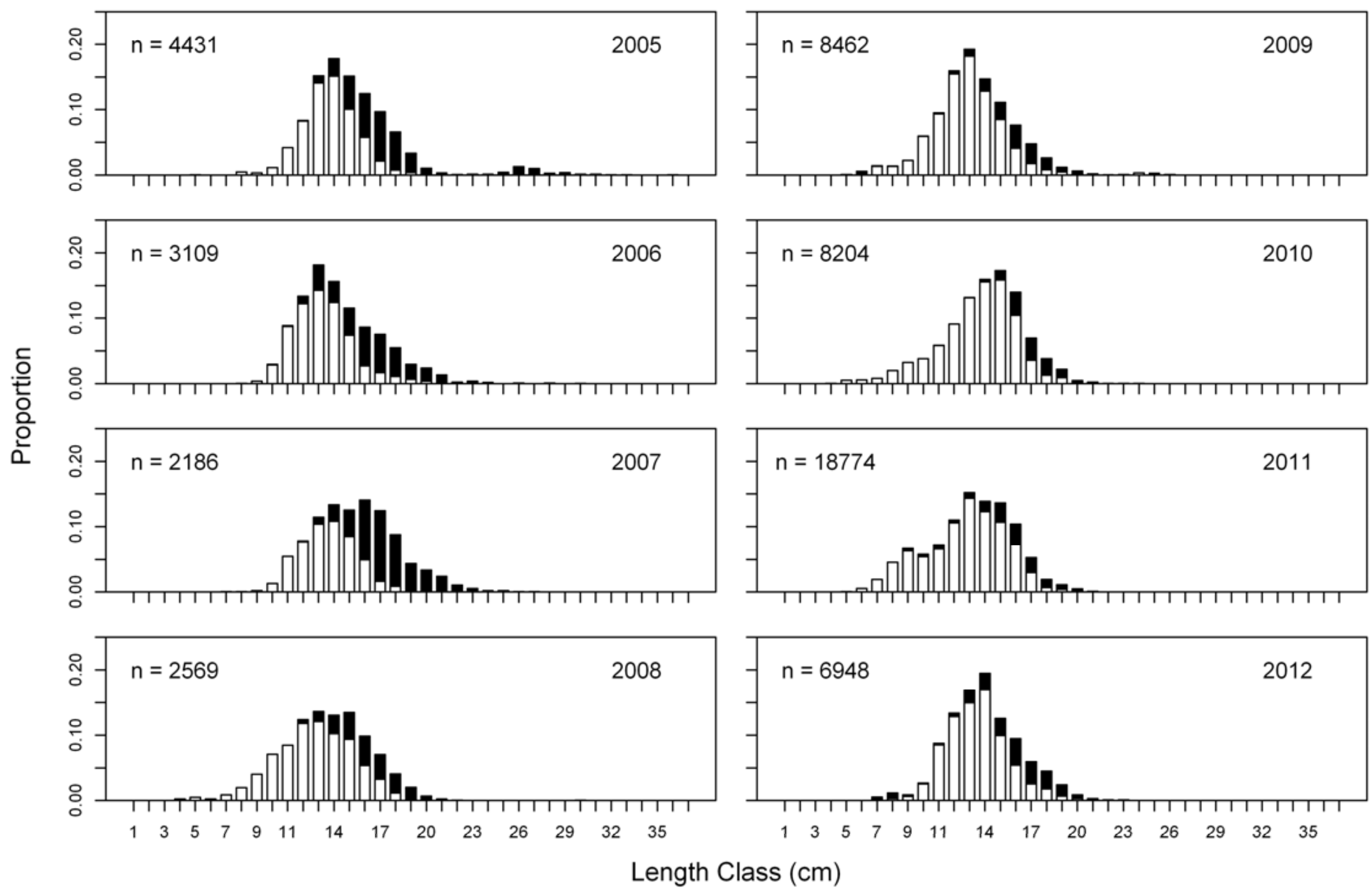

Figure A1.12. Length composition of butterfish from NMFS Observer Program, 2005-2012, with kept fish in black and discards in white. Bars are stacked. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

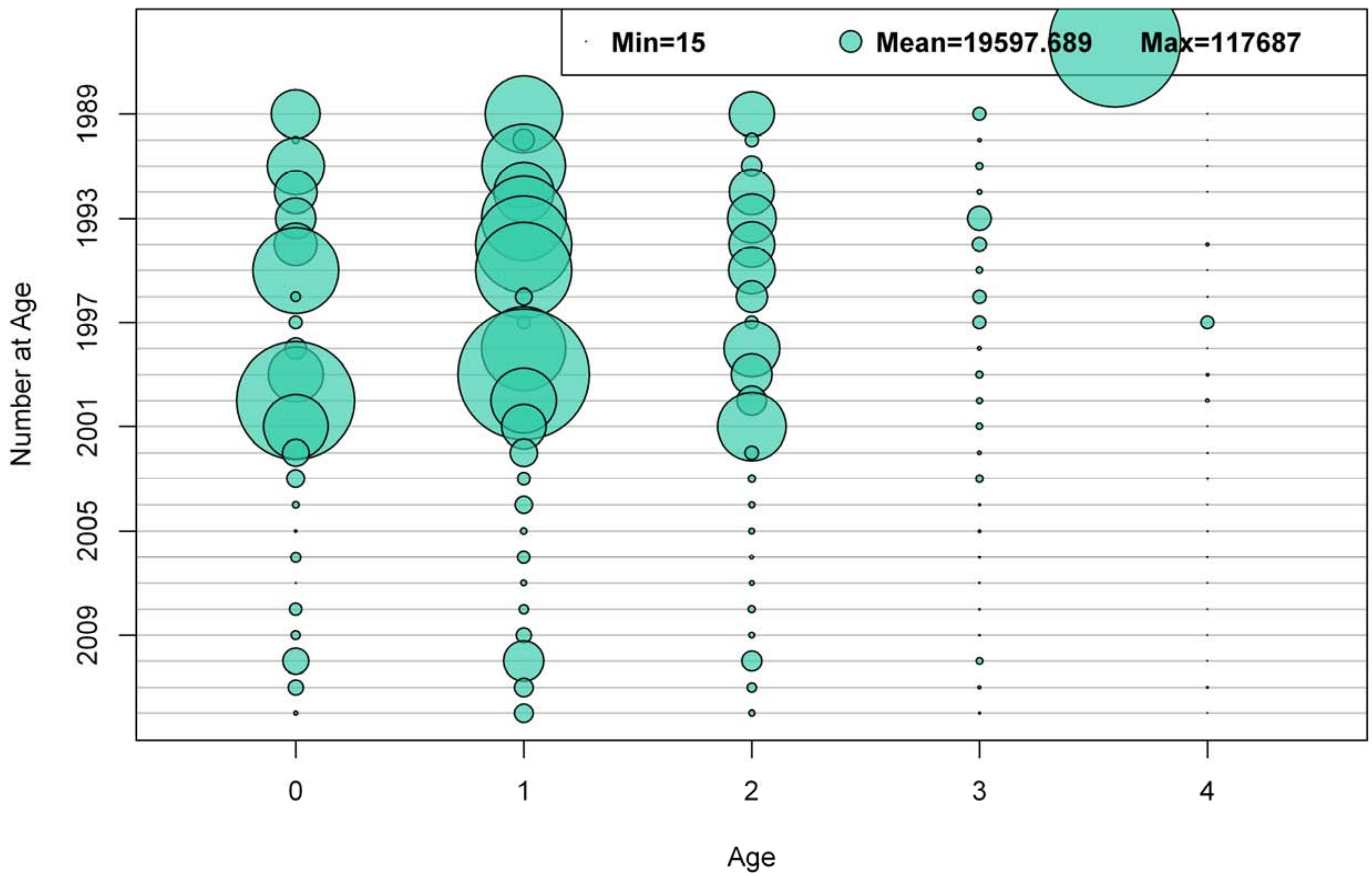

Figure A1.13. Butterfish commercial catch (number) at age, 1989-2012.

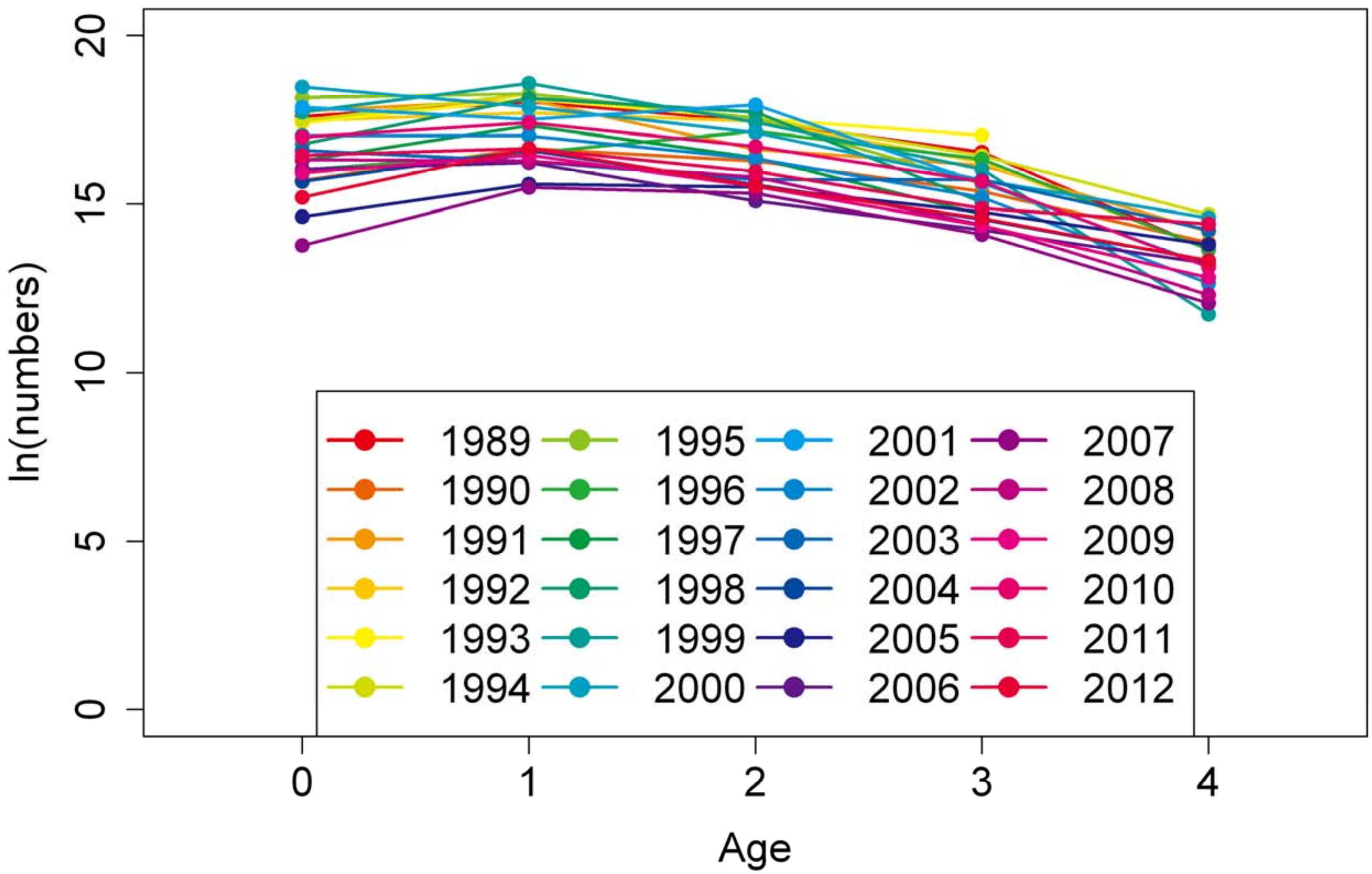

Figure A1.14. Commercial catch curves for butterfish, 1989-2012.

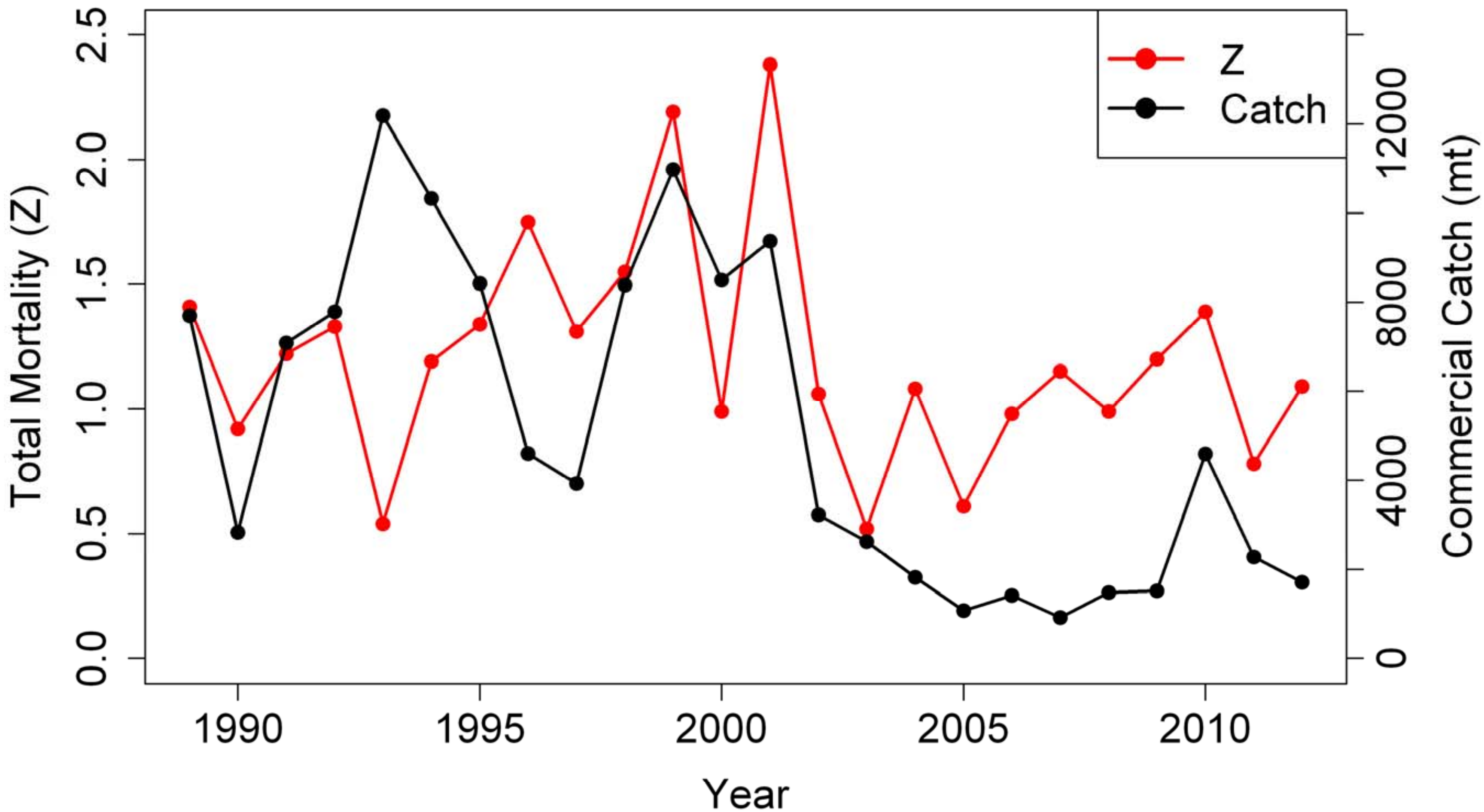

Figure A1.15. Estimates of total mortality (Z), and commercial catch (mt) for butterfish, 1989-2012.

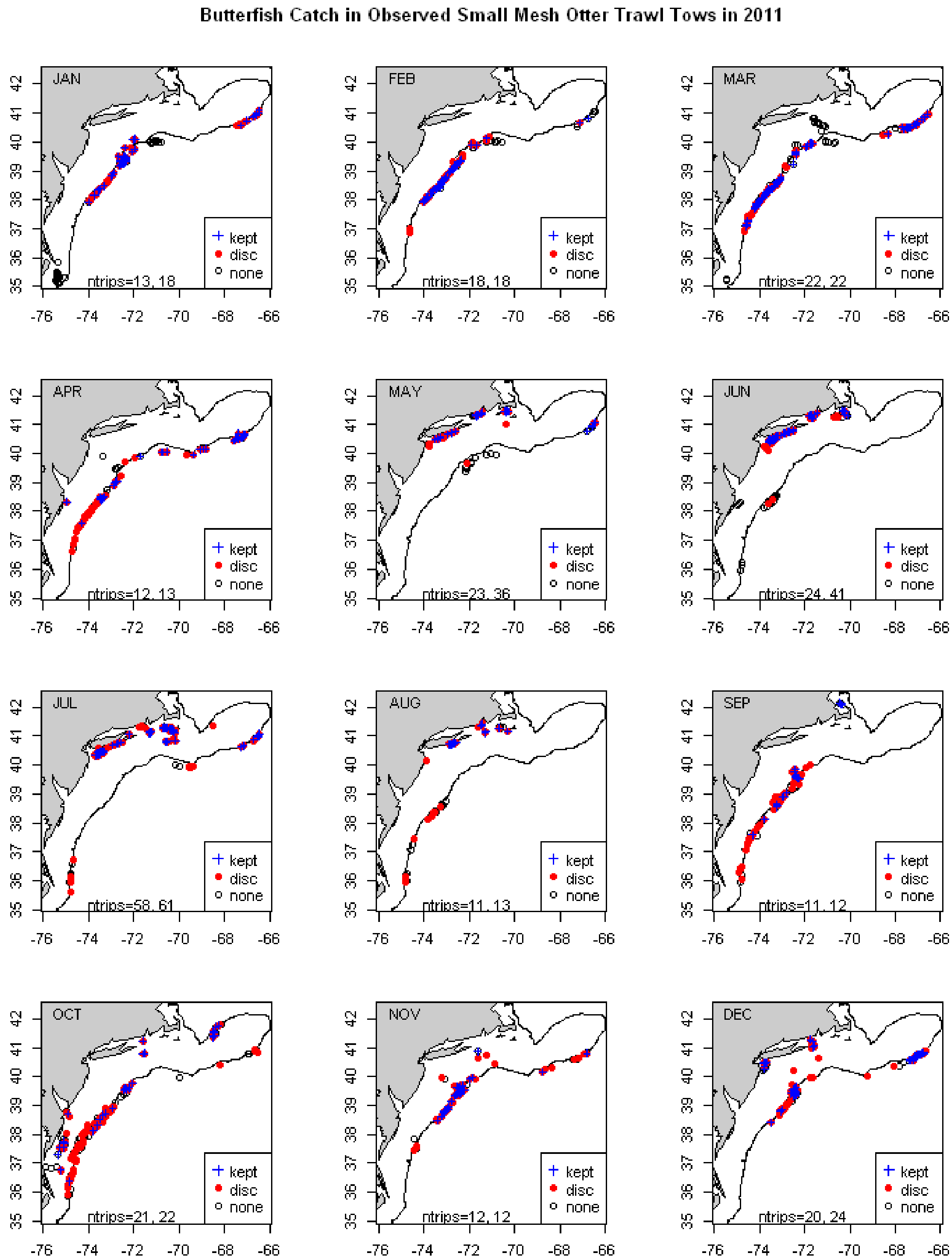

Figure A1.16. Observed commercial small mesh (< 4 inches) bottom trawl tows in 2011 where butterfish were absent (empty circle), present and discarded (red circle), or present and kept (blue +). Bathymetry contour is 100 m. The ntrips denotes the number of observed trips where butterfish were caught, and the total number of observed small mesh trips.

Butterfish Catch in Observed Small Mesh Otter Trawl Tows in 2012

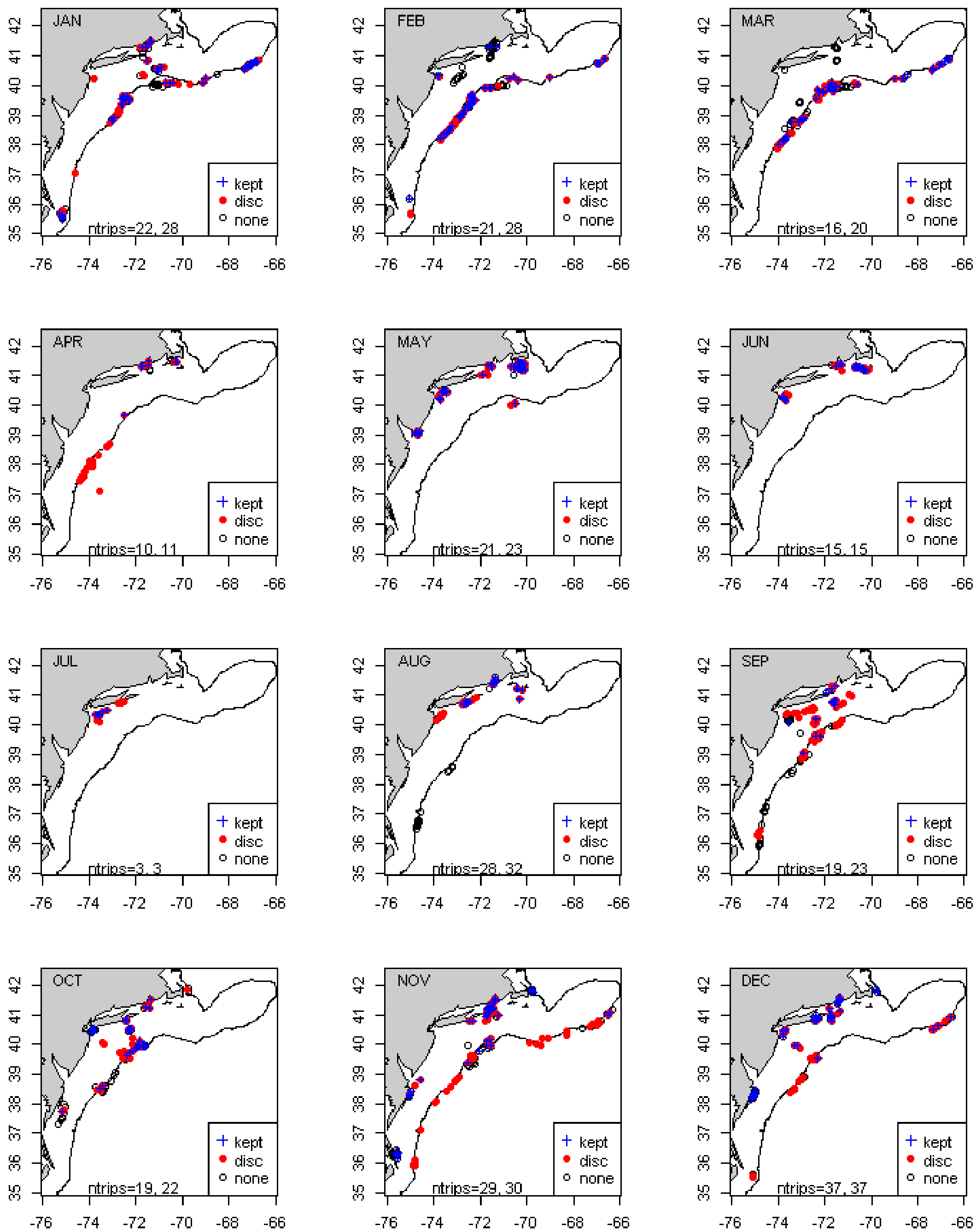

Figure A1.17. Observed commercial small mesh (< 4 inches) bottom trawl tows in 2012 where butterfish were absent (empty circle), present and discarded (red circle), or present and kept (blue +). Bathymetry contour is 100 m. The ntrips denotes the number of observed trips where butterfish were caught, and the total number of observed small mesh trips.

TOR2: Characterize the survey data that are being used in the assessment. Describe the magnitude of uncertainty in these sources of data.

Data

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 NEFSC bottom trawl surveys for the winter in 1992-2007, for the spring in 1973-2008, and fall in 1975-2008 were used (NEFSC, 2010). In the current assessment the working group chose to use the spring and fall surveys.

In the previous assessment (NEFSC, 2010) the spring indices used only offshore strata 1-14, 16, 19, 20, 23, 25, and 61-76; while the fall indices used same the offshore strata as well as inshore strata 1-92. In spring 2009 the FSV *Henry B. Bigelow* replaced the FRV *Albatross IV*. Due to the larger size of the FSV *Henry B. Bigelow* the two innermost inshore strata have not been surveyed since 2008. Thus, the working group decided on a modification to the strata: the offshore series (Figure A2.1) would include the outermost inshore strata (2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44-46, 56, 59-61 and 64-66) and offshore strata (1-14, 16, 19, 20, 23, 25 and 61-76); while the inshore series (Figure A2.2) would include the two innermost inshore strata (3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18, 19, 21, 22, 24, 25, 27, 28, 30, 31, 33, 34, 36, 37, 39, 40, 42, 43, 55, 58 and 63).

The Northeast Area Monitoring and Assessment Program (NEAMAP) survey has covered inshore waters from Cape Cod to Cape Hatteras since fall 2007 and has used consistent strata coverage. These strata are approximately the same as the NEFSC inshore strata. NEAMAP spring (2008-2012) and fall (2007-2012) survey data were used.

Indices are also available for a number of state survey programs: a Maine-New Hampshire survey; the Massachusetts Division of Marine Fisheries (MDMF) survey; the Rhode Island Department of Environmental Management (RIDEM) survey; the Connecticut Department of Energy and Environmental Protection (CDEEP) survey in Long Island Sound; the New York Department of Environmental Conservation (NYDEC) survey in Peconic Bay; the New Jersey Department of Environmental Protection (NJDEP) survey; the Delaware Department of Natural Resources and Environmental Control (DDNREC) survey; the Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) survey; the Virginia Institute of Marine Science (VIMS) juvenile survey; and the North Carolina Department of Environment and Natural Resources (NCDENR) survey in Pamlico Sound. Although the working group did not include these data in the assessment model they are presented as supplemental information.

NEFSC survey indices

Offshore indices from the Bigelow for 2009-2012 are converted to Albatross units using the calibration coefficients in Table A2.1.

The NEFSC spring offshore abundance indices (stratified mean number per tow) ranged from 8.4 in 1990 to 142.6 in 2012 (Table A2.2; Figure A2.7). The inshore strata were not sampled during the spring in 1994-1996, while the highest abundance was observed in 1991 (Table A2.3; Figure A2.7). The location and total number of butterfish per tow for spring 2011 and 2012 are shown in Figures A2.3 and A2.4, respectively.

The NEFSC fall offshore abundance indices ranged from 39.2 in 2005 to 510.4 in 1994 (Table A2.4; Figure A2.7), while the fall inshore abundance indices ranged from 39.5 in 1995 to 632.9 in 1997 (Table A2.5; Figure A2.7). The location and total number of butterfish per tow for fall 2011 and 2012 are shown in Figures A2.5 and A2.6, respectively.

Spring offshore biomass indices (stratified mean weight/tow in kg) ranged from 0.3 in 1990 to 4.3 in 2007 (Table A2.2; Figure A2.9). The inshore strata were not sampled during the spring in 1994-1996, while the highest biomass index was observed in 1991 (Table A2.3; Figure A2.9). Fall offshore biomass indices ranged from 1.0 in 2005 to 13.0 in 1994 (Table A2.4; Figure A2.9). The fall inshore biomass indices ranged from 2.3 in 1995 to 20.7 in 1989 (Table A2.5; Figure A2.9).

The estimated precision of the NEFSC survey abundance indices are poorest for the spring series, with CVs averaging 0.44 and 0.54 for the offshore and inshore, respectively (Tables A2.2 and A2.3, Figure A2.8). The fall offshore CV averages 0.28 (Table A2.4) while the fall inshore CV is generally the lowest, averaging 0.25 (Table A2.5). Similarly, precision of the biomass indices is poorest for the spring series, with CVs averaging 0.42 and 0.66 for the offshore and inshore, respectively (Tables A2.2 and A2.3, Figure A2.10). The fall offshore CV is generally the lowest, averaging 0.28 (Table A2.4), while the fall inshore CV averages 0.30 (Table A2.5).

Aged NEFSC survey indices

The number of stations where butterfish were sampled averaged 251, ranging from 145 in 1989 to 405 in 2012 (Table A2.6). The number of butterfish aged averaged 1,164, ranging from 588 in 1989 to 2,010 in 2011. The number of butterfish measured averaged 1,213, ranging from 588 in 1989 to 2,113 in 2011.

The NEFSC spring offshore abundance at age indices show that this survey generally catches age groups 1-3 and usually some fish from age group 4 (Tables A2.7 and A2.8; Figure A2.11). The same pattern holds for the spring inshore series, albeit with fewer butterfish (Tables A2.9 and A2.10; Figure A2.12). Fall offshore abundance at age indices show that this survey generally catches age groups 0-3, with the age 0 catch dominating the total catch (Tables A2.11 and A2.12; Figure A2.13). The same pattern holds for the fall inshore series (Tables A2.13 and A2.14; Figure A2.14).

NEAMAP survey

The NEAMAP spring abundance indices (stratified mean number per tow) were higher than the comparable NEFSC spring inshore abundance indices, ranging from 188.5 in 2009 to 525.6 in 2012 (Table A2.15; Figure A2.15). The fall abundance indices were generally higher than the comparable NEFSC fall inshore abundance indices, ranging from 625.7 in 2012 to 3,600.8 in 2009. The CVs for NEAMAP abundance indices were ≤ 0.21 with the exception of one outlier each in the spring and fall series (Table A2.15; Figure A2.16).

The NEAMAP spring biomass indices (stratified mean weight/tow in kg) were higher than the comparable NEFSC spring inshore biomass indices, ranging from 4.2 in 2009 to 22.4 in 2012 (Table A2.15; Figure A2.17). The fall biomass indices were generally higher than the comparable NEFSC fall inshore biomass indices, ranging from 13.1 in 2007 to 45.6 in 2009. The CVs for NEAMAP biomass indices were ≤ 0.2 with the exception of one outlier in spring 2010 (Table A2.15; Figure A2.18).

Maine-New Hampshire survey

The Maine-New Hampshire survey began in fall 2000 (Tables A2.16 and A2.17). There are gaps in the spring series during 2003-2005, and in 2009. The Maine-New Hampshire spring abundance indices (stratified mean number per tow) ranged from 0.03 in 2001 to 0.44 in 2012 (Table A2.16; Figure A2.19). The fall abundance indices were higher, ranging from 2.3 in 2000 to 303.6 in 2009. CVs for the spring and fall abundance indices averaged 0.41 and 0.29, respectively (Figure A2.20).

The Maine-New Hampshire spring biomass indices (stratified mean weight/tow in kg) ranged from 0.001 in 2006 to 0.016 in 2011 (Table A2.17; Figure A2.21). The fall biomass indices were higher, ranging from 0.2 in 2000 to 5.1 in 2009. CVs for the spring and fall biomass indices averaged 0.53 and 0.25, respectively (Figure A2.22).

MDMF survey

The MDMF survey began in spring 1978 although data presented are for 1989-2012 only. The MDMF spring abundance indices (stratified mean number per tow) ranged from 0.01 in 1989 to 1.72 in 2007 (Table A2.16; Figure A2.23). The fall abundance indices were generally higher, ranging from 1.2 in 2001 to 9.5 in 2011 and 2012. CVs for the spring and fall abundance indices averaged 0.62 and 0.25, respectively (Figure A2.24).

The MDMF spring biomass indices (stratified mean weight/tow in kg) ranged from 0.2 in 1989 to 46.1 in 2007 (Table A2.17; Figure A2.25). The fall biomass indices were higher, ranging from 72.0 in 2001 to 979.2 in 2009. CVs for the spring and fall biomass indices averaged 0.66 and 0.28, respectively (Figure A2.26).

RIDEM survey

The RIDEM survey began in spring 1979 (Tables A2.16 and A2.17). Data are presented for 1989-2012 only. The RIDEM spring abundance indices (stratified mean number per tow) ranged from 0 butterfish in 1989, 1992 and 2005, to a maximum of 405.0 in 2006 (Table A2.16; Figure A2.27). The fall abundance indices were generally higher, ranging from 42.7 in 2000 to 2507.7 in 2009. CVs for the spring and fall abundance indices averaged 0.71 and 0.38, respectively (Figure A2.28).

The RIDEM spring biomass indices (stratified mean weight/tow in kg) ranged from 0 butterfish in 1989, 1992 and 2005, to a maximum of 1.3 in 2006 (Table A2.17; Figure A2.29). The fall biomass indices were generally higher, ranging from 0.9 in 2000 to 18.3 in 2012. CVs for the spring and fall biomass indices averaged 0.71 and 0.35, respectively (Figure A2.30).

CDEEP survey

The CDEEP survey of Long Island Sound began in 1984, although weight data were not collected until 1992 (Tables A2.16 and A2.17). There was no survey in fall 2010. Data described below are for 1989-2012 only. The CDEEP spring abundance indices (geometric mean number per tow) ranged from 0.5 in 1993 to 18.7 in 2006 (Table A2.16; Figure A2.31). The fall abundance indices were higher, ranging from 39.6 in 2011 to 477.9 in 1999.

The CDEEP spring biomass indices (geometric mean weight/tow in kg) ranged from 0.1 in 1993 to 2.7 in 2011 (Table A2.17; Figure A2.32). The fall biomass indices were higher, ranging from 2.8 in 2011 to 15.4 in 1999.

NYDEC survey

The NYDEC survey of Peconic Bay began in 1987 (Table A2.16). Sixteen stations are sampled weekly during May-October. The survey did not run in 2005. Weight data are not collected. Data described below and presented in Figure A2.33 are annual means for 1989-2012 only. The NYDEC abundance indices (mean number per tow) ranged from 0.3 in 2007 to 5.2 in 2010 (Table A2.16; Figure A2.33).

NJDEP survey

The NJDEP survey began in August 1988. Surveys are conducted in January, April, June, August and October. Data described below are annual means for 1989-2012 only. The NYDEP abundance indices (stratified mean number per tow) ranged from 97.3 in 2012 to 2018.9 in 1994 (Table A2.16; Figure A2.34). The NYDEP biomass indices (stratified mean weight/tow in kg) ranged from 1.4 in 2000 to 18.9 in 2008 (Table A2.17; Figure A2.35).

DDNREC survey

Bottom trawl surveys of Delaware Bay were conducted during 1966-1971 and 1979-1984; the DDNREC re-instated a 30-foot multispecies bottom trawl survey in 1990 (Tables A2.16 and A2.17). The young-of-the-year seine survey in the estuaries of Delaware Bay began in 1980; in 1986 this was expanded to include Indian River and Rehoboth Bays (Table A2.16). Weight data are not collected for the seine survey. Data described below are annual means for 1989-2012 only.

The trawl survey abundance indices (mean number per tow) ranged from 3.6 in 1992 to 66.7 in 1993 (Table A2.16; Figure A2.36). The biomass indices (mean weight per tow) ranged from 0.2 in 2009 to 4.8 in 1993 (Table A2.17; Figure A2.37).

The seine survey abundance indices (mean number per tow) for estuaries ranged from 0.05 in 1994 and 2006 to 0.57 in 1999; while abundance indices for the bays ranged from 0 butterfish in 2001 to 2.27 in 2009 (Table A2.16; Figure A2.38).

ChesMMAP survey

The ChesMMAP survey began in spring 2002. The ChesMMAP annual abundance indices (geometric mean number per tow) ranged from 13.6 in 2010 to 126.7 in 2005 (Table A2.16; Figure A2.39). The ChesMMAP annual biomass indices (geometric mean weight per tow) ranged from 2.6 in 2010 to 10.3 in 2005 (Table A2.16; Figure A2.40).

VIMS juvenile survey

The Virginia Institute of Marine Science juvenile trawl survey began in 1988. Data are annual means for 1989-2012 only. The VIMS juvenile abundance indices (geometric mean number per tow) ranged from 0.2 in 2007 to 2.3 in 1990 (Table A2.16; Figure A2.41).

NCDENR survey

The NCDENR of Pamlico Sound began in 1990. The NCDENR annual abundance indices (weighted mean number per tow) ranged from 0.5 in 1997 to 7.8 in 2008 (Table A2.16; Figure A2.42).

Correlation coefficients

Correlation coefficients for spring abundance indices considered for inclusion in the final model are shown in Table A2.18. The NEFSC offshore survey had a correlation coefficient of 0.49 with the MDMF survey. The NEAMAP survey had correlations > 0.4 with the Maine-New Hampshire survey, the MDMF survey, and the RIDEM survey. Standardized spring abundance indices are plotted in Figure A2.43.

Correlation coefficients for spring biomass indices considered for inclusion in the final model are shown in Table A2.19. The NEFSC offshore survey had a correlation coefficient of 0.47 with the MDMF survey, while the NEFSC inshore survey had a correlation coefficient of 0.85 with the CDEEP survey. The NEAMAP survey had correlations > 0.4 with the Maine-New Hampshire survey, the MDMF survey, and the RIDEM survey. Standardized spring biomass indices are plotted in Figure A2.45.

Correlation coefficients for fall abundance indices considered for inclusion in the final model are shown in Table A2.20. The NEFSC offshore survey had a correlation coefficient of 0.54 with the NEAMAP survey. The NEAMAP survey had correlations > 0.4 with all the state surveys. The Maine-New Hampshire survey also had correlations > 0.4 with the three other state surveys. Standardized fall abundance indices are plotted in Figure A2.44.

Correlation coefficients for fall biomass indices considered for inclusion in the final model are shown in Table A2.21. The NEFSC offshore survey had a correlation coefficient of 0.84 and 0.40 with the NEAMAP and Maine-New Hampshire survey, respectively. The NEAMAP survey had correlations > 0.4 with the Maine-New Hampshire and RIDEM surveys, while the Maine-New Hampshire survey had correlations > 0.4 with the three other state surveys. Standardized fall biomass indices are plotted in Figure A2.46.

References

Miller TJ, Das C, Politis PJ, Miller AS, Lucey SM, Legault CM, Brown RJ, Rago PH. 2010. Estimation of Albatross IV to Henry B. Bigelow Calibration Factors. NEFSC Ref Doc 10-05. 230 p.

NEFSC. 2010. 49th Northeast Regional Stock Assessment Workshop (49th SAW) *Assessment Report*. NEFSC Ref Doc 10-03. 383 p.

Table A2.1. Bigelow to Albatross calibration coefficients for butterfish from Miller et al. (2010).

	Number		Weight	
	$\hat{\rho}$	SE($\hat{\rho}$)	$\hat{\rho}$	SE($\hat{\rho}$)
Spring	1.487	0.220	2.356	0.332
Fall	1.935	0.172	1.808	0.184

Table A2.2. Butterfish stratified mean number per tow and stratified mean weight (kg) per tow from NEFSC spring surveys, and corresponding coefficients of variation (CV), for data collected 1989-2012 in the outermost inshore strata (2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44-46, 56, 59-61 and 64-66) and offshore strata (1-14, 16, 19, 20, 23, 25 and 61-76). Bigelow data (2009-2012) are calibrated using the coefficients in Table A2.1.

Year	Number	CV	Weight	CV
1989	29.84	0.80	0.70	0.66
1990	8.39	0.44	0.33	0.38
1991	26.57	0.68	0.94	0.57
1992	16.40	0.21	0.56	0.20
1993	24.66	0.39	0.74	0.31
1994	33.01	0.28	1.32	0.27
1995	38.10	0.59	2.00	0.77
1996	10.37	0.40	0.47	0.31
1997	102.98	0.38	3.11	0.40
1998	37.23	0.61	1.95	0.74
1999	69.31	0.59	2.24	0.65
2000	33.44	0.36	0.90	0.33
2001	55.61	0.37	1.72	0.16
2002	42.64	0.44	1.57	0.39
2003	43.37	0.60	1.27	0.73
2004	115.11	0.32	1.99	0.31
2005	33.97	0.39	1.14	0.36
2006	64.63	0.39	1.82	0.35
2007	128.34	0.54	4.32	0.50
2008	122.83	0.70	2.81	0.57
2009	97.58	0.39	1.25	0.37
2010	73.47	0.28	1.26	0.31
2011	40.90	0.20	0.85	0.24
2012	142.55	0.21	3.03	0.21

Table A2.3. Butterfish stratified mean number per tow and stratified mean weight (kg) per tow from NEFSC spring surveys, and corresponding coefficients of variation (CV), for data collected 1989-2008 in the two innermost inshore strata (3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18, 19, 21, 22, 24, 25, 27, 28, 30, 31, 33, 34, 36, 37, 39, 40, 42, 43, 55, 58 and 63).

Year	Number	CV	Weight	CV
1989	0.42	0.85	0.06	0.88
1990	0.44	0.57	0.01	0.33
1991	47.19	0.25	1.83	0.35
1992	0.31	0.40	0.01	0.80
1993	0.32	0.08	0.01	0.33
1994	0	0	0	0
1995	0	0	0	0
1996	0	0	0	0
1997	1.98	0.24	0.07	0.32
1998	0.12	0.81	0.01	0.73
1999	0.02	1.00	0.00	1.00
2000	0.05	1.00	0.00	1.00
2001	0.03	1.00	0.00	1.00
2002	2.92	0.60	0.25	0.68
2003	0.03	1.00	0.00	1.00
2004	0.06	0.83	0.00	0.82
2005	0.02	1.00	0.00	1.00
2006	12.41	0.04	0.79	0.09
2007	0.22	0.78	0.00	0.69
2008	2.59	0.30	0.05	0.11

Table A2.4. Butterfish stratified mean number per tow and stratified mean weight (kg) per tow from NEFSC fall surveys, and corresponding coefficients of variation (CV), for data collected 1989-2012 in the outermost inshore strata (2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44-46, 56, 59-61 and 64-66) and offshore strata (1-14, 16, 19, 20, 23, 25 and 61-76). Bigelow data (2009-2012) are calibrated using the coefficients in Table A2.1.

Year	Number	CV	Weight	CV
1989	377.34	0.38	11.37	0.29
1990	379.94	0.23	9.18	0.23
1991	187.87	0.43	4.85	0.37
1992	246.05	0.27	4.54	0.26
1993	248.98	0.25	9.89	0.23
1994	510.35	0.47	12.98	0.34
1995	116.57	0.26	5.69	0.26
1996	78.85	0.22	2.67	0.27
1997	220.26	0.13	3.94	0.15
1998	214.49	0.33	6.58	0.39
1999	247.81	0.38	4.80	0.30
2000	202.92	0.28	7.29	0.25
2001	63.62	0.31	2.44	0.39
2002	92.61	0.21	2.13	0.21
2003	187.75	0.15	3.55	0.20
2004	75.50	0.29	2.18	0.35
2005	39.19	0.30	1.01	0.29
2006	179.31	0.24	4.87	0.22
2007	41.21	0.23	1.28	0.35
2008	131.93	0.23	2.70	0.22
2009	182.45	0.25	6.32	0.25
2010	128.16	0.24	5.59	0.30
2011	250.38	0.28	9.12	0.27
2012	66.59	0.31	3.48	0.42

Table A2.5. Butterfish stratified mean number per tow and stratified mean weight (kg) per tow from NEFSC fall surveys, and corresponding coefficients of variation (CV), for data collected 1989-2008 in the two innermost inshore strata (3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18, 19, 21, 22, 24, 25, 27, 28, 30, 31, 33, 34, 36, 37, 39, 40, 42, 43, 55, 58 and 63).

Year	Number	CV	Weight	CV
1989	594.95	0.52	20.70	0.66
1990	63.71	0.32	2.74	0.50
1991	172.60	0.24	8.98	0.25
1992	107.53	0.12	2.50	0.19
1993	292.31	0.25	6.44	0.27
1994	303.32	0.12	6.75	0.10
1995	39.52	0.35	2.34	0.37
1996	157.52	0.32	2.38	0.22
1997	632.94	0.10	9.96	0.20
1998	112.32	0.37	3.46	0.43
1999	185.17	0.30	5.20	0.19
2000	312.86	0.27	4.50	0.25
2001	368.50	0.24	10.75	0.28
2002	225.53	0.34	5.81	0.33
2003	267.15	0.19	9.31	0.23
2004	317.13	0.29	14.42	0.52
2005	228.52	0.07	2.95	0.14
2006	202.04	0.23	4.94	0.24
2007	220.95	0.14	4.29	0.31
2008	131.67	0.14	2.70	0.25

Table A2.6. NEFSC survey butterfish samples, ages, and lengths collected, 1989-2012.

		Season		
		Spring	Fall	Total
1989	Total number of stations sampled	32	113	145
	Total number of fish aged	122	466	588
	Total number of fish measured	122	466	588
1990	Total number of stations sampled	33	149	182
	Total number of fish aged	147	619	766
	Total number of fish measured	147	619	766
1991	Total number of stations sampled	52	182	234
	Total number of fish aged	209	852	1061
	Total number of fish measured	209	852	1061
1992	Total number of stations sampled	55	214	269
	Total number of fish aged	240	998	1238
	Total number of fish measured	241	1006	1247
1993	Total number of stations sampled	49	184	233
	Total number of fish aged	222	841	1063
	Total number of fish measured	222	856	1078
1994	Total number of stations sampled	45	210	255
	Total number of fish aged	216	995	1211
	Total number of fish measured	216	1006	1222
1995	Total number of stations sampled	60	190	250
	Total number of fish aged	282	845	1127
	Total number of fish measured	282	855	1137
1996	Total number of stations sampled	41	155	196
	Total number of fish aged	160	712	872
	Total number of fish measured	161	716	877
1997	Total number of stations sampled	82	169	251
	Total number of fish aged	438	771	1209
	Total number of fish measured	446	787	1233
1998	Total number of stations sampled	58	207	265
	Total number of fish aged	220	946	1166
	Total number of fish measured	225	967	1192
1999	Total number of stations sampled	49	165	214
	Total number of fish aged	221	777	998
	Total number of fish measured	226	786	1012
2000	Total number of stations sampled	67	150	217
	Total number of fish aged	252	633	885
	Total number of fish measured	262	663	925
2001	Total number of stations sampled	45	156	201
	Total number of fish aged	258	605	863
	Total number of fish measured	261	631	892
2002	Total number of stations sampled	73	173	246
	Total number of fish aged	309	755	1064
	Total number of fish measured	327	794	1121
2003	Total number of stations sampled	45	184	229
	Total number of fish aged	218	837	1055
	Total number of fish measured	231	884	1115

Table A2.6 continued.

2004	Total number of stations sampled	37	163	200
	Total number of fish aged	147	715	862
	Total number of fish measured	150	809	959
2005	Total number of stations sampled	41	167	208
	Total number of fish aged	203	760	963
	Total number of fish measured	279	810	1089
2006	Total number of stations sampled	66	228	294
	Total number of fish aged	286	1052	1338
	Total number of fish measured	293	1075	1368
2007	Total number of stations sampled	75	166	241
	Total number of fish aged	338	750	1088
	Total number of fish measured	346	773	1119
2008	Total number of stations sampled	78	201	279
	Total number of fish aged	355	888	1243
	Total number of fish measured	374	925	1299
2009	Total number of stations sampled	65	239	304
	Total number of fish aged	385	1220	1605
	Total number of fish measured	393	1251	1644
2010	Total number of stations sampled	111	253	364
	Total number of fish aged	570	1341	1911
	Total number of fish measured	590	1370	1960
2011	Total number of stations sampled	98	259	357
	Total number of fish aged	430	1580	2010
	Total number of fish measured	451	1662	2113
2012	Total number of stations sampled	197	208	405
	Total number of fish aged	953	788	1741
	Total number of fish measured	1146	947	2093

Table A2.7. Butterfish stratified mean number per tow for ages 0-3 and 4+ from NEFSC spring surveys for data collected 1989-2012 in the outermost inshore strata (2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44-46, 56, 59-61 and 64-66) and offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76). Bigelow data (2009-2012) are calibrated using the coefficients in Table A2.1.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0	24.27	4.70	0.87	0.01
1990	0.01	6.84	1.23	0.28	0.03
1991	0.02	24.63	1.35	0.57	0.02
1992	0	14.57	1.61	0.21	0.01
1993	0	21.51	2.67	0.47	0.00
1994	0	26.98	5.05	0.94	0.04
1995	0	24.00	11.74	2.37	0
1996	0	6.98	2.19	1.16	0.04
1997	0	98.19	4.15	0.64	0.00
1998	0	16.55	19.60	1.08	0
1999	0	57.44	10.09	1.78	0
2000	0	31.58	1.55	0.28	0.03
2001	0	44.78	10.12	0.72	0
2002	0	34.92	5.59	1.91	0.22
2003	0	35.80	4.99	2.42	0.16
2004	0	113.98	1.04	0.07	0.02
2005	0	25.60	7.02	0.91	0.44
2006	0	60.31	3.06	0.94	0.32
2007	0	109.78	15.47	2.90	0.19
2008	0	113.91	8.19	0.66	0.07
2009	0	92.76	3.86	0.79	0.17
2010	0	63.04	8.81	1.52	0.10
2011	0	33.68	5.19	1.43	0.60
2012	0	128.94	9.99	3.10	0.53

Table A2.8. Butterfish stratified mean weight (kg) per tow for ages 0-3 and 4+ from NEFSC spring surveys for data collected 1989-2012 in the outermost inshore strata (2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44-46, 56, 59-61 and 64-66) and offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76). Bigelow data (2009-2012) are calibrated using the coefficients in Table A2.1.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0	0.46	0.18	0.07	0.00
1990	0.00	0.20	0.10	0.03	0.00
1991	0.00	0.74	0.13	0.07	0.00
1992	0	0.43	0.11	0.03	0.00
1993	0	0.55	0.15	0.04	0.00
1994	0	0.89	0.33	0.09	0.01
1995	0	0.91	0.89	0.20	0
1996	0	0.19	0.17	0.10	0.00
1997	0	2.73	0.31	0.07	0.00
1998	0	0.47	1.38	0.10	0
1999	0	1.47	0.63	0.14	0
2000	0	0.78	0.09	0.03	0.00
2001	0	0.88	0.76	0.08	0
2002	0	1.01	0.34	0.19	0.02
2003	0	0.75	0.29	0.20	0.02
2004	0	1.94	0.04	0.01	0.00
2005	0	0.70	0.32	0.08	0.04
2006	0	1.52	0.16	0.09	0.04
2007	0	3.05	0.98	0.27	0.02
2008	0	2.30	0.45	0.06	0.01
2009	0	1.08	0.12	0.04	0.01
2010	0	0.94	0.26	0.06	0.00
2011	0	0.54	0.20	0.07	0.04
2012	0	2.43	0.41	0.16	0.03

Table A2.9. Butterfish stratified mean number per tow for ages 0-3 and 4+ from NEFSC spring surveys for data collected 1989-2008 in the two innermost inshore strata (3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18, 19, 21, 22, 24, 25, 27, 28, 30, 31, 33, 34, 36, 37, 39, 40, 42, 43, 55, 58 and 63).

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0.07	0	0.07	0.29	0
1990	0.19	0.25	0	0	0
1991	0	37.69	6.05	3.44	0.01
1992	0	0.14	0.14	0.02	0.02
1993	0	0.30	0.02	0	0
1994	0	0	0	0	0
1995	0	0	0	0	0
1996	0	0	0	0	0
1997	0	1.75	0.14	0.08	0
1998	0	0	0.09	0.03	0
1999	0	0	0	0.02	0
2000	0	0.03	0.03	0	0
2001	0	0.03	0	0	0
2002	0	0.72	1.76	0.17	0.28
2003	0	0.03	0	0	0
2004	0	0.06	0	0	0
2005	0	0	0	0.02	0
2006	0	2.93	7.68	1.57	0.23
2007	0	0.22	0	0	0
2008	0	2.01	0.46	0.06	0.06

Table A2.10. Butterfish stratified mean weight (kg) per tow for ages 0-3 and 4+ from NEFSC spring surveys for data collected 1989-2008 in the two innermost inshore strata (3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18, 19, 21, 22, 24, 25, 27, 28, 30, 31, 33, 34, 36, 37, 39, 40, 42, 43, 55, 58 and 63).

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0.00	0	0.01	0.05	0
1990	0.00	0.01	0	0	0
1991	0	1.00	0.44	0.39	0.00
1992	0	0.00	0.01	0.00	0.00
1993	0	0.01	0.00	0	0
1994	0	0	0	0	0
1995	0	0	0	0	0
1996	0	0	0	0	0
1997	0	0.04	0.02	0.01	0
1998	0	0	0.01	0.00	0
1999	0	0	0	0.00	0
2000	0	0.00	0.00	0	0
2001	0	0.00	0	0	0
2002	0	0.04	0.16	0.03	0.03
2003	0	0.00	0	0	0
2004	0	0.00	0	0	0
2005	0	0	0	0.00	0
2006	0	0.10	0.49	0.16	0.04
2007	0	0.00	0	0	0
2008	0	0.03	0.01	0.01	0.01

Table A2.11. Butterfish stratified mean number per tow for ages 0-3 and 4+ from NEFSC fall surveys for data collected 1989-2012 in the outermost inshore strata (2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44-46, 56, 59-61 and 64-66) and offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76). Bigelow data (2009-2012) are calibrated using the coefficients in Table A2.1.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	325.84	39.43	11.45	0.62	0
1990	343.42	32.55	3.15	0.82	0
1991	167.26	18.37	2.21	0.02	0
1992	232.64	9.93	3.43	0.05	0
1993	195.92	46.58	6.07	0.42	0
1994	475.76	23.85	9.38	1.33	0.03
1995	41.44	48.16	26.91	0.07	0
1996	59.40	15.01	4.21	0.24	0
1997	204.14	13.81	2.14	0.19	0
1998	164.99	41.97	6.84	0.69	0
1999	241.17	4.92	1.72	0	0
2000	151.05	45.85	5.73	0.29	0
2001	38.53	15.20	9.66	0.22	0
2002	80.45	9.27	2.84	0.05	0
2003	175.45	10.38	1.69	0.11	0.12
2004	57.31	12.75	4.81	0.22	0.41
2005	33.92	3.17	1.52	0.58	0
2006	155.83	17.51	5.17	0.74	0.06
2007	26.03	13.65	1.51	0.02	0
2008	124.81	6.17	0.94	0.02	0
2009	158.32	20.06	3.88	0.17	0.01
2010	84.10	35.90	6.90	1.25	0
2011	218.27	26.86	4.76	0.42	0.06
2012	27.15	28.83	9.91	0.62	0.07

Table A2.12. Butterfish stratified mean weight (kg) per tow for ages 0-3 and 4+ from NEFSC fall surveys for data collected 1989-2012 in the outermost inshore strata (2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44-46, 56, 59-61 and 64-66) and offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76). Bigelow data (2009-2012) are calibrated using the coefficients in Table A2.1.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	8.04	2.37	0.90	0.06	0
1990	7.01	1.78	0.31	0.08	0
1991	3.59	1.09	0.16	0.00	0
1992	3.61	0.64	0.28	0.01	0
1993	6.36	3.01	0.48	0.05	0
1994	10.41	1.60	0.84	0.12	0.00
1995	1.07	2.91	1.70	0.01	0
1996	1.58	0.74	0.33	0.02	0
1997	2.91	0.86	0.16	0.01	0
1998	3.31	2.57	0.62	0.08	0
1999	4.46	0.23	0.11	0	0
2000	3.27	3.50	0.48	0.03	0
2001	1.03	0.84	0.55	0.02	0
2002	1.58	0.34	0.21	0.01	0
2003	2.80	0.61	0.12	0.01	0.01
2004	1.01	0.72	0.39	0.02	0.05
2005	0.73	0.13	0.11	0.05	0
2006	3.28	1.12	0.40	0.06	0.01
2007	0.32	0.85	0.10	0.00	0
2008	2.27	0.36	0.07	0.00	0
2009	4.86	1.19	0.26	0.02	0.00
2010	2.71	2.24	0.54	0.10	0
2011	7.50	1.23	0.34	0.04	0.01
2012	0.91	1.85	0.65	0.05	0.01

Table A2.13. Butterfish stratified mean number per tow for ages 0-3 and 4+ from NEFSC fall surveys for data collected 1989-2008 in the two innermost inshore strata (3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18, 19, 21, 22, 24, 25, 27, 28, 30, 31, 33, 34, 36, 37, 39, 40, 42, 43, 55, 58 and 63).

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	397.24	144.43	49.62	3.65	0
1990	38.02	11.54	11.86	2.29	0
1991	115.28	28.59	21.61	7.12	0
1992	89.42	7.40	10.30	0.40	0
1993	250.77	28.49	11.64	1.41	0
1994	291.99	7.04	3.43	0.85	0.01
1995	24.11	7.99	7.20	0.22	0
1996	130.65	23.71	2.77	0.39	0
1997	589.52	41.98	1.44	0	0
1998	66.98	38.05	6.80	0.48	0
1999	145.37	30.57	8.88	0.34	0
2000	305.24	6.38	0.55	0.67	0
2001	345.76	19.79	2.73	0.23	0
2002	185.27	30.25	9.12	0.88	0
2003	220.99	39.48	3.01	2.90	0.77
2004	184.48	65.98	58.96	4.55	3.16
2005	210.89	10.62	3.60	3.25	0.16
2006	176.14	19.40	4.81	1.45	0.23
2007	194.59	20.58	5.70	0.08	0
2008	119.82	9.76	1.83	0.25	0

Table A2.14. Butterfish stratified mean weight (kg) per tow for ages 0-3 and 4+ from NEFSC fall surveys for data collected 1989-2008 in the two innermost inshore strata (3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18, 19, 21, 22, 24, 25, 27, 28, 30, 31, 33, 34, 36, 37, 39, 40, 42, 43, 55, 58 and 63).

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	10.08	6.64	3.66	0.32	0
1990	0.52	0.62	1.28	0.32	0
1991	3.70	2.26	2.22	0.79	0
1992	1.12	0.50	0.85	0.04	0
1993	4.02	1.44	0.84	0.14	0
1994	6.08	0.32	0.27	0.08	0.00
1995	0.98	0.68	0.64	0.03	0
1996	1.19	0.89	0.25	0.04	0
1997	8.77	1.08	0.11	0	0
1998	1.05	1.68	0.68	0.05	0
1999	2.58	1.61	0.96	0.05	0
2000	4.08	0.26	0.08	0.07	0
2001	9.43	1.04	0.25	0.03	0
2002	3.59	1.20	0.89	0.12	0
2003	6.51	2.15	0.25	0.33	0.07
2004	2.72	5.43	5.44	0.51	0.30
2005	2.01	0.33	0.28	0.31	0.02
2006	3.43	0.88	0.45	0.15	0.03
2007	2.38	1.44	0.46	0.01	0
2008	2.02	0.53	0.13	0.02	0

Table A2.15. Butterfish arithmetic mean number per tow and arithmetic mean weight (kg) per tow, and corresponding coefficients of variation (CV), provided by the Northeast Monitoring and Assessment Program (NEAMAP), for the spring (2008-2012) and fall (2007-2012) surveys.

	Spring				Fall			
Year	Number	CV	Weight	CV	Number	CV	Weight	CV
2007					1061.01	0.36	13.14	0.19
2008	343.18	0.21	4.97	0.12	1032.49	0.17	13.27	0.13
2009	188.48	0.12	4.20	0.15	3600.76	0.14	45.55	0.2
2010	521.88	0.58	19.14	0.65	1073.33	0.12	34.55	0.13
2011	458.63	0.15	9.28	0.18	1661.64	0.17	36.89	0.17
2012	525.57	0.16	22.37	0.16	625.73	0.21	23.88	0.2

Table A2.16. Butterfish mean number per tow for the various state surveys.

Year	ME-NH Spring	ME-NH Fall	MDMF Spring	MDMF Fall	RIDEM Spring	RIDEM Fall	CTDEEP Spring	CTDEEP Fall	NYDEC Peconic	NJDFW Annual
1978			1.19	148.48						
1979			0.31	83.29	17.06	4.38				
1980			6.18	430.68	5.58	37.23				
1981			1.04	109.91	0.83	60.54				
1982			0.10	184.98	0.17	97.09				
1983			1.31	197.55	1.03	78.46				
1984			2.69	66.45	0.17	111.73	8.92	51.93		
1985			5.96	133.13	0.62	35.79	0.62	89.72		
1986			1.54	185.82	3.00	230.77	2.38	63.41		
1987			0.67	10.06	0.02	94.94	0.25	60.09	0.03	
1988			0.60	808.10	0.00	1852.21	0.46	146.67	2.28	1644.67
1989			0.15	109.82	0.00	163.95	0.80	174.87	0.89	506.14
1990			8.82	297.93	0.02	497.84	1.60	154.65	1.38	356.26
1991			16.18	248.49	0.83	92.23	2.17	170.59	0.36	609.31
1992			0.64	660.11	0.00	277.94	2.60	301.72	0.90	2767.81
1993			1.06	731.89	27.35	688.06	0.48	87.73	0.40	214.66
1994			2.84	391.87	0.30	292.24	1.71	93.05	0.34	3220.32
1995			8.23	586.18	1.79	273.93	1.06	320.06	0.52	388.69
1996			2.59	337.35	3.71	281.52	3.22	173.74	0.36	1046.29
1997			5.14	401.52	1.73	1002.19	6.16	186.62	1.86	439.45
1998			3.05	921.22	3.73	399.59	6.51	355.49	0.75	233.08
1999			0.59	448.46	0.29	243.54	1.90	477.91	0.52	698.72
2000		2.26	24.94	148.36	3.24	42.70	3.35	125.97	0.99	247.85
2001	0.03	11.73	11.01	71.97	11.22	165.02	2.94	142.89	0.69	308.36
2002	0.06	37.90	9.55	283.15	10.88	213.23	7.09	165.07	0.66	348.65
2003		19.65	8.04	578.91	0.71	429.69	3.17	112.86	1.46	651.43
2004		37.24	2.49	135.54	24.08	193.71	2.10	175.37	0.65	584.18
2005		36.16	1.27	372.14	0.00	269.18	2.27	197.24		412.00
2006	0.14	38.91	7.55	147.40	404.98	292.71	18.67	140.23	3.09	1477.43
2007	0.18	24.85	46.06	293.85	1.00	378.59	3.48	154.53	0.25	504.23
2008	0.04	112.10	5.98	531.96	0.10	590.48	4.64	181.71	1.78	2529.77
2009		303.59	13.74	979.18	0.31	2507.67	9.44	409.75	2.33	1607.49
2010	0.39	63.24	26.45	129.26	0.51	437.07	1.99		5.24	319.73
2011	0.34	108.94	2.44	833.27	1.14	920.81	15.64	39.62	1.97	603.91

2012	0.44	130.27	29.08	587.53	13.57	580.16	13.44	132.47	0.49	116.53

Table A2.16 continued.

Year	DEDFW 30 ft	DEDFW Estuary	DEDFW Bays	ChesMMAP	VIMS Juvenile	NCDMF Annual
1966	0.93					
1967	14.87					
1968	9.23					
1969	0.38					
1970	7.61					
1971	21.22					
1972						
1973						
1974						
1975						
1976						
1977						
1978						
1979	0.93					
1980	4.34	0.04				
1981	2.21	0.01				
1982	1.65	0.02				
1983	0.16	0.38				
1984	2.20	0.18				
1985		0.05				
1986		0.11	0.18			
1987		0.06	0.18			
1988		0.17	0.96		0.75	
1989		0.25	0.78		1.86	
1990	8.02	0.41	0.51		2.27	2.59
1991	6.72	0.13	0.62		1.48	2.57
1992	3.60	0.19	0.32		0.88	1.31
1993	66.67	0.22	0.20		1.44	2.25
1994	5.68	0.05	0.31		0.52	1.91
1995	9.08	0.13	0.15		0.33	1.34
1996	12.64	0.06	0.04		1.14	2.26
1997	23.93	0.41	0.33		0.45	0.53
1998	35.41	0.36	0.07		1.03	1.72
1999	16.23	0.57	0.44		0.74	1.99
2000	9.83	0.46	0.07		0.87	1.8
2001	12.01	0.14	0.00		0.47	1.57
2002	10.90	0.10	0.25	31.16	0.40	1.49
2003	29.97	0.20	0.22	87.46	1.01	1.46
2004	32.02	0.24	0.33	59.34	0.86	1.38
2005	3.98	0.17	0.08	126.69	0.36	2.73
2006	8.34	0.05	0.77	81.79	1.26	1.96
2007	7.03	0.10	0.18	60.81	0.16	2.01
2008	14.62	0.17	0.44	73.82	0.98	7.79
2009	6.89	0.13	2.27	78.56	1.06	3.91
2010	14.98	0.41	0.42	13.62	1.45	5.18
2011	27.54	0.49	1.17	27.63	0.78	5.95
2012	9.98	0.21	0.13	15.12	0.27	2.54

Table A2.17. Butterfish mean weight (kg) per tow for the various state surveys.

Year	ME-NH Spring	ME-NH Fall	MDMF Spring	MDMF Fall	RIDEM Spring	RIDEM Fall	CTDEEP Spring	CTDEEP Fall	NJDFW Annual	DEDFW 30 ft	ChesMMAP
1978			0.16	1.48							
1979			0.03	0.98	0.20	0.22				0.05	
1980			0.41	4.72	0.51	0.87				0.16	
1981			0.11	2.52	0.07	1.18				0.09	
1982			0.01	1.74	0.02	1.16				0.11	
1983			0.14	2.19	0.07	1.24				0.00	
1984			0.28	1.28	0.01	2.99				0.08	
1985			0.35	2.34	0.05	1.09					
1986			0.12	3.19	0.18	4.23					
1987			0.05	0.41	0.00	2.47					
1988			0.06	7.19	0.00	12.33			17.99		
1989			0.01	1.59	0.00	2.94			7.70		
1990			0.51	3.78	0.00	5.10			6.68	0.42	
1991			0.68	2.53	0.05	1.95			7.90	0.29	
1992			0.04	5.34	0.00	3.47	0.43	6.31	21.23	0.25	
1993			0.09	6.30	0.88	5.30	0.10	4.12	3.46	4.76	
1994			0.19	6.07	0.02	5.60	0.31	3.40	29.59	0.47	
1995			0.24	3.84	0.08	4.55	0.19	10.26	3.73	0.54	
1996			0.20	4.72	0.23	2.79	0.73	9.30	7.35	0.84	
1997			0.25	4.94	0.07	9.33	1.27	6.97	2.53	1.59	
1998			0.23	8.65	0.12	4.71	1.06	13.27	1.32	2.53	
1999			0.03	5.63	0.02	3.32	0.52	15.43	3.22	1.11	
2000		0.18	0.97	2.19	0.16	0.88	0.69	4.45	2.11	0.67	
2001	0.00	0.60	0.84	1.22	1.04	2.19	0.79	7.80	4.16	0.85	
2002	0.00	0.71	0.50	2.98	0.65	2.05	1.48	6.56	6.24	0.60	3.9
2003		0.69	0.51	2.17	0.08	5.71	0.64	3.47	9.23	1.31	5.05
2004		0.84	0.19	2.06	1.03	2.15	0.41	6.24	7.12	2.08	6.53
2005		0.22	0.08	4.25	0.00	3.74	0.55	7.85	3.93	0.24	10.28
2006	0.00	1.28	0.29	2.33	1.27	6.99	2.30	7.73	10.87	0.48	7.91
2007	0.01	0.81	1.72	2.67	0.08	8.60	0.66	5.82	6.40	0.46	8.4
2008	0.00	0.88	0.43	4.62	0.00	6.59	1.06	8.97	29.28	0.46	9.89
2009		5.08	0.41	5.75	0.04	16.62	1.37	14.39	20.94	0.23	6.7
2010	0.01	0.98	1.14	3.04	0.04	14.74	0.49		7.06	0.54	2.57
2011	0.02	1.86	0.14	9.47	0.11	17.57	2.69	2.81	13.46	0.75	4.48

2012	0.01	2.16	1.03	9.47	0.52	18.27	1.87	6.14	3.95	0.60	4.24

Table A2.18. Correlation coefficients between NEFSC, NEAMAP, and the various state surveys for butterfish spring abundance indices (number per tow). Values > 0.4 are in bold. There is no correlation coefficient for NEFSC Inshore and NEAMAP due to the low sample size (*n* = 1 pair).

	NEFSC Offshore	NEFSC Inshore	ME-NH	MDMF	RIDEM	CDEEP	NEAMAP
NEFSC Offshore	1						
NEFSC Inshore	-0.11	1					
ME-NH	0.23	0.31	1				
MDMF	**0.49**	0.16	0.37	1			
RIDEM	0.05	0.19	-0.16	-0.05	1		
CDEEP	0.32	0.15	0.29	0.10	**0.60**	1	
NEAMAP	-0.09	NA	**0.98**	**0.47**	**0.49**	0.07	1

Table A2.19. Correlation coefficients between NEFSC, NEAMAP, and the various state surveys for butterfish spring biomass indices (kg per tow). Values > 0.4 are in bold. There is no correlation coefficient for NEFSC Inshore and NEAMAP due to the low sample size (*n* = 1 pair).

	NEFSC Offshore	NEFSC Inshore	ME-NH	MDMF	RIDEM	CDEEP	NEAMAP
NEFSC Offshore	1						
NEFSC Inshore	-0.11	1					
ME-NH	-0.31	-0.77	1				
MDMF	**0.47**	0.12	0.05	1			
RIDEM	0.07	0.11	-0.48	0.01	1		
CDEEP	0.12	**0.85**	0.27	0.03	0.21	1	
NEAMAP	0.26	NA	**0.49**	**0.85**	**0.71**	-0.09	1

Table A2.20. Correlation coefficients between NEFSC, NEAMAP, and the various state surveys for butterfish fall abundance indices (number per tow). Values > 0.4 are in bold. Note the correlation coefficient for NEFSC Inshore and NEAMAP is due to the low sample size (*n* = 2 pairs).

	NEFSC Offshore	NEFSC Inshore	ME-NH	MDMF	RIDEM	CDEEP	NEAMAP
NEFSC Offshore	1						
NEFSC Inshore	0.19	1					
ME-NH	0.27	-0.78	1				
MDMF	0.11	-0.40	**0.80**	1			
RIDEM	0.04	0.23	**0.96**	**0.63**	1		
CDEEP	-0.06	-0.35	**0.71**	0.35	0.27	1	
NEAMAP	**0.54**	**1**	**0.86**	**0.71**	**0.97**	**0.79**	1

Table A2.21. Correlation coefficients between NEFSC, NEAMAP, and the various state surveys for butterfish fall biomass indices (kg per tow). Values > 0.4 are in bold. Note the correlation coefficient for NEFSC Inshore and NEAMAP is due to the low sample size (*n* = 2 pairs).

	NEFSC Offshore	NEFSC Inshore	ME-NH	MDMF	RIDEM	CDEEP	NEAMAP
NEFSC Offshore	1						
NEFSC Inshore	0.22	1					
ME-NH	**0.40**	0.14	1				
MDMF	0.25	-0.49	**0.51**	1			
RIDEM	0.09	-0.18	**0.70**	**0.57**	1		
CDEEP	-0.21	-0.34	**0.65**	0.11	-0.03	1	
NEAMAP	**0.84**	-1	**0.74**	0.31	**0.77**	0.35	1

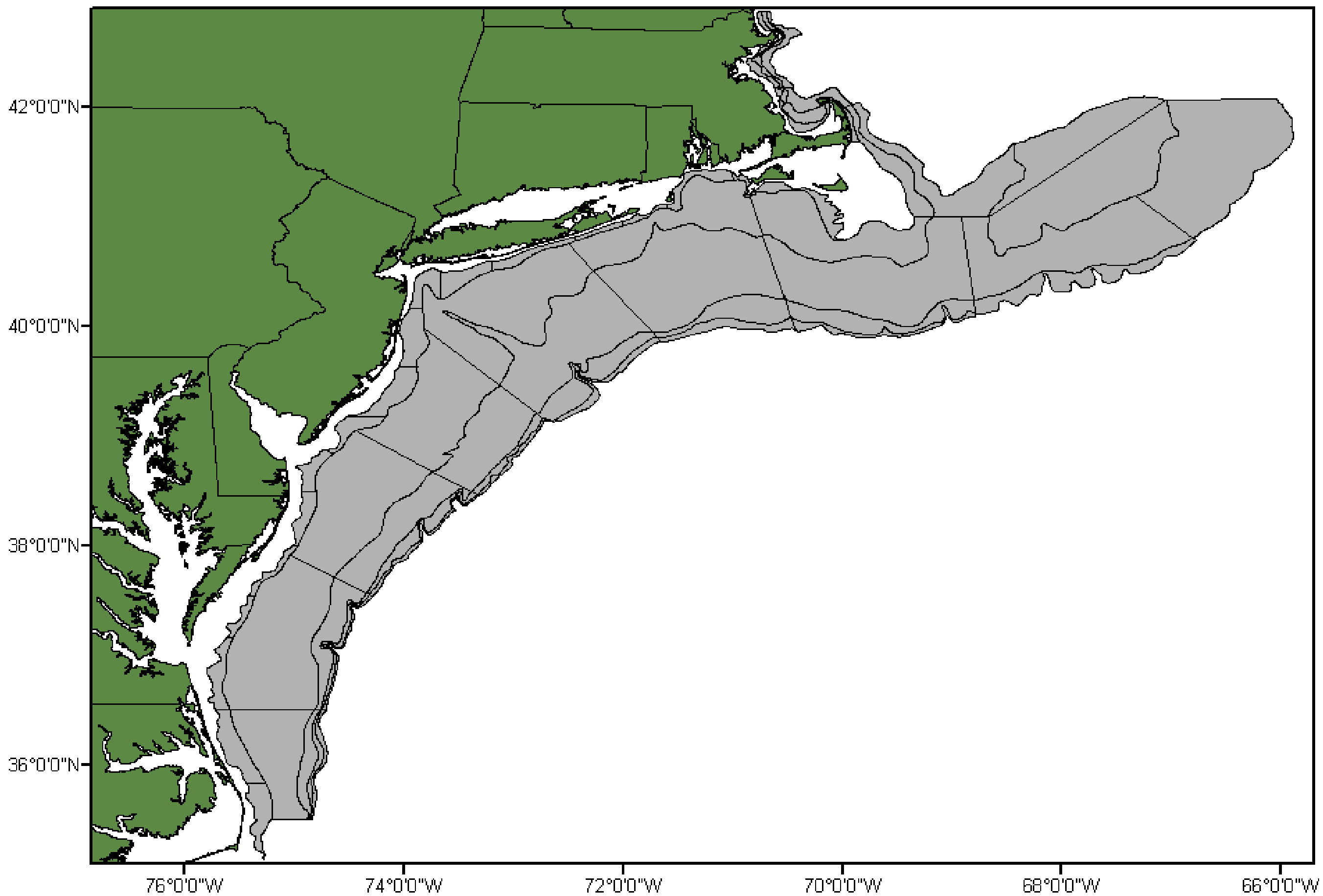

Figure A2.1. Strata used for NEFSC "offshore" indices for butterfish, 1989-2012. Strata include the outermost inshore strata (2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44-46, 56, 59-61 and 64-66) and offshore strata (1-14, 16, 19, 20, 23, 25 and 61-76).

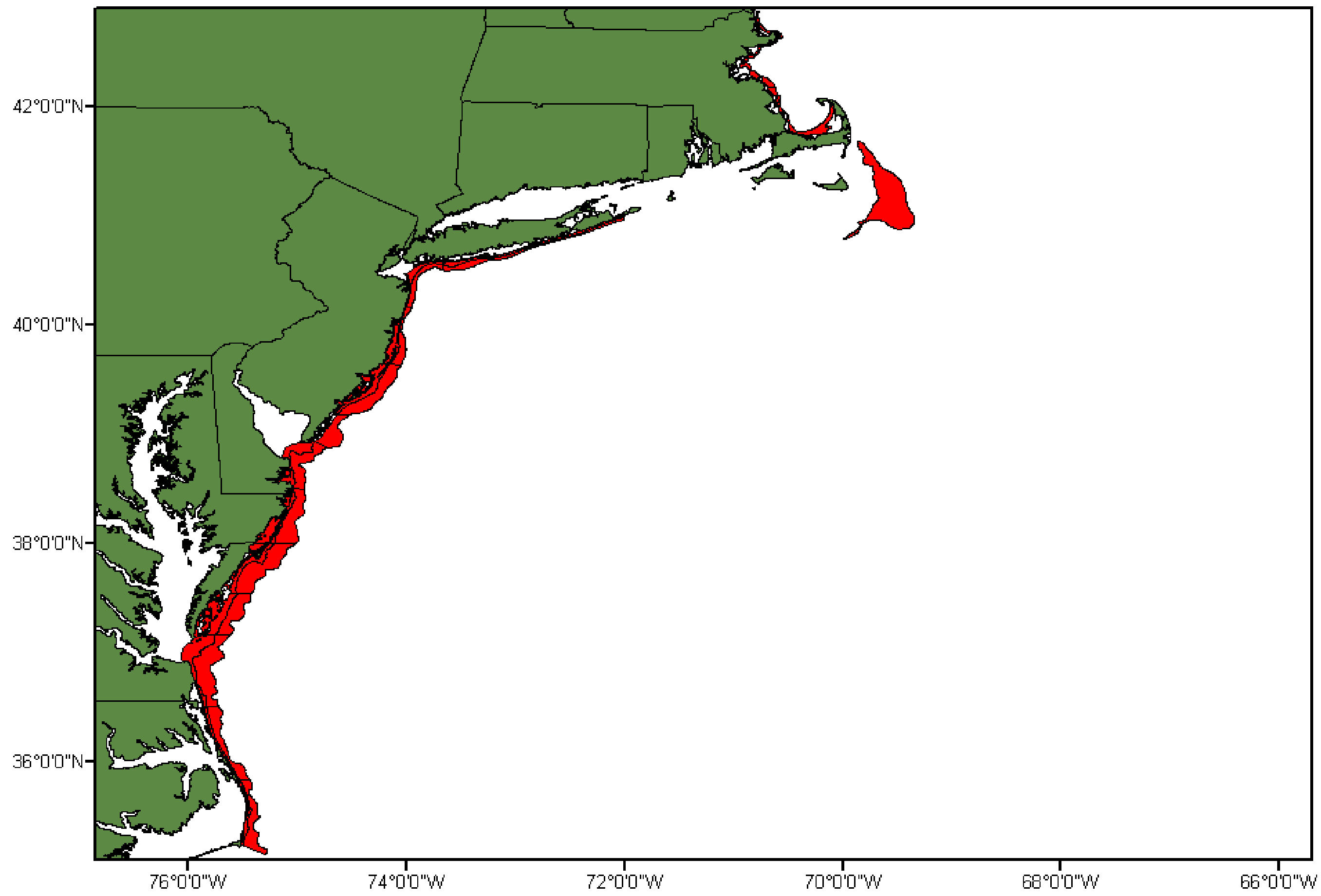

Figure A2.2. Strata used for NEFSC inshore indices for butterfish, 1989-2008. Strata include the two innermost inshore strata (3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18, 19, 21, 22, 24, 25, 27, 28, 30, 31, 33, 34, 36, 37, 39, 40, 42, 43, 55, 58 and 63).

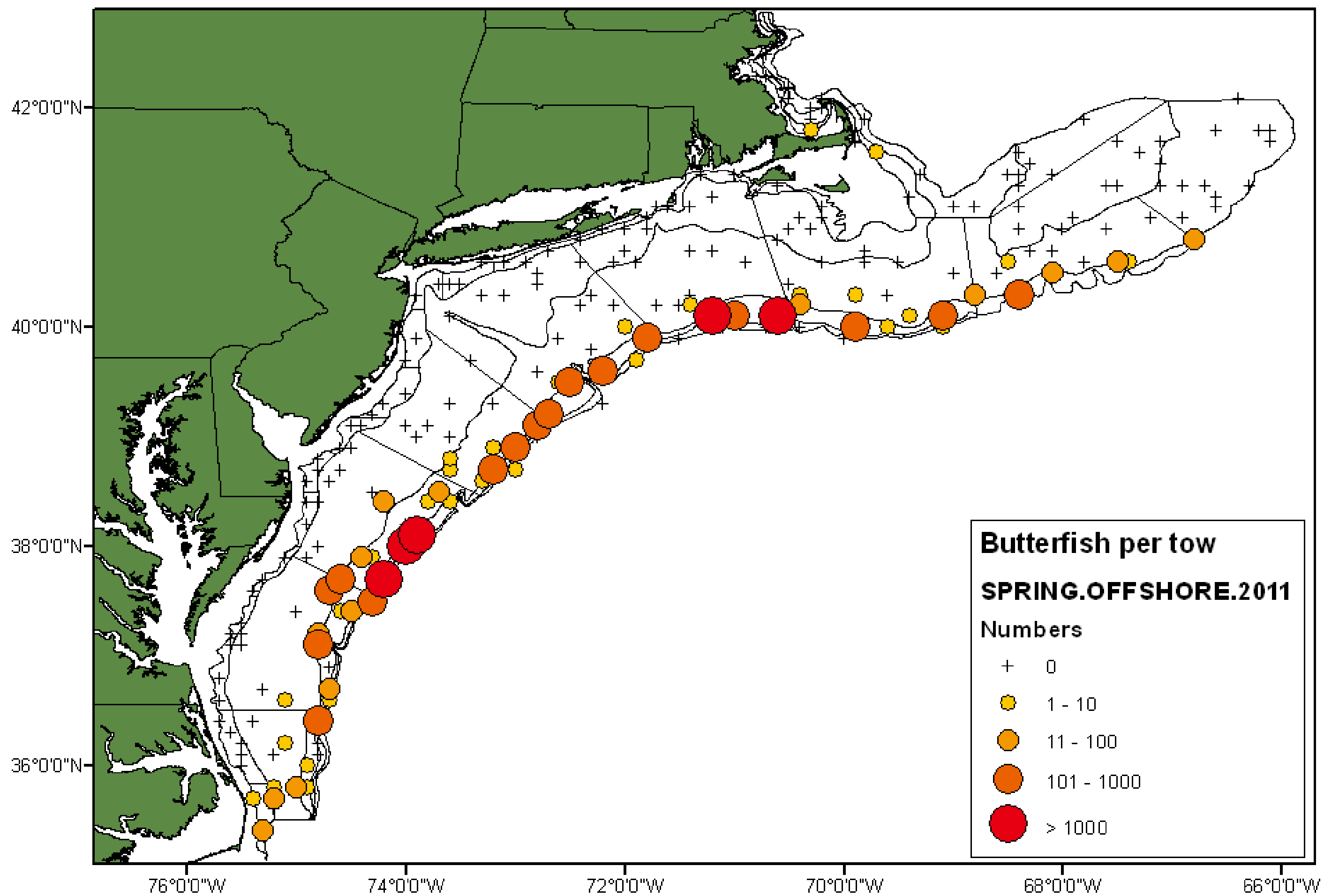

Figure A2.3. NEFSC 2011 spring survey number of butterfish per tow.

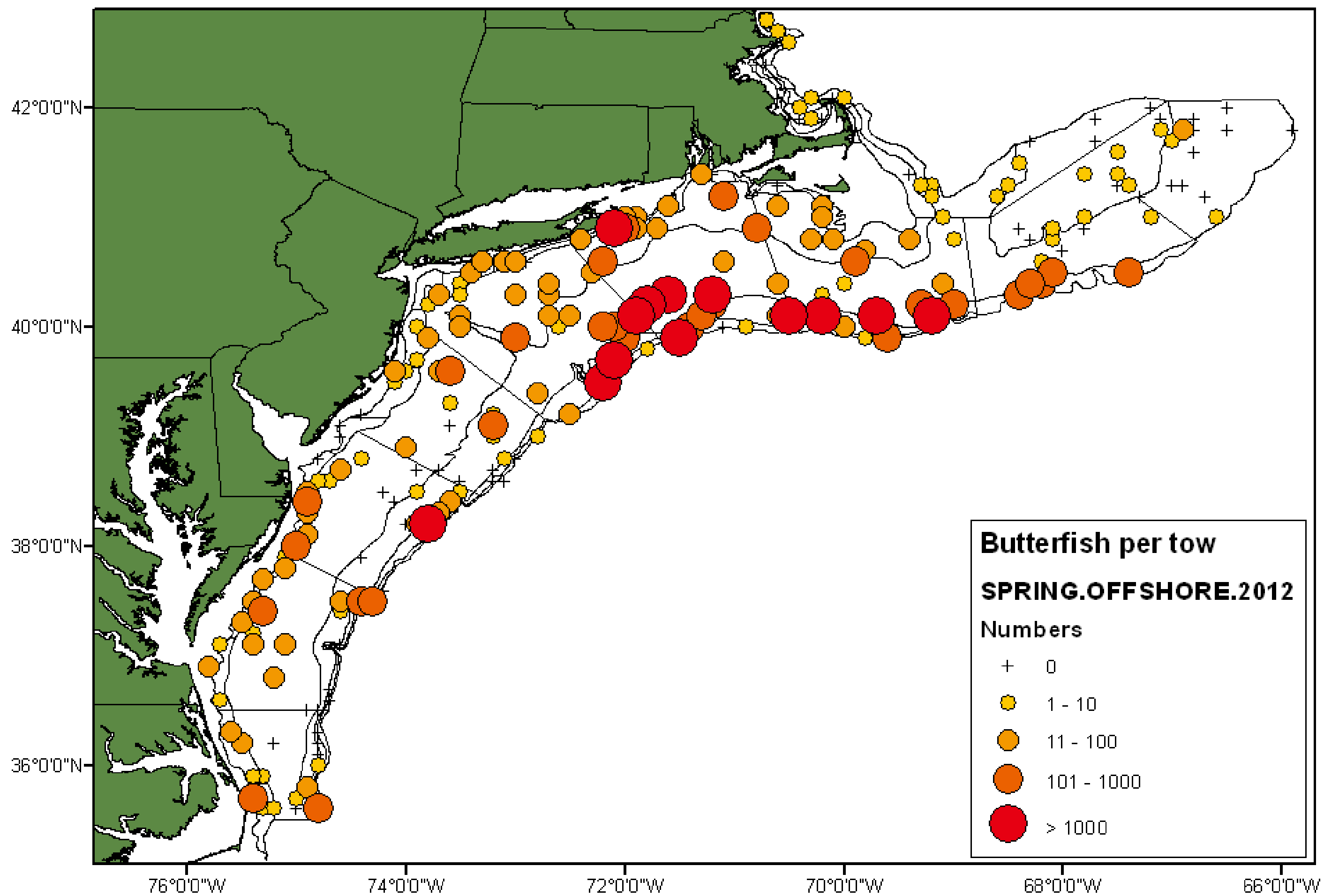

Figure A2.4. NEFSC 2012 spring survey number of butterfish per tow.

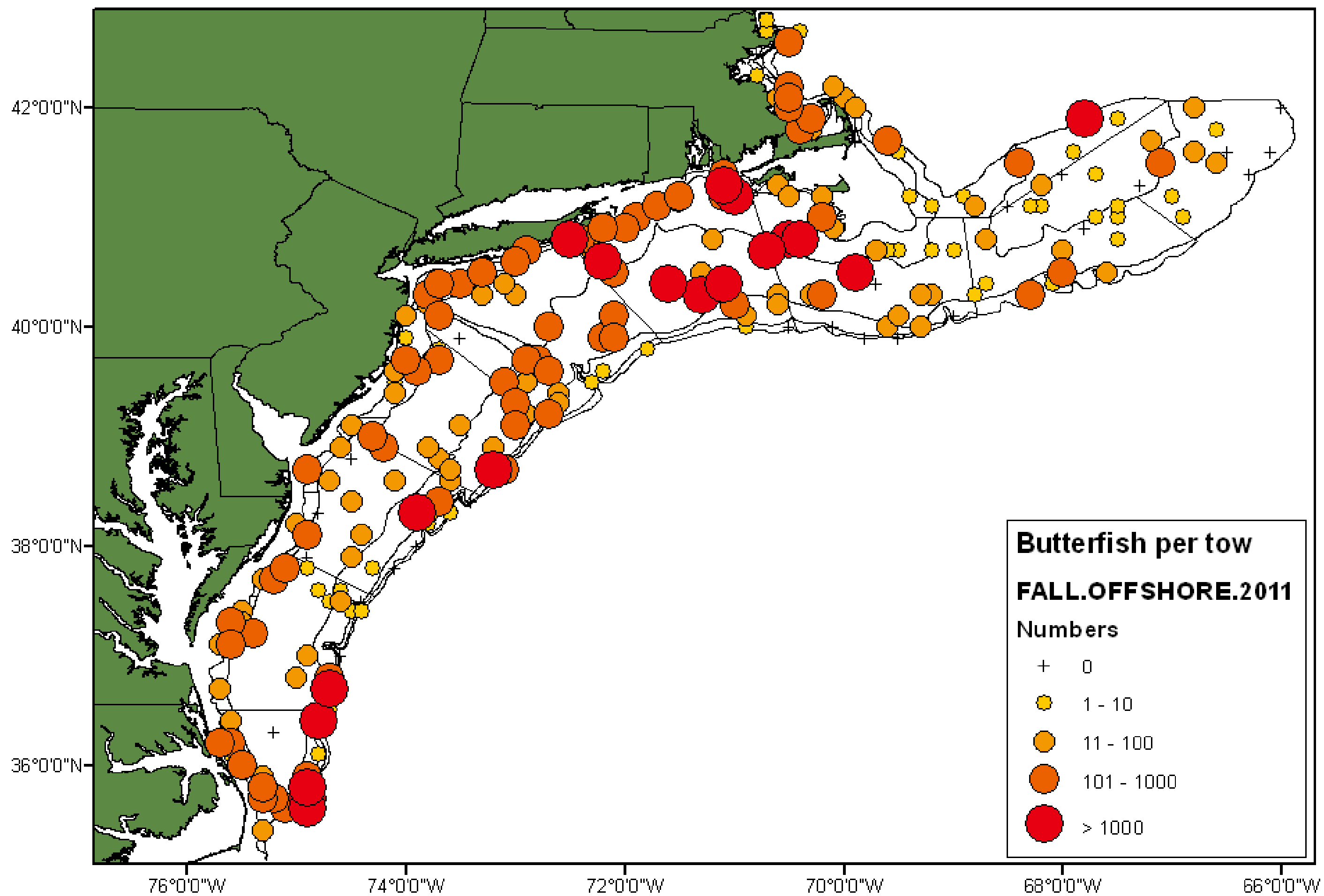

Figure A2.5. NEFSC 2011 fall survey number of butterfish per tow.

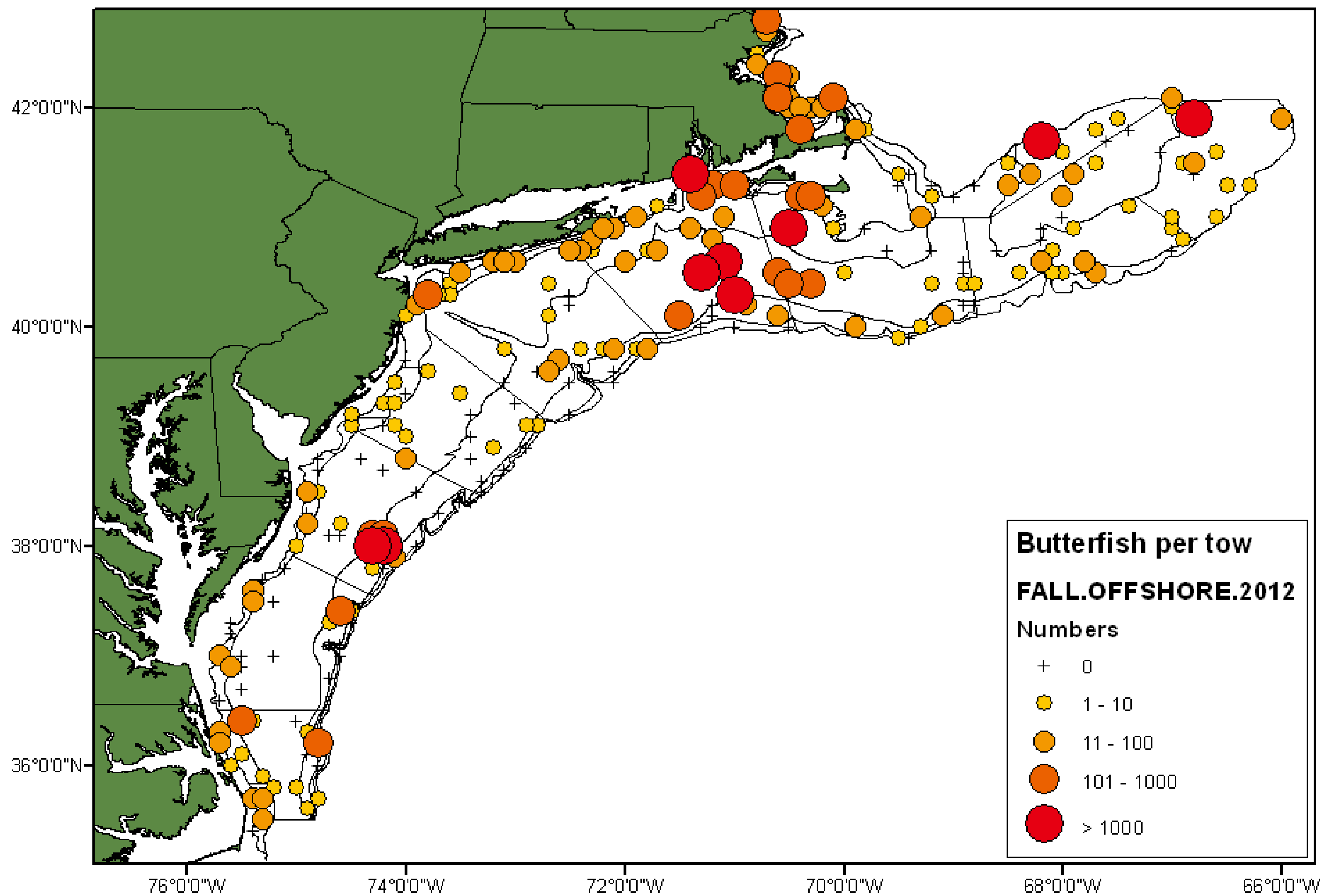

Figure A2.6. NEFSC 2012 fall survey number of butterfish per tow.

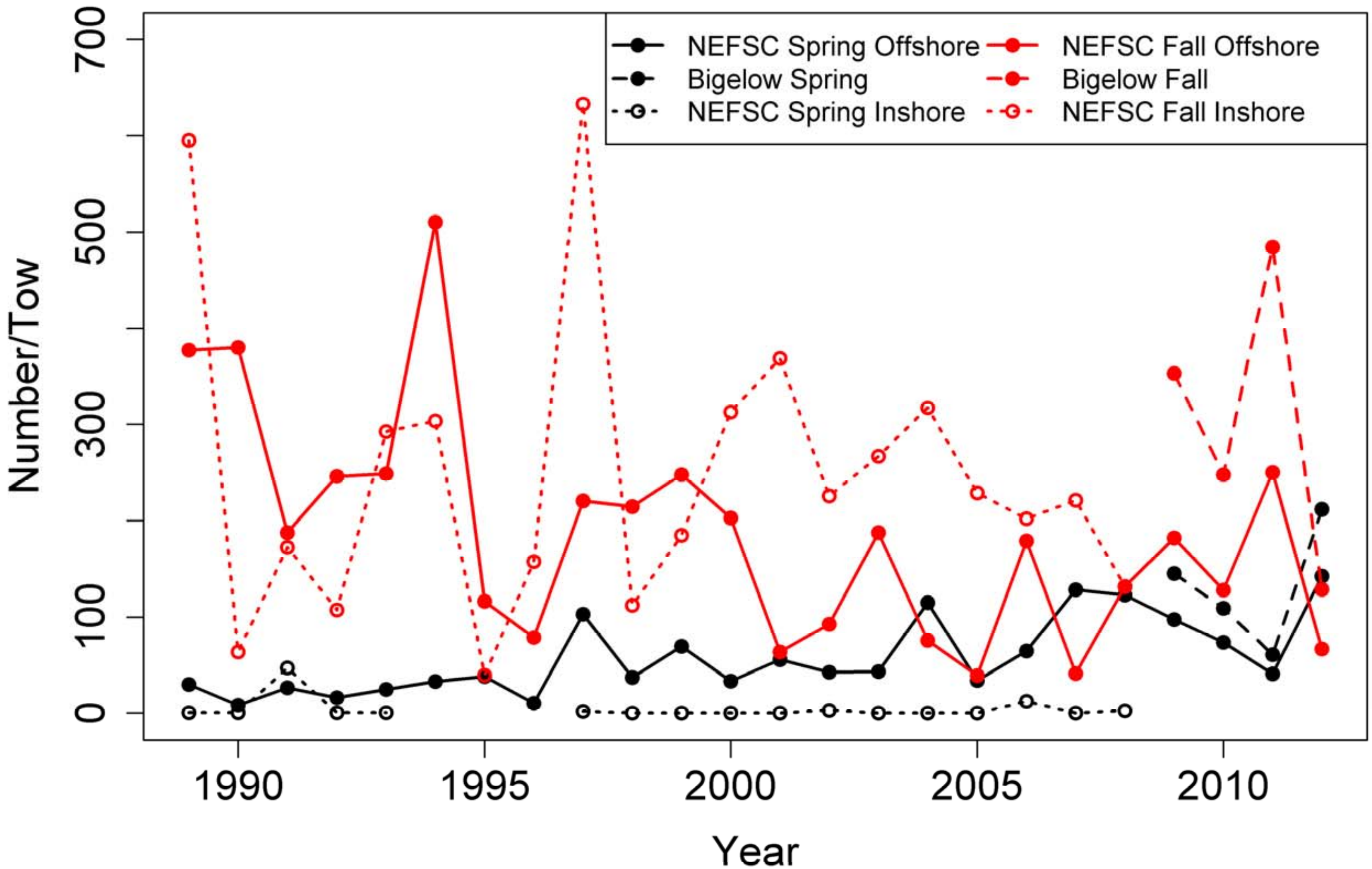

Figure A2.7. NEFSC spring offshore, spring inshore, fall offshore and fall inshore survey stratified mean number per tow for butterfish. Un-calibrated Bigelow data (2009-2012) are also shown.

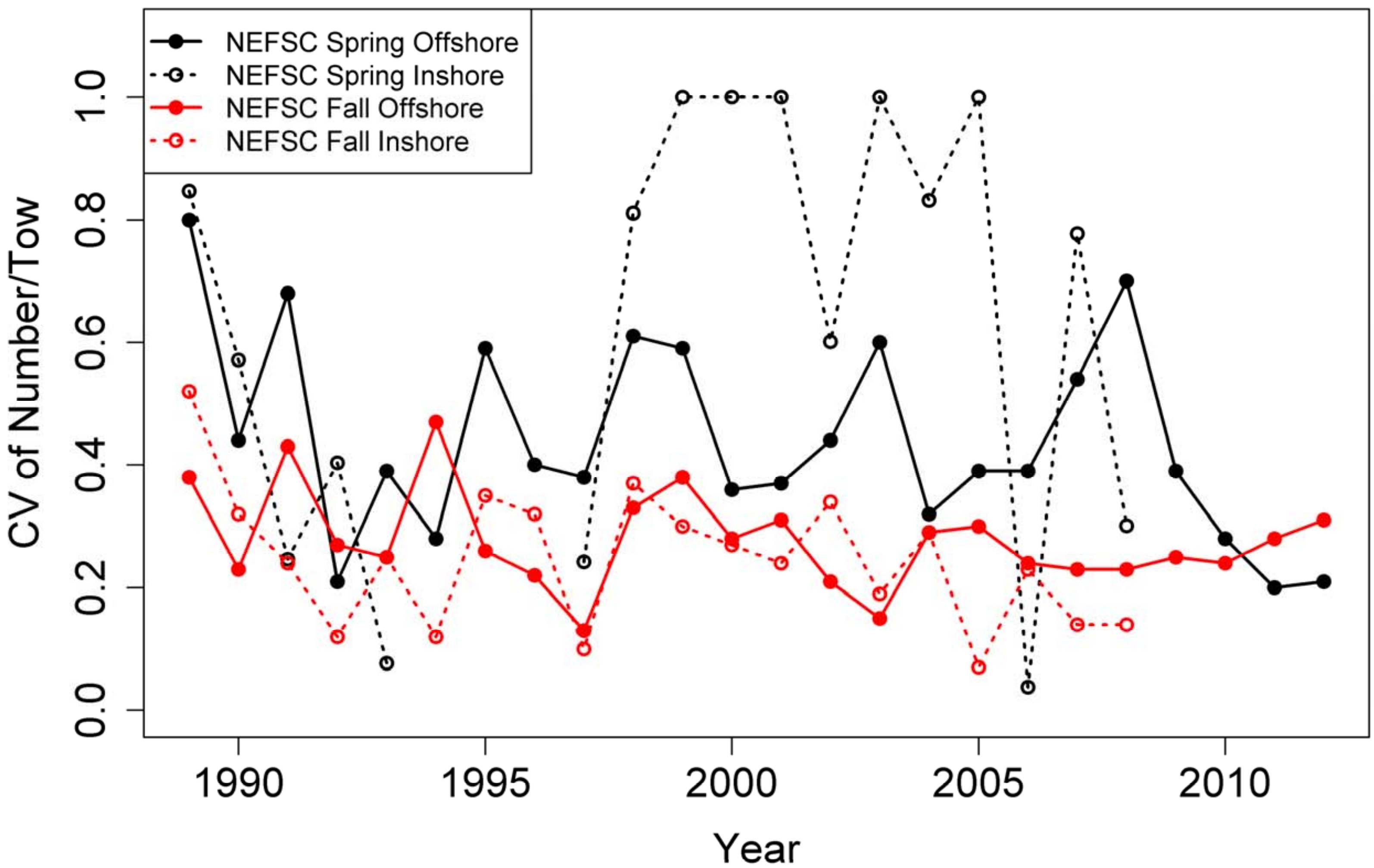

Figure A2.8. Coefficient of variation (CV) for NEFSC spring offshore, spring inshore, fall offshore and fall inshore survey stratified mean number per tow for butterfish.

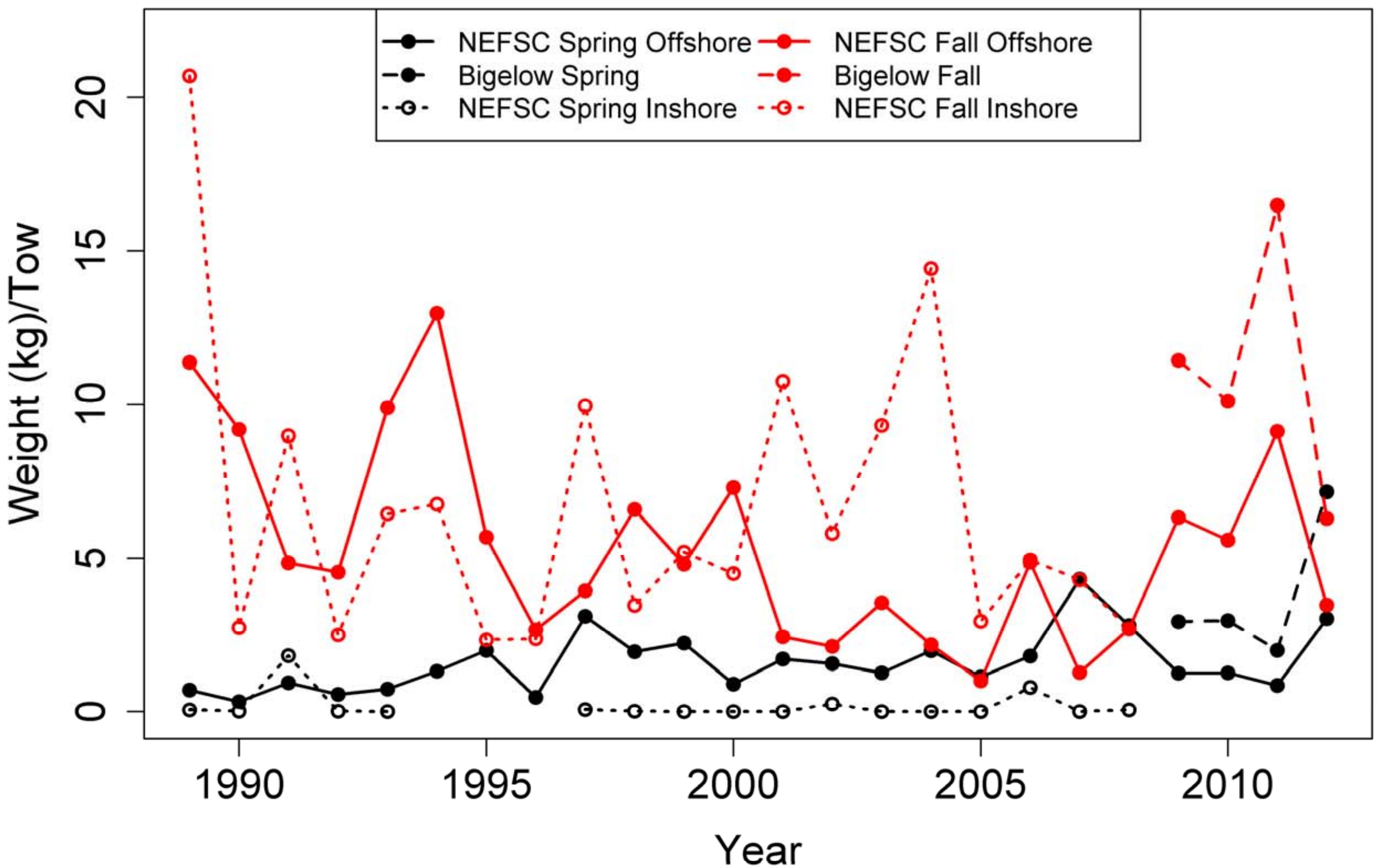

Figure A2.9. NEFSC spring offshore, spring inshore, fall offshore and fall inshore survey stratified mean weight per tow for butterfish. Un-calibrated Bigelow data (2009-2012) are also shown.

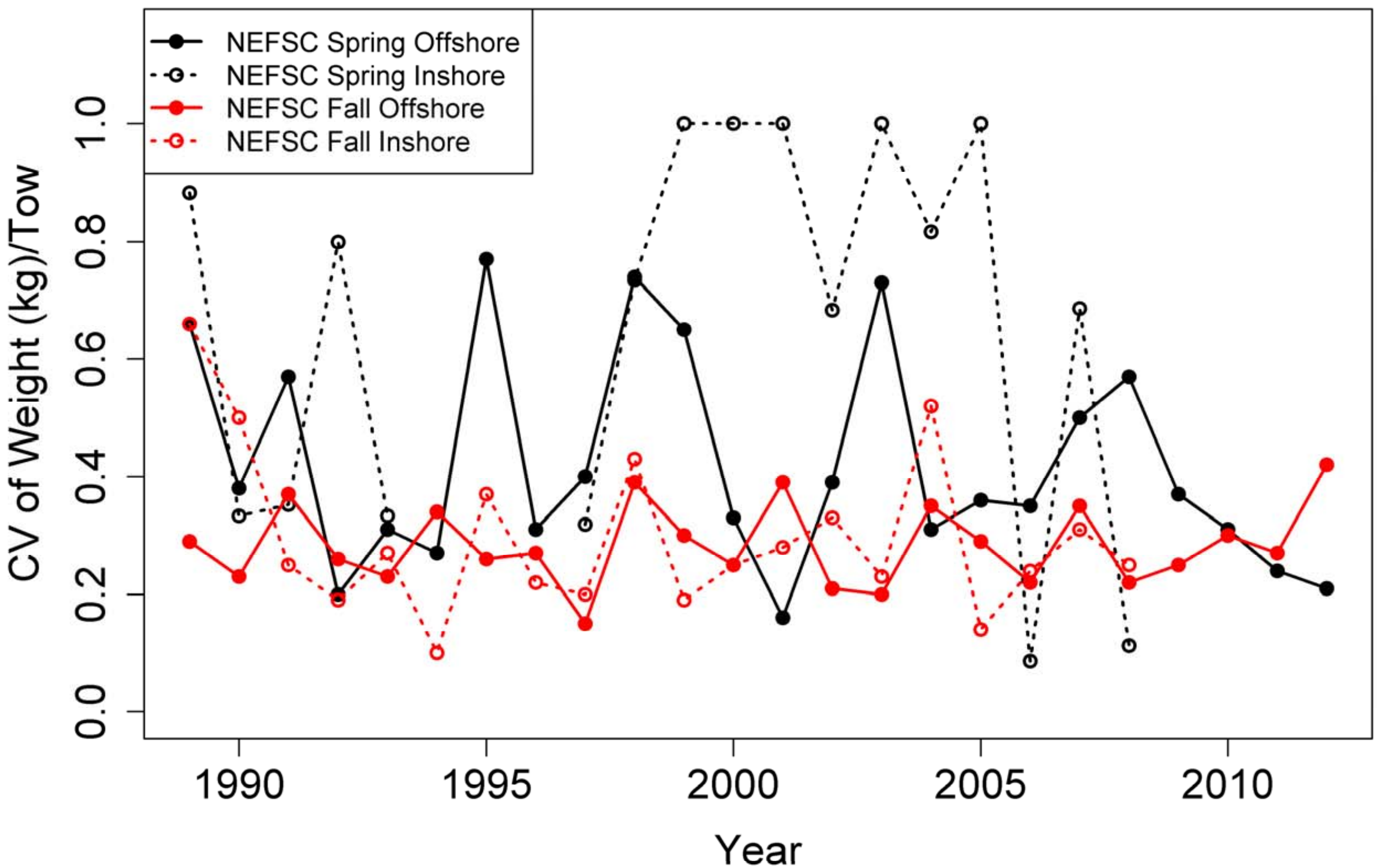

Figure A2.10. Coefficient of variation (CV) for NEFSC spring offshore, spring inshore, fall offshore and fall inshore survey stratified mean weight per tow for butterfish.

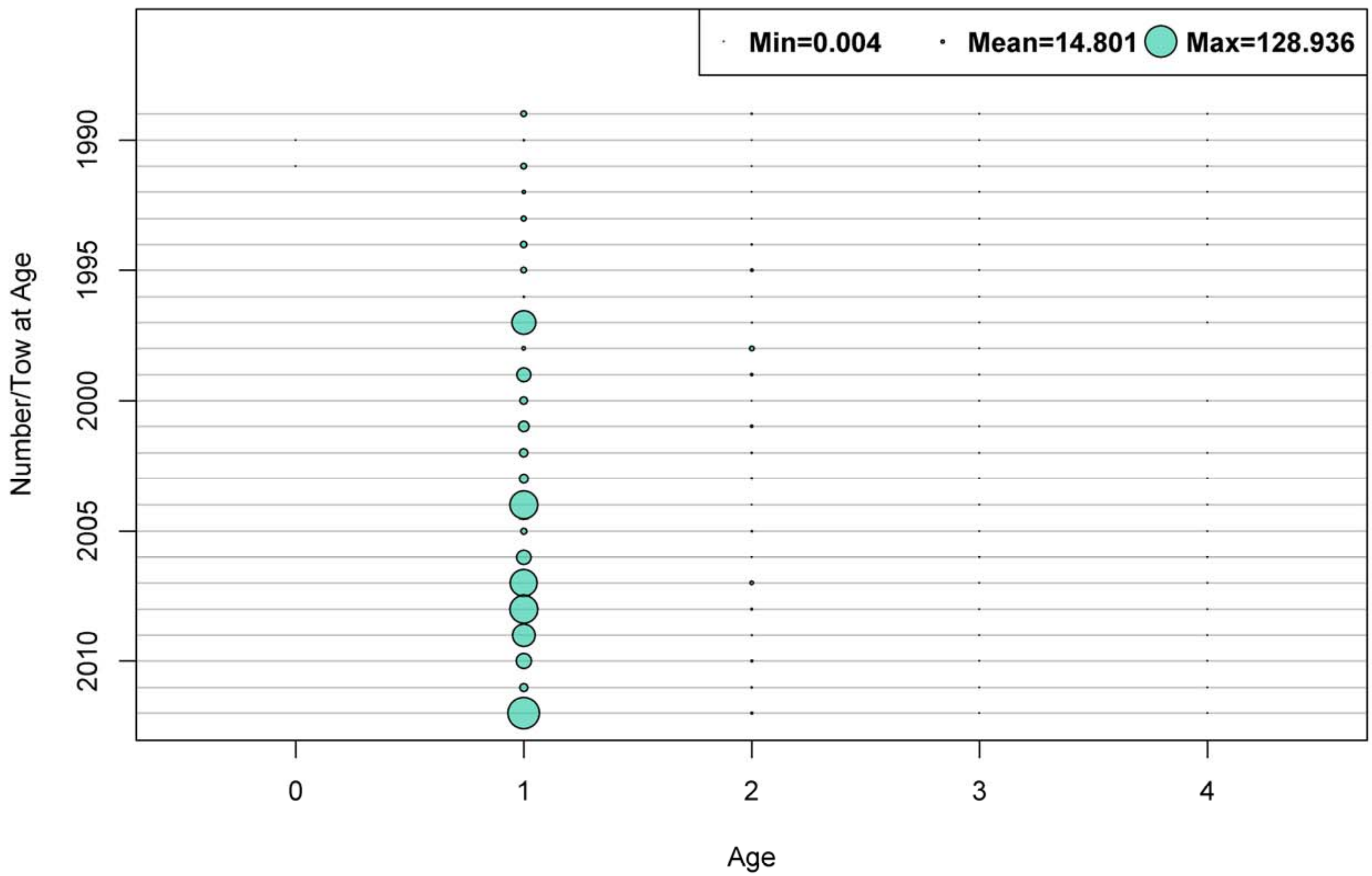

Figure A2.11. Age composition of butterfish in NEFSC spring offshore surveys, 1989-2012.

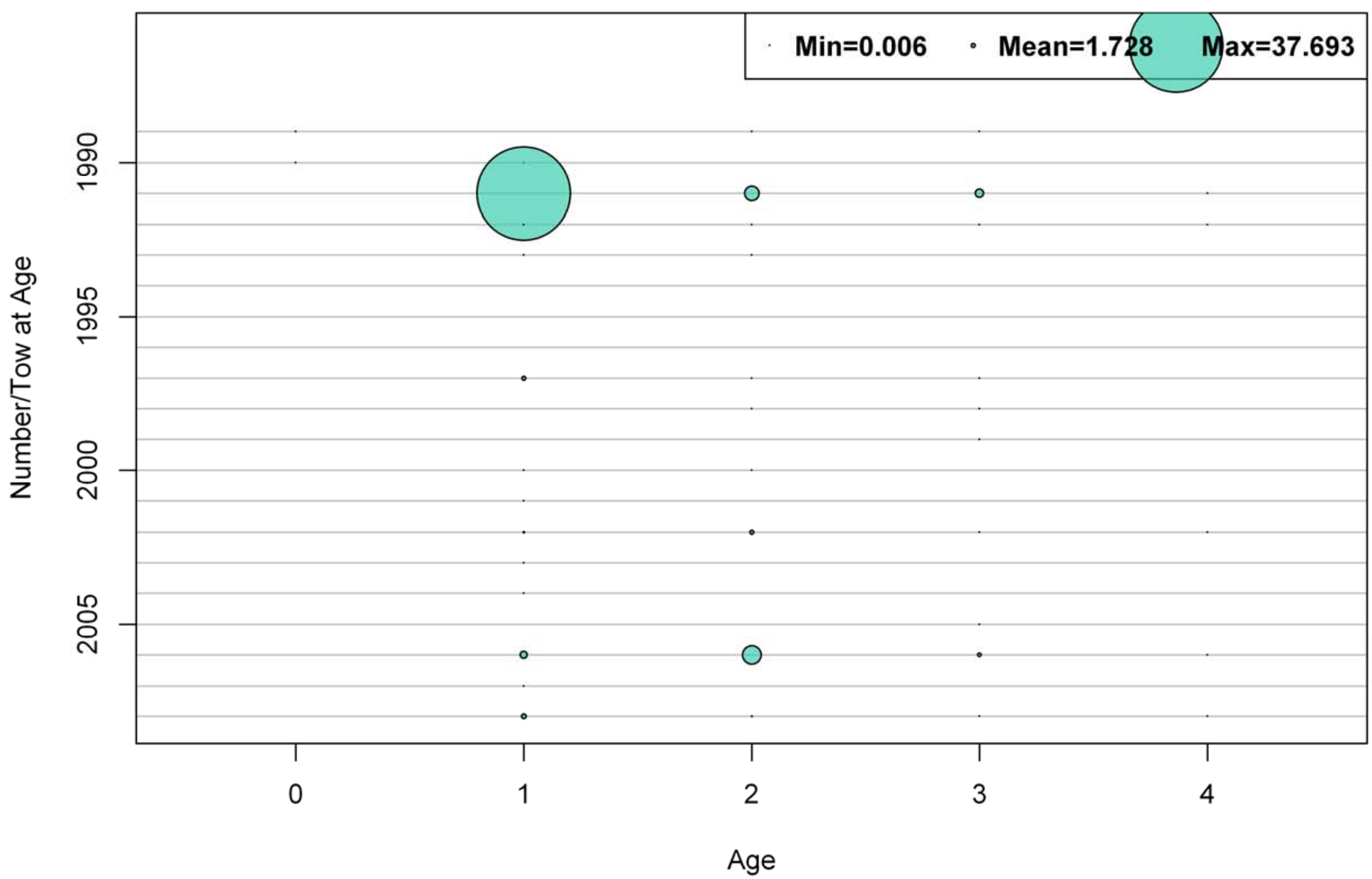

Figure A2.12. Age composition of butterfish in NEFSC spring inshore surveys, 1989-2008. Note: this graph has been re-scaled to the maximum value, which differs from other bubble plots.

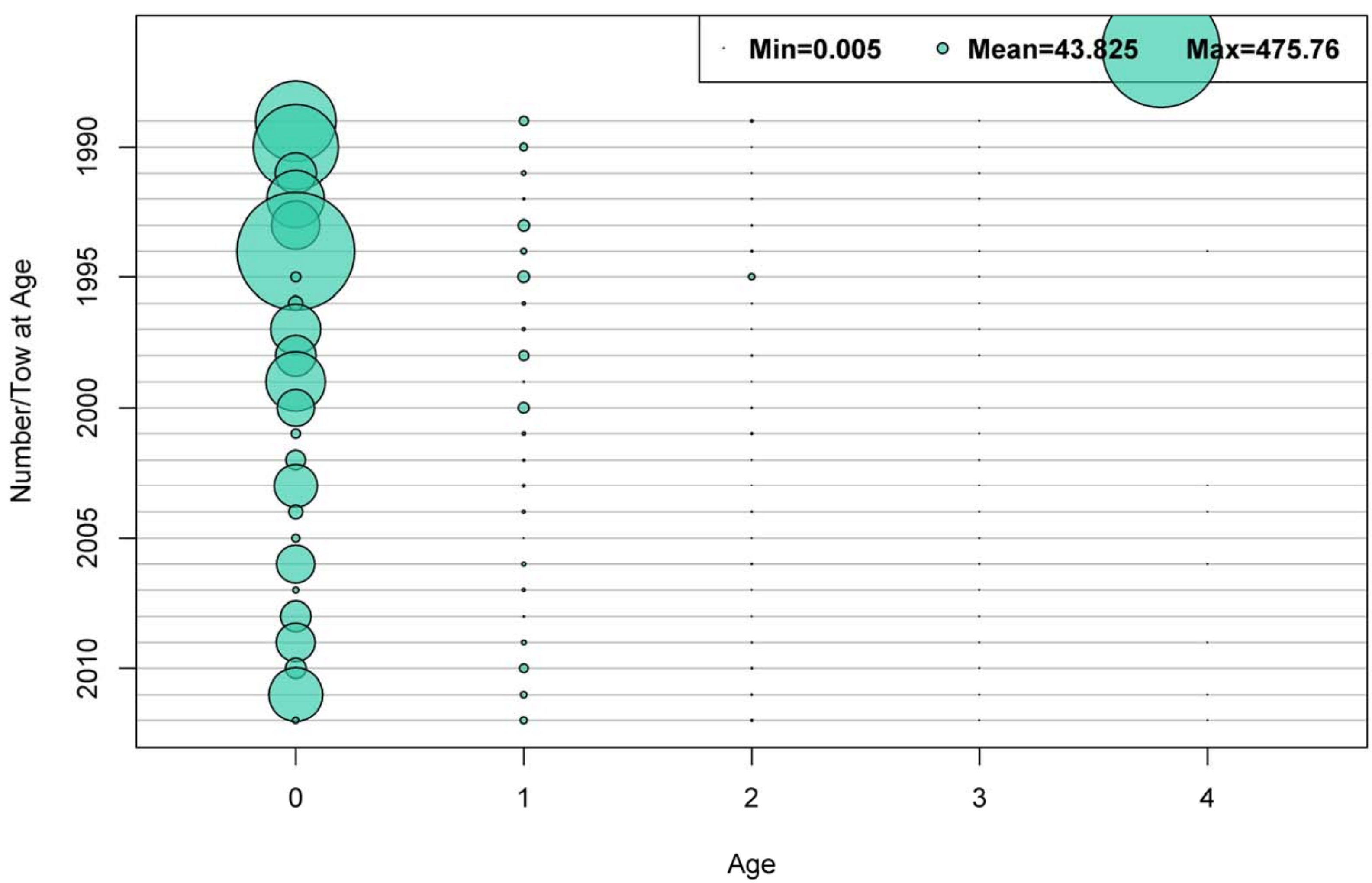

Figure A2.13. Age composition of butterfish in NEFSC fall offshore surveys, 1989-2012.

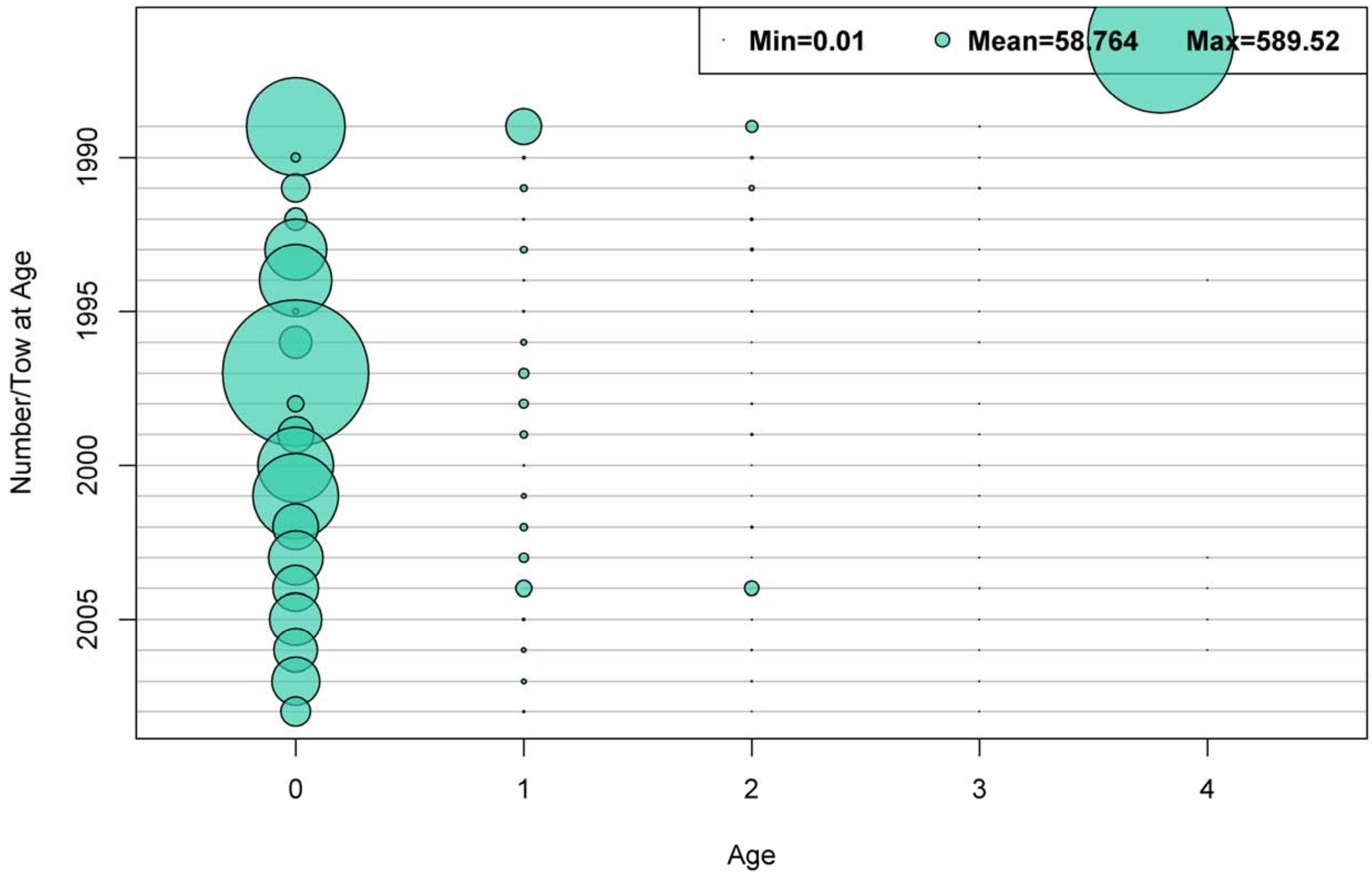

Figure A2.14. Age composition of butterfish in NEFSC fall inshore surveys, 1989-2008.

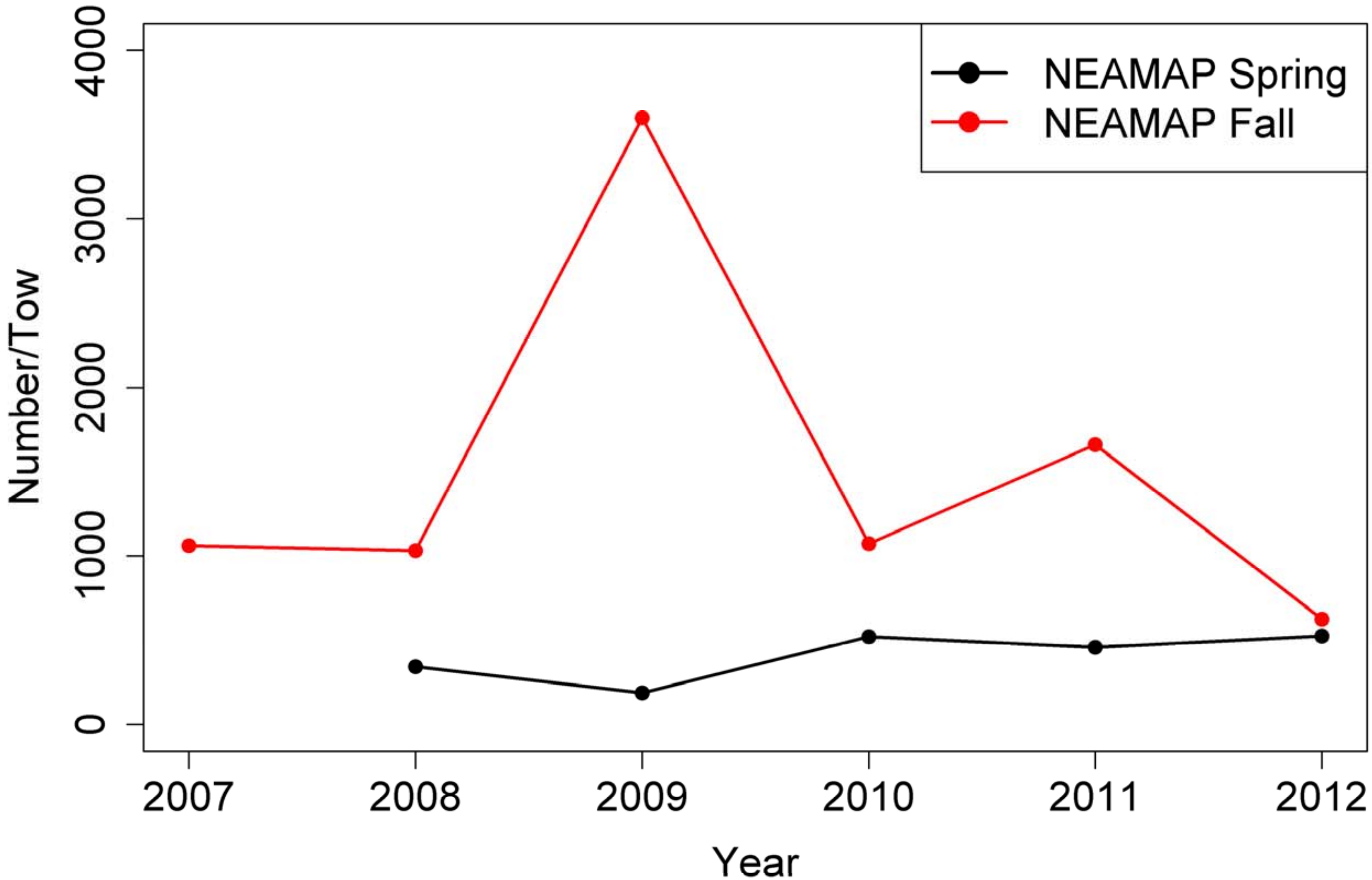

Figure A2.15. NEAMAP spring and fall survey arithmetic mean number per tow for butterfish.

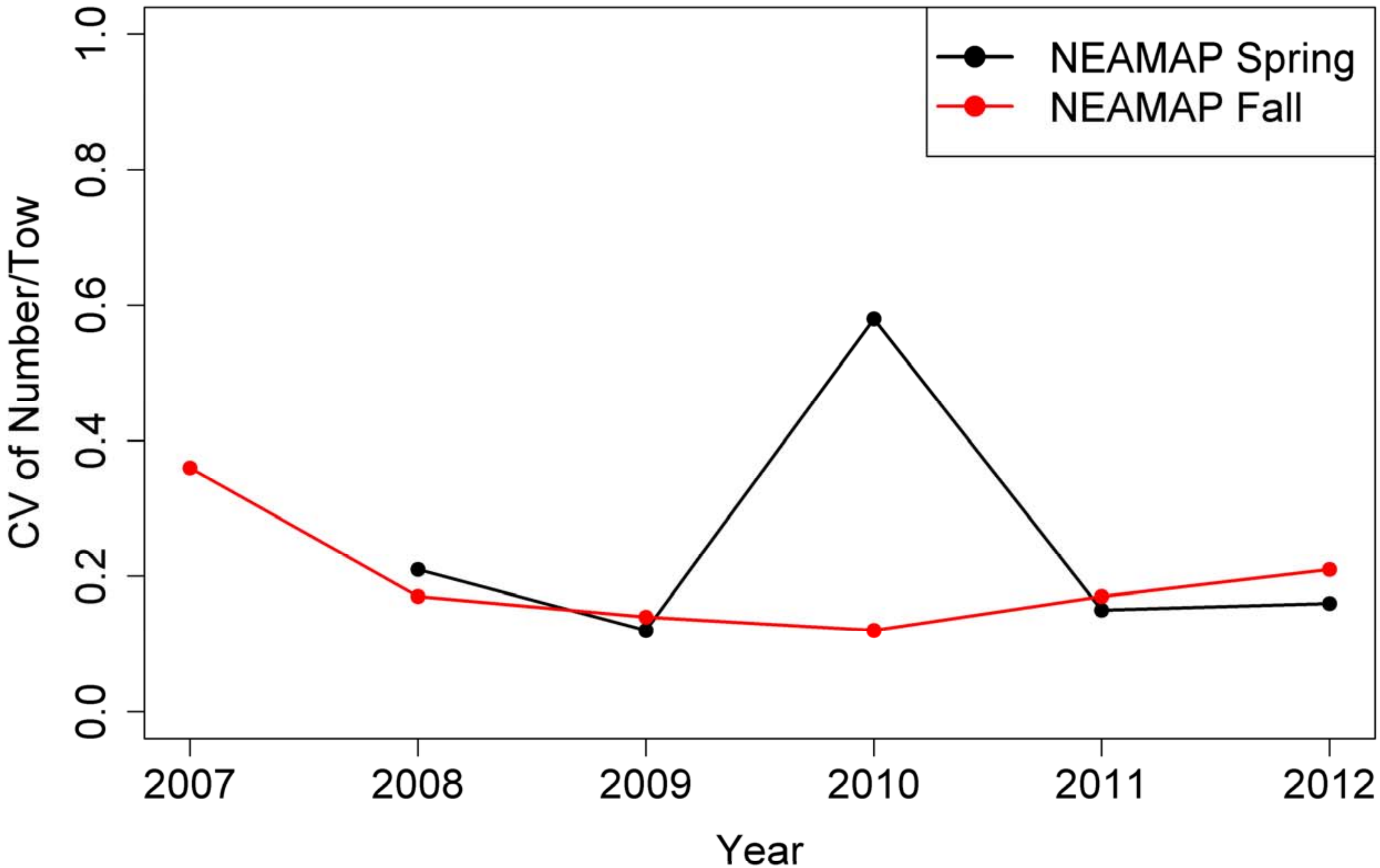

Figure A2.16. Coefficient of variation (CV) for NEAMAP spring and fall survey stratified mean number per tow for butterfish.

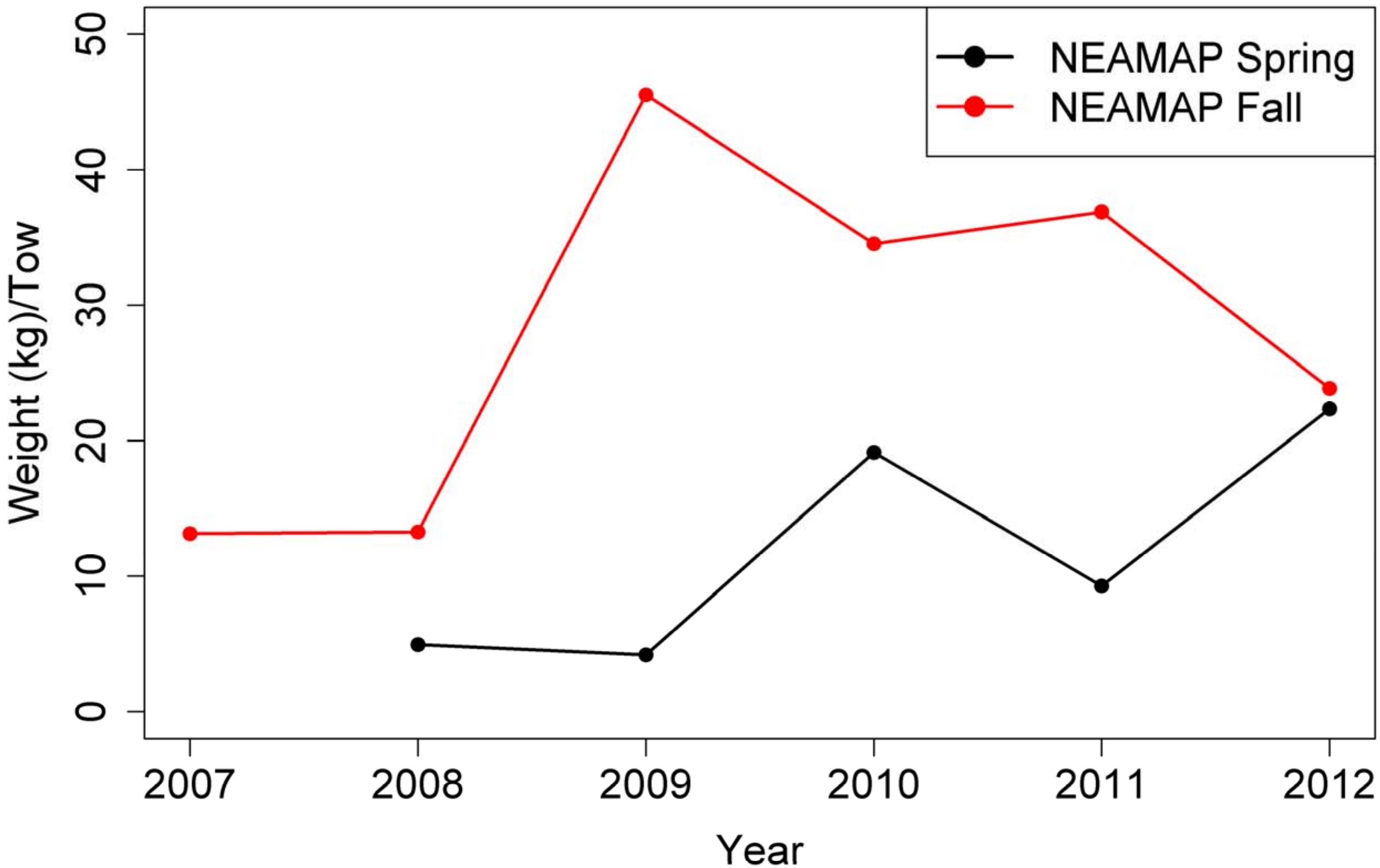

Figure A2.17. NEAMAP spring and fall survey arithmetic mean weight per tow for butterfish.

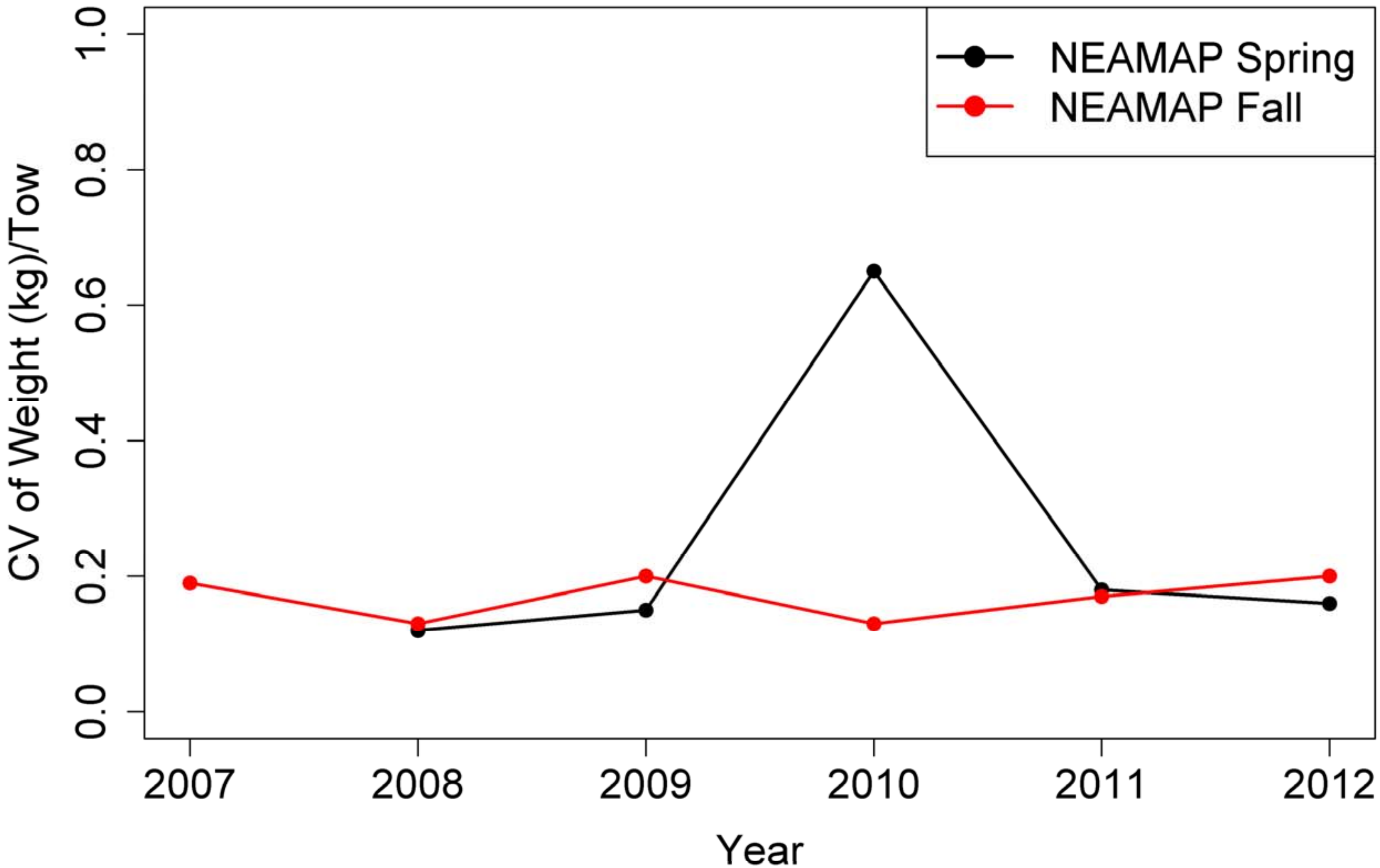

Figure A2.18. Coefficient of variation (CV) for NEAMAP spring and fall survey stratified mean weight per tow for butterfish.

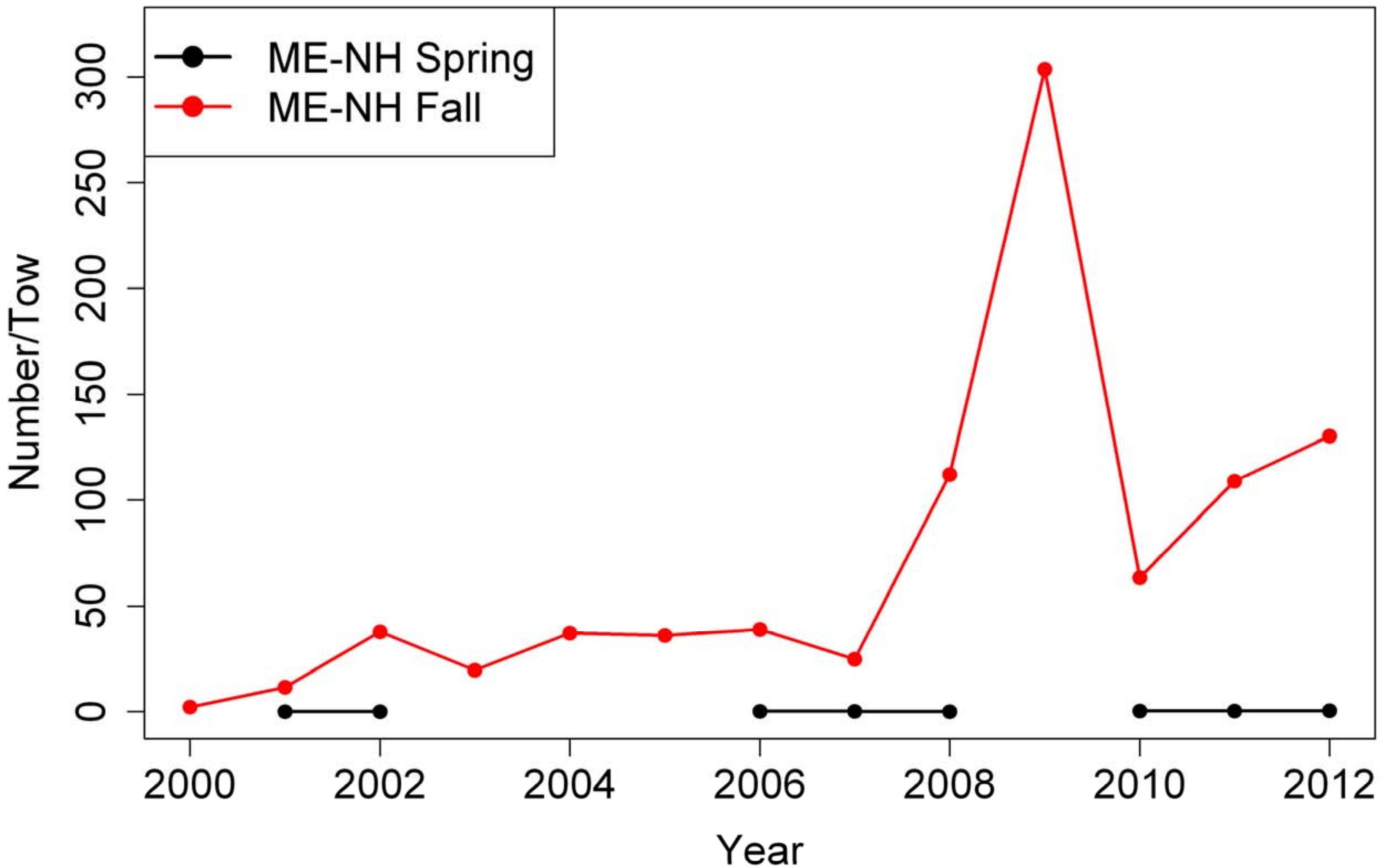

Figure A2.19. Maine-New Hampshire spring and fall survey mean number per tow for butterfish.

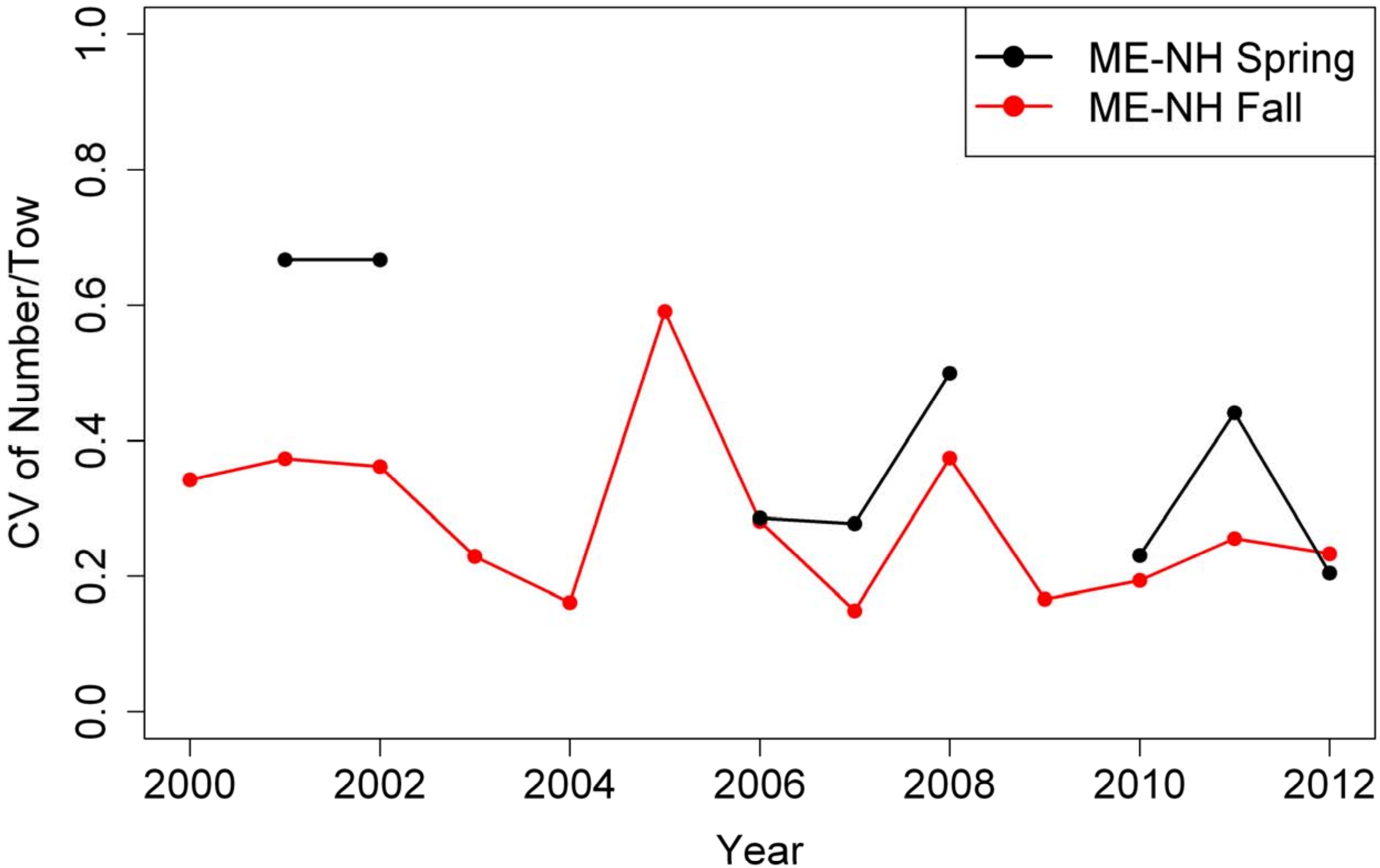

Figure A2.20. Coefficient of variation (CV) for Maine-New Hampshire spring and fall survey mean number per tow for butterfish.

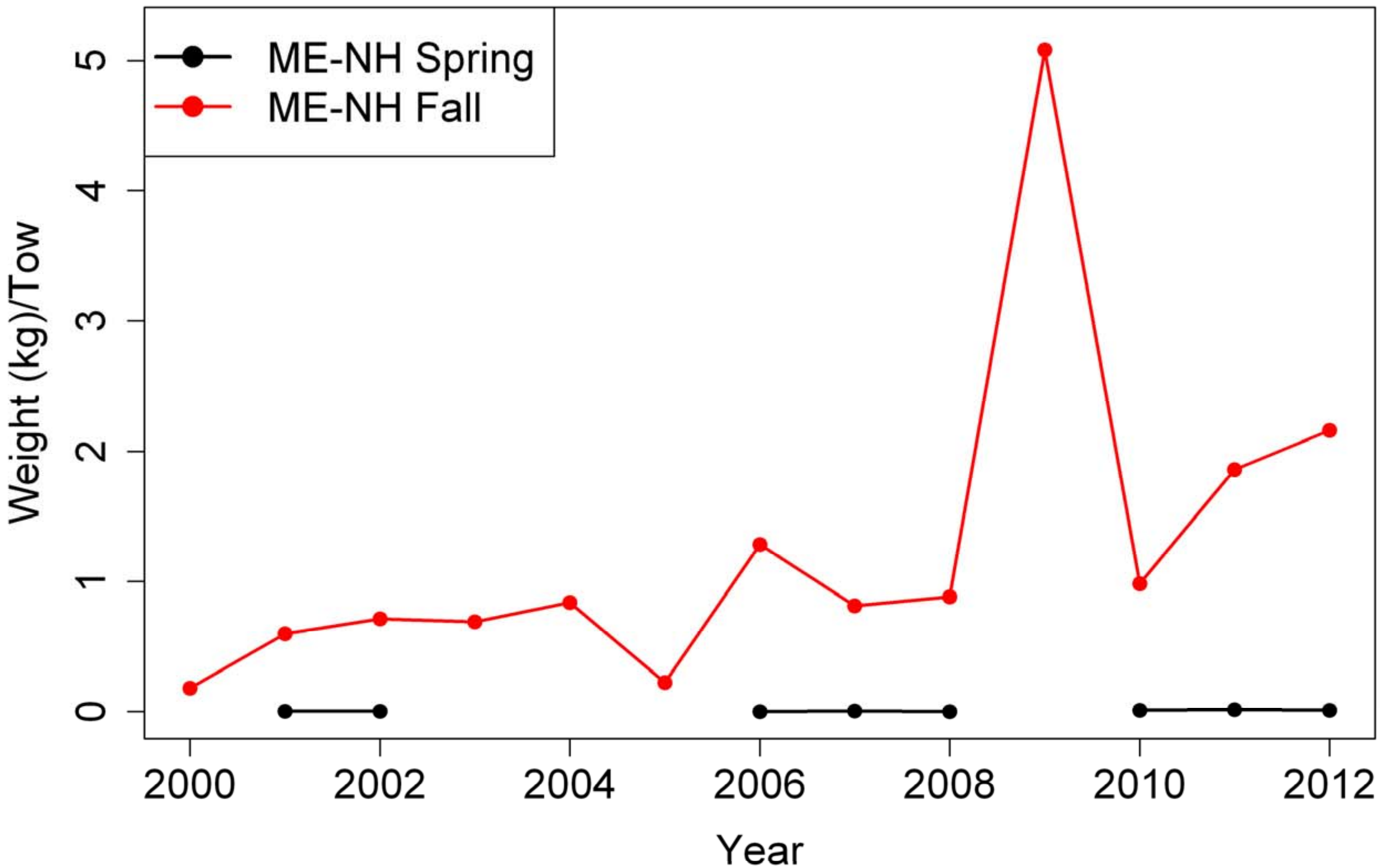

Figure A2.21. Maine-New Hampshire spring and fall survey mean weight per tow for butterfish.

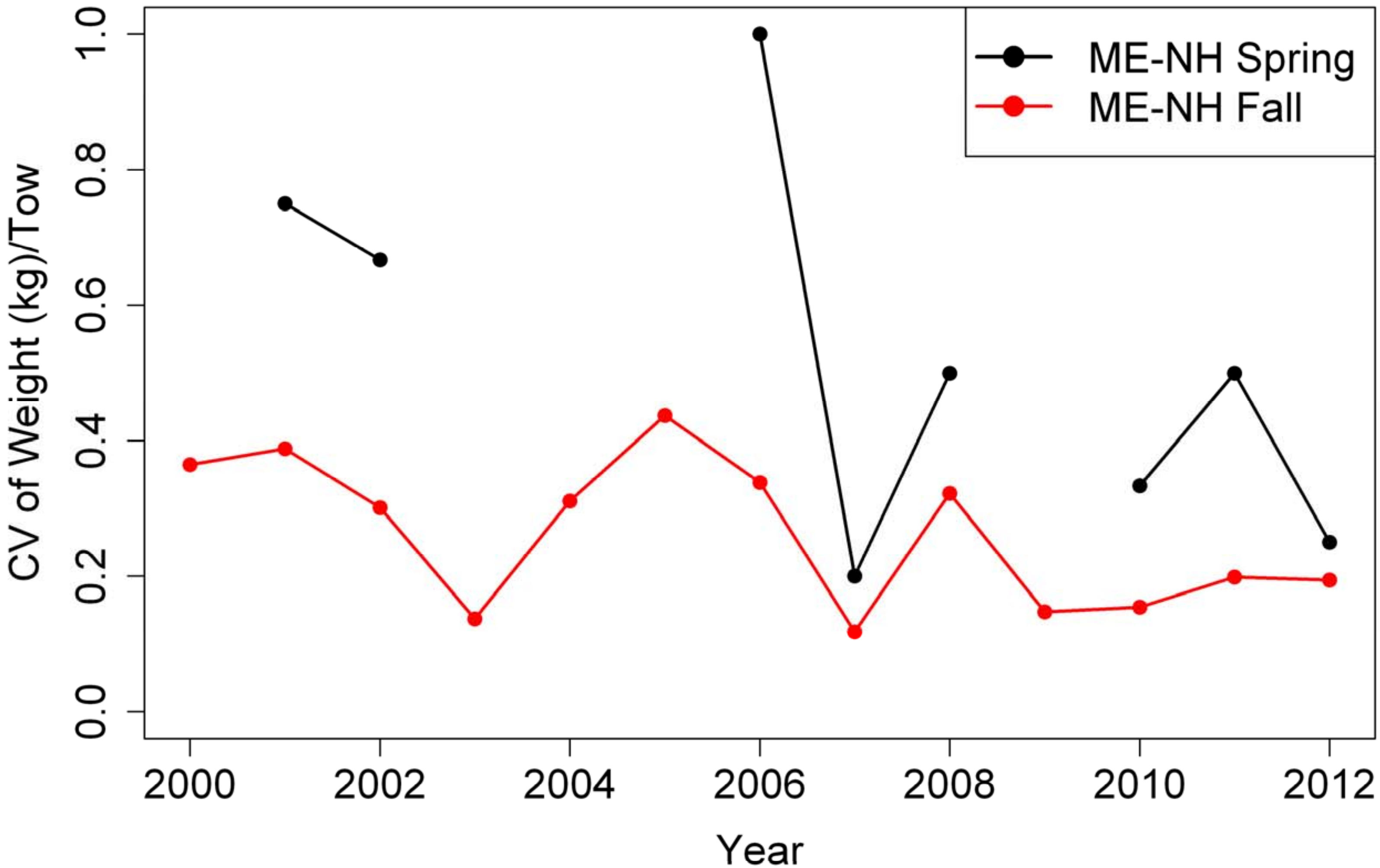

Figure A2.22. Coefficient of variation (CV) for Maine-New Hampshire spring and fall survey mean weight per tow for butterfish.

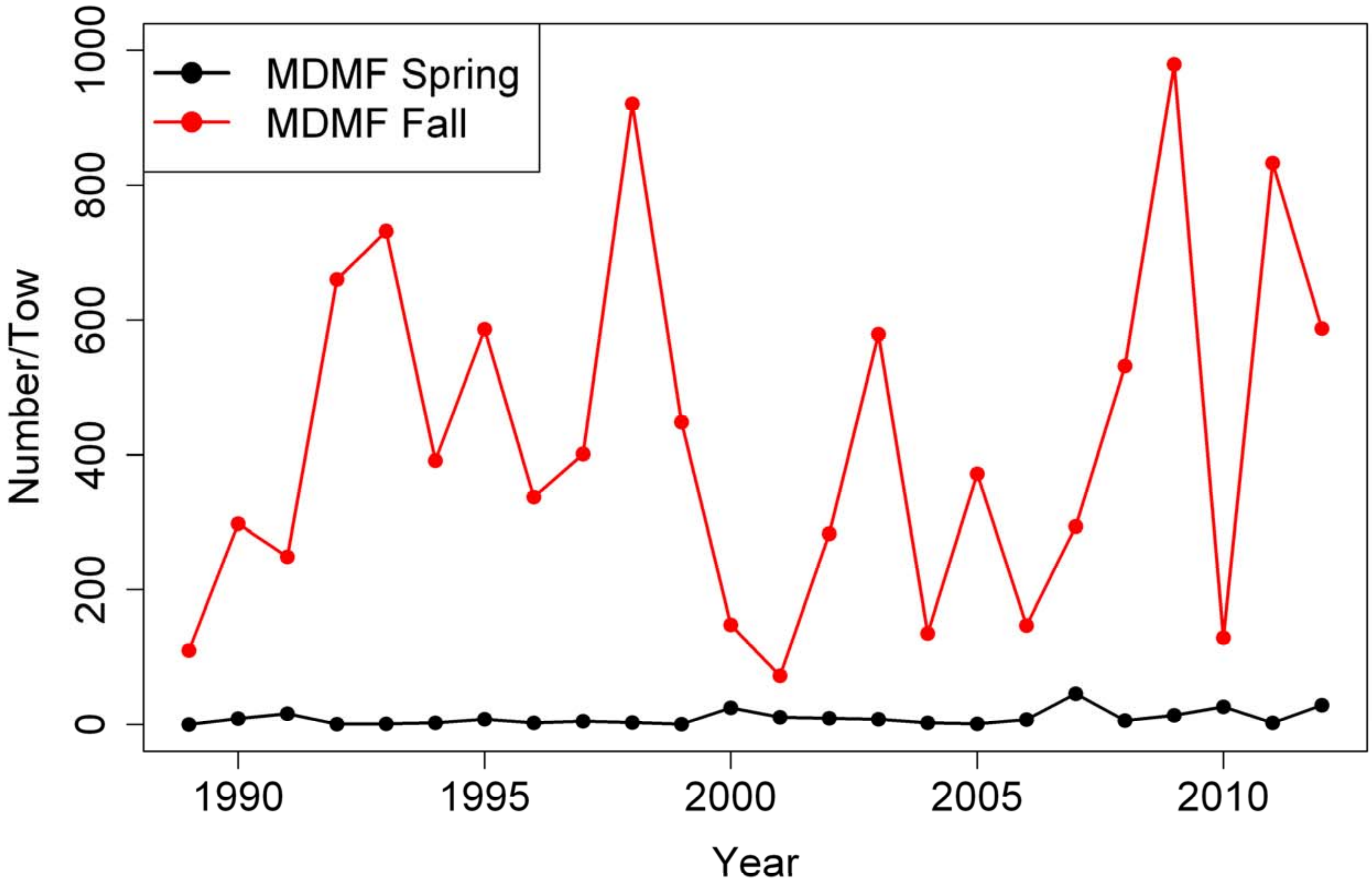

Figure A2.23. MDMF spring and fall survey mean number per tow for butterfish.

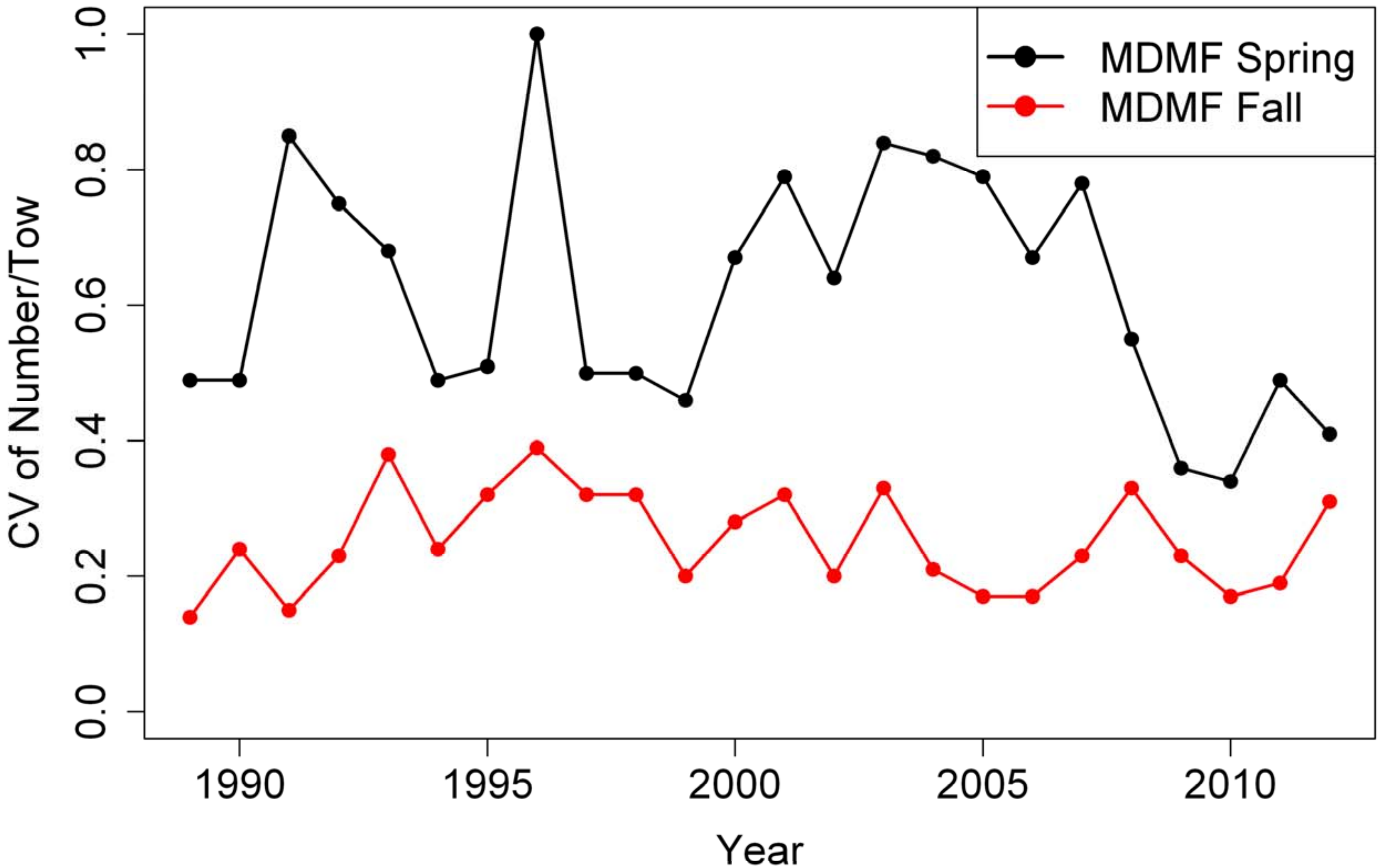

Figure A2.24. Coefficient of variation (CV) for MDMF spring and fall survey mean number per tow for butterfish.

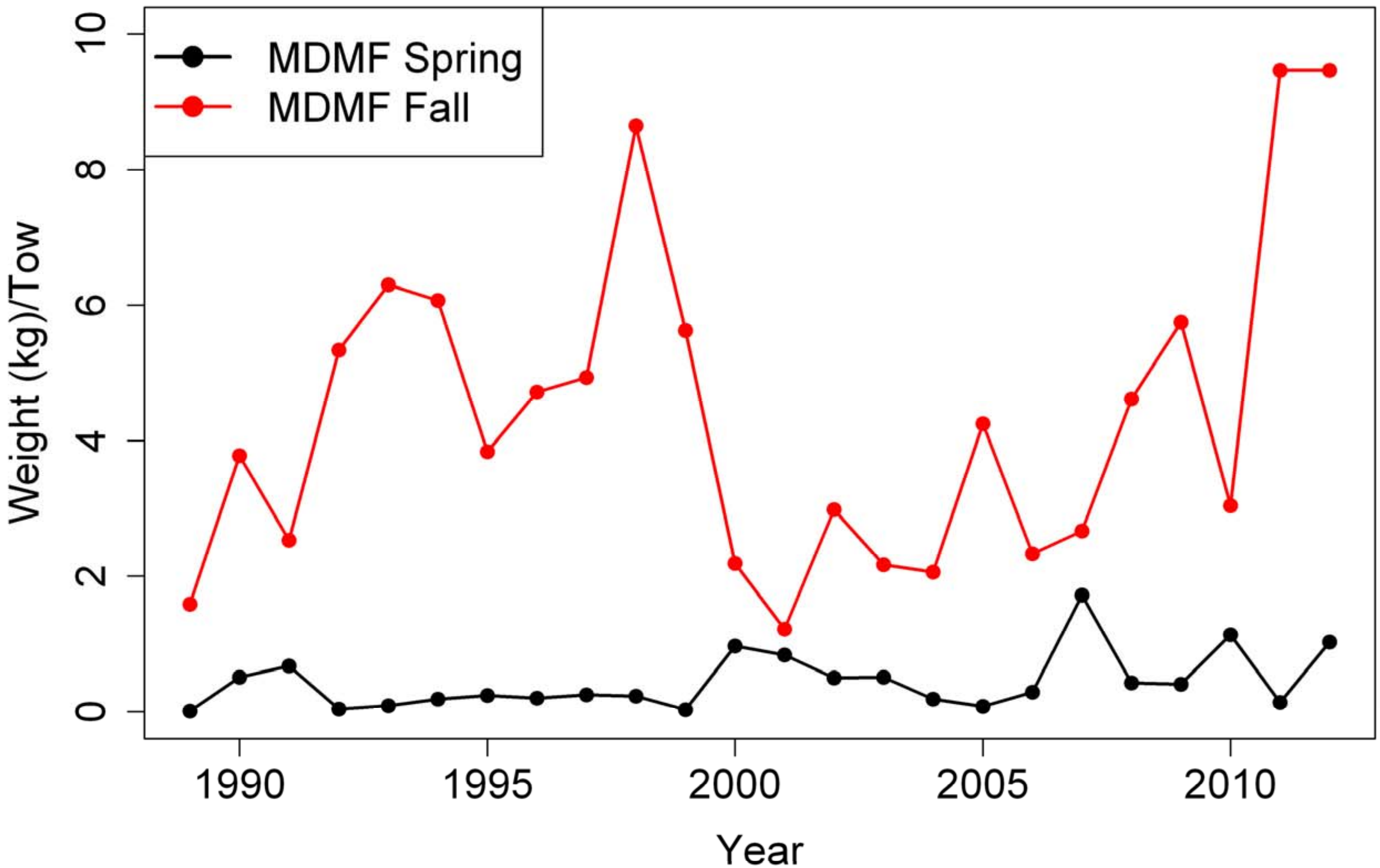

Figure A2.25 MDMF spring and fall survey mean weight per tow for butterfish.

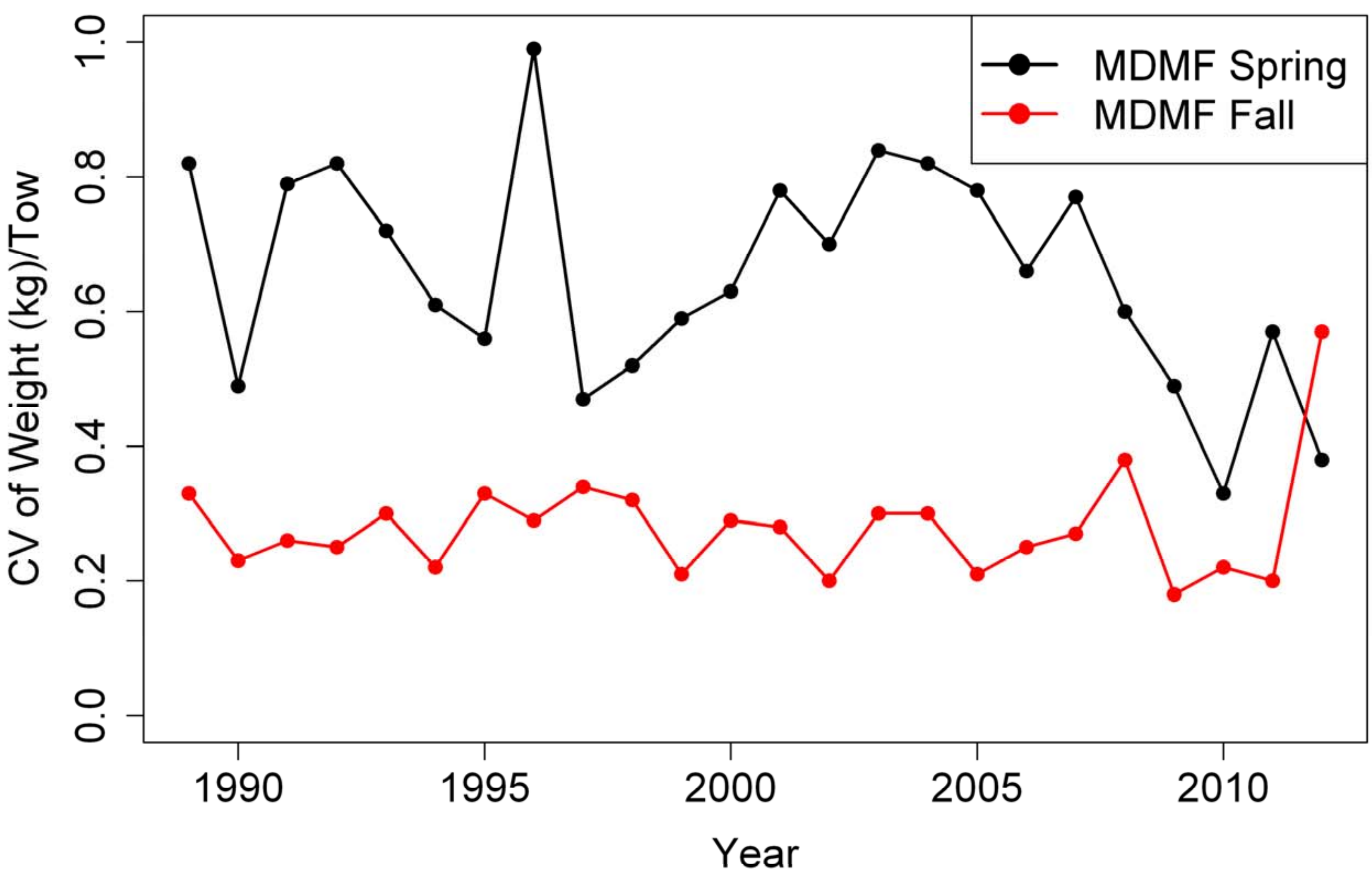

Figure A2.26. Coefficient of variation (CV) for MDMF spring and fall survey mean weight per tow for butterfish.

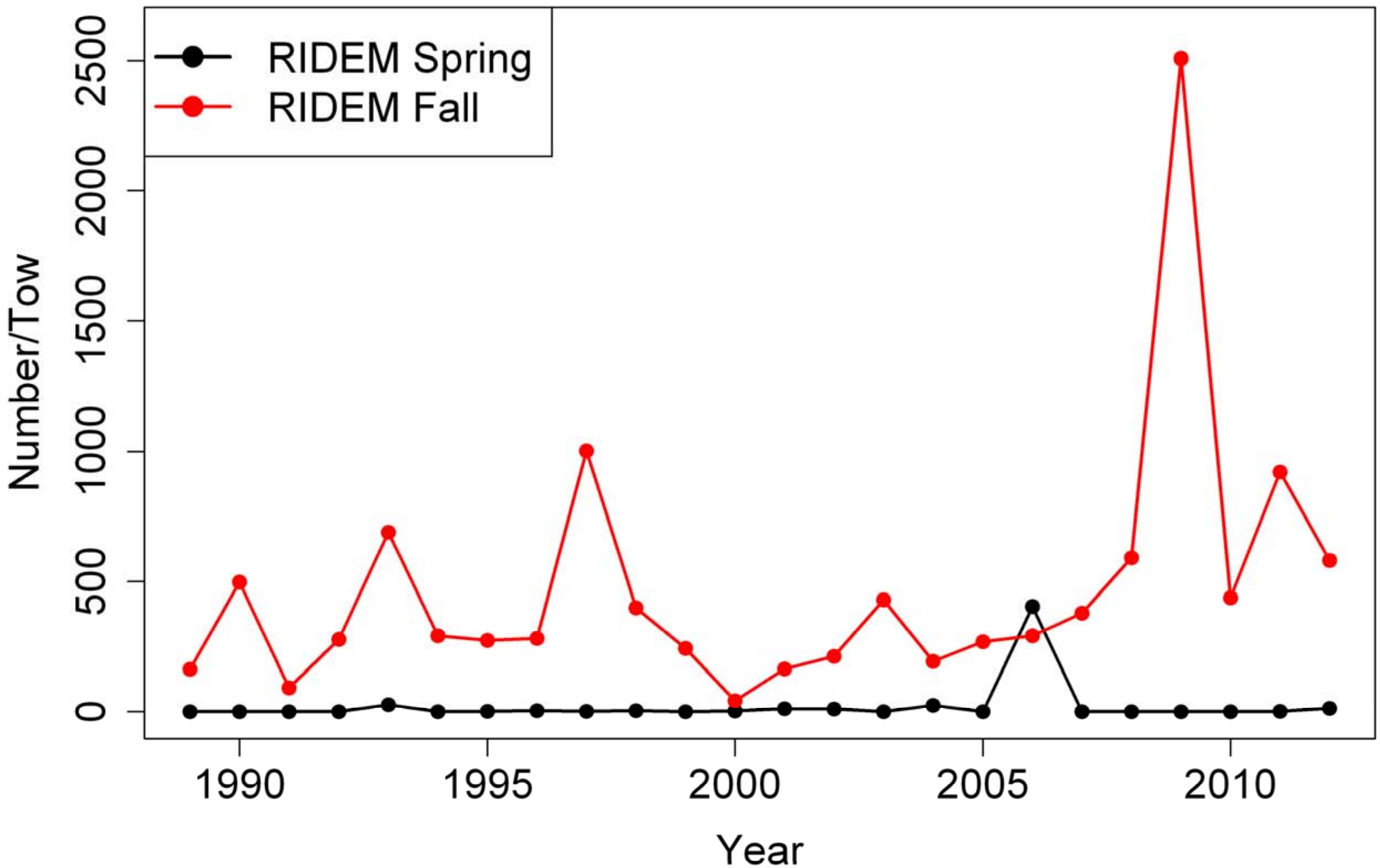

Figure A2.27. RIDEM spring and fall survey mean number per tow for butterfish.

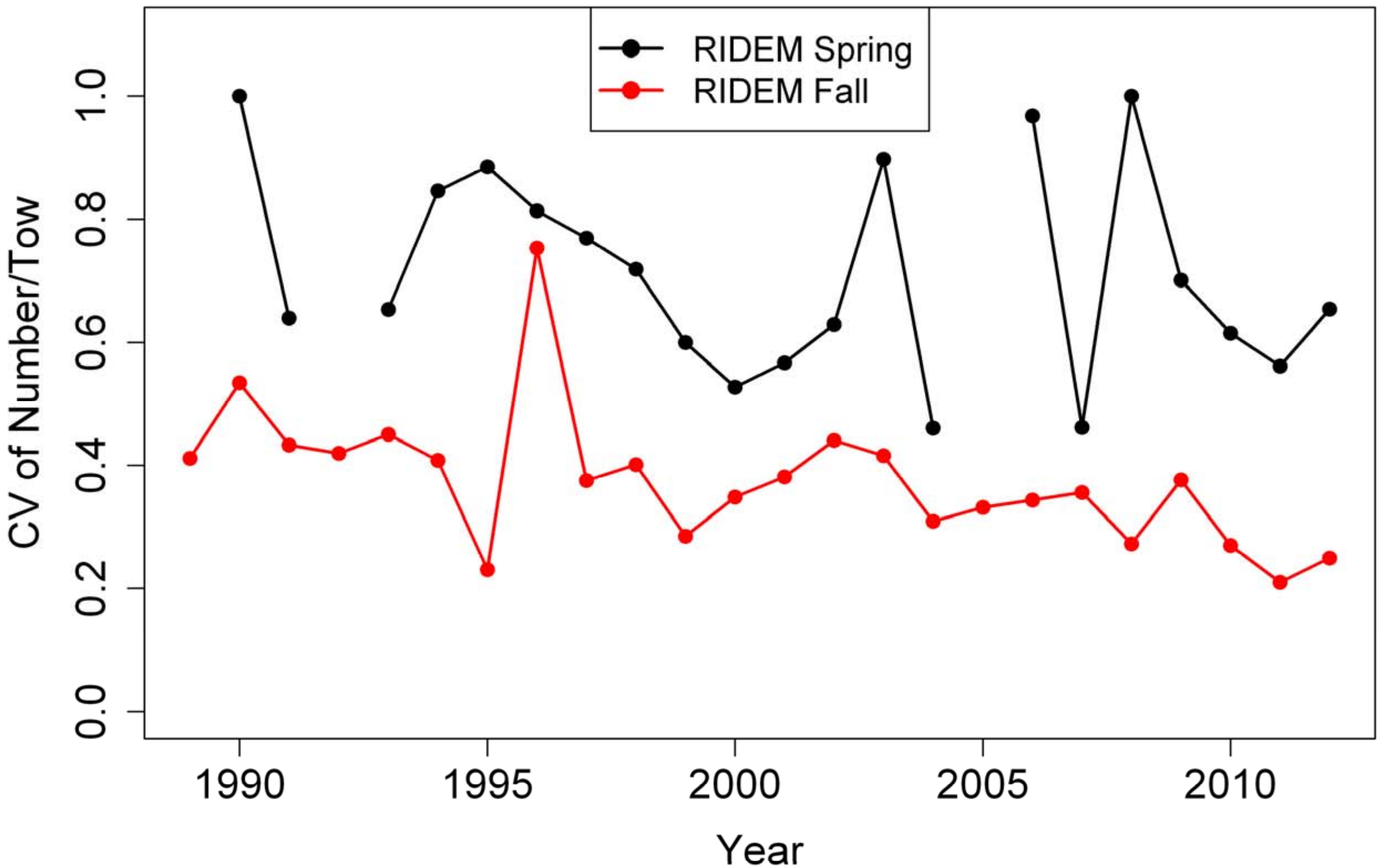

Figure A2.28. Coefficient of variation (CV) for RIDEM spring and fall survey mean number per tow for butterfish.

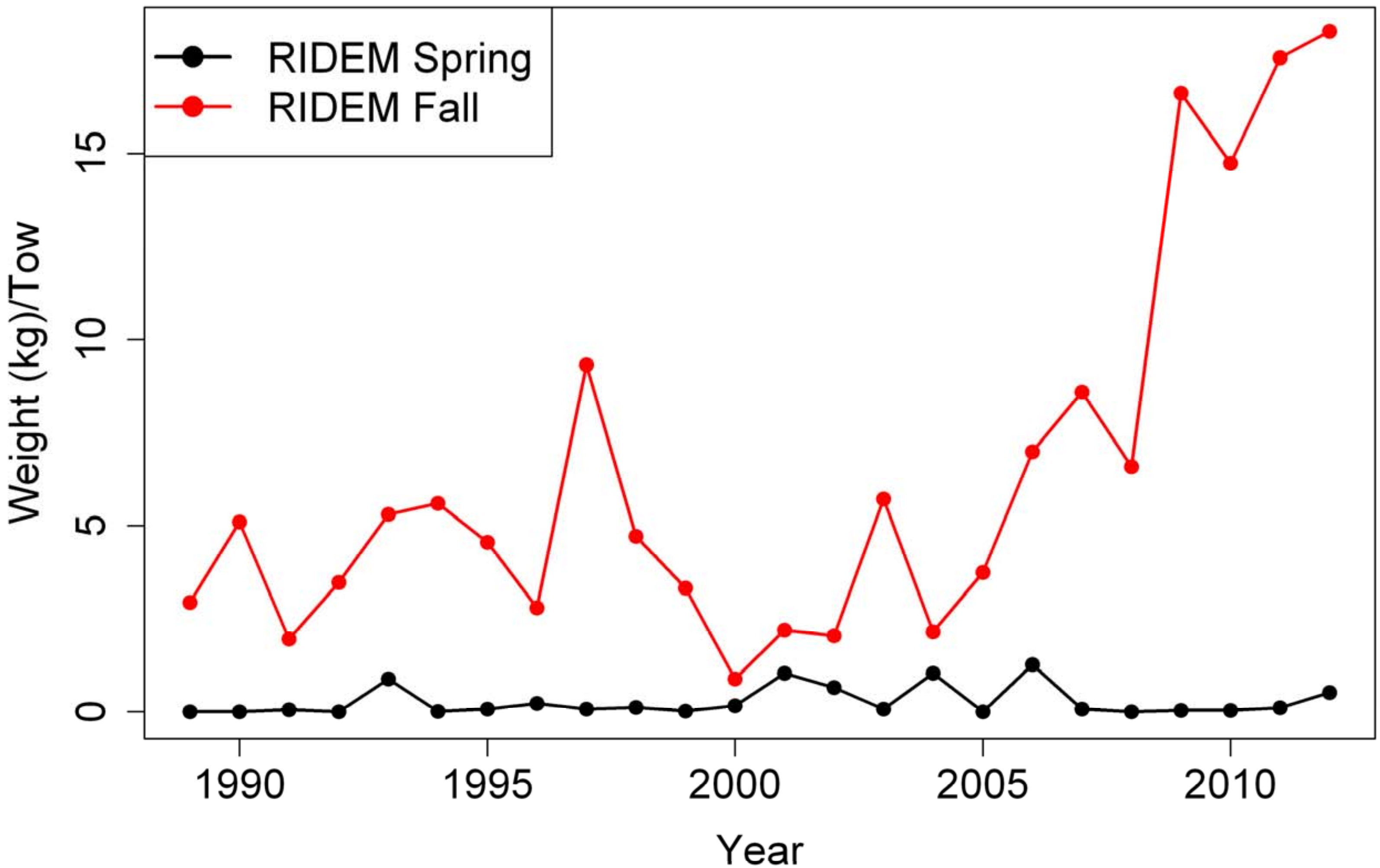

Figure A2.29. RIDEM spring and fall survey mean weight per tow for butterfish.

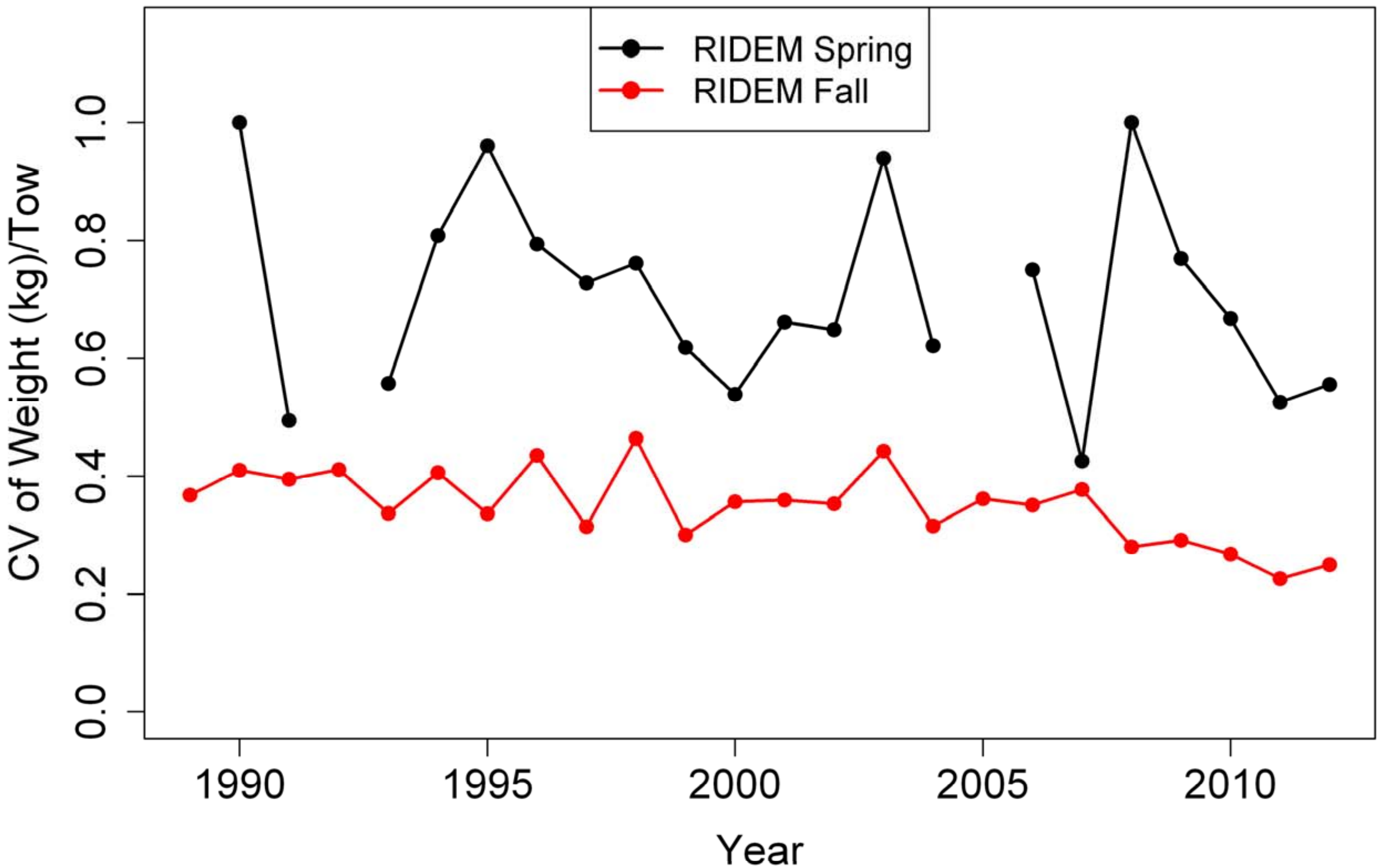

Figure A2.30. Coefficient of variation (CV) for RIDEM spring and fall survey mean weight per tow for butterfish.

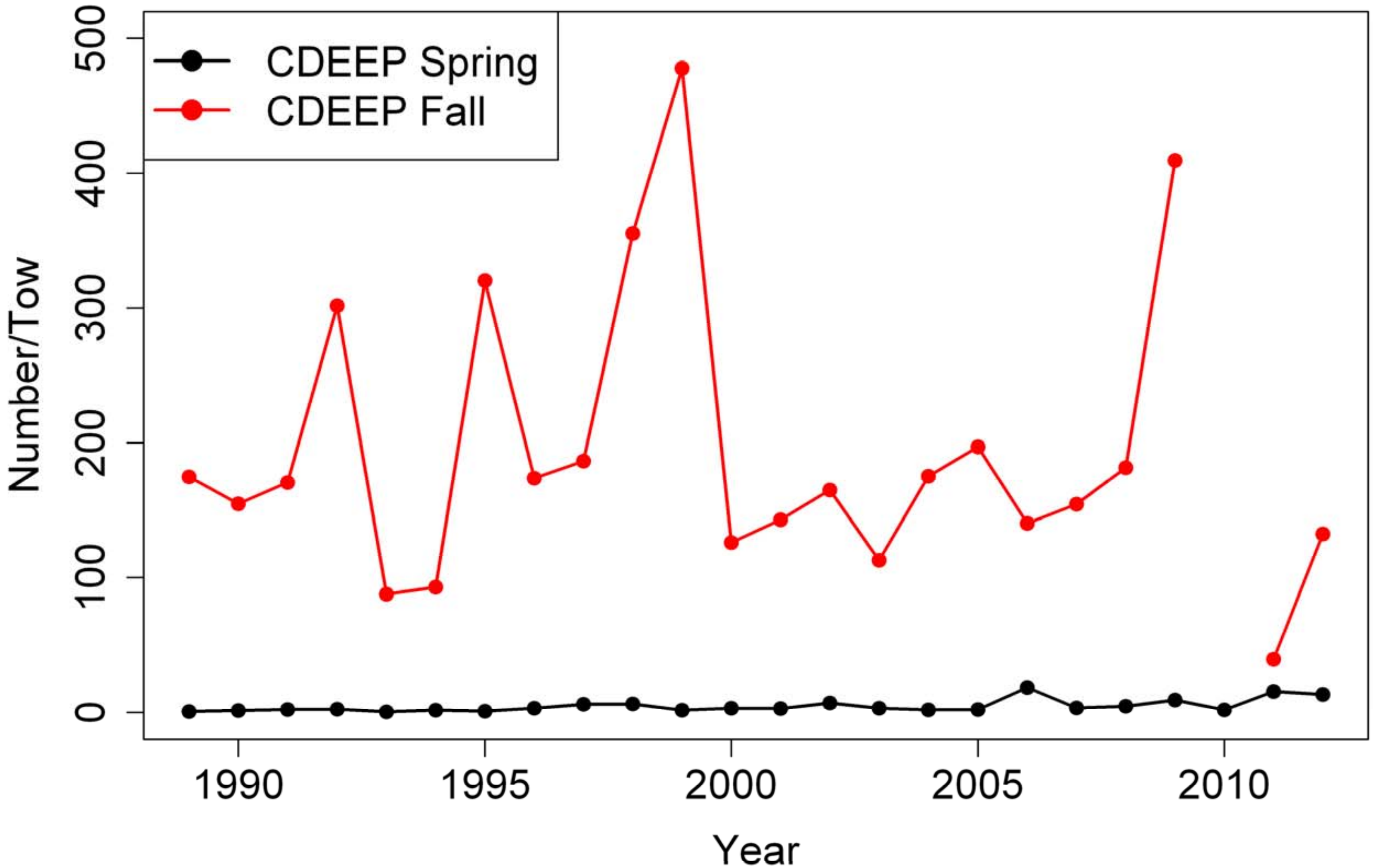

Figure A2.31. CDEEP Long Island Sound spring and fall survey geometric mean number per tow for butterfish.

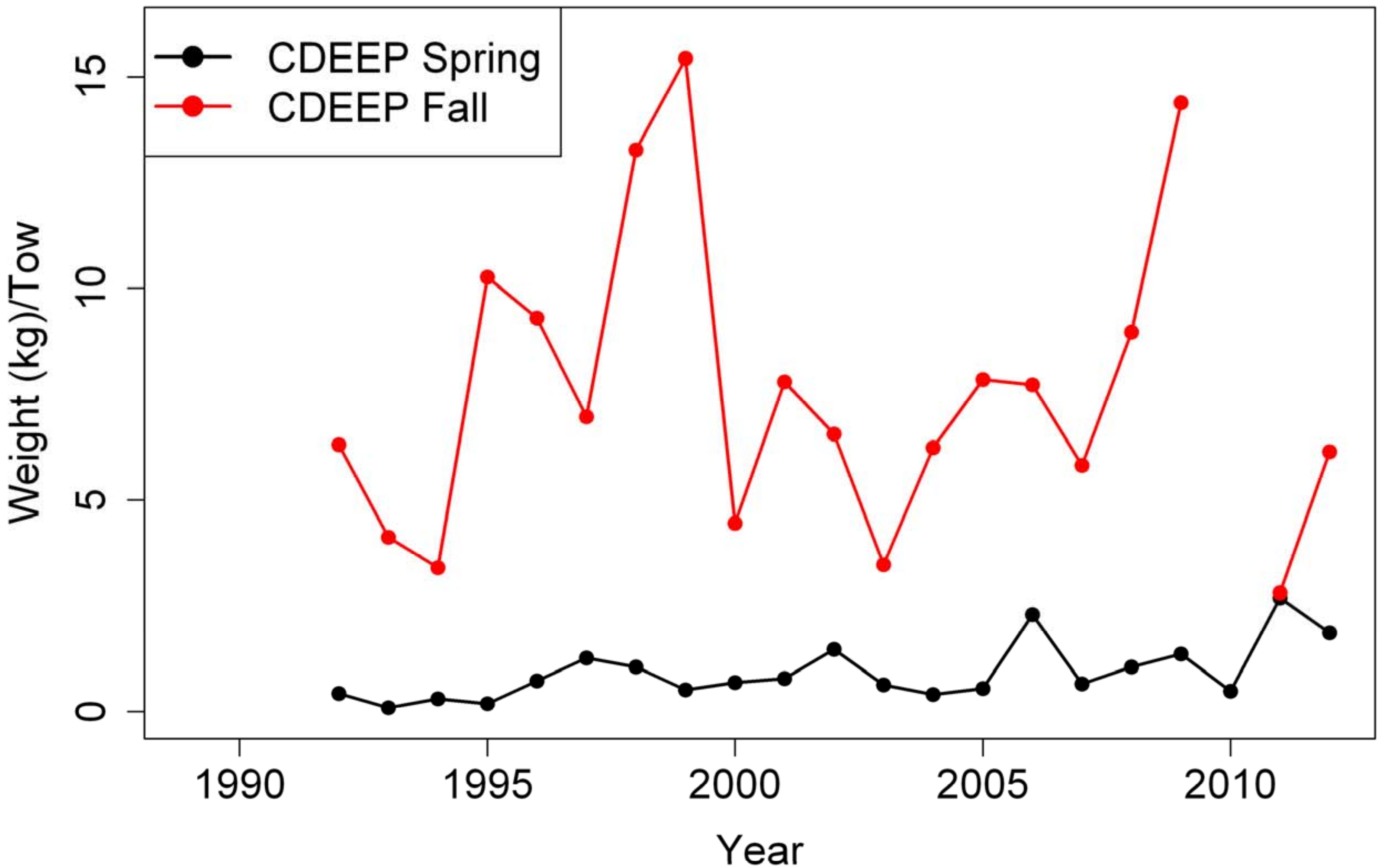

Figure A2.32. CDEEP Long Island Sound spring and fall survey geometric mean weight per tow for butterfish.

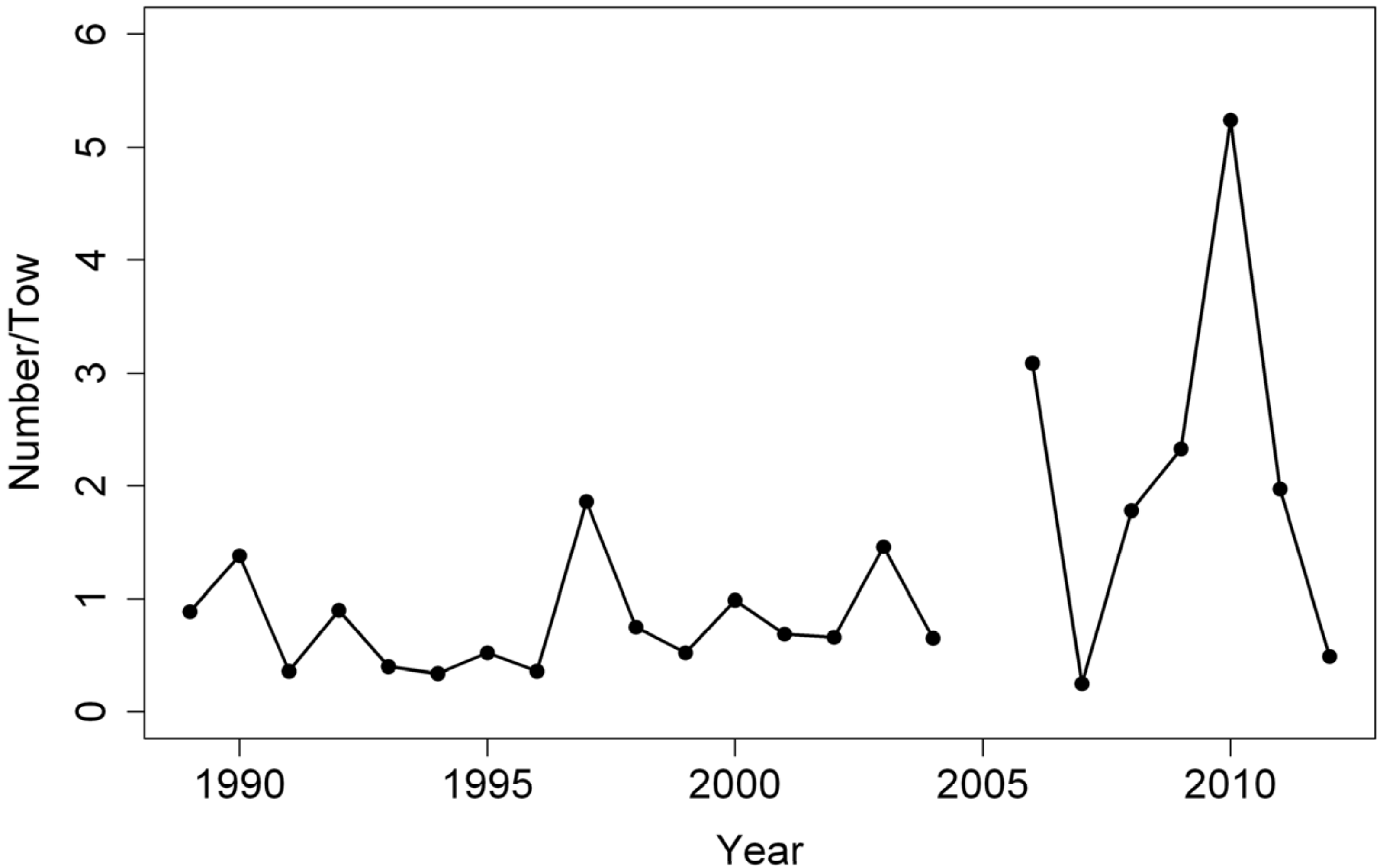

Figure A2.33. NYDEC Peconic Bay survey annual mean number per tow for butterfish.

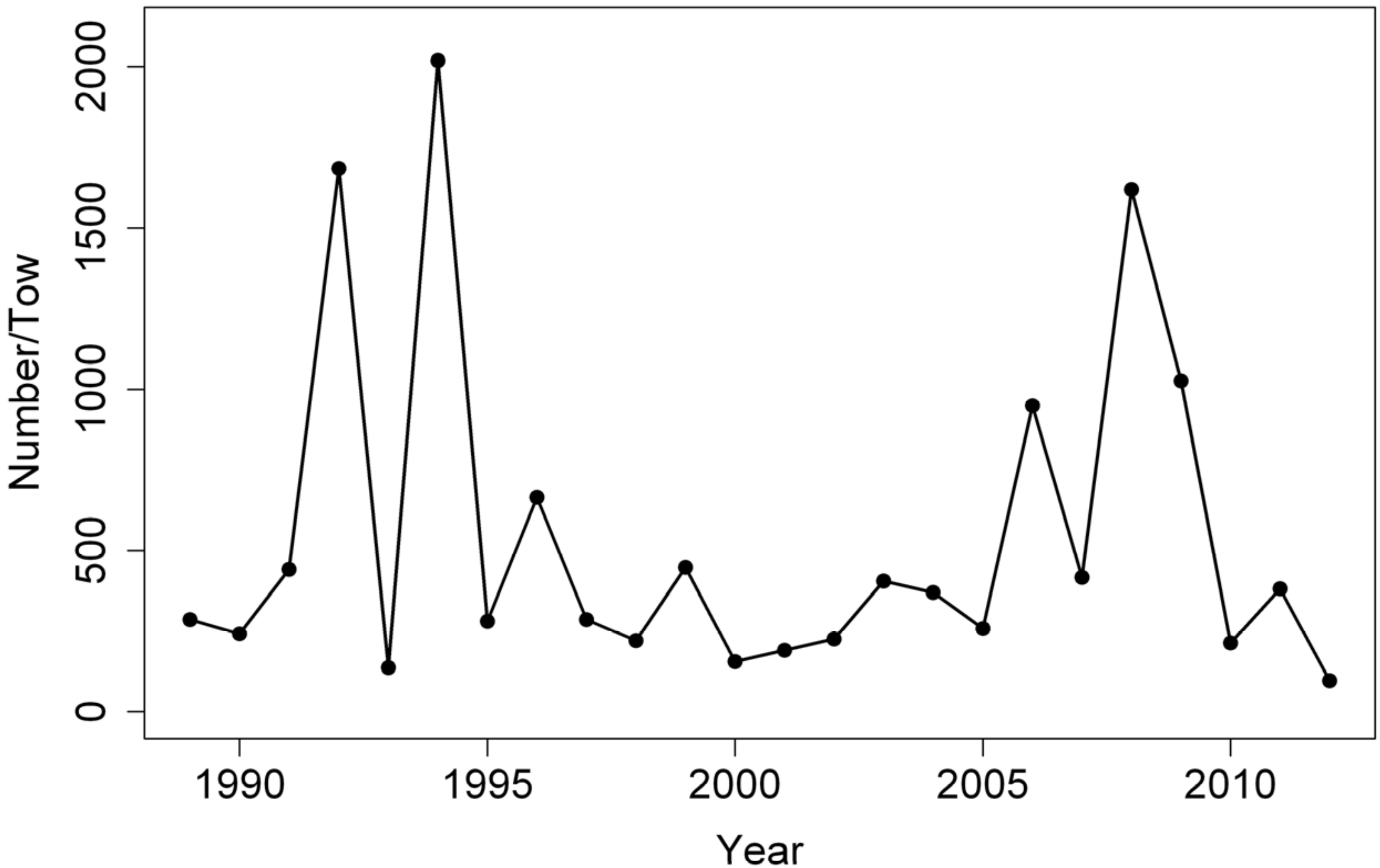

Figure A2.34. NJDEP survey annual stratified mean number per tow for butterfish.

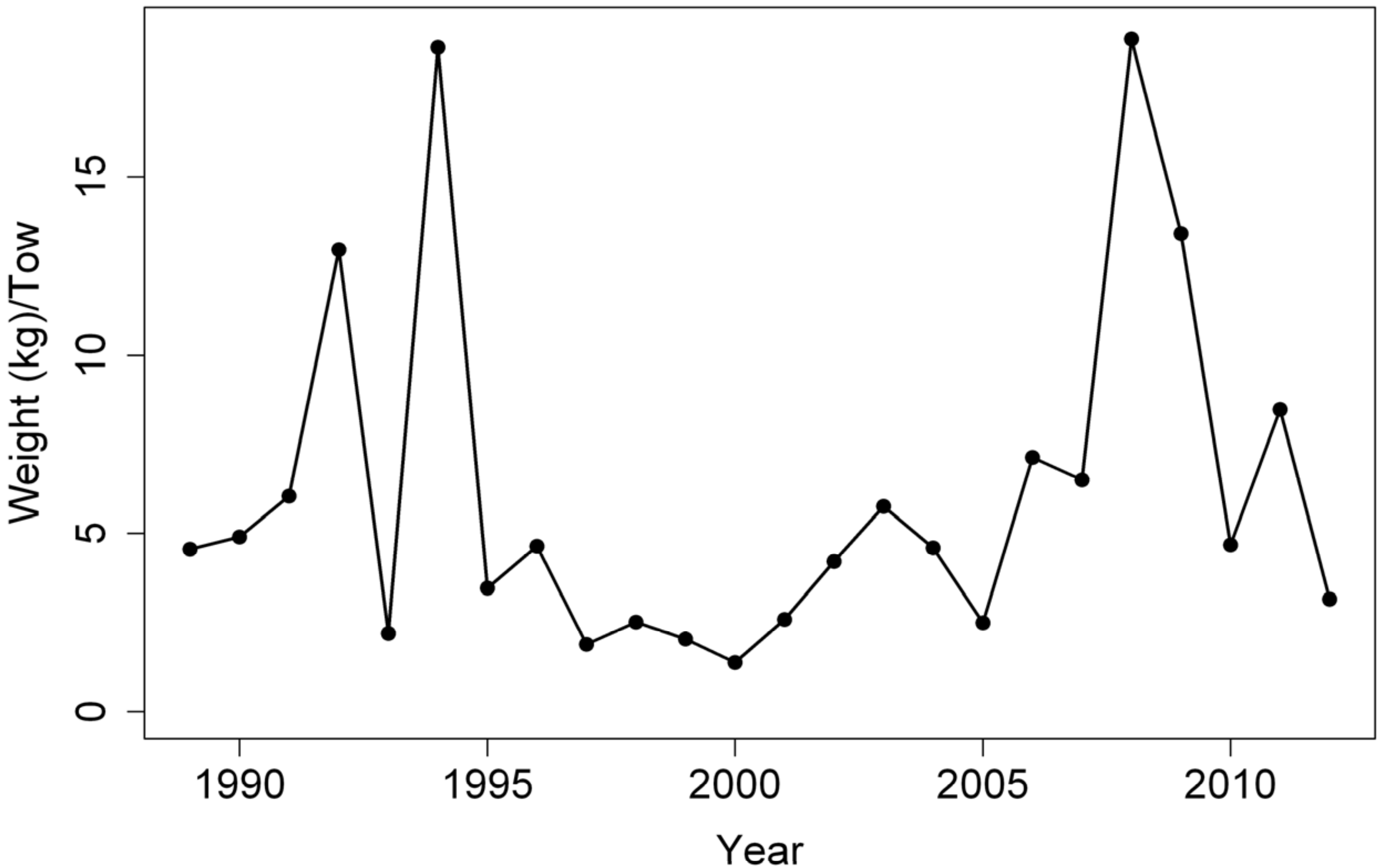

Figure A2.35. NJDEP survey annual stratified mean weight per tow for butterfish.

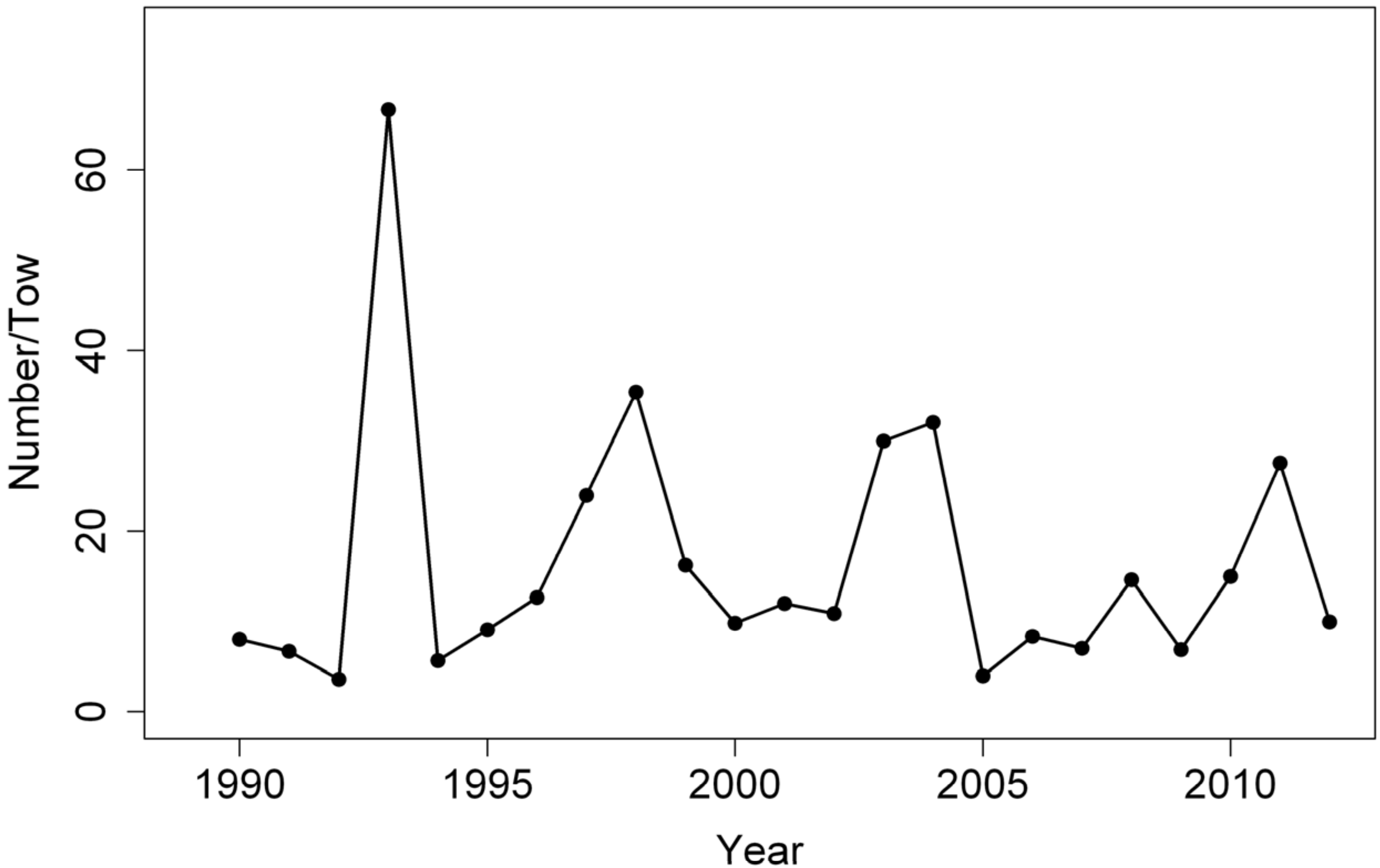

Figure A2.36. DDNREC survey annual mean number per tow for butterfish.

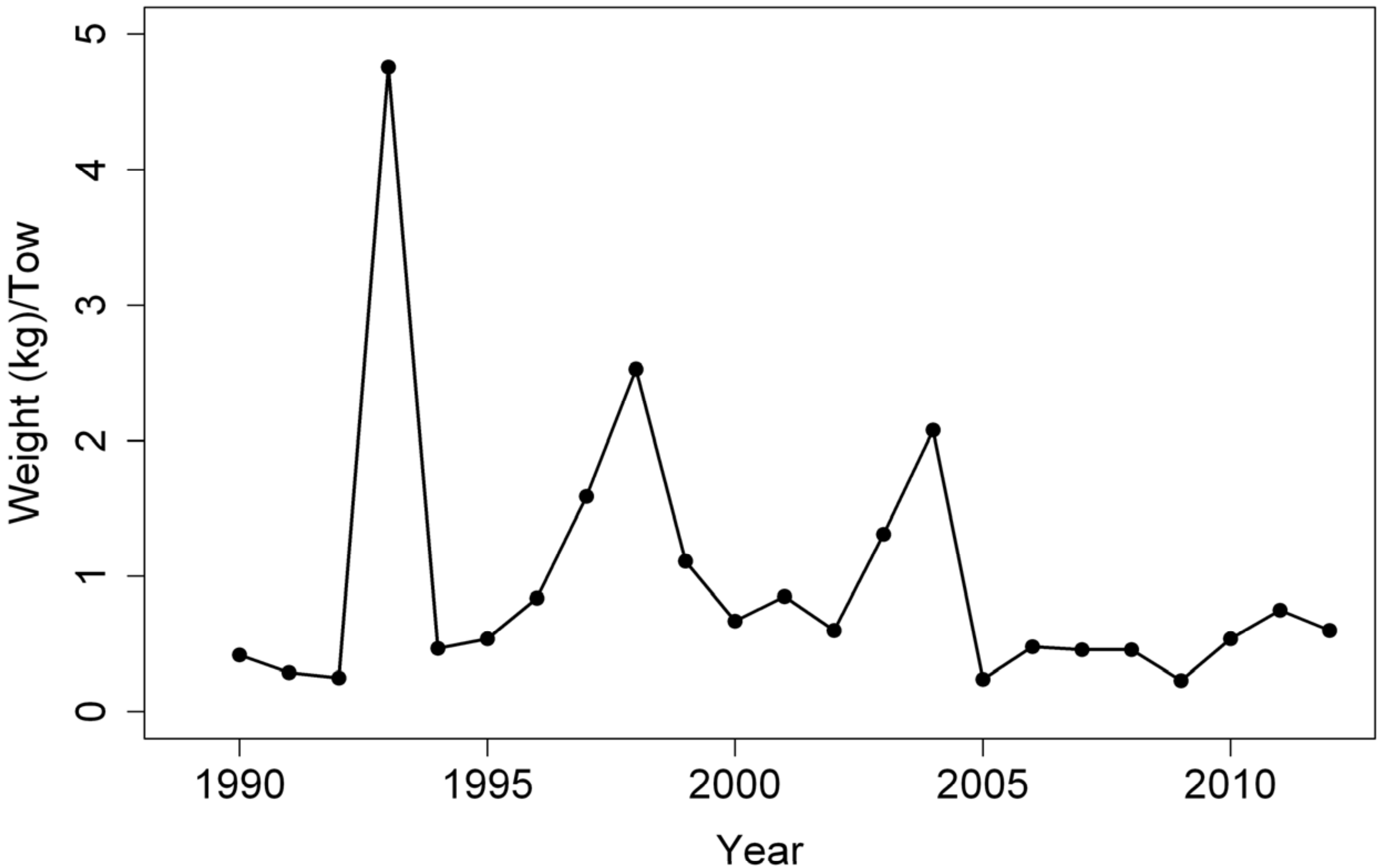

Figure A2.37. DDNREC survey annual mean weight per tow for butterfish.

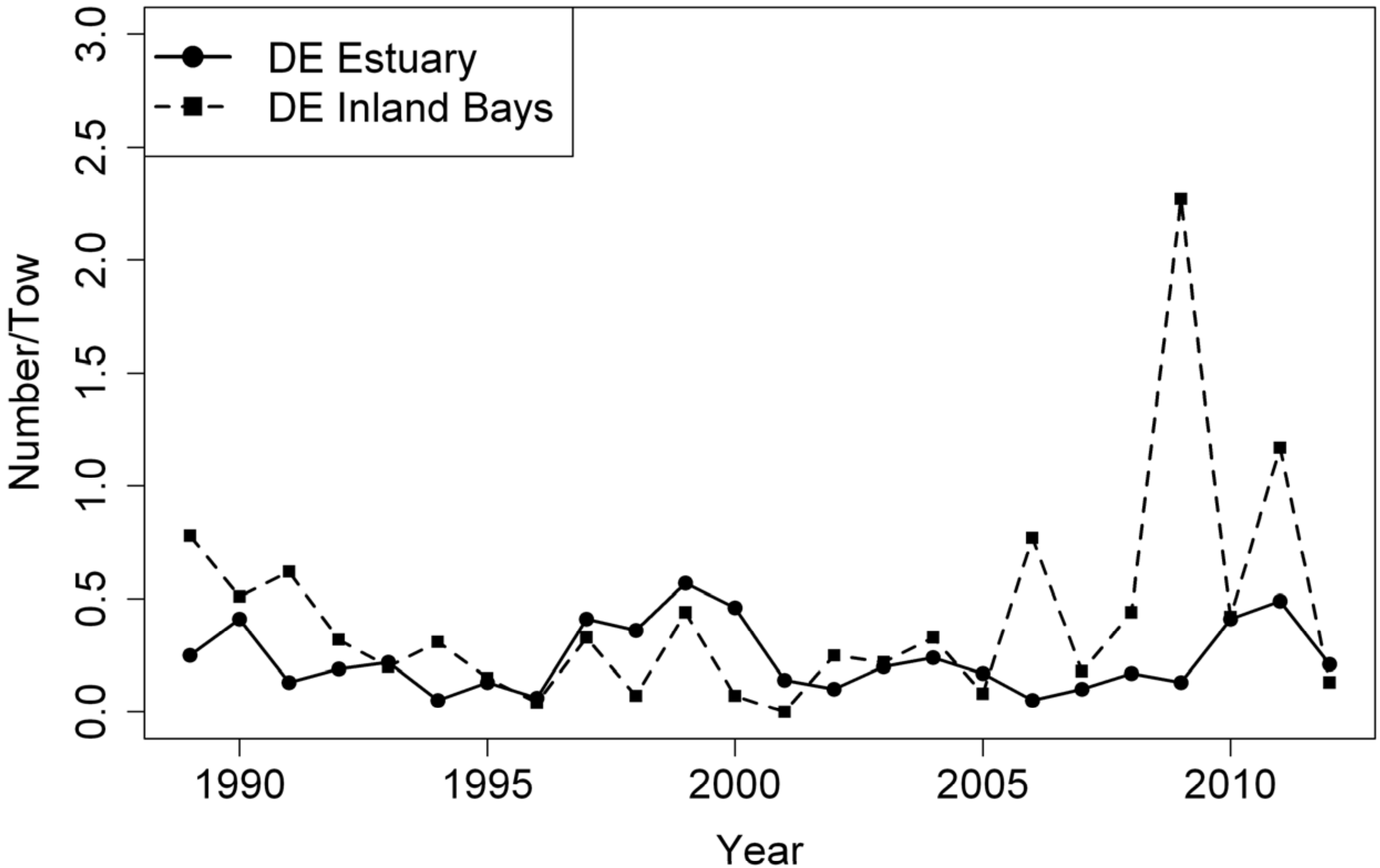

Figure A2.38. DDNREC juvenile survey annual mean number per tow for butterfish.

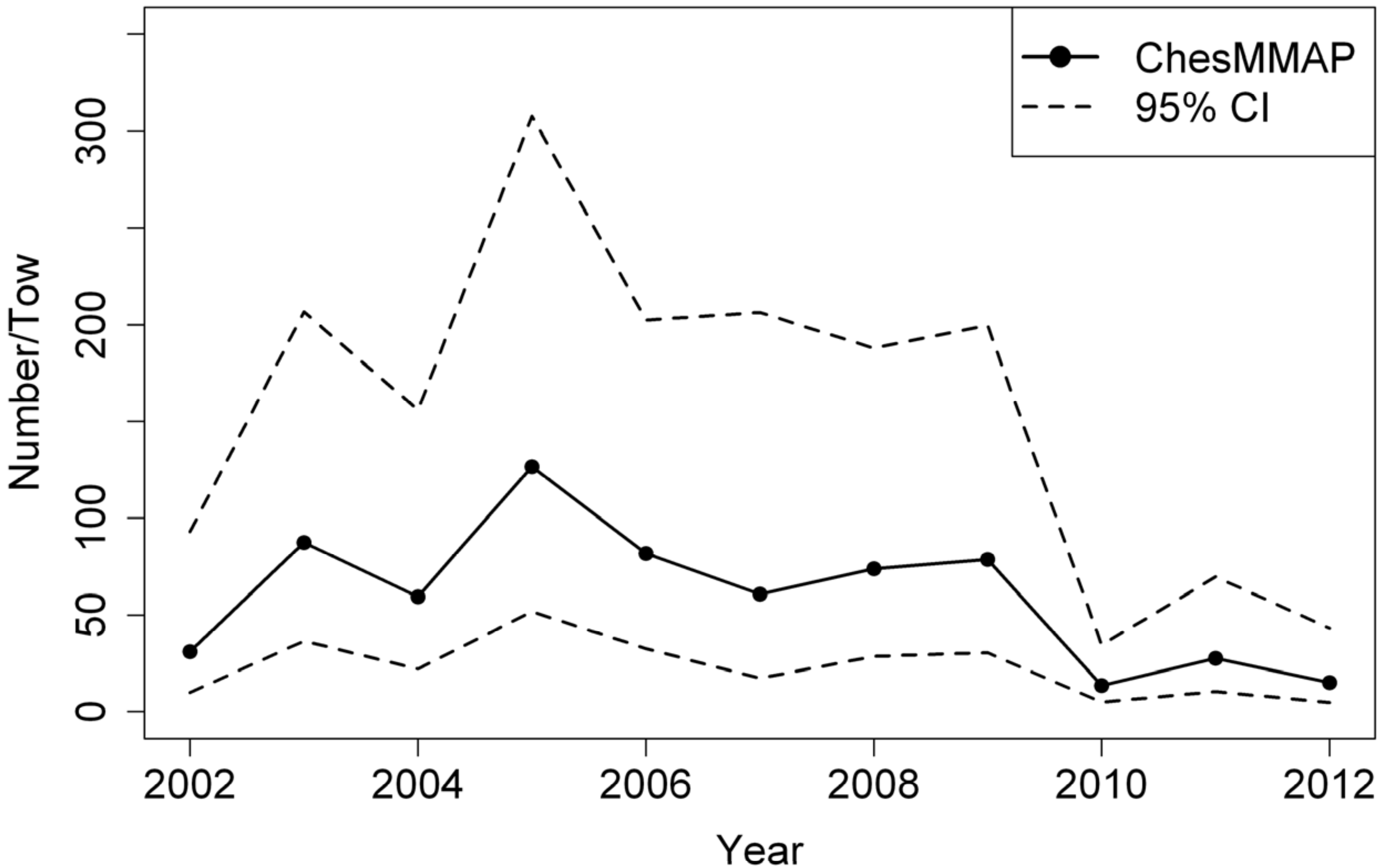

Figure A2.39. ChesMMAP survey geometric mean number per tow and 95% confidence interval for butterfish.

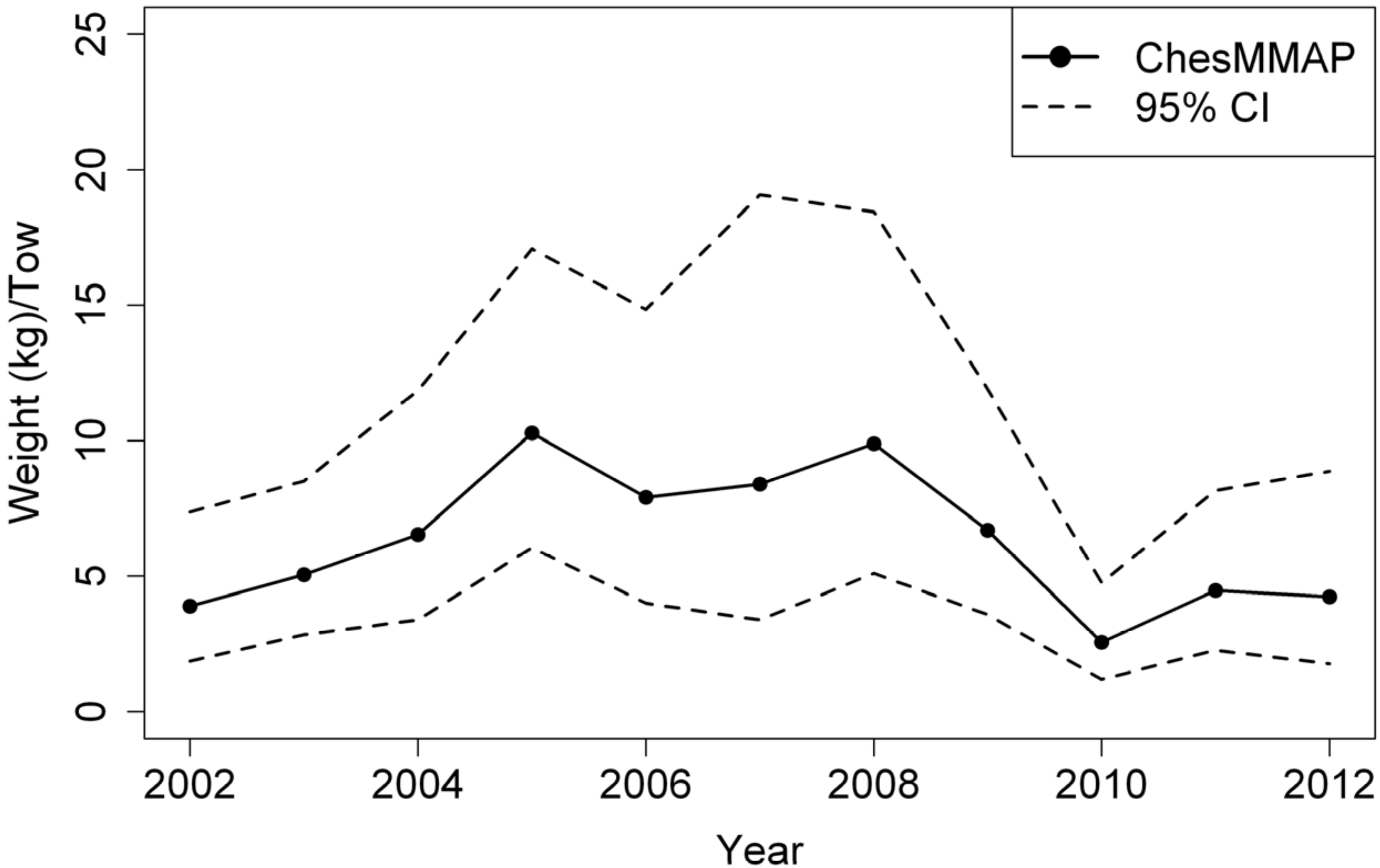

Figure A2.40. ChesMMAP survey geometric mean weight per tow and 95% confidence interval for butterfish.

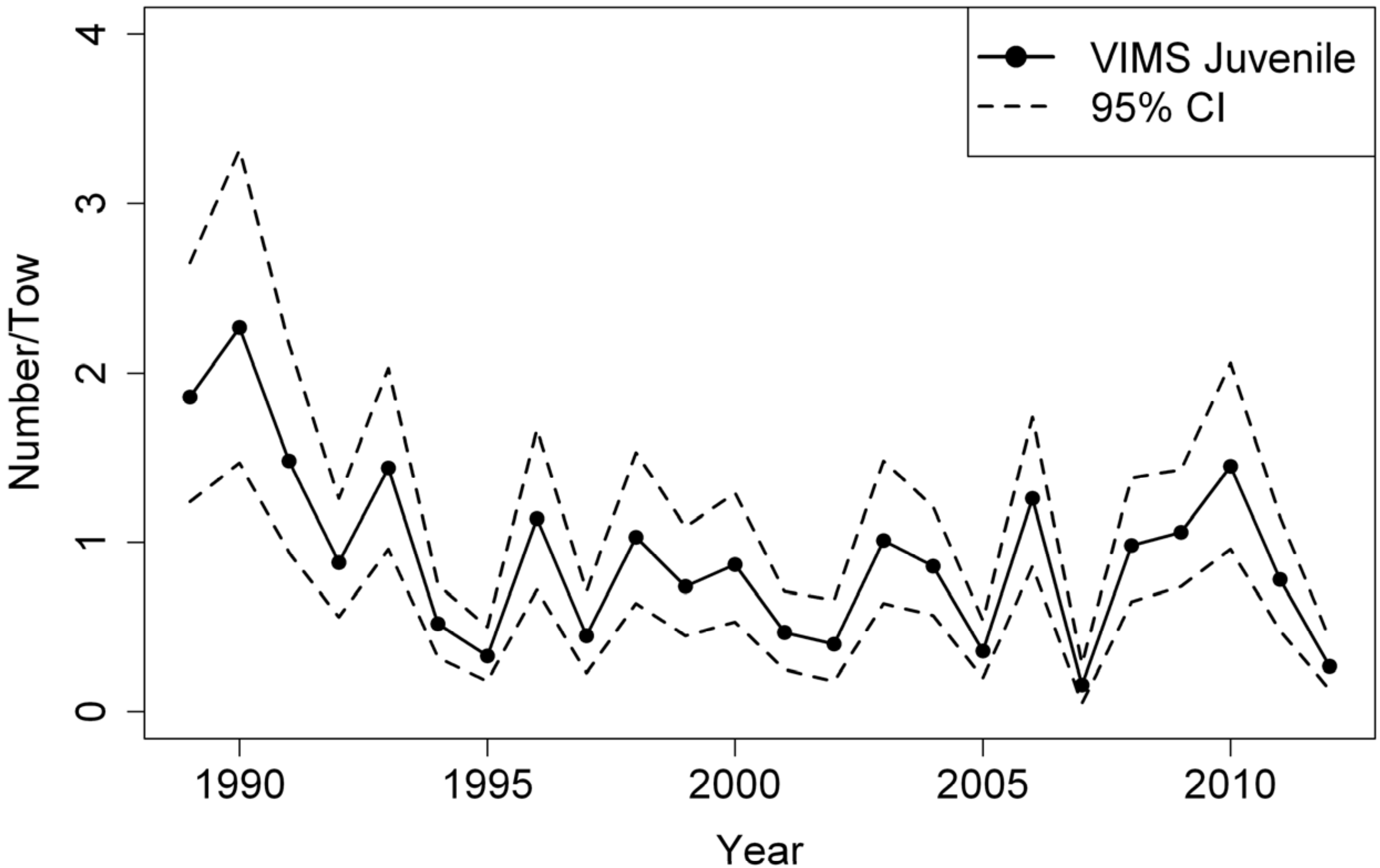

Figure A2.41. VIMS juvenile survey geometric mean number per tow and 95% confidence interval for butterfish.

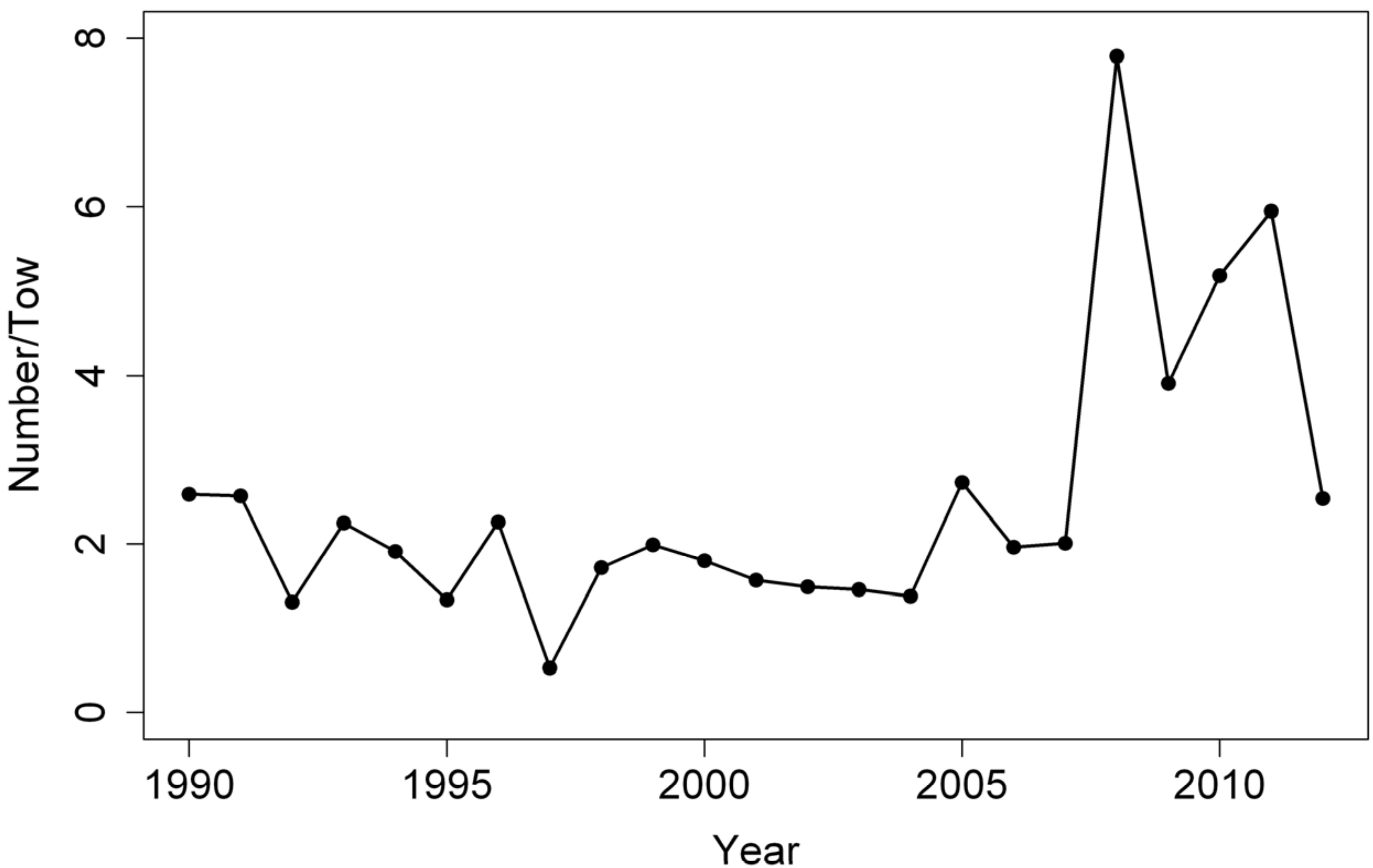

Figure A2.42. NCDENR survey in Pamlico Sound annual weighted mean number per tow for butterfish.

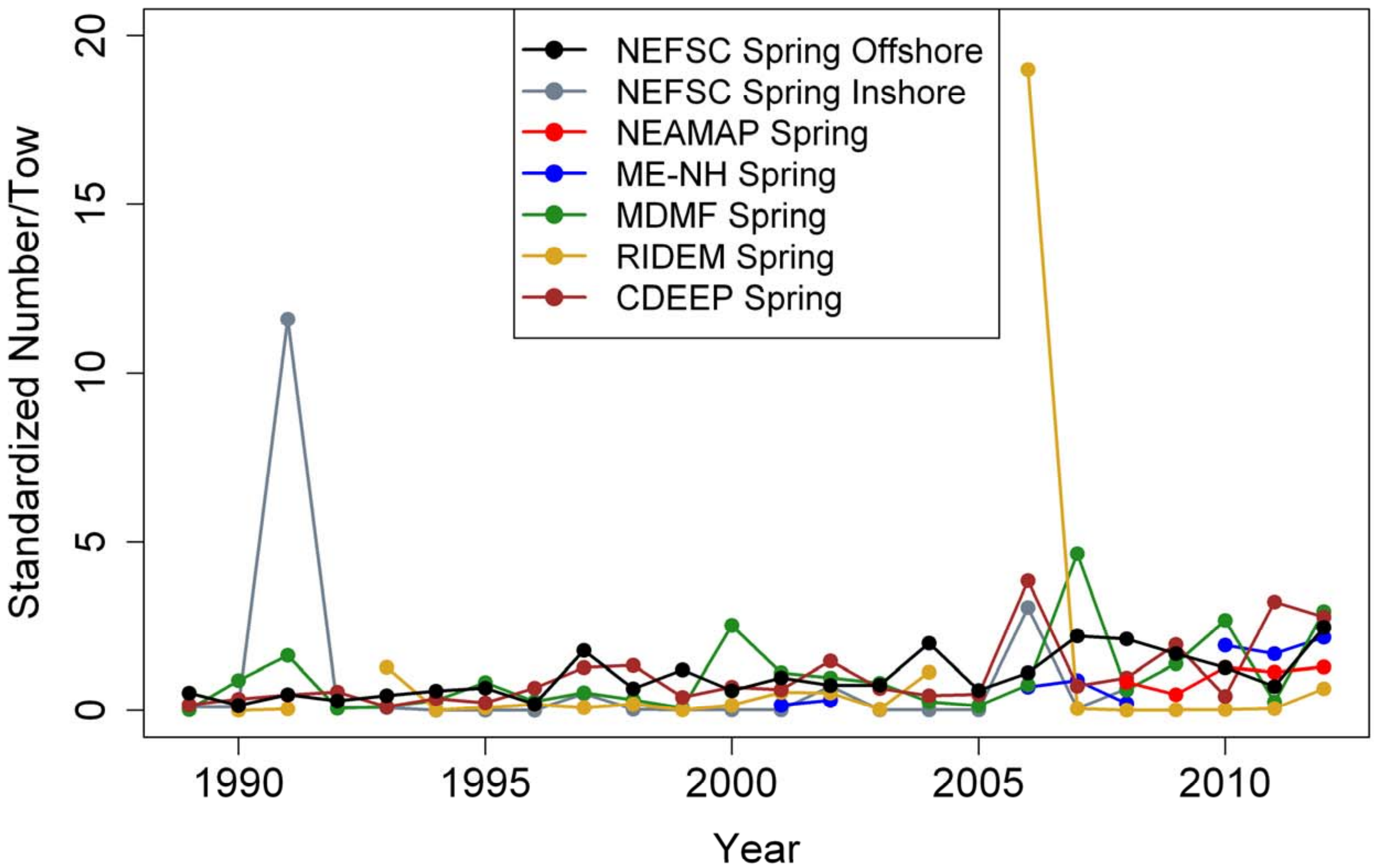

Figure A2.43. Butterfish mean number per tow for NEFSC, NEAMAP, and the various state surveys in spring, standardized to the mean of the respective time series.

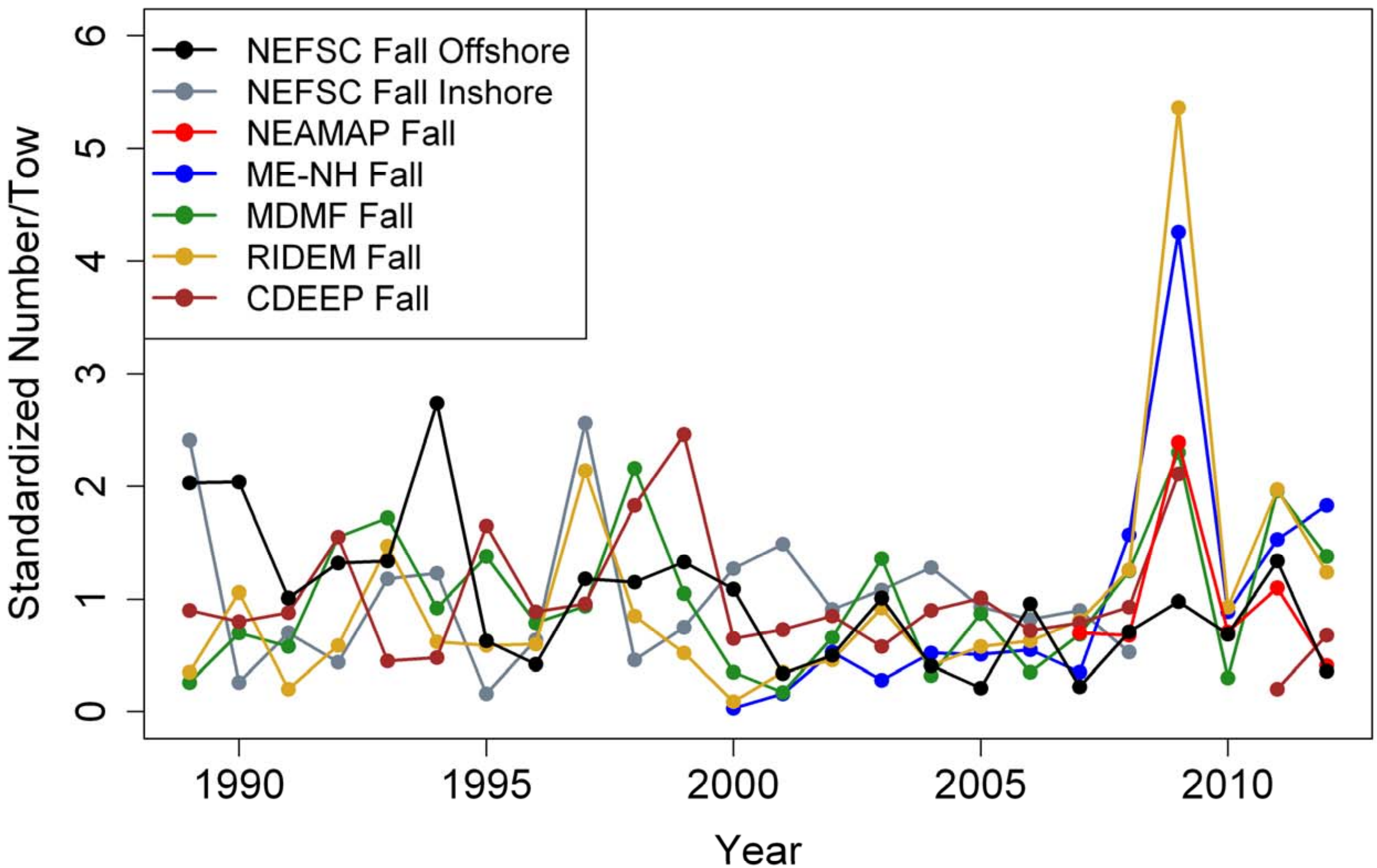

Figure A2.44. Butterfish mean number per tow for NEFSC, NEAMAP, and the various state surveys in fall, standardized to the mean of the respective time series.

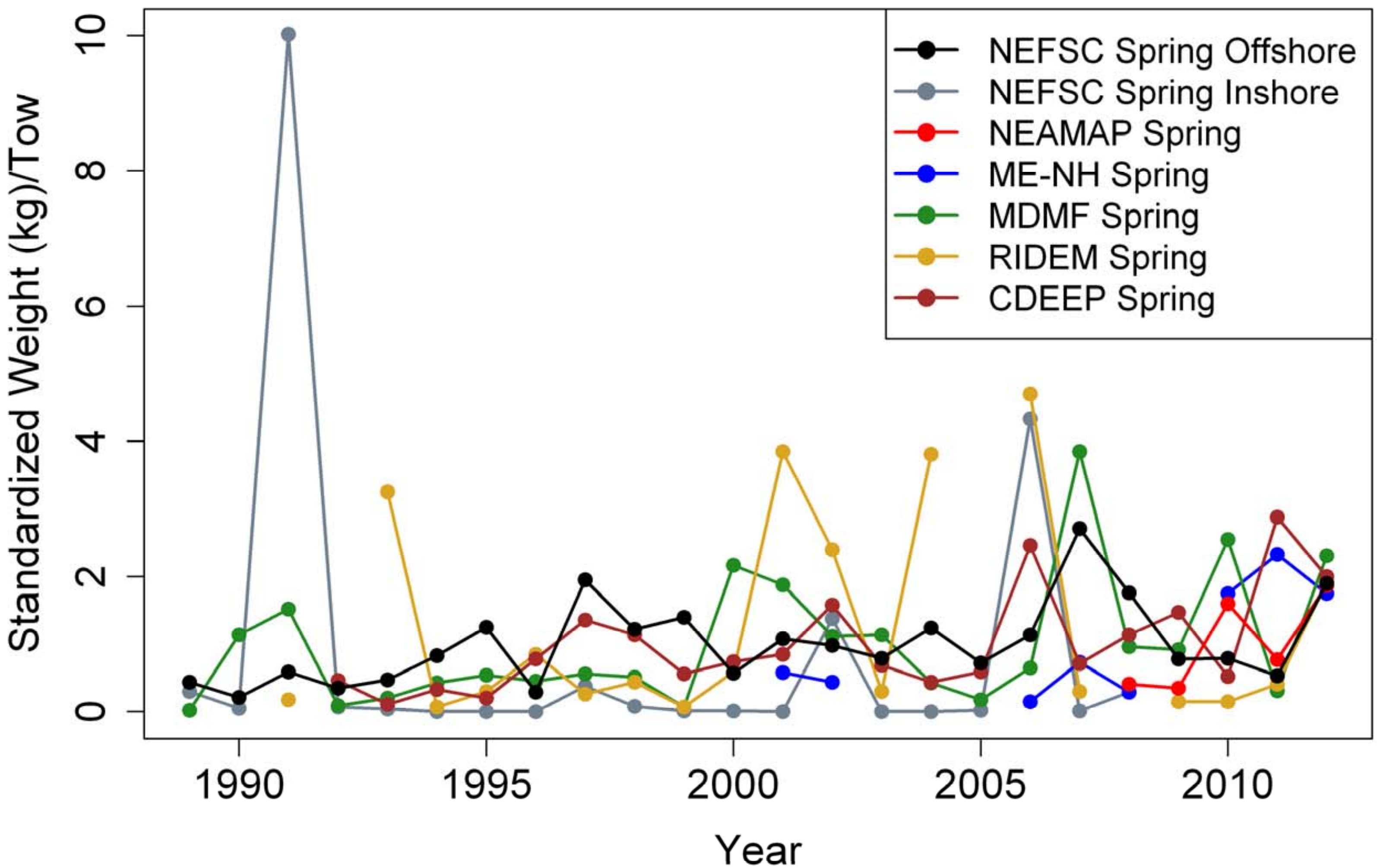

Figure A2.45. Butterfish mean weight per tow for NEFSC, NEAMAP, and the various state surveys in spring, standardized to the mean of the respective time series.

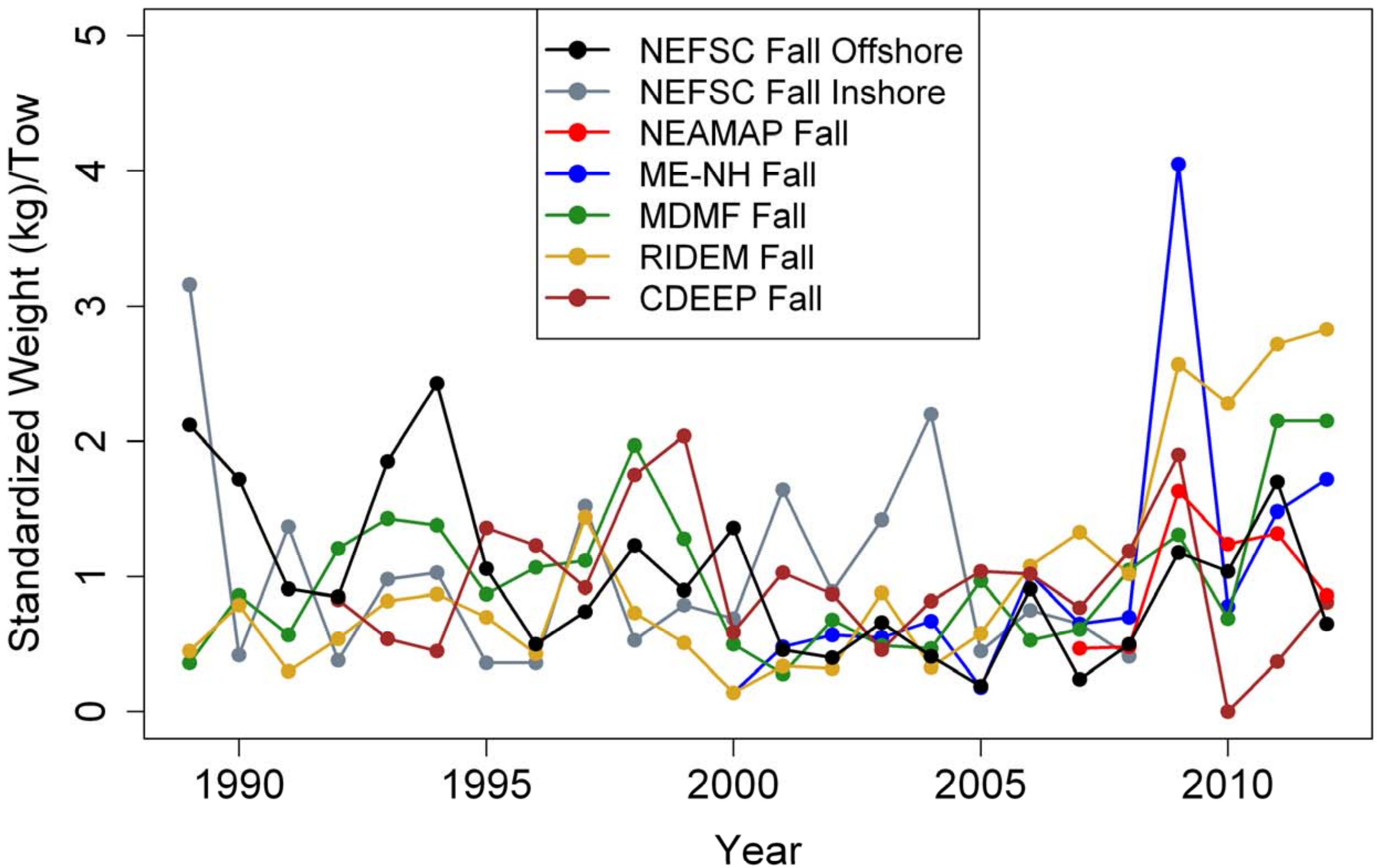

Figure A2.46. Butterfish mean weight per tow for NEFSC, NEAMAP, and the various state surveys in fall, standardized to the mean of the respective time series.

TOR 3. Characterize oceanographic and habitat data as it pertains to butterfish distribution and availability. If possible, integrate the results into the stock assessment (TOR-5).

BACKGROUND

Our purpose was to develop a time varying estimate of availability of the Atlantic butterfish stock to fishery surveys to be considered in the population assessment model. Availability was defined as the proportion of the stock falling within the space-time frame of a fishery independent survey. The primary reasons for focusing on availability were, 1) the assessment is largely driven by fishery independent surveys because fishery landings and discards have been low since 2000 and, 2) recent changes in ocean temperatures may have caused shifts in species range and migration dynamics that may be systematically affecting the availability of the stock to surveys. We assumed that catchability (Q) is the product of **availability** (ρ) and **detectability** (δ) where, availability (ρ) is as defined above and, detectability δ is the proportion of fish within the footprint of an average trawl tow captured in the net. We assumed availability can be estimated as the proportion of the stocks habitat area falling within the space-time frame of a fishery independent survey by combining information about environmental heterogeneity controlling species range and migration dynamics at a broad, regional extent with locations and times of survey samples.

We used a thermal niche model coupled to a regional hindcast of bottom water temperatures to develop a habitat-based estimate of availability (ρ_H) as the proportion of thermal habitat for butterfish available in the Northwest Atlantic sampled during a survey. We focused on thermal habitat for the following reasons. First, the high heat capacity and rate of heat transfer of seawater combined with the role of temperature in regulating metabolism and linked vital rates, make temperature the fundamental niche dimension controlling migration dynamics and broad scale distributions of mobile pelagic marine ectotherms like butterfish (Magnuson et al. 1979, Denny 1993, Brown 2004, Kooijman 2010). Secondly, recent shifts in the distributions of many marine ectotherms are associated with changes in ocean temperature with climate change (Petitgas et al. 2012, Cheung et al. 2013, Pinsky et al. 2013, and many others). Thirdly, numerical ocean circulation models can now be used to develop accurate hindcasts of ocean temperatures at resolutions and extents useful for regional marine resource assessment and management.

Materials and Methods

We built the habitat-based index of availability (ρ_H) of Atlantic Butterfish to assessment surveys in 5 steps (Fig. A3.1). Step 1), a thermal niche model was calibrated using catch and temperature data from fishery independent bottom trawl surveys conducted throughout the Northwest Atlantic. Step 2), a hindcast of bottom water temperature for Northwest Atlantic was constructed using historical climatology to de-bias output from a numerical circulation model. Step 3), butterfish catch data was used to evaluate patterns of sample occupancy in relation to hindcasts of thermal habitat suitability (tHSI) generated by coupling the thermal niche model to hindcast temperatures as well as temperatures measured *in situ* with samples. Step 4) availability (ρ) of the butterfish stock to assessment surveys was calculated using daily regional hindcasts of thermal habitat suitability and the locations and times of survey samples as the proportion of available habitat suitability sampled in the regional sea during the survey period. Step 5) Model based estimates of availability were compared with empirical estimates developed for simultaneous but non-overlapping fall surveys and day:night differences in detectability

Step 1. Thermal niche model

The thermal niche model was calibrated using catch densities of butterfish and bottom water temperatures measured in 7 fishery independent bottom trawl surveys conducted from shallow to deep water (95% CL 8-194 M) over 12 degrees of latitude in the Northwest Atlantic from Cape Hatteras, North Carolina into Coastal Maine (32.7°N to 44.8°N; N= 8957. *Appendix 1 table 1, Appendix 1 Figure 1*). The model was calibrated using daytime trawl tows from 2008 through 2012 because seasonal sampling was complete in all surveys during those years and detectability is higher during the day than night (Richardson et al. 2014, Manderson, et al., 2011). We used numbers of fish caught standardized by swept area of trawl tows as a proxy for relative habitat suitability. Before combining catch data we applied generalized additive modeling (GAM) to determine the form of the temperature response and whether the form was constant enough between surveys, seasons and years that the data could be aggregated for niche model calibration (*Appendix 1 table 2, Appendix 1 Figure 2*).

To develop a parametric thermal niche model we used the calibration data to estimate parameters for the Johnson and Lewin equation, a unimodal extension of the Boltzmann-Arrhenius function (Johnson & Lewin 1946, Dell et al. 2011; Fig. A3.2 top right). In the Johnson and Lewin equation:

Equation 1:

$$h(T) = \frac{ce^{-\frac{E_R}{k_b T}}}{1 + e^{-\frac{1}{k_b T}\left(E_D - \left(\frac{E_D}{T_{opt}} + k_b \, ln\left(\frac{E_R}{E_D - E_R}\right)\right)T\right)}}$$

where the response (h) is a function of absolute temperature (T; degrees Kelvin), a scaling constant (c), the Boltzmann's constant (k_b=8.62x10^{-5} eV K^{-1}, eV=electron volts), the thermodynamic activation energy for the increase in the response with temperature (E_R) up to the optimal temperature (T_{opt}), and the activation energy for decline in the response at temperatures higher (E_D) than the optima. Left skewed asymmetry is produced when $E_R < E_D$. This equation was chosen because it has a basis in temperature dependent enzyme kinetics, can exhibit the left skewed asymmetry typical of thermal performance curves, and has relatively few parameters (N=4; Angilletta 2009). Choosing the Johnson and Lewin equation also appeared to be justified by the similarity of the asymmetrical temperature response generated in a data driven manner with GAM (*Appendix 1 figure 2*).

We obtained parameter estimates for the niche model from the calibration data by minimizing the negative binomial likelihood of the Johnson and Lewin equation using standardized catch densities as the dependent and bottom water temperatures as the independent variable. We used the bmle library in R (Bolker 2012) and methods described in Bolker (2008) and Millar (2011). Calculation of the information matrix and uncertainties in parameter estimates required the use of minimal lower boundary constraints (T_{opt}=0, E_R=0.001, E_D=0.002, k=0.001, where k is the size of the negative binomial distribution) in the L-BFGS-B nonlinear optimization method and a fixed scaling coefficient (c). We chose the scaling coefficient based on preliminary maximum likelihood estimation and the height of the GAM generated temperature response curve that determined the start value for preliminary estimation (*Appendix 1 figure 2*). Parameter estimates and the inverse of the information matrix (=variance-covariance matrix) from maximum likelihood were used to generate population prediction intervals and integrate uncertainties in the niche model with uncertainties in bottom temperature (Bolker, 2008; Lande et al 2003).

Step 2: Bottom temperature hindcast

Bottom temperature was hindcast for fishery independent surveys from 1973 to 2012 using output from a 3-D numerical ocean circulation model that was de-biased with historical bottom temperature climatology. Daily bottom temperatures were hindcast using the Regional Ocean Modeling System (ROMS; Shchepetkin & McWilliams 2003, 2005) numerical ocean circulation model described in Kang & Curchitser (2013; *See appendix 1 for details*). This model that extends from the Gulf of Mexico to Nova Scotia, Canada has a horizontal resolution of 7 km and vertical resolution of 40 terrain-following levels. Bottom temperatures from ROMS were de-biased using Mid Atlantic Bight Ocean Climatology and Hydrographic Analysis (MOCHA; Fleming & Wilkin 2010; *e.g. Appendix 1 figure 4*). MOCHA is three-dimensional climatological analysis of temperature and salinity derived from the ODC World Ocean Database 2005 and the NOAA North East Fisheries Science Center oceanographic database. The MOCHA grid has a spatial extent from 45°N to 32°N, 77°W to 64°W, a horizontal resolution of 5 km, and 55 standard depths.

Daily bottom temperatures from ROMS were interpolated onto the MOCHA grid. We then computed the difference between monthly mean ROMS bottom temperatures and expected monthly mean bottom temperatures from MOCHA. These monthly spatial differences (*e.g. Appendix 1 figure 5*) were applied to ROMS bottom temperatures so they matched the spatial variability of climatology more closely. The result was a de-biased bottom temperature hindcast with the same 5 km x 5 km = 25 km^2 resolution as MOCHA (e.g. Fig. A3.2, top left).

We measured the skill of the de-biased hindcast using bottom temperatures recorded in the NODC World Ocean Database, in the NOAA Northeast Fisheries Science Center hydrographic database, and measured on the 7 fisheries independent bottom trawl surveys used in niche model calibration and evaluation (*Appendix 1 table 1*). These data were used to calculate a variety of statistics including root mean standard errors (RMSE) of the de-biased hindcast *(see Appendix 1)*. RMSEs of the de-biased hindcast were calculated for shallow (bottom depth ≤ 30M) and deep water (bottom depth >30M) during spring (Feb.-Jun.) and fall (Sept.-Dec.) on a yearly basis from 1973-2012.

We used the RMSEs to develop warm and cold ocean temperature states for integration of uncertainties in the de-biased temperature hindcast with niche model uncertainties. We applied RMSEs stratified by water depth, season and year to de-biased hindcast temperatures (T) to construct warm (T + 2*RMSE) and cold ocean temperature states (T – 2*RMSE).

Step 3. Evaluation of niche model & projections of thermal habitat suitability

We used catch data collected from 1973 to 2012 in the 7 fisheries independent bottom trawl surveys (*Appendix 1 table 1, figure 1*) to evaluate the thermal niche model and projections of habitat suitability from it using the de-biased temperature hindcast. Thermal habitat suitability index values (*tHSI*) for evaluation samples were computed by coupling the niche model defined by mean parameter estimates to de-biased bottom temperatures from ROMS (& de-biased ROMS +/- 2* RMSE), as well as temperatures measured *in situ* with samples. *tHSI* values were rescaled from 0 (unsuitable thermal habitat) to 1 (highly suitable thermal habitat) and classified into 10 ordered groups. Binomial GAM with a cubic spline smoother was then used with presence-absence information in the evaluation data to calculate probabilities of sample occupancy (+/-se) with trends in thermal habitat suitability. We used catches of 0, 1, 5 and 10 fish as thresholds for absence to investigate potential effects of field sampling error (e.g. incidental surface water catches, sample contamination, species misidentification). We mapped positive catches of butterfish occurring in samples with low tHSI values (<0.1) to investigate potential spatial bias in false negatives generated by the niche model.

The thermal niche model was evaluated using *in situ* temperature and catch data collected before 2008 and not used in niche model calibration (Total N=31,499 samples). We evaluated trends in sample occupancy with *tHSI* projected from the niche model coupled to the de-biased temperature hindcast (+/- 2 RMSE) using all available data (N=37,515 samples).

Step 4. Availability index

We developed a habitat based index of the availability (ρ_H) for the butterfish stock that used the thermal niche model coupled to the de-biased bottom temperature hindcast to calculate the proportion of cumulative thermal habitat suitability (*tHSI*) available to the butterfish within the regional sea that was sampled during a survey. The habitat-based index of availability ρ_H was calculated as follows:

Equation 2:

$$\rho_H = \sum_{k=1}^{o} \frac{HSI_{k_{j,i}} * \frac{area\ of\ survey\ strata_k}{p}}{\sum_{j=1}^{n} HSI_{j,i} * Area\ of\ j}$$

Here the model based index of habitat suitability (ranging between 0-1) for survey sample *k*, occurring at location *j* on day *i* ($HSI_{k_{j,i}}$) was extrapolated to the spatial area sample k represented in the survey design. This spatial extrapolation was achieved by dividing the *area of the survey strata* (km^2) in which sample k occurred by the total number of samples (*p*) taken within the strata during the survey (see Fig. A3.2). k's suitability index ($HSI_{k_{j,i}}$) was then multiplied by this value to produce an area weighted suitability index for k. Sample k's area weighted suitability index was then divided by the sum of habitat suitability index values for all locations *j=1..n* within the model domain for the day for sampling (*i)* multiplied their surface areas. The model domain was restricted to bottom depths ranging from 10 to 350 meters between latitudes 35°N to 45°N and longitudes 78°W to 65°W. The surface area of locations was 25 km^2 as defined by the resolution (5 km x 5 km) of coupled niche model-bottom temperature hindcast. Estimates of the proportion of habitat suitability sampled for each station in the survey (*k*=1…*o*) were then summed to calculate a habitat-based estimate of the availability of the stock to the survey (ρ_H).

Availability ρ_H calculated in this way was a dimensionless ratio that estimated the proportion of thermal habitat suitability within the model domain sampled within the space-time frame of the survey. It explicitly accounted for the trajectory of sampling on regional surveys with respect to the spatial dynamics of thermal habitat that can change at coarse spatial scales over weekly to decadal time scales.

Uncertainties in niche model parameters and bottom temperature hindcast were integrated into calculations of availability (ρ_H) in the following manner. Availability indices were calculated using the niche model coupled to de-biased bottom temperature hindcast, as well as cold and warm ocean temperature states (de-biased hindcast +/- 2 RMSE). For each ocean temperature state, niche model parameter estimates (Table A3.1a) and the variance-covariance matrix (= inverse of information matrix) for them (Table A3.1b) were used to generate 1000 multivariate random deviates of the parameters (T_{opt}, E_R, E_D; Lande et al. 2003, Bolker 2008). For each ocean temperature state these 1000 realizations of the niche model generated habitat suitability index values (HSI) used in equation 2 above. Median and 95% confidence limits of availabilities ρ_H (N=1000) were computed for each survey and ocean temperature state.

We calculated availability ρ_H for bottom trawl surveys conducted during the spring and fall throughout the northwest Atlantic by the Northeast Fishery Science Center (NEFSC) and in the coastal ocean from Cape Hatteras to Cape Cod by the Northeast Area Monitoring and Assessment Program (NEAMAP). The NEAMAP survey has been performed since 2008 using the commercial trawler *F/V Darana* at shallow depths ranging from 7 to 30 meters. The NEFSC survey has been performed from 1963 to the present. From the beginning of the NEFSC survey until 2008 sampling was performed primarily with the *R/V Albatross* at bottom depths ranging from 15 to 230 M. From 2008 onward the *R/V Bigelow* has been used and sampling has been restricted to bottom depths > 30 meters. To account for these differences, we made availability calculations using NEFSC stations assigned to inshore (shallow) and offshore (deeper) strata in the assessment.

Step 5. Availability index evaluation

We evaluated model based estimates of the availability of the butterfish stock to surveys by comparing them to empirical estimates developed in Richardson's (2014) analysis of simultaneous but non-overlapping fishery independent surveys and day:night differences in detectability. The NEAMAP bottom trawl survey of waters < 30M deep, and the NEFSC survey of waters ≥ 30m deep have been conducted simultaneously in the Fall (September- November) using the same type of bottom trawl since 2008. If double counting is rare, the two surveys sample different components of the same population. Differences in swept area biomass estimates in the NEAMAP and NEFSC surveys then arise from differences in the catchability (Q) of butterfish. As a result, the following equivalent ratios can be defined

$$\frac{B_{NEFSC}}{B_{NEAMAP}} = \frac{Q_{NEFSC}}{Q_{NEAMAP}} = \frac{\rho_{NEFSC} * \delta_{NEFSC}}{\rho_{NEAMAP} * \delta_{NEAMAP}}$$

These ratios can be rearranged to:

Equation 3

$$\frac{\rho_{NEFSC}}{\rho_{NEAMAP}} = \frac{B_{NEFSC}}{B_{NEAMAP}} * \frac{\delta_{NEAMAP}}{\delta_{NEFSC}}$$

where B is swept area biomass, ρ is availability and δ is detectability. We develop an empirical estimate of the $\rho_{NEFSC}/\rho_{NEAMAP}$ availability ratio using Richardson's (2014) calculations of swept area biomass (B) and detectability δ of butterfish in the NEAMAP and NEFSC surveys. The accuracy of the empirical estimate depends on meeting the assumption that the NEAMAP and NEFSC Fall surveys do not double-count butterfish. Further it assumes that relative detectability's of butterfish to the surveys can be accurately estimated. Since similar nets are used, we assume detectability of butterfish is similar in all but the following respect. NEAMAP only samples during daylight hours while NEFSC samples throughout the 24 hour day. In general butterfish are more strongly associated with the seabed during the day than the night (Richardson, 2014; Manderson et al., 2011). Thus detectability of the animal in bottom trawls is higher on average in the NEAMAP survey than in the NEFSC survey.

RESULTS

Step 1. Thermal niche model

The thermal niche model developed with parameters that minimized the negative binomial likelihood of the Johnson and Lewin equation was highly asymmetric [$E_R < E_D$; Table A3.1, *Appendix 1 Fig 3*, Fig A3.2 top right]. The function rose gradually from cold temperatures through a half maximum of 15.1°C to an optimal temperature (T_{opt}) of 19.2 °C. The response then declined rapidly through an upper half maxima at 21°C to low values at temperatures above 25 °C.

Step 2: Bottom temperature hindcast

De-biasing the bottom temperature hindcast from ROMS using MOCHA climatology increased the accuracy of the hindcast with respect to temperatures measured *in situ* (*Appendix 1 table 3a, b, c, d*). The mean RMSE of de-biased temperatures averaged 1.57°C (0.75-3.91; Fig. A3.3). RMSE was higher where bottom depths were ≤ 30 M, and higher in the spring than the fall [RMSE μ (min-max). Fall: Depth ≤ 30M, μ=1.57°C (0.90-3.28); Depth > 30M μ=1.43°C (0.95-3.00). Spring: Depth ≤ 30M, μ=1.77°C (0.84 -3.91), Depth > 30M, μ=1.52°C (0.75-3.41)]. In general RMSEs of hindcast temperatures were less than 2°C until 2008. After 2008 RMSEs were somewhat higher in waters > 30m deep.

*Step 3. Evaluation of niche model & projections of thermal habitat suitability (*tHSI)

Trends in butterfish occupancy in samples not used in model calibration were well explained by trends in the tHSI computed with the niche model and temperatures measured *in situ* (Fig. A3.4). Probability of occupancy rose rapidly from a minimum of 6% (SE= 0.3) at tHSI=0 (Total N=1486) to 77% (SE=0.6) at tHSI=0.4 (N=1861). Occupancy probabilities then increased more gradually to reach a maximum of nearly 90% at tHSI = 1 (p=87%, SE= 0.9; N=1121 samples). When the threshold for absence was increased to account for possible field sampling errors, false negatives (tHSI =0) fell to 4% of samples (SE= 0.2) when the threshold increased from 0 to 1 fish and to 1.9% (SE= 0.1) when the threshold was increased to 10 fish. Trends in median standardized catch densities of butterfish with tHSI predicted using *in situ* temperatures were similar to trends in occupancy (*Appendix 1 Fig. 7*).

Evaluation results indicated that patterns of butterfish occupancy were best explained by tHSI values generated by the niche model coupled to the de-biased temperature hindcast than to warm or cold ocean temperature states. Predictions of thermal habitat suitability made using the de-biased temperatures hindcast produced patterns of sample occupancy most similar to those generated when the niche model was coupled to temperatures measured *in situ* (Fig. A3.5). Raw ROMS bottom temperatures produced slightly higher sample occupancy at low tHSIs than the de-biased model temperatures. The warm ocean state (de-biased temperatures + 2RMSE) produced low tHSIs that produced high probabilities of sample occupancy. Thermal habitat suitability values generated using the cold ocean state (de-biased temperatures - 2RMSE) also exhibited relatively high sample occupancy at tHSI values <0.2 but to a lesser degree than the warm ocean state. Trends in the central tendency of butterfish catch densities with tHSI followed trends in occupancy (*Appendix 1 figure 8*).

Most false negative samples with low thermal habitat suitability index values (tHSI< 0.1) that produced butterfish were concentrated in the southern mid-Atlantic bight coastal zone where warm temperatures were hindcast or measured *in situ* in September (24-29°C; Fig. A3.6). The de-biased bottom temperature hindcast generated false negatives for 1.3% of fall evaluation samples (Total N=17,045). However, less than 1% of evaluation samples had low tHSI values and produced 10 or more fish (0.6% for de-biased temperature hindcast and 0.8% for *in situ* temperatures). During spring less than 15 samples (total N=21,022) were identified as false negatives. These samples were not spatially clustered.

Step 4. Availability index

We focused our discussion on availability estimates (ρ_H) of butterfish to surveys derived from the niche model coupled to the de-biased bottom temperature hindcast because the model evaluation (step 3) indicated that thermal habitat suitabilities (tHSI) derived from this hindcast explained patterns of butterfish occupancy in samples better than the cold and warm ocean temperature states.

NEFSC stations classified as being offshore sampled between 62% and 75% of the estimated thermal habitat suitability available to butterfish within the model domain during the fall (*Appendix 1 table 4a*) while offshore stations sampled 53% to 59% of the thermal habitat available during the spring survey (*Appendix 1 table 4b,* Fig. A3.7). These habitat based availability estimates for the fall NEFSC surveys fell well within the range of consensus bounds ($0.5<\rho>0.9$) used in the 2009 assessment (http://www.nefsc.noaa.gov/publications/crd/crd1003/pdfs/butterfish.pdf; Pg. 71). NEAMAP stations sampled between 10 and 12% of the thermal habitat suitability available in the fall (*Appendix 1 table 4c)* while NEFSC inshore stations sampled <11% of available thermal habitat (*Appendix 1 table 4d)*. The index of availability suggested that thermal habitat for butterfish was poorly sampled in inshore NEFSC strata and the NEAMAP surveys during the spring (*Appendix 1 table 4e,f)*.

Step 5. Availability index evaluation

During the fall, the NEFSC:NEAMAP availability ratio (ρ_H) estimated using the thermal niche model coupled to bottom temperature hindcast and equation 2 was 5.96:1 (5.67:1-6.48:1). This model based estimate is similar to the empirical estimate of 6.24:1 (5.75:1-6.72:1) calculated based on Richardson's (2014) analysis of the simultaneous but non spatially overlapping surveys and day:night detectability ratios for butterfish. From 2009-2012, the swept area biomass ratios of the NEFSC:NEAMAP surveys (B_{NEFSC}/B_{NEMAP}) averaged=3.9:1 during the fall. Richardson calculated the detectability ratio of NEAMAP to NEFSC $\delta_{NEAMAP}/\delta_{NEFSC}$ to be ~1.6:1 (95% CI 1.47:1 - 1.72:1) if differences in detectability were related to day:night differences in sampling. Based on these values the empirical estimate of the NEFSC:NEAMAP availability ratio using equation 3 $\rho_{NEFSC}/ \rho_{NEAMAP} \sim 3.9*1.6 = 6.24:1$ (5.75:1-6.72:1).

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Table A3.1a. Parameter estimates for the Johnson & Lewin equation (Equation 1, *Appendix 1 figure 3*) that served as the Atlantic Butterfish thermal niche model (Fig.2; top right). Estimates of optimal temperature (T_{opt} C in degrees centigrade), activation energy for the increase in the response (E_R), activation energy for the decrease in the response (E_D), and constant (c) for the equation which minimized the negative binomial likelihood using standardized butterfish catch in trawl tows of the 7 surveys of the Northwest Atlantic from 2008-2012 as the response (h) and bottom water temperatures as the independent variable. k is the estimate of the size parameter for the negative binomial distribution given the catch data.

					Profile confidence interval	
Coefficient	**Estimate**	**Standard Error**	**z value**	**Pr(z)**	**2.50 %**	**97.50 %**
T_{opt}	19.1630	0.2295	83.4990	0.0000	18.7055	19.6036
E_R	1.4029	0.0008	1712.831	0.0000	1.4012	1.4044
E_D	8.4759	0.4480	18.9200	0.0000	7.6246	9.3807
c	7.5E+26					
k	0.1208	0.0019	62.9770	0.0000	0.1171	0.1171
-2 log L	65565.47					

Table A3.1b. Variance-Covariance matrix for estimated parameters of the Johnson and Lewin equation generated in minimizing negative binomial likelihood. Parameter estimates and the matrix were for integration of uncertainties in the niche model with uncertainties in bottom temperatures for calculation of the availability of the butterfish stock to assessment surveys.

	T_{opt}	E_R	E_D	k
T_{opt}	5.267226e-02	6.250185e-05	9.261793e-02	-1.099532e-06
E_R	6.250185e-05	6.708104e-07	7.306747e-05	-2.109360e-09
E_D	9.261793e-02	7.306747e-05	2.006907e-01	-1.845831e-06
K	-1.099532e-06	-2.109360e-09	-1.845831e-06	3.681757e-06

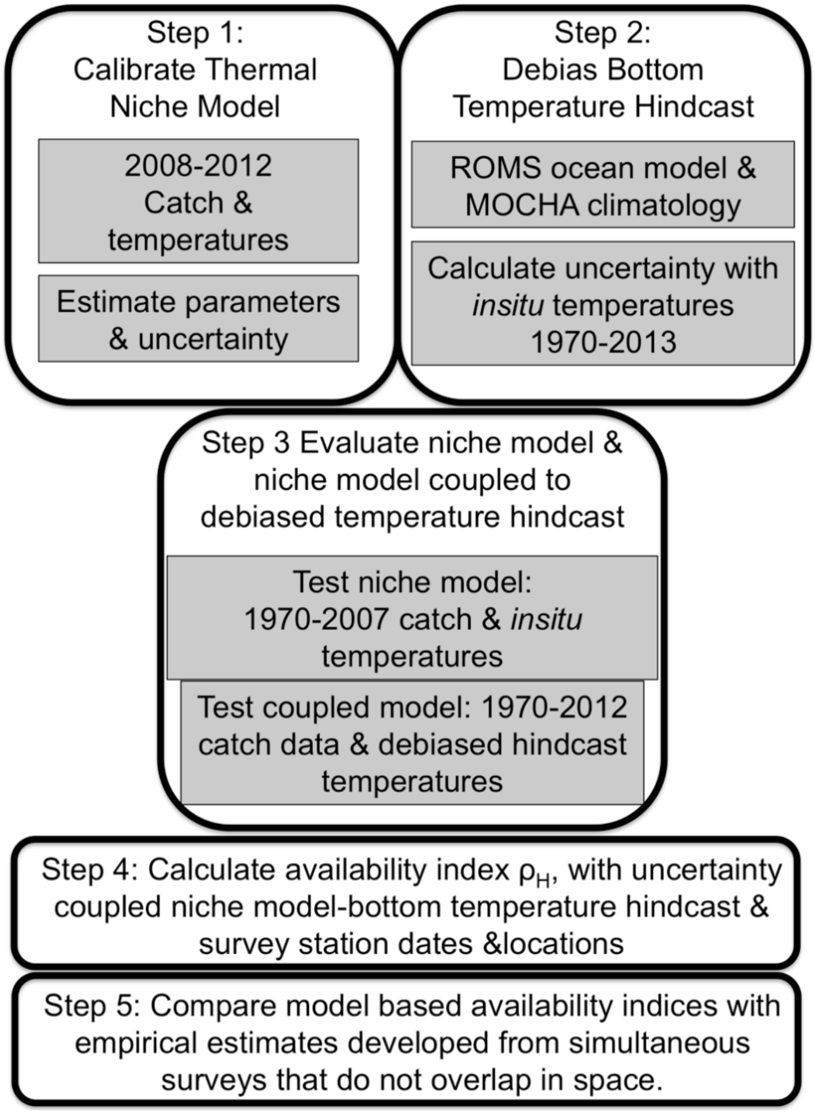

Figure A3.1. Steps in the development of a stock availability estimate to fishery independent surveys based upon thermal habitat. In step 1, Catch and temperatures from 7 fishery independent surveys throughout the Northwest Atlantic were used to calibrate a thermal niche model. Step 2, bottom temperatures for stock assessment surveys from 1973-2012 from a hindcast of a Regional Ocean Modeling System (ROMS) numerical circulation model were de-biased using a regional climatology. In step 3) catch data was used to evaluate the niche model and the niche model coupled to the de-biased temperature hindcast. Step 4) the index of availability (ρ_H) of butterfish to assessment surveys was estimated using the niche model coupled to the de-biased temperature hindcast and the locations and dates of fishery independent survey samples. In step 5) ratios of model based indices of availability (ρ_H) and empirical estimates were compared for regional surveys that did not overlap in space but were performed simultaneously in the fall.

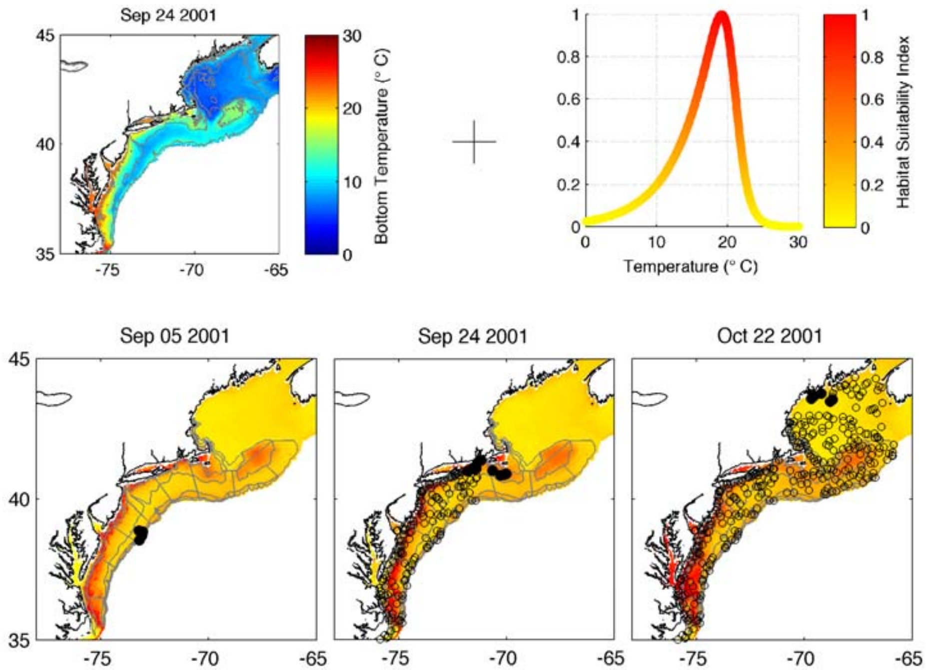

Figure A3.2. Thermal habitat suitability was projected in space and time by coupling the niche model rescaled from 0 (unsuitable habitat) to 1 (highly suitable habitat) to daily hindcasts of bottom temperature. De-biased ROMS bottom water temperature hindcast for the median date of the 2001 fall NEFSC survey (September 24th; top left) was coupled to a realization of the thermal niche model (top right) to produce a daily hindcast of thermal habitat suitability for butterfish for September 24th, 2001 (bottom middle). Thermal habitat suitability for the first day (September, 5, bottom left) and last day of the fall survey in 2001 (October, 22, bottom right) are also shown. Color scale in habitat suitability plots (bottom panels) is the same as the color scale of the niche model response function (top right). Twenty, 50 and 150 meter isobaths are shown in the bottom temperature hindcast (top left). Lines in bottom panels show offshore NEFSC survey strata included in the assessment. Solid circles in bottom panels indicate NEFSC survey samples taken on the day of the habitat hindcast. Open circles are NEFSC survey samples taken prior to the hindcast date. The habitat suitability projections were used to calculate the proportion of the total habitat suitability in the regional sea sampled at each station on the day of sampling. These values summed across survey stations to estimate the availability of the butterfish stock to the survey as a function of the total available thermal habitat sampled.

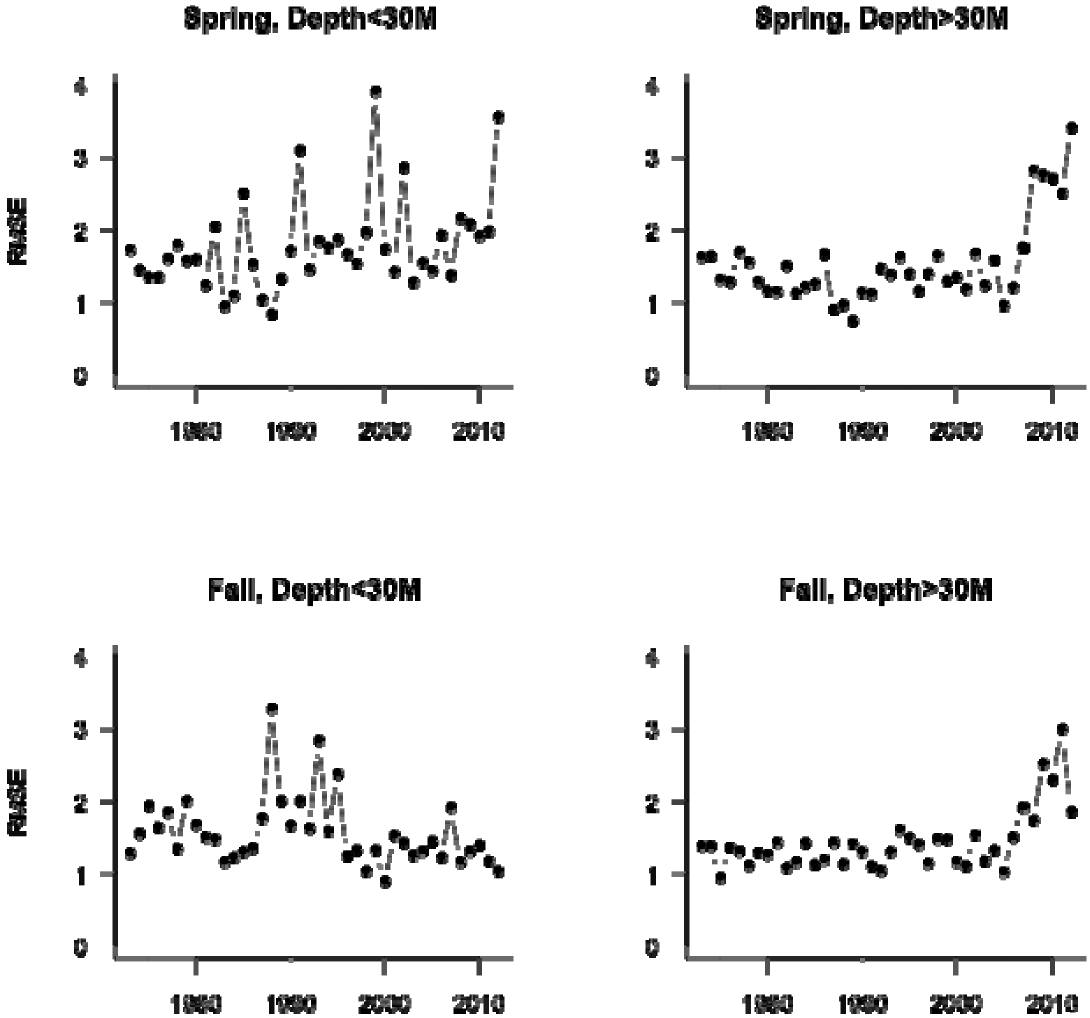

Figure A3.3. Root Mean Square Standard Errors RMSE de-biased bottom temperatures hindcast by ROMS calculated using bottom water temperatures measured *in situ* for shallow (<30 m) and deeper waters (>30 m), during spring and fall, from 1973-2012 (see *Appendix 1*). RMSEs were applied to mean de-biased bottom temperatures (T) to construct the warm (T + 2*RMSE) and cold ocean temperature states (T - 2*RMSE) for integration of uncertainties in the temperature hindcast into the availability ρ_H calculation.

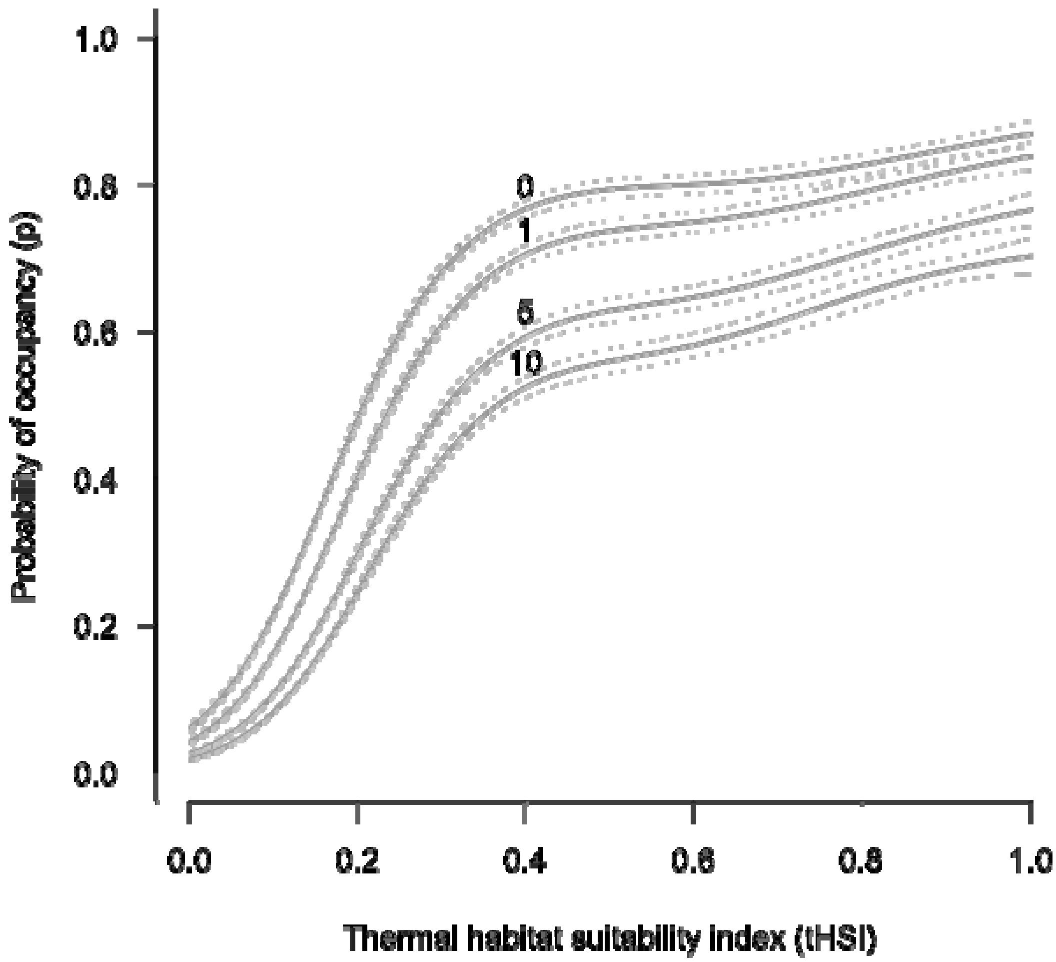

Figure A3.4. Probability of butterfish occupancy (+/- 2 SE) in samples collected in 7 fishery independent surveys from 1970-2007 in relation to thermal habitat suitability (tHSI) predicted by coupling the niche model to bottom water temperatures measured *in situ* with the samples. Data used in model evaluation was not used in calibration. Occupancy probabilities were generated using binomial GAM. Numbers above occupancy curves indicate the effects of varying the number of fish used as the threshold for absence from 0-10 in order to investigate the effects of potential field sampling error (incidental catch in surface waters, sample contamination, false identification).

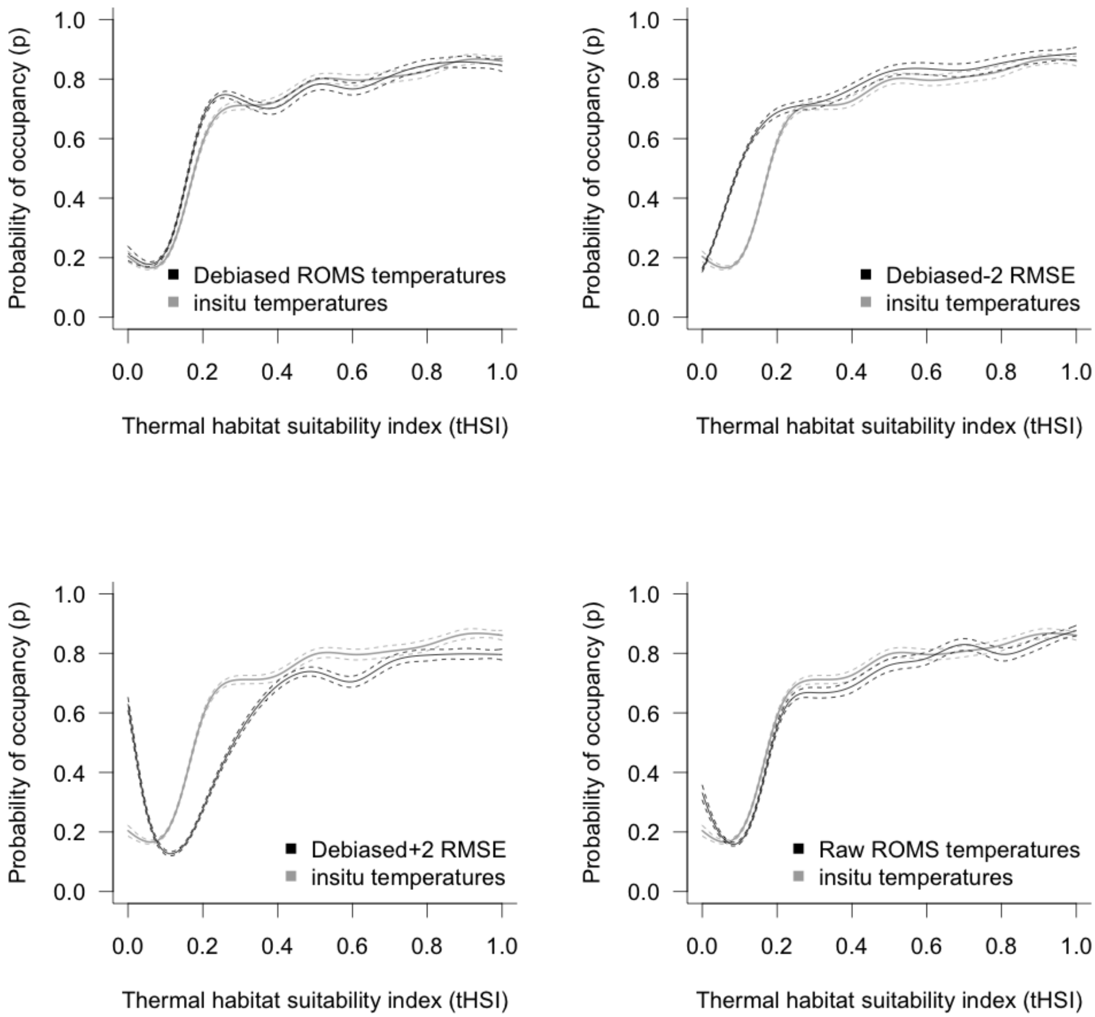

Figure A3.5. Trends in butterfish sample occupancy (+/- 2 SE) with thermal habitat suitability in 1973-2012 evaluation samples predicted using the niche model coupled to the ROMS temperature hindcast (black lines) and temperature measured *in situ* (gray lines). Trends in sample occupancy with tHSI values projected using ROMs temperatures de-biased using MOCHA climatology were most similar to those made using temperatures measured *in situ* (top left). Occupancy trends with tHSI values hindcast using the cold ocean state (de-biased ROMs – 2 RMSE; top right), warm ocean state (de-biased ROMs + 2 RMSE; bottom left), and ROMS hindcast temperatures with no de-biasing (bottom right) that were less similar to those generated with *in situ* temperatures.

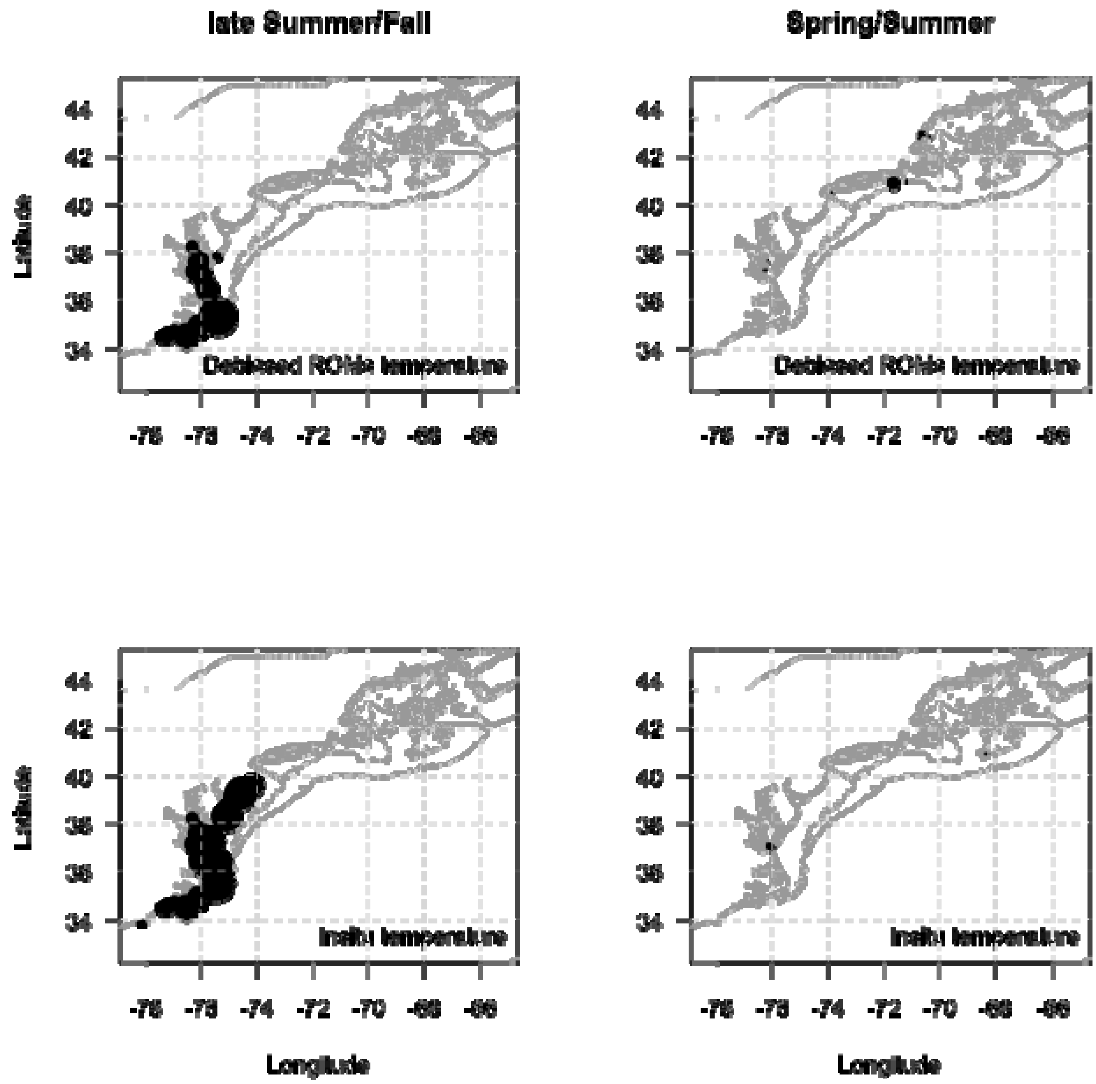

Figure A3.6. Evaluation of spatial pattern in evaluation samples collected during late summer and fall (left panels) and spring and early summer (right panels) that produced butterfish but which had low thermal habitat suitability (<0.1; i.e. "false negatives") predicted using bottom temperatures de-biased from the ROMS hindcast (top panels) and measured *in situ* (bottom panels). Less than 1% of evaluation samples had tHSI values < 0.1 and produced 10 or more fish during the fall or spring. Evaluation samples collected prior to 2008 were used to evaluate the accuracy of the niche model coupled to *in situ* temperatures (bottom two panels). Symbols sizes indicate relative catch densities.

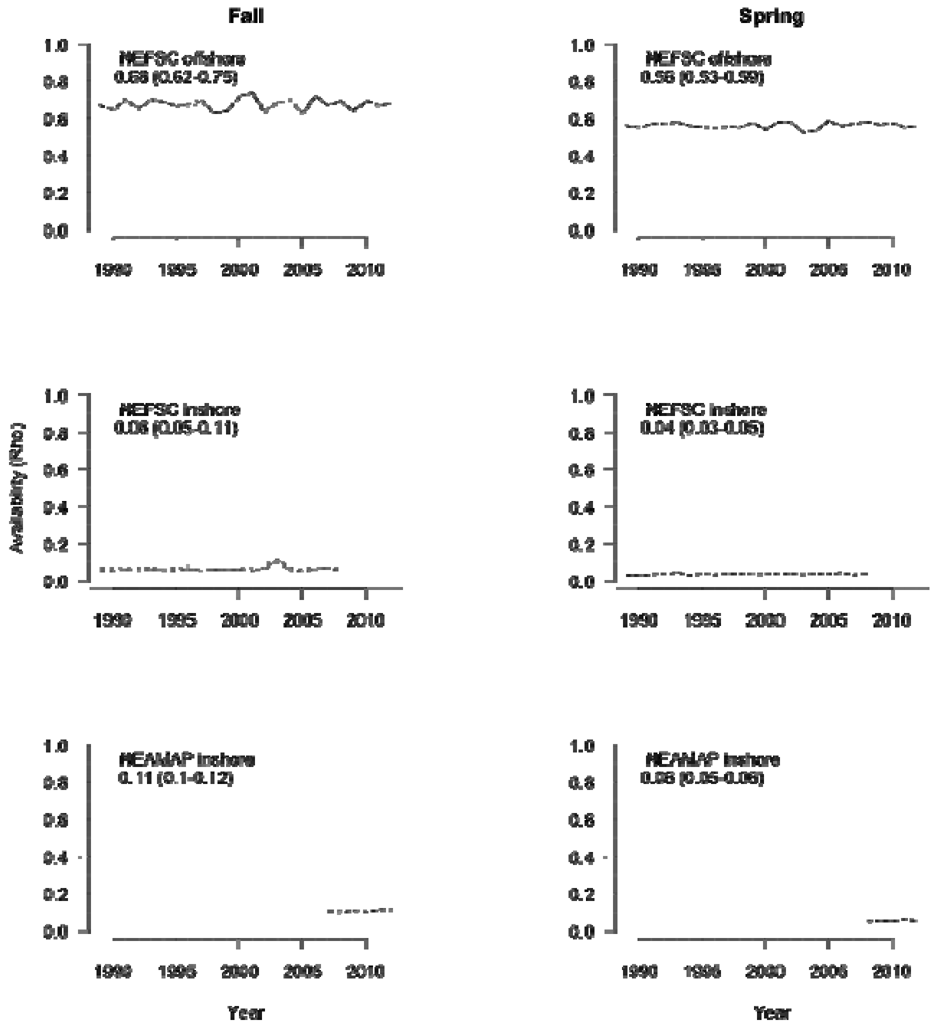

Figure A3.7. Availability ρ_H of butterfish to spring and fall NEFSC and NEAMAP surveys from 1989 through 2012 calculated as the proportion of available thermal habitat suitability sampled within the model domain estimated using the thermal niche model coupled to the de-biased ROMS bottom temperature hindcast and locations and times of survey samples. Solid line indicates the median estimate while dashed lines show 2.5% and 97.5% confidence intervals. Numbers below survey labels indicate median ρ_H of the time series (95% confidence intervals). NEFSC survey stations were separated into inshore and offshore strata in the assessment (see *Appendix 1 table 3*).

TOR 4. Evaluate consumptive removals of butterfish by its predators. If possible, integrate results into the stock assessment (TOR-5).

Introduction

Fish diet data from NEFSC bottom trawl surveys were evaluated for a broad suite of butterfish predators. The total amount of food eaten and the type of food eaten were the primary diet data examined. From these basic food habits data, diet composition of butterfish, per capita consumption, total consumption, and the amount of butterfish removed by the fish predators were calculated. Combined with abundance estimates of these predators, butterfish consumption was summed across all predators as total butterfish consumption.

Methods

Every predator that contained butterfish was identified from the NEFSC Food Habits Database (FHDBS). From this list, a subset of 6 fish predators that consistently ate butterfish with a diet composition > 1 % by mass for any 5-year block of time were selected to estimate butterfish consumption. The consistent butterfish predators are listed in Table A4.1. Minimum predator sizes for butterfish predation were derived from FHDBS (Table A4.1). Diet data were not restricted by geographic area and were evaluated for the entire northeast U.S. shelf as one geographic unit to approximate the single butterfish stock structure (see above).

Estimates were calculated on a seasonal basis (two 6 month periods) for each predator and summed for each annum. Although diet data collections for some predators started quantitatively in 1973 (silver hake only) and extends to the present (through 2012), not all butterfish predators were sampled during the full extent of this sampling program. Stomach sampling for species other than silver hake began in 1977 and extends through 2012. For more details on the food habits sampling protocols and approaches, see Link and Almeida (2000) and Smith and Link (2010). This sampling program was part of the NEFSC bottom trawl survey program; further details of the survey program can be found in Azarovitz (1981), NEFC (1988), and Reid et al. (1999).

Basic Food Habits Data

To estimate mean total stomach contents (S_i), each butterfish predator had the total amount of food eaten (as observed from food habits sampling) calculated for each temporal (*t*, fall or spring; year) scheme and was inclusive of empty stomachs (Tables A4.2 & A4.3). Mean total stomach contents was a sum of all prey items across each predator's stomachs. Mean butterfish amounts were weighted by the number of fish at length per tow and by the area of each stratum sampled. Means were presented as mean weight of butterfish per individual predator (i.e. per stratified mean number of fish predator). Units for this estimate are in grams (g). These estimates were taken as proportions of butterfish per mean total stomach contents for each temporal scheme (Tables A4.4 & A4.5).

Numbers of Stomachs

The adequacy of stomach sample sizes were assessed with trophic diversity curves by estimating the mean cumulative Shannon-Wiener diversity of stomach contents plotted as a function of stomach number. The order of stomachs sampled was randomized 100 times, and cumulative diversity curves were constructed for each species focusing on the early 1980s when stomach sampling effort was generally lowest for the entire time series. The criteria for asymptotic diversity was met when the slope of the three proceeding mean cumulative values was ≤ 0.1 which was similar to previous fish trophic studies (e.g. Koen Alonso et al. 2002; Belleggia et al. 2008; Braccini 2008). A minimum sample size approximately equal to 20 stomachs for each predator per year-season emerged as the general cutoff for these asymptotes.

For each predator, years when stomach sample sizes were < 20 (Table A4.6) were excluded from analyses (i.e. zero contribution to total butterfish consumption). This minimized the potential inflation of consumption estimates due to data extrapolation across years.

Consumption Rates

To estimate per capita consumption, the gastric evacuation rate method was used (Eggers 1977, Elliott and Persson 1978). There are several approaches for estimating consumption, but this approach was chosen as it was not overly simplistic (as compared to % body weight; Bajkov 1935) or overly complex (as compared to highly parameterized bioenergetics models; Kitchell et al. 1977). Additionally, there has been extensive use of these models (Durbin et al. 1983, Ursin et al 1985, Pennington 1985, Overholtz et al. 1991, 1999, 2000, Tsou and Collie 2001a, 2001b, Link and Garrison 2002, Link et al. 2002, Overholtz and Link 2007). Units are in g year^{-1}.

Using the evacuation rate model to calculate consumption requires two variables and two parameters. The per capita consumption rate, C_{it} is calculated as:

$$C_{it} = 24 \cdot E_{it} \cdot \overline{S_{it}}^{\gamma} \quad ,$$

where 24 is the number of hours in a day. The evacuation rate E_{it} is:

$$E_{it} = \alpha e^{\beta T} \quad ,$$

and is formulated such that estimates of mean total stomach contents (S_i) and ambient temperature (T; here used as bottom temperature from the NEFSC bottom trawl surveys associated with the presence of each predator [Taylor and Bascuñán 2000, Taylor et al. 2005]) are the only data required. The parameters α and β are set as values chosen from the literature (Tsou and Collie 2001a, 2001b, Overholtz et al. 1999, 2000). The parameter γ is a shape function and is typically set to 1 (Gerking 1994).

To evaluate the performance of the evacuation rate method for calculating consumption, a simple sensitivity analysis had been previously executed (NEFSC 2007). The results of that sensitivity analysis indicate that the single most sensitive factor when well within normal ranges is the mean stomach contents of a predator. The ranges of α and β within those reported from the literature do not appreciably impact consumption estimates (< half an order of magnitude), nor do ranges of T which were well within observed values (<< quarter an order of magnitude). An order of magnitude change in the amount of food eaten linearly results in an order of magnitude change in per capita consumption. Variance about any particular species of predator stomach contents has a CV of ~50%. Thus, within any given species for each temporal scheme, the variability of S_{it} is likely to only influence per capita consumption by half an order of magnitude or less. Estimates of abundance, and changes in estimates thereof, are likely going to dominate the scaling of total consumption by a broader range of magnitudes than the parameters and variables requisite for an evacuation method of estimating consumption. The parameters α and β were set as 0.002 and 0.115 for the elasmobranch predators respectively and 0.004 and 0.115 for the teleost predators respectively.

Fish Predator Abundance Estimation

The scaling of total consumption requires information on predator population abundance of sizes actively preying on butterfish (Table A4.1). Abundance and variance estimates were based on swept area biomass collected with the fall bottom trawl survey for each predator generated by the NEFSC software Survey Analysis Graphical Assistant (SAGA) version 6.9. An assumed q = 1.0 was applied to all predators. Predator-specific biomass conversion factors from *Albatross IV* to *Henry B. Bigelow* to account for the vessel change in 2009 were taken from Miller *et al.* (2010). Annual predator abundances by species used to estimate the scaled total amount of butterfish removed are provided in Table A4.7.

Scaling Consumption

Following the estimation of per capita consumption rates for each predator and temporal (t) scheme, those estimates were scaled up to a seasonal estimate ($C'_{it} = C_{fall}$ or C_{spring}) by multiplying the number of days in each half year:

$$C'_{it} = C_{it} \cdot 182.5 \quad .$$

Estimates of total per capita consumption (all prey) by season for each predator and year are available in Tables A4.8 & A4.9. These were then multiplied by the diet composition D_{ijt} that was butterfish (taken as a proportion), to estimate the seasonal per capita consumption of butterfish C_{ijt}:

$$C_{ijt} = C'_{it} \cdot D_{ijt} \quad .$$

Estimates of per capita butterfish consumption are available by season for each predator in Tables A4.10 & A4.11. These were then summed to provide an annual estimate, C'_{ij}:

$$C'_{ij} = C_{ij,fall} + C_{ij,spring} \quad ,$$

and were then scaled by the stock abundance to estimate a total amount of butterfish (j) removed by any predator i, Cij:

$$C_{ij} = C'_{ij} \cdot N_i \quad ;$$

N_i is the swept area estimate of abundance for each predator according to Table A4.7. Although consumption estimates of butterfish were available from 1973-2012 for silver hake, the primary time series considering the major fish predators was 1977-2012; thus, the final butterfish consumption time series was 1977-2012.

The total amount of butterfish removed (C_{ij}) were then summed across all i predators to estimate a total amount of butterfish removed by all consistent butterfish predators, C_j:

$$C_j = \sum_i C_{ij} \quad .$$

The total consumption of butterfish per predator and total amount of butterfish removed by all predators are presented as thousands of metric tons year^{-1}.

Modeling Consumption Time Series

A familiar question with regard to ecological time series is whether there are any common patterns. Through the use of multivariate autoregressive state-space models and the application of dynamic factor analysis, one can reduce the number of dimensions available to identify common trends (Zuur *et al*. 2003). Here, time series of annual consumption data by predator were standardized by creating z-scores with mean = 0 and SD = 1. Multivariate autoregressive state-space models with 1-5 (1-*n*, *n* being the number of time series available) trends were applied to the consumption data and of the form:

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \end{bmatrix}_t = \begin{bmatrix} Z_{1,1} & Z_{1,2} & Z_{1,3} & Z_{1,4} & Z_{1,5} \\ Z_{2,1} & Z_{2,2} & Z_{2,3} & Z_{2,4} & Z_{2,5} \\ Z_{3,1} & Z_{3,2} & Z_{3,3} & Z_{3,4} & Z_{3,5} \\ Z_{4,1} & Z_{4,2} & Z_{4,3} & Z_{4,4} & Z_{4,5} \\ Z_{5,1} & Z_{5,2} & Z_{5,3} & Z_{5,4} & Z_{5,5} \\ Z_{6,1} & Z_{6,2} & Z_{6,3} & Z_{6,4} & Z_{6,5} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix} + \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \end{bmatrix} + \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ v_6 \end{bmatrix}$$

where the observed consumption data (y_n) are modeled as a linear combination of factor loadings ($Z_{n,n}$) and hidden trends (x_n) plus an offset term (a_n) and noise (v_n). In this case, $a_n = 0$ with the data being standardized with z-scores. The noise term (v_n) was modeled as

$$\begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_6 \end{bmatrix} \sim \text{MVN}\left(\begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix}, \begin{bmatrix} \text{R}_{1,1} & \text{R}_{1,2} & \dots & \text{R}_{1,6} \\ \text{R}_{2,1} & \text{R}_{2,2} & \cdots & \text{R}_{2,6} \\ \vdots & \vdots & \ddots & \vdots \\ \text{R}_{6,1} & \text{R}_{6,2} & \dots & \text{R}_{6,6} \end{bmatrix} \right)$$

Where (R) is the covariance matrix structure chosen by the model, but following one of three matrix forms: diagonal and equal, diagonal and unequal, or unconstrained. Modeling multivariate datasets and identifying common trends were made with the MARSS package in R (version 3.0.0). Model selection criteria were based on AICc.

Results

Total consumption of butterfish by the fish predators was variable from 1977-2012 with 20 to over 25,000 MT yr^{-1} removed, but in general, estimates were between 1,000 and 8,000 MT yr^{-1} (Fig. A4.1). Based on dynamic factor analysis, a single trend model fit the butterfish consumption data best according to AICc (Table A4.12). This implied the trend in butterfish consumption was similar among these predators. Additionally, for each predator, fitted consumption was generally constant relative to the time series mean (Fig. A4.2; data were z-scored, mean = 0 and SD = 1). Annual CV estimates for total consumption across all fish predators were between 27 and 106 %, and a time series mean of 45 % (Table A4.13). These results support the use of a constant natural mortality rate.

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Table A4.1. Major butterfish (*Peprilus triacanthus*) predators, methods for estimating predator abundance, and minimum sizes for butterfish predation from the NEFSC Food Habits Database.

Species	Method	Minimum Size (cm)
smooth dogfish	swept area biomass- fall inshore and offshore strata	42
spiny dogfish	swept area biomass- fall inshore and offshore strata	32
silver hake	swept area biomass- fall inshore and offshore strata	23
summer flounder	swept area biomass- fall inshore and offshore strata	29
bluefish	swept area biomass- fall inshore and offshore strata	12
goosefish	swept area biomass- fall inshore and offshore strata	10

Table A4.2. Fall total mean stomach contents (all prey) for each predator by year, 1973-2012. Units: grams per individual. NAs represent years when sampling did not occur. Years with < 20 stomachs samples were excluded from analysis.

Year	Smooth dogfish	Spiny dogfish	Silver hake	Summer flounder	Bluefish	Goosefish
1973	NA	NA	6.07	NA	NA	NA
1974	NA	NA	1.74	NA	NA	NA
1975	NA	NA	0.40	NA	NA	NA
1976	NA	NA	0.23	NA	NA	NA
1977	39.75	4.89	2.10	2.77	1.32	67.96
1978	37.71	0.22	3.28	1.93	10.22	85.83
1979	46.63	0.70	1.99	10.64	30.36	62.77
1980	41.37	1.85	2.05	4.80	40.32	32.44
1981	51.80	1.72	3.74	5.98	9.08	59.07
1982	50.03	6.32	0.47	1.54	7.92	217.23
1983	46.48	12.82	9.42	7.00	18.63	5.35
1984	27.49	8.73	3.14	6.21	10.49	12.67
1985	62.74	8.14	2.23	2.92	12.88	58.19
1986	58.88	7.27	3.13	2.88	69.49	33.14
1987	60.58	4.18	4.11	2.95	49.44	28.79
1988	44.03	3.90	1.96	1.76	17.28	19.65
1989	42.83	6.57	1.42	2.07	4.28	15.41
1990	37.62	4.09	2.35	7.07	10.26	5.92
1991	67.90	8.89	4.66	0.42	10.91	18.19
1992	79.75	9.44	2.26	3.53	21.88	12.81
1993	58.66	6.25	2.24	3.36	58.91	16.52
1994	80.43	6.42	1.49	2.03	5.17	16.74
1995	50.03	4.76	2.67	1.89	35.16	43.91
1996	40.80	3.98	1.40	1.83	13.47	79.08
1997	44.99	7.34	2.11	1.66	43.80	38.69
1998	59.48	7.36	2.33	2.81	13.24	29.58
1999	39.00	7.62	1.92	3.45	15.80	18.13
2000	69.03	13.75	3.38	2.80	4.90	38.15
2001	35.65	3.95	17.74	5.89	12.16	17.39
2002	54.39	10.59	2.64	2.66	12.86	47.20
2003	50.02	25.09	1.75	7.28	5.81	35.65
2004	71.98	7.48	3.64	3.61	6.49	33.33
2005	65.70	4.24	1.77	8.32	5.78	29.71
2006	68.87	10.14	4.46	6.46	16.88	13.20
2007	45.00	4.47	1.50	5.44	9.51	70.43
2008	66.40	25.91	1.50	6.73	30.33	37.76
2009	59.43	6.26	2.51	3.12	15.03	43.10
2010	61.10	3.75	2.23	2.69	15.72	59.45
2011	51.43	2.32	2.05	7.78	10.80	39.77
2012	54.56	13.49	4.34	5.28	36.40	50.13

Table A4.3. Spring total mean stomach contents (all prey) for each predator by year, 1973-2012. Units: grams per individual. NAs represent years when sampling did not occur. Years with < 20 stomachs samples were excluded from analysis.

Year	Smooth dogfish	Spiny dogfish	Silver hake	Summer flounder	Bluefish	Goosefish
1973	NA	NA	4.916	NA	NA	NA
1974	NA	NA	0.919	NA	NA	NA
1975	NA	NA	1.895	NA	NA	NA
1976	NA	NA	2.691	NA	NA	NA
1977	11.378	3.071	1.85	0.255	NA	51.44
1978	23.421	4.142	2.559	1.02	NA	37.763
1979	4.56	1.488	1.534	3.361	0	11.041
1980	3.328	4.13	0.294	3.059	NA	40.209
1981	50	9.283	3.254	2	NA	55.513
1982	7.385	9.774	4.407	1.652	0	74.473
1983	NA	6.463	7.28	0.36	8.901	62.882
1984	2.471	11.722	1.317	0	NA	238.312
1985	35	3.957	2.469	0	15.409	2.338
1986	39.899	16.181	3.545	2.955	43.833	39.194
1987	18.157	20.316	1.193	19.554	NA	37.271
1988	33.42	14.585	0.794	0.085	68.44	22.855
1989	7.659	9.876	1.47	0.422	NA	2.296
1990	18.577	5.891	2.836	1.393	0.7	0.596
1991	14.246	11.455	1.014	1.193	NA	12.642
1992	21.291	8.265	1.494	1.65	51.115	25.357
1993	13.384	6.766	0.703	3.093	16.109	19.305
1994	4.438	4.754	0.413	1.457	27.325	39.956
1995	32.272	7.565	1.801	1.428	NA	29.164
1996	13.565	9.467	0.221	0.375	14.945	20.846
1997	9.881	8.351	1.266	0.711	13.335	20.244
1998	15.624	10.419	0.808	1.897	1.951	17.783
1999	17.914	8.864	1.929	1.924	3.097	37.307
2000	7.246	10.741	2.134	1.83	28.395	18.565
2001	8.18	5.296	3.114	2.131	1.587	23.855
2002	14.912	13.341	1.39	2.625	1.601	27.796
2003	16.503	12.263	1.513	3.36	0.034	42.125
2004	6.593	10.014	5.718	3.35	NA	29.235
2005	31.157	14.905	0.978	3.227	139.435	24.062
2006	26.32	17.675	2.498	8.117	24.567	31.838
2007	12.695	6.82	1.741	3.375	4.469	17.374
2008	34.9	6.935	2.135	1.902	13.965	20.356
2009	72.531	21.417	1.704	1.148	NA	43.602
2010	21.639	5.266	2.366	1.074	12.337	41.542
2011	12.507	3.526	4.19	0.847	13.142	25.847
2012	43.916	5.989	3.524	2.866	61.733	32.379

Table A4.4. Fall proportion of butterfish (*Peprilus triacanthus*) for each predator by year, 1973-2012. NAs represent years when sampling did not occur. Years with < 20 stomachs samples were excluded from analysis.

Year	Smooth dogfish	Spiny dogfish	Silver hake	Summer flounder	Bluefish	Goosefish
1973	NA	NA	0.01806	NA	NA	NA
1974	NA	NA	0.00000	NA	NA	NA
1975	NA	NA	0.00000	NA	NA	NA
1976	NA	NA	0.00000	NA	NA	NA
1977	0.00091	0.00000	0.00000	0.00000	0.00000	0.00000
1978	0.00645	0.00047	0.00000	0.00000	0.12912	0.00000
1979	0.00074	0.00000	0.00000	0.00000	0.00282	0.00942
1980	0.00000	0.00000	0.00000	0.00000	0.00089	0.03984
1981	0.00000	0.00000	0.00000	0.00798	0.06334	0.00000
1982	0.00000	0.01702	0.12604	0.00000	0.60275	0.02296
1983	0.00000	0.00274	0.00000	0.00000	0.00000	0.00000
1984	0.00000	0.00000	0.00000	0.00000	0.03125	0.00356
1985	0.00000	0.00000	0.00000	0.00000	0.10912	0.00000
1986	0.00000	0.00000	0.02538	0.00763	0.00170	0.00000
1987	0.00000	0.00000	0.00148	0.00268	0.00205	0.00000
1988	0.00045	0.00000	0.01829	0.12255	0.00986	0.00000
1989	0.00000	0.00008	0.00256	0.08408	0.24696	0.00000
1990	0.00000	0.00023	0.10085	0.04027	0.02260	0.00000
1991	0.00000	0.00000	0.00606	0.11342	0.14062	0.00000
1992	0.00029	0.00544	0.00587	0.09159	0.02170	0.00000
1993	0.00000	0.00000	0.00599	0.00363	0.19001	0.00829
1994	0.00000	0.00405	0.03810	0.00000	0.00000	0.00536
1995	0.00023	0.00000	0.00002	0.00000	0.00000	0.00000
1996	0.00014	0.00015	0.00000	0.00078	0.00720	0.00000
1997	0.00045	0.02089	0.07304	0.07173	0.07592	0.04373
1998	0.00000	0.00661	0.00681	0.00826	0.00295	0.00000
1999	0.03554	0.01220	0.00804	0.03500	0.05210	0.00229
2000	0.00000	0.00004	0.00000	0.04000	0.10300	0.07020
2001	0.00224	0.00000	0.00000	0.00337	0.18137	0.00000
2002	0.00017	0.00656	0.00106	0.01941	0.00094	0.00000
2003	0.00195	0.00378	0.00162	0.00089	0.04653	0.00000
2004	0.00003	0.00486	0.00000	0.03868	0.01262	0.00685
2005	0.00019	0.00016	0.00000	0.01481	0.01110	0.00000
2006	0.00000	0.05100	0.00000	0.01553	0.03596	0.02125
2007	0.00000	0.00000	0.02713	0.00136	0.00445	0.00000
2008	0.00135	0.00000	0.01989	0.00973	0.02374	0.00000
2009	0.00000	0.00298	0.00503	0.04264	0.26843	0.01187
2010	0.00526	0.00000	0.00000	0.00758	0.00476	0.01382
2011	0.00000	0.01026	0.00332	0.00133	0.26851	0.03860
2012	0.00000	0.00008	0.00061	0.00000	0.01953	0.00221

Table A4.5. Spring proportion of butterfish (*Peprilus triacanthus*) for each predator by year, 1973-2012. NAs represent years when sampling did not occur. Years with < 20 stomachs samples were excluded from analysis.

Year	Smooth dogfish	Spiny dogfish	Silver hake	Summer flounder	Bluefish	Goosefish
1973	NA	NA	0.00652	NA	NA	NA
1974	NA	NA	0.00000	NA	NA	NA
1975	NA	NA	0.00000	NA	NA	NA
1976	NA	NA	0.00000	NA	NA	NA
1977	0.00000	0.00000	0.00000	0.00000	NA	0.00000
1978	0.00000	0.00000	0.00000	0.00000	NA	0.00000
1979	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1980	0.00000	0.00000	0.00000	0.00000	NA	0.00000
1981	0.00000	0.00426	0.00030	0.00000	NA	0.00000
1982	0.00000	0.00000	0.00503	0.00000	0.00000	0.00146
1983	NA	0.00692	0.30306	0.00000	0.00000	0.00000
1984	0.00000	0.00000	0.00000	0.00000	NA	0.00000
1985	0.00000	0.04921	0.00701	0.00000	0.80252	0.00000
1986	0.00000	0.00020	0.00301	0.00000	0.00000	0.00000
1987	0.00000	0.00006	0.00000	0.00000	NA	0.00000
1988	0.00000	0.00048	0.00000	0.00000	0.00000	0.00000
1989	0.00000	0.00400	0.00092	0.00000	0.00000	0.00000
1990	0.00000	0.00030	0.00000	0.00000	0.00000	0.00000
1991	0.02807	0.00070	0.00692	0.00000	NA	0.02827
1992	0.00000	0.00690	0.00000	0.01399	0.00000	0.00000
1993	0.00000	0.05324	0.00655	0.19729	0.00000	0.00489
1994	0.00000	0.00245	0.00000	0.04774	0.66950	0.00000
1995	0.04103	0.00346	0.00197	0.01526	NA	0.00143
1996	0.00000	0.00066	0.03714	0.01898	0.00000	0.00000
1997	0.00000	0.00064	0.02718	0.08915	0.00000	0.00240
1998	0.00000	0.00194	0.00135	0.00898	0.00000	0.00077
1999	0.00290	0.00056	0.00000	0.00000	0.00000	0.00179
2000	0.00000	0.00394	0.00000	0.00000	0.20831	0.00319
2001	0.00000	0.00090	0.00667	0.01478	0.00000	0.01824
2002	0.00000	0.00128	0.00000	0.00000	0.04884	0.00000
2003	0.00000	0.00207	0.00000	0.00000	0.00000	0.02821
2004	0.00000	0.00043	0.00000	0.05610	NA	0.00064
2005	0.00000	0.00000	0.01929	0.00000	0.05527	0.00200
2006	0.00000	0.00003	0.00000	0.00000	0.00000	0.00182
2007	0.00000	0.00574	0.00093	0.00136	0.00000	0.03163
2008	0.00000	0.02585	0.00000	0.02249	0.00000	0.00000
2009	0.00000	0.00000	0.00590	0.00000	NA	0.02472
2010	0.00000	0.00694	0.00014	0.12542	0.00000	0.00281
2011	0.00000	0.00000	0.00000	0.02916	0.25773	0.09563
2012	0.00144	0.00343	0.00035	0.03198	0.00000	0.00299

Table A4.6. Number of stomachs examined for each predator in the fall and (spring), 1973-2012.

Year	Smooth dogfish	Spiny dogfish	Silver hake	Summer flounder	Bluefish	Goosefish
1973	0 (0)	0 (0)	219 (129)	0 (0)	0 (0)	0 (0)
1974	0 (0)	0 (0)	118 (199)	0 (0)	0 (0)	0 (0)
1975	0 (0)	0 (0)	154 (78)	0 (0)	0 (0)	0 (0)
1976	0 (0)	0 (0)	182 (179)	0 (0)	0 (0)	0 (0)
1977	78 (39)	240 (347)	182 (184)	53 (38)	2 (0)	90 (79)
1978	178 (50)	385 (249)	239 (185)	89 (27)	122 (0)	139 (59)
1979	197 (5)	312 (251)	166 (67)	140 (33)	199 (4)	156 (55)
1980	46 (10)	268 (221)	131 (98)	43 (26)	77 (0)	125 (122)
1981	123 (1)	529 (959)	173 (340)	96 (1)	182 (0)	69 (69)
1982	105 (30)	560 (926)	36 (491)	30 (52)	125 (2)	68 (120)
1983	50 (0)	874 (1027)	13 (105)	5 (39)	17 (15)	59 (66)
1984	96 (10)	805 (1137)	174 (113)	20 (3)	88 (0)	46 (26)
1985	123 (6)	756 (1631)	1092 (956)	103 (38)	206 (7)	60 (36)
1986	102 (24)	648 (1355)	928 (886)	33 (100)	118 (11)	45 (79)
1987	98 (9)	497 (1425)	727 (772)	118 (28)	226 (0)	60 (41)
1988	141 (5)	627 (1004)	798 (471)	110 (45)	86 (6)	44 (61)
1989	259 (22)	877 (1821)	1144 (448)	57 (30)	303 (1)	70 (78)
1990	264 (29)	793 (1713)	1096 (436)	111 (14)	240 (4)	71 (48)
1991	200 (42)	1251 (1788)	1024 (455)	166 (42)	152 (0)	236 (89)
1992	158 (79)	1982 (2322)	1176 (414)	210 (400)	188 (8)	95 (233)
1993	172 (85)	1205 (2415)	1232 (605)	208 (458)	130 (6)	219 (337)
1994	153 (15)	1091 (2076)	1163 (579)	10 (482)	3 (8)	144 (234)
1995	195 (115)	1478 (2641)	1183 (571)	212 (504)	7 (0)	240 (408)
1996	210 (160)	775 (2421)	685 (680)	313 (911)	250 (22)	87 (454)
1997	204 (64)	877 (2291)	684 (581)	349 (691)	149 (8)	78 (398)
1998	325 (83)	1166 (2406)	741 (636)	515 (702)	186 (30)	89 (316)
1999	189 (109)	611 (2280)	415 (591)	237 (872)	160 (20)	147 (446)
2000	118 (124)	440 (1190)	481 (391)	285 (629)	107 (9)	176 (419)
2001	189 (102)	450 (1151)	378 (430)	230 (672)	127 (8)	151 (545)
2002	163 (279)	365 (1058)	300 (425)	253 (764)	118 (18)	145 (439)
2003	260 (167)	281 (724)	286 (195)	180 (539)	130 (13)	130 (350)
2004	174 (91)	281 (798)	235 (268)	227 (587)	126 (0)	76 (430)
2005	204 (74)	329 (550)	233 (214)	205 (407)	140 (14)	89 (249)
2006	148 (110)	355 (668)	287 (256)	148 (354)	192 (21)	76 (217)
2007	143 (107)	250 (647)	250 (315)	172 (356)	118 (8)	59 (211)
2008	108 (41)	309 (422)	331 (233)	158 (104)	148 (5)	56 (56)
2009	85 (32)	272 (430)	396 (456)	169 (208)	104 (0)	255 (246)
2010	50 (34)	140 (394)	366 (283)	156 (225)	103 (3)	233 (204)
2011	75 (34)	262 (268)	324 (328)	131 (201)	87 (13)	234 (238)
2012	59 (63)	281 (474)	450 (441)	138 (230)	73 (3)	268 (288)

Table A4.7. Predator abundance estimates (millions) from fall survey swept area biomass, 1973-2012.

Year	Smooth dogfish	Spiny dogfish	Silver hake	Summer flounder	Bluefish	Goosefish
1973	6.70	101.00	154.00	6.64	7.06	6.35
1974	4.51	31.30	519.00	7.70	8.11	1.94
1975	10.60	128.00	403.00	11.70	9.59	3.51
1976	10.90	97.30	447.00	6.74	30.90	2.32
1977	11.60	45.40	451.00	8.59	38.30	3.38
1978	6.35	175.00	308.00	2.38	9.69	2.61
1979	7.07	153.00	233.00	4.69	28.90	3.96
1980	4.67	42.20	252.00	6.74	23.70	4.19
1981	5.45	492.00	259.00	4.17	71.50	4.80
1982	4.98	94.60	377.00	5.30	21.20	2.68
1983	1.98	230.00	324.00	6.26	13.60	4.10
1984	6.00	190.00	186.00	4.75	37.60	2.61
1985	6.05	276.00	745.00	4.27	14.40	3.15
1986	4.08	193.00	428.00	3.16	26.00	2.88
1987	2.90	241.00	198.00	1.87	5.57	2.61
1988	2.89	250.00	381.00	1.94	17.30	1.75
1989	4.41	94.60	367.00	1.33	58.00	2.54
1990	4.91	198.00	439.00	1.94	6.96	2.68
1991	2.00	279.00	528.00	3.62	10.10	4.19
1992	2.78	267.00	583.00	5.15	12.00	3.80
1993	2.58	84.00	348.00	2.32	2.20	3.81
1994	2.49	207.00	265.00	3.41	9.06	5.97
1995	3.47	233.00	675.00	5.28	8.34	4.36
1996	4.35	251.00	184.00	4.17	6.99	2.59
1997	2.92	217.00	313.00	6.74	4.70	2.51
1998	8.13	263.00	770.00	9.98	7.39	2.87
1999	11.40	160.00	593.00	8.47	16.90	4.70
2000	4.23	177.00	671.00	7.27	4.79	7.75
2001	10.40	303.00	461.00	6.76	13.40	5.68
2002	6.88	224.00	383.00	6.20	12.40	6.50
2003	11.50	145.00	685.00	6.65	23.60	6.36
2004	9.51	239.00	409.00	9.77	8.30	33.10
2005	10.60	303.00	93.30	6.55	22.60	3.77
2006	8.10	351.00	286.00	7.02	21.70	3.73
2007	8.48	302.00	267.00	7.80	10.30	2.46
2008	5.60	225.00	255.00	6.14	9.85	2.87
2009	5.61	354.00	1830.00	17.00	7.17	13.80
2010	3.42	385.00	3480.00	10.00	6.59	19.20
2011	4.09	454.00	2110.00	15.00	6.13	24.10
2012	4.21	987.00	4120.00	11.60	3.62	18.60

Table A4.8. Fall total per capita consumption (all prey) for each predator by year, 1973-2012. NAs represent years when insufficient numbers of stomachs were collected (i.e. < 20). Units: grams per individual.

Year	Smooth dogfish	Spiny dogfish	Silver hake	Summer flounder	Bluefish	Goosefish
1973	NA	NA	453.81	NA	NA	NA
1974	NA	NA	115.63	NA	NA	NA
1975	NA	NA	26.54	NA	NA	NA
1976	NA	NA	16.24	NA	NA	NA
1977	1988.01	141.32	102.46	239.56	NA	3658.86
1978	2287.87	5.66	135.58	169.95	1596.08	4228.86
1979	2168.12	22.12	89.07	963.43	2579.21	3508.61
1980	1789.49	63.10	101.01	634.28	4453.14	1855.87
1981	2860.57	50.68	185.74	614.82	1141.58	3144.71
1982	3300.53	169.84	26.89	252.63	1159.42	11731.47
1983	2522.20	355.89	NA	NA	NA	281.80
1984	1473.09	269.37	186.97	896.00	915.08	701.38
1985	4005.44	249.81	144.49	402.59	1600.03	3406.50
1986	3013.98	203.45	195.50	273.87	6294.58	1699.70
1987	3011.32	109.02	205.53	274.12	4374.08	1495.61
1988	1852.54	103.73	102.29	157.80	1395.67	979.58
1989	2239.85	189.91	77.82	201.98	440.01	796.39
1990	2503.20	93.10	129.55	1047.74	1680.98	297.52
1991	3957.08	244.29	261.41	60.43	1193.40	997.38
1992	4551.49	259.40	127.28	418.65	2092.39	666.40
1993	2685.18	173.56	124.79	338.31	5688.59	825.11
1994	4643.74	203.37	96.35	NA	NA	1220.51
1995	3595.95	156.02	173.93	273.72	NA	2586.76
1996	2873.88	114.87	76.40	270.36	1794.63	4174.79
1997	2861.16	224.46	125.02	186.56	4984.88	2112.54
1998	3115.16	195.75	118.42	275.00	1298.43	1430.26
1999	2548.91	245.34	123.72	435.48	2053.46	1165.06
2000	4748.62	458.96	211.37	329.38	645.29	2194.14
2001	2229.81	118.44	1046.82	687.63	1367.63	944.67
2002	3367.26	348.34	173.47	330.59	1800.16	2926.51
2003	3036.40	784.75	101.04	869.76	775.75	2031.39
2004	4179.02	215.51	197.38	395.68	813.05	1532.09
2005	3448.76	128.55	100.62	938.33	710.45	1648.44
2006	4132.39	331.90	283.23	716.12	1984.83	781.08
2007	2651.47	118.08	74.86	588.54	1171.92	3504.10
2008	4124.74	670.49	76.45	819.52	3293.02	1741.84
2009	3946.26	201.78	162.56	342.58	1809.39	2708.24
2010	3203.27	121.29	147.73	284.86	1576.89	3861.54
2011	2736.83	79.37	137.07	793.45	1208.10	2622.77
2012	2904.90	449.10	295.40	539.38	4156.20	3317.79

Table A4.9. Spring total per capita consumption (all prey) for each predator by year, 1973-2012. NAs represent years when insufficient numbers of stomachs were collected (i.e. < 20). Units: grams per individual.

Year	Smooth dogfish	Spiny dogfish	Silver hake	Summer flounder	Bluefish	Goosefish
1973	NA	NA	201.69	NA	NA	NA
1974	NA	NA	43.97	NA	NA	NA
1975	NA	NA	75.78	NA	NA	NA
1976	NA	NA	107.60	NA	NA	NA
1977	294.17	55.12	63.48	10.43	NA	1765.05
1978	706.98	67.73	87.33	41.72	NA	1211.03
1979	NA	25.31	49.80	151.06	NA	362.44
1980	NA	78.41	10.03	138.48	NA	1419.92
1981	NA	170.54	124.77	NA	NA	2097.99
1982	243.25	177.20	161.28	73.83	NA	2850.04
1983	NA	134.07	271.36	16.48	NA	2533.69
1984	NA	236.78	50.48	NA	NA	8738.15
1985	NA	80.32	97.30	0.00	NA	100.74
1986	1032.26	340.04	152.23	131.22	NA	1693.80
1987	NA	381.13	44.76	798.28	NA	1411.33
1988	NA	286.92	31.09	3.46	NA	941.99
1989	286.56	201.38	61.85	17.62	NA	89.54
1990	512.47	115.32	114.63	NA	NA	24.38
1991	437.10	225.58	37.97	58.70	NA	519.20
1992	667.69	157.93	57.82	72.84	NA	963.17
1993	412.88	121.24	25.49	119.87	NA	665.08
1994	NA	91.41	16.48	56.87	NA	1584.77
1995	1034.42	150.53	77.15	64.58	NA	1196.10
1996	328.15	176.06	8.65	14.82	867.15	873.84
1997	451.54	168.98	52.32	34.82	NA	834.47
1998	485.32	187.51	28.76	72.37	111.52	618.02
1999	715.25	171.99	76.17	87.11	265.28	1433.97
2000	210.70	222.17	88.23	82.79	NA	769.59
2001	250.72	103.29	117.94	90.08	NA	901.44
2002	472.19	293.39	57.79	131.51	NA	1181.77
2003	450.41	210.92	51.56	121.04	NA	1480.93
2004	168.87	163.44	185.51	114.58	NA	916.23
2005	972.72	265.73	35.36	124.01	NA	865.69
2006	860.89	359.96	104.05	388.99	1647.90	1308.47
2007	368.55	128.12	66.76	135.79	NA	662.53
2008	858.47	128.44	79.59	85.97	NA	773.21
2009	2375.39	403.45	63.64	46.43	NA	1617.98
2010	536.58	103.01	99.66	43.89	NA	1769.65
2011	350.82	72.31	174.67	34.70	NA	1112.51
2012	1479.69	145.40	164.89	154.97	NA	1597.50

Table A4.10. Fall per capita consumption of butterfish (*Peprilus triacanthus*) for each predator by year, 1973-2012. NAs represent years when insufficient numbers of stomachs were collected (i.e. < 20). Units: grams per individual.

Year	Smooth dogfish	Spiny dogfish	Silver hake	Summer flounder	Bluefish	Goosefish
1973	NA	NA	8.20	NA	NA	NA
1974	NA	NA	0.00	NA	NA	NA
1975	NA	NA	0.00	NA	NA	NA
1976	NA	NA	0.00	NA	NA	NA
1977	1.81	0.00	0.00	0.00	NA	0.00
1978	14.76	0.00	0.00	0.00	206.09	0.00
1979	1.60	0.00	0.00	0.00	7.27	33.05
1980	0.00	0.00	0.00	0.00	3.96	73.94
1981	0.00	0.00	0.00	4.91	72.31	0.00
1982	0.00	2.89	3.39	0.00	698.84	269.35
1983	0.00	0.98	NA	NA	NA	0.00
1984	0.00	0.00	0.00	0.00	28.60	2.50
1985	0.00	0.00	0.00	0.00	174.60	0.00
1986	0.00	0.00	4.96	2.09	10.70	0.00
1987	0.00	0.00	0.30	0.73	8.97	0.00
1988	0.83	0.00	1.87	19.34	13.76	0.00
1989	0.00	0.02	0.20	16.98	108.67	0.00
1990	0.00	0.02	13.07	42.19	37.99	0.00
1991	0.00	0.00	1.58	6.85	167.82	0.00
1992	1.32	1.41	0.75	38.34	45.40	0.00
1993	0.00	0.00	0.75	1.23	1080.89	6.84
1994	0.00	0.82	3.67	NA	NA	6.54
1995	0.83	0.00	0.00	0.00	NA	0.00
1996	0.40	0.02	0.00	0.21	12.92	0.00
1997	1.29	4.69	9.13	13.38	378.45	92.38
1998	0.00	1.29	0.81	2.27	3.83	0.00
1999	90.59	2.99	0.99	15.24	106.99	2.67
2000	0.00	0.02	0.00	13.18	66.47	154.03
2001	4.99	0.00	0.00	2.32	248.05	0.00
2002	0.57	2.29	0.18	6.42	1.69	0.00
2003	5.92	2.97	0.16	0.77	36.10	0.00
2004	0.13	1.05	0.00	15.30	10.26	10.49
2005	0.66	0.02	0.00	13.90	7.89	0.00
2006	0.00	16.93	0.00	11.12	71.37	16.60
2007	0.00	0.00	2.03	0.80	5.22	0.00
2008	5.57	0.00	1.52	7.97	78.18	0.00
2009	0.00	0.60	0.82	14.61	485.69	32.15
2010	16.85	0.00	0.00	2.16	7.51	53.37
2011	0.00	0.81	0.46	1.06	324.39	101.24
2012	0.00	0.04	0.18	0.00	81.17	7.33

Table A4.11. Spring per capita consumption of butterfish (*Peprilus triacanthus*) for each predator by year, 1973-2012. NAs represent years when insufficient numbers of stomachs were collected (i.e. < 20). Units: grams per individual.

Year	Smooth dogfish	Spiny dogfish	Silver hake	Summer flounder	Bluefish	Goosefish
1973	NA	NA	1.32	NA	NA	NA
1974	NA	NA	0.00	NA	NA	NA
1975	NA	NA	0.00	NA	NA	NA
1976	NA	NA	0.00	NA	NA	NA
1977	0.00	0.00	0.00	0.00	NA	0.00
1978	0.00	0.00	0.00	0.00	NA	0.00
1979	NA	0.00	0.00	0.00	NA	0.00
1980	NA	0.00	0.00	0.00	NA	0.00
1981	NA	0.73	0.04	NA	NA	0.00
1982	0.00	0.00	0.81	0.00	NA	4.16
1983	NA	0.93	82.24	0.00	NA	0.00
1984	NA	0.00	0.00	NA	NA	0.00
1985	NA	3.95	0.68	NA	NA	0.00
1986	0.00	0.07	0.46	0.00	NA	0.00
1987	NA	0.02	0.00	0.00	NA	0.00
1988	NA	0.14	0.00	0.00	NA	0.00
1989	0.00	0.81	0.06	0.00	NA	0.00
1990	0.00	0.03	0.00	NA	NA	0.00
1991	12.27	0.16	0.26	0.00	NA	14.68
1992	0.00	1.09	0.00	1.02	NA	0.00
1993	0.00	6.45	0.17	23.65	NA	3.25
1994	NA	0.22	0.00	2.71	NA	0.00
1995	42.44	0.52	0.15	0.99	NA	1.71
1996	0.00	0.12	0.32	0.28	0.00	0.00
1997	0.00	0.11	1.42	3.10	NA	2.00
1998	0.00	0.36	0.04	0.65	0.00	0.48
1999	2.07	0.10	0.00	0.00	0.00	2.57
2000	0.00	0.88	0.00	0.00	NA	2.45
2001	0.00	0.09	0.79	1.33	NA	16.44
2002	0.00	0.38	0.00	0.00	NA	0.00
2003	0.00	0.44	0.00	0.00	NA	41.78
2004	0.00	0.07	0.00	6.43	NA	0.59
2005	0.00	0.00	0.68	0.00	NA	1.73
2006	0.00	0.01	0.00	0.00	0.00	2.38
2007	0.00	0.74	0.06	0.18	NA	20.96
2008	0.00	3.32	0.00	1.93	NA	0.00
2009	0.00	0.00	0.38	0.00	NA	40.00
2010	0.00	0.71	0.01	5.50	NA	4.97
2011	0.00	0.00	0.00	1.01	NA	106.39
2012	2.13	0.50	0.06	4.96	NA	4.78

Table A4.12. Model selection results from dynamic factor analysis. AICc = selection measure.

Covariance matrix	Number of trends	AICc
diagonal and equal	1	615.07
diagonal and unequal	1	625.58
diagonal and equal	2	626.06
diagonal and equal	3	635.25
diagonal and unequal	2	637.13
diagonal and equal	4	642.39
diagonal and unequal	3	646.78
diagonal and equal	5	647.27
diagonal and unequal	4	654.30
unconstrained	1	657.55
diagonal and unequal	5	659.44
unconstrained	2	671.20
unconstrained	3	682.49
unconstrained	4	691.30
unconstrained	5	697.39

Table A4.13. CV estimates for total butterfish (*Peprilus triacanthus*) consumption, 1977-2012.

Year	CV
1977	0.462
1978	0.334
1979	0.338
1980	0.548
1981	0.607
1982	0.463
1983	0.305
1984	0.850
1985	0.484
1986	1.426
1987	0.349
1988	0.414
1989	0.660
1990	0.551
1991	0.589
1992	0.329
1993	0.433
1994	0.412
1995	0.310
1996	0.419
1997	0.488
1998	0.350
1999	0.414
2000	0.340
2001	0.581
2002	0.310
2003	0.416
2004	0.602
2005	0.443
2006	0.562
2007	0.319
2008	0.465
2009	0.340
2010	0.499
2011	0.315
2012	0.276

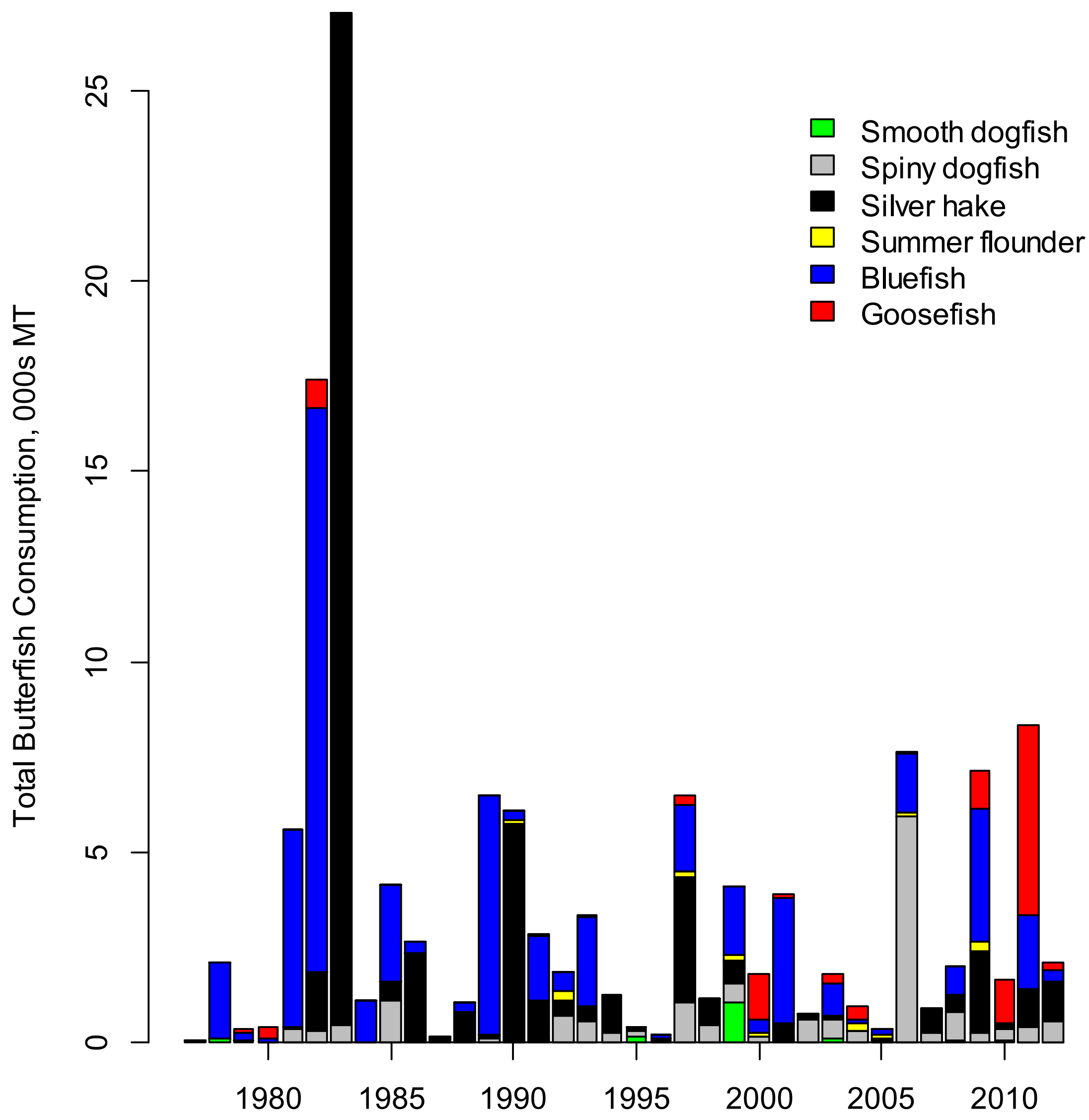

Figure A4.1. Total butterfish (*Peprilus triacanthus*) consumption by each fish predator (1977-2012).

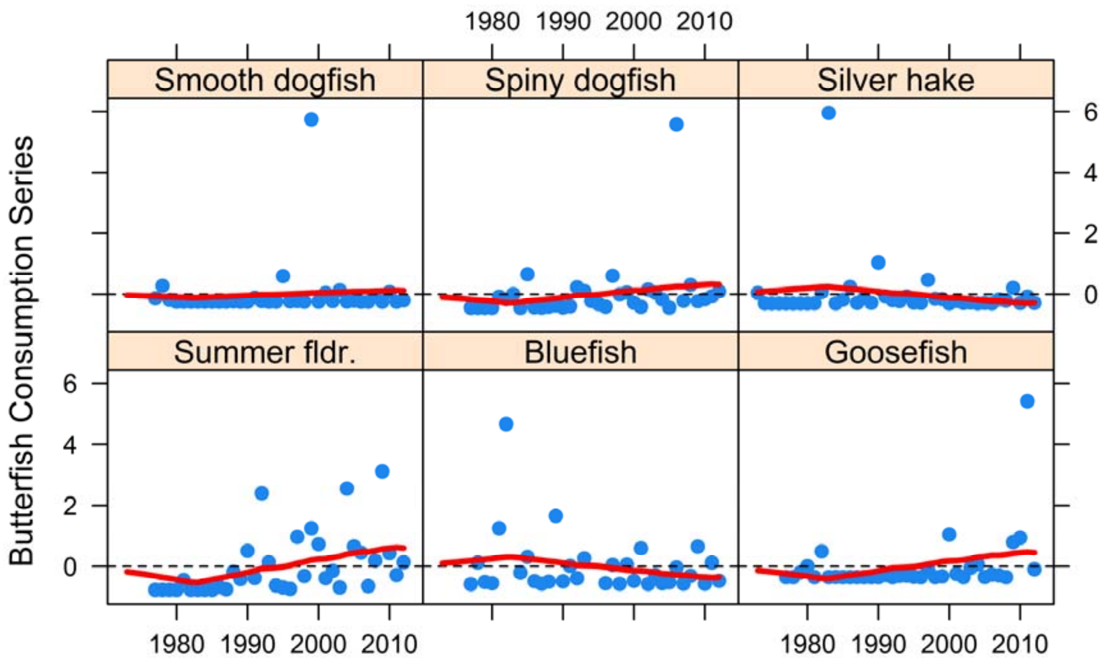

Figure A4.2. Fitted values (red lines) for annual butterfish consumption data by predator (blue dots). Chosen model contains 1 trend and a diagonal and equal covariance matrix (Table A4.12). Data were transformed with mean = 0 and SD = 1.

TOR 5. Use assessment models to estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Include a comparison with previous assessment results and previous projections.
Term of Reference 5: Stock biomass and fishing mortality

[SAW Editor's Note: ***Readers should refer to Butterfish Appendix 4 for final results of the SAW/SARC58 peer review. Appendix 4 contains the results, reference points, and projections for the final model accepted by SARC58. During the course of the SAW/SARC58 the review panel asked for several changes, which were incorporated into the final model and results (see Appendix 4).***

The following content (included directly below in the current section) provides documentation of all work that was done before the analyses in Appendix 4.]

Background

The last butterfish assessment (NEFSC, 2010), as well as the previous assessment (NEFSC, 2004), both used the KLAMZ model, which is an implementation of a delay difference model (Deriso, 1980; Schnute, 1985) developed by Dr. Larry Jacobson at the NEFSC. Briefly, 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 recruited individuals to be fully selected to the fishery. Survey indices supply information on trend of the two components of the population, while annual catches allow estimation of fishing mortality. In the last assessment (NEFSC, 2010), scale of the population was difficult to estimate in the KLAMZ model without auxiliary information on the catchability of butterfish for one or more of the survey indices.

Bridging between previous and current models

Four survey biomass indices were used in the KLAMZ model during the last assessment:

1. NEFSC spring offshore age 1+ (1973-2008)
2. NEFSC fall offshore age 0 (1992-2007)
3. NEFSC fall offshore age 1+ (1975-2008)
4. NEFSC winter offshore age 1+ (1975-2008)

Catch data covered the period 1973-2008. Estimates of total biomass from the last assessment for 1989-2008 are shown in Figure A5.1.

The 2014 SAW 58 model development process started with updates to the model used in the last assessment (NEFSC, 2010), with the goal of building a bridge to the Age Structured Assessment Program (ASAP) statistical catch at age model (Legault and Restrepo, 1999) used in the current assessment. Fishing mortality rates and stock sizes were estimated using a modified version of ASAP. These modifications are described below under *ASAP augmentations*. The standard GUI-interface ASAP (NFT, 2013) is an age-structured model that uses forward computations assuming the separability of fishing mortality into year and age components to estimate population sizes given observed catches, catch-at-age, and indices of abundance. The objective function is the sum of the likelihood components for aggregate annual catch and indices and respective age composition data various penalties may be specified. Observations of proportions at age are modeled assuming a multinomial distribution, while all other model components are assumed to have a lognormal error distribution. Diagnostics include index fits, residuals in catch and catch-at-age, and effective sample size calculations. Weights can be specified for different components of the objective function and allow for relatively simple age-structured production models to fully parameterized statistical catch-at-age models.

The working group agreed that the first step in building the bridge would be to truncate the data set in 1989, then update with data through 2012. These results are also shown in Figure A5.1. Note that values at the beginning of the series are now much lower because the series starts in 1989 (rather than 1973), and recruitment is not estimated for the first year. Removal of the NEFSC winter offshore age 1+ series had a negligible effect and thus is not shown. Three more changes were necessary for the ASAP bridge: 1) a proportion weights at age matrix; 2) a catch at age matrix; and 3) swept area abundances, which were calculated for each series, as ASAP requires absolute numbers rather than biomass. The results, shown in Figure A5.1, were considered comparable by the working group, and model building proceeded in ASAP.

ASAP augmentations and specifications for the base model

Specifications for the base model that are equivalent in the basic ASAP3 interface are described in Table A5.1. Three additional features and specifications for the base model are described below.

Covariate effects on survey catchability

Survey catchability is reparameterized as a product of efficiency E and availability A. Each of these components are bounded between 0 and 1 and A is allowed to be functions of covariates $\boldsymbol{X}_A$,

$$\log\left(\frac{A}{1-A}\right) = \boldsymbol{X}_A^T \boldsymbol{\beta}_A$$

Normal priors/penalties are allowed on $\log(E/(1-E))$ and average $\log(A/(1-A))$ across years as well.

We used this parameterization for the NEFSC fall offshore survey in the base model. We used the annual estimates of availability of the Atlantic butterfish stock to the NEFSC fall offshore survey provided in Appendix 1. For efficiency, we used a similar approach to that used in Appendix 3 to estimate a maximum detectability (equivalent to efficiency) in the envelope analysis. The difference here is we were interested in efficiency in terms of numbers rather than biomass so numbers-based indices were used. First, the relative efficiency of the survey between the day and night was used to scale the maximum efficiency of this survey over the standard 24-hour operations. We used the solar zenith angle to define day (<90.8) and night (>90.8) (Jacobson et al. 2011) and we assumed daytime tows conducted by the Henry B. Bigelow (HBB) to detect all available butterfish (δ_{day} =1) and that average efficiency for the day and night tows combined is less than 1. From the survey data we calculated the stratified mean day and night catch rates for 1989-2008 fall survey data to obtain the nighttime efficiency:

$$\frac{\delta_{night,max}}{\delta_{day,max}} = \delta_{night,max} = \frac{Catch_{day}}{Catch_{night}}$$

and in turn a maximum value for the average efficiency for all tows combined:

$$\delta_{max} = \delta_{day,max} * Proportion\ day\ tows + \ \delta_{night,max} * Proportion\ night\ tows.$$

There was a major change in 2009 in vessel and gear used for annual bottom trawl surveys carried out by the NEFSC. Prior to retiring the Albatross IV (AIV) in 2008, there was a large-scale paired gear experiment carried out with the new Henry B. Bigelow (HBB). There has been substantial effort on analyzing these data to estimate relative efficiency for various species (Miller et al 2010). The paired-gear study indicated that the HBB was much more efficient than the Albatross IV (AIV) for most species. On average, the HBB was estimated to catch 1.935 times the butterfish in numbers per tow as the AIV. Additionally, the ratio of the average HBB and AIV swept area per tow is 0.0239 km^2/0.0382 km^2 = 0.63. Combining these two factors indicates that the efficiency per km^2 of the AIV is 0.33 that of the HBB on a numbers tow^{-1} basis and combined with the maximum efficiency of the HBB, the maximum efficiency of the AIV is 0.197. This analysis assumes the HBB daytime tows are fully efficient and estimates the maximum efficiency for all HBB tows and a constant calibration factor from Miller et al. (2010) to provide an estimate of maximum efficiency for the AIV for the entire time series. Note, that using an estimate of maximum efficiency is conservative since abundance estimates are inversely related to efficiency with all other parameters equal.

Incorporation of length-based relative catch efficiency of HBB:AIV

For many species there are substantial size effects on this calibration factor (e.g., Miller 2013). To incorporate uncertainty in size-based estimates of relative catch efficiency in the assessment model, a penalty is added to the likelihood for the estimates of the p spline smoother coefficients $\boldsymbol{\beta}$ provided by Miller (2013),

$$f(\hat{\boldsymbol{\beta}}) = (2\pi)^{-\frac{p}{2}} |\boldsymbol{\Sigma}|^{-\frac{1}{2}} e^{-\frac{1}{2}(\boldsymbol{\beta}-\hat{\boldsymbol{\beta}})^T \boldsymbol{\Sigma}^{-1}(\boldsymbol{\beta}-\hat{\boldsymbol{\beta}})}$$

where $\boldsymbol{\Sigma}$ is the estimated variance-covariance matrix from the fitted hierarchical generalized additive model. The data file includes the estimates of $\boldsymbol{\beta}$ and $\boldsymbol{\Sigma}$ as well as the design matrix for calculating the relative catch efficiency at length and, for the HBB surveys, the numbers-at-length indices and age-length keys. The calibrated (AIV scale) survey indices are calculated as

$$\hat{I}_A = \sum_{l=1}^{L} I_{H,l}\rho_l$$

where $I_{H,l}$ is the HBB numbers-at length l,

$$\rho_l = e^{-X_l^T \boldsymbol{\beta}}$$

is the relative catch efficiency (AIV:HBB) at length l and X_l is the row of the design matrix for the spline smoother associated with length l. The AIV proportions at age are calculated from the indices-at-age,

$$\hat{I}_{A,a} = \sum_{l=1}^{L} p(a \mid l) I_{H,l} \rho_l$$

where $p(a \mid l)$ is the proportion at age a given length l from the age length key. The indices $\hat{I}_A$ are used in the normal calculations of the survey likelihood components using the CVs supplied with the index data. Therefore, we are implicitly assuming that the CVs of the indices and effective sample sizes for the proportions-at-age are the same as if the AIV were being used in those years to conduct the bottom trawl survey. The calibrated indices and proportions at age also replace the normal index data for the calibrated years in the report file. Note that there will be p more parameters estimated when calibrated indices are used so that deviations from $\boldsymbol{\beta}$ can be allowed. This approach allows the catchability in years when the HBB was used to differ from those years when the AIV was used, but in a way that is informed by the paired-gear experiment.

The base butterfish model includes internal length-based calibration for the spring and fall NEFSC offshore survey data from 2009-2012. The same length-based calibration estimates and penalties are used for both seasons (Table A5.2). The sizes observed in the data on butterfish from the paired gear study ranged from 2 to 21 cm, but there is sometimes sizes observed in the 2009-2012 data outside of this range. Therefore, for sizes greater than 21cm we assumed the same relative efficiency as that at 21 cm and any the relative efficiency at 2cm was applied to any observations at 1cm. Observations outside the 2-21cm are rare and this type of extrapolation has little effect on the calibrated aggregate indices or the age composition.

Estimation of natural mortality effects

There is also a change in the parameterization of natural mortality so that annual or age-specific effects of covariates on natural mortality can be specified or estimated. The annual and age-specific effects are linear on the log scale

$$\log M_{y,a} = \boldsymbol{X}_y^T \boldsymbol{\beta}_{M,y} + \boldsymbol{X}_a^T \boldsymbol{\beta}_{M,a}.$$

Estimating effects of covariates on or M by subsets of ages or years is accomplished by specifying appropriate design matrices.

Given the parameterization described above which constrains the catchability of the NEFSC fall offshore survey, we were able to estimate a constant natural mortality rate in the base model.

Diagnostics for the base model

The other data components in the base model did not have a major effect on the length-based relative efficiency estimates for the HBB and AIV (Figure A5.2).

Objective function components for the base model are shown in Table A5.3. Root MSE for data components from the base model are generally close to 1 (Table A5.4).

No trends are apparent in the residuals for catch (Figure A5.3), the NEFSC surveys (Figures A5.4 – A5.6), or the NEAMAP surveys (Figures A5.7 and A5.8). Similarly, no trends are apparent in the residuals for catch age composition (Figure A5.9), NEFSC survey age compositions (Figures A5.10 – A5.12), or NEAMAP survey age compositions (Figures A5.13 and A5.14).

Results for the base model

The peak in fishing mortality rate on fully selected ages (ages 2 to 4+) was F = 0.22, which occurred in 1993 (Tables A5.5 and A5.6; Figure A5.15). Fishing mortality ranged between 0.06 and 0.20 during 1994-2001, but has been ≤ 0.05 since 2002. Butterfish are fully selected by age 2 in the fishery (Figure A5.16).

Spawning stock biomass (Age 1+) has varied over time (Table A5.5; Figures A5.17 – A5.20). Since 1989 spawning biomass averaged 64,703 mt (142.6 million lb), and during 2000-2012 averaged 68,262 mt (150.5 million lb). Spawning stock biomass peaked in 2012 at 90,693 mt (199.9 million lb).

Recruitment averaged 8.1 billion fish during 1989-2012 (Table A5.5; Figures A5.19 – A5.21). The 1997, 1999 and 2011 year classes were the largest, at 12.7, 12.6 and 12.5 billion fish, respectively. The 2012 year class, estimated to be 3.5 billion fish, is the smallest of the time series. Estimated numbers at age are shown in Table A5.7 and Figure A5.22.

CVs for SSB and recruitment were ≤ 0.30 (Table A5.5; Figure A5.23), while CVs for F were variable, ranging from 0.21 to 0.98.

Index catchabilities and selectivities are shown in Figures A5.24 and A5.25, respectively.

Sensitivities

We explored five sets of sensitivities of annual estimates of spawning biomass, recruitment, and fishing mortality rate and minimized objective function components to various assumptions and each of the augmentations of the basic ASAP3 model. First, various models employing each of the ASAP3 augmentations singly were compared to the base model (see Table A5.8). Included in this set were models that used length-based calibration but fixed at the values estimated by Miller (2013) rather than allowing deviations from these results within the assessment model. Constraining the deviations to zero is equivalent to performing the length-based calibration externally to the assessment model. The largest difference in predicted indices and annual estimates of spawning biomass, recruitment and fishing mortality are due to the type of calibration used for the NEFSC surveys (Figures A5.26 and A5.27). Usage of the constant calibration led to higher predicted indices, SSB, and recruitment and lower fishing mortality than when the length-based calibration was used. Whether the length-based calibration was assumed known at the estimates provided by Miller (2013) or penalized deviations were allowed had a smaller effect on the results. Models that did not use length based calibration allowed better fit to the aggregate indices, but poorer fit to the survey age composition (Figure A5.28). Survey age composition also appeared to be fit better when estimation of natural mortality was allowed, but the fit to the age composition of the catch was poorer. There is also a substantial reduction in the total minimized objective function when the length-based calibration is allowed to deviate from the estimates provided by Miller (2013).

In the second set, we compared results from the base model to alternatives that excluded all spring survey data or assumed full selectivity of all surveys except age 0 for spring surveys. Recent spawning biomass estimates are higher in the base model than when full survey selectivity is assumed or when the spring surveys are excluded (Figure A5.29). Similarly, recent fishing mortality rates are somewhat lower for the base model. Constraining full selectivity of all ages for the surveys (except age 0 in the spring surveys) reduces the goodness of fit as measured by the total objective function and as expected the survey age composition is the component is the cause (Figure A5.30). The total catch and catch age composition are fit a bit better when the spring surveys are excluded. The relative catch efficiency penalty is reduced in both sensitivities indicating that there is less deviation from the curve estimated by Miller (2013).

The third set evaluated effects of natural mortality on results with assumed values ranging between 0.6 and 1.4. The relationship of natural mortality to SSB, recruitment and fishing mortality rate estimates is as expected: a positive correlation with recruitment, but a generally negative correlation with SSB and fishing mortality rate (Figure A5.31). At the lowest assumed values of natural mortality rate there were implausibly high fishing mortality rates estimated for some years with poor precision of discard estimates which presumably traded off with a better fit for some other objective components in those years. As expected the total objective function is minimized at the natural mortality estimated in the base model and all of the likelihood components except total catch indicated a better fit at higher natural mortality rate (Figure A5.34).

Fourth, we explored the sensitivity to assumptions about the catchability of the NEFSC fall survey, by fitting models with catchability ranging between approximately 0.1 and 0.3. The values are approximate because the annual habitat-based measures of availability were still included, but the constant efficiency was set to achieve the specified approximate or "average" catchability. The relationship of catchability to SSB, recruitment and fishing mortality rate estimates is straightforward: an inverse relationship to catchability for SSB and recruitment and positive correlation with fishing mortality rate (Figure A5.33). Best fits in terms of total objective function were obtained at the lowest catchability and all components favored lower catchability (Figure A5.34).

The final sensitivity compared the base model results to a the same, but allowed penalized deviation of the efficiency of the NEFSC fall offshore survey from an estimate of the maximum AIV efficiency in terms of numbers/tow rather than biomass as described in Appendix 2 for the envelope analysis. The penalty is based on the uncertainty of the estimate which pairs 10,000 parametric bootstraps of the constant calibration factor from Miller et al. (2010) and the rescaling bootstrapping technique outlined in Smith (1997) as described in Appendix 2 for the envelope analysis. Because the penalty in the model is parameterized in terms of the logit efficiency, this transformation was performed for all bootstraps and the mean (-1.39) and standard deviation (0.11) of this transformation was calculated. There was very little difference in annual estimates when the efficiency was estimated and the penalty included (Figure A5.35). Similarly, there were negligible differences in objective function components and the difference in the total objectives is due to the penalty on the efficiency (Figure A5.36). Although there is little effect on the point estimates when the efficiency is penalized, this model may be preferable to the base because uncertainty in the efficiency estimate is included in the model and propagated in uncertainty in the estimates of primary interest.

Simulations

The base model includes the habitat-based measure of availability, internal length-based calibration, and estimation of natural mortality. Because these features required modification of the ASAP model we performed two sets of 100 simulations aimed at the latter two modification to evaluate the behavior of the model statistically and to strengthen confidence in the results for the base model. For each set of simulations, means and 95% confidence intervals of estimates were calculated.

In each of the first set of simulations, randomly generated index, index age composition, catch, and catch age composition observations based on the estimated population numbers at age, annual fishing mortalities, and catchability and selectivity parameters from the base model. For each simulated data set, the model was re-estimated and the means and confidence intervals for annual SSB, F, and recruit estimates, and natural mortality estimates were compared to those from the base model. There was no estimation of length-based calibration parameters necessary in this set of simulations. The model performs well with respect to bias in annual estimates in that confidence intervals nearly always include the estimates from which the simulations were based (Figure A5.37). Similarly, the confidence interval for natural mortality estimates (1.252, 1.273) included the estimate from the base model (1.270).

In each of the second set of simulations, we generated parametric bootstraps of the smoother coefficients for the length-based relative catch efficiency based on the estimated covariance matrix for these coefficients from Miller (2013). Again for each generated data set, the model was re-estimated and we calculated means and confidence intervals for SSB, F, M and recruit estimates, but we also made these calculations for predicted relative catch efficiency at size. All annual estimates were estimated very precisely and there was no indication of bias (Figure A5.38). Similarly, the confidence interval for natural mortality estimates (1.269012, 1.27052) included the estimate from the base model (1.27046). There was also no evidence of bias in the predicted relative catch efficiency from the simulated data (Figure A5.39).

Retrospective patterns

We conducted a retrospective analysis of the base model by comparing annual SSB, recruitment and fishing mortality rate estimates for models fit to trimming the terminal year of data to 2011, 2010, 2009, and 2008 using Mohn's rho (Mohn 1999). There was a trend in terminal year estimates of SSB, recruitment and fishing mortality prior to inclusion of 2012 data, but the trend was reversed when this last year was included (Figure A5.40). Furthermore, the scale of the differences is relatively small based on calculated Mohn's rho values.

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Table A5.1. Specifications for the base model that are also specified in ASAP3.

Catch CVs	based on variance estimation for discards
Aggregate survey index CVs	design-based estimates were rescaled for RMSE diagnostics

Fishery effective sample size (input)	27
Starting value for fishery selectivity, Age 0	1
Starting value for fishery selectivity, Age 1	1
Starting value for fishery selectivity, Age 2	1 (fixed)
Starting value for fishery selectivity, Age 3	1 (fixed
Starting value for fishery selectivity, Age 4+	1 (fixed)
NEFSC spring offshore effective sample size (input)	12
NEFSC fall offshore effective sample size (input)	19
NEFSC fall inshore effective sample size (input)	14
NEAMAP spring effective sample size (input)	25
NEAMAP fall effective sample size (input)	41
Starting value for NEFSC spring offshore survey, Age 0	0 (fixed)
Starting value for NEFSC spring offshore survey, Age 1	1 (fixed)
Starting value for NEFSC spring offshore survey, Age 2	0.474
Starting value for NEFSC spring offshore survey, Age 3	0.346
Starting value for NEFSC spring offshore survey, Age 4+	0.346 (fixed)
Starting value for NEFSC fall offshore survey, Age 0	1 (fixed)
Starting value for NEFSC fall offshore survey, Age 1	0.58
Starting value for NEFSC fall offshore survey, Age 2	0.632
Starting value for NEFSC fall offshore survey, Age 3	0.632 (fixed)
Starting value for NEFSC fall offshore survey, Age 4+	0.632 (fixed)
Starting value for NEFSC fall inshore survey, Age 0	1 (fixed)
Starting value for NEFSC fall inshore survey, Age 1	0.461
Starting value for NEFSC fall inshore survey, Age 2	0.657
Starting value for NEFSC fall inshore survey, Age 3	0.349
Starting value for NEFSC fall inshore survey, Age 4+	0.349 (fixed)
Starting value for NEAMAP spring survey, Age 0	0.005
Starting value for NEAMAP spring survey, Age 1	1 (fixed)
Starting value for NEAMAP spring survey, Age 2	1 (fixed)
Starting value for NEAMAP spring survey, Age 3	1 (fixed)
Starting value for NEAMAP spring survey, Age 4+	1 (fixed)
Starting value for NEAMAP fall survey, Age 0	1 (fixed)
Starting value for NEAMAP fall survey, Age 1	1
Starting value for NEAMAP fall survey, Age 2	0.298
Starting value for NEAMAP fall survey, Age 3	0.298
Starting value for NEAMAP fall survey, Age 4+	0.298
Fraction of year at NEFSC spring offshore survey	0.25
Fraction of year at NEFSC fall offshore survey	0.75
Fraction of year at NEFSC fall inshore survey	0.75
Fraction of year at NEAMAP spring survey	0.33
Fraction of year at NEAMAP fall survey	0.67
Fraction of year at spawning	0.5

Table A5.2. Estimated smoother coefficients and covariance matrix for Atlantic butterfish length-based relative catch efficiency from Miller (2013) used to specify penalty in base model.

Coefficient	Covariance matrix									
-1.231	0.018	0.003	-0.006	-0.010	-0.012	-0.012	-0.010	-0.003	0.008	0.020
-0.102	0.003	0.059	0.009	-0.020	-0.034	-0.041	-0.041	-0.031	-0.026	-0.028
-1.047	-0.006	0.009	0.090	0.091	0.100	0.103	0.097	0.057	0.005	-0.018
-0.838	-0.010	-0.020	0.091	0.129	0.145	0.153	0.141	0.085	0.018	-0.015
-0.764	-0.012	-0.034	0.100	0.145	0.183	0.193	0.179	0.110	0.027	-0.012
-0.753	-0.012	-0.041	0.103	0.153	0.193	0.217	0.202	0.126	0.036	-0.007
-0.807	-0.010	-0.041	0.097	0.141	0.179	0.202	0.203	0.132	0.047	0.008
-0.468	-0.003	-0.031	0.057	0.085	0.110	0.126	0.132	0.114	0.073	0.057
0.222	0.008	-0.026	0.005	0.018	0.027	0.036	0.047	0.073	0.180	0.311
0.737	0.020	-0.028	-0.018	-0.015	-0.012	-0.007	0.008	0.057	0.311	0.949

Table A5.3. Objective function components for the base model.

Objective Function Components	Base
Aggregate catch	189.96
Aggregate survey indices	1047.01
Catch age composition	181.995
Survey age composition	239.294
Relative catch efficiency penalty	-2.26577
Total	1656

Table A5.4. Root MSE for data components from the base model.

Data	Base
Aggregate catch	0.12
Aggregate survey indices	1.28
NEFSC spring offshore indices	1.1
NEFSC fall offshore indices	1.36
NEFSC fall inshore indices	1.32
NEAMAP spring indices	1.55
NEAMAP fall indices	1.25

Table A5.5. Annual estimates of spawning biomass (mt), recruitment (millions), and fully selected fishing mortality from the base model.

Year	Spawning Biomass	CV	Recruitment	CV	Full F	CV
1989	41,056	0.28	5,784	0.25	0.21	0.53
1990	56,262	0.24	7,125	0.21	0.05	0.26
1991	49,128	0.21	5,827	0.21	0.18	0.72
1992	50,508	0.19	6,434	0.19	0.16	0.39
1993	55,929	0.18	9,365	0.20	0.22	0.27
1994	52,787	0.18	9,706	0.19	0.20	0.32
1995	59,674	0.17	4,293	0.23	0.14	0.38
1996	56,621	0.18	10,499	0.20	0.08	0.25
1997	85,255	0.17	12,693	0.17	0.06	0.30
1998	85,836	0.15	8,361	0.22	0.09	0.98
1999	72,399	0.17	12,581	0.21	0.15	0.35
2000	87,599	0.18	9,880	0.21	0.11	0.27
2001	81,795	0.18	7,506	0.21	0.11	0.34
2002	70,240	0.18	7,631	0.20	0.05	0.77
2003	67,331	0.18	9,390	0.18	0.04	0.87
2004	74,722	0.16	4,882	0.21	0.03	0.27
2005	48,712	0.17	7,007	0.17	0.02	0.21
2006	57,178	0.16	6,464	0.19	0.03	0.45
2007	64,877	0.16	6,057	0.18	0.02	0.23
2008	53,711	0.16	6,812	0.17	0.03	0.47
2009	48,095	0.17	11,266	0.19	0.03	0.28
2010	69,057	0.18	9,115	0.19	0.08	0.34
2011	73,395	0.19	12,456	0.20	0.03	0.23
2012	90,693	0.19	3,466	0.30	0.02	0.30

Table A5.6. Estimated fishing mortality at age from the base model.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0.006	0.056	0.209	0.209	0.209
1990	0.002	0.014	0.053	0.053	0.053
1991	0.005	0.049	0.182	0.182	0.182
1992	0.005	0.042	0.156	0.156	0.156
1993	0.007	0.059	0.218	0.218	0.218
1994	0.006	0.053	0.195	0.195	0.195
1995	0.004	0.038	0.142	0.142	0.142
1996	0.002	0.020	0.076	0.076	0.076
1997	0.002	0.015	0.055	0.055	0.055
1998	0.003	0.025	0.093	0.093	0.093
1999	0.005	0.040	0.150	0.150	0.150
2000	0.003	0.030	0.112	0.112	0.112
2001	0.003	0.031	0.115	0.115	0.115
2002	0.001	0.012	0.045	0.045	0.045
2003	0.001	0.010	0.037	0.037	0.037
2004	0.001	0.007	0.027	0.027	0.027
2005	0.001	0.006	0.021	0.021	0.021
2006	0.001	0.007	0.027	0.027	0.027
2007	0.000	0.004	0.015	0.015	0.015
2008	0.001	0.008	0.031	0.031	0.031
2009	0.001	0.008	0.030	0.030	0.030
2010	0.002	0.021	0.078	0.078	0.078
2011	0.001	0.009	0.033	0.033	0.033
2012	0.001	0.006	0.022	0.022	0.022

Table A5.7. Estimated numbers at age (millions) on January 1 from the base model.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	5,784	1,901	515	146	10
1990	7,125	1,614	504	117	35
1991	5,827	1,997	447	134	41
1992	6,434	1,627	534	104	41
1993	9,365	1,798	438	128	35
1994	9,706	2,612	476	99	37
1995	4,293	2,709	696	110	31
1996	10,499	1,200	732	169	34
1997	12,693	2,940	330	190	53
1998	8,361	3,557	813	88	65
1999	12,581	2,340	974	208	39
2000	9,880	3,516	631	235	60
2001	7,506	2,764	957	158	74
2002	7,631	2,100	752	240	58
2003	9,390	2,139	582	202	80
2004	4,882	2,633	595	158	76
2005	7,007	1,369	734	162	64
2006	6,464	1,966	382	202	62
2007	6,057	1,813	548	104	72
2008	6,812	1,700	507	151	49
2009	11,266	1,910	473	138	55
2010	9,115	3,159	532	129	52
2011	12,456	2,553	868	138	47
2012	3,466	3,493	710	236	50

Table A5.8. Description of models fitted to evaluate sensitivity to augmentations to basic ASAP3 model.

M+H+C	base model including all 3 augmentations
M+Cfixed+H	Same as base model implementation except length-based calibration is done externally
M	Same as ASAP3 implementation except natural mortality is estimated
H	Same as ASAP3 implementation except habitat-based availability is added
C	Same as ASAP3 implementation except length-based calibration is done internally with penalized deviations away from input calibration coefficients.
Cfixed	Same as ASAP3 implementation except length-based calibration is done externally
ASAP3	No additional features implemented, constant (seasonal) calibration done externally

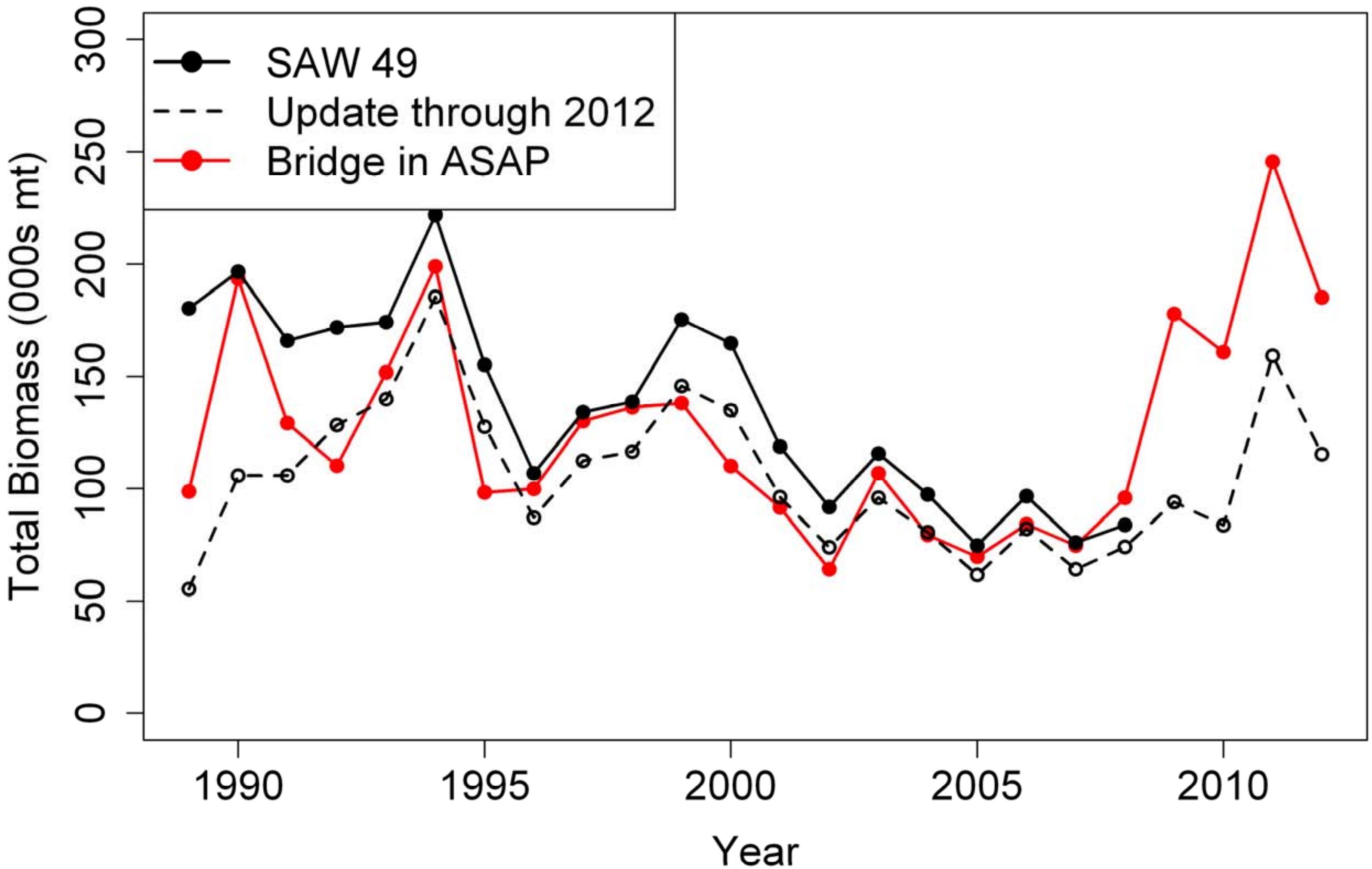


Figure A5.1. KLAMZ estimated total biomass from the last assessment (NEFSC, 2010), KLAMZ update using data through 2012, and total biomass in ASAP using the same parameters as the KLAMZ model.

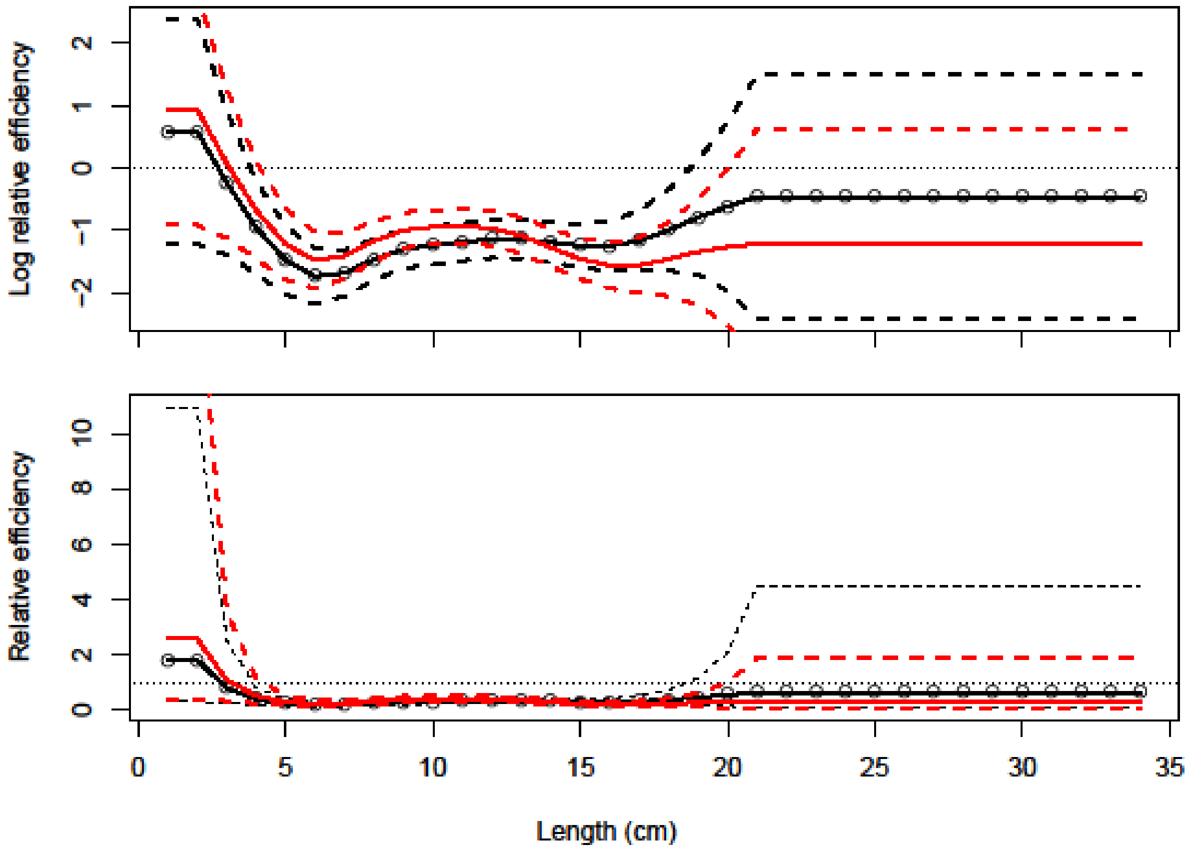


Figure A5.2. Estimates of relative catch efficiency (black) from Miller (2013) and modified from the base model (red).

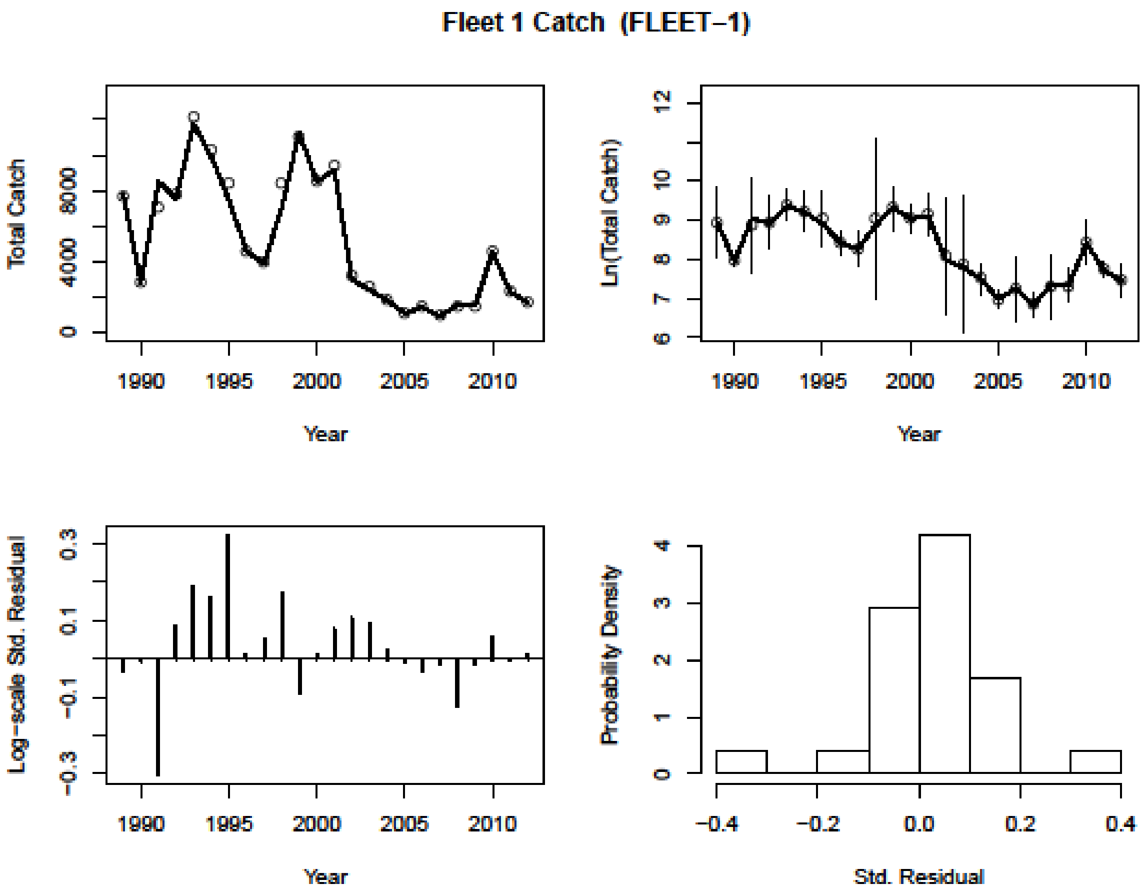


Figure A5.3. Diagnostics for aggregate catch from the base model.

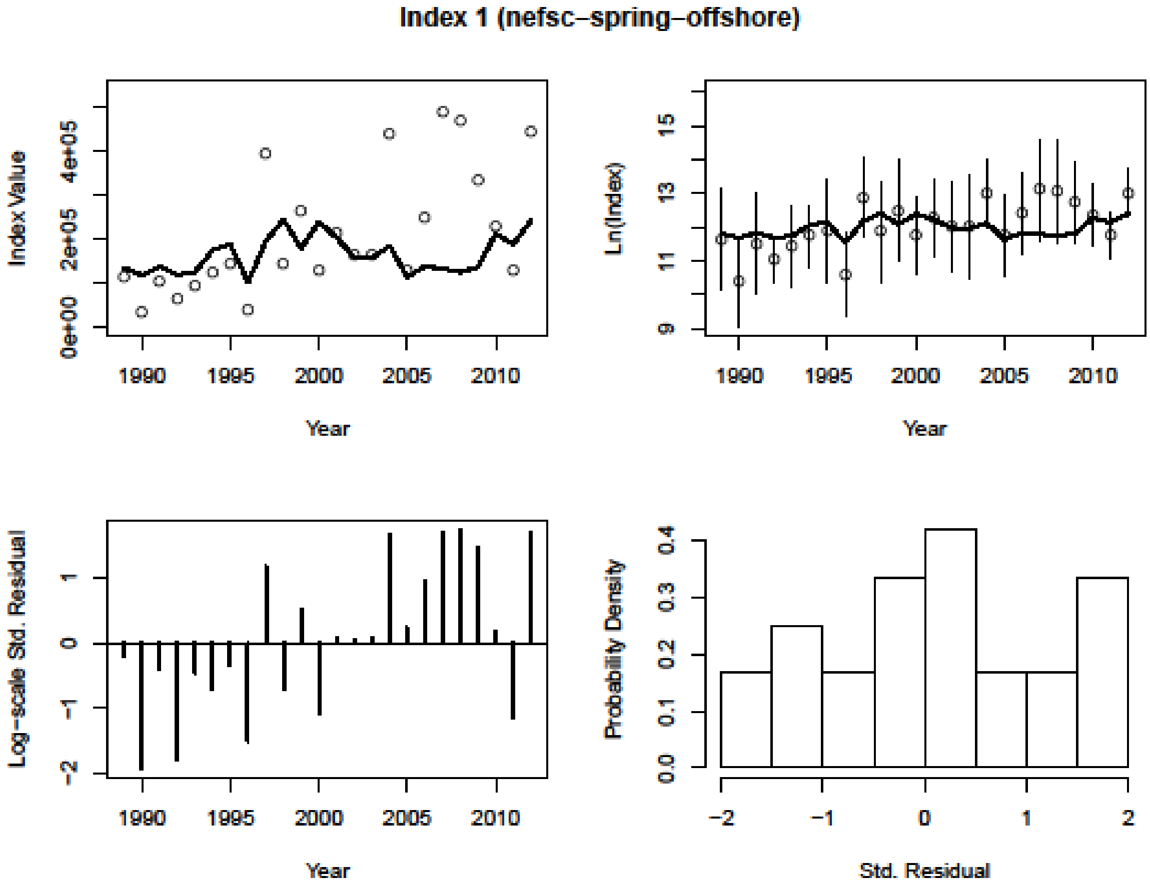


Figure A5.4. Diagnostics for NEFSC spring offshore survey from the base model.

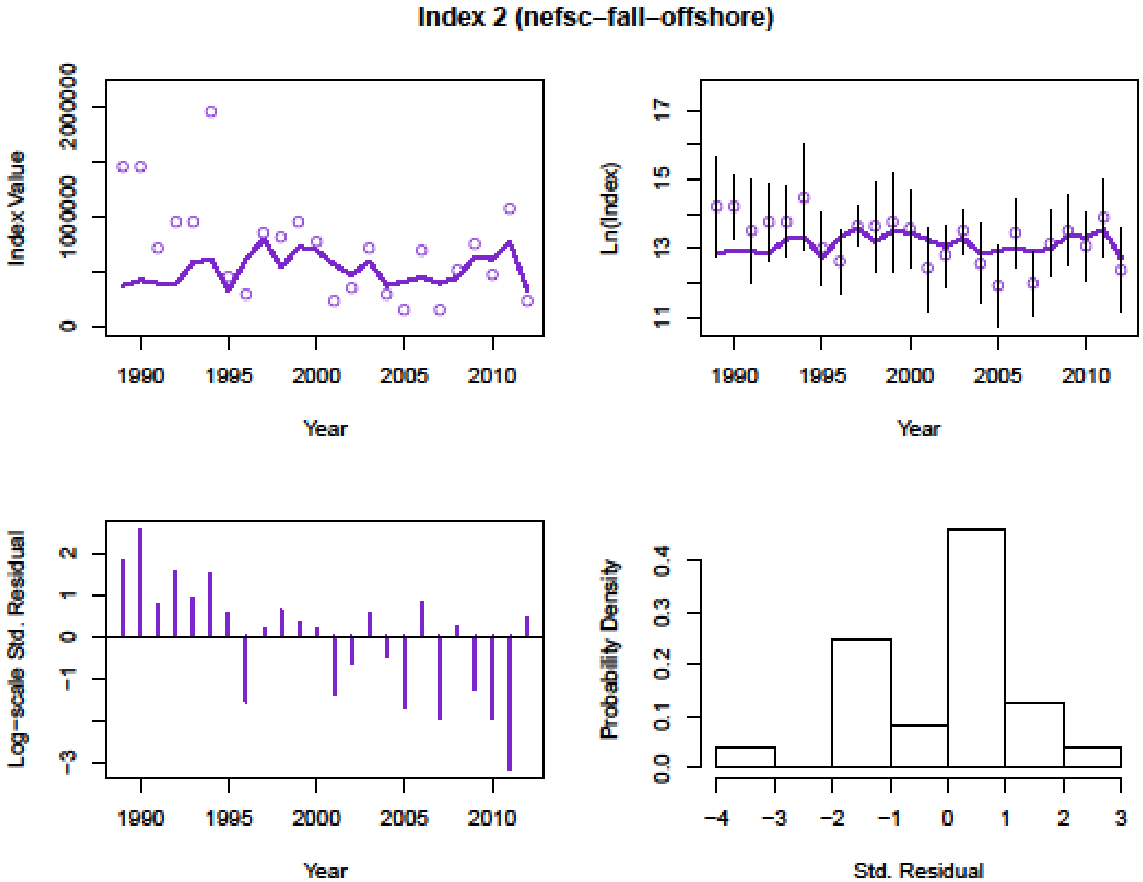


Figure A5.5. Diagnostics for NEFSC fall offshore survey from the base model.

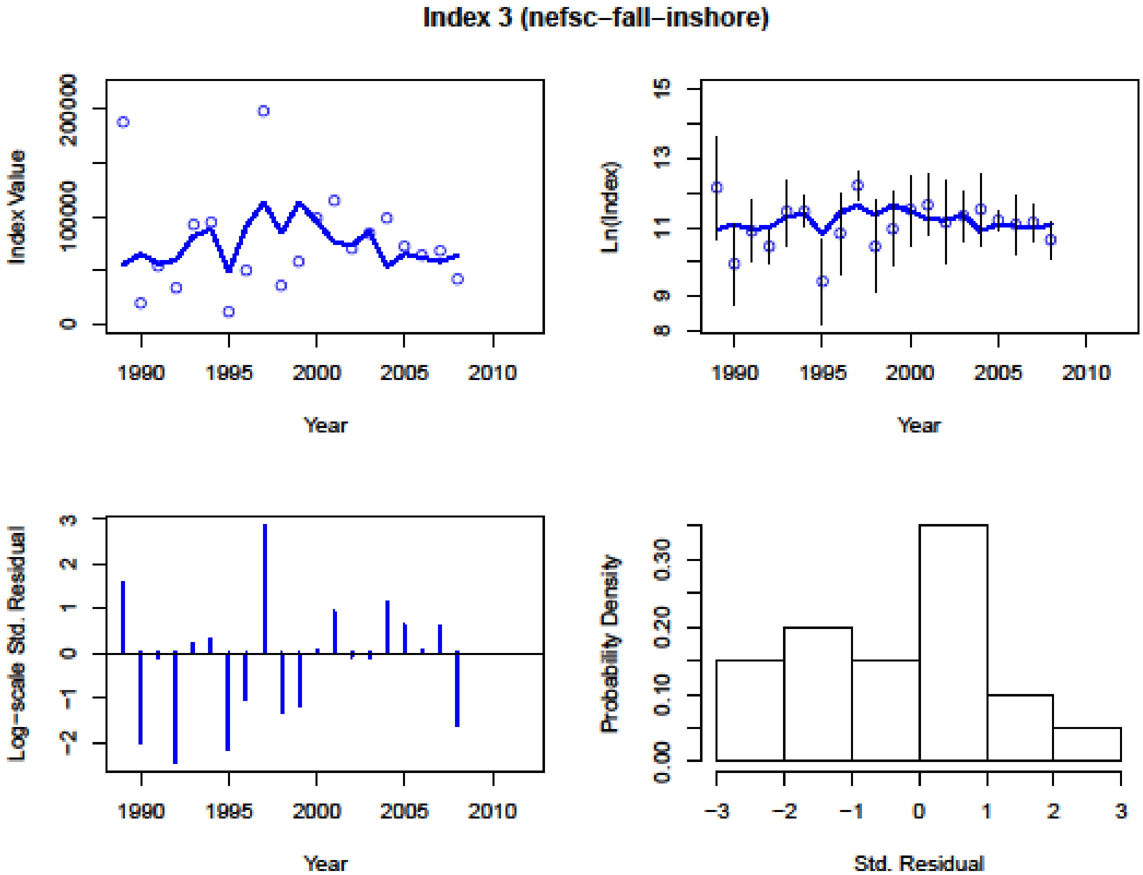


Figure A5.6. Diagnostics for NEFSC fall inshore survey from the base model.

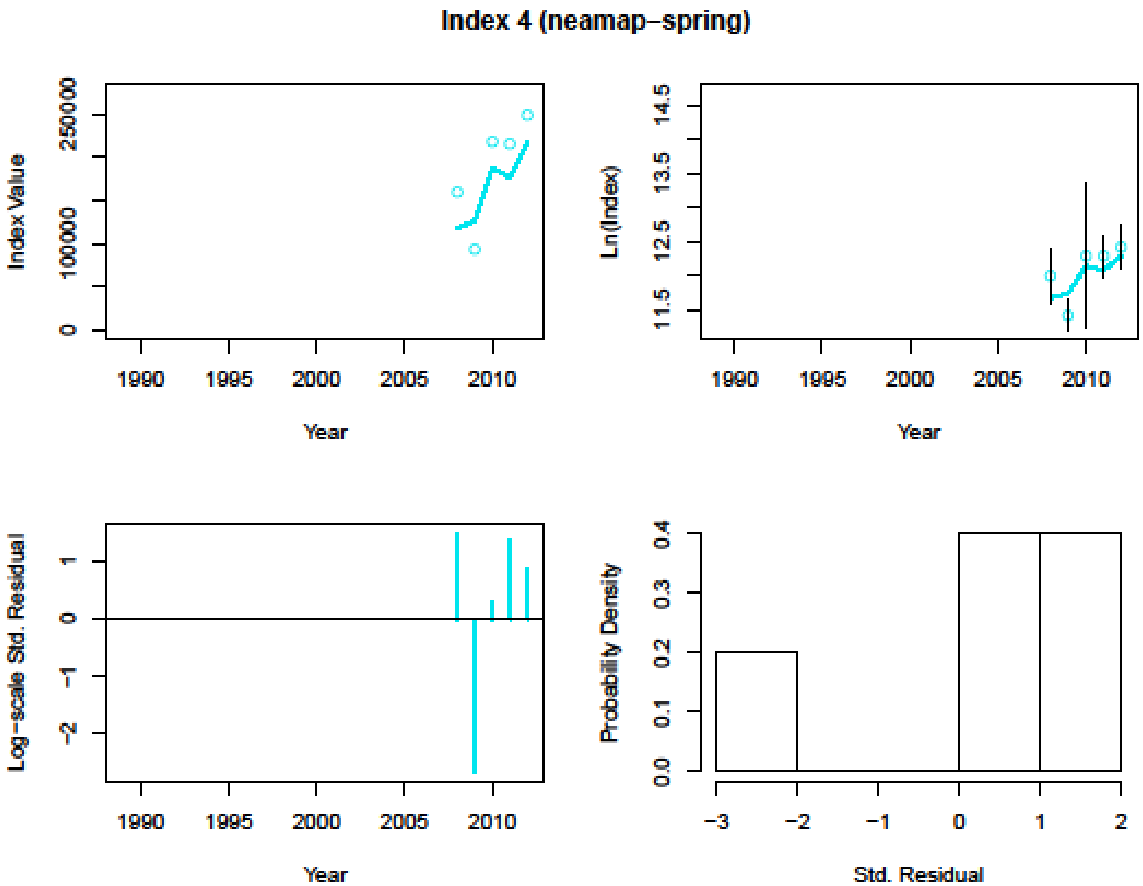


Figure A5.7. Diagnostics for NEAMAP spring survey from the base model.

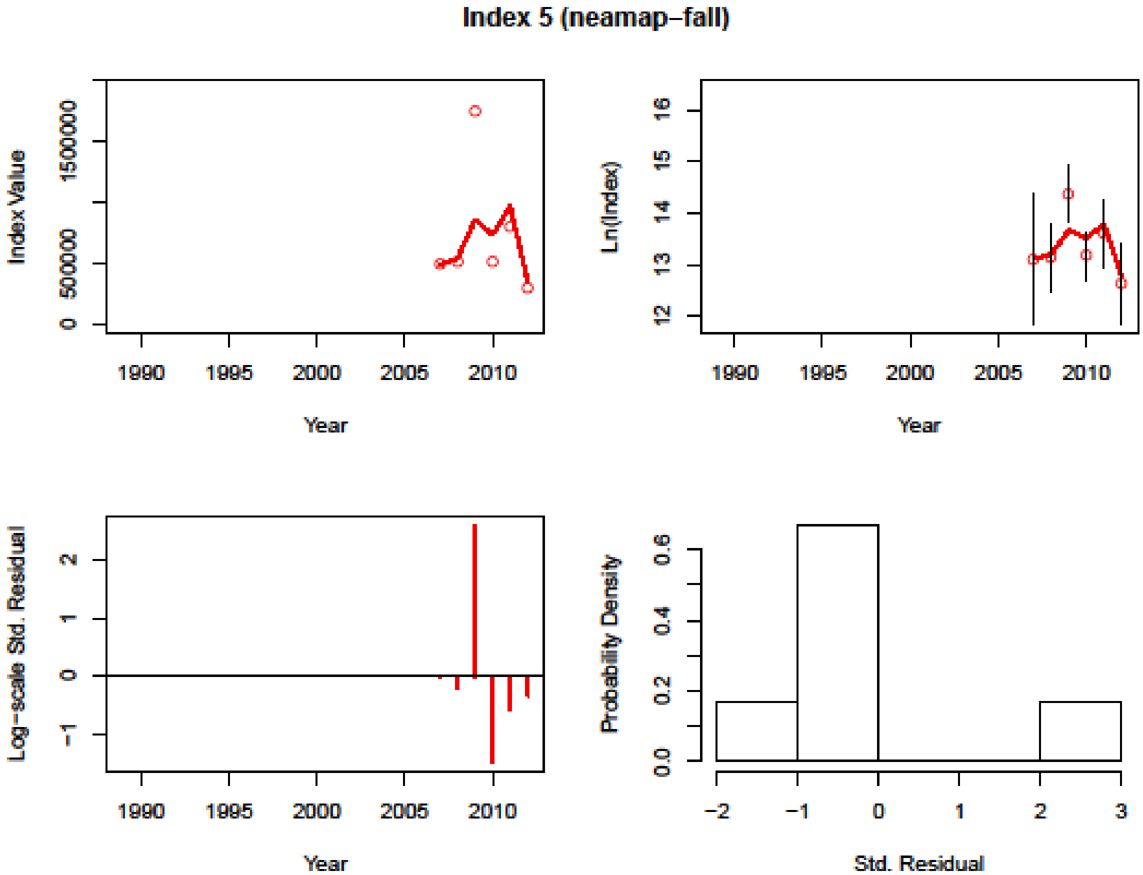


Figure A5.8. Diagnostics for NEAMAP fall survey from the base model.

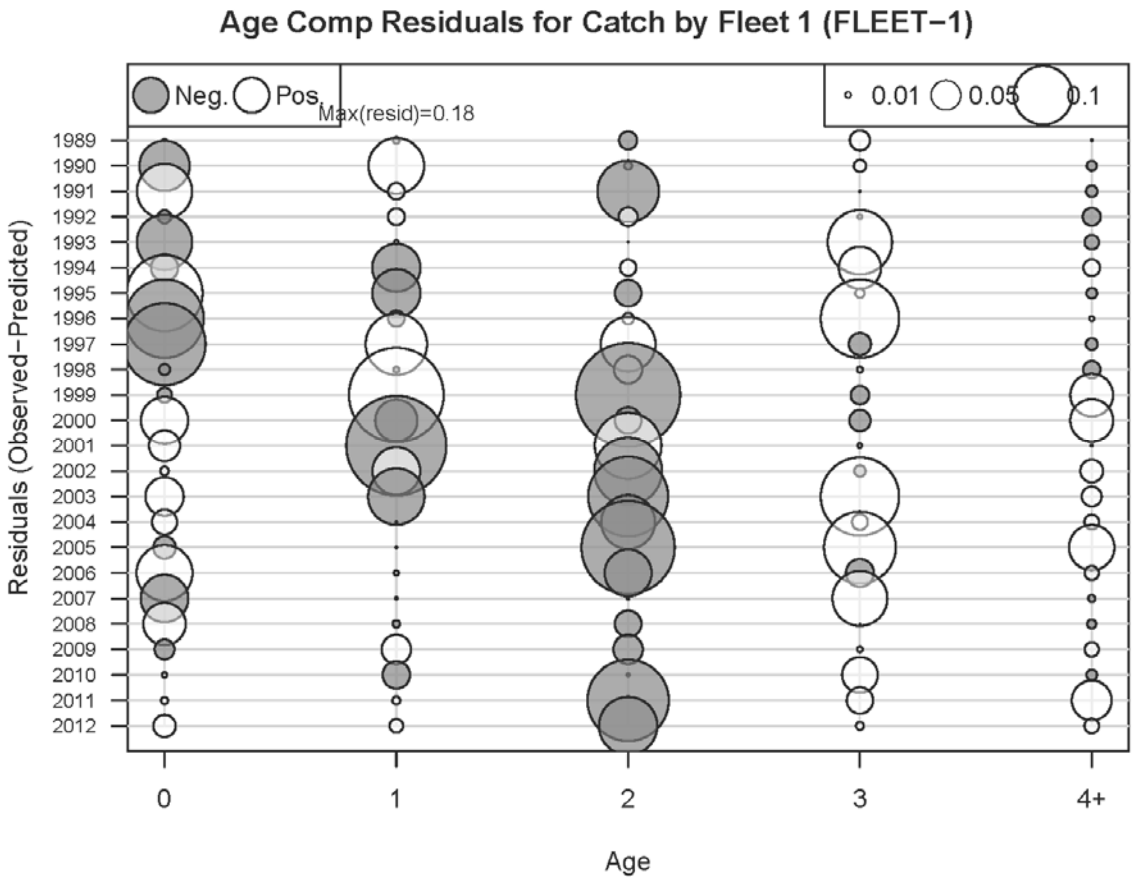


Figure A5.9. Residuals for catch age composition from the base model.

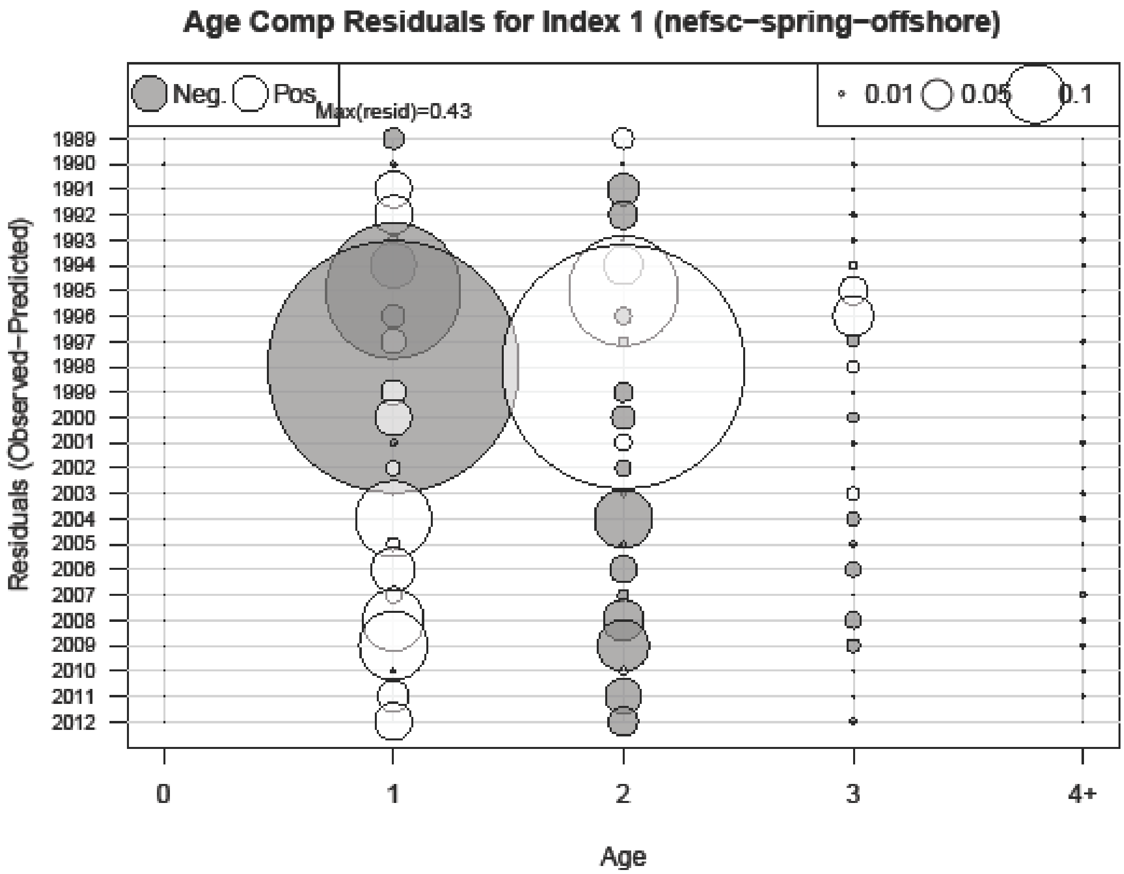


Figure A5.10. Residuals for NEFSC spring offshore age composition from the base model.

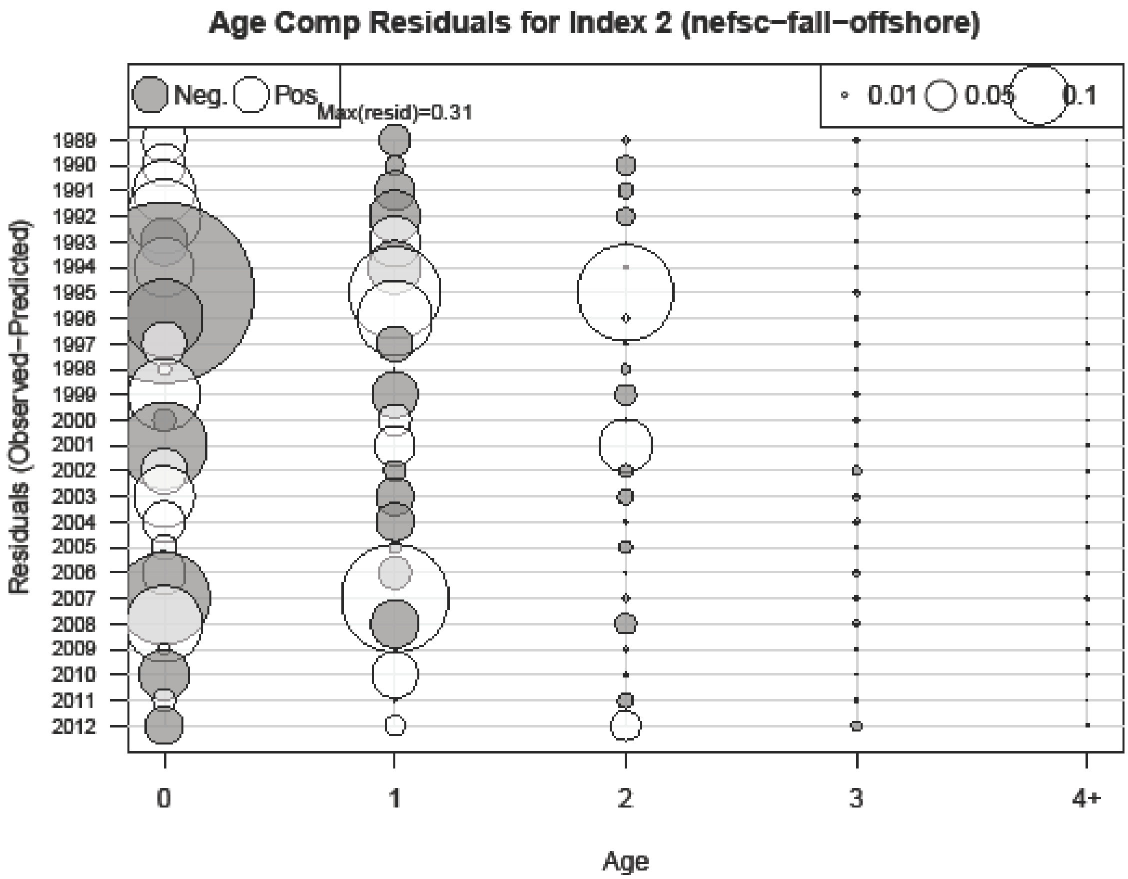


Figure A5.11. Residuals for NEFSC fall offshore age composition from the base model.

Figure A5.12. Residuals for NEFSC fall inshore age composition from the base model.

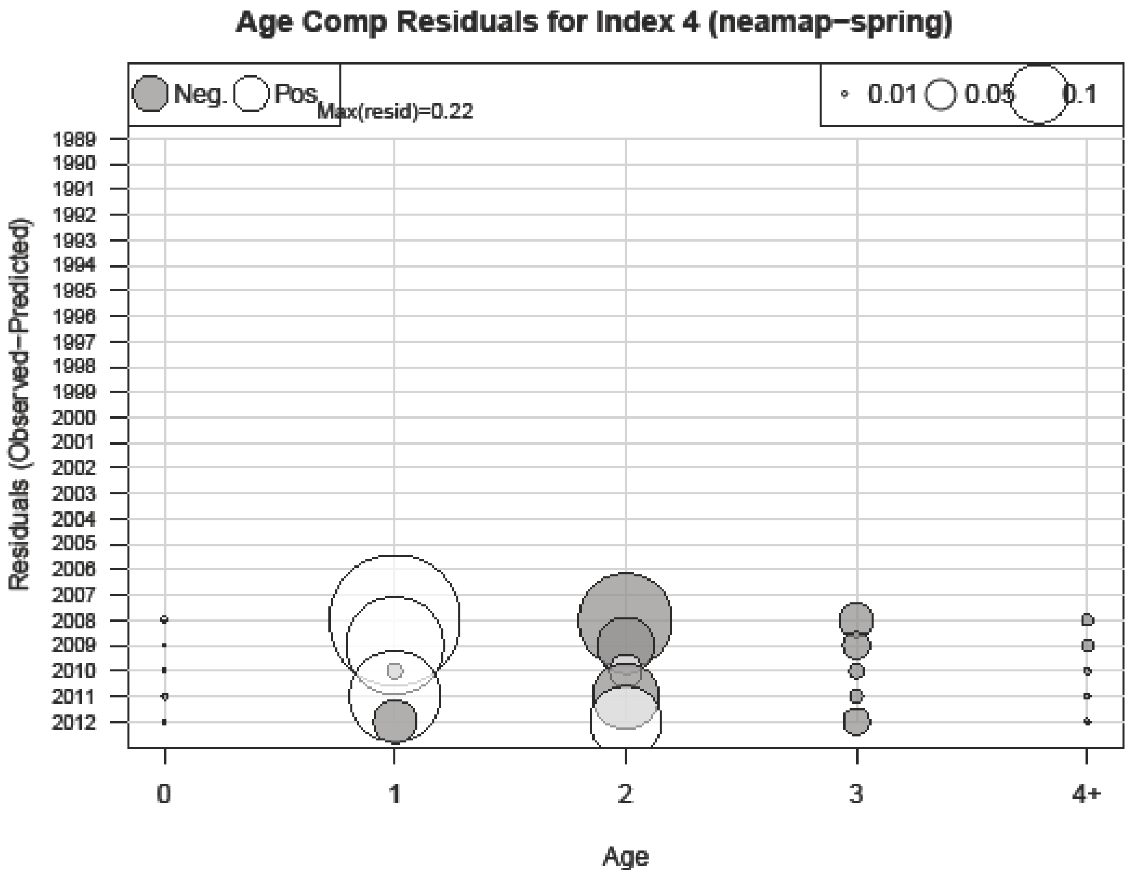


Figure A5.13. Residuals for NEAMAP spring age composition from the base model.

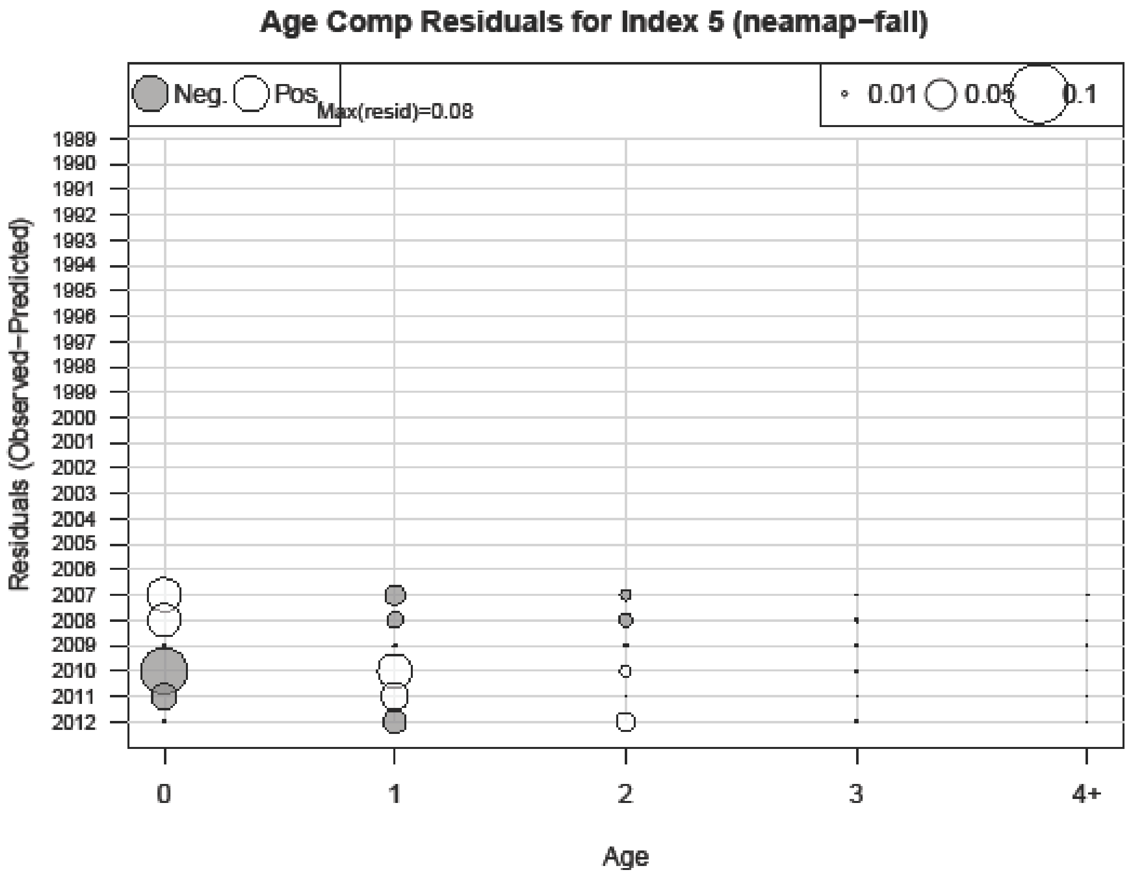


Figure A5.14. Residuals for NEAMAP fall age composition from the base model.

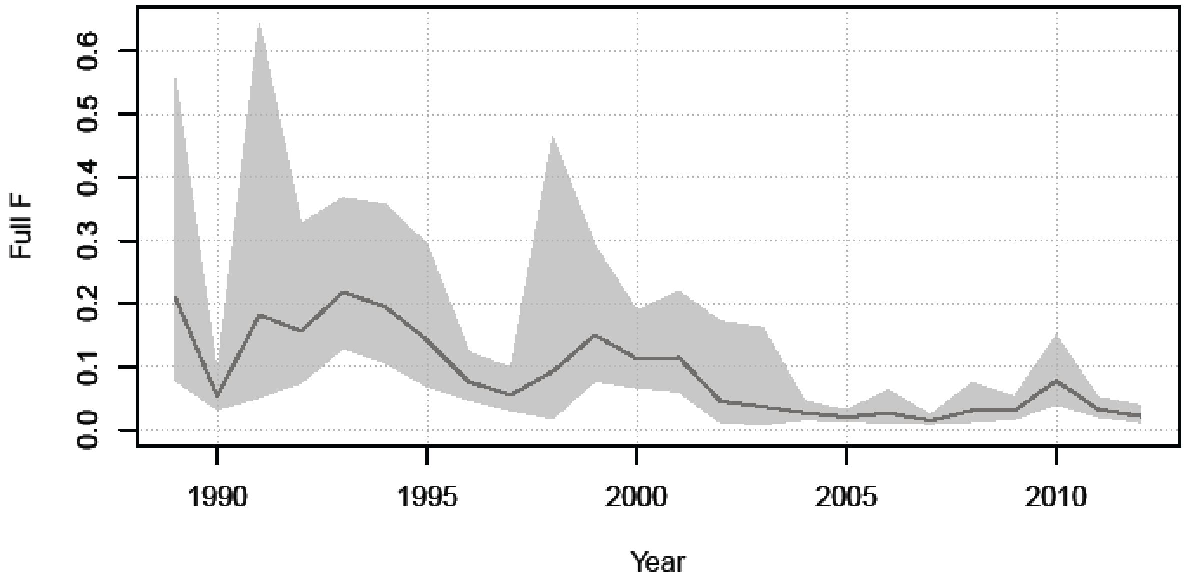


Figure A5.15. Estimated fully selected fishing mortality rate and 95% confidence intervals from the base model.

Figure A5.16. Fleet selectivity at age from the base model.

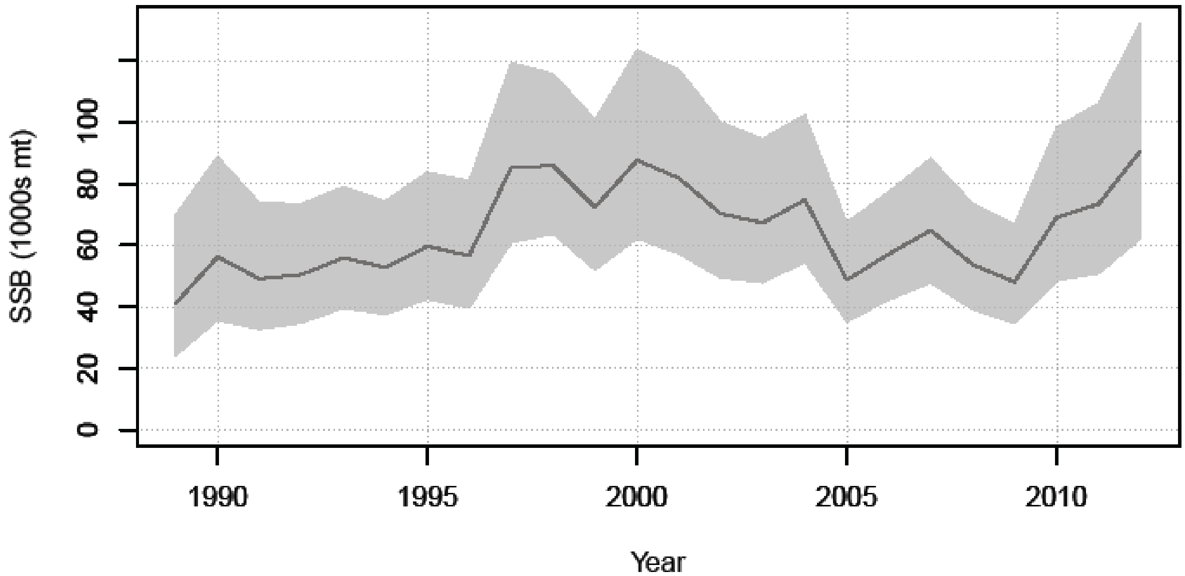


Figure A5.17. Estimated spawning biomass and 95% confidence intervals from the base model.

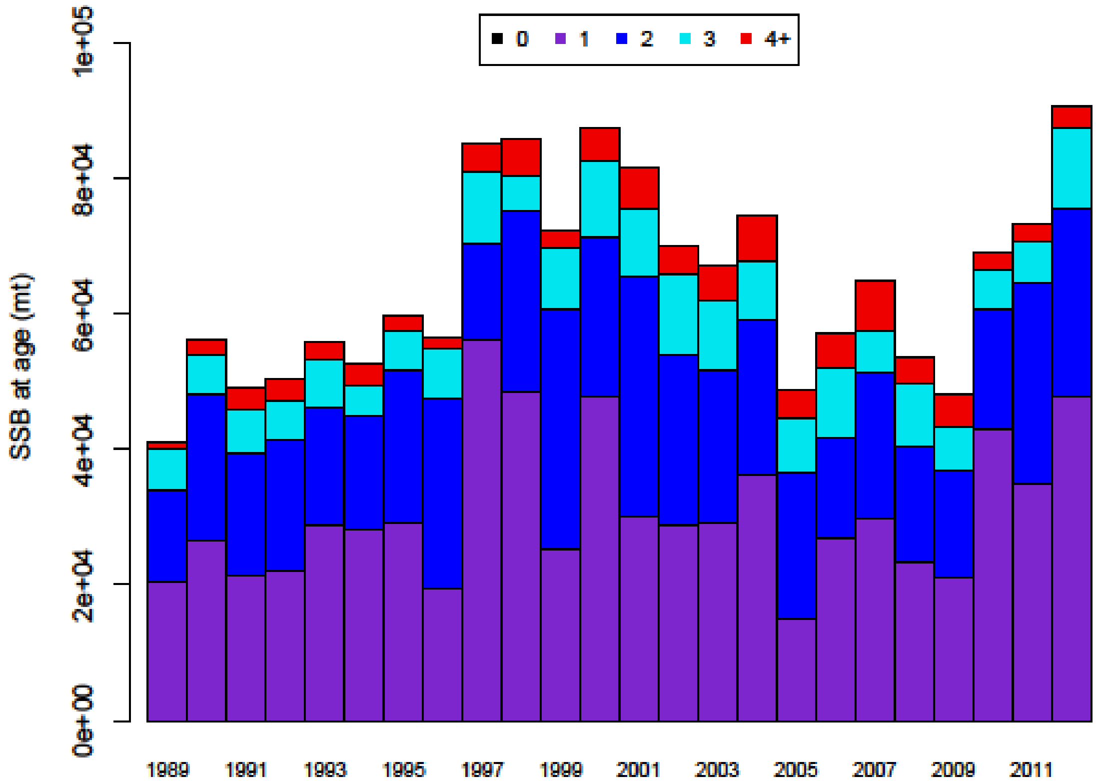


Figure A5.18. Estimated annual spawning biomass at age from the base model.

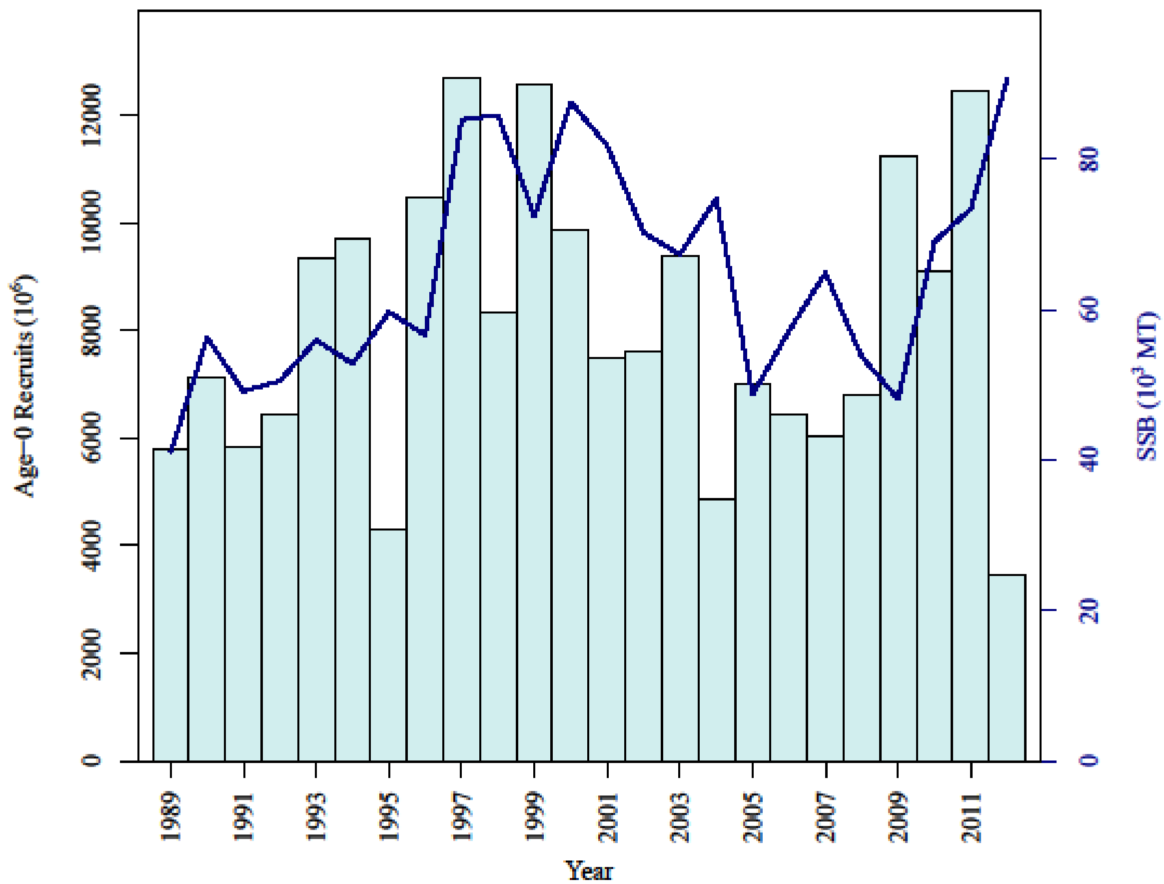


Figure A5.19. Butterfish recruitment (vertical bars), and the spawning stock biomass (blue line) that produced the corresponding recruitment. Year refers to spawning year.

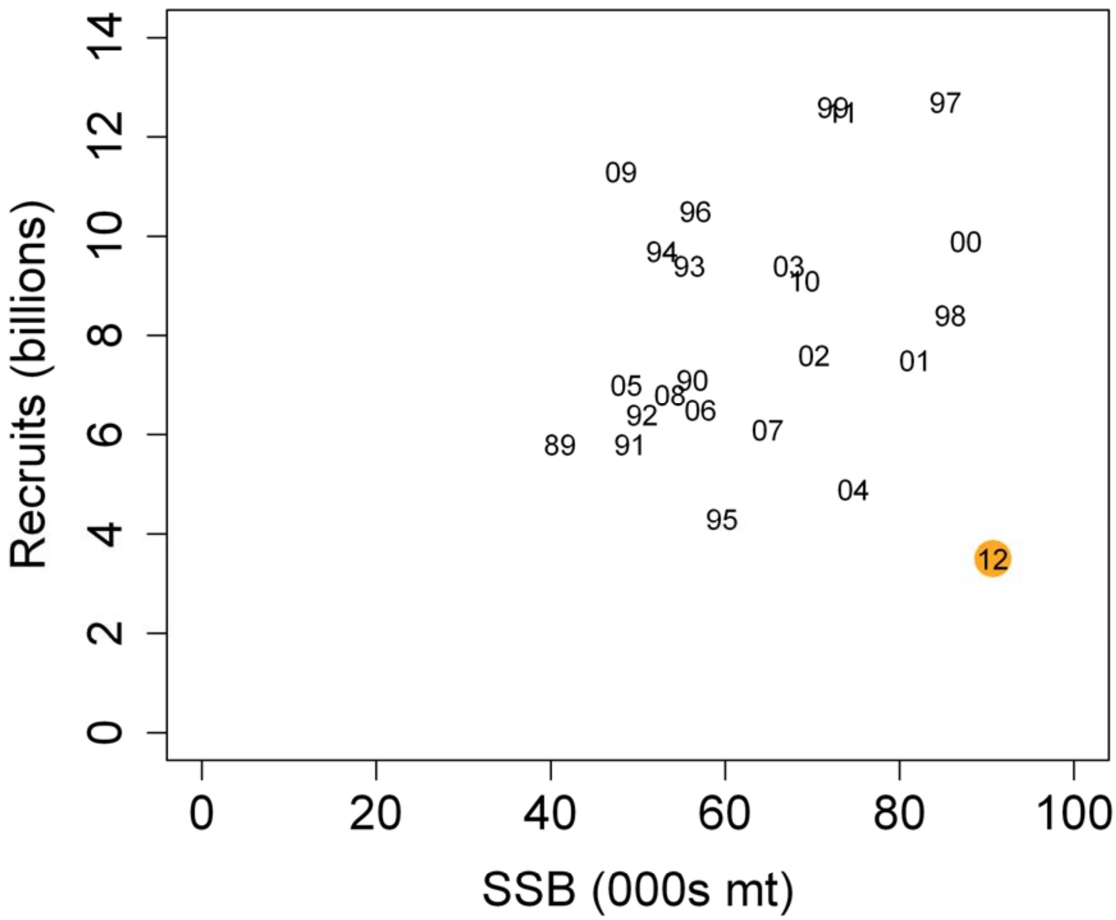


Figure A5.20. Butterfish stock-recruitment scatter plot, with two digit indicator of model SSB year.

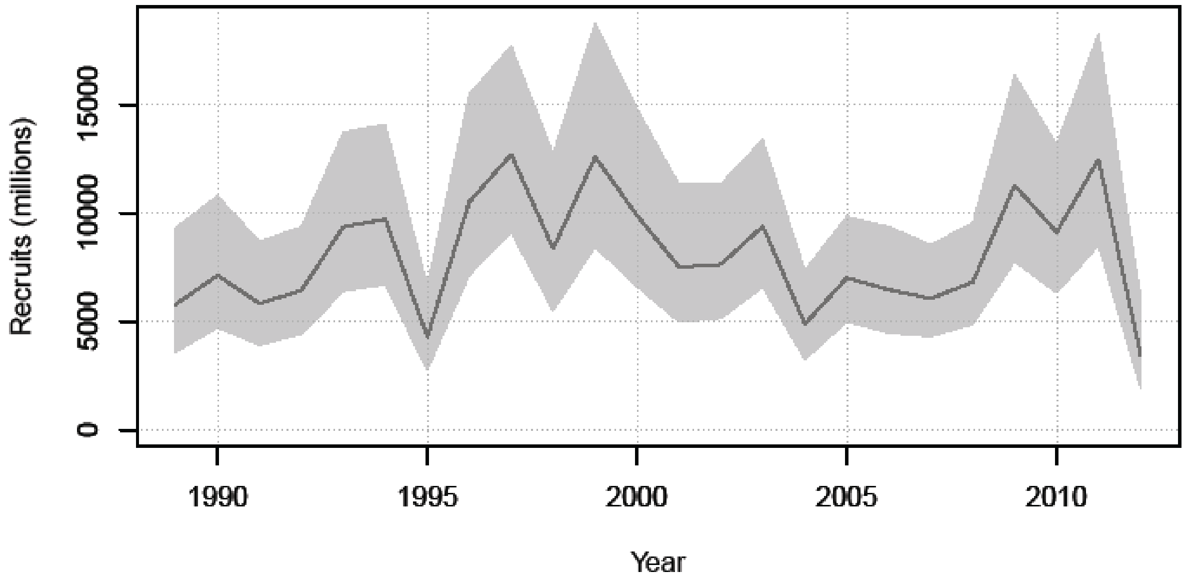


Figure A5.21. Estimated recruitment and 95% confidence intervals from the base model.

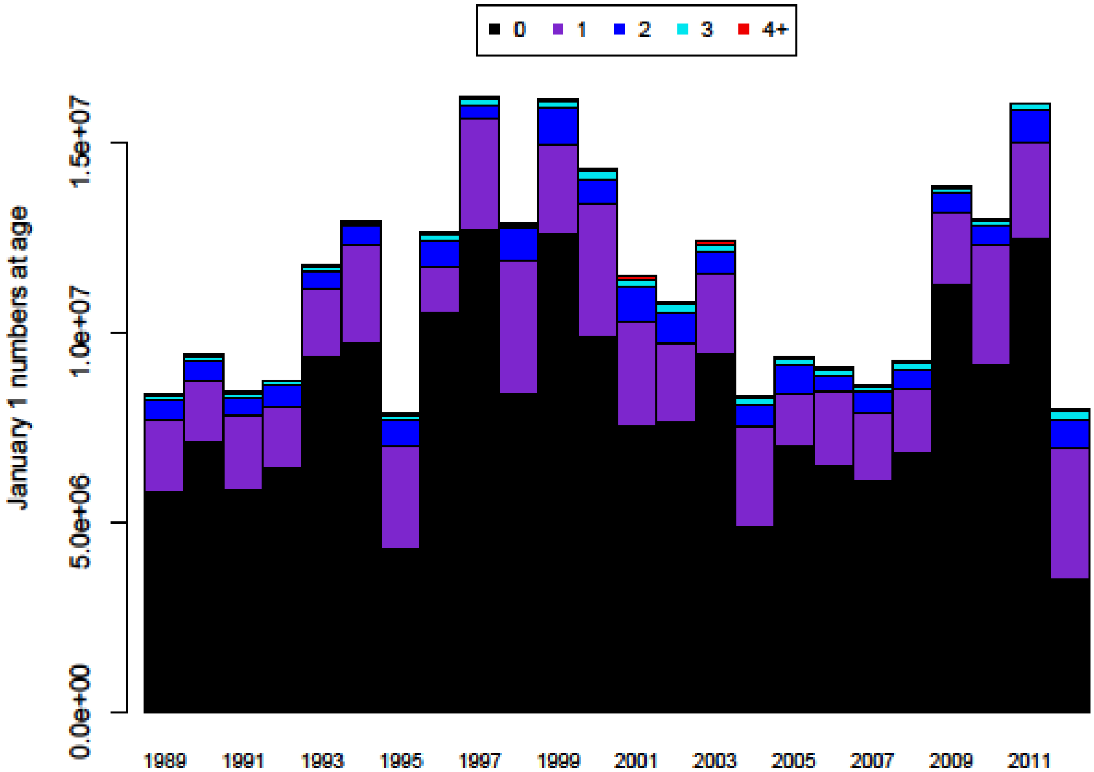


Figure A5.22. Estimated numbers at age at beginning of year from the base model.

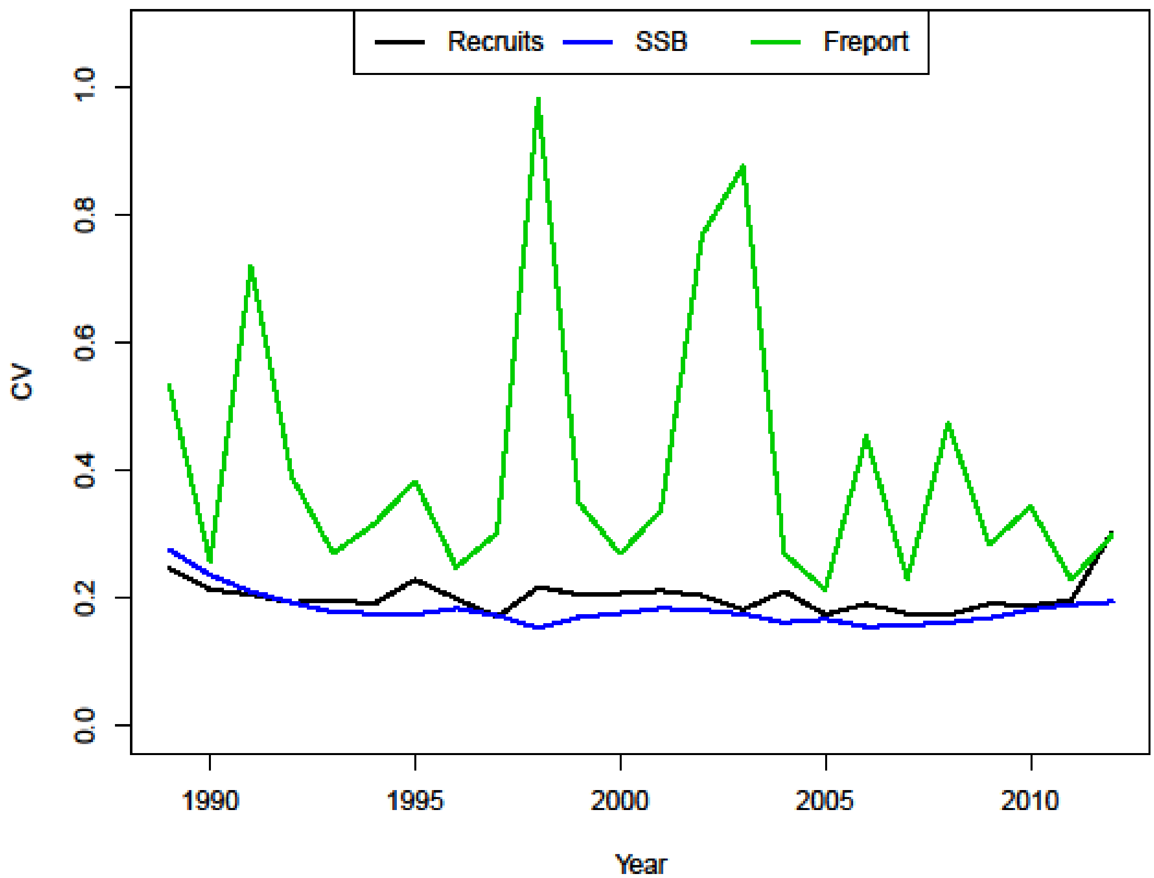


Figure A5.23. Coefficients of variation for estimates of SSB, recruits and fully selected fishing mortality rate from the base model.

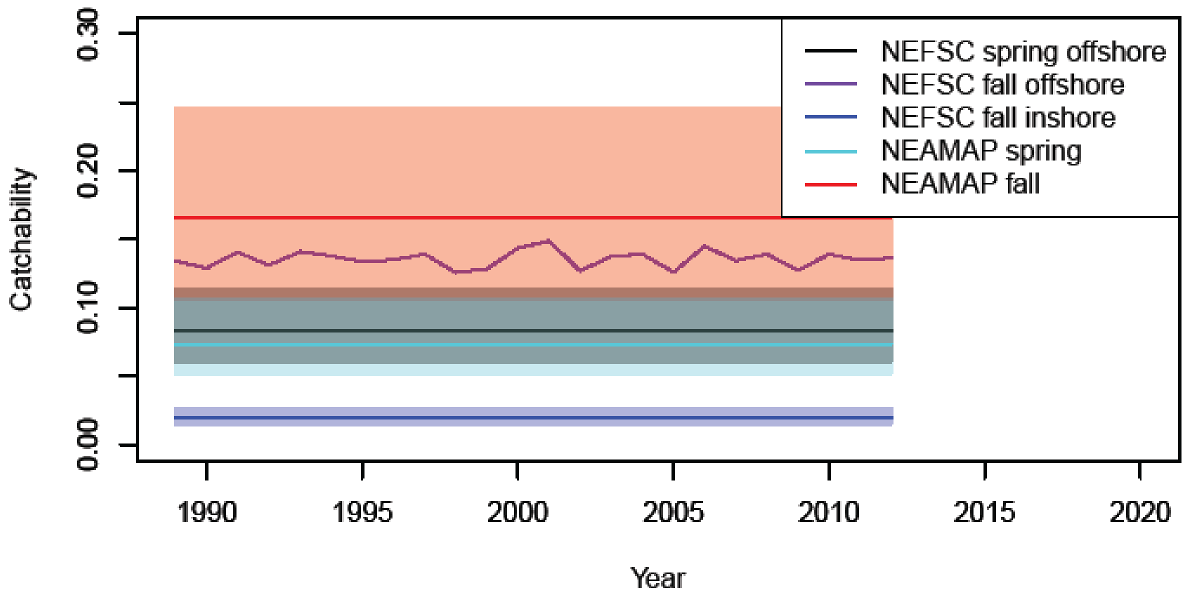


Figure A5.24. Index catchability and 95% confidence intervals from the base model.

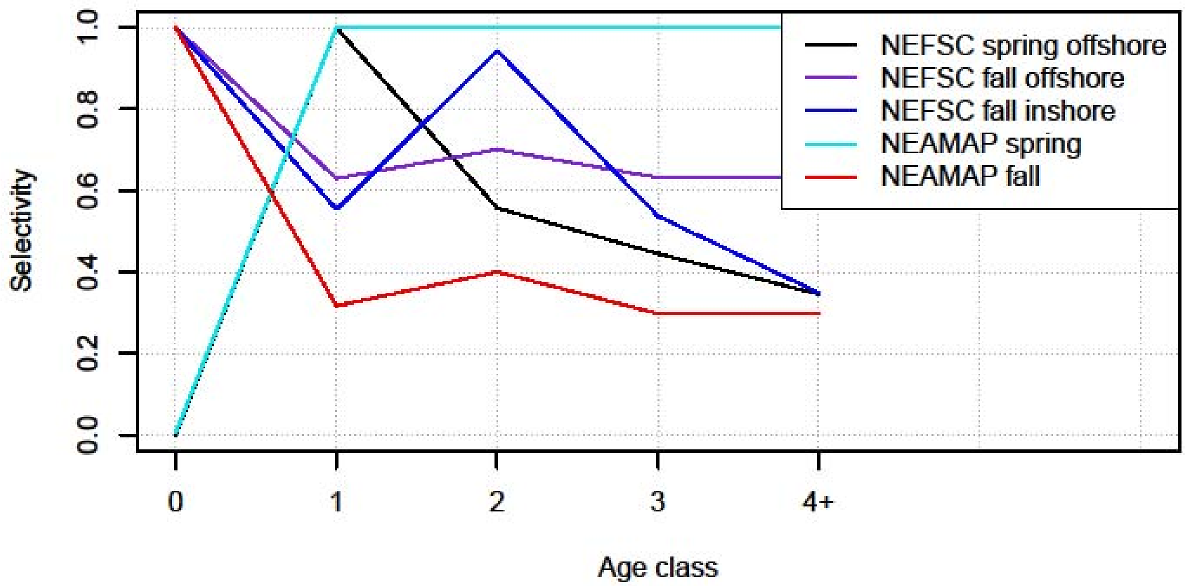


Figure A5.25. Index selectivities from the base model.

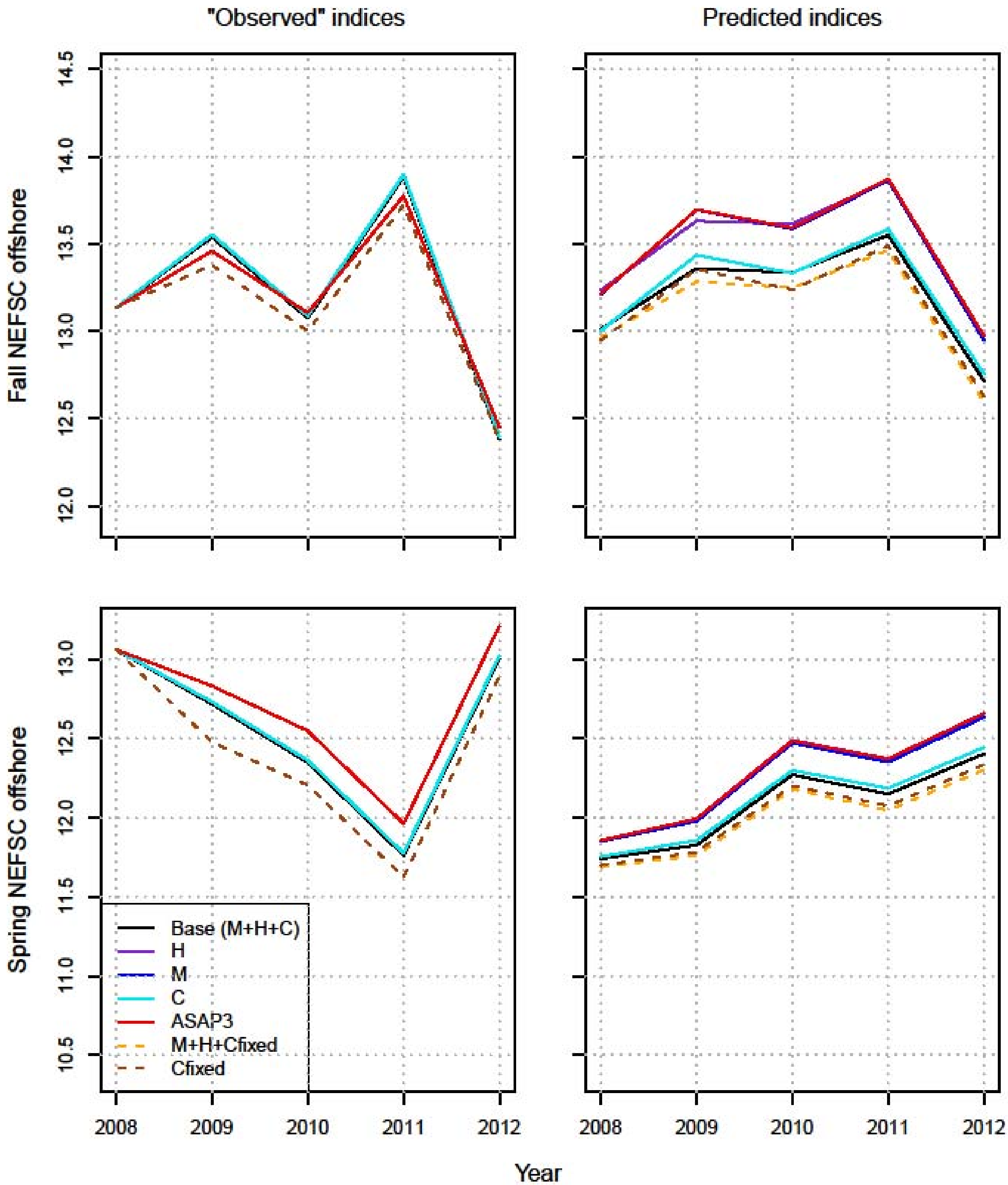


Figure A5.26. Log-scale observed and predicted abundance indices in years 2008-2012 for models described in Table 1.

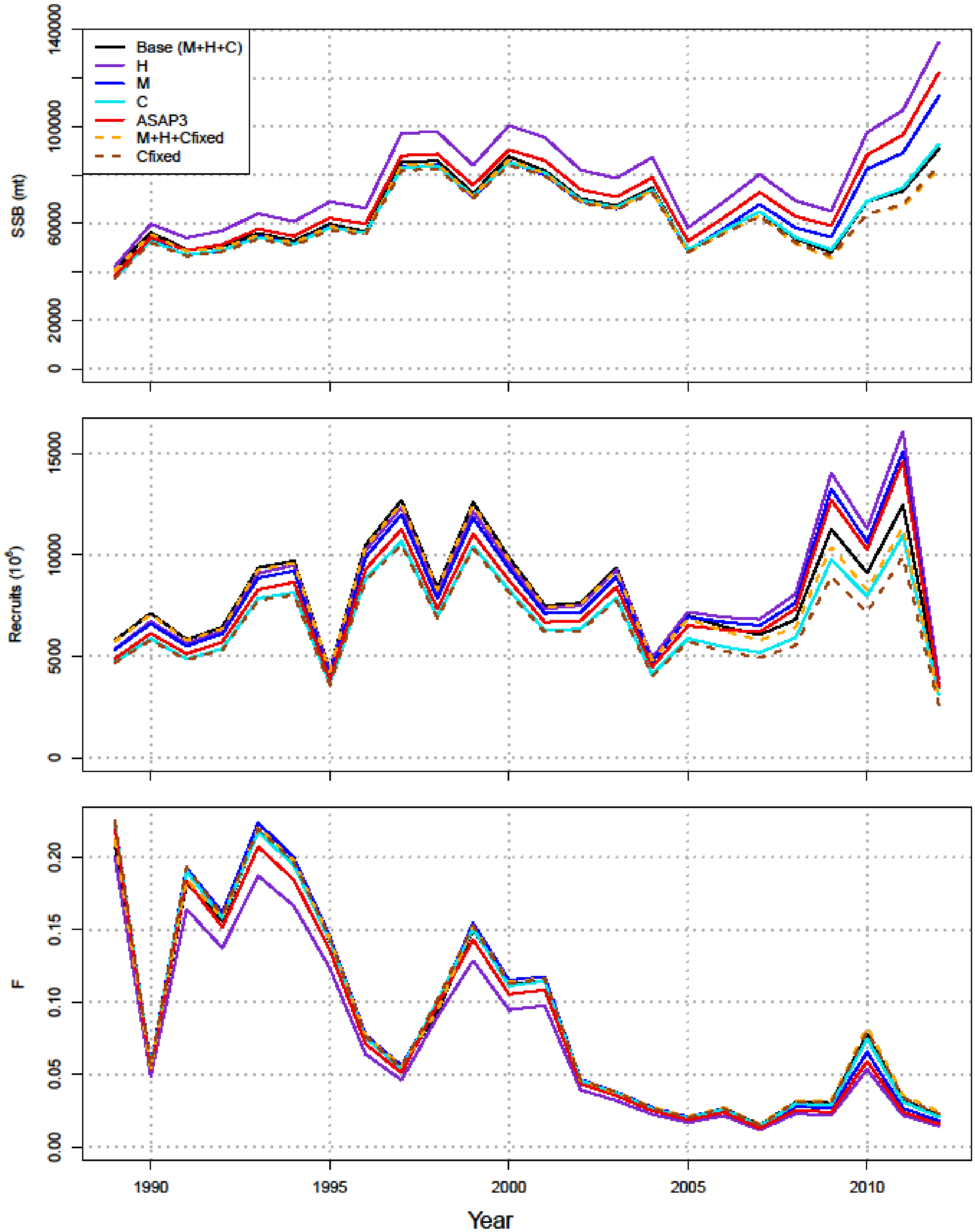


Figure A5.27. Annual estimates of spawning biomass, recruitment and fishing mortality rate for models described in Table 1.

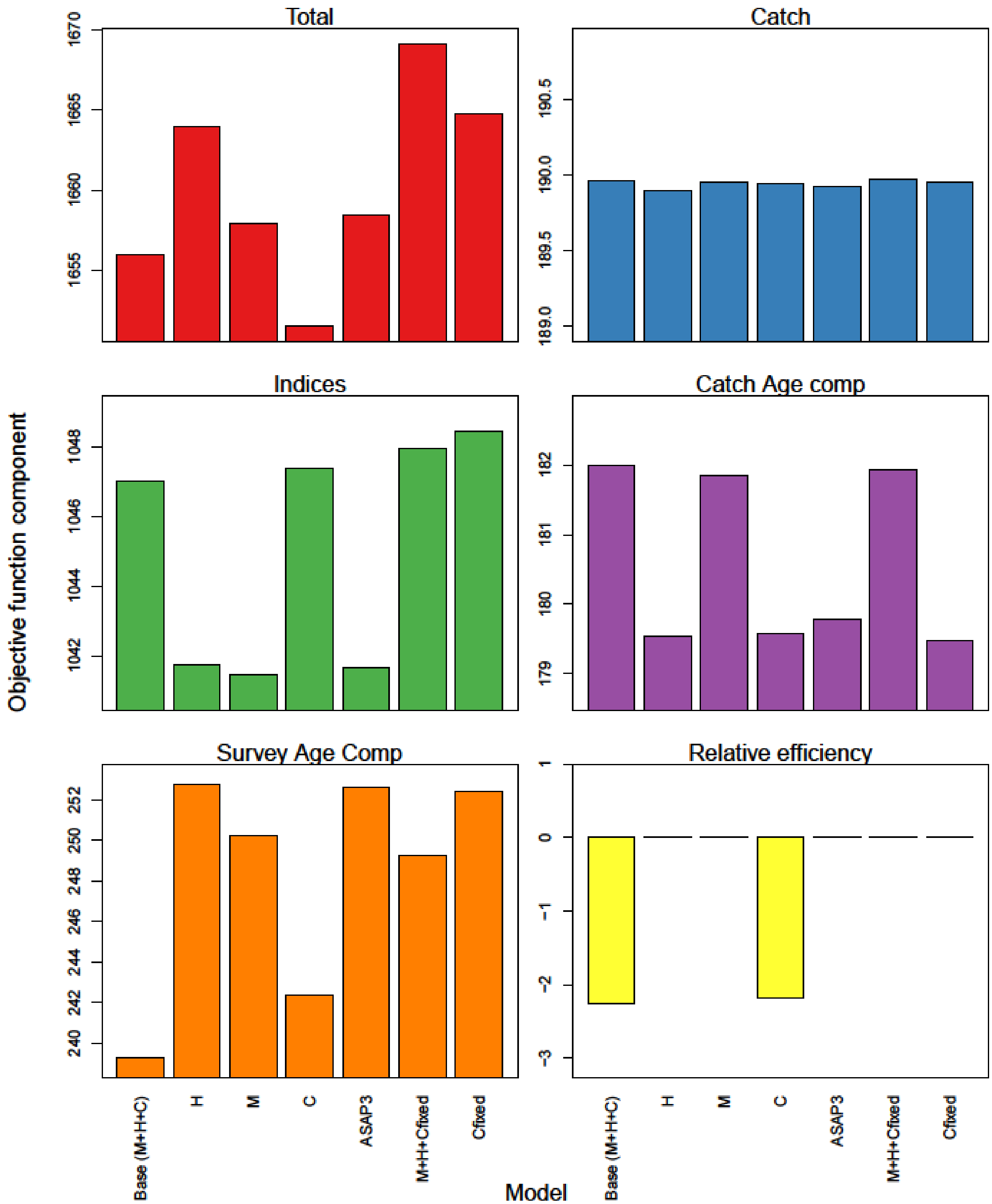


Figure A5.28. Minimized objective function and components for each of the models described in Table 1.

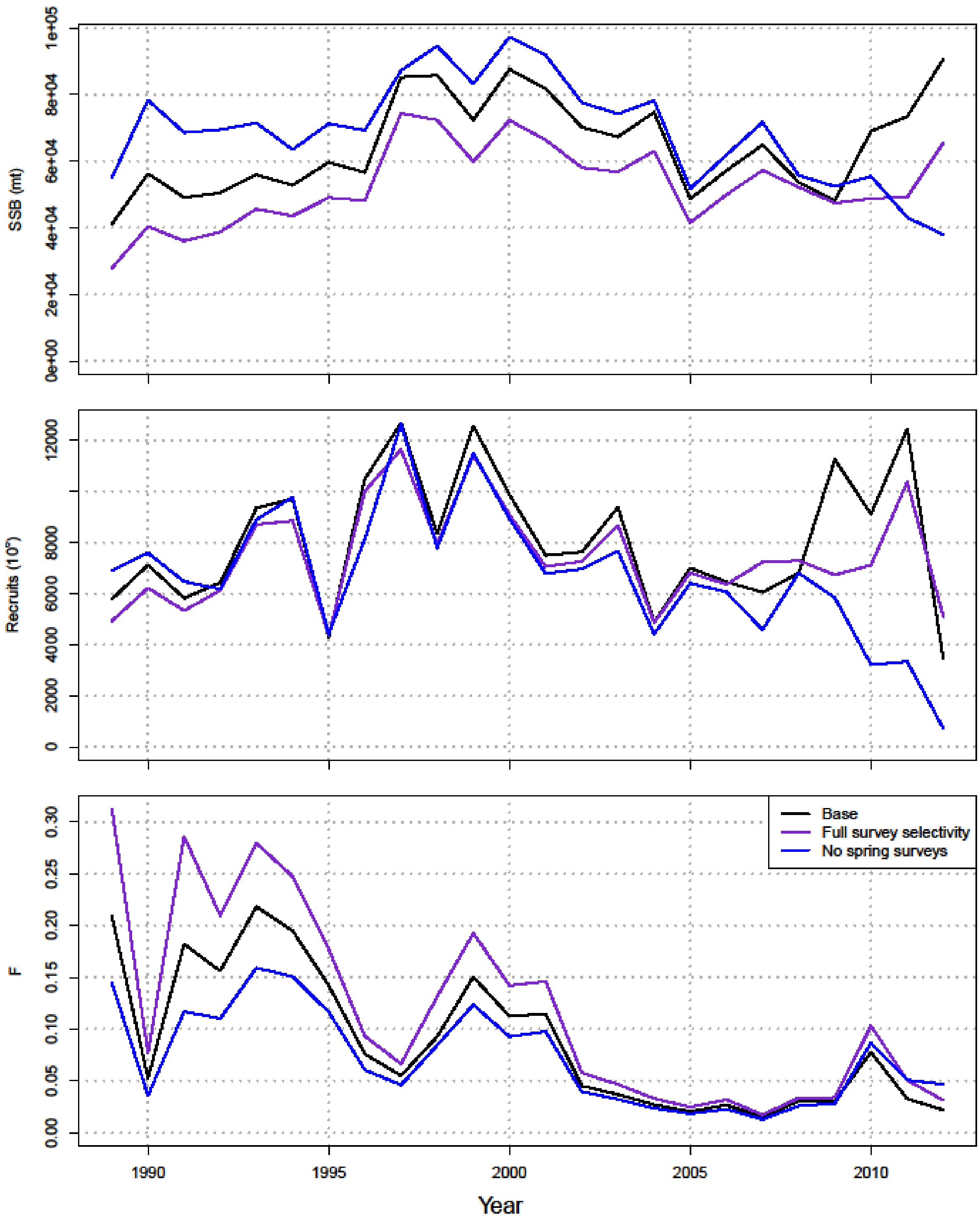


Figure A5.29. Annual estimates of spawning biomass, recruitment, and fishing mortality rate for the base model and alternatives with full survey selectivity assumed and without any spring survey data.

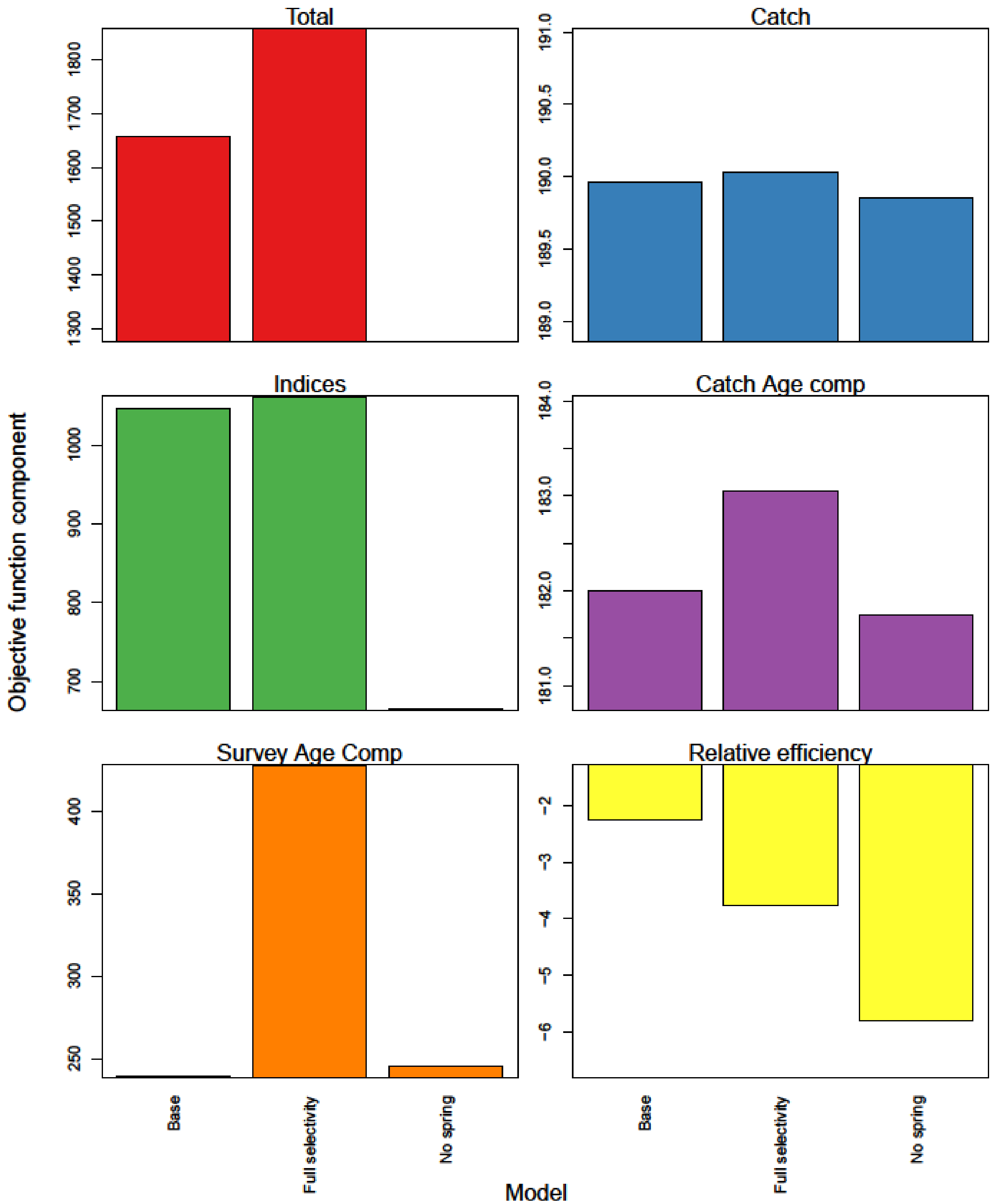


Figure A5.30. Minimized objective function and components for the base model and alternatives with full survey selectivity assumed and without any spring survey data.

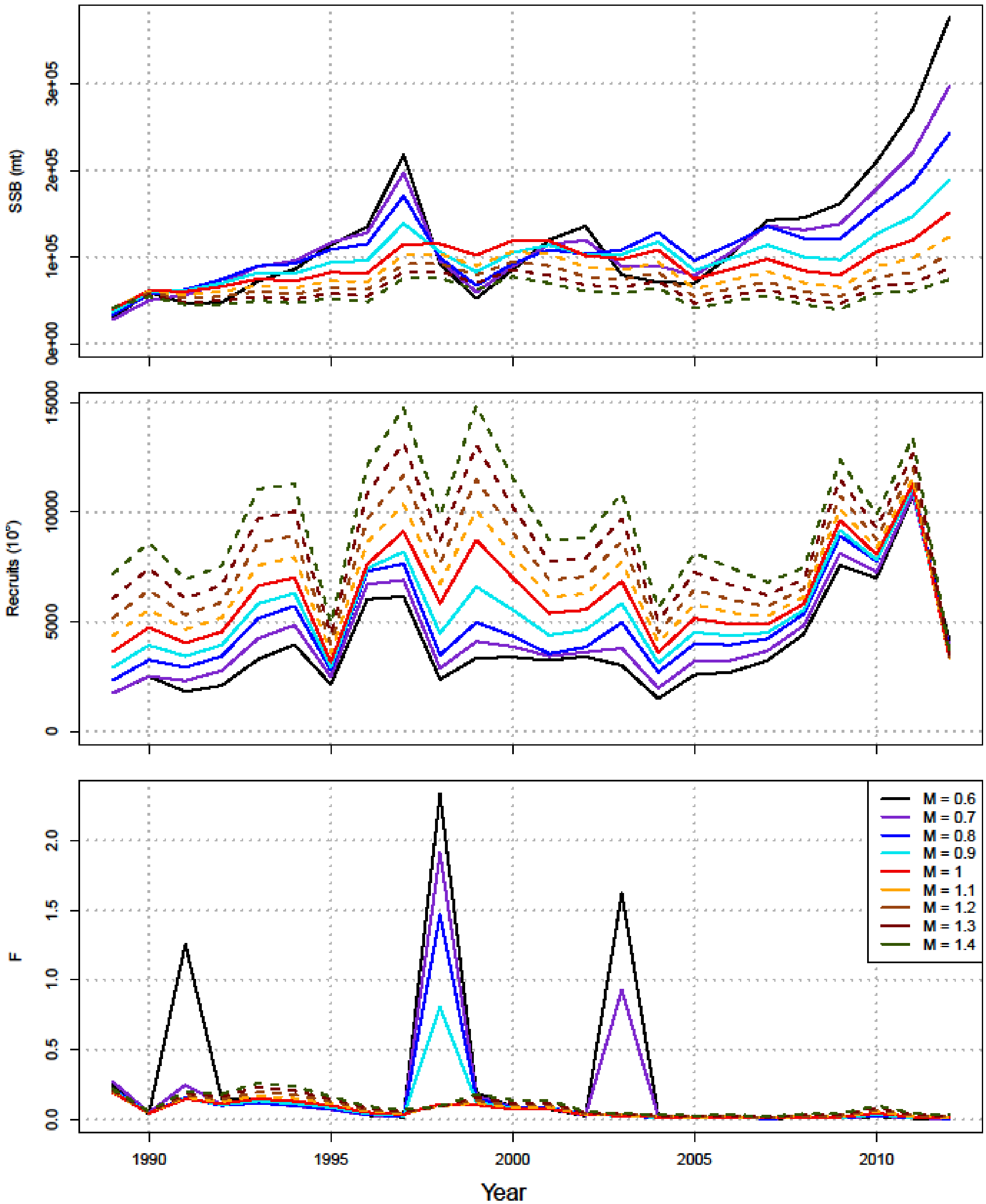


Figure A5.31. Annual estimates of spawning biomass, recruitment, and fishing mortality rate for models with a range of assumed natural mortality rates.

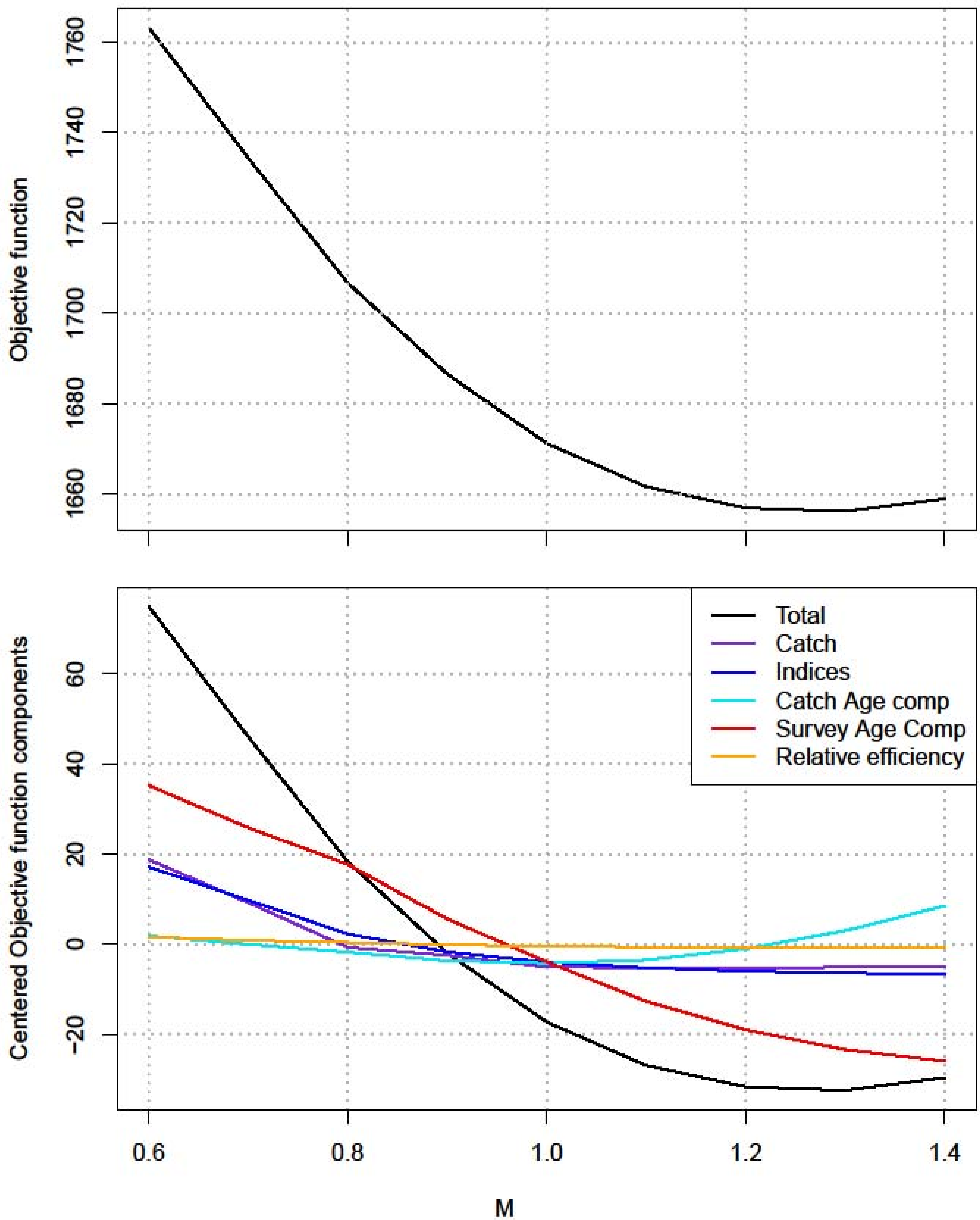


Figure A5.32. Minimized objective function and components for models with a range of assumed natural mortality rates.

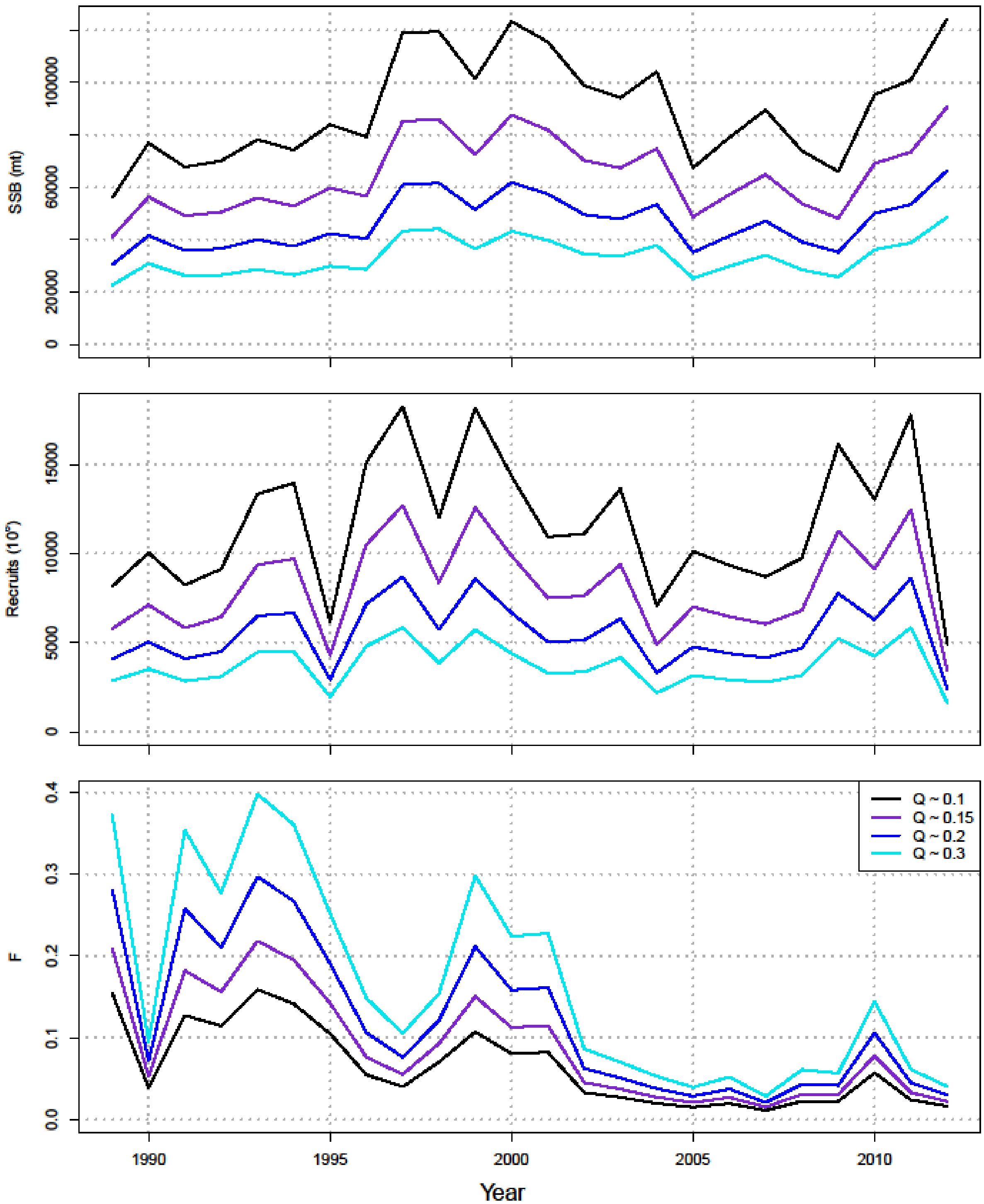


Figure A5.33. Annual estimates of spawning biomass, recruitment, and fishing mortality rate for models with a range of assumed NEFSC fall offshore survey catchabilities.

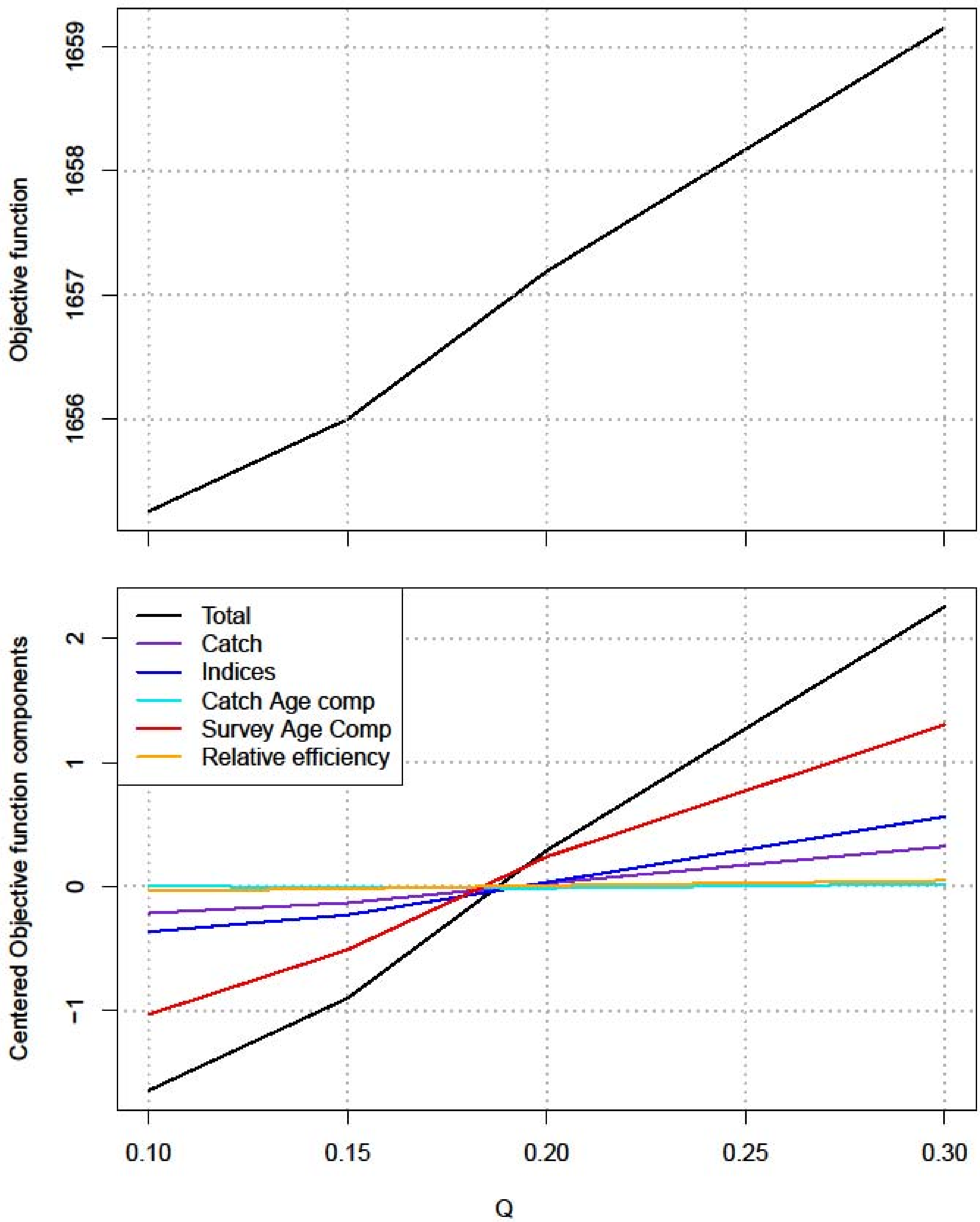


Figure A5.34. Minimized objective function and components for models with a range of assumed NEFSC fall offshore survey catchabilities.

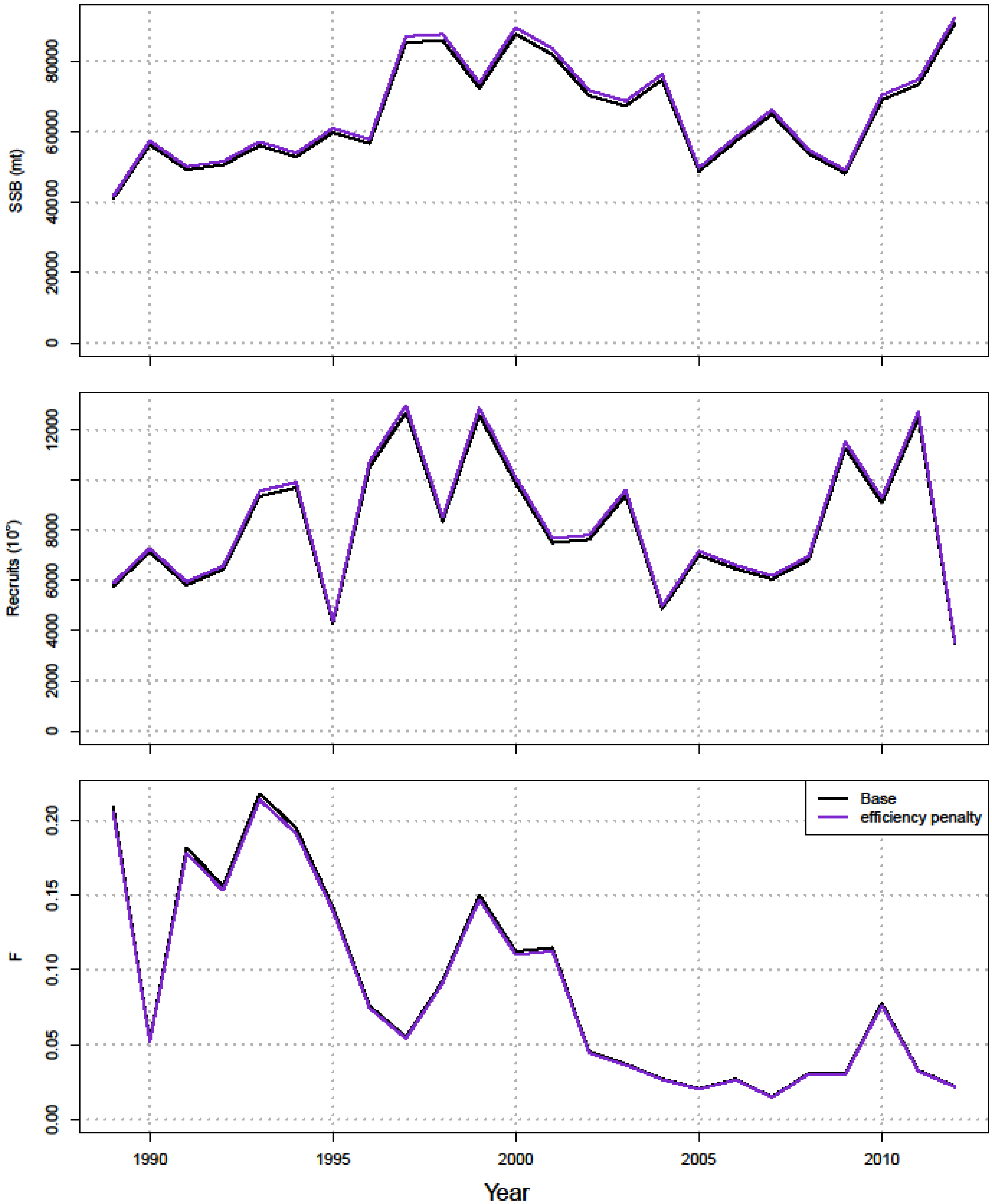


Figure A5.35. Annual estimates of spawning biomass, recruitment, and fishing mortality rate for the base model and alternative with penalized estimation of NEFSC fall offshore survey efficiency.

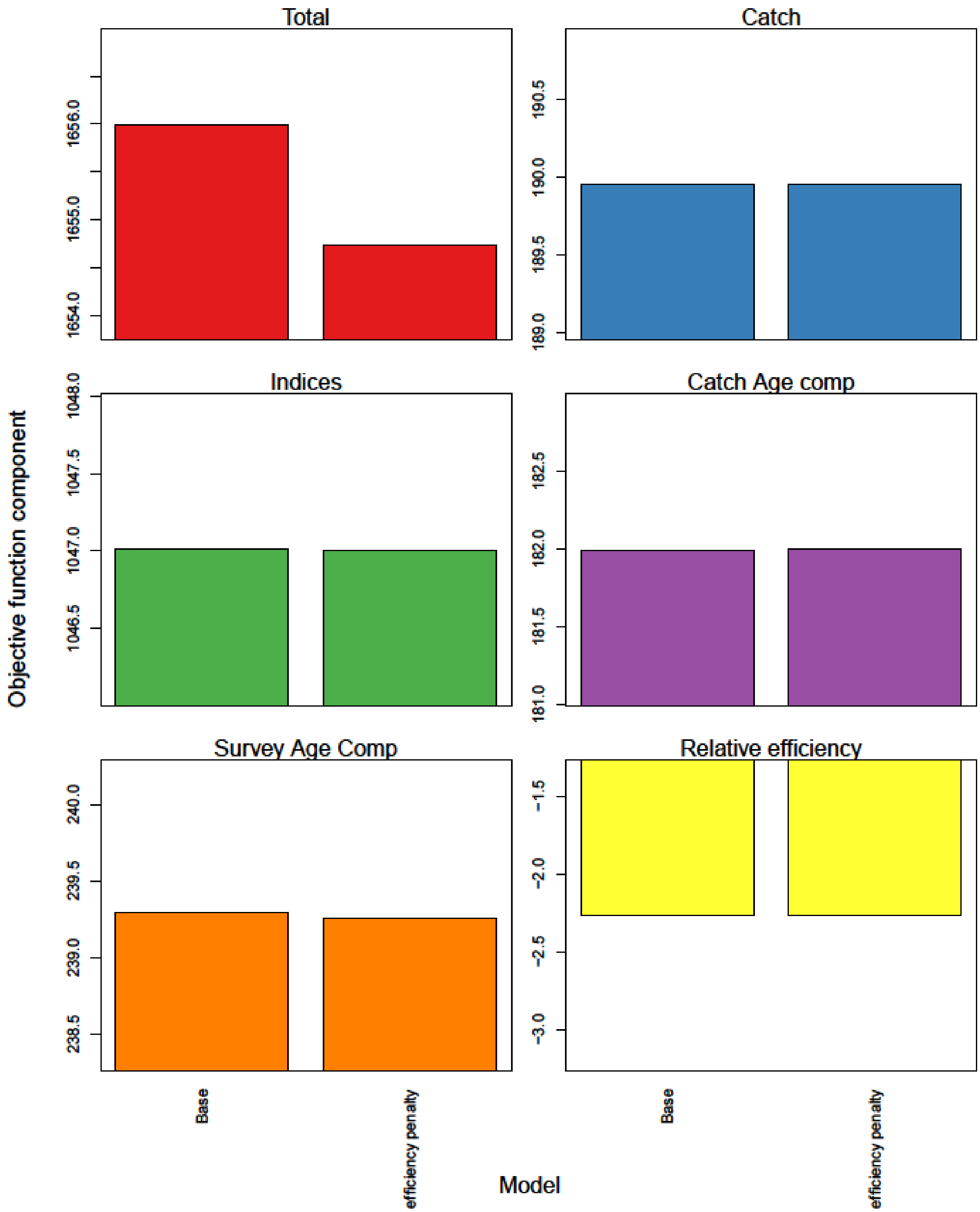


Figure A5.36. Minimized objective function and components for the base model and alternative with penalized estimation of NEFSC fall offshore survey efficiency.

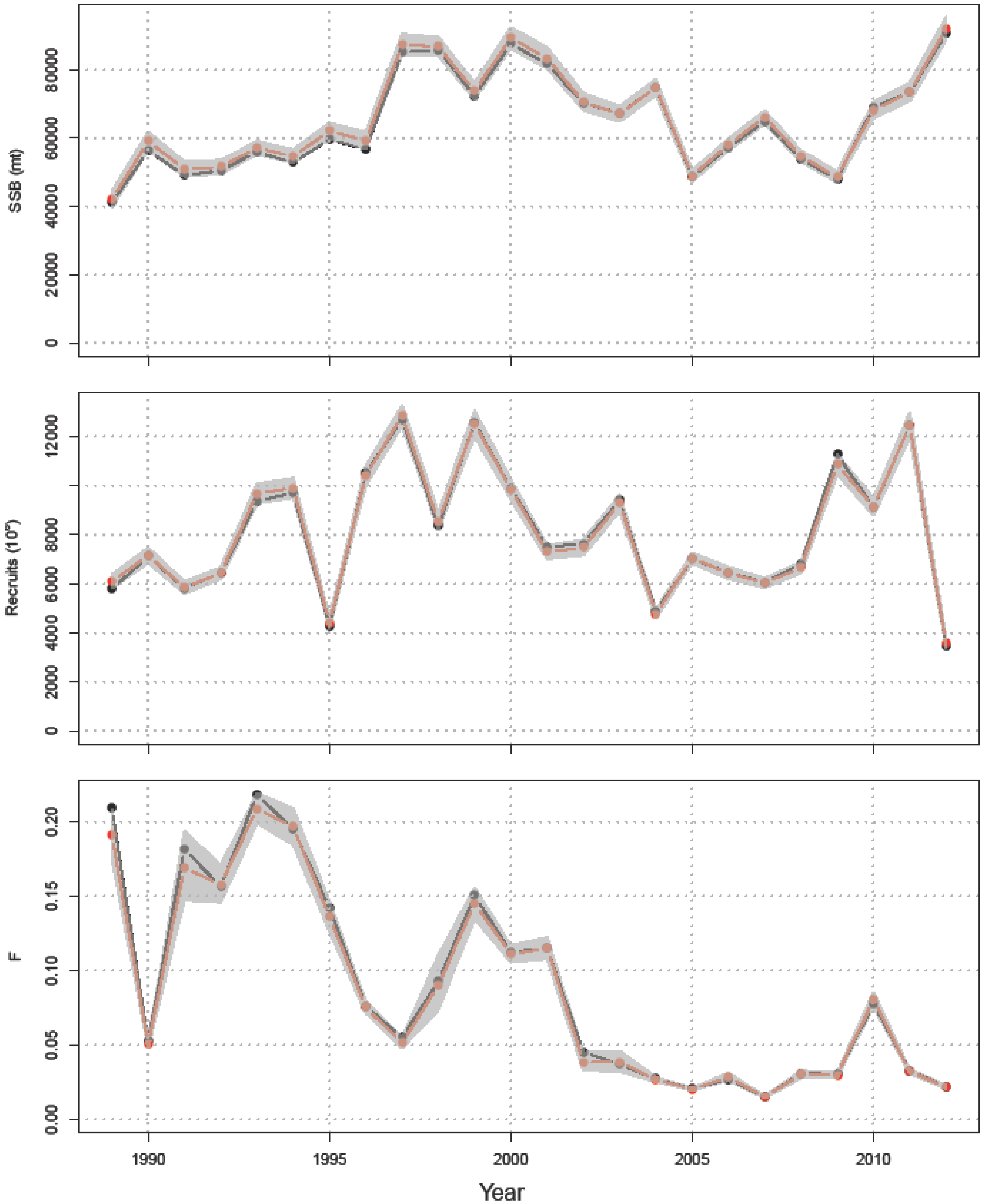


Figure A5.37. Annual spawning biomass, recruitment, and fishing mortality rate, estimated from the base model (black), and mean estimates from 100 simulations based on model estimates where observations of catch, indices and associated age compositions were randomly distributed. No length-based calibration was required. Grey bands represent 95% confidence intervals of the simulated estimates.

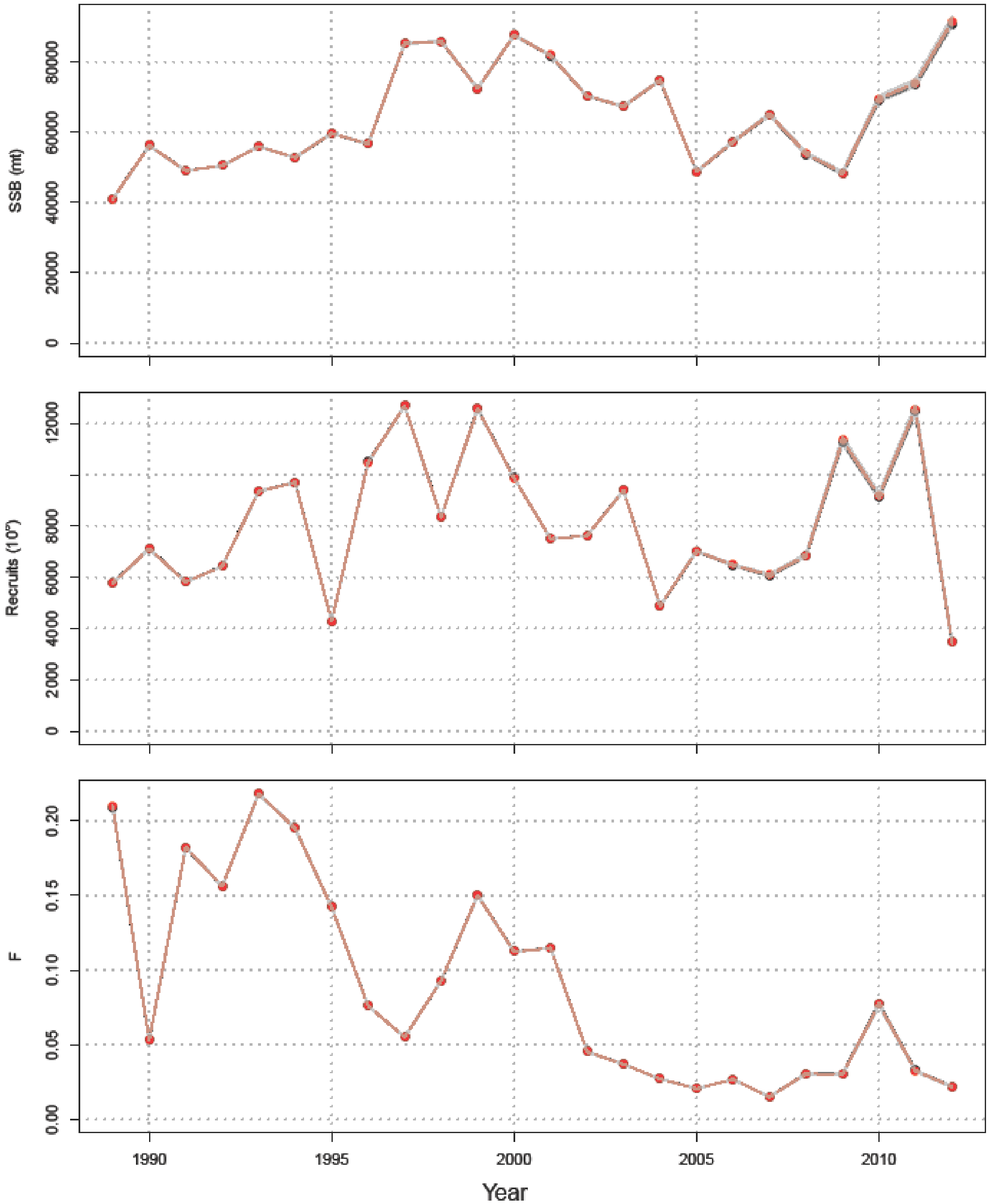


Figure A5.38. Annual spawning biomass (SSB), recruitment, and fishing mortality rate (F), estimated from the base model (black), and mean estimates from 100 simulations based on model estimates where length-based calibration parameters were drawn from a multivariate normal distribution with mean and variance based on estimates provided by Miller (2013). Grey bands represent 95% confidence intervals of the simulated estimates.

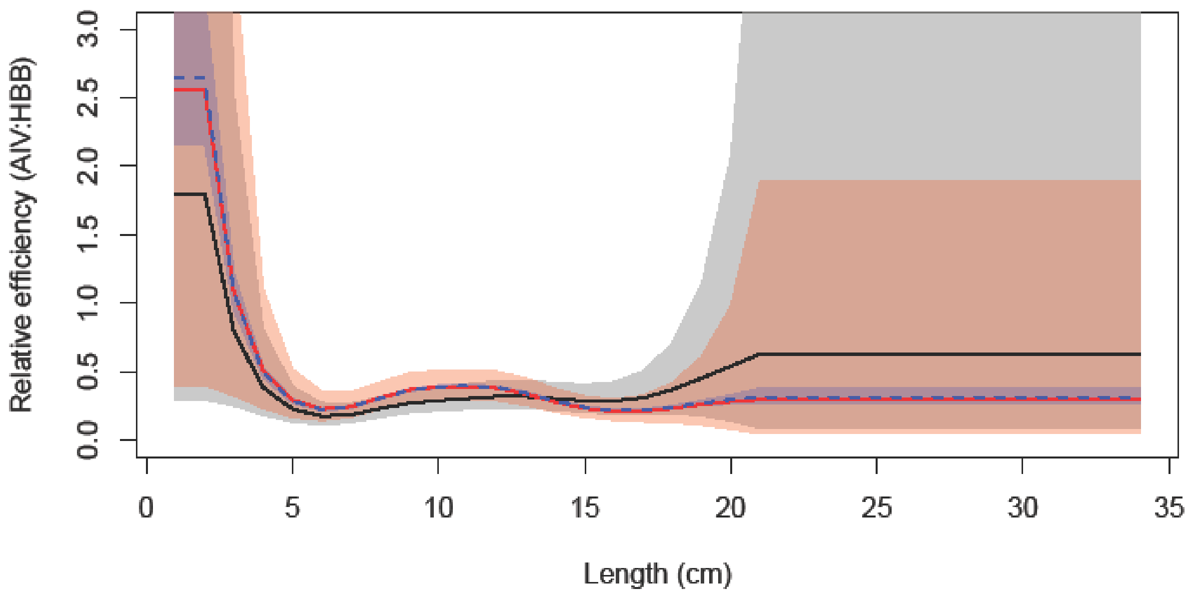


Figure A5.39. Relative catch efficiency from Miller (2013) (black, gray 95% confidence interval), from the base model with estimated deviations (red), and from average of predictions from fitting base model to simulated data (blue).

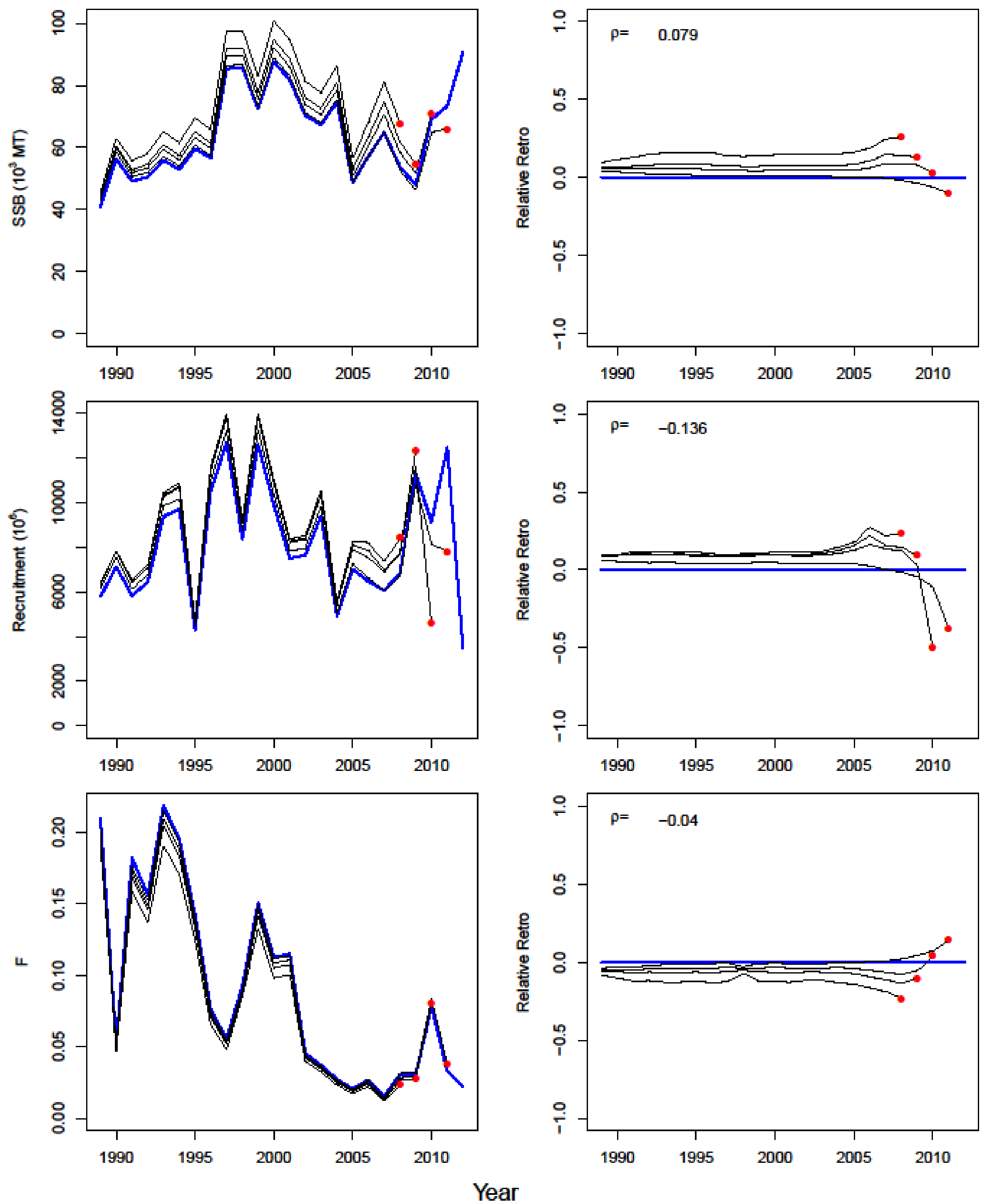


Figure A5.40. Retrospective patterns for spawning biomass, recruitment and fishing mortality in base model.

TOR 6. State the existing stock status definitions for "overfished" and "overfishing". Given that the stock status is currently unknown, update or redefine biological reference points (BRPs; point estimates for BMSY, BTHRESHOLD, FMSY and MSY, or their proxies) and provide estimates of their uncertainty. Consider effects of environmental factors on stability of reference points and implications for stock status.

> **[SAW Editor's Note:** ***Readers should refer to Butterfish Appendix 4 for final results of the SAW/SARC58 peer review. Appendix 4 contains the results, reference points, and projections for the final model accepted by SARC58. During the course of the SAW/SARC58 the review panel asked for several changes, which were incorporated into the final model and results (see Appendix 4).***
>
> ***The following content (included directly below in the current section) provides documentation of all work that was done before the analyses in Appendix 4.]***

History

The butterfish stock was last assessed in 2009 as part of SAW 49 (NEFSC, 2010). The SARC panel determined that the stock was not 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 (F_{MSY} proxy = $F_{0.1}$ = $F_{20\%}$ = 1.04; $SSB_{0.1}$ = 16,262 mt [35.9 million lb]) were rejected. The reference points (F_{MSY} = 0.38; MSY = 12,175 mt [26.8 million lb]; B_{MSY} = 22,798 mt [50.3 million lb]) from the previous assessment (NEFSC, 2004) were also found to be unacceptable for the same reason, as well as the unlikely scale of the estimates of biomass and fishing mortality upon which the reference points were based. Despite the rejection of the reference points, there was consensus that overfishing was not likely occurring. Determination of an overfished vs. not overfished condition was unresolved, leaving the status of butterfish unknown.

The butterfish fishery is managed by the Mid-Atlantic Fishery Management Council (MAFMC) under a single Fishery Management Plan (FMP) that also includes Atlantic mackerel, longfin squid and *Illex* squid. Because an estimate of OFL was not available from the last assessment (NEFSC, 2010), the MAFMC Scientific and Statistical Committee recently decided (MAFMC, 2012) to use the F:M ratio of 67% for small pelagic species suggested by Patterson (1992) as a proxy. Assuming M = 0.8 (Murawski and Waring, 1979; NEFSC, 2010), this translated to an F = 0.536 as a maximum fishing mortality threshold (MFMT) proxy.

SARC 58 Biological Reference Points

Based on Patterson (1992), the proposed overfishing reference point is F = 2M/3 = 2×1.27/3 = 0.85; CV = 0.04. The current fishing mortality (F_{2012} = 0.02) is well below the proposed overfishing reference point (Figure A6.1). The proposed biomass reference point SSB_{MSY} proxy is 39,515 mt (87.1 million lb); CV = 0.26. SSB_{2012} is estimated to be 90,693 mt (199.9 million lb), which is well above the proposed SSB_{MSY} proxy (Figure A6.2). The proposed MSY proxy is 30,672 mt (67.6 million lb); CV = 0.21. Overfishing is not occurring and the stock is not overfished.

Effect of environmental factors

Environmental factors such as predators and food availability strongly determine survival to recruitment and therefore annual variation in total number of recruits to the spawning stock. Because the spawning biomass of this short-lived stock is dominated by one or two age classes, recruitment variation propagates into variation in spawning biomass. Our projection methodology accounts for variation in recruitment and therefore, environmental variation is an important contributor to our uncertainty in estimates of reference points and stock status.

A more direct way that environmental factors influenced our assessment was through the use of bottom temperature during the NEFSC fall offshore survey to estimate availability of the butterfish stock to the survey. In turn, our annual estimates of recruitment were informed by these estimates of availability and these recruitment estimates are used in long-term projections to establish the biological reference points.

References

Mid-Atlantic Fishery Management Council (MAFMC). 2012. Report of May 2012 Meeting of the MAFMC Scientific and Statistical Committee. 10 p.

Patterson K.1992. Fisheries for small pelagic species: an empirical approach to management targets. Rev Fish Biol Fisher 2:321-338.

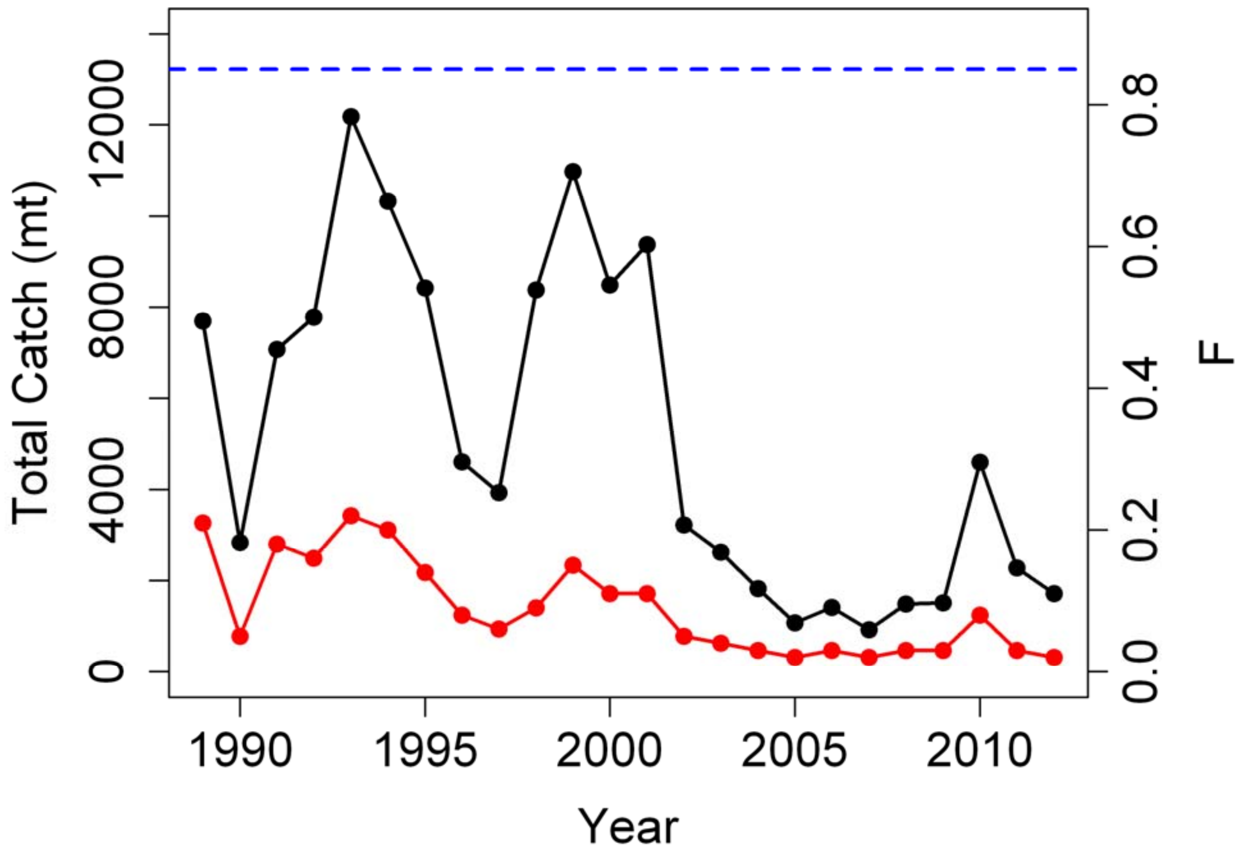


Figure A6.1. Butterfish total catch (mt) and fishing mortality (F). Dashed blue line is the 2014 SAW/SARC F_{MSY} proxy.

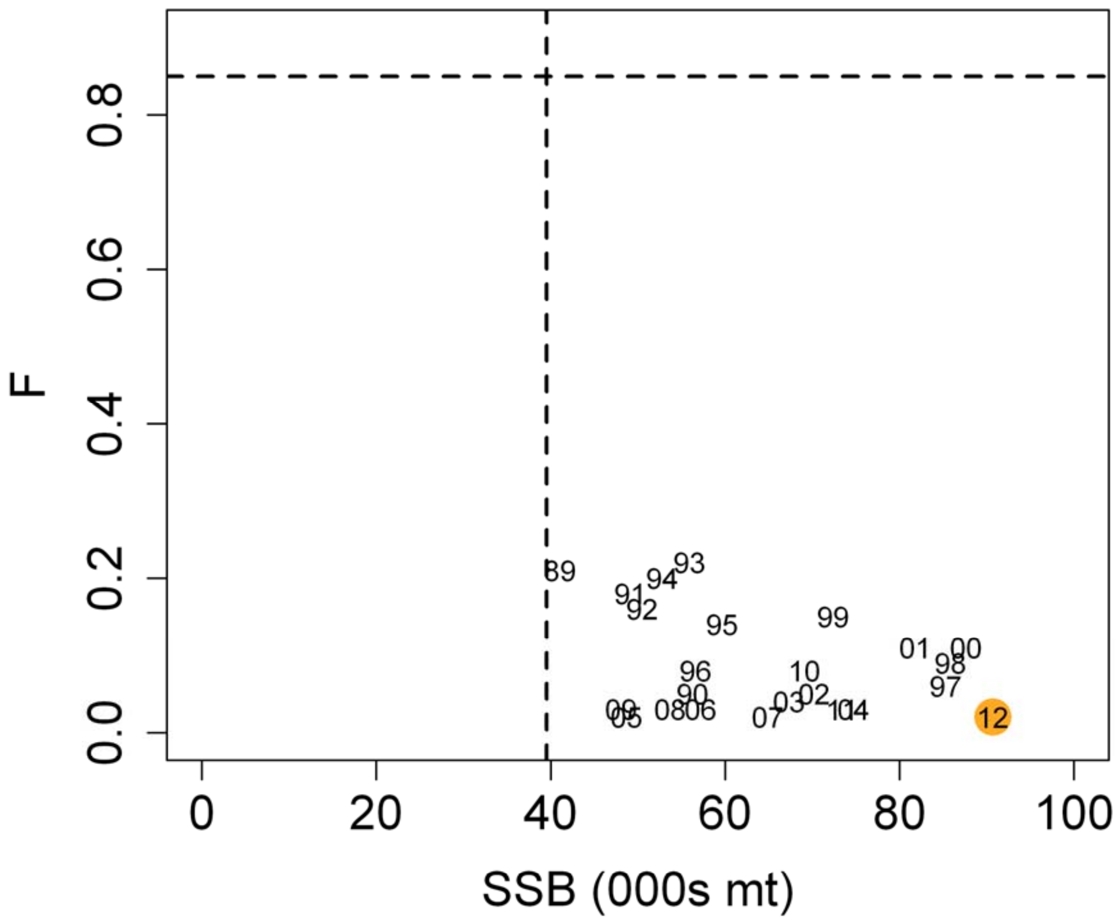


Figure A6.2. Butterfish spawning stock biomass (SSB) and fishing mortality (F) relative to the 2014 SAW/SARC biological reference points SSB_{MSY} proxy = 39,515 mt and F_{MSY} proxy = 0.85.

TOR 7. Evaluate stock status with respect to a newly proposed model and with respect to "new" BRPs and their estimates (from TOR-6). Evaluate whether the stock is rebuilt.

[SAW Editor's Note: ***Readers should refer to Butterfish Appendix 4 for final results of the SAW/SARC58 peer review. Appendix 4 contains the results, reference points, and projections for the final model accepted by SARC58. During the course of the SAW/SARC58 the review panel asked for several changes, which were incorporated into the final model and results (see Appendix 4).***

The following content (included directly below in the current section) provides documentation of all work that was done before the analyses in Appendix 4.]

The final model run adopted by the working group for evaluation of stock status. Fishing mortality was estimated to be 0.02 in 2012, which is well below the proposed overfishing reference point F_{MSY} proxy = 0.85 (Figure A7.1). There is a < 1% chance the estimated fishing mortality is above the F_{MSY} proxy (Figure A7.2).

SSB was estimated to be 90,693 mt (199.9 million lb), which is well above the proposed biomass reference point SSB_{MSY} proxy = 39,515 mt (87.1 million lb). There is a < 1% chance the estimated SSB is below the SSB_{MSY} proxy (Figure A7.3).

The butterfish stock was not overfished and the overfishing was not occurring in 2012 relative to the new biological reference points.

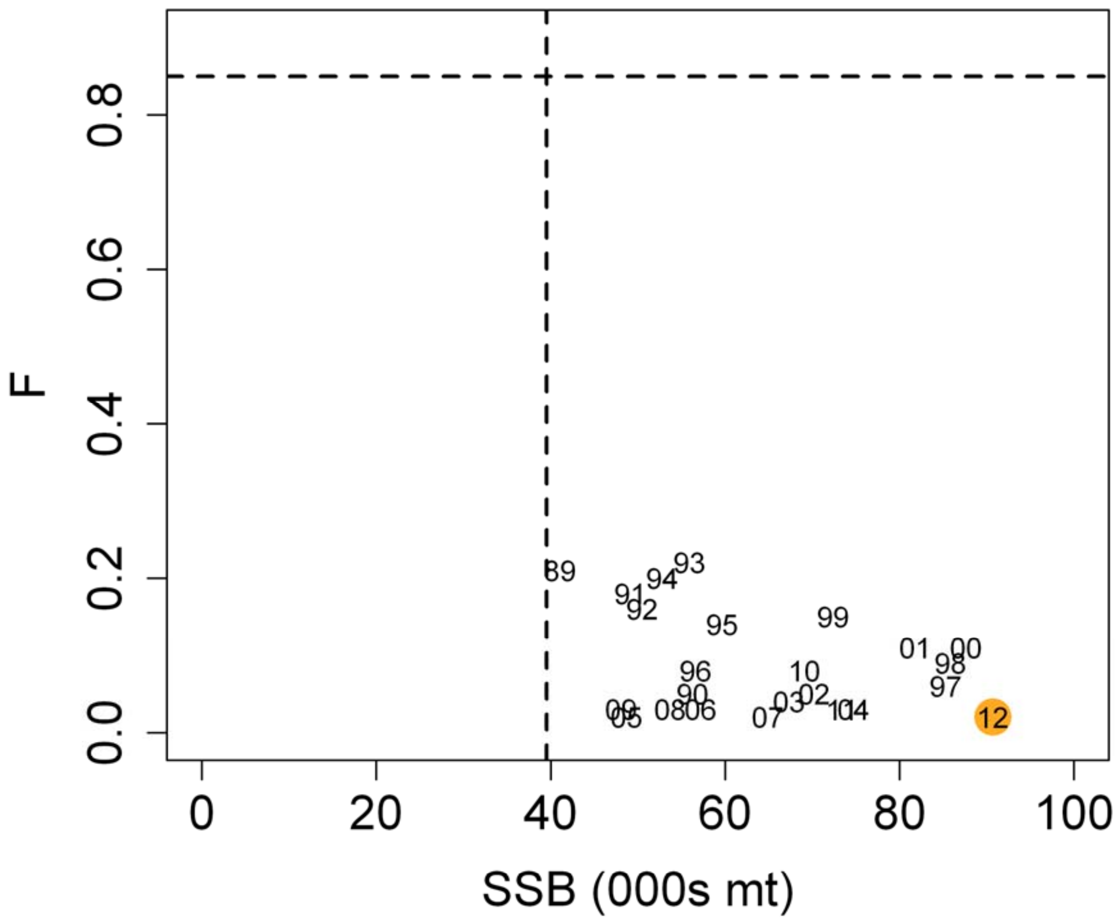


Figure A7.1. Butterfish spawning stock biomass (SSB) and fishing mortality (F) relative to the 2014 SAW/SARC biological reference points SSB_{MSY} proxy = 39,515 mt and F_{MSY} proxy = 0.85.

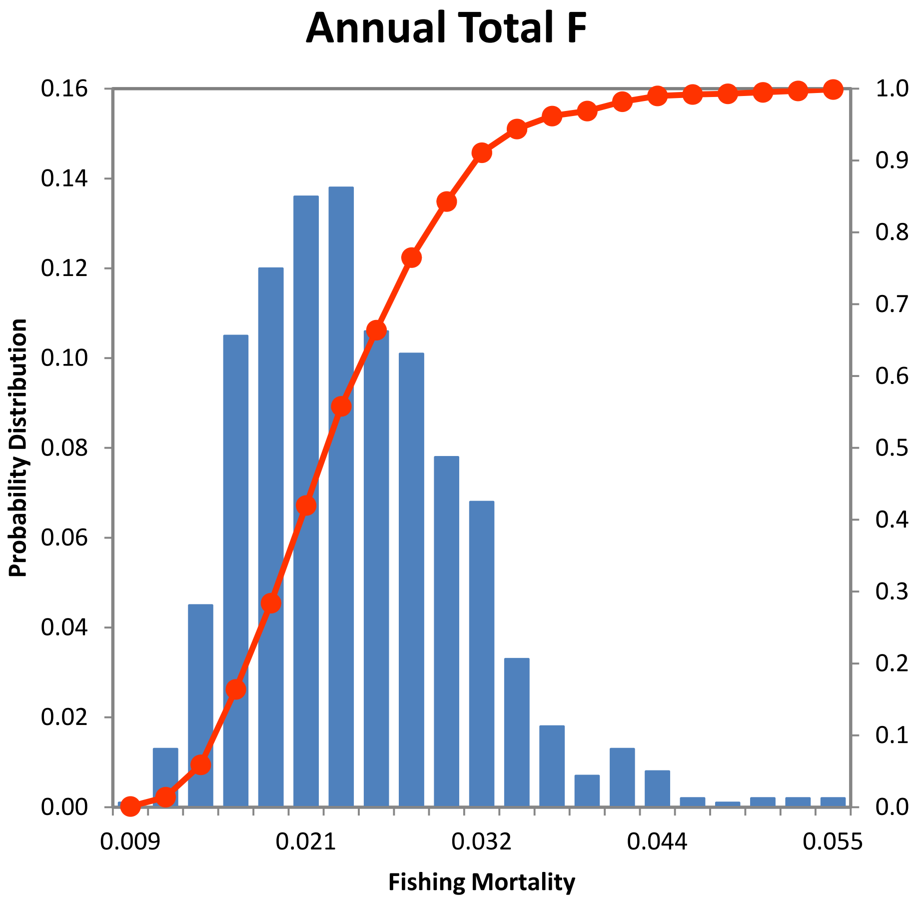


Figure A7.2. Markov Chain Monte Carlo distribution plots for annual total F

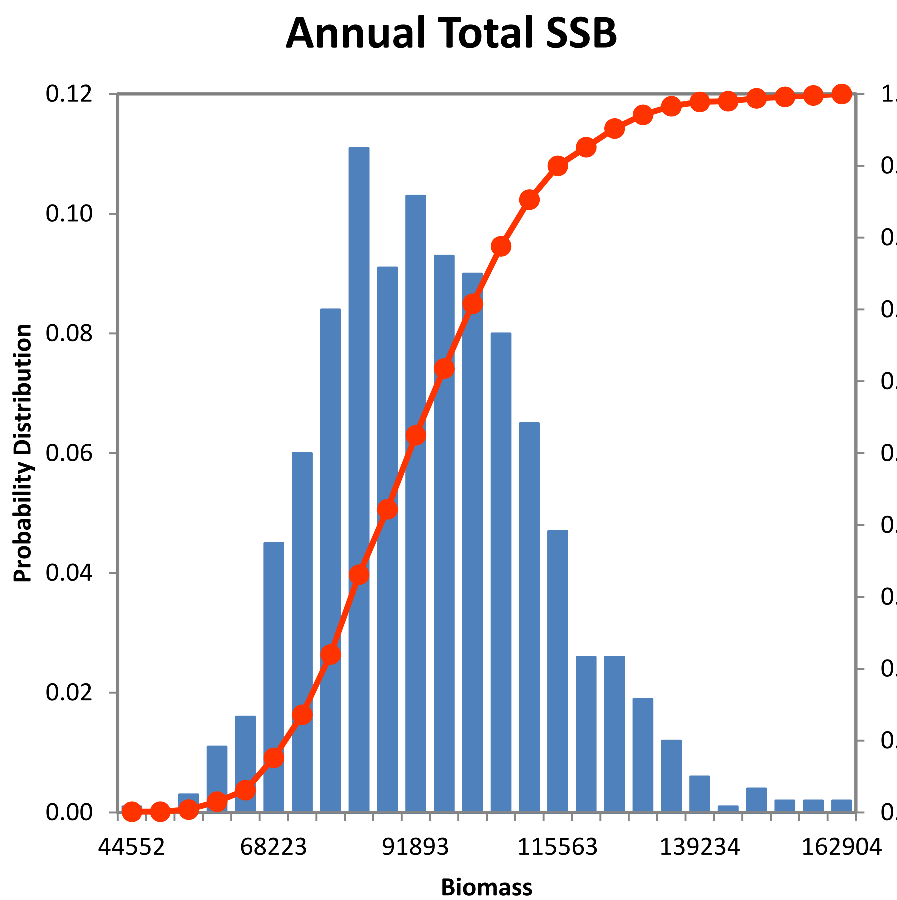


Figure A7.3. Markov Chain Monte Carlo distribution plots for annual total SSB.

TOR 8. Develop approaches and apply them to conduct stock projections and to compute the statistical distribution (e.g., probability density function) of the OFL (overfishing level) and candidate ABCs (Acceptable Biological Catch; see Appendix to the SAW TORs).

a. Provide numerical annual projections (2 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment). Comment on which projections seem most realistic.

b. Describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming overfished, and how this could affect the choice of ABC.

[SAW Editor's Note: ***Readers should refer to Butterfish Appendix 4 for final results of the SAW/SARC58 peer review. Appendix 4 contains the results, reference points, and projections for the final model accepted by SARC58. During the course of the SAW/SARC58 the review panel asked for several changes, which were incorporated into the final model and results (see Appendix 4).***

The following content (included directly below in the current section) provides documentation of all work that was done before the analyses on Appendix 4.]

Stochastic projections were made to provide forecasts of stock size and catches in 2013-2014 consistent with the new (updated) 2014 SAW 58 biological reference points (Tables A8.1, Fig. A8.1-A8.2). The projections assume that recent patterns of fishery selectivity, discarding, maturity at age and mean weight at age will continue over the time span of the projections. One hundred projections were made for each of 1000 Markov Chain Monte Carlo (MCMC) realizations of 2012 stock sizes using AGEPRO version 4.2.2 (NFT, 2013). Future recruitment at age 1 was generated randomly from the probability density function of the updated recruitment series for 1989-2012 (average recruitment = 8.1 billion fish).

If the current fully recruited F (0.02) was maintained for 2013, the median projection of SSB is 60,037 mt (132.4 million lb), with 5% and 95% confidence limits of 41,642 mt (91.8 million lb) and 86,241 mt (190.1 million lb), respectively. The median projected total catch is 1,251 mt (2.8 million lb), with 5% and 95% confidence limits of 884 mt (1.9 million lb) and 1,776 mt (3.9 million lb), respectively.

If the proposed overfishing reference point (F_{MSY} = 0.85) is used for 2014, the median projection of SSB is 43,686 mt (96.3 million lb), with 5% and 95% confidence limits of 32,646 mt (72.0 million lb) and 58,333 mt (128.6 million lb), respectively. The median projected total catch is 34,671 mt (76.4 million lb), with 5% and 95% confidence limits of 26,157 mt (57.7 million lb) and 45,293 mt (99.9 million lb), respectively.

Applying the recent MAFMC policy of reducing the OFL by 50%, the ABC for 2014 would be 17,336 mt (38.2 million lb).

Given the current management regime, and recent catch history, it is unlikely the ABC of 17,336 mt (38.2 million lb) will be exceeded in 2014.

References

NOAA Fisheries Toolbox. (NFT). 2013. Age structured projection model (AGEPRO) version 4.2.2 (Internet address: http://nft.nefsc.noaa.gov).

Table A8.1. Biological reference point for F_{MSY} and SSB_{MSY} with 95% confidence interval

	95% Confidence Interval	
SSB_{MSY}	Lower	Upper
39,515	25,586	59,812

FMSY	CV
0.85	0.04

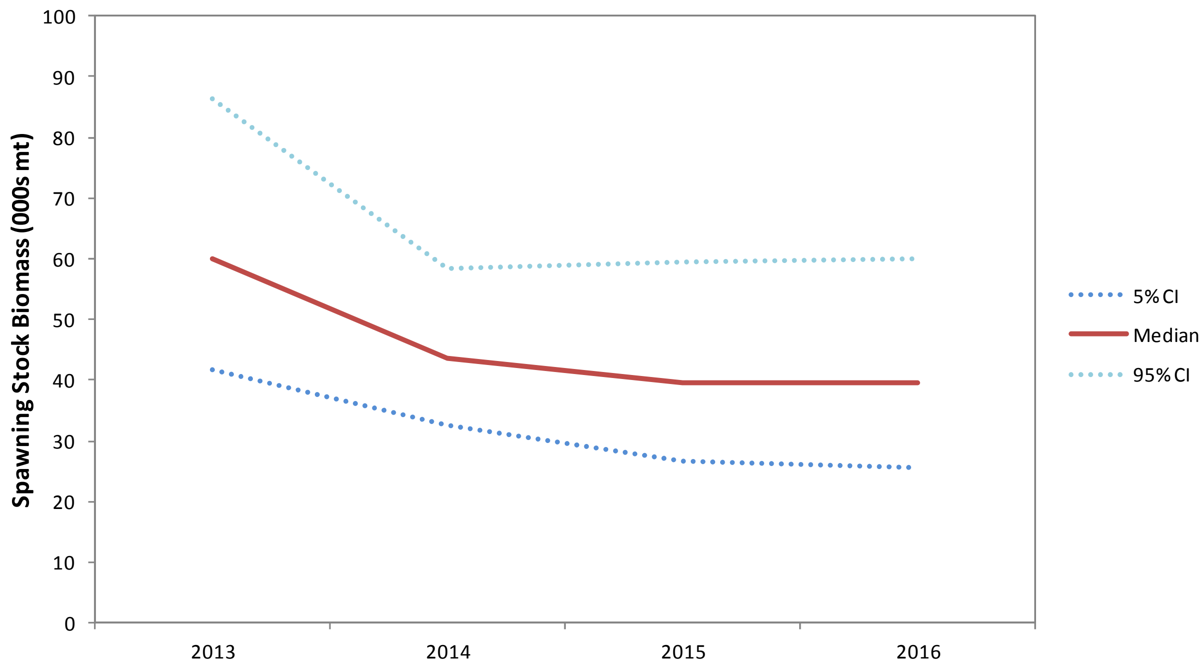


Figure A8.1. Projection of median butterfish spawning stock biomass (000s mt) + 95% confidence interval with status quo F in 2013 and F_{MSY} in 2014 and beyond.

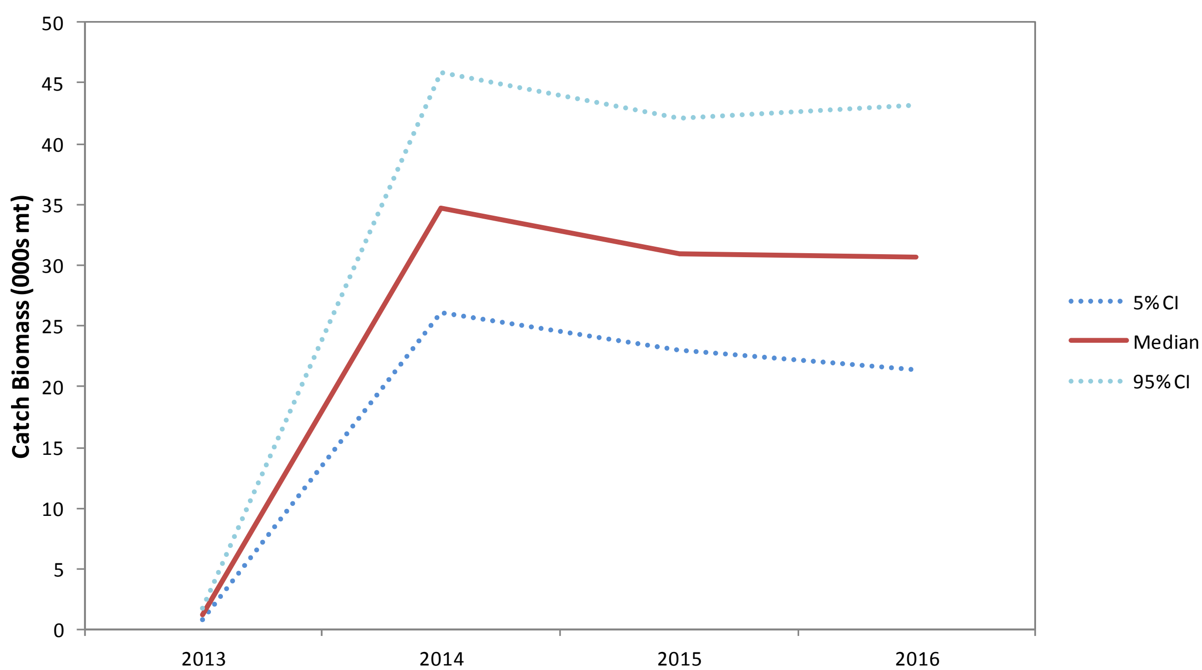


Figure A8.2. Projection of median butterfish catch (000s mt) + 95% confidence interval with status quo F in 2013 and F_{MSY} in 2014 and beyond.

TOR 9. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in most recent SARC reviewed assessment and review panel reports. Identify new research recommendations.

No new research recommendations were made in the last assessment. Rather, the research recommendations for SAW 38 were presented and progress on each recommendation was described:

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 F_{MSY} proxy (F0.1=1.01, B_{MSY} 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*.

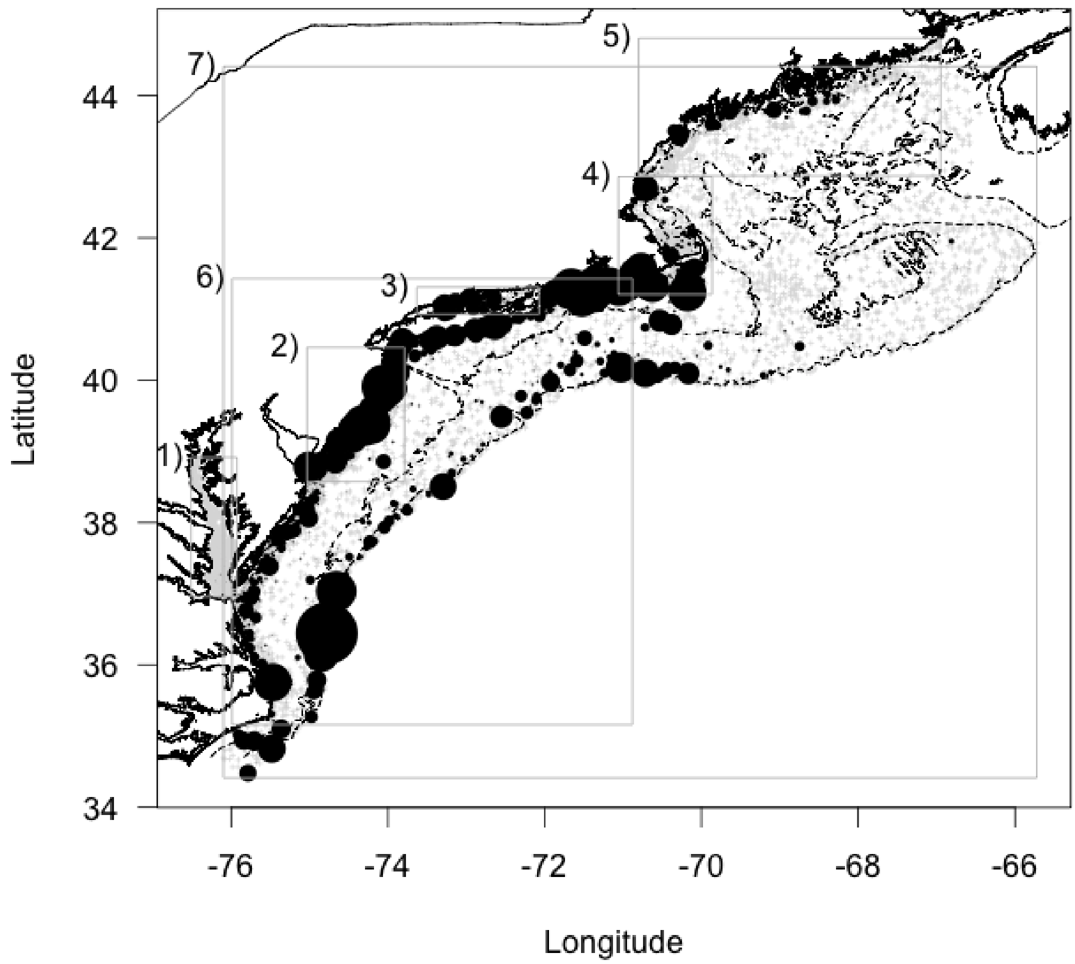
SARC 58 Research recommendations:

1. Encourage field experiments to examine efficiency and catchability of survey gear for the benefit of improving assessment models. Particular emphasis should be on the catchability of the Bigelow net configuration.
2. Explore the possibility of spawning south of Cape Hatteras, NC and potential contribution to the northern stock.
3. Continue development of the modified ASAP model incorporating environmental covariates, particularly the addition of additional survey qs.
4. The current estimate of F implies that existing fisheries have little impact on the stock dynamics. The WG recommends no additional assessments be conducted until such time as the fishery has developed to the point that it could influence the total stock biomass.

Butterfish App. A1. Habitat dependent species distribution shifts

Appendix Table 1. The thermal niche model for butterfish was calibrated using catch densities in bottom trawls and bottom water temperatures measured from 2008-2012 in 7 fishery independent surveys summarized below. Median (5th & 95th quantiles) for temperature and depth are reported.

					2008-2012					
									Butterfish	
Area Surveyed	Lead Agency	First year	Frequency	Samples N		Swept area (km^2)	Bottom Temperature Celsius	Depth Meters	Frequency %	Mean CPUE
Chesapeake Bay	VIMS	2002	Bimonthly	2761	1150	0.014	18.1 (7.1, 26.6)	11.0 (6.1, 23.0)	25	2
New Jersey Coast	NJ DEP	1988	Bimonthly	4509	925	0.022	13.3 (4.0, 20.7)	17 (8.5, 27.0)	69	509
Long Island Sound	CONN DEP	1984	Apr-Jun, Sep-Oct	4041	802	0.026	13.6 (6.3 22.2)	22.0 (7.5, 40.9)	66	321
Massachusetts & Buzzards Bays	MASS DIV Fish	1981	May, Sept	4754	787	0.013	11.1 (4.5, 20.5)	16.0 (8.0, 56.0)	58	279
Coastal Maine-New Hampshire	Maine DMR	2000	May-Jun, Oct-Nov	2370	995	0.015	7.1 (4.3, 12.4)	79.5 (18.3, 135.0)	44	70
Coastal Cape Hatteras to Martha' Vineyard	NEAMAP	2007	Apr-May, Sept-Oct	1626	1478	0.025	14.9 (8.2,19.8)	14 (7.6 , 33.8)	92	829
Cape Hatteras to Gulf of Maine	NEFSC	1970	Feb-Apr, Sept-Nov	20476	2821	0.024	9 (4.4, 20.5)	73.0 (21.0, 242.0)	44	178



App. A1 Figure 1. Study area extent and samples of Atlantic butterfish and bottom temperatures collected from 2008 through 2012 in 7 fishery independent bottom trawl surveys used to calibrate the thermal niche model (see *Appendix Table 1*). The calibration dataset integrated surveys of 1) Chesapeake Bay, 2) New Jersey coast, 3) Long Island Sound, 4) Massachusetts and Buzzards bay, 5) coastal Maine and New Hampshire, 6) the coastal zone from Cape Hatteras, North Carolina to Martha's Vineyard, Massachusetts (NEAMAP), as well as 7) deeper waters on the North West Atlantic Continental Shelf (NOAA/NEFSC). Grey symbols are stations sampled while filled black symbols are scaled to indicate the relative size of positive catches of butterfish standardized by the swept area of trawl tows. Dashed black lines are 50 m and 150 m isobaths.

Data & preliminary GAM analysis of effects on catch

Methods

Since our objective was to calibrate a thermal niche model for Atlantic butterfish that could be applied to describe species range dynamics at the population level of organization and thus used to estimate the availability of the entire stock to regional surveys, we wanted to merge catch densities and associated bottom water temperatures measured from shallow to deep water throughout the entire Northwest Atlantic regional sea. We therefor assemble a calibration dataset of daytime collections made from 2008 through 2012 on 7 fishery independent bottom trawl surveys (*Appendix Table 1, Appendix Figure 1*). We used data from 2008 through 2012 because complete seasonal sampling was performed in each of the 7 surveys during those years. We used daytime collections because detectability of butterfish in bottom trawls is generally higher during day than night (Richardson et al. 2014, Manderson, et al., 2011) and sampling was performed only during daylight hours except on the NEFSC survey.

We applied generalized additive modeling (GAM) to determine the general form of the response of butterfish catch density to bottom temperature and the relative consistency of the temperature response between surveys, seasons and years. GAMs fit unspecified nonparametric functions to dependent and independent variables and are therefore useful for exploring shapes of species-environmental relationships including interactions or dependencies among variables (Aarts, et al., 2013; Bacheler, et al., 2012; Ciannelli, et al., 2008; Guisan, et al., 2002; Swartzman, et al., 1992). We used GAM to inform the choice of a parametric temperature response function for the niche model, the data distribution function, and to justify data aggregation. Prior to GAM we identified eight tows with catches of more than 30,000 fish that inhibited model convergence. These were removed, leaving a total of 7533 observations.

We first used nested analysis with backward selection to develop a base model starting with the following terms.

$$C_{ij} = \text{offset}(\log[\text{swept area km}^2]) + s(\text{Bottom water temperature}) + \text{Survey}_j + \text{Season} + \text{Year} + e_{ij}$$

Numbers of butterfish caught (C_{ij}) was the dependent variable while the log transform of the swept area estimate of each trawl tow (km^2) was used as a model offset (Ciannelli, et al., 2005; Wood, 2006). We treated survey, year, and season as factors. In GAMs bottom temperature was modeled using a penalized regression spline and mgcv library in R defaults (Wood, 2006; Zuur, et al., 2009). As a result, the degree of smoothing was determined by Generalized Cross Validation (GCV) that balanced penalties for "wiggliness" and goodness of fit. We used the base model to identify the appropriate distribution assumption (Lognormal, Poisson, Negative Binomial) and whether a fully nonlinear model was necessary. We selected the distribution that produced the smallest residual dispersion and Akaike's Information Criterion (AIC) for the base model (Zuur, et al., 2012). The theta parameter for the negative binomial link function was selected by within models by iteration (Venables and Ripley, 2002; Wood, 2006).

We then incorporated survey, year and season in the smoothing spline for temperature to determine whether the butterfish catch response to temperature varied with these factors. This approach produced data driven temperature responses for each level of each factor. We constructed separate models for survey, year and seasonal effects on the temperature response because more complex models failed to converge. To analyze seasonal effects, samples were grouped based on whether they were collect before or after July 2nd (Day of the year 182). Because the schedule of seasonal sampling differed among the 7 surveys, finer temporal parsing of the data confounded season and spatial effects. We compared temperature responses by determining temperatures at which minimum 2 standard error confidence bands crossed into and out of the region of positive effects in partial deviance plots, the location of a mode (if one existed) in the GAM response functions.

Results

Model comparison statistics, particularly dispersion and AIC, indicated that a GAM with a smoothing spline for temperature and a negative binomial distribution was the appropriate framework to investigate the effects of survey, year and season on the response of butterfish catch densities (*Appendix Table 2a*; m3 vs. m5, m6 & m7). Analysis of nested GAM models indicated that temperature had the largest effect on catch accounting for 32% of the total deviance, followed by survey and year. The addition of season did not substantially improve the fit of the model after the effects of the other factors were accounted for. Further nested analysis indicated that about 1/3 of the temperature effect was also accounted for by survey and year effects. The model with the lowest AIC included the survey dependent temperature response as well as the independent factors survey and year (model m8).

Partial deviance plots from GAM (not shown) indicated catches of butterfish were lowest in the Chesapeake Bay survey and highest in the NEAMAP survey of the coastal zone from Cape Hatteras to Martha's Vineyard. On average catch was lowest in 2008, peaked in 2010 and declined in 2011 and 2012.

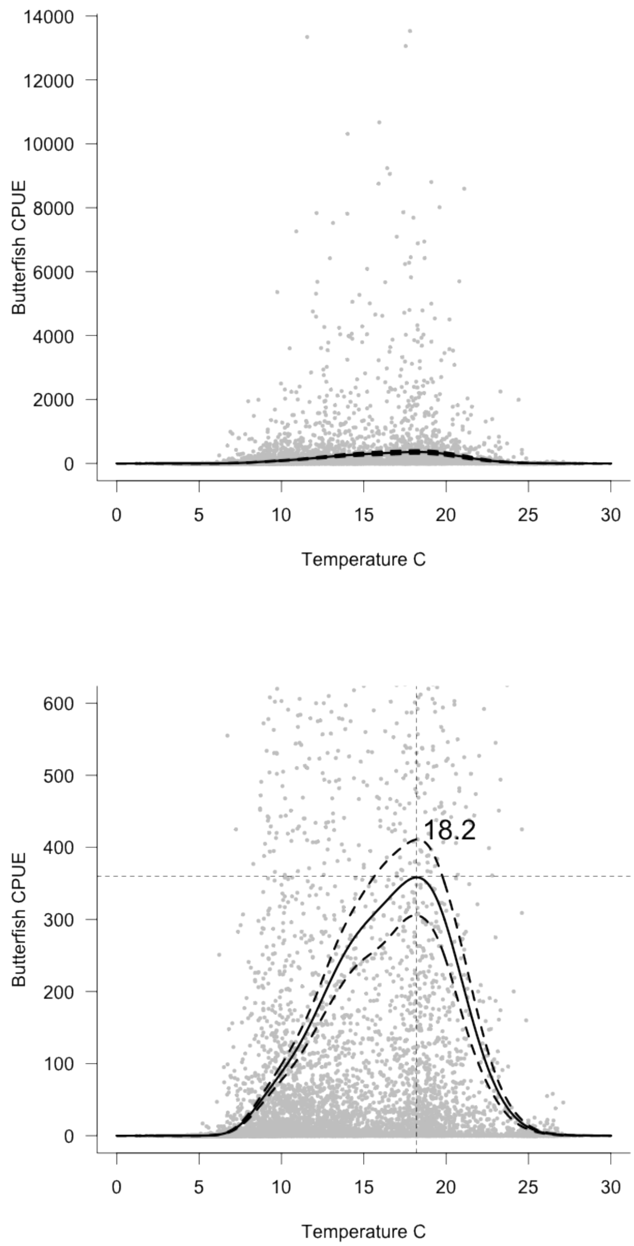
Although GAM indicated the model with the survey dependent temperature response had higher explanatory power (m8), response curves were only slightly different across the range of temperatures with positive effects on catch (not shown). Instead the strongest survey effects were associated with the northernmost surveys in the range of cold temperatures negatively influencing catch. Catches crossed into the range of positive effects at temperatures averaging 9.7C (SD=1.3; 8-11.2C). The upper temperature thresholds averaged 24.7C. Variability at the upper threshold was somewhat greater among the surveys (SD=2.14C). A clear latitudinal gradient in temperature thresholds was not evident, although the partial temperature response remained positive at relatively high temperature in Chesapeake Bay and Maine/New Hampshire. A clear mode in the partial temperature response was only evident for the NEAMAP survey of the near shore mid-Atlantic Bight coastal ocean (16C). Strong negative effects of cold temperatures on catch occurred in the NEFSC offshore survey of the entire Northwest Atlantic continental shelf, and the northernmost surveys (Maine-New Hampshire).

Additional examination of variation in the seasonal temperature response curves (1st half and 2nd half of year) indicated of most of the seasonal dependence was associated with the distribution of temperatures during the spring and fall. The strongest effects on catch were negative and associated cold temperatures during the first half of the year. From January through June temperatures below 9.3C had strong negative effects while the 2 standard error confidence bands widened above 21C because few samples were collected in warm temperatures.

GAM analysis indicated that dependencies in response of butterfish catch to bottom water temperature on survey, year and seasonal were relatively small and nonsystematic. As a result, we pooled calibration data to examine the mean response of butterfish catch standardized by swept area of tows (x 100; CPUE) to bottom water temperature. This GAM was used to examine the mean response of CPUE to bottom temperature, guide the choice of the parametric equation to serve as the niche model, and develop starting values for maximum likelihood estimation. The thermal response curve generated with GAM was asymmetrical and left skewed (*Appendix Figure 2*) supporting the choice of the parametric Johnson and Lewin (1946) equation. The GAM response rose gradually from cold temperatures to a maximum at approximately 18.2C before declining rapidly at higher temperatures.

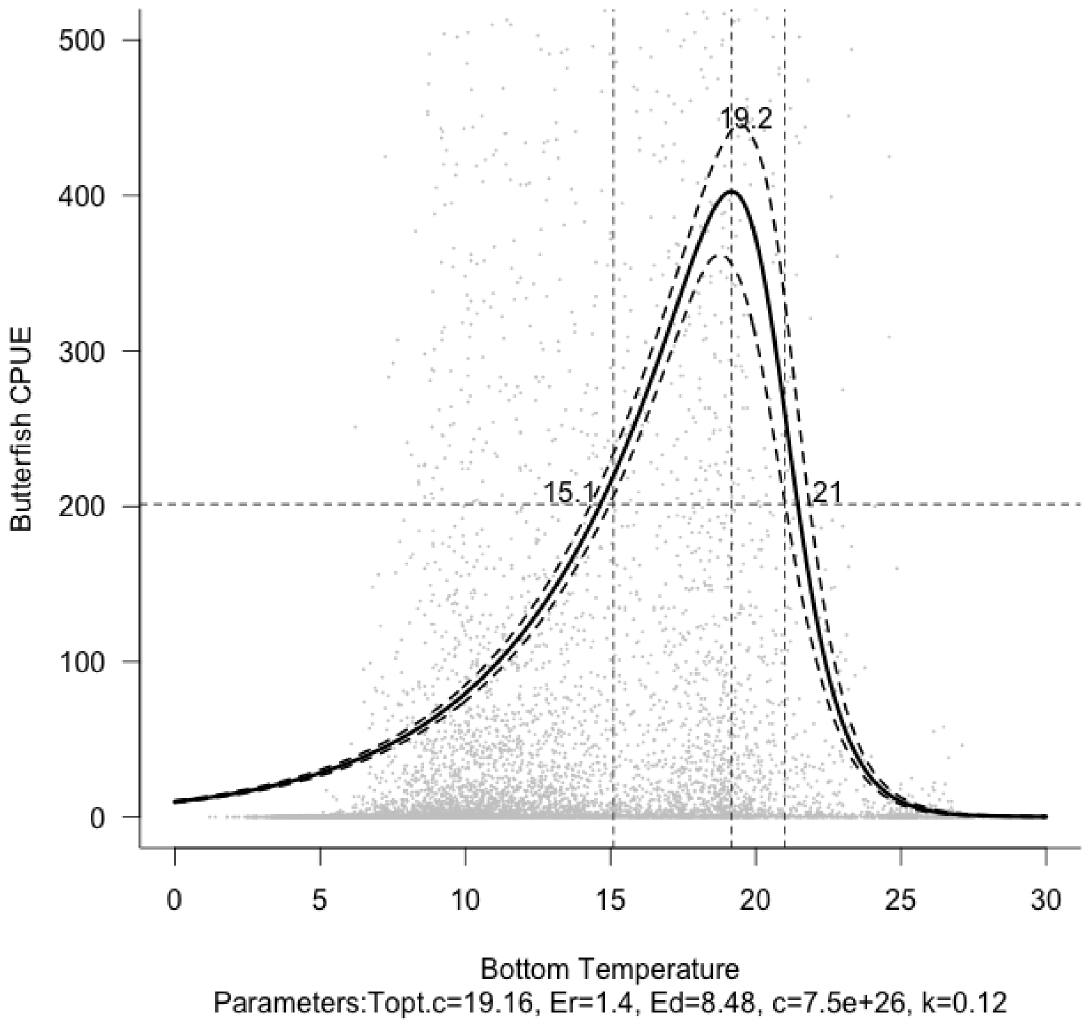
App. A1 Table 2a. Generalized additive models to determine effects of survey, year, and season on the response of butterfish catch to bottom water temperature in the 2008-2012 calibration data used to develop the parametric niche model. Number of butterfish per tow was the dependent variable. All models included log (swept area of trawl tow) as a model offset. Temperature was modeled using a nonlinear penalized smoothing spline (s) except m7 which was linear. Models m0-m4, m7-m11 assumed a negative binomial distribution. m0-m4 were nested and used to develop the base model. m3,m5,m6 were used to determine the appropriate link function. m7-m11 were used to determine whether the temperature response varied substantially with survey, year or season. Theta (is the scale parameter for the negative binomial distribution estimated within the best fitting GAM m8.

Model number	Model Terms	Residual deviance	Deviance Explained %	Dispersion	AIC	Δ AIC	logLik
m0	Null model	8474	0	2	66354		-33176
m1	s(bottom temperature)	5762	32	2	63657	2697	-31820
m2	s(bottom temperature)+survey	4879	42	2	62787	870	-31379
m3	s(bottom temperature)+survey+year	4856	43	2	62772	15	-31367
m4	s(bottom temperature)+survey+year+season	4853	43	2	62770	2	-31365
m5	s(bottom temperature)+survey+year: Loglinear	3134450324	9	342600	142886		-71427
m6	s(bottom temperature)+factor(survey)+ factor(year): Poisson	3762904	33	1229	3788284		-1894122
m7	bottom temperature+survey+year: Linear (NB)	8733	27	3	63650		-31812
m8	s(bottom temperature, by=survey)+survey+year: theta=0.07	4555	46	1	62525	245	-31217
m9	s(bottom temperature, by=year)+survey+year	4709	44	2	62676		-31294
m10	s(bottom temperature, by=season)+survey+year	4827	43	2	62756		-31352
m11	s(bottom temperature, by=season) +survey+year+season	4816	43	2	62746		-31347



App. A1 Figure 3. Generalized additive model (GAM) of the relationship between butterfish CPUE (catch standardized by swept area km2 x 100) and bottom water temperature in the 2008-2012 calibration data. The response left skewed in a manner typical of a thermal reaction norm and explained 31% of the deviance in CPUE. Top panel shows all data while in the bottom panel the y axis is cropped to better show the thermal response. The dotted vertical line is the approximate thermal optima used as a start value for maximum likelihood parameter estimation of the Johnson & Lewin equation. The horizontal line is set at the CPUE value of the thermal optima. This was used to determine the start value of the scaling parameter c of the Johnson and Lewin equation. The size parameter k (theta) estimated by iteration within the model was 0.05.

Maximum likelihood estimation (See main text for details)



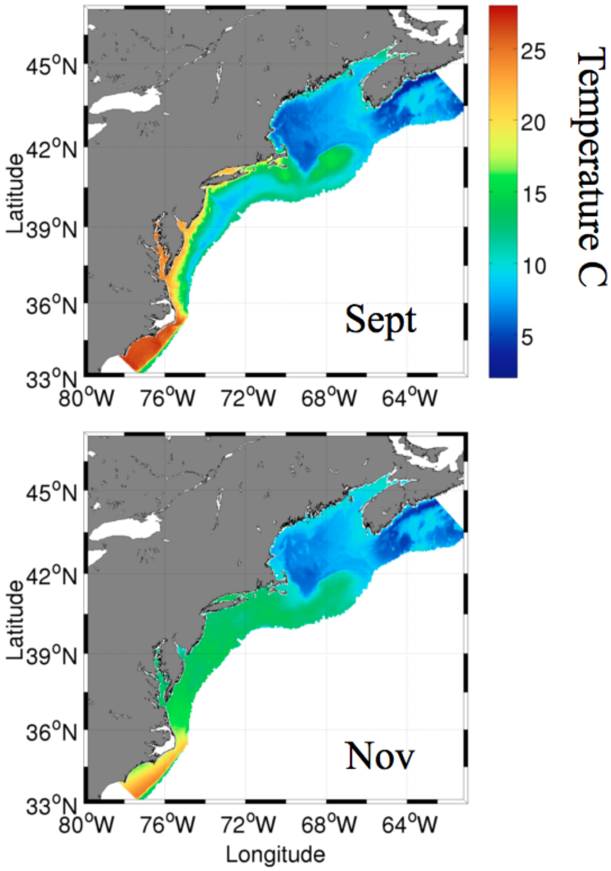
App A1 Figure 4. Plot of the thermal response curve for Atlantic butterfish constructed by estimating parameters of the Johnson and Lewin equation (solid black line) minimizing negative binomial likelihood using standardized butterfish catch as the response (h) and bottom water temperature as the independent variable. Calibration data was from 7 surveys the Northwest Atlantic from 2008-2012 (*Appendix table 1, Fig 1*). Dashed curved lines are 2.5% and 97.5% population prediction intervals developed using parameter estimates, the variance covariance matrix, in the method described in Lande et al. (2003) and Bolker (2008). The horizontal line is located at half the maximum value of the parameterized equation. Vertical dashed lines indicate temperature in degrees centigrade of the optimal temperature (T_{opt}) and where the 2.5% population prediction interval crosses the ½ maxima.

Bottom temperature hindcast

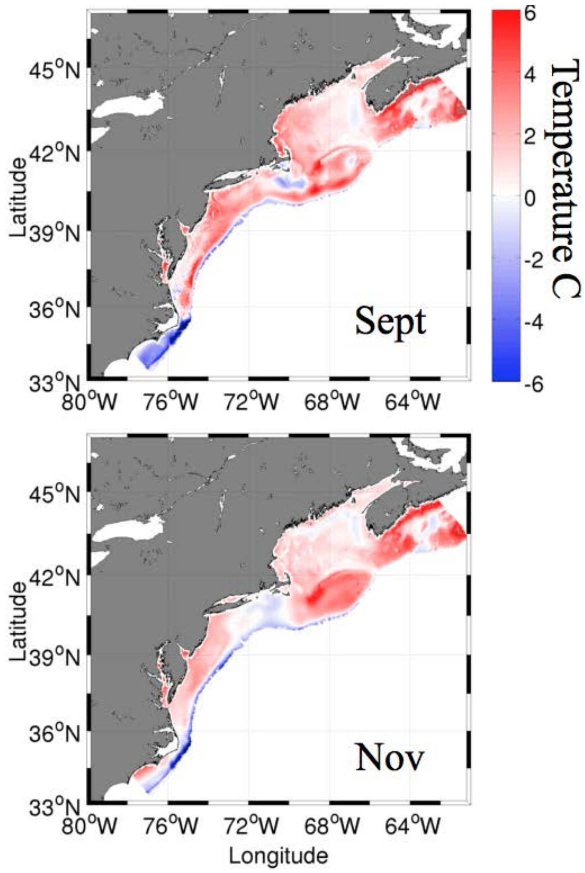
Methods

The Regional Ocean Modeling System (ROMS) model simulation described in Kang & Curchitser (2013) originally designed to study variability in the Gulf Stream over the 50 years (1958-2007) was used to generate the bottom temperature hindcast. Bottom bathymetry for the model was derived from the Shuttle Radar Topography Mission (SRTM) database (Farr et al. 2007), and initial and ocean boundary conditions were from reanalysis data of Simple Ocean Data Assimilation (SODA) (Carton & Giese 2008) version 2.1.6 (1958-2007) and the global HYCOM model (2005-2012). Surface forcing was extracted from the Coordinated Ocean-ice Reference Experiments (CORE) datasets (Large & Yeager 2009). Ten major tidal components extracted from TPXO dataset (Egbert & Erofeeva 2002) were included in the model. Model output was averaged daily over a 55-year (1958-2012) hindcast.

Monthly mean bottom temperatures in the Mid Atlantic Bight Ocean Climatology and Hydrographic Analysis (MOCHA) (Fleming and Wilkin, 2010) were used to make a "semi-prognostic adjustment (SPA)" and debias bottom temperatures from ROMS (*Appendix Figure 4*). This was achieved by interpolating ROMS temperatures onto the MOCHA grid, and then calculating differences between the monthly mean bottom temperatures from ROMS and monthly means from MOCHA (*Appendix Figure 5)*. The monthly mean difference field for the model was then subtracted from each daily hindcast temperature field of the corresponding month.



App. A1 Figure 5. Monthly mean MOCHA bottom temperature climatology for the fall used to make semiprognostic adjustment (SPA) and debias the ROMs bottom temperature hindcast.



App. A1 Figure 6. Spatial differences between the monthly mean bottom temperatures from ROMS for Fall of 2006 and monthly mean bottom temperatures from MOCHA climatology (*Appendix figure 4*). These monthly spatial differences were applied to daily temperatures from ROMS to make the semiprognostic adjustment (SPA) and debias the bottom temperature hindcast.

MOCHA bottom temperatures, raw ROMS hindcast bottom temperatures and the bottom temperature hindcast debiased with SPA were evaluated using bottom temperatures observed *insitu* and recorded in the NODC World Ocean Database, in the NOAA Northeast Fisheries Science Center hydrographic database, and/or measured on the 7 fisheries independent bottom trawl surveys. Measured and modeled (climatological average) temperatures were compared by calculating root mean standard errors (RMSE), root mean square centered differences (RMSD), standard deviations (σ) and correlation coefficients (R) as follows.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(o_i - m_i)^2}$$

$$RMSD = \sqrt{\frac{1}{n}\sum_{i=1}^{n}[(o_i - \bar{o}) - (m_i - \bar{m})]^2}$$

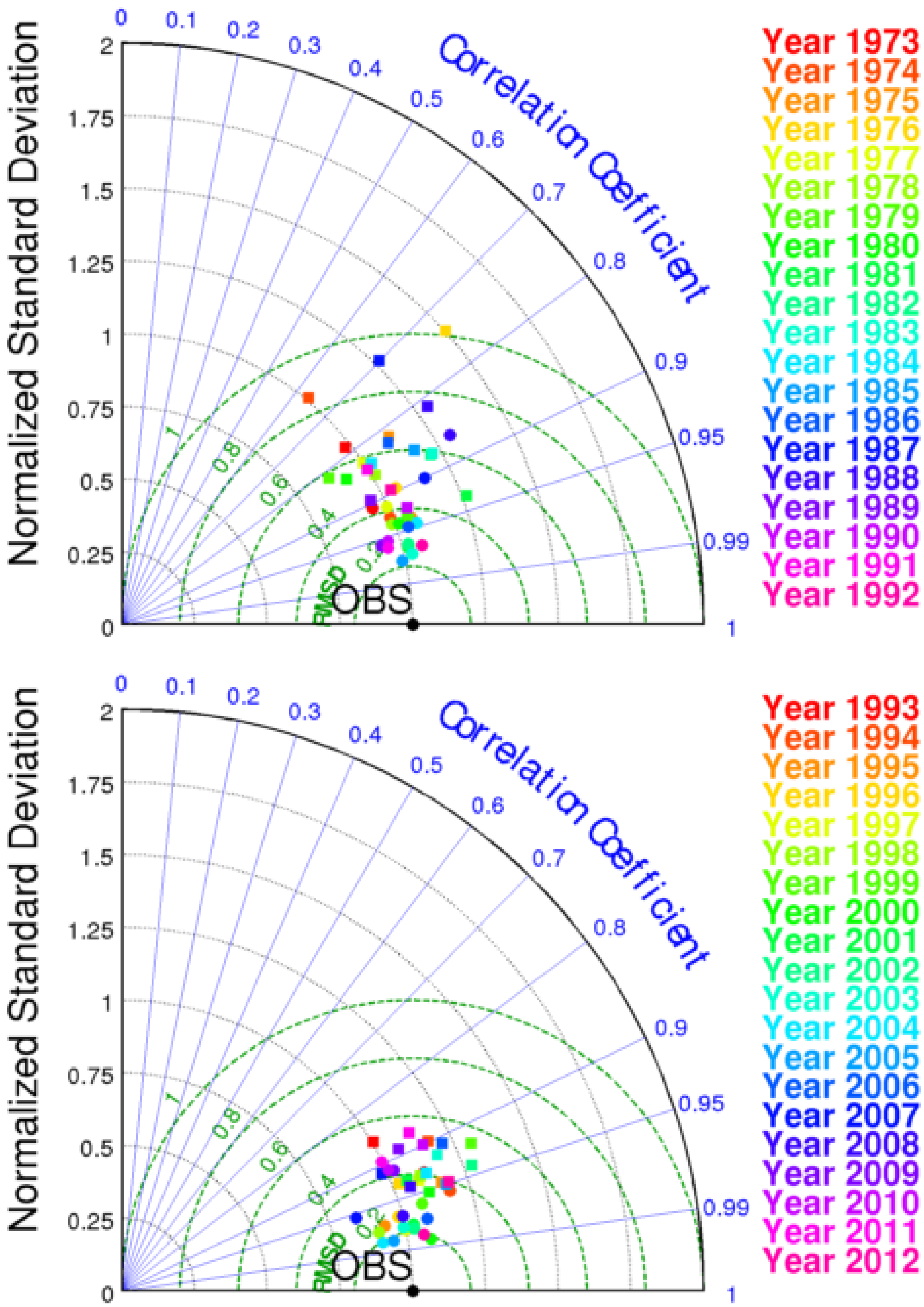
$$\boldsymbol{\sigma_o} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(o_i - \bar{o})^2}$$

$$R = \sqrt{\frac{1}{n\sigma_o\sigma_m}\sum_{i=1}^{n}(o_i - \bar{o}) - (m_i - \bar{m})}$$

where *o* is an observed value, *m* is a modeled value and the overbar indicates the mean.

Results

Comparison of model output with *in situ* temperature observations for waters with bottom depths <30M and > 30M indicated that MOCHA climatology had a lower RMSE when compared to bottom temperature observations than ROMS modeled bottom temperature (Appendix *Tables 3a,b,c,d*). As a result, a semiprognostic adjustment (SPA) which involved subtracting the monthly mean difference field between MOCHA and the model from each daily temperature hindcast was applied to reduce the spatial bias in the hindcast while preserving the predicted variability (*Appendix table 3a,b,c,d*; *Appendix figure 6*). The debiased (SPA) model hindcast had a lower RMSE for each year when compared to observations than the RAW ROMS hindcast.



App. A1 Figure 7. Normalized Taylor diagram (Taylor, 2001) showing model bottom temperature performance from 1973-1992 (top panel) and 1993-2012 (bottom panel). Filled circles are debiased ROMS bottom temperatures using SPA while squares are the raw bottom temperature hindcast from ROMs.

App. A1 Table 3a. Statistics for fall bottom temperatures in waters less than 30M deep measured *in situ* (Obs), averaged in monthly MOCHA climatology, hindcast using ROMS (model), and hindcast by debiasing the ROMS hindcast using MOCHA (Model SPA).											
Year	Mean				Standard Deviation				RMSE		
	OBS	MOCHA	Model	Model SPA	OBS	MOCHA	Model	Model SPA	Model	MOCHA	Model SPA
1973	14.81	15.12	16.98	15.33	2.86	2.45	2.39	2.65	2.43	1.45	1.29
1974	16.66	15.92	19.24	16.80	3.97	3.52	3.51	3.58	3.21	1.76	1.56
1975	14.23	14.32	16.76	15.12	2.56	3.83	2.31	3.02	2.81	2.23	1.94
1976	14.93	15.65	19.16	16.07	4.45	3.42	4.79	3.64	4.46	1.65	1.64
1977	16.35	17.13	18.62	17.35	2.75	2.70	2.61	3.00	2.82	2.01	1.85
1978	17.82	18.50	19.54	18.52	3.53	3.59	3.30	3.71	2.04	1.47	1.35
1979	17.76	17.99	18.80	18.76	3.98	4.31	3.76	4.49	2.65	1.80	2.01
1980	17.48	18.22	18.38	18.24	4.97	4.22	3.61	4.27	2.80	2.08	1.68
1981	19.32	20.59	23.49	20.24	4.48	4.34	5.33	4.23	4.98	1.84	1.51
1982	17.70	17.87	20.67	18.12	3.46	3.54	4.12	3.93	3.62	1.68	1.48
1983	20.57	20.53	24.74	20.90	4.97	4.66	6.31	4.93	5.18	1.29	1.17
1984	17.87	17.98	20.08	18.57	2.81	3.35	2.80	3.13	2.67	1.59	1.23
1985	22.44	21.12	27.19	21.70	3.81	3.60	5.33	4.12	5.18	1.87	1.31
1986	17.15	17.42	19.11	17.77	3.15	3.84	2.94	3.30	2.83	1.64	1.36
1987	11.81	13.06	15.35	13.48	3.68	1.99	3.55	3.11	3.59	2.06	1.77
1988	12.53	15.49	16.28	15.28	2.15	3.32	2.65	2.75	4.02	3.73	3.28
1989	15.52	16.27	18.12	16.50	5.61	4.76	4.32	4.49	3.43	2.01	2.01
1990	18.51	18.38	21.36	18.55	3.88	2.93	3.44	3.03	3.63	1.96	1.67
1991	18.36	17.60	20.25	18.13	4.57	4.29	3.86	3.76	3.91	1.97	2.01
1992	17.09	18.21	19.19	18.29	3.07	2.84	2.52	2.99	2.72	1.81	1.63
1993	17.40	19.22	18.84	19.10	3.73	3.30	2.85	3.31	3.14	2.93	2.84
1994	17.84	18.87	19.79	18.67	2.25	2.65	2.50	2.82	2.85	1.63	1.59
1995	20.48	18.96	22.33	18.91	2.79	2.56	2.51	2.84	2.65	2.32	2.38
1996	18.51	18.87	20.22	18.63	3.33	3.01	3.17	3.02	2.18	1.48	1.25
1997	19.11	18.92	20.57	19.15	3.39	3.04	3.29	2.95	2.64	1.37	1.33
1998	17.36	16.58	19.66	17.44	3.73	3.95	3.02	3.54	2.69	1.43	1.04
1999	15.91	15.56	18.95	15.96	4.25	4.87	4.23	4.37	3.48	1.72	1.33
2000	18.90	19.05	20.51	19.12	2.96	2.85	2.50	2.91	2.39	0.89	0.90
2001	18.23	18.37	19.35	18.24	2.85	3.17	3.11	3.56	2.21	1.25	1.53
2002	19.04	18.62	22.41	18.69	4.15	4.07	4.08	3.73	3.86	1.33	1.43
2003	18.16	17.41	20.73	17.85	2.74	2.90	3.71	3.02	3.84	2.22	1.26
2004	19.17	18.64	22.12	18.89	4.45	4.30	5.38	4.19	4.33	2.19	1.32

2005	19.83	18.90	22.70	19.26	4.74	4.46	5.33	4.08	3.92	1.97	1.45
2006	18.31	18.47	21.46	18.52	4.26	4.30	5.19	4.51	4.36	1.77	1.23
2007	19.61	17.53	21.60	18.16	2.89	2.86	2.59	2.45	2.89	2.89	1.92
2008	19.12	18.55	21.64	19.37	4.10	3.74	4.20	3.88	2.85	1.50	1.17
2009	17.87	17.76	20.05	17.91	3.73	3.71	4.05	4.07	2.59	1.84	1.32
2010	17.97	17.31	19.88	17.52	3.91	3.65	4.05	3.69	2.48	1.87	1.40
2011	18.79	18.19	20.96	18.63	3.53	3.54	3.82	3.61	2.49	1.55	1.18
2012	23.52	22.07	25.88	23.34	4.55	3.64	4.71	4.21	3.21	2.07	1.04

App. A1 Table 3b. Statistics for fall bottom temperatures in waters greater than 30M deep measured *in situ* (Obs), averaged in MOCHA climatology, hindcast using ROMS (model), and hindcast by debiasing the ROMS hindcast using MOCHA (Model SPA).

Year	Mean				Standard Deviation				RMSE		
	OBS	MOCHA	Model	Model SPA	OBS	MOCHA	Model	Model SPA	Model	MOCHA	Model SPA
1973	10.79	10.17	11.14	10.13	2.81	2.56	2.55	2.52	1.96	1.40	1.39
1974	11.34	10.48	10.35	10.51	2.77	2.60	2.29	2.67	2.74	1.39	1.39
1975	9.98	9.51	10.59	9.58	2.58	2.45	2.67	2.49	1.93	0.96	0.95
1976	10.17	9.69	12.10	9.70	2.31	2.30	3.76	2.32	3.52	1.39	1.37
1977	9.78	9.57	11.82	9.61	2.76	2.37	2.73	2.44	2.83	1.35	1.32
1978	9.06	9.19	11.64	9.22	2.46	2.26	2.68	2.30	3.10	1.06	1.12
1979	9.89	9.62	10.10	9.58	2.85	2.76	1.94	2.74	2.07	1.32	1.30
1980	8.95	8.80	9.57	8.81	2.41	2.20	2.02	2.31	2.10	1.17	1.27
1981	9.21	9.85	9.83	9.82	2.31	2.42	2.25	2.42	1.73	1.40	1.44
1982	9.36	9.52	10.37	9.62	2.73	2.59	3.22	2.72	2.51	1.07	1.09
1983	9.60	9.64	12.53	9.68	2.39	2.48	3.50	2.56	4.03	1.06	1.17
1984	10.51	9.74	11.39	9.76	2.72	2.49	2.28	2.51	2.32	1.37	1.43
1985	9.27	8.73	10.79	8.77	2.79	2.73	2.74	2.75	3.05	1.14	1.13
1986	10.79	10.14	12.18	10.11	2.74	2.60	3.12	2.59	2.52	1.20	1.20
1987	8.40	9.09	10.91	9.06	2.42	2.80	3.10	2.82	3.42	1.45	1.44
1988	9.58	9.39	10.85	9.53	2.53	2.51	2.61	2.45	2.24	1.18	1.14
1989	9.13	9.58	11.77	9.85	2.85	2.68	3.29	2.76	3.41	1.29	1.42
1990	10.27	9.63	11.40	9.95	3.23	2.73	2.96	2.93	1.95	1.49	1.31
1991	9.47	9.16	11.68	9.23	2.59	2.40	3.08	2.41	3.29	1.12	1.11
1992	9.41	9.49	11.59	9.49	2.85	2.64	3.27	2.77	2.98	0.99	1.05
1993	10.33	9.86	10.66	9.98	3.02	2.86	2.62	2.83	2.16	1.32	1.31
1994	10.91	9.89	11.30	9.86	2.87	2.85	3.14	2.85	2.03	1.61	1.61

1995	10.30	9.33	10.40	9.27	3.19	2.74	3.84	2.69	2.06	1.44	1.50
1996	8.85	9.15	10.40	9.10	2.66	2.70	2.89	2.73	2.63	1.40	1.41
1987	9.83	9.28	9.81	9.34	3.71	3.36	3.53	3.35	1.96	1.18	1.15
1988	7.85	8.74	8.86	8.80	2.74	2.37	3.11	2.38	2.32	1.47	1.49
1999	10.04	9.03	10.33	9.16	2.48	2.27	3.69	2.39	2.25	1.57	1.48
2000	9.84	9.03	10.12	9.08	2.91	2.95	3.28	3.00	1.68	1.23	1.17
2001	9.22	8.73	9.04	8.74	3.48	3.07	2.80	3.09	1.97	1.16	1.11
2002	10.02	8.84	9.38	8.86	3.61	3.51	3.71	3.54	2.18	1.58	1.54
2003	9.02	8.76	9.41	8.78	3.18	2.93	2.66	2.99	1.93	1.17	1.18
2004	8.56	9.14	10.19	9.20	3.94	3.42	4.01	3.47	2.71	1.35	1.33
2005	9.28	9.04	9.77	9.05	2.97	2.95	2.91	2.97	1.80	1.03	1.03
2006	9.79	8.92	10.25	8.92	2.92	2.81	2.56	2.82	2.11	1.53	1.51
2007	8.83	9.32	11.26	9.36	3.36	3.12	3.62	3.15	3.64	1.80	1.92
2008	9.70	9.41	11.19	9.41	3.64	3.19	3.35	3.21	2.84	1.75	1.74
2009	10.34	9.47	11.24	9.50	3.74	3.09	3.41	3.18	2.93	2.46	2.52
2010	10.61	10.04	11.23	10.00	2,78	2.91	3.36	2.88	2.71	2.30	2.30
2011	10.29	9.79	11.31	9.86	3.67	3.30	4.16	3.35	3.66	3.03	3.00
2012	10.43	8.97	10.46	8.98	2.89	2.67	3.79	2.77	2.36	1.81	1.86

App. A1 Table 3c. Statistics for spring bottom temperatures in waters less than 30M deep measured *in situ* (Obs), averaged in monthly MOCHA climatology, hindcast using ROMS (model), and hindcast by debiasing the ROMS hindcast using MOCHA (Model SPA).

Year	Mean				Standard Deviation				RMSE		
	OBS	MOCHA	Model	Model SPA	OBS	MOCHA	Model	Model SPA	Model	MOCHA	Model SPA
1973	8.45	6.96	9.40	7.21	4.40	4.08	4.37	4.58	1.70	1.80	1.73
1974	6.96	5.65	10.09	5.90	2.52	2.77	3.34	2.35	3.59	1.82	1.45
1975	6.60	6.31	10.73	6.18	1.76	2.91	2.55	2.71	4.36	1.52	1.35
1976	7.80	6.77	11.20	6.94	2.21	2.25	2.88	2.49	3.77	1.49	1.35
1977	9.17	9.43	12.92	9.45	3.06	2.23	2.72	2.23	4.10	1.90	1.61
1978	6.58	7.42	9.47	7.65	3.83	3.15	3.90	3.34	3.37	1.75	1.80
1979	6.23	7.63	9.51	7.13	2.84	2.77	2.93	2.77	3.54	1.87	1.58
1980	6.26	7.01	8.47	6.97	3.52	2.96	3.41	3.53	2.56	1.72	1.60
1981	7.68	8.23	10.12	8.20	3.93	3.53	4.60	3.76	2.89	1.15	1.24
1982	12.11	11.85	14.09	11.52	5.25	4.31	4.37	3.72	2.40	1.74	2.05
1983	6.31	6.18	8.82	6.07	3.60	3.71	3.47	3.67	2.78	0.86	0.95
1984	6.14	6.60	9.32	6.69	3.43	3.31	3.19	3.56	3.45	1.32	1.10
1985	8.67	7.64	10.75	6.73	3.53	3.06	3.73	2.68	2.23	1.55	2.51
1986	10.38	10.19	13.86	10.21	3.57	3.37	4.09	3.68	3.84	1.48	1.53

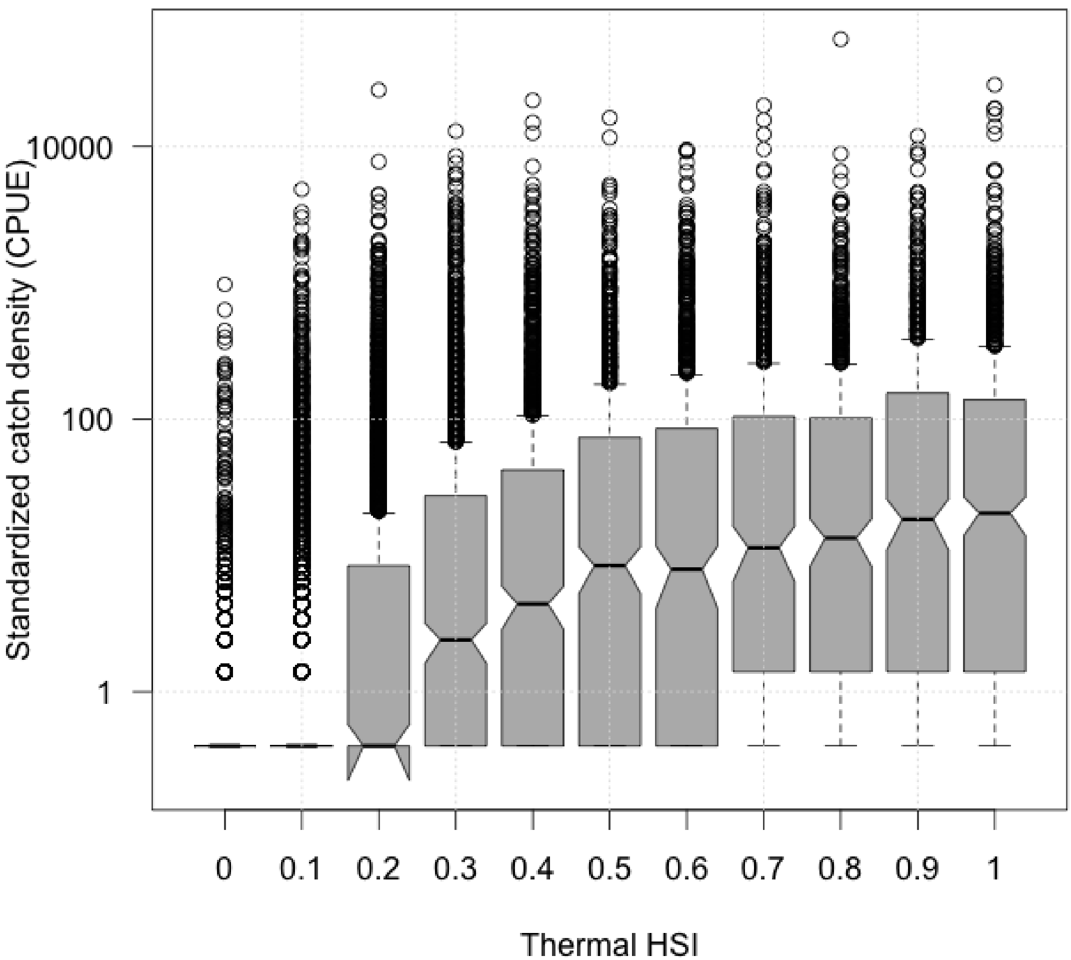
1987	8.48	8.66	10.85	8.51	2.89	2.93	3.27	2.70	2.70	1.21	1.04
1988	5.87	6.31	8.82	5.58	1.42	1.77	2.32	1.49	3.22	0.72	0.84
1989	9.27	8.76	12.21	9.06	3.79	3.45	3.85	3.46	3.26	1.97	1.33
1990	8.77	7.88	12.36	7.61	3.33	3.55	4.09	3.38	3.95	1.50	1.72
1991	9.87	7.47	12.25	7.47	4.71	3.25	4.69	3.48	2.87	3.24	3.10
1992	9.41	8.75	12.24	8.66	3.90	3.48	4.06	3.60	3.11	1.44	1.46
1993	7.10	7.74	9.07	7.71	3.36	3.43	3.32	3.05	2.74	1.92	1.85
1994	6.36	7.40	9.30	7.34	3.75	3.11	4.03	3.47	3.54	1.79	1.76
1995	10.32	8.53	11.57	8.86	4.07	3.36	3.60	3.39	1.75	2.26	1.87
1996	8.26	8.17	10.87	8.39	3.40	2.68	3.94	2.73	3.41	1.78	1.67
1997	7.12	6.22	9.17	6.37	2.33	2.08	2.28	2.45	2.56	1.30	1.54
1998	10.59	10.31	13.48	10.40	3.65	4.73	4.62	4.65	3.53	2.12	1.97
1999	10.52	7.93	11.65	7.81	5.60	3.06	4.70	3.46	2.23	4.11	3.91
2000	9.35	7.89	11.23	8.02	3.44	3.08	3.33	3.10	2.50	1.77	1.74
2001	9.04	8.28	9.97	8.43	3.88	3.15	3.59	3.26	1.67	1.60	1.43
2002	11.60	8.82	13.18	8.96	4.54	4.09	4.29	4.30	2.06	3.12	2.86
2003	9.74	9.71	11.36	10.01	4.34	4.32	4.27	4.44	2.11	1.47	1.28
2004	10.19	9.32	12.06	9.92	4.56	4.14	4.70	4.20	2.54	1.96	1.55
2005	9.68	9.93	11.26	9.62	4.19	4.13	4.23	3.72	2.40	1.83	1.44
2006	11.50	9.29	12.96	9.89	5.37	5.18	5.77	5.53	2.24	2.53	1.93
2007	9.12	8.46	11.01	8.59	4.31	3.95	4.40	3.84	2.49	1.64	1.38
2008	11.34	9.29	14.32	9.91	3.91	4.31	4.90	4.57	3.44	2.73	2.16
2009	9.28	7.66	11.08	7.94	3.49	2.76	3.28	2.69	2.35	2.21	1.08
2010	10.74	8.97	12.99	9.55	4.20	3.80	5.23	3.78	3.05	2.66	1.92
2011	10.38	8.73	13.32	9.52	4.41	3.75	5.49	4.14	3.80	2.63	1.98
2012	12.17	9.08	14.57	9.11	4.21	4.36	5.00	4.60	3.15	3.69	3.56

App. A1 Table 3c. Statistics for spring bottom temperatures in waters greater than 30M deep measured *in situ* (Obs), averaged in monthly MOCHA climatology, hindcast using ROMS (model), and hindcast by debiasing the ROMS hindcast using MOCHA (Model SPA).

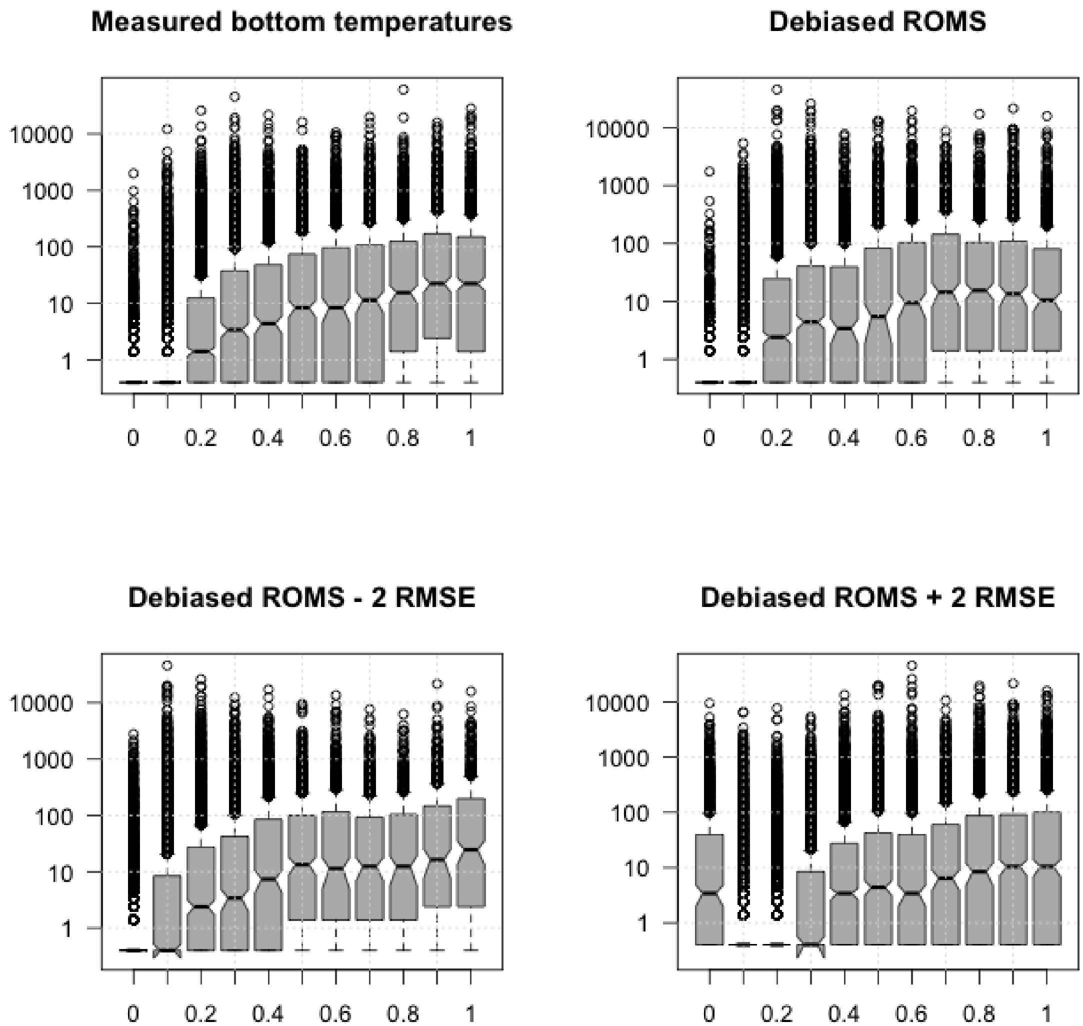
Year	Mean				Standard Deviation				RMSE		
	OBS	MOCHA	Model	Mode l SPA	OBS	MOCHA	Model	Model SPA	Mode l	MOCHA	Model SPA
1973	7.77	7.16	8.32	7.06	2.95	2.23	1.56	2.19	2.37	1.57	1.63
1974	8.12	7.18	8.42	7.18	2.75	2.42	1.82	2.47	2.63	1.59	1.64
1975	7.3	6.92	8.77	6.91	2.39	1.99	1.87	1.99	3.05	1.3	1.32
1976	7.41	6.57	8.87	6.56	2.24	2.13	2.05	2.11	2.53	1.26	1.29

1977	6.43	6.86	9.34	6.88	2.23	2.12	1.92	2.13	3.43	1.72	1.7
1978	5.65	6.67	8.83	6.64	1.94	1.84	1.96	1.92	3.73	1.54	1.56
1979	5.95	6.34	7.58	6.26	2.32	2.01	1.61	2.07	2.6	1.28	1.29
1980	6.25	6.45	7.58	6.45	2.21	1.84	1.43	1.89	2.39	1.12	1.16
1981	6.28	6.53	7.46	6.52	2.48	2.21	1.33	2.21	2.48	1.18	1.15
1982	7.01	7.07	8.52	7.12	2.76	2.17	1.99	2.25	2.59	1.43	1.51
1983	6.78	6.59	9.01	6.59	2.3	2.11	2.3	2.17	3.07	1.06	1.13
1984	6.88	6.6	9.38	6.59	2.9	2.39	2.08	2.43	3.49	1.18	1.22
1985	7.38	6.84	9.75	6.85	2.87	2.57	1.92	2.61	3.6	1.17	1.26
1986	7.82	6.74	9.73	6.77	2.45	2.34	1.76	2.28	2.8	1.7	1.67
1987	6.8	6.87	8.67	6.89	2.22	2	1.76	2.02	2.47	0.89	0.91
1988	6.72	6.66	8.72	6.66	2.25	2.2	2.48	2.24	2.93	0.97	0.97
1989	6.25	6.31	8.13	6.35	2.53	2.45	1.58	2.52	2.53	0.76	0.75
1990	7.08	6.81	8.94	6.71	2.47	2.36	2.11	2.49	2.7	1.11	1.14
1991	6.73	6.29	8.93	6.27	2.29	2.05	2.14	2.11	2.77	1.06	1.12
1992	6.34	6.88	8.86	6.88	2.76	2.45	1.98	2.46	3.37	1.46	1.47
1993	6.79	7.2	8.32	7.19	2.89	2.55	1.88	2.57	2.75	1.34	1.39
1994	7.81	7.05	8.64	7.05	2.51	1.73	2.09	1.81	2.19	1.67	1.63
1995	7.36	6.62	7.89	6.59	2.29	1.74	1.82	1.82	1.95	1.38	1.4
1996	6.82	6.79	8.61	6.74	2.31	1.99	1.97	2.09	2.79	1.17	1.16
1997	7.03	6.64	7.57	6.59	2.36	1.94	1.79	1.99	1.94	1.27	1.4
1998	6.44	6.9	7.48	6.86	1.99	1.98	1.75	1.99	1.79	1.66	1.65
1999	7.07	6.51	7.94	6.49	2.13	1.79	1.46	1.81	2.05	1.3	1.3
2000	8.04	7.09	8.67	7.07	2.26	2.17	1.39	2.18	1.91	1.33	1.35
2001	7.56	7.24	8.02	7.19	2.48	2.07	1.61	2.08	1.73	1.12	1.19
2002	8.18	7.38	8.55	7.42	2.49	2.69	3.44	2.86	3.17	1.57	1.68
2003	6.67	6.97	7.25	6.96	2.57	2.29	1.39	2.32	2.01	1.27	1.24
2004	5.76	6.61	7.35	6.58	2.45	2.14	1.84	2.13	2.41	1.56	1.59
2005	6.02	6.29	7.42	6.24	2.21	1.97	2.02	2.01	2.11	0.94	0.96
2006	6.89	6.09	7.89	6.1	2.16	1.79	1.28	1.8	1.82	1.17	1.21
2007	7.31	7.06	8.7	7.02	2.62	2.33	1.99	2.37	2.58	1.75	1.76
2008	7.61	7.05	9.68	7.04	2.69	2	2.36	2.07	3.21	2.78	2.82
2009	7.4	7.33	8.51	7.31	2.34	2.21	1.89	2.22	2.89	2.75	2.76
2010	8.02	6.66	8.31	6.78	2.47	1.78	2.03	1.84	2.87	2.74	2.71
2011	8.14	7.08	8.06	7.06	2.57	2.38	2.13	2.44	2.41	2.52	2.51
2012	8.16	7.18	9.68	7.16	2.42	2.25	2.3	2.34	3.05	3.33	3.41

Niche and thermal habitat suitability hindcast evaluation (See main text for details)



App. A1 Figure 8. Boxplots of median standardized catch densities (CPUE) for butterfish collected in 7 fishery independent surveys from 1970 -2007 in relation to thermal habitat suitability (tHSI) predicted using bottom water temperatures measured *in situ* in the niche model. Data used in this evaluation were not used in niche model calibration. A small number (0.4) was added to CPUE values to plot values on log scale.



App. A1 Figure 9. Comparison of trends in butterfish catch density with thermal habitat suitability predicted using the niche model coupled to bottom temperatures measured *in situ* (top left), the debiased hindcast from ROMS (top right) as well as those projected using the cold (debiased ROMs – 2*RMSE, bottom left), and warm (debiased ROMs + 2*RMSE, bottom right) ocean bottom temperature states. Trends with tHSI values hindcast using the mean debiased state were most similar to those generated with *insitu* temperatures.

Availability indices computed using coupled niche bottom temperature model for survey time series used in butterfish assessment

App. A1 table 4a. Availability (ρ_H) estimates with uncertainties for NEFSC offshore stations during the fall made using a thermal niche model coupled to debiased hindcasts of bottom temperature from ROMS. Mean, median, 2.5% & 97.5% quantile, standard deviations and maximum and minimum ρ_H (rho) are reported for the mean debiased ocean temperature state (normal ocean) as well as the warm ocean (+2RMSE) and cold ocean (-. 2RMSE) states. (FILENAME: Appendix_table_4a_OpenOcean_fall_offshore_availabilityindex_NEFSC_110413.csv)

App. A1 table 4b. Availability (ρ_H) estimates with uncertainties for NEFSC offshore stations during the spring made using a thermal niche model coupled to debiased hindcasts of bottom temperature from ROMS. Mean, median, 2.5% & 97.5% quantile, standard deviations and maximum and minimum ρ_H (rho) are reported for the mean debiased ocean temperature state (normal ocean) as well as the warm ocean (+2RMSE) and cold ocean (-2RMSE) states. (FILENAME: Appendix_table_4b_OpenOcean_spring_offshore_availabilityindex_NEFSC_110413.csv)

App. A1 table 4c. Availability (ρ_H) estimates with uncertainties for NEAMAP inshore stations during the fall made using a thermal niche model coupled to debiased hindcasts of bottom temperature from ROMS. Mean, median, 2.5% & 97.5% quantile, standard deviations and maximum and minimum ρ_H (rho) are reported for the mean debiased ocean temperature state (normal ocean) as well as the warm ocean (+2RMSE) and cold ocean (-2RMSE) states. (FILENAME: Appendix_table_4c_OpenOcean_fall_inshore_availabilityindex_NEAMAP_110413.csv)

App. A1 table 4d. Availability (ρ_H) estimates with uncertainties for NEFSC inshore stations during the fall made using a thermal niche model coupled to debiased hindcasts of bottom temperature from ROMS. Mean, median, 2.5% & 97.5% quantile, standard deviations and maximum and minimum ρ_H (rho) are reported for the mean debiased ocean temperature state (normal ocean) as well as the warm ocean (+2RMSE) and cold ocean (-2RMSE) states. (FILENAME: Appendix_table_4d_OpenOcean_fall_inshore_availabilityindex_NEFSC_110413.csv)

App. A1 table 4e. Availability (ρ_H) estimates with uncertainties for NEFSC inshore stations during the spring made using a thermal niche model coupled to debiased hindcasts of bottom temperature from ROMS. Mean, median, 2.5% & 97.5% quantile, standard deviations and maximum and minimum ρ_H (rho) are reported for the mean debiased ocean temperature state (normal ocean) as well as the warm ocean (+2RMSE) and cold ocean (-2RMSE) states. (FILENAME: Appendix_table_4e_OpenOcean_spring_inshore_availabilityindex_NEFSC_110413.csv)

App. A1 table 4f. Availability (ρ_H) estimates with uncertainties for NEAMAP inshore stations during the spring made using a thermal niche model coupled to debiased hindcasts of bottom temperature from ROMS. Mean, median, 2.5% & 97.5% quantile, standard deviations and maximum and minimum ρ_H (rho) are reported for the mean debiased ocean temperature state (normal ocean) as well as the warm ocean (+2RMSE) and cold ocean (-2RMSE) states. (FILENAME: Appendix_table 4f_OpenOcean_spring_inshore_availabilityindex_NEAMAP_110413.csv)

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A. Butterfish Appendix A2.

Feasible Bounds on Historic Butterfish Stock Size and Fishing Mortality Rates from Survey and Catch Data

Tim Miller, Charles Adams, and Paul Rago
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National Marine Fisheries Service
Woods Hole, MA 02543
May 20, 2013

Report to the Mid-Atlantic Fishery Management Council
Science and Statistical Committee

Summary

This updates some results provided by Miller and Rago (2012) based an empirical analysis of Atlantic butterfish survey and catch data to include 2012. The results provide a likely range of historic stock size and fishing mortality rates under a range of assumptions for survey catchability (0.1 and 1) and natural mortality (0.8 and 1.1). Survey data were expanded to total swept area biomasses for assumed catchabilities. For each combination of the catchabilities and natural mortality rates, historic fishing mortality and January 1 biomasses were also obtained by coupling with catch data. Results of an analytical stock assessment model (SARC 49, NEFSC 2010) comport well with the time series of F and biomass obtained from this method.

An examination of scenarios for biomass in 2013 based on survey and catch data in 2006-2012 suggest that overfishing is unlikely to occur in 2013 if catch is less than 17,700 mt even under the most extreme assumptions of 100% survey catchability, $M = 0.8$. If instead biomass in 2013 is assumed to be similar to those in 2009-2012, overfishing is unlikely for catches less than 35,700 mt. A sensitivity analysis indicates that an eight-fold increase in catches in 2012 would not have resulted in overfishing. Based on survey results, stock biomass appeared to increase by more than three-fold between 2008 and 2011, but then dropped back down to almost 2008 levels in 2012.

Introduction

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.

Here we use the same simple approach as Miller and Rago (2012) that provides a feasible range or "envelope" of possible population sizes. Coherence between the envelope of derived stock sizes and the estimates provided by the last assessment allows us to draw some general conclusions about the relationship of catch and the probability of overfishing.

Method

Our method is the same as that provided by Miller and Rago (2012) in the section "Envelope method without the fishing mortality assumption." Let I_t represent the observed index of biomass at time *t* and C_t represent the catch at time *t*. The estimated swept area total biomass consistent with the index is

$$B_t = \frac{I_t}{q}\frac{A}{a} \tag{1}$$

where the catchability or efficiency q, is an assumed value. The average area swept per tow is *a* and the total area of the survey is *A*. The biomass consistent with observed catch can be obtained from the Baranov catch equation as

$$B_0 = \frac{C_t}{\frac{F}{F+M}\left(1-e^{-(F+M)}\right)}$$

$$B_t = B_0 e^{-(F+M)t} \tag{2}$$

where F is unknown. The second equation in Eq. 2 adjusts the biomass to the time of year when the survey occurs, thus keeping Eq. 1 and 2 consistent. Thus biomass can be written as a function of arbitrary scalars q and F.

Assessment models commonly assume that the efficiency of the survey is constant over time, but it is unlikely that fishing mortality is constant from year to year. Given assumed values of survey efficiency and natural mortality, and known annual total catch and relative biomass indices, Equation 2 can be used to obtain fishing mortality in year y numerically, and therefore the January 1 stock biomass as well. The equation to satisfy is

$$C_y = \frac{F_y}{F_y+M}\left(1-e^{-(F_y+M)}\right)B_{0,y} \tag{3}$$

which from Equation 2 is related to the survey index I that occurs after fraction f of the year has passed,

$$B_{0,y} = B_{f,y}e^{(F_y+M)f} = \frac{I_{f,y}}{q}\frac{A}{a}e^{(F_y+M)f}. \tag{4}$$

Results

We provide the same results found in Miller and Rago (2012), but updated to include 2012. Assumed survey efficiencies are 0.1 and 1 to provide a range of biomasses implied by the survey index in a given year. The two natural mortality rates are 0.8 and 1.1. The lower values were used in the assessment model presented at SARC 49, but there was also evidence provided at that meeting that it could be greater than the assumed rate (NEFSC 2010). We specified the NEFSC fall survey to occur 0.75 (=*f*) through each year.

The results prior to 2012 are identical to Figures 4 and 5 in Miller and Rago (2012). The implied fishing mortality in 2012 is not noticeably different than others since 2003 (Fig. 2, this document). The implied January 1 biomass in 2012 is lower than others since the last assessment (2009-2011) and more similar to those in 2008 (Fig. 3).

We also explored fishing mortality rates associated with specified catches given January 1 biomasses in recent years under the assumptions that survey catchability (q) equals 1 and natural mortality (M) equals 0.8. More specifically, given the January 1 stock biomass implied by the realized catch and biomass at the time of the survey, we determined the fishing mortality over a range of assumed total catches. Our results also accounted for the uncertainty in catches (due to discards) and survey indices using a parametric bootstrap so that an estimate of probability of fishing mortality being greater than some value at a given catch can be obtained under the various assumptions. We assumed catches and indices were log-normal distributed. Letting X be the natural log of catch or survey index and CV the estimated coefficient of variation of the untransformed catch or survey index, bootstrapped values X^* were normally distributed,

$$X^* \sim N\left(X - \frac{CV^2}{2}, CV^2\right)$$

where CV^2 is a delta-method based variance of X. The subtraction of half of the variance from the mean provides a bias correction so that

$$E\left(e^{X^*}\right) = e^X.$$

Similar to Miller and Rago (2012), we used the average January 1 biomass in the recent years in a given bootstrap to determine F at the specified catches for that bootstrap. When these results are used to evaluate potential catch levels in 2013, this implies that January 1 biomass in 2013 is predicted to be similar to the mean January 1 biomass in the recent years. We performed two sets of bootstraps using catches and survey indices from 2006-2012, and just the years 2009-2012 that did not require calibration of Bigelow survey data (Tables 1 and 2). We performed these calculations for 1000 bootstrap realizations.

When survey and catch data between 2006-2012 are used with the M = 0.8 and q = 1 assumptions that provide conservative biomasses, the median of average January 1 biomasses is 61,481 mt (Figs. 4 and 5). The median fishing mortality is less than any of the proposed overfishing reference points or F=2M/3, for specified total catches less than 17,700 mt, a catch that is 8.7 times greater than the average catch (2,035 mt) in that period (Fig. 6). The catch limit of 17,700 mt is somewhat larger than the 16,300 mt found by Miller and Rago (2012, in the presentation to the SSC). The probability of fishing mortality being below $F_{40\%} \approx 2M/3$ changes from 1 to 0.2 over a relatively small range of annual total catch, 12,800 –19,600 mt (Fig. 7).

In the alternative scenario based on data between 2009-2012, the median of average January 1 biomasses is 124,000 mt (Figs. 8 and 9). Median fishing mortality is less than any of the reference points when total catch is less than 35,700 mt, which is 13.7 times greater than the average catch (2,614 mt), in that period (Fig. 10). In the alternative scenario, the probability of fishing mortality being below $F_{40\%} \approx 2M/3$ changes from 1 to 0.2 over a relatively broader range of annual total catch, 23,700 – 40,400 mt (Fig. 11).

Discussion and Conclusions

There are some important assumptions associated with the approach we used that were previously noted by Miller and Rago (2012) and they discuss implications of departures from them on the calculated F and biomass values. For the sake of completeness, the assumptions are summarized in Appendix 2.

The parametric bootstrap method is the same as that used to generate results provided to the SSC in the presentation at their May 2012 meeting. The analysis was carried out after the Miller and Rago (2012) report was supplied to the SSC and was intended to both account for uncertainty in the catch and index data and provide a probabilistic evaluation of fishing mortalities associated with potential catch specifications. Given the role of butterfish in the ecosystem as a prey species, the SSC determined that an $F = 2M/3$ is an appropriate target based on Patterson (1992). For $M = 0.8$, $F_{40\%}$ (0.52) from the previous assessment is approximately the same as $2M/3$ (0.54).

The results from the bootstrap analysis are different because 2012 data were included and 2005 data were omitted. The catch providing median $F = F_{40\%}$ is slightly greater than the analyses presented at the May 2012 meeting because the 2012 January 1 biomass is slightly higher than the 2005 January 1 biomass that was omitted. The alternative analysis is also different because it only includes 2009-2012 data. The catch associated with median $F = F_{40\%}$ is greater than the base analysis because the lower 2007 and 2008 January 1 biomasses are omitted. Both results show median F associated with current average catch is less than $F_{40\%} \approx 2M/3$.

Our results suggest the following:

- Current fishing mortality rates are low in absolute terms and relative to natural mortality and a suite of candidate biological reference points.
- Median stock biomass over 2009-2012 is 124,000 mt with a 95% CI of 93,577 to 167,206 mt.
- Irrespective of the time period used (i.e., 2006-12 vs. 2009-2012) butterfish catches less than 11,000 mt would have almost no chance of exceeding a fishing mortality threshold of $2M/3$.

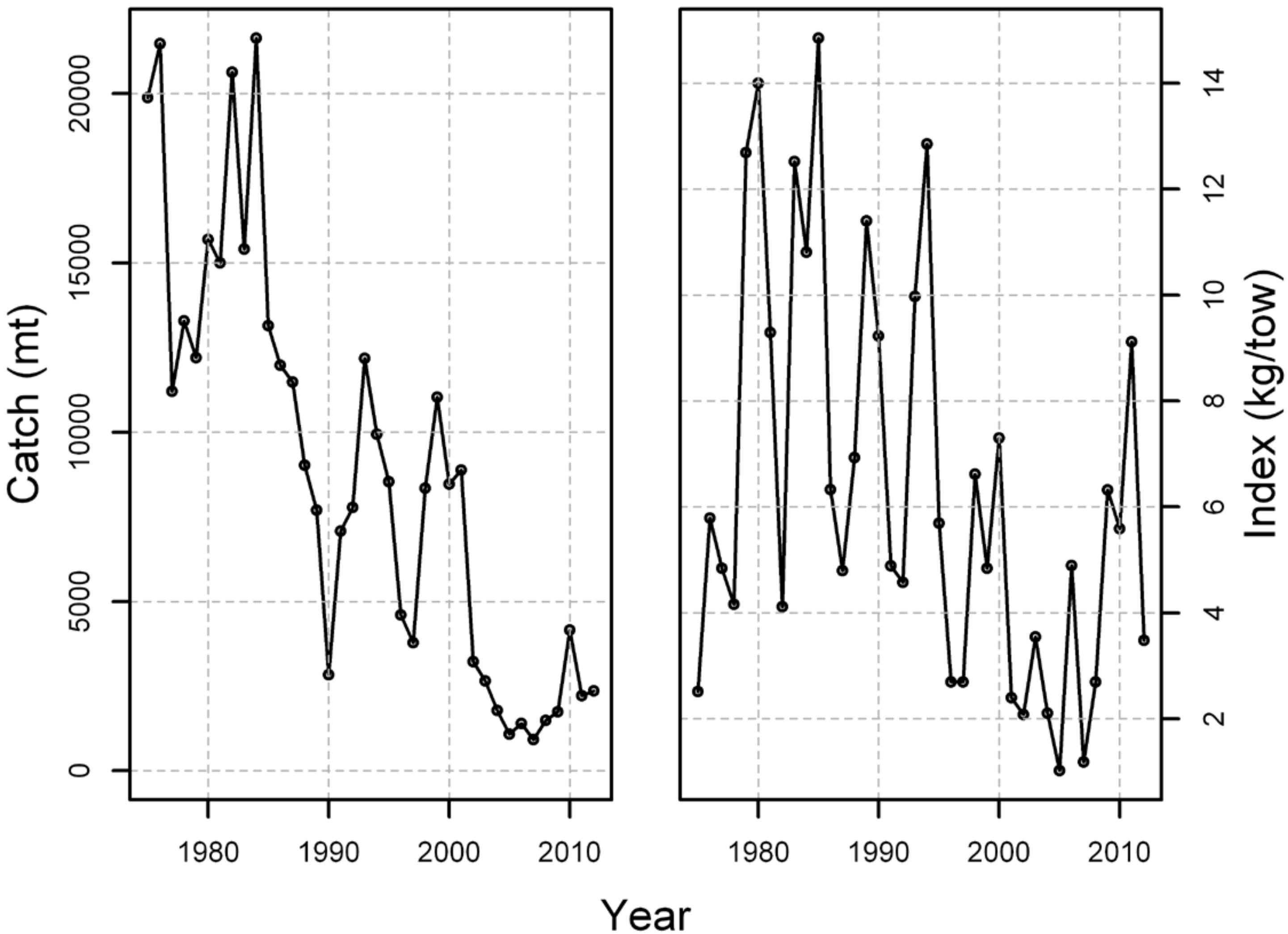
References

Miller, T. J., Das, C., Politis, P. J., Miller, A. S., Lucey, S. M., Legault, C. M., Brown, R. W., and Rago, P. J. 2010. Estimation of Albatross IV to Henry B. Bigelow calibration factors. NEFSC Ref. Doc. 10-05.

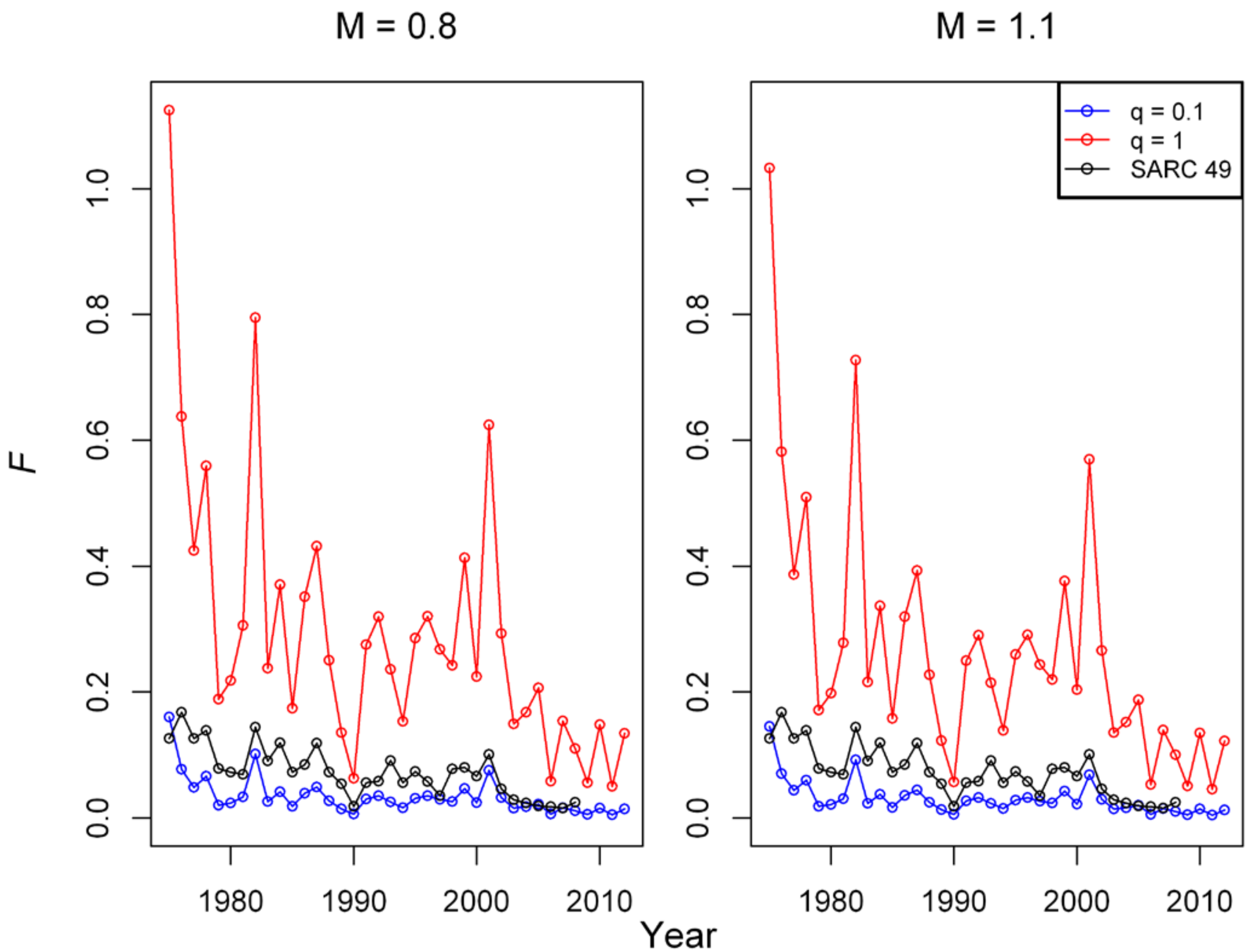
Miller, T., and P. Rago. 2012. Empirical exploration of feasible bounds on butterfish stock size and fishing mortality rates, 1975-2011. Report to the Mid-Atlantic Fishery Management Council Scientific and Statistical Committee. 14 pp.

NEFSC. 2010. 49th Northeast Regional Stock AssessmentWorkshop (49th SAW) Assessment Report. NEFSC Ref. Doc. 10-03.

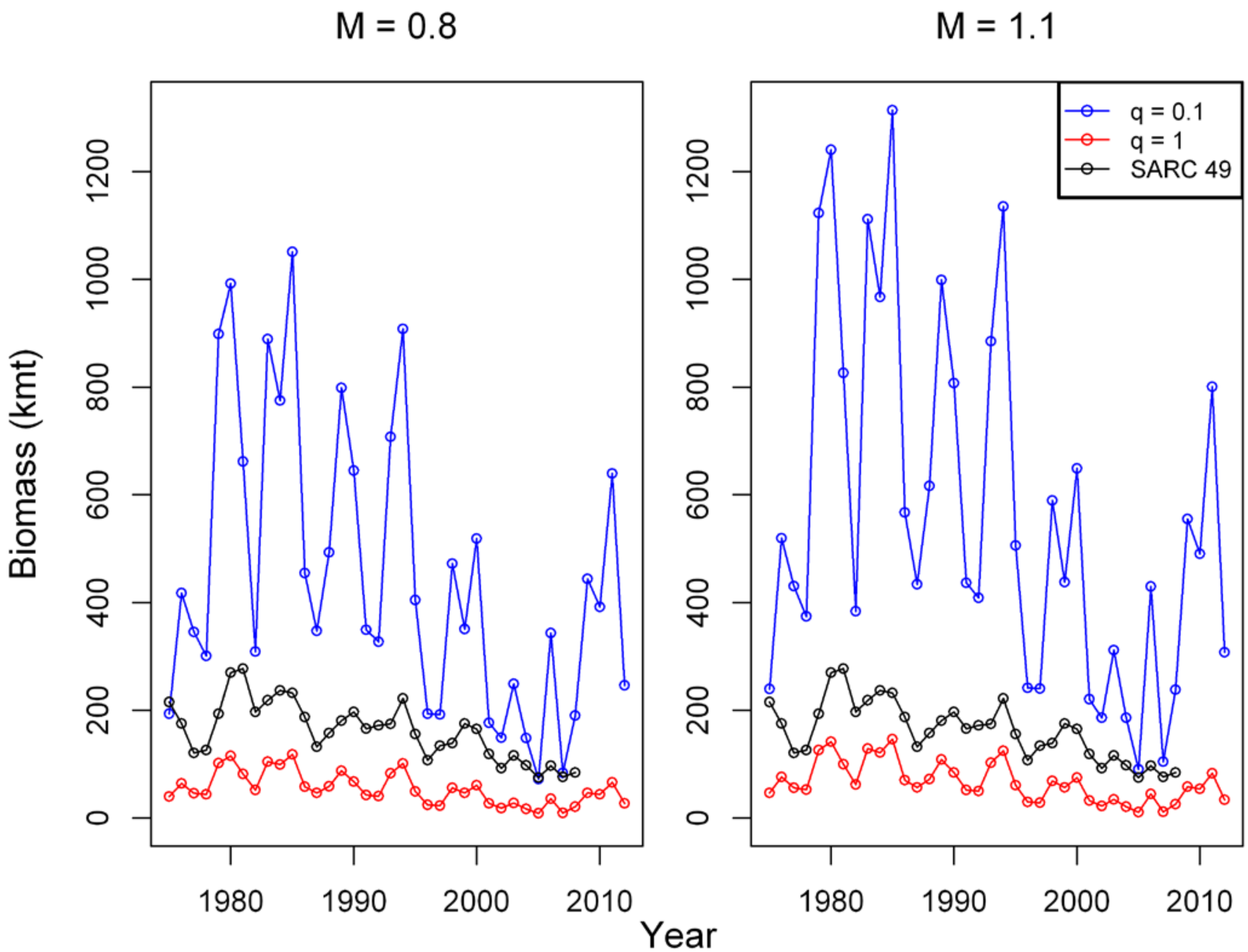
Patterson, K. 1992. Fisheries for small pelagic species: an empirical approach to management targets. Reviews in Fish and Fisheries 2:321-338.



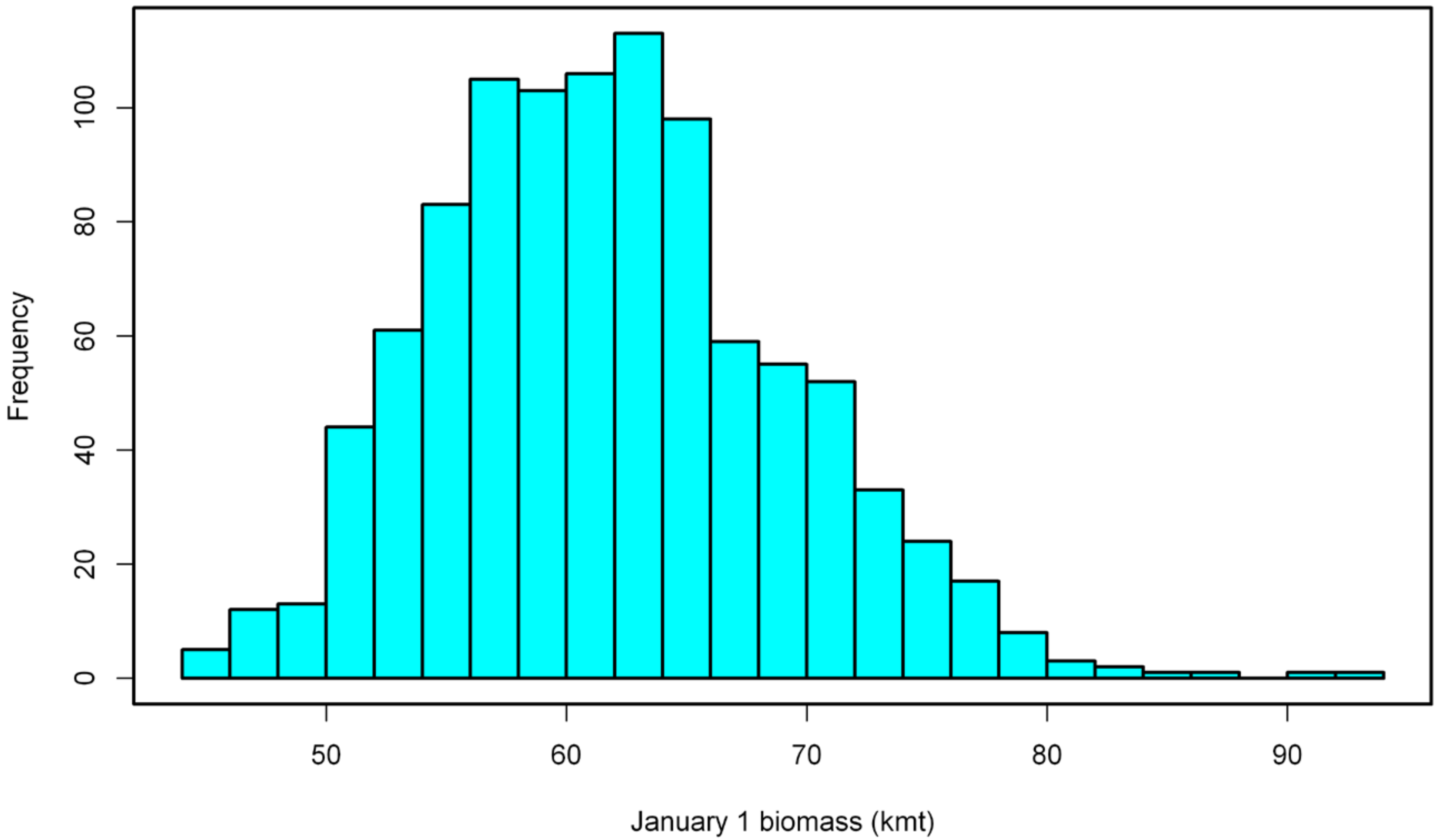
App. A2 Figure 1. Annual total catches and fall NEFSC biomass indices for Atlantic butterfish.



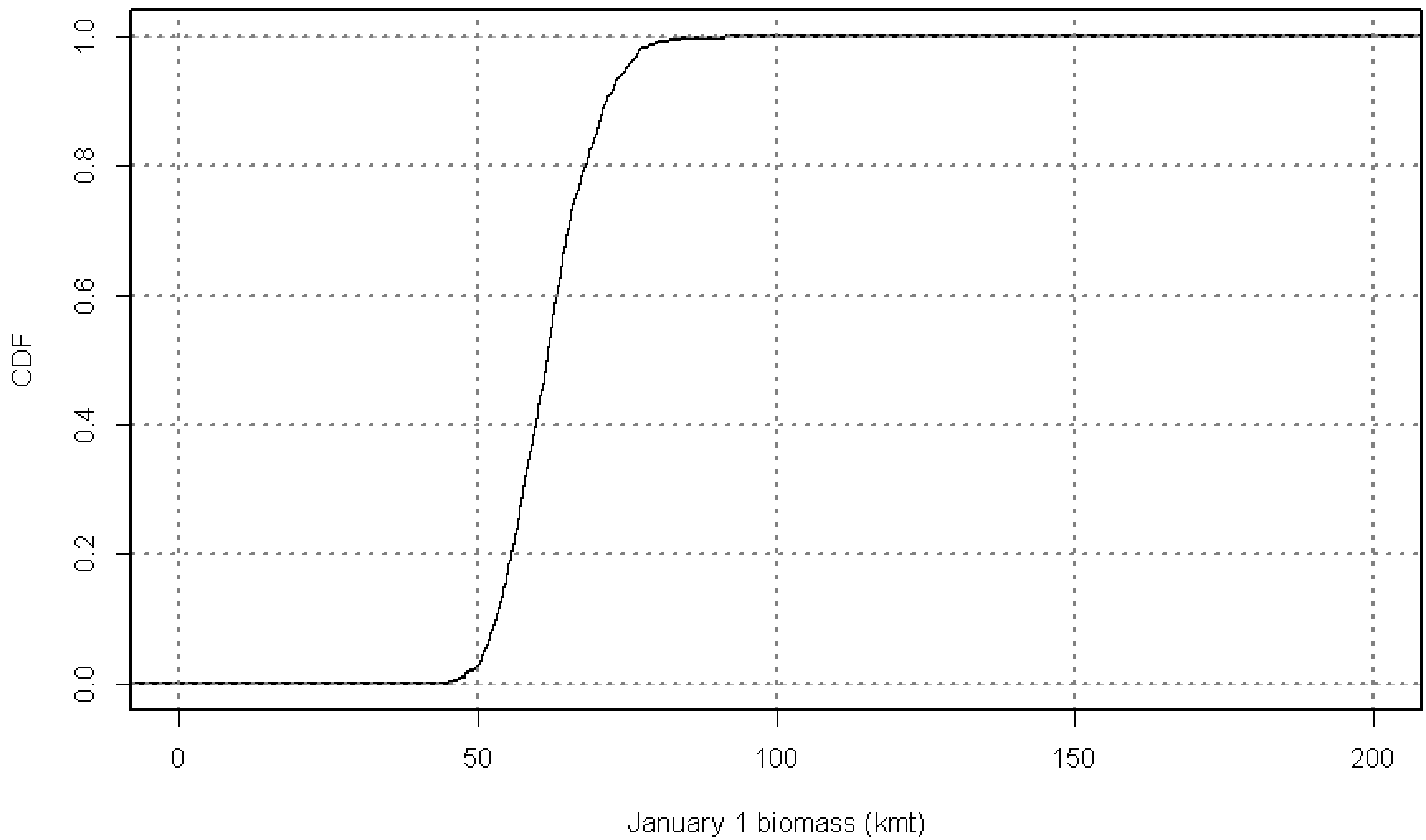
App. A2 Figure 2. Implied annual fishing mortality rates under two different survey efficiency and natural mortality assumptions and the fishing mortality rate estimates from SARC 49 (NEFSC 2010). See Equation 3.



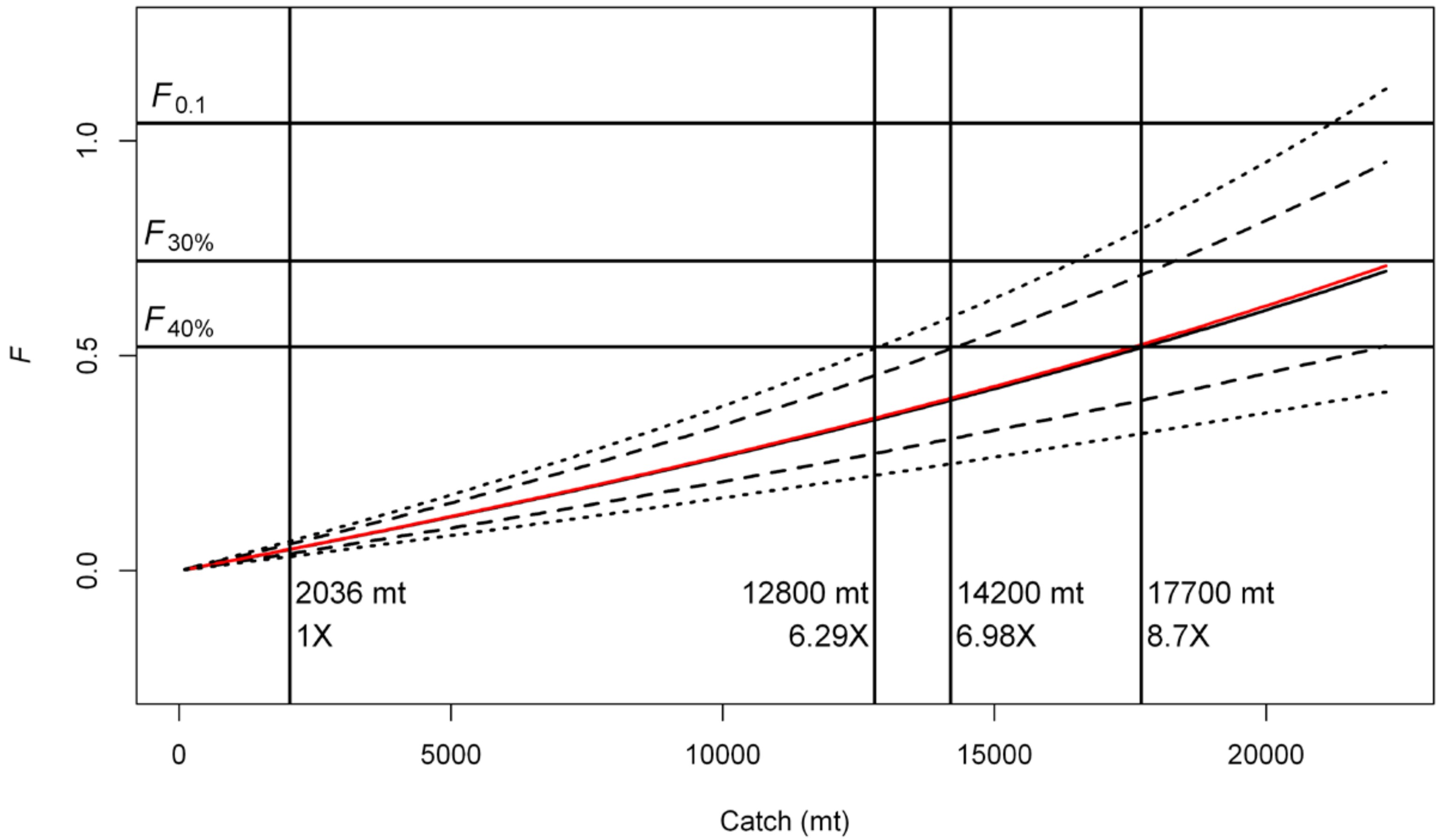
App. A2 Figure 3. Implied annual January 1 butterfish stock biomass under 2 different survey efficiency and natural mortality assumptions and the biomass estimates from SARC 49 (NEFSC 2010). See Equation 4.



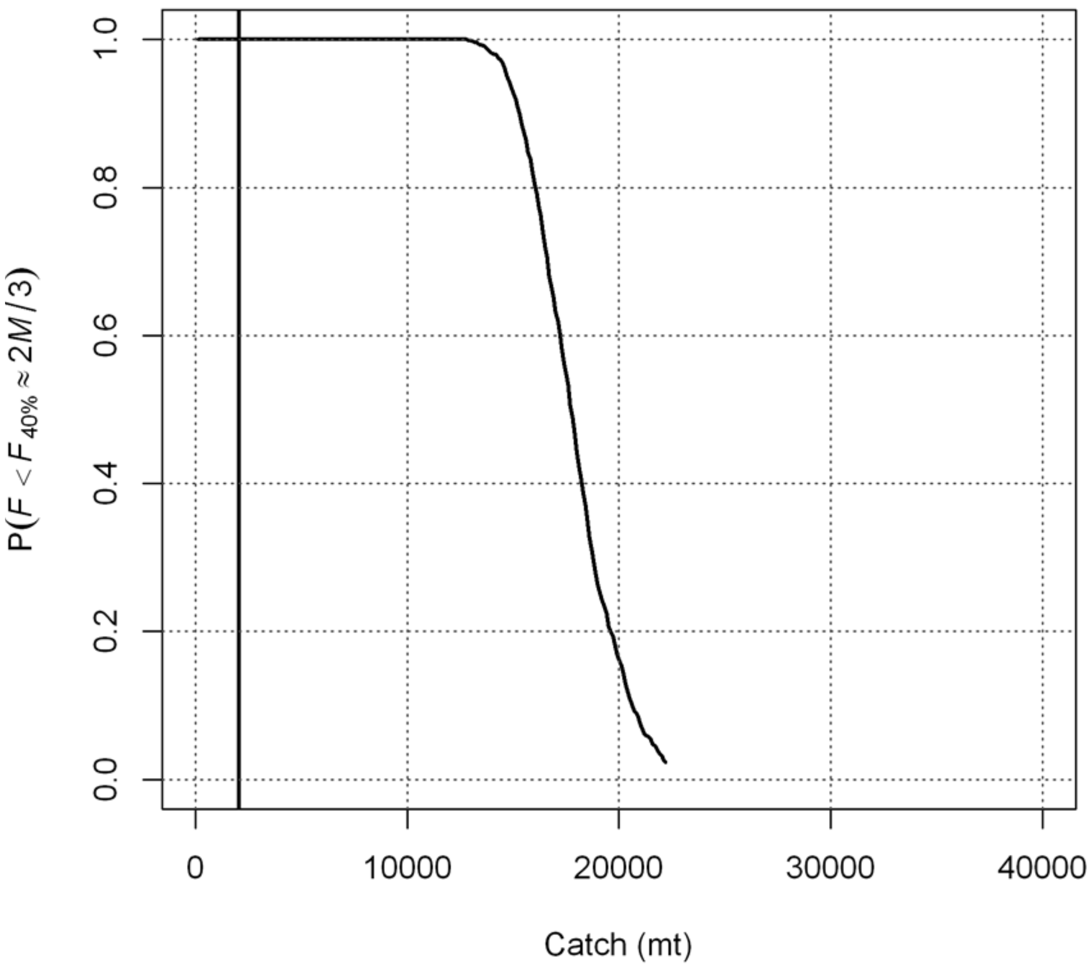
App. A2 Figure 4. Histogram of 1000 parametric bootstraps of average January 1 biomasses for Atlantic butterfish in 2006-2012.



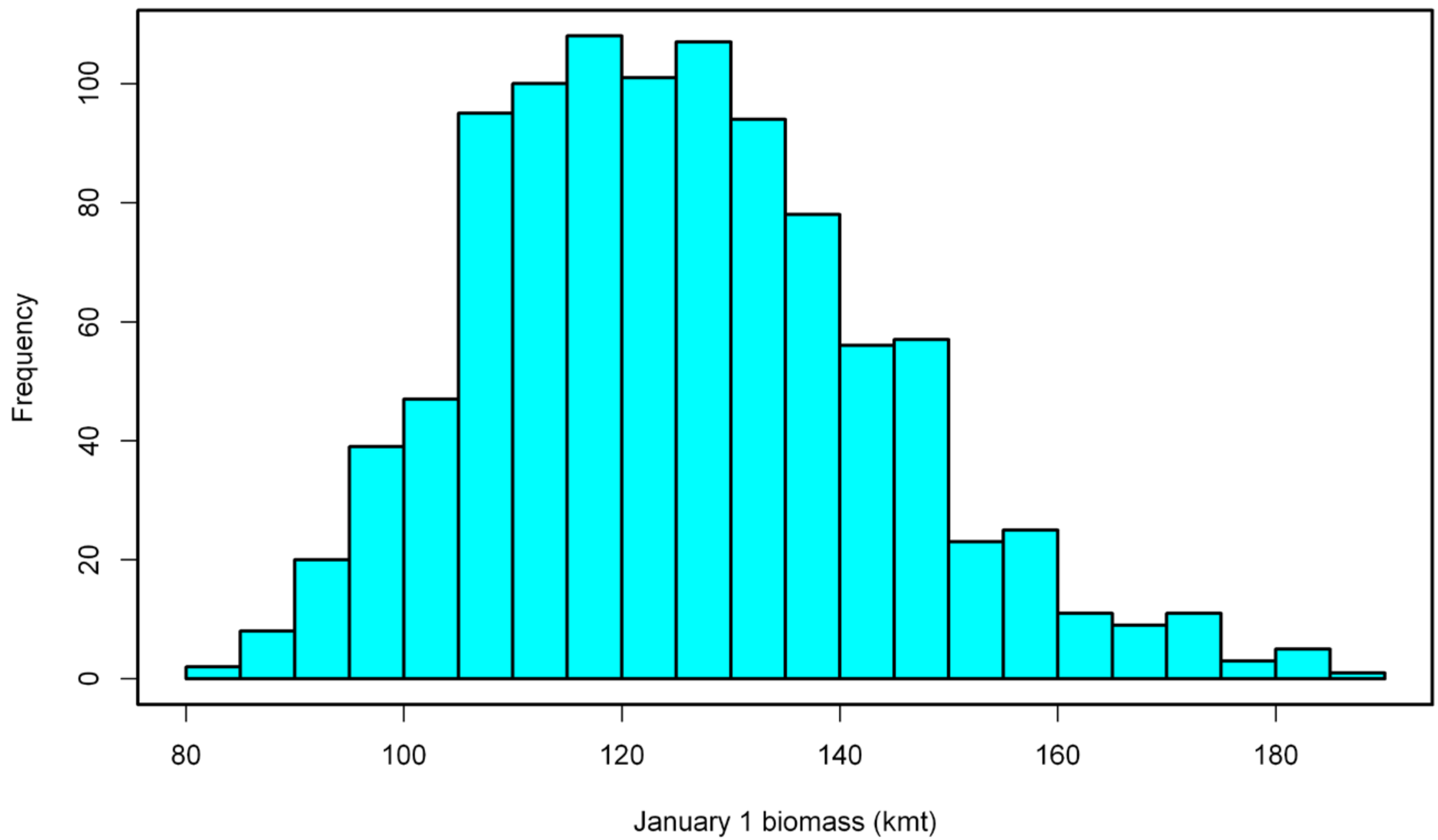
App. A2 Figure 5. Cumulative distribution of 1000 parametric bootstraps of average January 1 biomasses for Atlantic butterfish in 2006-2012.



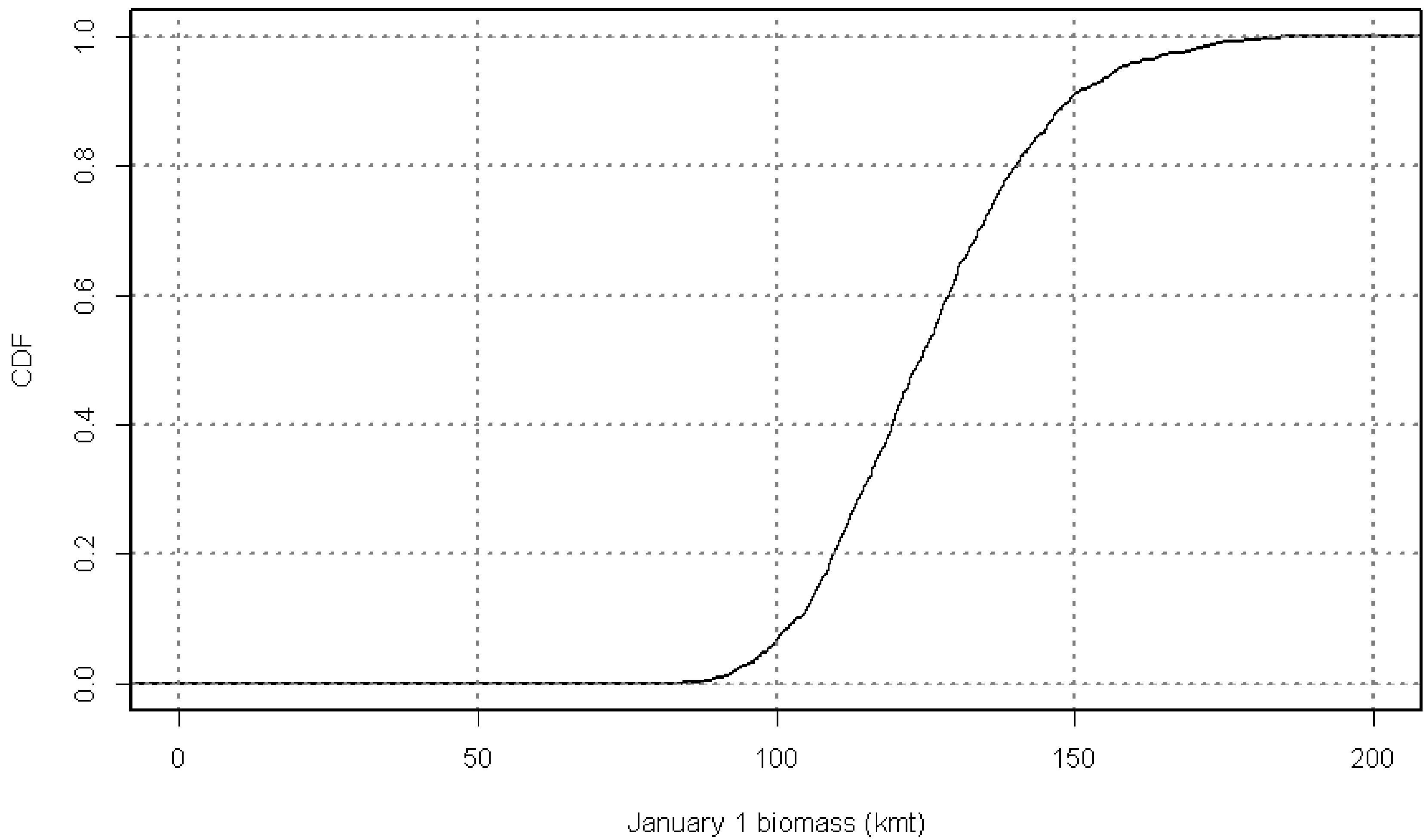
App. A2 Figure 6. Mean (solid red), median (solid black), 0.025 and 0.975 confidence limits (dashed), minimum and maximum (dotted) of *F* for 1000 bootstraps, based on average 2006-2012 January 1 biomasses. Overfishing reference points are from SARC 49 (NEFSC 2010). Vertical lines are for average 2006-2012 total catch (1X); maximum (6.29X), 95% upper (6.98X), and median (8.7X) total catch associated with the most conservative stock size (q = 1 and M = 0.8) and fishing mortality equal to overfishing reference point ($F_{40\%} \approx 2M/3$).



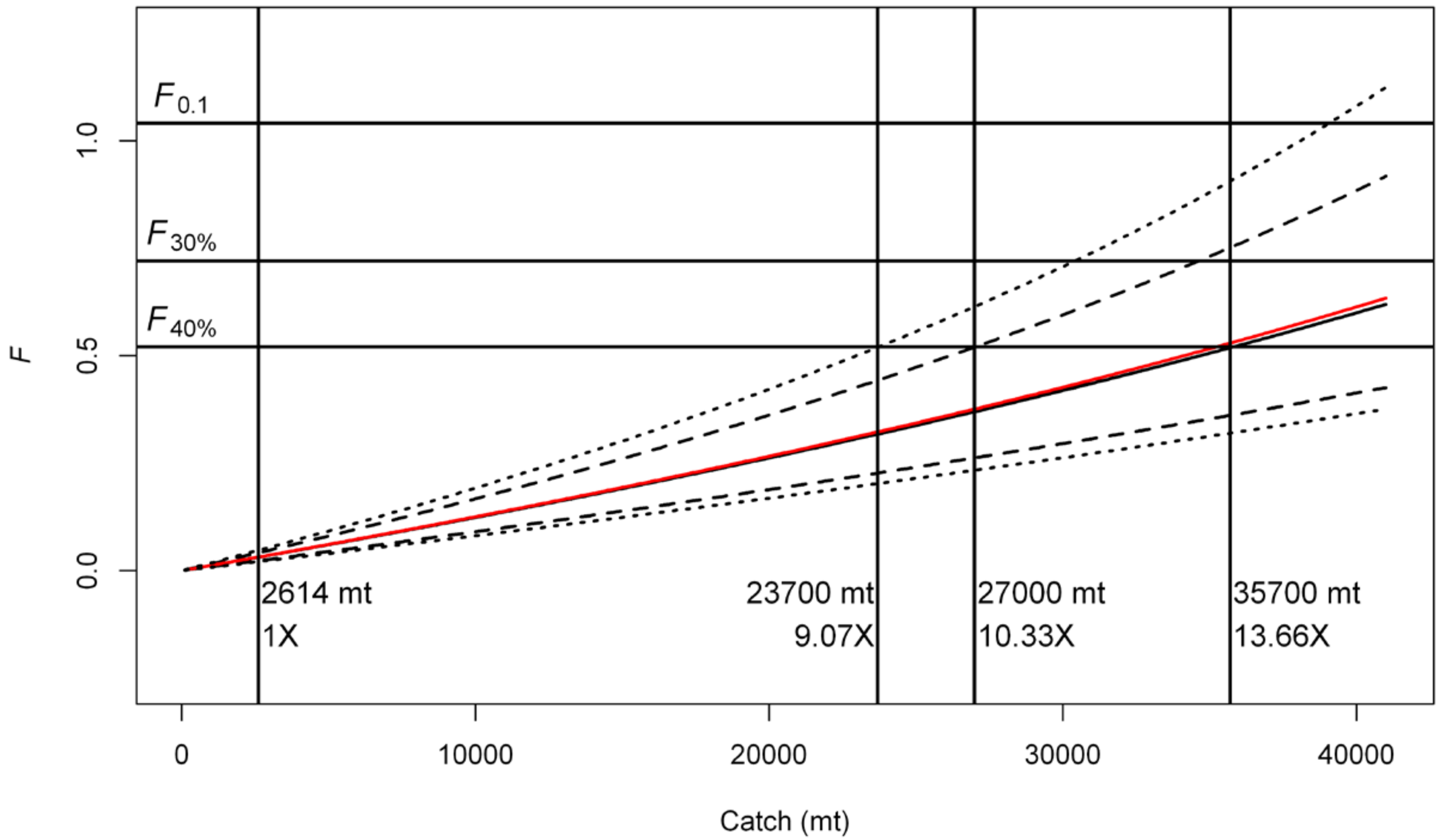
App. A2 Figure 7. Probability fishing mortality at specified catch is less than $F_{40\%} \approx 2M/3$ based on parametric bootstrap of average 2006-2012 January 1 biomasses. Vertical line represents average annual catch 2006-2012.



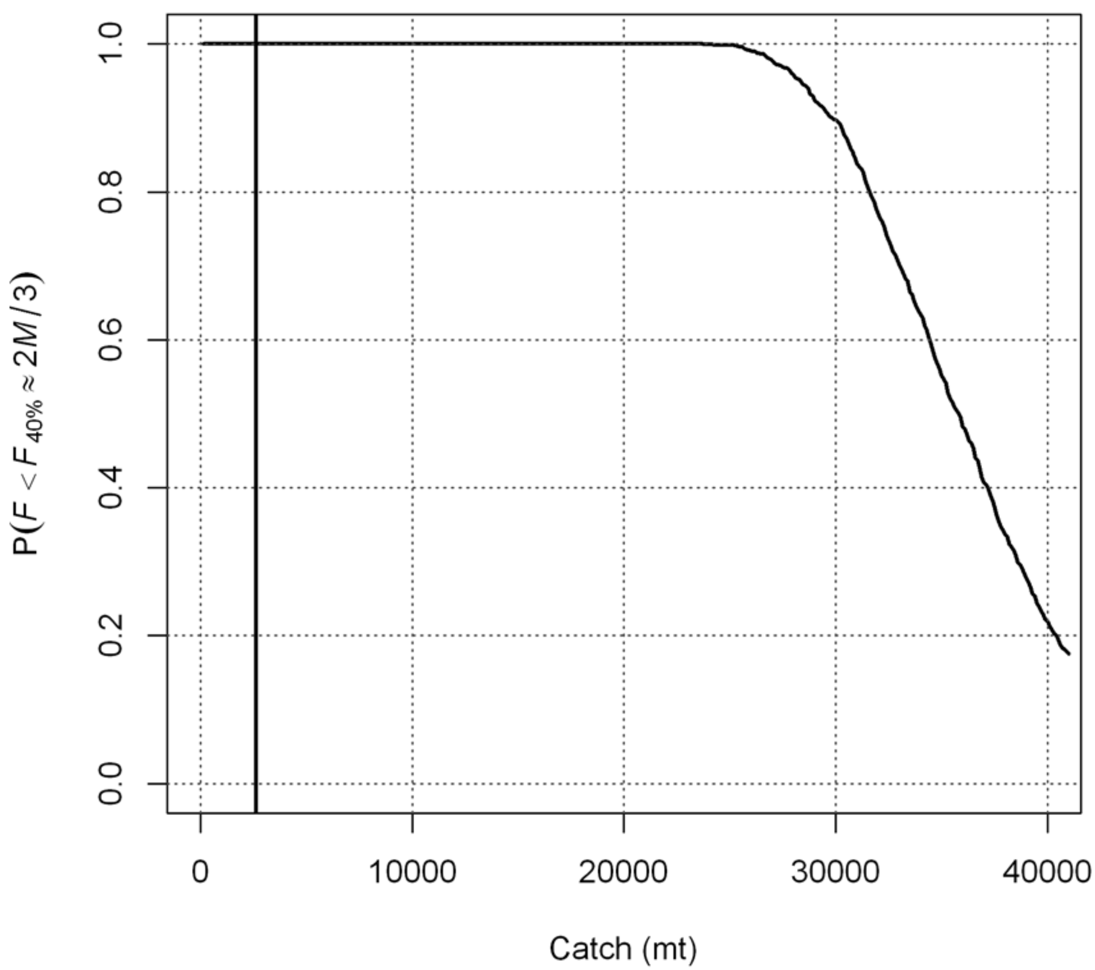
App. A2 Figure 8. Histogram of 1000 parametric bootstraps of average January 1 biomasses for Atlantic butterfish in 2009-2012.



App. A2 Figure 9. Cumulative distribution of 1000 parametric bootstraps of average January 1 biomasses for Atlantic butterfish in 2009-2012.



App. A2 Figure 10. Mean (solid red), median (solid black), 0.025 and 0.975 confidence limits (dashed), minimum and maximum (dotted) of *F* for 1000 bootstraps, based on average 2009-2012 January 1 biomasses, and un-calibrated Bigelow data. Overfishing reference points are from SARC 49 (NEFSC 2010). Vertical lines are for average 2009-2012 total catch (1X); maximum (9.07X), 95% upper (10.33X), and median (13.66X) total catch associated with the most conservative stock size (q = 1 and M = 0.8) and fishing mortality equal to overfishing reference point
($F_{40\%} \approx 2M/3$).



App. A2 Figure 11. Probability fishing mortality at specified catch is less than $F_{40\%} \approx 2M/3$ based on parametric bootstrap of average 2009-2012 January 1 biomasses. Vertical line represents average annual catch 2009-2012.

App. A2 Table 1. Annual NEFSC fall bottom trawl survey biomass index (kg/tow), survey area (A), average swept area per tow (a), landings (mt) discards (mt) and combined total catch (mt).

Year	Index	CV	*A*	*a*	Landings	Discards	Total Catch	CV
1975	2.51	0.31	41947	0.0112	14737	5148	19885	0.41
1976	5.79	0.23	41777	0.0112	15813	5663	21476	0.40
1977	4.84	0.31	42220	0.0112	4608	6599	11207	0.94
1978	4.16	0.16	42220	0.0112	5314	7971	13285	0.88
1979	12.69	0.22	42855	0.0112	3753	8443	12196	1.02
1980	14.00	0.54	42795	0.0112	6564	9126	15690	0.87
1981	9.29	0.30	42669	0.0112	6255	8744	14999	0.87
1982	4.11	0.29	42737	0.0112	10415	10214	20629	0.72
1983	12.52	0.23	42798	0.0112	5373	10037	15410	0.95
1984	10.81	0.30	42694	0.0112	12144	9494	21638	0.61
1985	14.85	0.24	42888	0.0112	5437	7703	13140	0.81
1986	6.33	0.19	42855	0.0112	4582	7397	11979	0.81
1987	4.80	0.29	42893	0.0112	4578	6905	11483	0.74
1988	6.93	0.19	42855	0.0112	2107	6921	9028	0.93
1989	11.40	0.29	42572	0.0112	3216	4480	7696	0.49
1990	9.23	0.23	42750	0.0112	2298	533	2831	0.07
1991	4.89	0.37	42945	0.0112	2189	4887	7076	0.68
1992	4.57	0.26	42788	0.0112	2754	5025	7779	0.35
1993	9.97	0.23	42795	0.0112	4608	7577	12185	0.20
1994	12.85	0.35	42888	0.0112	3634	6300	9934	0.23
1995	5.69	0.27	42687	0.0112	2067	6466	8533	0.38
1996	2.69	0.27	42945	0.0112	3555	1047	4602	0.16
1997	2.70	0.23	42855	0.0112	2794	986	3780	0.27
1998	6.62	0.39	42945	0.0112	1966	6378	8344	1.29
1999	4.84	0.30	42945	0.0112	2110	8927	11037	0.29
2000	7.30	0.25	42888	0.0112	1449	7015	8464	0.19
2001	2.40	0.40	42828	0.0112	4404	4474	8878	0.24
2002	2.08	0.22	42870	0.0112	872	2348	3220	0.91
2003	3.54	0.20	42660	0.0112	536	2114	2650	1.15
2004	2.10	0.36	42780	0.0112	497	1320	1783	0.21
2005	1.02	0.30	42705	0.0112	428	648	1077	0.13
2006	4.89	0.22	42893	0.0112	555	839	1393	0.44
2007	1.18	0.39	42945	0.0112	679	241	919	0.16
2008	2.70	0.22	42945	0.0112	452	1029	1481	0.44
2009	6.32	0.25	42945	0.0112	435	1298	1733	0.20
2010	5.59	0.30	42593	0.0112	576	3576	4152	0.31
2011	9.12	0.27	42945	0.0112	664	1555	2218	0.11
2012	3.48	0.42	42945	0.0112	627	997	1624	0.22

App. A2 Table 2. Annual NEFSC fall bottom trawl survey biomass index (kg/tow) using un-calibrated Bigelow data, survey area (*A*), average Bigelow swept area per tow (*a*), landings (mt) discards (mt) and combined total catch (mt).

Year	Index	CV	*A*	*a*	Landings	Discards	Total Catch	CV
2009	11.43	0.25	42945	0.007	435	1298	1733	0.20
2010	10.11	0.30	42593	0.007	576	3576	4152	0.31
2011	16.48	0.27	42945	0.007	664	1555	2218	0.11
2012	6.29	0.42	42945	0.007	627	997	1624	0.22

App. A2 Table 3. Range, 0.025 and 0.975 quantiles, and median fishing mortalities implied by specified catches from bootstrapped January 1 biomasses between years 2006 and 2012 when M = 0.8 and q = 1 is assumed.

Catch	Minimum	Maximum	0.025 Quantile	Median	0.975 Quantile
100	0.00	0.00	0.00	0.00	0.00
200	0.00	0.01	0.00	0.00	0.01
300	0.00	0.01	0.01	0.01	0.01
400	0.01	0.01	0.01	0.01	0.01
500	0.01	0.02	0.01	0.01	0.01
600	0.01	0.02	0.01	0.01	0.02
700	0.01	0.02	0.01	0.02	0.02
800	0.01	0.03	0.02	0.02	0.02
900	0.01	0.03	0.02	0.02	0.03
1000	0.02	0.03	0.02	0.02	0.03
1100	0.02	0.04	0.02	0.03	0.03
1200	0.02	0.04	0.02	0.03	0.04
1300	0.02	0.04	0.02	0.03	0.04
1400	0.02	0.05	0.03	0.03	0.04
1500	0.02	0.05	0.03	0.04	0.04
1600	0.03	0.05	0.03	0.04	0.05
1700	0.03	0.06	0.03	0.04	0.05
1800	0.03	0.06	0.03	0.04	0.05
1900	0.03	0.06	0.04	0.05	0.06
2000	0.03	0.07	0.04	0.05	0.06
2100	0.03	0.07	0.04	0.05	0.06
2200	0.04	0.07	0.04	0.05	0.07
2300	0.04	0.08	0.04	0.06	0.07
2400	0.04	0.08	0.05	0.06	0.07
2500	0.04	0.08	0.05	0.06	0.08
2600	0.04	0.09	0.05	0.06	0.08
2700	0.04	0.09	0.05	0.07	0.08
2800	0.04	0.10	0.05	0.07	0.09
2900	0.05	0.10	0.06	0.07	0.09
3000	0.05	0.10	0.06	0.07	0.09
3100	0.05	0.11	0.06	0.08	0.09
3200	0.05	0.11	0.06	0.08	0.10
3300	0.05	0.11	0.06	0.08	0.10
3400	0.05	0.12	0.07	0.08	0.10
3500	0.06	0.12	0.07	0.09	0.11
3600	0.06	0.12	0.07	0.09	0.11
3700	0.06	0.13	0.07	0.09	0.11

3800	0.06	0.13	0.07	0.09	0.12
3900	0.06	0.13	0.08	0.10	0.12
4000	0.06	0.14	0.08	0.10	0.12
4100	0.07	0.14	0.08	0.10	0.13
4200	0.07	0.15	0.08	0.10	0.13
4300	0.07	0.15	0.08	0.11	0.13
4400	0.07	0.15	0.09	0.11	0.14
4500	0.07	0.16	0.09	0.11	0.14
4600	0.07	0.16	0.09	0.11	0.14
4700	0.08	0.16	0.09	0.12	0.15
4800	0.08	0.17	0.09	0.12	0.15
4900	0.08	0.17	0.10	0.12	0.15
5000	0.08	0.18	0.10	0.12	0.16
5100	0.08	0.18	0.10	0.13	0.16
5200	0.08	0.18	0.10	0.13	0.16
5300	0.09	0.19	0.11	0.13	0.17
5400	0.09	0.19	0.11	0.14	0.17
5500	0.09	0.19	0.11	0.14	0.17
5600	0.09	0.20	0.11	0.14	0.18
5700	0.09	0.20	0.11	0.14	0.18
5800	0.10	0.21	0.12	0.15	0.18
5900	0.10	0.21	0.12	0.15	0.19
6000	0.10	0.21	0.12	0.15	0.19
6100	0.10	0.22	0.12	0.15	0.19
6200	0.10	0.22	0.12	0.16	0.20
6300	0.10	0.23	0.13	0.16	0.20
6400	0.11	0.23	0.13	0.16	0.20
6500	0.11	0.23	0.13	0.16	0.21
6600	0.11	0.24	0.13	0.17	0.21
6700	0.11	0.24	0.13	0.17	0.22
6800	0.11	0.25	0.14	0.17	0.22
6900	0.11	0.25	0.14	0.18	0.22
7000	0.12	0.25	0.14	0.18	0.23
7100	0.12	0.26	0.14	0.18	0.23
7200	0.12	0.26	0.15	0.18	0.23
7300	0.12	0.27	0.15	0.19	0.24
7400	0.12	0.27	0.15	0.19	0.24
7500	0.12	0.27	0.15	0.19	0.24
7600	0.13	0.28	0.15	0.20	0.25
7700	0.13	0.28	0.16	0.20	0.25
7800	0.13	0.29	0.16	0.20	0.26

7900	0.13	0.29	0.16	0.20	0.26
8000	0.13	0.30	0.16	0.21	0.26
8100	0.14	0.30	0.16	0.21	0.27
8200	0.14	0.30	0.17	0.21	0.27
8300	0.14	0.31	0.17	0.21	0.27
8400	0.14	0.31	0.17	0.22	0.28
8500	0.14	0.32	0.17	0.22	0.28
8600	0.14	0.32	0.18	0.22	0.28
8700	0.15	0.33	0.18	0.23	0.29
8800	0.15	0.33	0.18	0.23	0.29
8900	0.15	0.33	0.18	0.23	0.30
9000	0.15	0.34	0.18	0.23	0.30
9100	0.15	0.34	0.19	0.24	0.30
9200	0.15	0.35	0.19	0.24	0.31
9300	0.16	0.35	0.19	0.24	0.31
9400	0.16	0.36	0.19	0.25	0.32
9500	0.16	0.36	0.20	0.25	0.32
9600	0.16	0.36	0.20	0.25	0.32
9700	0.16	0.37	0.20	0.26	0.33
9800	0.17	0.37	0.20	0.26	0.33
9900	0.17	0.38	0.20	0.26	0.33
10000	0.17	0.38	0.21	0.26	0.34
10100	0.17	0.39	0.21	0.27	0.34
10200	0.17	0.39	0.21	0.27	0.35
10300	0.17	0.40	0.21	0.27	0.35
10400	0.18	0.40	0.22	0.28	0.35
10500	0.18	0.41	0.22	0.28	0.36
10600	0.18	0.41	0.22	0.28	0.36
10700	0.18	0.41	0.22	0.29	0.37
10800	0.18	0.42	0.23	0.29	0.37
10900	0.19	0.42	0.23	0.29	0.37
11000	0.19	0.43	0.23	0.29	0.38
11100	0.19	0.43	0.23	0.30	0.38
11200	0.19	0.44	0.23	0.30	0.39
11300	0.19	0.44	0.24	0.30	0.39
11400	0.19	0.45	0.24	0.31	0.39
11500	0.20	0.45	0.24	0.31	0.40
11600	0.20	0.46	0.24	0.31	0.40
11700	0.20	0.46	0.25	0.32	0.41
11800	0.20	0.47	0.25	0.32	0.41
11900	0.20	0.47	0.25	0.32	0.42

12000	0.21	0.48	0.25	0.33	0.42
12100	0.21	0.48	0.26	0.33	0.42
12200	0.21	0.49	0.26	0.33	0.43
12300	0.21	0.49	0.26	0.33	0.43
12400	0.21	0.50	0.26	0.34	0.44
12500	0.22	0.50	0.26	0.34	0.44
12600	0.22	0.51	0.27	0.34	0.45
12700	0.22	0.51	0.27	0.35	0.45
12800	0.22	0.52	0.27	0.35	0.45
12900	0.22	0.52	0.27	0.35	0.46
13000	0.23	0.53	0.28	0.36	0.46
13100	0.23	0.53	0.28	0.36	0.47
13200	0.23	0.54	0.28	0.36	0.47
13300	0.23	0.54	0.28	0.37	0.48
13400	0.23	0.55	0.29	0.37	0.48
13500	0.23	0.55	0.29	0.37	0.48
13600	0.24	0.56	0.29	0.38	0.49
13700	0.24	0.56	0.29	0.38	0.49
13800	0.24	0.57	0.30	0.38	0.50
13900	0.24	0.57	0.30	0.39	0.50
14000	0.24	0.58	0.30	0.39	0.51
14100	0.25	0.58	0.30	0.39	0.51
14200	0.25	0.59	0.31	0.40	0.52
14300	0.25	0.59	0.31	0.40	0.52
14400	0.25	0.60	0.31	0.40	0.52
14500	0.25	0.61	0.31	0.41	0.53
14600	0.26	0.61	0.32	0.41	0.53
14700	0.26	0.62	0.32	0.41	0.54
14800	0.26	0.62	0.32	0.42	0.54
14900	0.26	0.63	0.32	0.42	0.55
15000	0.26	0.63	0.33	0.42	0.55
15100	0.27	0.64	0.33	0.43	0.56
15200	0.27	0.64	0.33	0.43	0.56
15300	0.27	0.65	0.33	0.43	0.57
15400	0.27	0.66	0.34	0.44	0.57
15500	0.27	0.66	0.34	0.44	0.58
15600	0.28	0.67	0.34	0.44	0.58
15700	0.28	0.67	0.34	0.45	0.59
15800	0.28	0.68	0.35	0.45	0.59
15900	0.28	0.68	0.35	0.45	0.60
16000	0.28	0.69	0.35	0.46	0.60

16100	0.29	0.70	0.35	0.46	0.61
16200	0.29	0.70	0.36	0.46	0.61
16300	0.29	0.71	0.36	0.47	0.62
16400	0.29	0.71	0.36	0.47	0.62
16500	0.29	0.72	0.36	0.47	0.63
16600	0.30	0.73	0.37	0.48	0.63
16700	0.30	0.73	0.37	0.48	0.64
16800	0.30	0.74	0.37	0.49	0.64
16900	0.30	0.74	0.37	0.49	0.65
17000	0.30	0.75	0.38	0.49	0.65
17100	0.31	0.76	0.38	0.50	0.66
17200	0.31	0.76	0.38	0.50	0.66
17300	0.31	0.77	0.39	0.50	0.67
17400	0.31	0.78	0.39	0.51	0.67
17500	0.31	0.78	0.39	0.51	0.68
17600	0.32	0.79	0.39	0.51	0.68
17700	0.32	0.79	0.40	0.52	0.69
17800	0.32	0.80	0.40	0.52	0.69
17900	0.32	0.81	0.40	0.53	0.70
18000	0.32	0.81	0.40	0.53	0.70
18100	0.33	0.82	0.41	0.53	0.71
18200	0.33	0.83	0.41	0.54	0.71
18300	0.33	0.83	0.41	0.54	0.72
18400	0.33	0.84	0.41	0.54	0.72
18500	0.34	0.85	0.42	0.55	0.73
18600	0.34	0.85	0.42	0.55	0.74
18700	0.34	0.86	0.42	0.56	0.74
18800	0.34	0.87	0.43	0.56	0.75
18900	0.34	0.87	0.43	0.56	0.75
19000	0.35	0.88	0.43	0.57	0.76
19100	0.35	0.89	0.43	0.57	0.76
19200	0.35	0.89	0.44	0.57	0.77
19300	0.35	0.90	0.44	0.58	0.77
19400	0.35	0.91	0.44	0.58	0.78
19500	0.36	0.91	0.44	0.59	0.79
19600	0.36	0.92	0.45	0.59	0.79
19700	0.36	0.93	0.45	0.59	0.80
19800	0.36	0.94	0.45	0.60	0.80
19900	0.36	0.94	0.46	0.60	0.81
20000	0.37	0.95	0.46	0.61	0.81
20100	0.37	0.96	0.46	0.61	0.82

20200	0.37	0.96	0.46	0.61	0.83
20300	0.37	0.97	0.47	0.62	0.83
20400	0.38	0.98	0.47	0.62	0.84
20500	0.38	0.99	0.47	0.63	0.84
20600	0.38	0.99	0.48	0.63	0.85
20700	0.38	1.00	0.48	0.63	0.86
20800	0.38	1.01	0.48	0.64	0.86
20900	0.39	1.02	0.48	0.64	0.87
21000	0.39	1.02	0.49	0.65	0.87
21100	0.39	1.03	0.49	0.65	0.88
21200	0.39	1.04	0.49	0.65	0.89
21300	0.40	1.05	0.50	0.66	0.89
21400	0.40	1.06	0.50	0.66	0.90
21500	0.40	1.06	0.50	0.67	0.91
21600	0.40	1.07	0.50	0.67	0.91
21700	0.40	1.08	0.51	0.68	0.92
21800	0.41	1.09	0.51	0.68	0.92
21900	0.41	1.10	0.51	0.68	0.93
22000	0.41	1.10	0.52	0.69	0.94
22100	0.41	1.11	0.52	0.69	0.94
22200	0.42	1.12	0.52	0.70	0.95

App. A2 Table 4. Range, 0..25 and 0.975 quantiles, and median fishing mortalities implied by specified catches from bootstrapped January 1 biomasses between years 2009 and 2012 when M = 0.8 and q = 1 is assumed.

Catch	Minimum	Maximum	0.025 Quantile	Median	0.975 Quantile
100	0.00	0.00	0.00	0.00	0.00
200	0.00	0.00	0.00	0.00	0.00
300	0.00	0.01	0.00	0.00	0.00
400	0.00	0.01	0.00	0.00	0.01
500	0.00	0.01	0.00	0.01	0.01
600	0.00	0.01	0.01	0.01	0.01
700	0.01	0.01	0.01	0.01	0.01
800	0.01	0.01	0.01	0.01	0.01
900	0.01	0.02	0.01	0.01	0.01
1000	0.01	0.02	0.01	0.01	0.02
1100	0.01	0.02	0.01	0.01	0.02
1200	0.01	0.02	0.01	0.01	0.02
1300	0.01	0.02	0.01	0.02	0.02
1400	0.01	0.03	0.01	0.02	0.02
1500	0.01	0.03	0.01	0.02	0.02
1600	0.01	0.03	0.01	0.02	0.03
1700	0.01	0.03	0.01	0.02	0.03
1800	0.01	0.03	0.02	0.02	0.03
1900	0.01	0.03	0.02	0.02	0.03
2000	0.02	0.04	0.02	0.02	0.03
2100	0.02	0.04	0.02	0.02	0.03
2200	0.02	0.04	0.02	0.03	0.03
2300	0.02	0.04	0.02	0.03	0.04
2400	0.02	0.04	0.02	0.03	0.04
2500	0.02	0.05	0.02	0.03	0.04
2600	0.02	0.05	0.02	0.03	0.04
2700	0.02	0.05	0.02	0.03	0.04
2800	0.02	0.05	0.02	0.03	0.04
2900	0.02	0.05	0.03	0.03	0.05
3000	0.02	0.05	0.03	0.04	0.05
3100	0.02	0.06	0.03	0.04	0.05
3200	0.03	0.06	0.03	0.04	0.05
3300	0.03	0.06	0.03	0.04	0.05
3400	0.03	0.06	0.03	0.04	0.05
3500	0.03	0.06	0.03	0.04	0.06
3600	0.03	0.07	0.03	0.04	0.06
3700	0.03	0.07	0.03	0.04	0.06
3800	0.03	0.07	0.03	0.05	0.06
3900	0.03	0.07	0.03	0.05	0.06
4000	0.03	0.07	0.04	0.05	0.06
4100	0.03	0.07	0.04	0.05	0.07
4200	0.03	0.08	0.04	0.05	0.07
4300	0.03	0.08	0.04	0.05	0.07

4400	0.03	0.08	0.04	0.05	0.07
4500	0.04	0.08	0.04	0.05	0.07
4600	0.04	0.08	0.04	0.06	0.07
4700	0.04	0.09	0.04	0.06	0.08
4800	0.04	0.09	0.04	0.06	0.08
4900	0.04	0.09	0.04	0.06	0.08
5000	0.04	0.09	0.04	0.06	0.08
5100	0.04	0.09	0.05	0.06	0.08
5200	0.04	0.10	0.05	0.06	0.08
5300	0.04	0.10	0.05	0.06	0.09
5400	0.04	0.10	0.05	0.07	0.09
5500	0.04	0.10	0.05	0.07	0.09
5600	0.04	0.10	0.05	0.07	0.09
5700	0.05	0.11	0.05	0.07	0.09
5800	0.05	0.11	0.05	0.07	0.09
5900	0.05	0.11	0.05	0.07	0.10
6000	0.05	0.11	0.05	0.07	0.10
6100	0.05	0.11	0.05	0.07	0.10
6200	0.05	0.12	0.06	0.08	0.10
6300	0.05	0.12	0.06	0.08	0.10
6400	0.05	0.12	0.06	0.08	0.10
6500	0.05	0.12	0.06	0.08	0.11
6600	0.05	0.12	0.06	0.08	0.11
6700	0.05	0.12	0.06	0.08	0.11
6800	0.05	0.13	0.06	0.08	0.11
6900	0.06	0.13	0.06	0.08	0.11
7000	0.06	0.13	0.06	0.09	0.11
7100	0.06	0.13	0.06	0.09	0.12
7200	0.06	0.13	0.06	0.09	0.12
7300	0.06	0.14	0.07	0.09	0.12
7400	0.06	0.14	0.07	0.09	0.12
7500	0.06	0.14	0.07	0.09	0.12
7600	0.06	0.14	0.07	0.09	0.12
7700	0.06	0.14	0.07	0.09	0.13
7800	0.06	0.15	0.07	0.10	0.13
7900	0.06	0.15	0.07	0.10	0.13
8000	0.06	0.15	0.07	0.10	0.13
8100	0.07	0.15	0.07	0.10	0.13
8200	0.07	0.15	0.07	0.10	0.13
8300	0.07	0.16	0.07	0.10	0.14
8400	0.07	0.16	0.08	0.10	0.14
8500	0.07	0.16	0.08	0.10	0.14
8600	0.07	0.16	0.08	0.11	0.14
8700	0.07	0.17	0.08	0.11	0.14
8800	0.07	0.17	0.08	0.11	0.15
8900	0.07	0.17	0.08	0.11	0.15
9000	0.07	0.17	0.08	0.11	0.15
9100	0.07	0.17	0.08	0.11	0.15

9200	0.07	0.18	0.08	0.11	0.15
9300	0.08	0.18	0.08	0.11	0.15
9400	0.08	0.18	0.08	0.12	0.16
9500	0.08	0.18	0.09	0.12	0.16
9600	0.08	0.18	0.09	0.12	0.16
9700	0.08	0.19	0.09	0.12	0.16
9800	0.08	0.19	0.09	0.12	0.16
9900	0.08	0.19	0.09	0.12	0.16
10000	0.08	0.19	0.09	0.12	0.17
10100	0.08	0.19	0.09	0.12	0.17
10200	0.08	0.20	0.09	0.13	0.17
10300	0.08	0.20	0.09	0.13	0.17
10400	0.08	0.20	0.09	0.13	0.17
10500	0.09	0.20	0.10	0.13	0.18
10600	0.09	0.20	0.10	0.13	0.18
10700	0.09	0.21	0.10	0.13	0.18
10800	0.09	0.21	0.10	0.13	0.18
10900	0.09	0.21	0.10	0.14	0.18
11000	0.09	0.21	0.10	0.14	0.18
11100	0.09	0.22	0.10	0.14	0.19
11200	0.09	0.22	0.10	0.14	0.19
11300	0.09	0.22	0.10	0.14	0.19
11400	0.09	0.22	0.10	0.14	0.19
11500	0.09	0.22	0.10	0.14	0.19
11600	0.09	0.23	0.11	0.14	0.20
11700	0.10	0.23	0.11	0.15	0.20
11800	0.10	0.23	0.11	0.15	0.20
11900	0.10	0.23	0.11	0.15	0.20
12000	0.10	0.23	0.11	0.15	0.20
12100	0.10	0.24	0.11	0.15	0.20
12200	0.10	0.24	0.11	0.15	0.21
12300	0.10	0.24	0.11	0.15	0.21
12400	0.10	0.24	0.11	0.16	0.21
12500	0.10	0.25	0.11	0.16	0.21
12600	0.10	0.25	0.12	0.16	0.21
12700	0.10	0.25	0.12	0.16	0.22
12800	0.10	0.25	0.12	0.16	0.22
12900	0.11	0.25	0.12	0.16	0.22
13000	0.11	0.26	0.12	0.16	0.22
13100	0.11	0.26	0.12	0.16	0.22
13200	0.11	0.26	0.12	0.17	0.23
13300	0.11	0.26	0.12	0.17	0.23
13400	0.11	0.27	0.12	0.17	0.23
13500	0.11	0.27	0.12	0.17	0.23
13600	0.11	0.27	0.12	0.17	0.23
13700	0.11	0.27	0.13	0.17	0.24
13800	0.11	0.27	0.13	0.17	0.24
13900	0.11	0.28	0.13	0.18	0.24

14000	0.12	0.28	0.13	0.18	0.24
14100	0.12	0.28	0.13	0.18	0.24
14200	0.12	0.28	0.13	0.18	0.24
14300	0.12	0.29	0.13	0.18	0.25
14400	0.12	0.29	0.13	0.18	0.25
14500	0.12	0.29	0.13	0.18	0.25
14600	0.12	0.29	0.13	0.19	0.25
14700	0.12	0.29	0.14	0.19	0.25
14800	0.12	0.30	0.14	0.19	0.26
14900	0.12	0.30	0.14	0.19	0.26
15000	0.12	0.30	0.14	0.19	0.26
15100	0.12	0.30	0.14	0.19	0.26
15200	0.13	0.31	0.14	0.19	0.26
15300	0.13	0.31	0.14	0.19	0.27
15400	0.13	0.31	0.14	0.20	0.27
15500	0.13	0.31	0.14	0.20	0.27
15600	0.13	0.31	0.14	0.20	0.27
15700	0.13	0.32	0.15	0.20	0.27
15800	0.13	0.32	0.15	0.20	0.28
15900	0.13	0.32	0.15	0.20	0.28
16000	0.13	0.32	0.15	0.20	0.28
16100	0.13	0.33	0.15	0.21	0.28
16200	0.13	0.33	0.15	0.21	0.28
16300	0.14	0.33	0.15	0.21	0.29
16400	0.14	0.33	0.15	0.21	0.29
16500	0.14	0.34	0.15	0.21	0.29
16600	0.14	0.34	0.15	0.21	0.29
16700	0.14	0.34	0.16	0.21	0.29
16800	0.14	0.34	0.16	0.22	0.30
16900	0.14	0.35	0.16	0.22	0.30
17000	0.14	0.35	0.16	0.22	0.30
17100	0.14	0.35	0.16	0.22	0.30
17200	0.14	0.35	0.16	0.22	0.30
17300	0.14	0.36	0.16	0.22	0.31
17400	0.14	0.36	0.16	0.22	0.31
17500	0.15	0.36	0.16	0.23	0.31
17600	0.15	0.36	0.16	0.23	0.31
17700	0.15	0.36	0.17	0.23	0.31
17800	0.15	0.37	0.17	0.23	0.32
17900	0.15	0.37	0.17	0.23	0.32
18000	0.15	0.37	0.17	0.23	0.32
18100	0.15	0.37	0.17	0.23	0.32
18200	0.15	0.38	0.17	0.24	0.32
18300	0.15	0.38	0.17	0.24	0.33
18400	0.15	0.38	0.17	0.24	0.33
18500	0.15	0.38	0.17	0.24	0.33
18600	0.16	0.39	0.17	0.24	0.33
18700	0.16	0.39	0.18	0.24	0.33

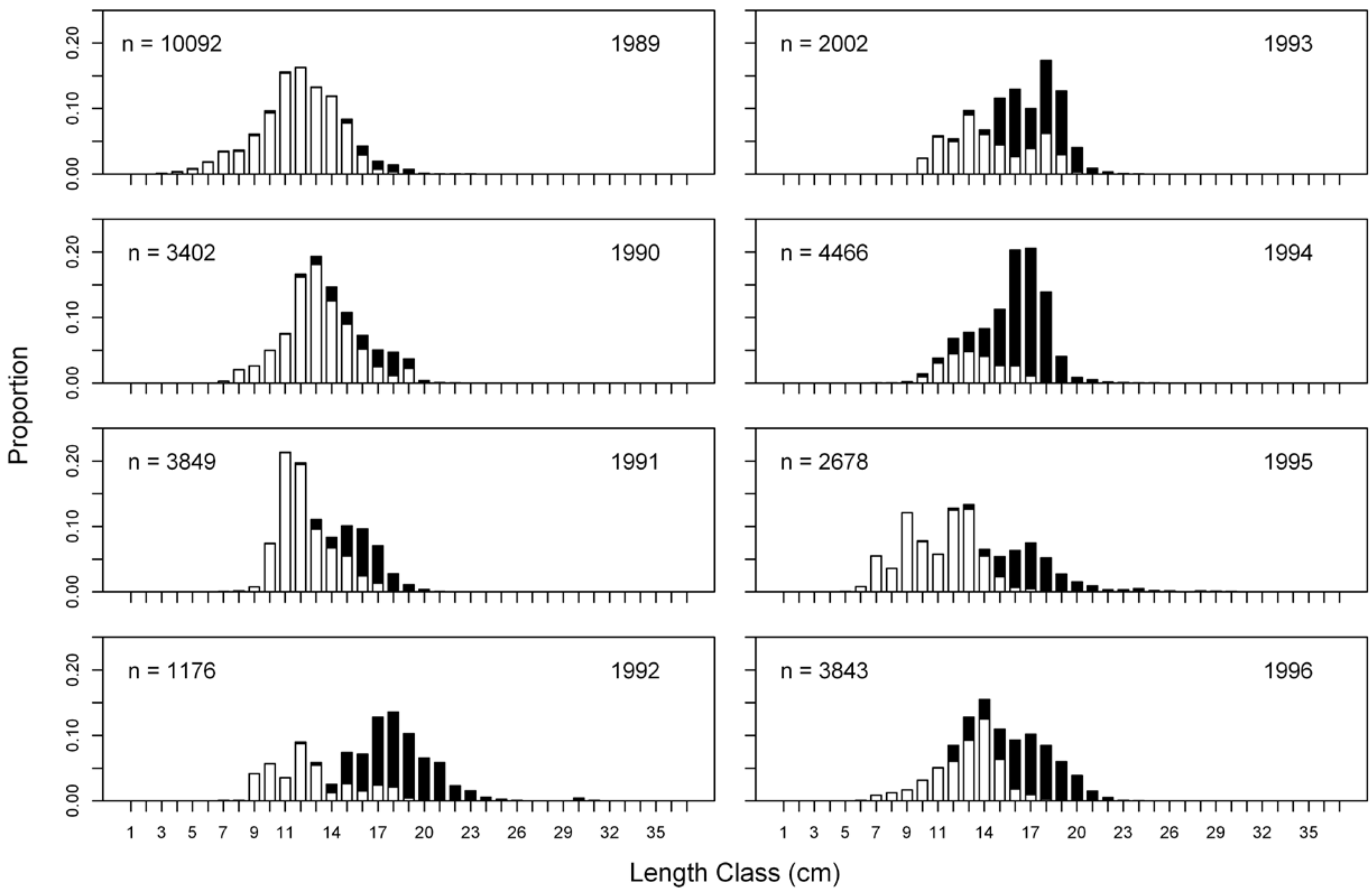
18800	0.16	0.39	0.18	0.24	0.34
18900	0.16	0.39	0.18	0.25	0.34
19000	0.16	0.40	0.18	0.25	0.34
19100	0.16	0.40	0.18	0.25	0.34
19200	0.16	0.40	0.18	0.25	0.34
19300	0.16	0.40	0.18	0.25	0.35
19400	0.16	0.41	0.18	0.25	0.35
19500	0.16	0.41	0.18	0.25	0.35
19600	0.16	0.41	0.18	0.26	0.35
19700	0.17	0.41	0.19	0.26	0.35
19800	0.17	0.42	0.19	0.26	0.36
19900	0.17	0.42	0.19	0.26	0.36
20000	0.17	0.42	0.19	0.26	0.36
20100	0.17	0.42	0.19	0.26	0.36
20200	0.17	0.43	0.19	0.26	0.37
20300	0.17	0.43	0.19	0.27	0.37
20400	0.17	0.43	0.19	0.27	0.37
20500	0.17	0.43	0.19	0.27	0.37
20600	0.17	0.44	0.19	0.27	0.37
20700	0.17	0.44	0.20	0.27	0.38
20800	0.18	0.44	0.20	0.27	0.38
20900	0.18	0.44	0.20	0.28	0.38
21000	0.18	0.45	0.20	0.28	0.38
21100	0.18	0.45	0.20	0.28	0.38
21200	0.18	0.45	0.20	0.28	0.39
21300	0.18	0.46	0.20	0.28	0.39
21400	0.18	0.46	0.20	0.28	0.39
21500	0.18	0.46	0.20	0.28	0.39
21600	0.18	0.46	0.20	0.29	0.40
21700	0.18	0.47	0.21	0.29	0.40
21800	0.18	0.47	0.21	0.29	0.40
21900	0.19	0.47	0.21	0.29	0.40
22000	0.19	0.47	0.21	0.29	0.40
22100	0.19	0.48	0.21	0.29	0.41
22200	0.19	0.48	0.21	0.29	0.41
22300	0.19	0.48	0.21	0.30	0.41
22400	0.19	0.48	0.21	0.30	0.41
22500	0.19	0.49	0.21	0.30	0.42
22600	0.19	0.49	0.22	0.30	0.42
22700	0.19	0.49	0.22	0.30	0.42
22800	0.19	0.49	0.22	0.30	0.42
22900	0.19	0.50	0.22	0.31	0.42
23000	0.20	0.50	0.22	0.31	0.43
23100	0.20	0.50	0.22	0.31	0.43
23200	0.20	0.51	0.22	0.31	0.43
23300	0.20	0.51	0.22	0.31	0.43
23400	0.20	0.51	0.22	0.31	0.44
23500	0.20	0.51	0.22	0.31	0.44

23600	0.20	0.52	0.23	0.32	0.44
23700	0.20	0.52	0.23	0.32	0.44
23800	0.20	0.52	0.23	0.32	0.44
23900	0.20	0.52	0.23	0.32	0.45
24000	0.20	0.53	0.23	0.32	0.45
24100	0.21	0.53	0.23	0.32	0.45
24200	0.21	0.53	0.23	0.33	0.45
24300	0.21	0.54	0.23	0.33	0.46
24400	0.21	0.54	0.23	0.33	0.46
24500	0.21	0.54	0.24	0.33	0.46
24600	0.21	0.54	0.24	0.33	0.46
24700	0.21	0.55	0.24	0.33	0.47
24800	0.21	0.55	0.24	0.33	0.47
24900	0.21	0.55	0.24	0.34	0.47
25000	0.21	0.56	0.24	0.34	0.47
25100	0.22	0.56	0.24	0.34	0.47
25200	0.22	0.56	0.24	0.34	0.48
25300	0.22	0.56	0.24	0.34	0.48
25400	0.22	0.57	0.24	0.34	0.48
25500	0.22	0.57	0.25	0.35	0.48
25600	0.22	0.57	0.25	0.35	0.49
25700	0.22	0.58	0.25	0.35	0.49
25800	0.22	0.58	0.25	0.35	0.49
25900	0.22	0.58	0.25	0.35	0.49
26000	0.22	0.58	0.25	0.35	0.50
26100	0.22	0.59	0.25	0.35	0.50
26200	0.23	0.59	0.25	0.36	0.50
26300	0.23	0.59	0.25	0.36	0.50
26400	0.23	0.60	0.26	0.36	0.51
26500	0.23	0.60	0.26	0.36	0.51
26600	0.23	0.60	0.26	0.36	0.51
26700	0.23	0.60	0.26	0.36	0.51
26800	0.23	0.61	0.26	0.37	0.51
26900	0.23	0.61	0.26	0.37	0.52
27000	0.23	0.61	0.26	0.37	0.52
27100	0.23	0.62	0.26	0.37	0.52
27200	0.24	0.62	0.26	0.37	0.52
27300	0.24	0.62	0.27	0.37	0.53
27400	0.24	0.63	0.27	0.38	0.53
27500	0.24	0.63	0.27	0.38	0.53
27600	0.24	0.63	0.27	0.38	0.53
27700	0.24	0.63	0.27	0.38	0.54
27800	0.24	0.64	0.27	0.38	0.54
27900	0.24	0.64	0.27	0.38	0.54
28000	0.24	0.64	0.27	0.39	0.54
28100	0.24	0.65	0.27	0.39	0.55
28200	0.24	0.65	0.28	0.39	0.55
28300	0.25	0.65	0.28	0.39	0.55

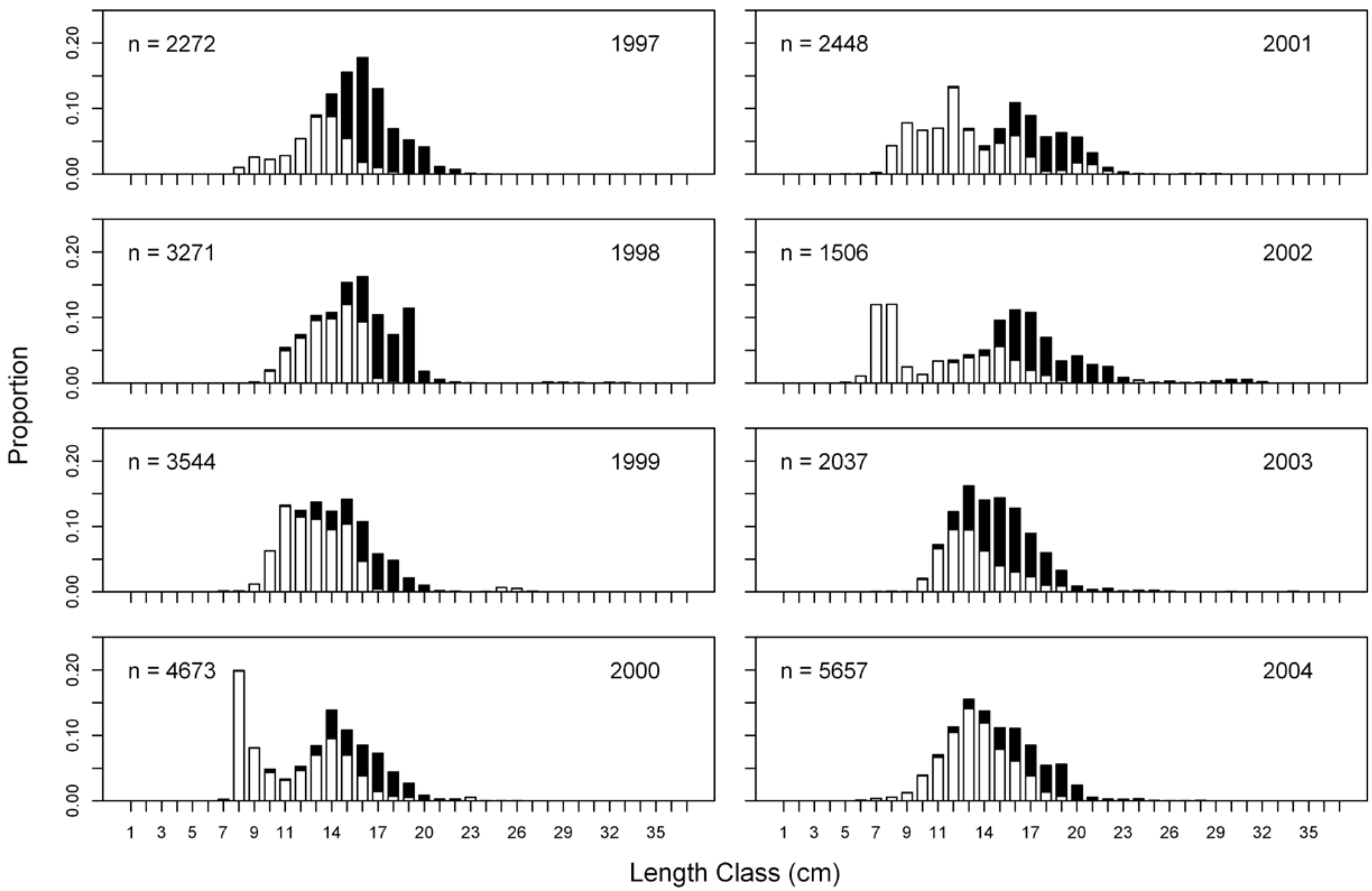
28400	0.25	0.66	0.28	0.39	0.55
28500	0.25	0.66	0.28	0.39	0.56
28600	0.25	0.66	0.28	0.40	0.56
28700	0.25	0.67	0.28	0.40	0.56
28800	0.25	0.67	0.28	0.40	0.56
28900	0.25	0.67	0.28	0.40	0.57
29000	0.25	0.67	0.28	0.40	0.57
29100	0.25	0.68	0.29	0.40	0.57
29200	0.25	0.68	0.29	0.41	0.57
29300	0.26	0.68	0.29	0.41	0.58
29400	0.26	0.69	0.29	0.41	0.58
29500	0.26	0.69	0.29	0.41	0.58
29600	0.26	0.69	0.29	0.41	0.58
29700	0.26	0.70	0.29	0.41	0.59
29800	0.26	0.70	0.29	0.42	0.59
29900	0.26	0.70	0.29	0.42	0.59
30000	0.26	0.71	0.30	0.42	0.59
30100	0.26	0.71	0.30	0.42	0.60
30200	0.26	0.71	0.30	0.42	0.60
30300	0.27	0.72	0.30	0.42	0.60
30400	0.27	0.72	0.30	0.43	0.60
30500	0.27	0.72	0.30	0.43	0.61
30600	0.27	0.73	0.30	0.43	0.61
30700	0.27	0.73	0.30	0.43	0.61
30800	0.27	0.73	0.30	0.43	0.62
30900	0.27	0.74	0.31	0.43	0.62
31000	0.27	0.74	0.31	0.44	0.62
31100	0.27	0.74	0.31	0.44	0.62
31200	0.27	0.75	0.31	0.44	0.63
31300	0.28	0.75	0.31	0.44	0.63
31400	0.28	0.75	0.31	0.44	0.63
31500	0.28	0.76	0.31	0.44	0.63
31600	0.28	0.76	0.31	0.45	0.64
31700	0.28	0.76	0.31	0.45	0.64
31800	0.28	0.77	0.32	0.45	0.64
31900	0.28	0.77	0.32	0.45	0.64
32000	0.28	0.77	0.32	0.45	0.65
32100	0.28	0.78	0.32	0.45	0.65
32200	0.28	0.78	0.32	0.46	0.65
32300	0.29	0.78	0.32	0.46	0.66
32400	0.29	0.79	0.32	0.46	0.66
32500	0.29	0.79	0.32	0.46	0.66
32600	0.29	0.79	0.32	0.46	0.66
32700	0.29	0.80	0.33	0.46	0.67
32800	0.29	0.80	0.33	0.47	0.67
32900	0.29	0.80	0.33	0.47	0.67
33000	0.29	0.81	0.33	0.47	0.67
33100	0.29	0.81	0.33	0.47	0.68

33200	0.29	0.81	0.33	0.47	0.68
33300	0.30	0.82	0.33	0.48	0.68
33400	0.30	0.82	0.33	0.48	0.69
33500	0.30	0.82	0.34	0.48	0.69
33600	0.30	0.83	0.34	0.48	0.69
33700	0.30	0.83	0.34	0.48	0.69
33800	0.30	0.84	0.34	0.48	0.70
33900	0.30	0.84	0.34	0.49	0.70
34000	0.30	0.84	0.34	0.49	0.70
34100	0.30	0.85	0.34	0.49	0.70
34200	0.30	0.85	0.34	0.49	0.71
34300	0.31	0.85	0.34	0.49	0.71
34400	0.31	0.86	0.35	0.49	0.71
34500	0.31	0.86	0.35	0.50	0.72
34600	0.31	0.86	0.35	0.50	0.72
34700	0.31	0.87	0.35	0.50	0.72
34800	0.31	0.87	0.35	0.50	0.72
34900	0.31	0.88	0.35	0.50	0.73
35000	0.31	0.88	0.35	0.51	0.73
35100	0.31	0.88	0.35	0.51	0.73
35200	0.31	0.89	0.35	0.51	0.74
35300	0.32	0.89	0.36	0.51	0.74
35400	0.32	0.89	0.36	0.51	0.74
35500	0.32	0.90	0.36	0.51	0.75
35600	0.32	0.90	0.36	0.52	0.75
35700	0.32	0.91	0.36	0.52	0.75
35800	0.32	0.91	0.36	0.52	0.75
35900	0.32	0.91	0.36	0.52	0.76
36000	0.32	0.92	0.36	0.52	0.76
36100	0.32	0.92	0.37	0.53	0.76
36200	0.32	0.92	0.37	0.53	0.77
36300	0.33	0.93	0.37	0.53	0.77
36400	0.33	0.93	0.37	0.53	0.77
36500	0.33	0.94	0.37	0.53	0.77
36600	0.33	0.94	0.37	0.53	0.78
36700	0.33	0.94	0.37	0.54	0.78
36800	0.33	0.95	0.37	0.54	0.78
36900	0.33	0.95	0.38	0.54	0.79
37000	0.33	0.96	0.38	0.54	0.79
37100	0.33	0.96	0.38	0.54	0.79
37200	0.34	0.96	0.38	0.55	0.80
37300	0.34	0.97	0.38	0.55	0.80
37400	0.34	0.97	0.38	0.55	0.80
37500	0.34	0.98	0.38	0.55	0.80
37600	0.34	0.98	0.38	0.55	0.81
37700	0.34	0.98	0.38	0.56	0.81
37800	0.34	0.99	0.39	0.56	0.81
37900	0.34	0.99	0.39	0.56	0.82

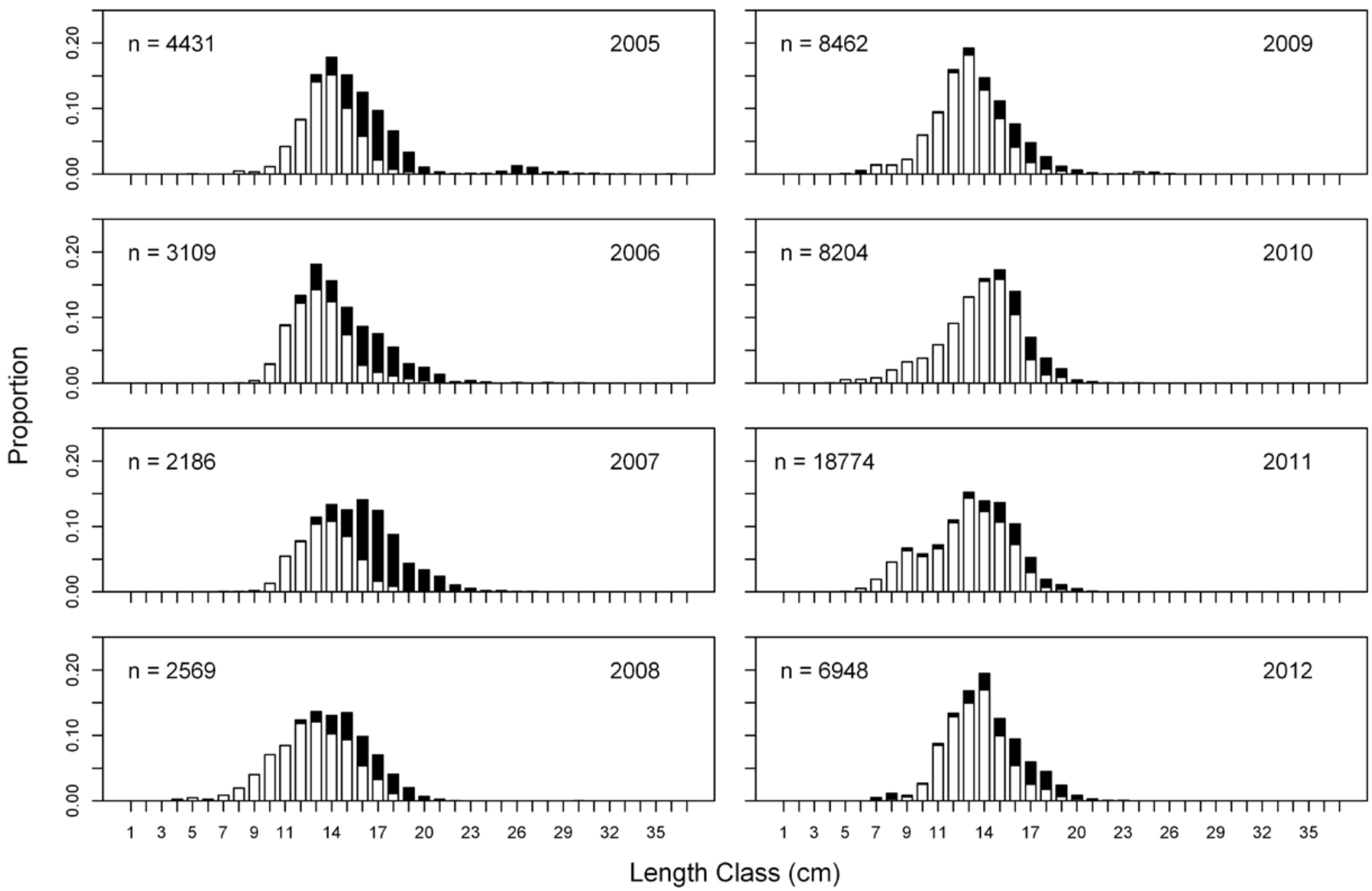
38000	0.34	1.00	0.39	0.56	0.82
38100	0.34	1.00	0.39	0.56	0.82
38200	0.35	1.00	0.39	0.56	0.83
38300	0.35	1.01	0.39	0.57	0.83
38400	0.35	1.01	0.39	0.57	0.83
38500	0.35	1.02	0.39	0.57	0.84
38600	0.35	1.02	0.40	0.57	0.84
38700	0.35	1.02	0.40	0.57	0.84
38800	0.35	1.03	0.40	0.58	0.85
38900	0.35	1.03	0.40	0.58	0.85
39000	0.35	1.04	0.40	0.58	0.85
39100	0.36	1.04	0.40	0.58	0.85
39200	0.36	1.05	0.40	0.58	0.86
39300	0.36	1.05	0.40	0.59	0.86
39400	0.36	1.05	0.41	0.59	0.86
39500	0.36	1.06	0.41	0.59	0.87
39600	0.36	1.06	0.41	0.59	0.87
39700	0.36	1.07	0.41	0.59	0.87
39800	0.36	1.07	0.41	0.60	0.88
39900	0.36	1.08	0.41	0.60	0.88
40000	0.36	1.08	0.41	0.60	0.88
40100	0.37	1.08	0.41	0.60	0.89
40200	0.37	1.09	0.42	0.60	0.89
40300	0.37	1.09	0.42	0.61	0.89
40400	0.37	1.10	0.42	0.61	0.90
40500	0.37	1.10	0.42	0.61	0.90
40600	0.37	1.11	0.42	0.61	0.90
40700	0.37	1.11	0.42	0.61	0.91
40800	0.37	1.12	0.42	0.61	0.91
40900	0.37	1.12	0.42	0.62	0.91
41000	0.38	1.12	0.43	0.62	0.92



App. A2 Figure A1. Length composition for NMFS Observer Program for butterfish between 1989 and 1996 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.



App. A2 Figure A2. Length composition for NMFS Observer Program for butterfish between 1997 and 2004 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.



App. A2 Figure A3. Length composition for NMFS Observer Program for butterfish between 2005 and 2012 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.

Appendix A2. Abundance indices for NEFSC fall surveys.

App. A2 Table B1. 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 1982-2012 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
2009	158.31	20.06	3.88	0.17	0.01
2010	84.09	35.90	6.90	1.25	0
2011	218.26	26.86	4.76	0.42	0.06
2012	27.15	28.83	9.91	0.62	0.07

Butterfish Appendix A3. Implications of model assumptions for estimates of abundance and fishing mortality (Miller and Rago 2012).

The simple models we used here have some important underlying assumptions:

1) Fish are fully selected at the same ages by the surveys and fishery.
2) All recruitment to the stock occurs at the beginning of the year.
3) The entire stock is available to the trawl survey.

These three assumptions are not likely to apply to the actual butterfish stock, but these inconsistencies will affect the results in predictable ways. When the first assumption does not hold and the fishery selects younger fish on average than the survey, then survey efficiency is effectively lower and actual fishing mortalities would be less than those implied by the second model that does not require a fishing mortality assumption. Conversely, if the fishery selects older fish on average, the fishing mortality rates would be greater than those provided by the model.

Butterfish are likely to recruit to the fishery over some period of the calendar year and this violation of assumption 2 would cause all annual fishing mortality rates provided by the model to be greater than actual values. Assumption 3 is violated when only a fraction of the stock is available to the survey. In these instances effective efficiency would be even less than that assumed and model-based fishing mortality rates would be greater than the actual values. Therefore, violating the latter two assumptions would likely lead to over-estimation of fishing mortality rates which makes the results of the model conservative and current catches levels would be even less likely to exceed candidate reference points over a broad range of assumptions.

Estimates of the minimum bound on butterfish biomass

BACKGROUND

The purpose of this analysis to provide a minimum estimate of butterfish biomass using only fisheries-independent trawl survey data. This work builds off previous evaluations of butterfish catchability and the likely ranges of butterfish biomass based on Northeast Fisheries Science Center trawl survey data (Northeast Fisheries Science Center 2009, Miller and Rago 2012), and similar analyses for other species such as Longfin squid (Northeast Fisheries Science Center 2011). This analysis is not meant as an alternative to the more comprehensive modeling done within a stock assessment. Rather, it is meant to provide additional context for interpreting the butterfish biomass estimates obtained from these models.

For the purposes of this working paper we use the two components of catchability that were considered in the 2009 butterfish assessment. The first component, **availability,** is the proportion of the total population within the footprint covered by the survey. The second component, **detectability**, represents the proportion of fish within the footprint of an average individual trawl that are captured within by trawl. Fish in the water column, or that escape above, below or to the sides of a bottom trawl all contribute to detectability values that are less than 1. Catchability (q) is the product of availability and detectability.

We also designate two different measures of the average swept area of an individual tow of the bottom trawl (Fig. 1). The first measure, the **wing swept area,** is a product of the average distance between the wings of the trawl gear and the distance towed. This is the standard measure of swept area used in most assessments, as it corresponds to the area of the bottom covered by the portion of the gear capable of catching fish. The second measure, the **door swept area**, is a product of the distance between the doors of the trawl gear and the distance towed. Certain species of fish have been shown to be herded into the trawl mouth due to interactions with the doors, sand clouds or sweeps. For herding to occur, fish must swim at a speed and in a direction to avoid being overtaken by the gear while in the path of the sweeps or doors, before eventually being overtaken by the gear when in the path of the trawl mouth.

The basic premise of our analysis is that the detectability of any given trawl net cannot exceed one during any defined period of sampling. In other words the net cannot catch more fish than are in its path. Furthermore, the combined availability of fish to a suite of simultaneous surveys cannot exceed one. With these constraints, and available data, it is possible to establish a maximum bound on catchability for any particular survey time series. With this maximum bound on catchability a minimum bound on stock biomass can be calculated. The details of these calculations are provided below.

METHODS

The catchability equation

The relationship between the trawl survey index, detectability, availability and population biomass is defined using the following equation (Northeast Fisheries Science Center 2009):

$$I_t = \delta \frac{a}{A} \rho C B_t \qquad \text{[eq. 1]}$$

Where:

I_t: Index value at year t (kg tow^{-1})
δ: detectability of butterfish by the net
a: area covered by a single trawl
A: area covered by a survey
ρ: availability of butterfish to the survey
C: a constant (10^6) used to scale weight from kilograms to 1000 metric tons.

Within this equation I_t, ***a*** and ***A*** are all values that are measured on a survey or are part of the survey design. Values of detectability and availability are unknown.

Analysis of detectability using day-night differences in catch levels

Detectability of many fishes in a trawl net varies substantially over a day-night cycle. For butterfish, daytime catch rates are higher. The dominant driver of this diel cycle is most likely changes in vertical distribution related to feeding, though other factors may contribute. This day-night behavior is relevant to broader analyses of survey catchability for two reasons. First, the NEFSC survey uses 24-hour operations whereas the NEAMAP and most state surveys sample only during daylight hours. Second, the relative detectability of the NEFSC survey between the day and night can be used to scale the maximum detectability of this survey. We can assume that detectability during day and night is less than 1:

$$\delta_{day} < 1 \quad \text{and} \quad \delta_{night} < 1 \qquad \text{[eqs. 2]}$$

From the survey data we can calculate the day and night catch rates to obtain the ratio of daytime to nighttime detectability:

$$\frac{\delta_{day}}{\delta_{night}} = \frac{Catch_{day}}{Catch_{night}} \qquad \text{[eq 3]}$$

By setting daytime detectability to its assumed maximum value (1) we can calculate a maximum value for nighttime detectability. In turn we can calculate a maximum value for the average detectability for the 24-hour survey:

$$\delta_{max} = \delta_{day,max} * Proportion\ day\ tows + \delta_{night,max} * Proportion\ night\ tows \qquad \text{[eq. 4]}$$

The solar zenith angle was used to define day (<90.8), night (>90.8) (Jacobson et al. 2011). The stratified mean catch tow^{-1} for both the daytime and nighttime was calculated for 1989-2008 fall survey.

Analysis of catchability with two simultaneous non-overlapping surveys

It is possible to rearrange equation 1 to define population biomass as a function of survey indices:

$$B_t = \frac{A}{a\rho\delta C} I_t \qquad \text{[eq. 5]}$$

When two surveys of a resource are available the catch levels on one can be used to inform the catchability on the other assuming that two criteria are met. First the surveys must be occur at approximately the same time to minimize the extent of "double-counting" of fish moving from one survey area to another, and 2) the surveys must not overlap in space. The NEFSC fall trawl survey and the NEAMAP fall trawl survey fulfill these two criteria at a reasonable level of approximation. That is, these two surveys can be assumed to measure different components of the same butterfish population at approximately the same time. This is not the case for the NEAMAP and NEFSC spring surveys which are offset in time.

With two paired surveys it is possible to rewrite the catchability equations for these two surveys as follows:

$$B_t = \frac{A_B}{a_B\rho_B\delta_B c} I_{B,t} = \frac{A_N}{a_N\rho_N\delta_N c} I_{N,t} \qquad \text{[eq. 6]}$$

Here the subscript *B* refers to the NEFSC fall trawl survey on the R/V Henry Bigelow and the subscript *N* refers to the NEAMAP survey on the F/V Darana R. This equation can be rearranged to put the components of catchability on one side of the equations and the known/measured values on the other side:

$$\frac{A_B}{A_N}\frac{a_N}{a_B}\frac{I_B}{I_N} = \frac{\rho_B}{\rho_N}\frac{\delta_B}{\delta_N} \qquad \text{[eq. 7]}$$

For the NEAMAP survey, which occurs solely during daylight hours, we can set the maximum detectability of butterfish at 1. For the NEFSC survey the maximum bound of detectability is established using Equation 4.

Furthermore we can assume that butterfish available to one survey cannot be simultaneously available to the other survey as there is no spatial overlap among surveys and they sample at the same time. We also know that butterfish occur outside of the footprint of both surveys in areas such as Long Island sound:

$$(\rho_B + \rho_N) < 1 \qquad \text{[eq. 9]}$$

Inclusion of Long Island Sound and Massachusetts survey data

The CT DEP Long Island Sound Survey and Massachusetts state fall trawl surveys occur concurrently with the NEAMAP and the NEFSC trawl survey but do not overlap in space. These two surveys utilize substantially different nets from those used by the NEFSC and NEAMAP surveys. In order to further refine the maximum bounds on the NEFSC Bigelow survey catchability we included these surveys in the analysis. The most conservative approach to including these surveys was to assume 1) that the three inshore surveys (NEAMAP, LIS, Mass) have a detectability of 1.0 and 2) that in aggregate the inshore surveys and the Bigelow survey are sampling the entire area occupied by the butterfish population. With these assumptions it is possible to rewrite equations:

$$B_t = \frac{A_B}{a_B \rho_B \delta_B c} I_{B,t} = \left(\frac{A_N * I_{N,t}}{a_N} + \frac{A_N * I_{M,t}}{a_M} + \frac{A_N * I_{LIS,t}}{a_{LIS}}\right) * \frac{1}{\rho_{inshore} \delta_{inshore} c} \qquad \text{[eq. 10]}$$

Under the most conservative assumptions $\delta_{inshore} = 1$ and $(\rho_{inshore} + \rho_B) = 1$. As with the previous analysis we can calculate a maximum Bigelow availability (ρ_B) for every assumed value of Bigelow detectability (δ_B).

Confidence intervals on the maximum bounds of catchability

Confidence intervals on the catchability estimates were obtained using the rescaling bootstrapping technique outlined in Smith (1997). This approach maintains the random stratified sampling design of the survey in estimating confidence intervals. For our analyses we have six different survey estimates of biomass that contribute to the final estimate of the maximum bounds of catchability: 1) Daytime NEFSC, 2) Nightime NEFSC, 3) NEFSC 24 hour, 4) NEAMAP, 5) Long Island Sound, and 6) Massachusetts state trawl survey. For surveys 3-6 we used the 2009-2012 data when all of the surveys were operating concurrently and the Bigelow net and vessel were in use. We used the 1989-2008 data to obtain the nighttime and daytime catch levels. We calculated a total of 10,000 bootstrap samples for each survey and proceeded through the calculations above for each of these runs.

Bigelow-Albatross calibration

The NEFSC trawl survey underwent a significant change in gear and vessel from 2008 to 2009. The calibration study between these two survey vessels and gears indicated that the R/V H.B. Bigelow was much more efficient (i.e. had a higher detectability) than the net on the Albatross IV. Specifically, the Bigelow net caught 1.808x the butterfish biomass per tow as the Albatross IV net. Additionally, the ratio of the average Bigelow to Albatross swept area per tow is 0.0239 km^2/0 .0382 km^2 = 0.63. Combining these two factors indicates that the detectability per km^2 of the Albatross net is 0.35 that of the Bigelow net. Currently, the standard in most assessments is to continue working in Albatross units. When working with Albatross indices it is necessary to scale down the maximum catchability levels (by 0.35).

RESULTS

Maximum bound on detectability

The median value of daytime and nighttime biomass tow^{-1} of the 10,000 bootstrap samples was 8.36 and 1.92 kg tow^{-1}. In total there were 1639 daytime tows and 1561 nighttime tows in the sampling. The median of the maximum 24-hour detectability value from the bootstrapping was 0.625 (95% CI 0.592-0.668); this estimate assumes a daytime detectability value of 1.0.

Maximum bound on availability using inshore trawl survey data

A comparison of the average 2009-2012 NEFSC and NEAMAP survey indices, area per tow, and survey area covered appear in table 1. These values can be incorporated into Equation 2 yielding for weight/tow:

$$\frac{\rho_B}{\rho_N}\frac{\delta_B}{\delta_N} = \frac{A_B}{A_N}\frac{a_N}{a_B}\frac{I_B}{I_N} = 3.89 \qquad \text{[eq 11]}$$

The purpose of this equation is to establish maximum bounds for the NEFSC fall survey availability and detectability values. We assumed value of 1 for the NEAMAP detectability ($\delta_N = 1$) and also assumed that all of the butterfish are either in the NEAMAP or the NEFSC survey area ($\rho_N+\rho_B=1 \rightarrow \rho_N=1-\rho_B$); these two assumptions are the most conservative possible. Equation 11 can then be rewritten to obtain the maximum bounds on availability to the NEFSC Bigelow survey given any particular value of detectability:

$$\frac{\rho_B}{1-\rho_B} = \frac{3.89}{\delta_B}$$

With this equation simultaneously high detectabilities/availabilities to the NEFSC survey are eliminated from the prior distribution as they would require that the NEAMAP detectability is greater than 1. The Long Island Sound and Massachusetts survey further reduce the calculated availability values for any given detectability of the NEFSC survey.

The most conservative estimate of detectability for the 24 hour NEFSC survey comes from the previous analysis of day:night catch ratios. We can use this value to calculate the most conservative estimate of availability. The median of the maximum availability estimates was 0.83 (95% CI: 0.760-0.878). In turn, the median of the maximum catchability estimate was 0.517 (95% CI: 0.4714-0.5625). The maximum catchability values are further scaled down when working in Albatross units (median 0.1811, 95% CI: 0.1650-0.1969).

Estimates of Minimum bounds on Biomass

We developed two different time series of butterfish biomass based on the calculated catchability values.

Time series 1: The first time series assumes that the **wing swept area** (Fig. 1) is an appropriate measure of the area sampled by the bottom trawl, that detectability of butterfish during the daytime NEFSC survey on the R/V H.B. Bigelow equals 1, and that detectability of the inshore surveys does not exceed 1. We used the median of the maximum catchability value from the analysis and scaled up all Albatross survey indices to Bigelow units. Over the 1989-2012 survey period the average minimum biomass of butterfish on the trawl survey was 116,431 mt during the fall under this set of assumptions. For the 2009-2012 period, which removes any of the uncertainty associated with converting Albatross to Bigelow kg $tow^{-1}$the average minimum biomass was 131,387.

Time series 2: The second time series was calculated using the most conservative numbers and assumptions possible. Instead of using the area swept by the wings we used the larger (2.55x) door swept area. This value assumes that the gear is 100% efficient at herding butterfish into the trawl net across the entire 20 minute tow. We also used the upper limit of the 95% CI from the bootstrapping estimate of catchability. With these two assumptions the median minimum biomass from 1989-2012 was 42,006 mt. For the 2009-2012 period, during which the Bigelow sampled, the value is 47,006 mt.

DISCUSSION

This analysis was designed to provide minimum estimates of butterfish biomass that are consistent with available trawl survey data, and are based on very conservative sets of assumptions concerning the catchability of butterfish. The first assumption is that the NEAMAP, Long Island Sound and Massachusetts state trawl surveys and the NEFSC daytime Bigelow tows all have detectabilities of 1.0. This assumption of equal and high detectability on all of these surveys is necessitated by the absence of paired-gear studies (e.g. Miller 2013) between any of these survey vessels/gear. The results of the Bigelow to Albatross calibration study reveal just how much detectability (i.e. a 3x difference) can vary among survey gears and vessels. Scaling down the detectability of any one of these surveys to values <1 in the analysis would decrease the maximum Bigelow catchability and scale up the biomass estimates. The second assumption of the analysis is that fish do not occur outside of the composite NEFSC, NEAMAP, Massachusetts, Long Island Sound survey area during the fall survey period. Fish outside these survey areas would also scale up the butterfish biomass estimates.

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App. A3 Table 1. Values for the various surveys used in the analysis of catchabilities. All area measurements are in km^2.

	NEFSC		NEAMAP		LIS		MASS	
A_s	147,297 [1]		12,097		3,400		6,285	
a_s	0.024 [2]		0.024		0.0259 [4]		0.013	
	Weight	**Number**	**Weight**	**Number**	**Weight**	**Number**	**Weight**	**Number**
I_{2009}	11.68	360.08	45.8	3,633.8	33.9	1,223.4	5.7	977.62
I_{2010}	9.96	245.64	34.5	1,074.8			3.0	129.26
I_{2011}	17.12	496.66	36.1	1,662.9	9.3	393.7	9.5	833.27
I_{2012}	6.31	129.70	24.2	635.7	15.27	569.4	9.5	587.53
Mean	**11.3**	**308.0**	**35.2**	**1751.8**	**19.5**	**728.8**	**6.9**	**631.9**

[1] NEFSC survey strata same as used in the 2009 assessment (offshore: 1-14, 16 19, 20, 23, 25, 61-76; inshore 1-92); Area surveyed 2012-2009 is 42945 nmi^2

[2] converted from reported swept areas of .007 nmi^2

[3] Arithmetic means used for all surveys. Geometric means, reported in many documents, are not suitable for these calculations

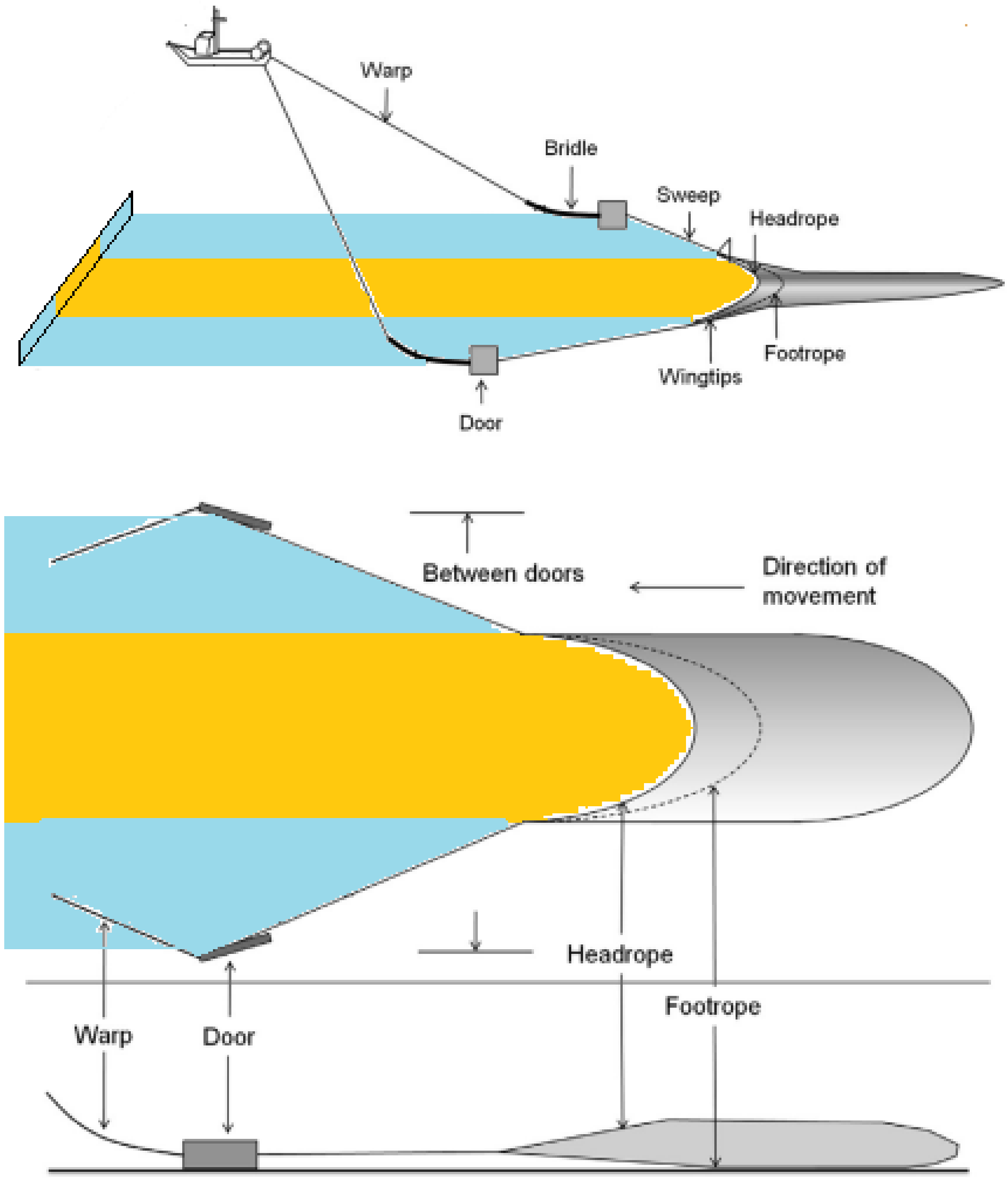
[4] Used 30 minute tow at 3.5 knots with a wing spread of 8 meters (26.24 ft).

[5]LIS Survey not complete for 2010

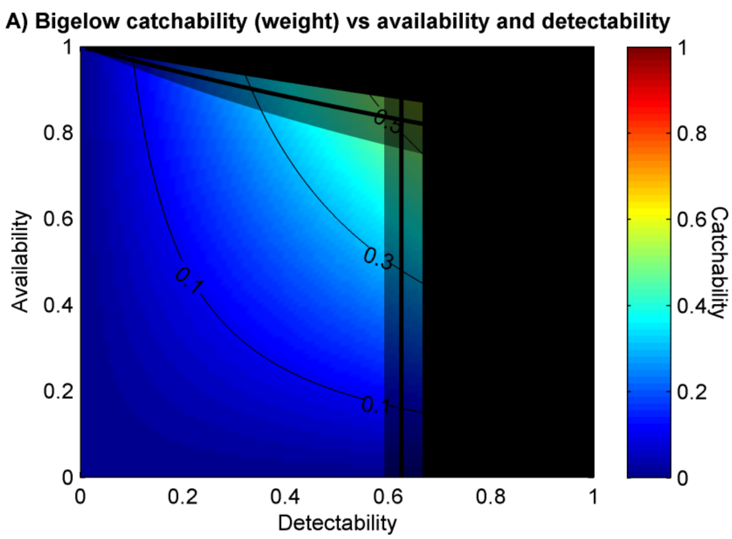
App. A3 Table 2: Estimates of the minimum bounds on total butterfish biomass during the fall survey period. The total biomass estimates using the door swept area assumes complete herding of butterfish into the trawl net, and also includes the upper 95% CI on catchability. The total biomass estimate using the wing swep area assumes a detectability of 1 across the area of the net capable of catching butterfish.

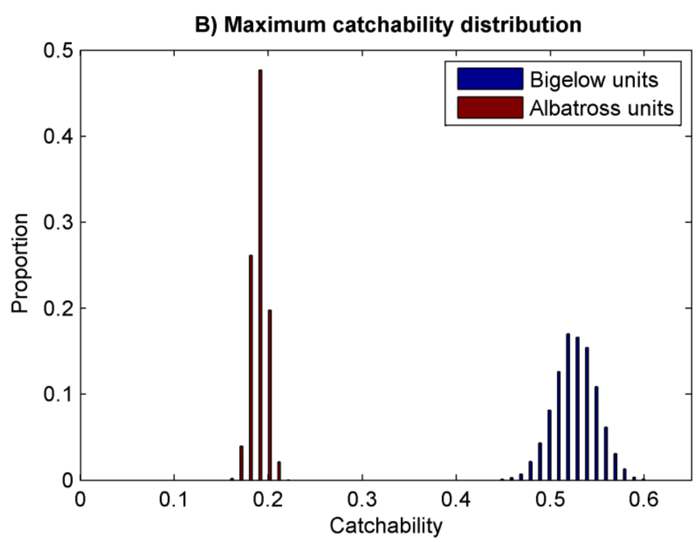
Year	Weight Tow^{-1} Alb IV[1]	Weight Tow^{-1} Bigelow	Total Biomass Fall metric ton-Doors	Total Biomass Fall metric ton Wings
1989	12	21.7	92,832	257,307
1990	8.74	15.8	67,613	187,405
1991	5.15	9.3	39,841	110,428
1992	4.38	7.9	33,884	93,917
1993	9.63	17.4	74,498	206,489
1994	12.51	22.6	96,778	268,243
1995	5.45	9.9	42,161	116,860
1996	2.65	4.8	20,500	56,822
1997	4.38	7.9	33,884	93,917
1998	6.34	11.5	49,046	135,944
1999	4.83	8.7	37,365	103,566
2000	7.09	12.8	54,848	152,026
2001	3.05	5.5	23,595	65,399
2002	2.4	4.3	18,566	51,461
2003	3.96	7.2	30,635	84,911
2004	3.02	5.5	23,363	64,756
2005	1.16	2.1	8,974	24,873
2006	4.87	8.8	37,674	104,424
2007	1.5	2.7	11,604	32,163
2008	2.7	4.9	20,887	57,894
2009	6.32	11.4	48,892	135,515
2010	5.59	10.1	43,244	119,862
2011	9.12	16.5	70,553	195,553
2012	3.48	6.3	26,921	74,619
Average	**5.4**	**9.8**	**42,007**	**116,432**

App. A3 Fig. 1. Diagram of bottom trawl gear. The area in orange corresponds to the wing swept area typically used as a measure of the area sampled by the bottom trawl gear. The door swept area also includes the area in blue. The use of door swept areas assumes that the sampled fish are herded by the sweep and doors into the area in front of the mouth of the net before eventually falling back into the net cod end.

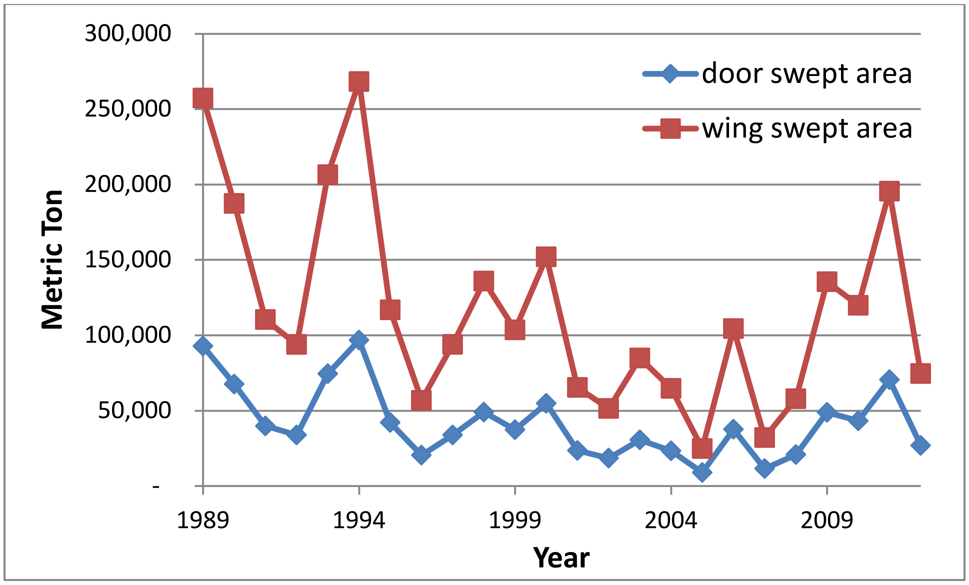


App. A3 Fig. 2. A) Plot of catchability different values of availability and detectability. The black shaded areas correspond to catchability values for the 24-hour Bigelow survey that are not possible given the analyses presented in this paper. Restrictions on detectability are due to the day:night analyses while restrictions on availability are due to the analyses of inshore survey data. The black lines are the median estimates of the maximum bounds on catchability and the shaded areas correspond to the 95% confidence intervals of these maximum bounds. B) Distribution of the maximum catchability estimates in Bigelow and Albatross units using 10,000 bootstrap runs.





App. A3 Figure 3. Time series of the minimum biomass estimates assuming that either the wings (red) or the doors (blues) are the appropriate measure of the area sampled by the trawl net.



Butterfish Appendix A4. Results, reference points and projections for the final model accepted by SARC 58

During the course of SAW 58 the review panel asked for several changes: 1) revised reference point calculations in AGEPRO for the ASAP3 and M+H+C base models using the preliminary catch for 2013 (2,489 mt) and the 2014 ABC (9,100 mt) as inputs for Harvest Scenario in 2013 and 2014, respectively; 2) opposing trends in spring vs. fall survey indices led to a request for two new models using the spring only and fall only survey data; and 3) an additional run of the fall only survey data without the time varying thermal habitat index (HSI). The panel concluded that the fall index model was appropriate and the annual HSI covariate did not improve the model. Consequently the most parsimonious configuration using only the fall survey indices without the time varying HSI was adopted as the final model. **The remainder of this appendix describes the results, reference points and projections for the final model accepted by SARC 58.** Comparisons with the M+H+C base model are provided in diagnostics, sensitivities, and projections.

Diagnostics for the final model

Objective function components for the final model are shown in Table 1. Root MSE for data components for the final model are generally closer to 1 than those for the M+H+C base model (App. A4 Table 2).

No trends are apparent in the residuals for catch (Figure 1), the NEFSC surveys (Figures 2 and 3), or the NEAMAP survey App 4. (App. A4 Figure 4). Similarly, no trends are apparent in the residuals for catch age composition (App. A4 Figure 5), NEFSC survey age compositions (App. A4 Figures 6 and 7), or NEAMAP survey age composition (App. A4 Figure 8).

Results for the final model

The peak in fishing mortality rate on fully selected ages (ages 2+) was F = 0.15, which occurred in 1993 (App. A4 Tables 3 and 4; Figure 9). Fishing mortality ranged between 0.04 and 0.14 during 1994-2001, but has been ≤ 0.07 since 2002. Butterfish are fully selected by age 2 in the fishery (App. A4 Figure 10). The model also provided a new estimate of natural mortality equal to 1.22.

Spawning stock biomass (Age 1+) averaged 79,410 mt (175.1 million lb) during 1989-2012 (App. A4 Table 3; Figures 11 – 14). Spawning stock biomass peaked in 2000 at 106,590 mt (235.0 million lb).

Recruitment averaged 8.5 billion fish during 1989-2012 (Table 3; Figures 13 – 15). The 1997 year class was the largest, at 14.8 billion fish, while the 2012 year class, estimated to be 2.4 billion fish, was the smallest of the time series. Estimated numbers at age are shown in App. A4 Table 5 and App A4 Figure 16.

CVs for SSB and recruitment were ≤ 0.33 (App. A4 Table 3; Figure 17), while CVs for F were variable, ranging from 0.22 to 1.00.

Index catchabilities and selectivities are shown in App. A4 Figures 18 and 19, respectively.

Sensitivities

Annual estimates of spawning biomass were higher with the final model, with the exception of 2011 and 2012 (App. A4 Figure 20). Recruitment was generally comparable between the two models, although from 2010 forward estimates from the final model were lower. Estimated fishing mortality was lower throughout the times series with the final model.

Retrospective patterns for the final model

A retrospective analysis of the final model using a four year peel was done by for spawning biomass, recruitment and fishing mortality estimates. There was no trend in terminal year estimates of SSB, recruitment and fishing mortality (App A4 Figure 21). Furthermore, the scale of the differences is relatively small based on calculated Mohn's rho values.

SARC 58 biological reference points based on the final model

The accepted overfishing reference point is F = 2M/3 = 2 ×1.22/3 = 0.81; CV = 0.05. The current fishing mortality (F_{2012} = 0.02, CV = 0.33) is well below the accepted overfishing reference point (App. A4 Figure 22). The accepted biomass reference point SSB_{MSY} proxy (median SSB based on a 50 year projection at F_{MSY}) is 45,616 mt (100.6 million lb); CV = 0.25. SSB_{2012} is estimated to be 79,451 mt (175.2 million lb), which is well above the accepted SSB_{MSY} proxy (App. A4 Figure 23). The accepted MSY proxy is 36,199 mt (79.8 million lb); CV = 0.20. $SSB_{threshold}$ is one half the SSB_{MSY} proxy, or 22,808 mt (50.3 million lb). Overfishing is not occurring and the stock is not overfished.

Stock status

Fishing mortality was estimated to be 0.02 in 2012, which is well below the accepted overfishing reference point F_{MSY} proxy = 0.81 (App. A4 Figure 23). There is a < 1% chance the estimated fishing mortality is above the F_{MSY} proxy (App. A4 Figure 24), therefore overfishing is not occurring.

SSB_{2012} was estimated to be 79,451 mt (175.2 million lb), which is well above the accepted biomass reference point SSB_{MSY} proxy = 45,616 mt (100.6 million lb). The stock is not overfished and there is a < 1% chance the estimated SSB is below $SSB_{threshold}$ (App. A4 Figure 25).

Projections

Stochastic projections were made to provide forecasts of stock size and catches in 2013-2014 with the same methodology described in TOR 8, albeit with the catch described below for 2013 and 2014, and the accepted SARC 58 reference point F_{MSY} proxy = 0.81 (App. A4 Table 6) for 2015 and beyond.

If preliminary butterfish catch (landings plus discards) for 2013 (2,489 mt; 5.5 million lb) is used, the median projection of SSB in 2013 is 51,746 mt (114.1 million lb), with 5% and 95% confidence limits of 32,489 mt (71.6 million lb) and 81,073 mt (178.7 million lb), respectively (App. A4 Figure 26). Because the catch is fixed at 2,489 mt, the median projected total catch is

2,489 mt, with 5% and 95% confidence limits of 2,489 mt and 2,489 mt, respectively (App. A4 Figure 27).

If the 2014 butterfish ABC (9,100 mt; 20.1 million lb) is assumed for 2014 catch, the median projection of SSB in 2014 is 53,580 mt (118.1 million lb), with 5% and 95% confidence limits of 38,365 mt (84.6 million lb) and 73,885 mt (162.9 million lb), respectively (App. A4 Figure 26). Because the catch is fixed at 9,100 mt, the median projected total catch is 9,100 mt, with 5% and 95% confidence limits of 9,100 mt and 9,100 mt, respectively (App. A4 Figure 27).

App. A4 Table 1. Objective function components for the final model.

Objective Function Components	Final
Aggregate catch	189.851
Aggregate survey indices	659.819
Catch age composition	180.909
Survey age composition	161.395
Relative catch efficiency penalty	-5.7373
Total	1186.24

App. 4 Table 2. Root MSE for data components from the base and final models.

Data	Base	Final
Aggregate catch	0.12	0.07
Aggregate survey indices	1.28	1.15
NEFSC spring offshore indices	1.1	NA
NEFSC fall offshore indices	1.36	0.98
NEFSC fall inshore indices	1.32	1.35
NEAMAP spring indices	1.55	NA
NEAMAP fall indices	1.25	1.00

App A4. Table 3. Annual estimates of spawning biomass (mt), recruitment (millions), fully selected fishing mortality (age 2+), and respective coefficients of variation (CV) from the final model.

Year	Spawning Biomass	CV	Recruitment	CV	Full F	CV
1989	62,910	0.31	8,196	0.28	0.13	0.56
1990	89,052	0.27	9,030	0.24	0.03	0.29
1991	76,674	0.23	7,573	0.23	0.11	0.72
1992	77,013	0.21	7,175	0.21	0.10	0.41
1993	78,509	0.19	10,438	0.21	0.15	0.28
1994	69,763	0.19	11,587	0.20	0.14	0.33
1995	78,885	0.18	5,000	0.24	0.11	0.40
1996	75,485	0.19	9,403	0.22	0.06	0.26
1997	94,390	0.19	14,836	0.17	0.04	0.31
1998	103,490	0.16	8,873	0.23	0.08	1.00
1999	90,151	0.18	13,628	0.22	0.12	0.35
2000	106,590	0.18	10,586	0.22	0.09	0.28
2001	100,740	0.19	7,934	0.22	0.09	0.34
2002	85,021	0.19	8,044	0.21	0.04	0.78
2003	80,428	0.19	9,135	0.19	0.03	0.88
2004	85,343	0.17	5,126	0.22	0.02	0.28
2005	56,055	0.18	7,581	0.18	0.02	0.22
2006	67,460	0.17	7,397	0.20	0.02	0.45
2007	79,627	0.17	5,691	0.19	0.01	0.24
2008	62,643	0.18	7,595	0.19	0.02	0.47
2009	57,039	0.18	11,113	0.22	0.02	0.29
2010	77,877	0.20	6,546	0.24	0.07	0.36
2011	71,239	0.23	9,483	0.26	0.03	0.26
2012	79,451	0.25	2,432	0.33	0.02	0.33

App. A4 Table 4. Estimated fishing mortality age from the final model.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0.005	0.040	0.132	0.132	0.132
1990	0.001	0.010	0.032	0.032	0.032
1991	0.004	0.032	0.107	0.107	0.107
1992	0.004	0.031	0.102	0.102	0.102
1993	0.005	0.045	0.150	0.150	0.150
1994	0.005	0.043	0.143	0.143	0.143
1995	0.004	0.033	0.109	0.109	0.109
1996	0.002	0.017	0.057	0.057	0.057
1997	0.002	0.013	0.044	0.044	0.044
1998	0.003	0.024	0.078	0.078	0.078
1999	0.004	0.035	0.116	0.116	0.116
2000	0.003	0.026	0.088	0.088	0.088
2001	0.003	0.027	0.091	0.091	0.091
2002	0.001	0.011	0.037	0.037	0.037
2003	0.001	0.009	0.030	0.030	0.030
2004	0.001	0.007	0.022	0.022	0.022
2005	0.001	0.005	0.017	0.017	0.017
2006	0.001	0.006	0.022	0.022	0.022
2007	0.000	0.004	0.012	0.012	0.012
2008	0.001	0.007	0.024	0.024	0.024
2009	0.001	0.007	0.025	0.025	0.025
2010	0.002	0.020	0.067	0.067	0.067
2011	0.001	0.009	0.031	0.031	0.031
2012	0.001	0.007	0.024	0.024	0.024

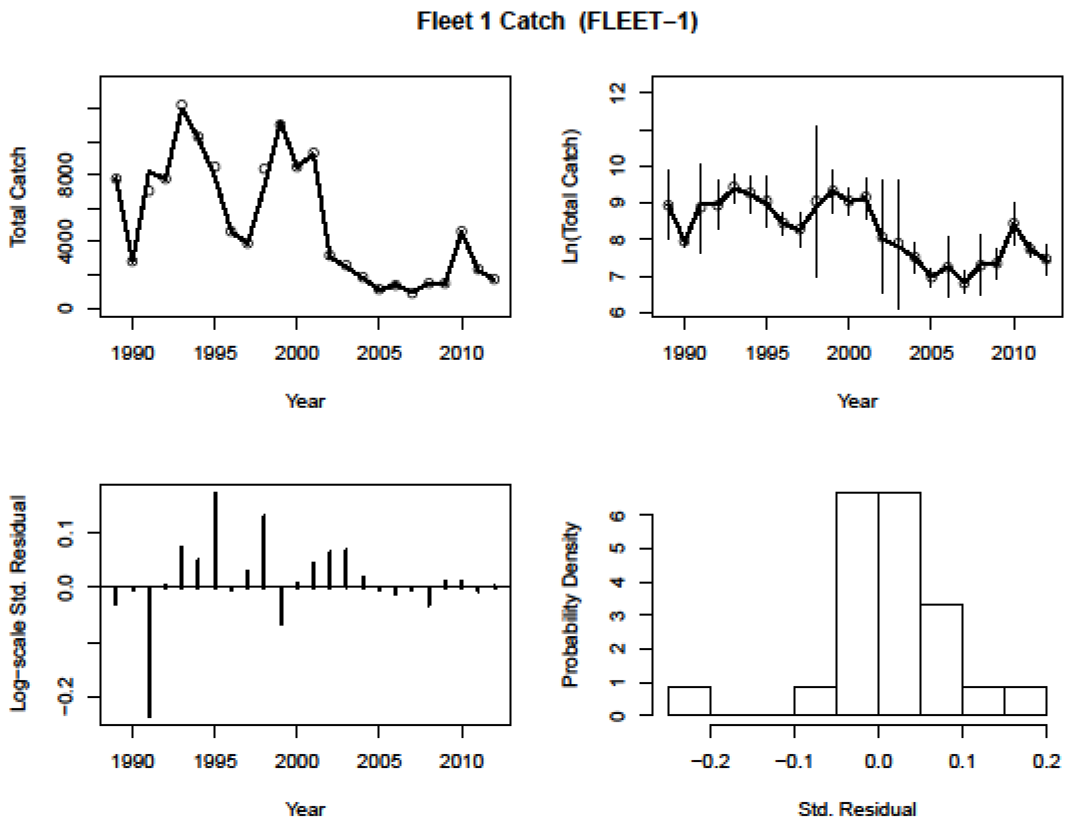
App. A4 Table 5. Estimated numbers at age (millions) on January 1 from the final model.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	8,196	2,784	742	217	15
1990	9,030	2,397	786	191	60
1991	7,573	2,650	698	224	71
1992	7,175	2,217	754	184	78
1993	10,438	2,101	632	200	70
1994	11,587	3,051	590	160	68
1995	5,000	3,387	859	150	58
1996	9,403	1,463	963	226	55
1997	14,836	2,757	423	267	78
1998	8,873	4,352	799	119	97
1999	13,628	2,600	1,249	217	59
2000	10,586	3,988	738	327	72
2001	7,933	3,101	1,141	199	107
2002	8,044	2,324	886	306	82
2003	9,135	2,361	675	251	110
2004	5,126	2,681	687	192	103
2005	7,581	1,505	783	197	85
2006	7,397	2,226	440	226	82
2007	5,691	2,172	650	127	88
2008	7,595	1,672	636	189	62
2009	11,113	2,230	488	182	72
2010	6,546	3,263	650	140	73
2011	9,483	1,919	940	179	58
2012	2,432	2,783	559	268	68

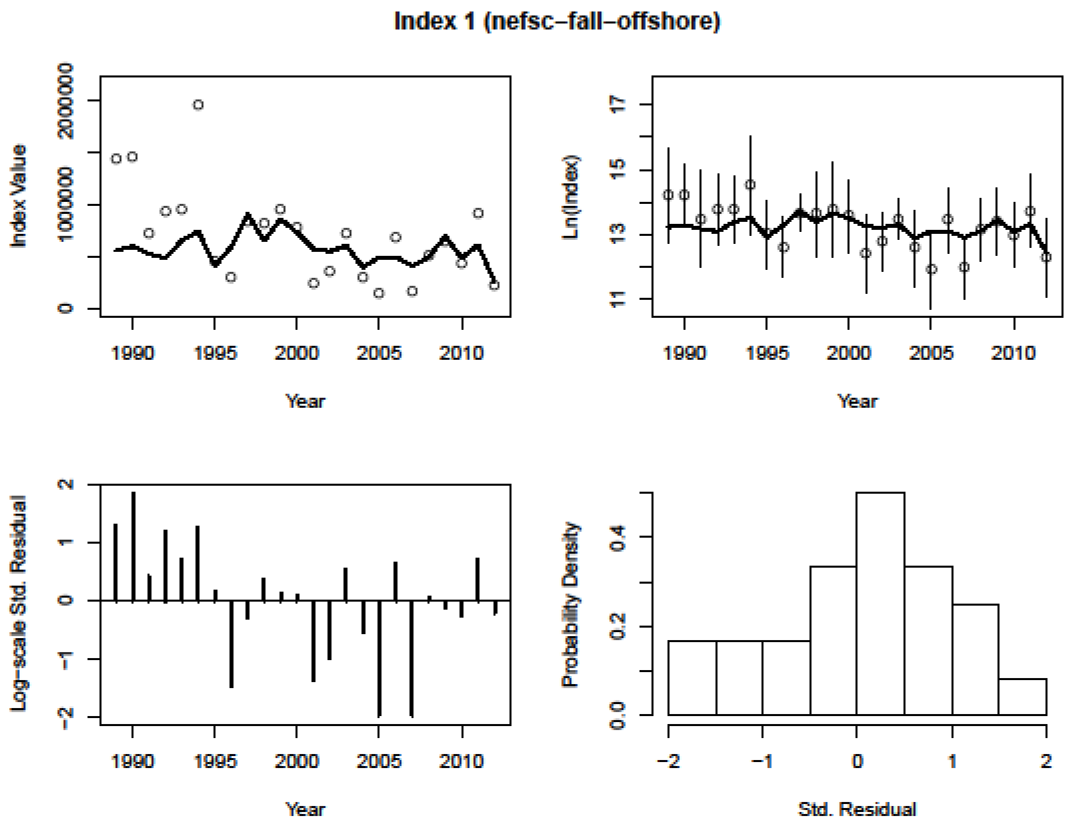
App. A4 Table 6. Accepted biological reference point for F_{MSY} and SSB_{MSY}, with 95% confidence interval, from the final model.

	Confidence Interval	
SSB_{MSY}	Lower	Upper
45,616	29,726	67,373

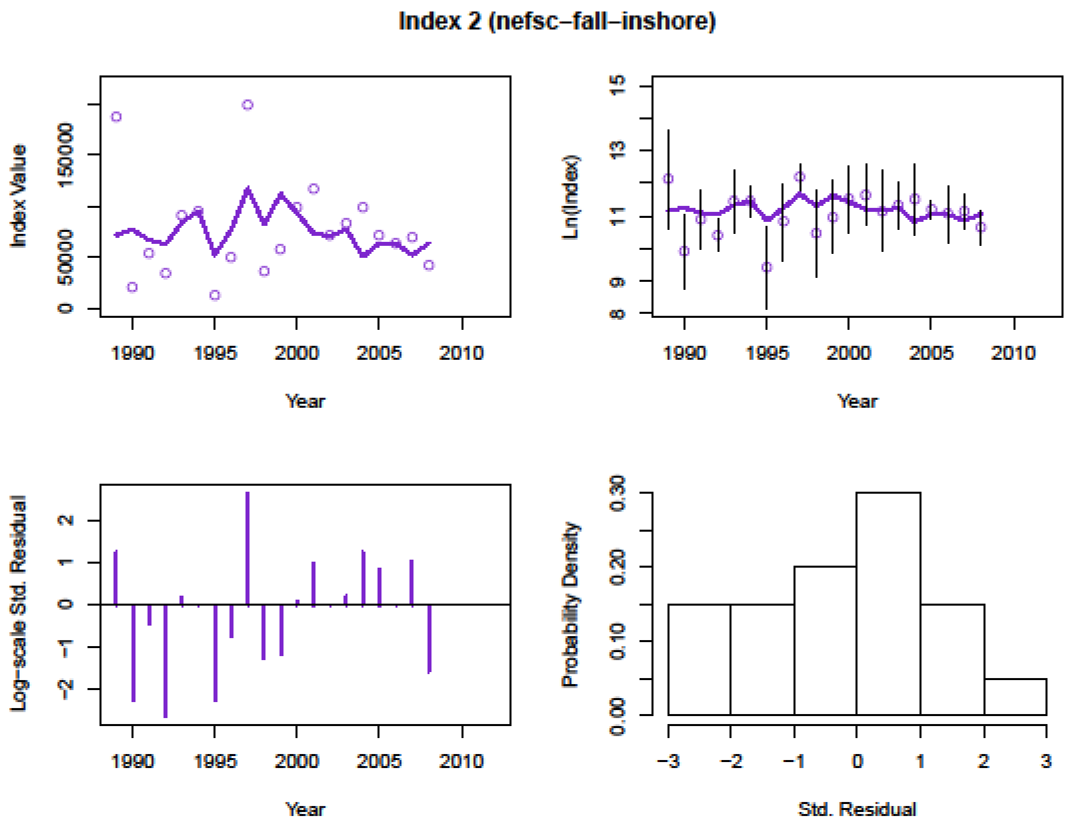
F_{MSY}	CV
0.81	0.05



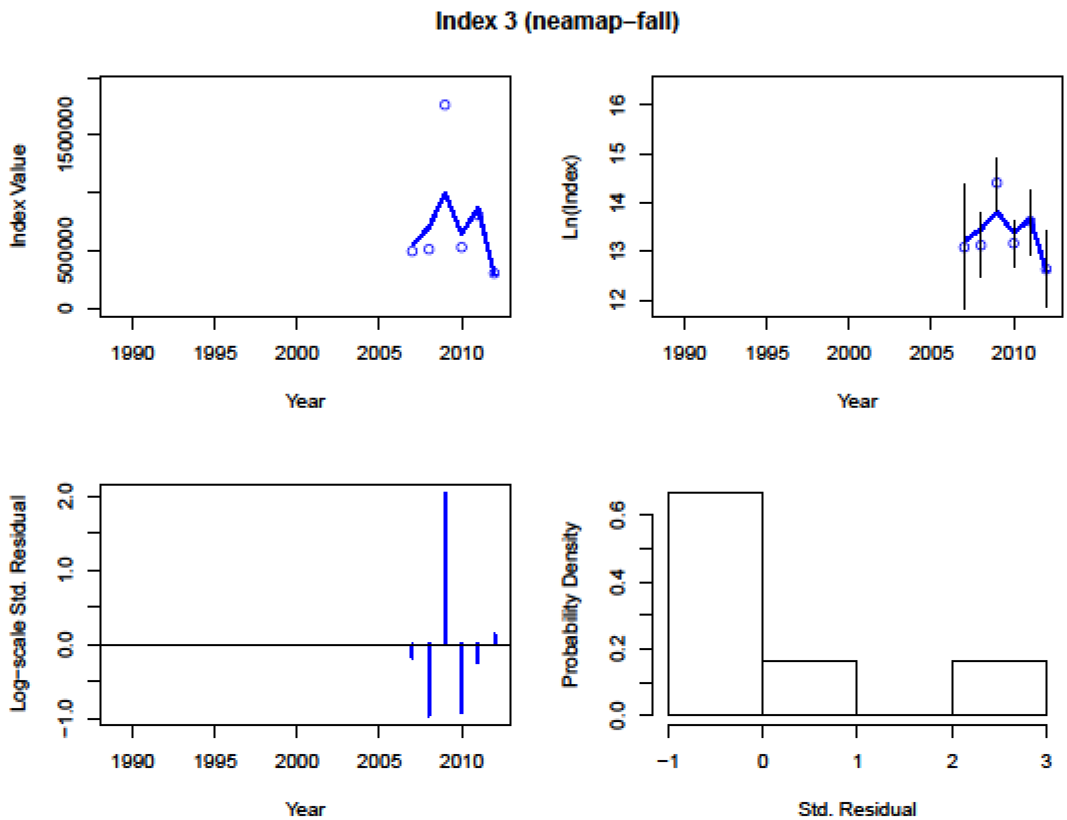
App. A4 Figure 1. Diagnostics for aggregate catch from the final model.



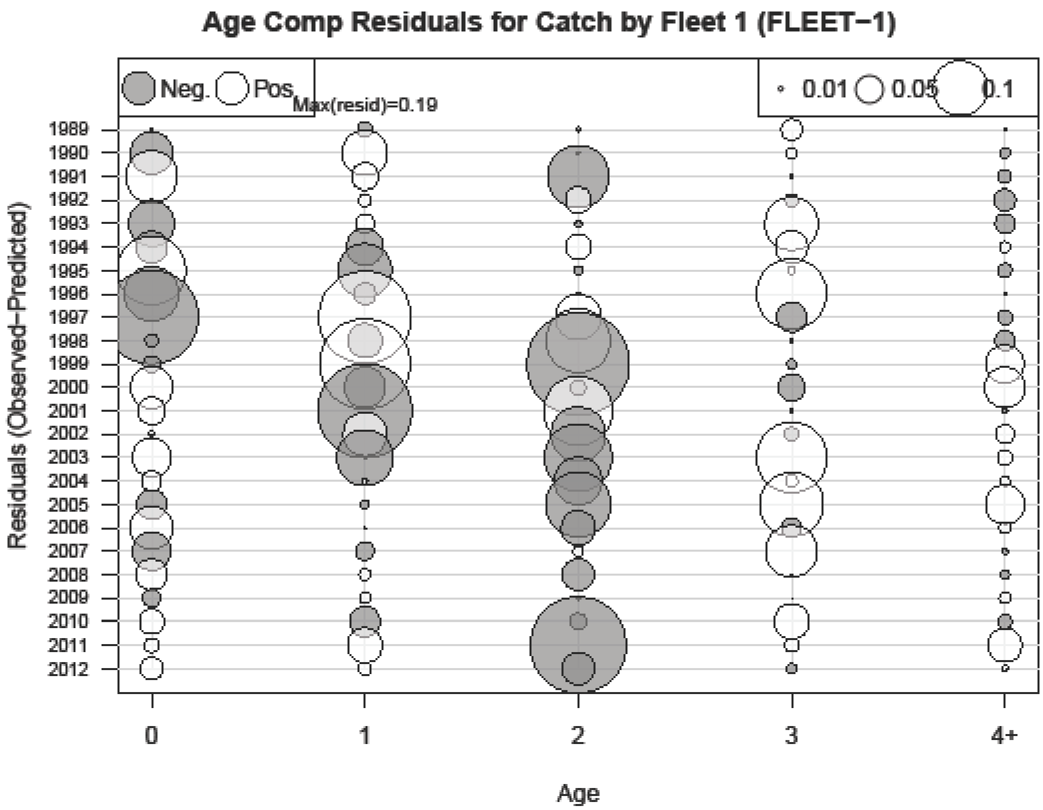
App. A4 Figure 2. Diagnostics for the NEFSC fall offshore survey from the final model.



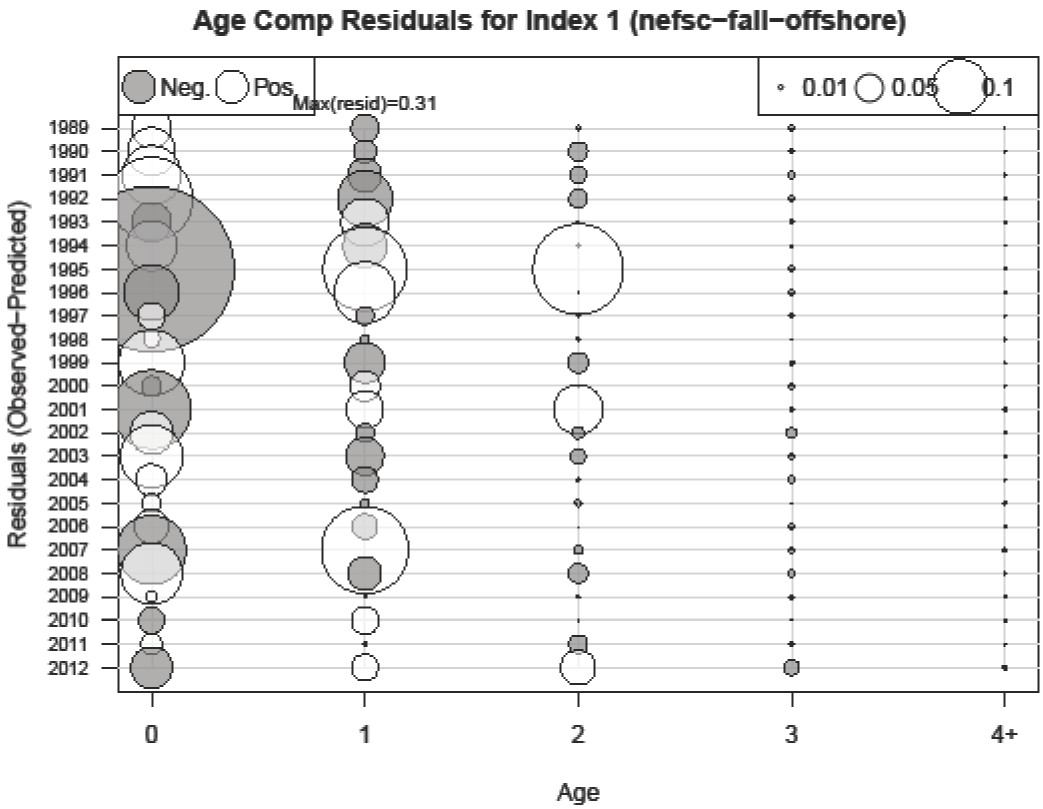
App. A4 Figure 3. Diagnostics for the NEFSC fall inshore survey from the final model.



App. A4 Figure 4. Diagnostics for the NEAMAP fall survey from the final model.

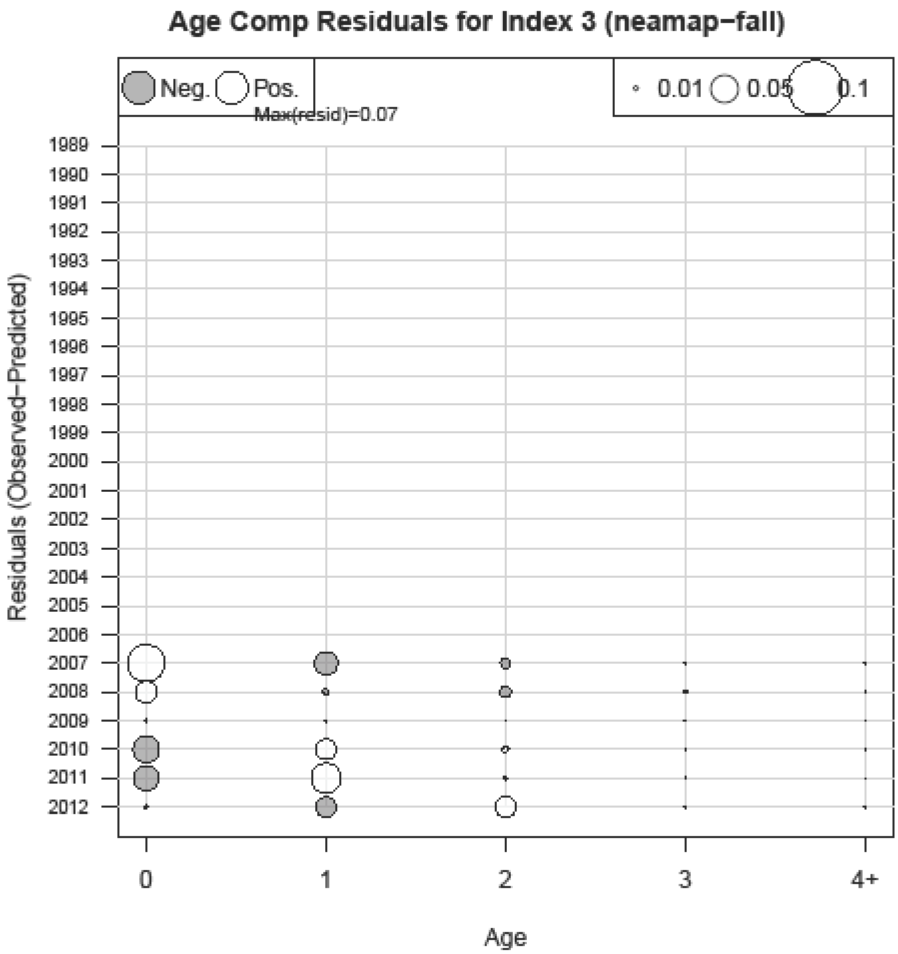


App. A4 Figure 5. Residuals for catch age composition from the final model.

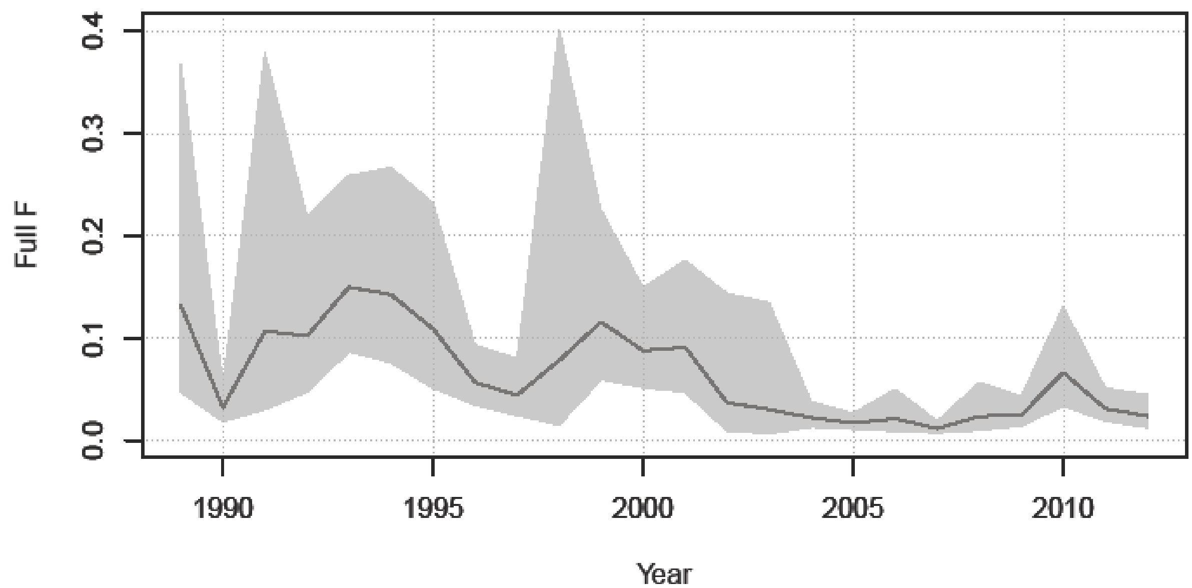


App. A4 Figure 6. Residuals for NEFSC fall offshore age composition from the final model.

App A4. Figure 7. Residuals for NEFSC fall inshore age composition from the final model.

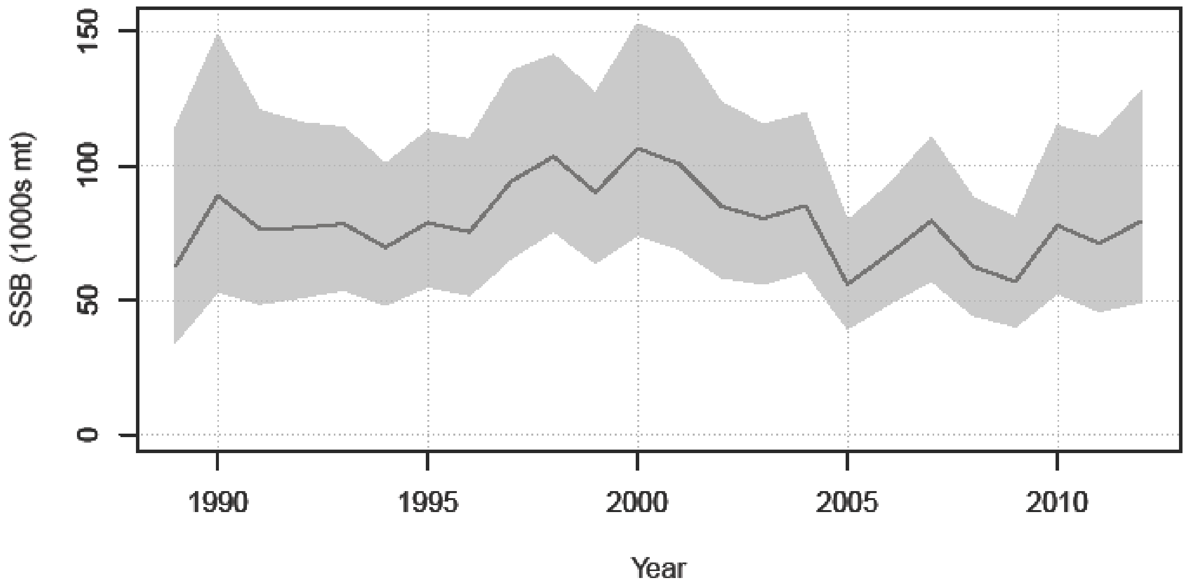


App. A4 Figure 8. Residuals for NEAMAP fall age composition from the final model

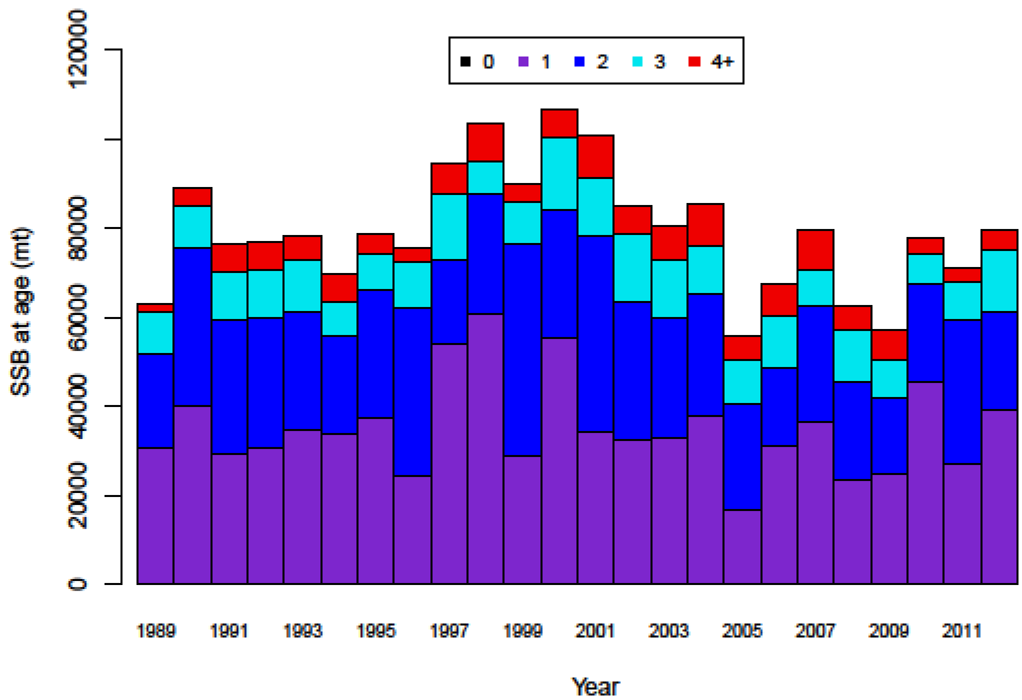


App.A4 Figure 9. Estimated fully selected fishing mortality rate and 95% confidence interval from the final model.

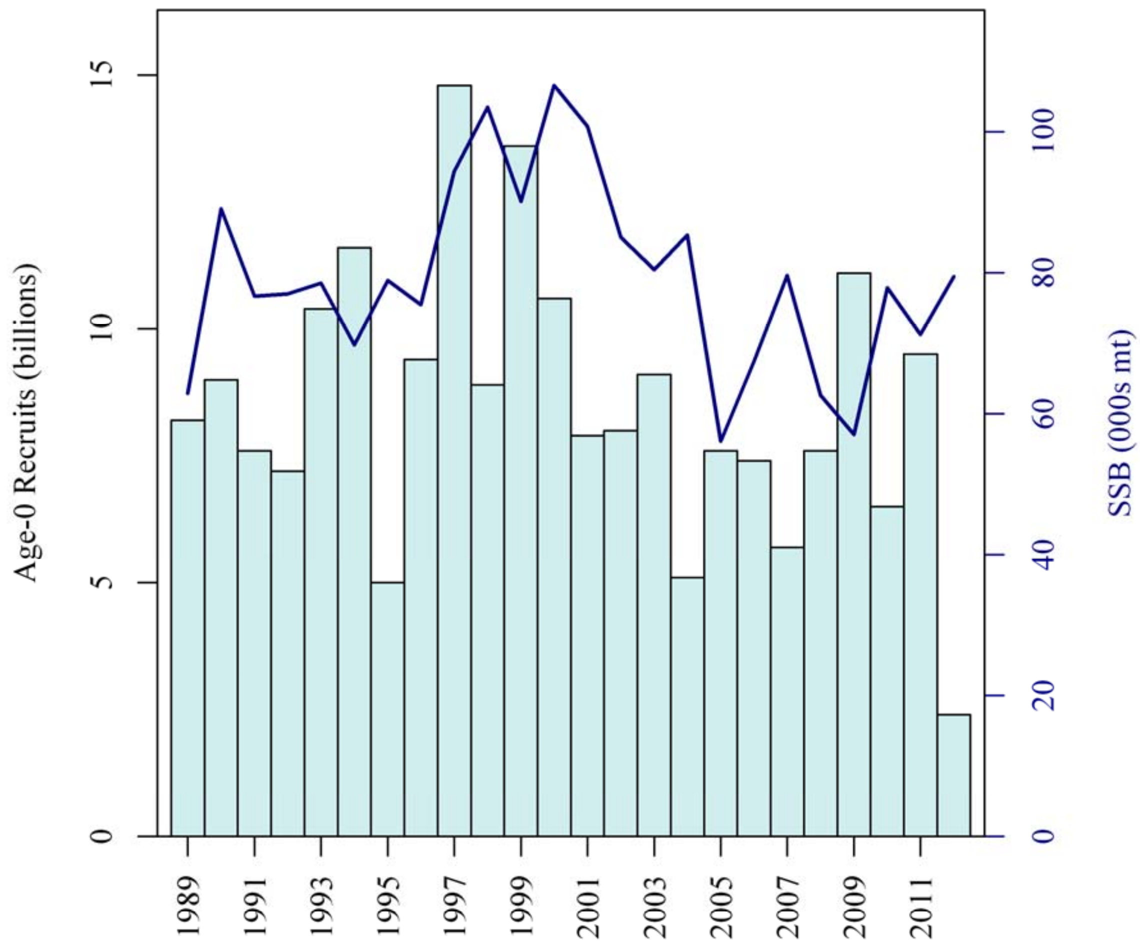
App. A4 Figure 10. Fleet selectivity at age from the final model.



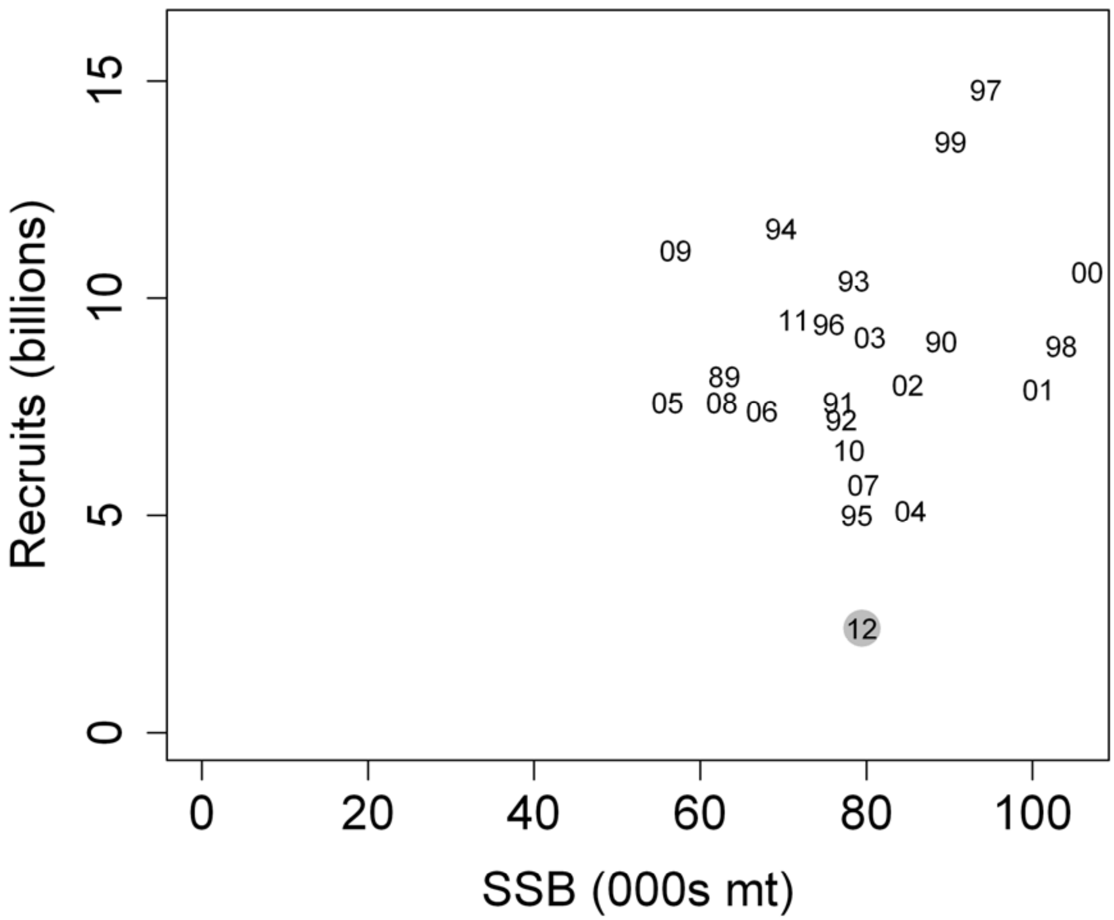
App. A4 Figure 11. Estimated spawning biomass and 95% confidence interval from the final model.



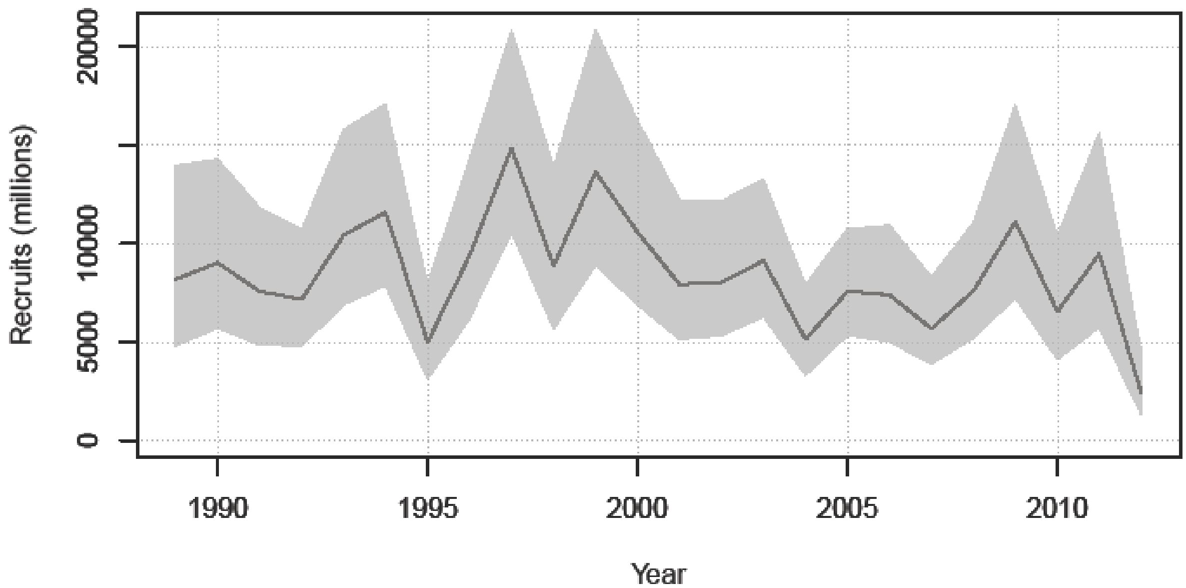
App. A4 Figure 12. Estimated annual spawning biomass at age from the final model.



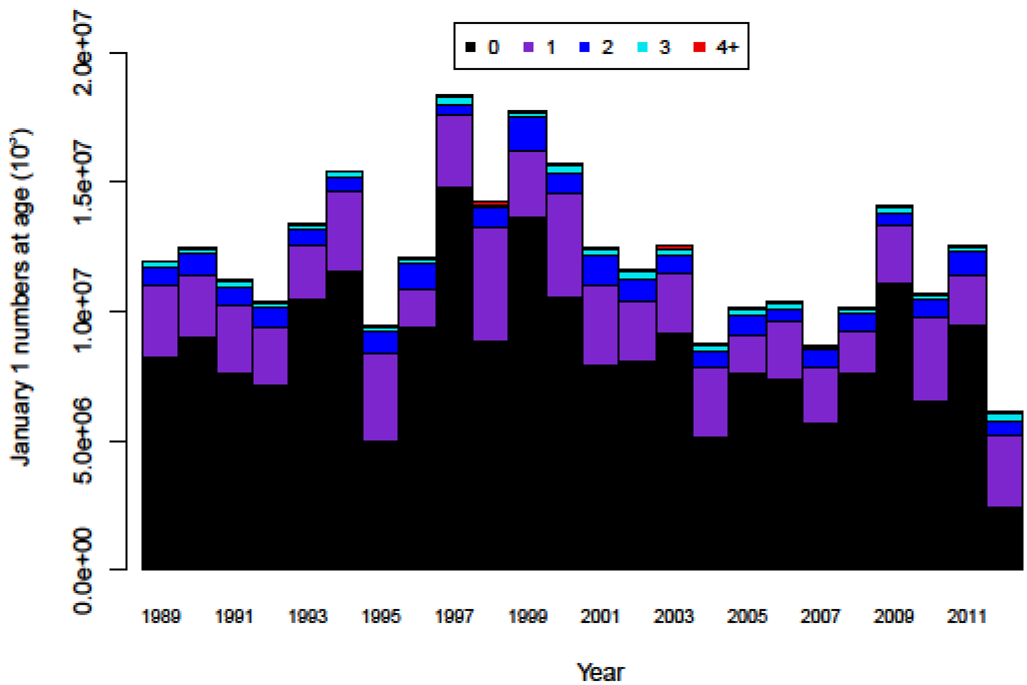
App. A4 Figure 13. Butterfish recruitment (vertical bars), and the spawning stock biomass (blue line) that produced the corresponding recruitment. Year refers to spawning year.



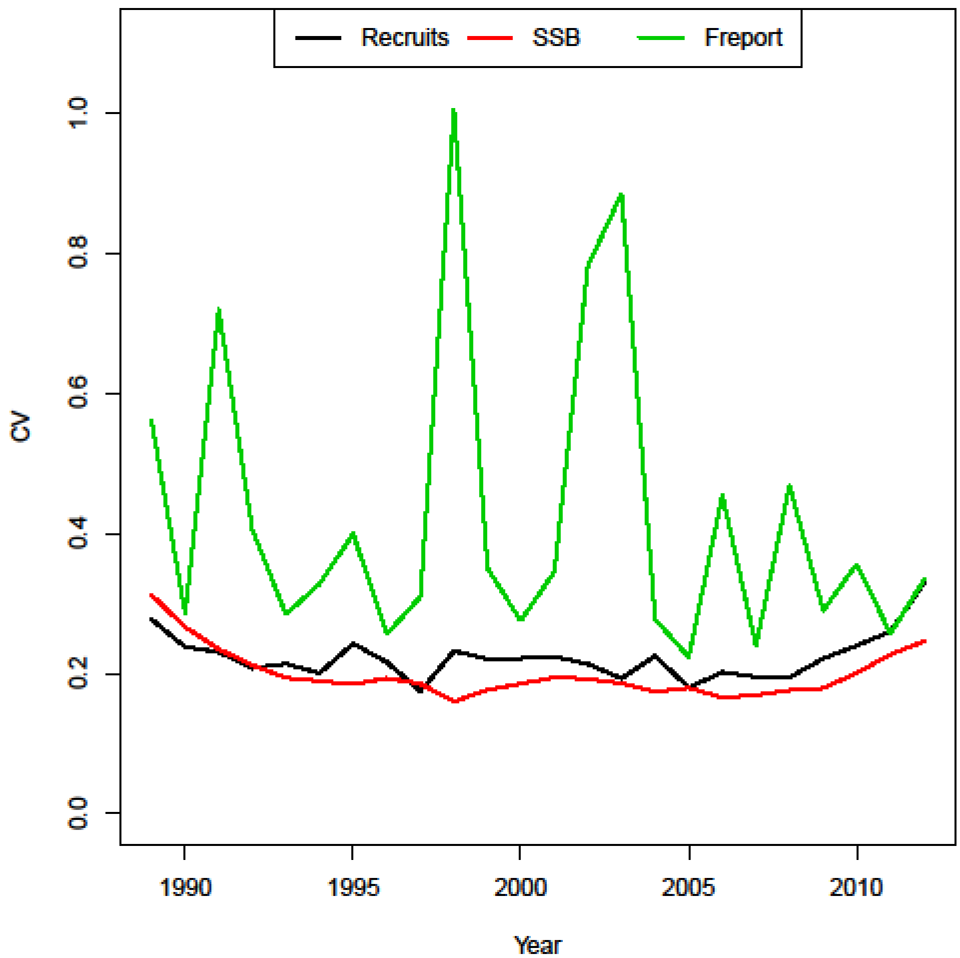
App. A4 Figure 14. Butterfish stock-recruitment scatter plot, with two digit indicator of model year.



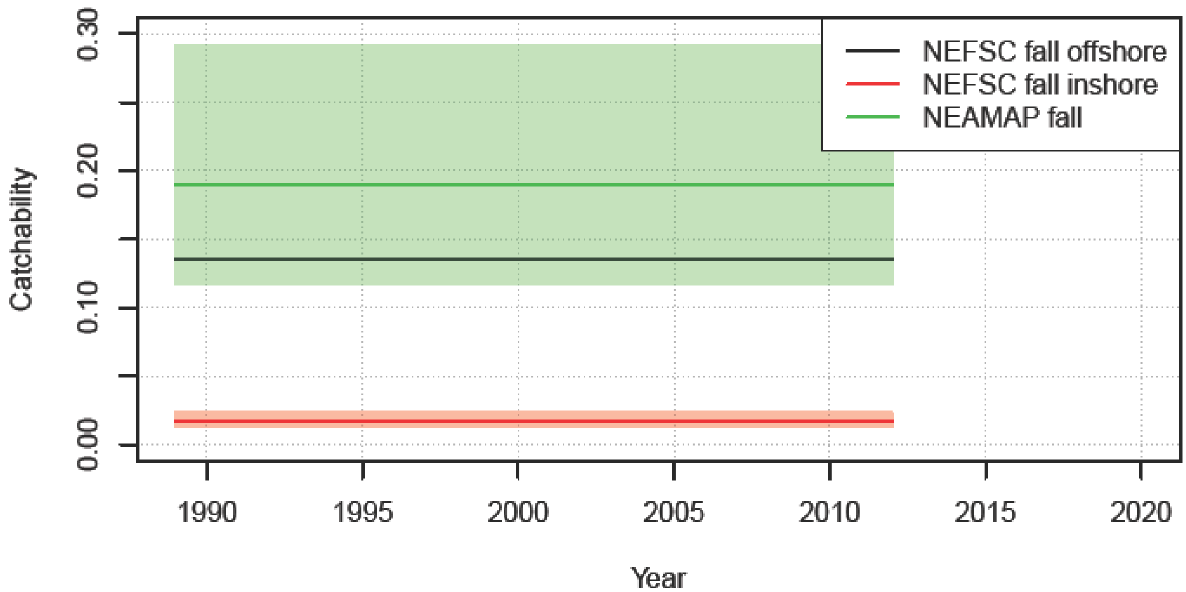
App. A4 Figure 15. Estimated recruitment and 95% confidence interval from the final model.



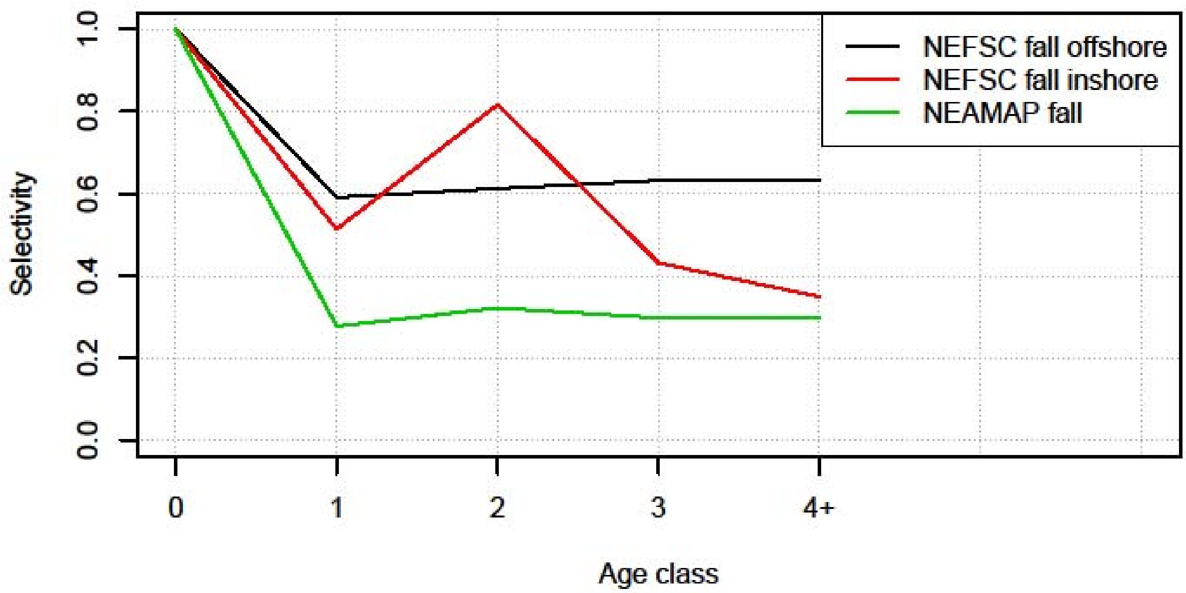
App. A4 Figure 16. Estimated numbers at age on January 1 from the final model.



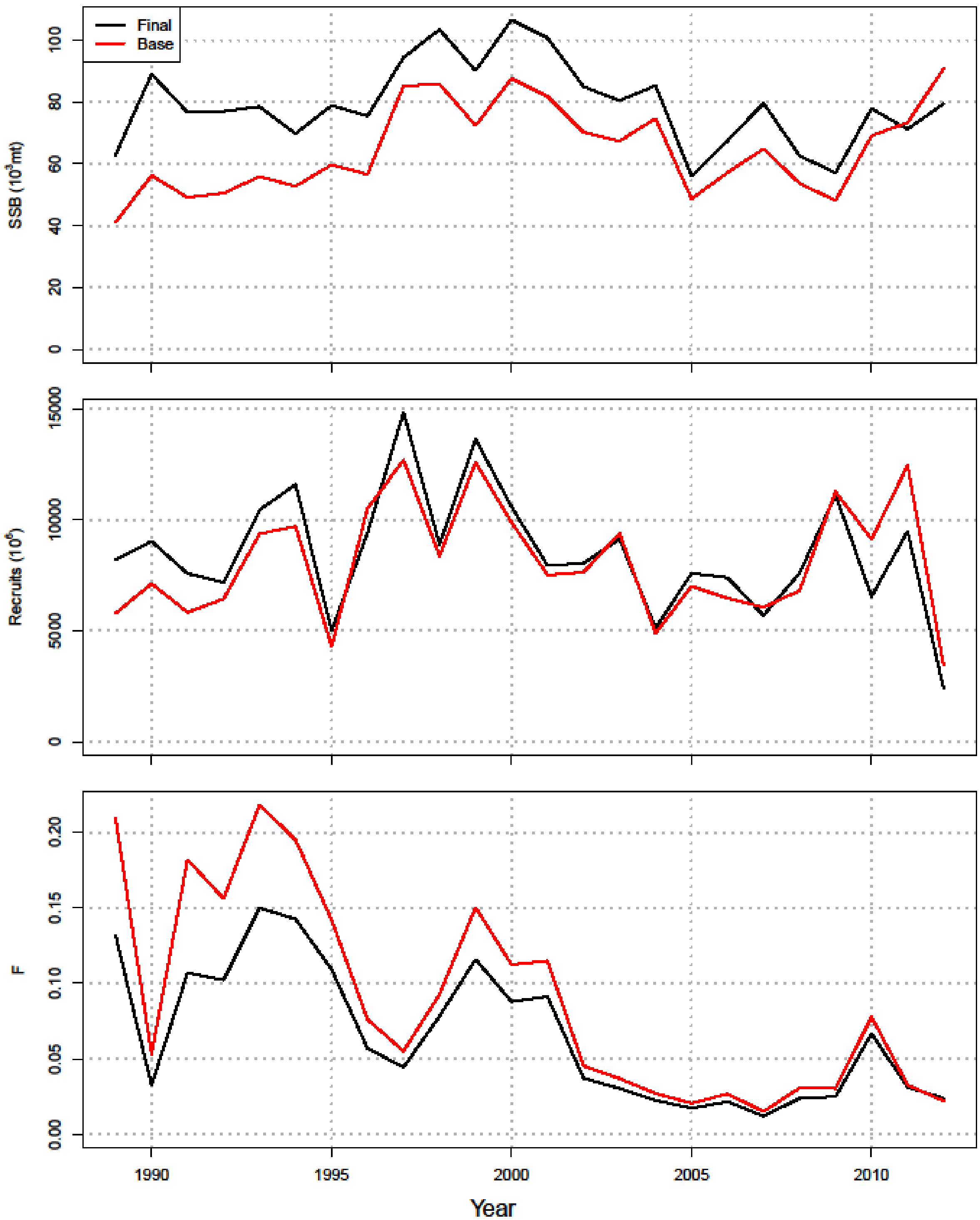
App. A4 Figure 17. Coefficients of variation for estimates of SSB, recruits and fully selected fishing mortality from the final model.



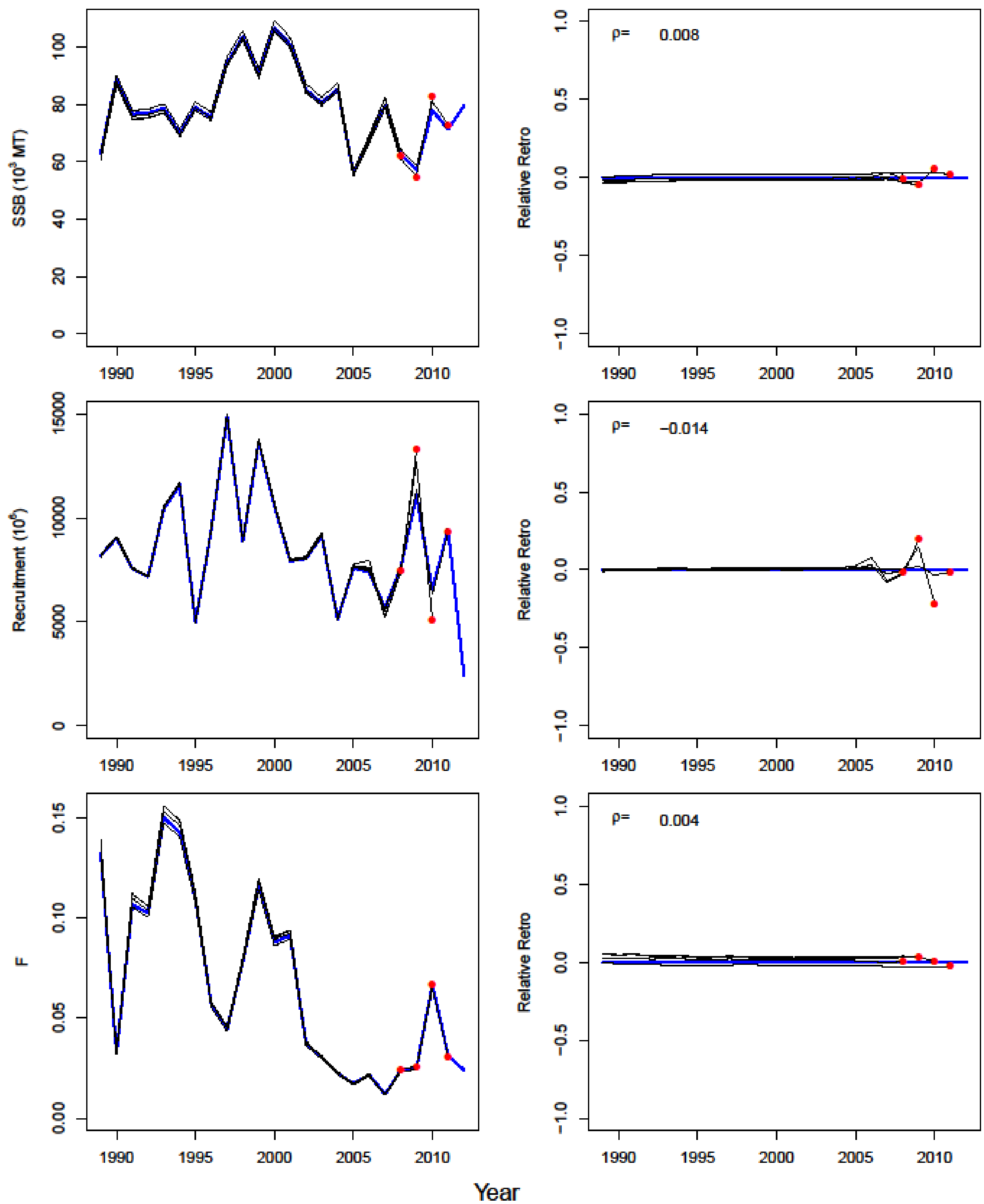
App. A4 Figure 18. Index catchability and 95% confidence interval from the final model.



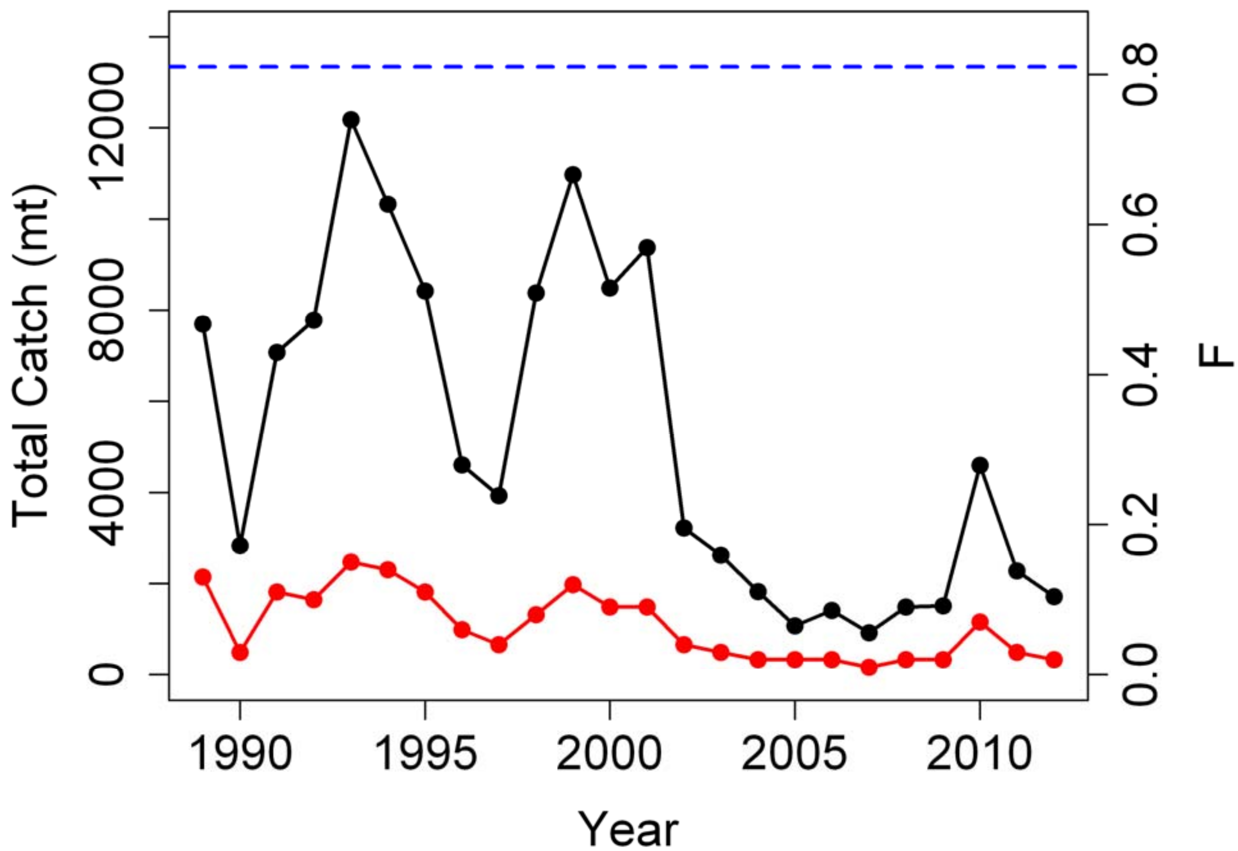
App. A4 Figure 19. Index selectivity from the final model.



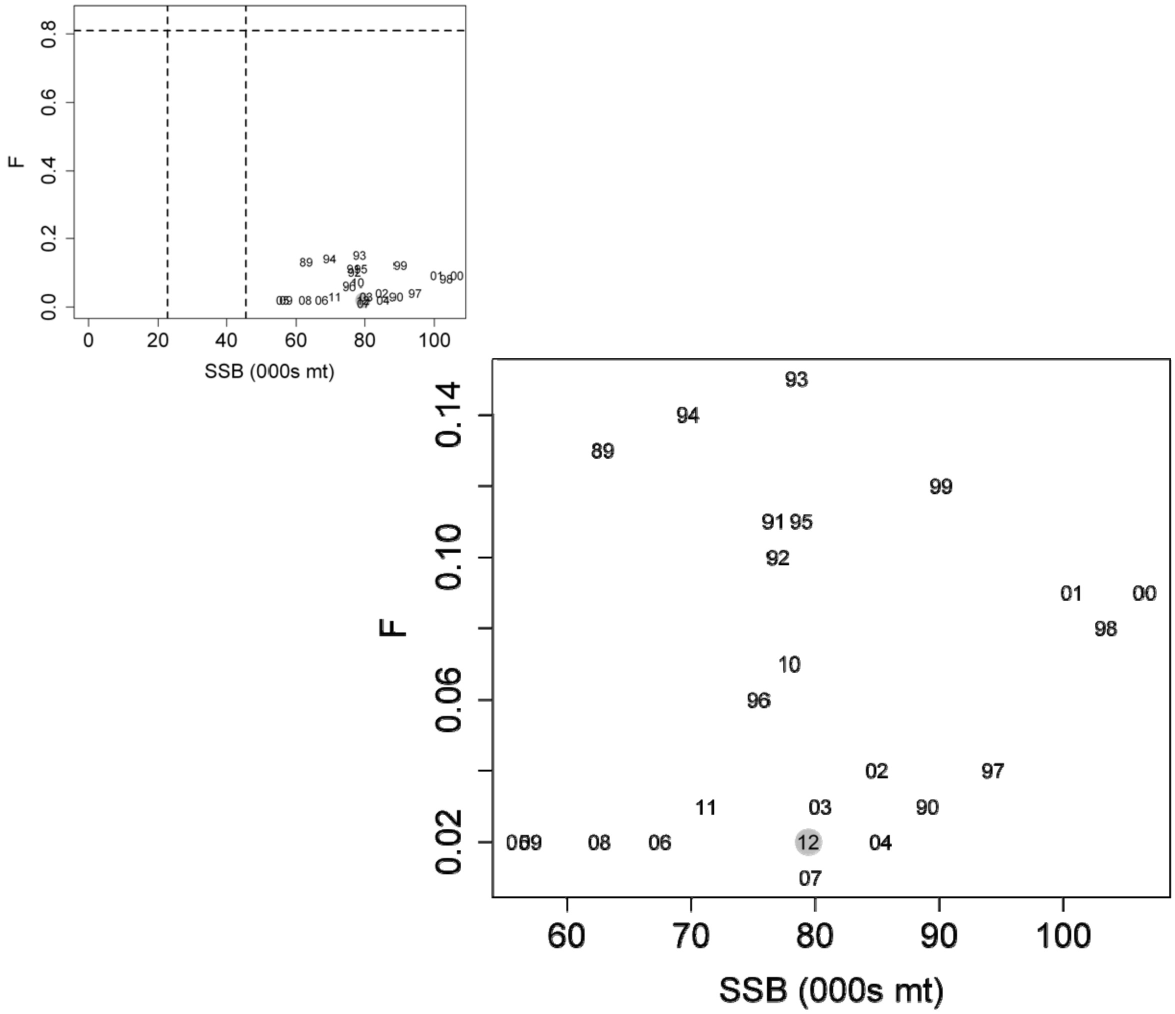
App. A4 Figure 20. Annual estimates of spawning biomass, recruitment and fishing mortality for the base and final models.



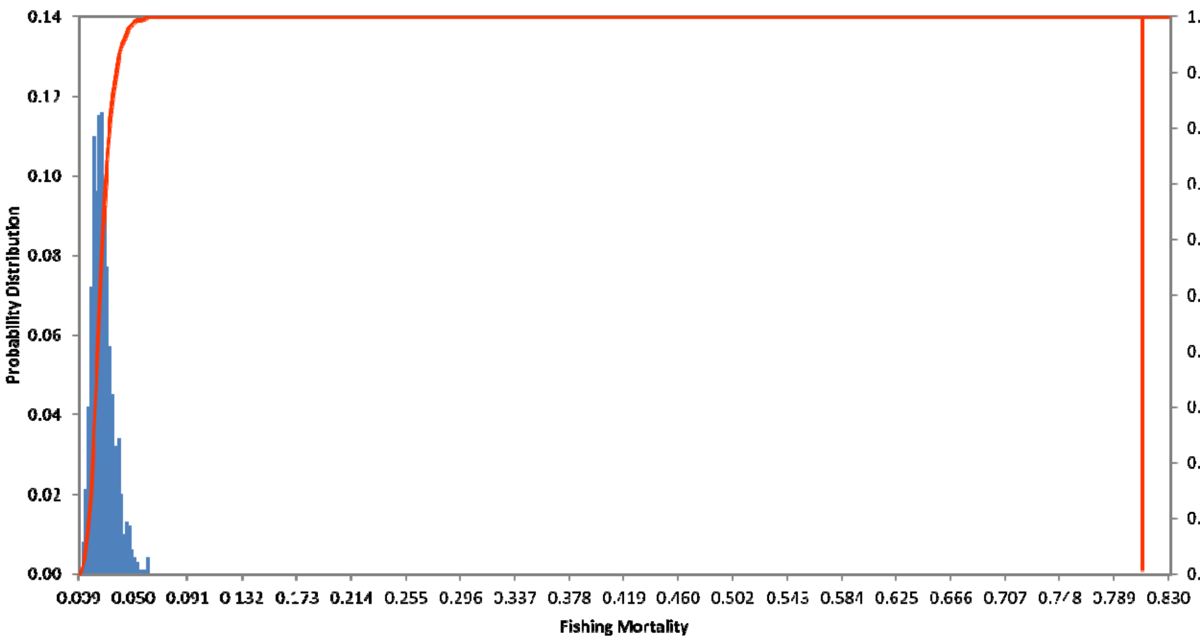
App. A4 Figure 21. Retrospective patterns for spawning biomass, recruitment and fishing mortality in the final model.



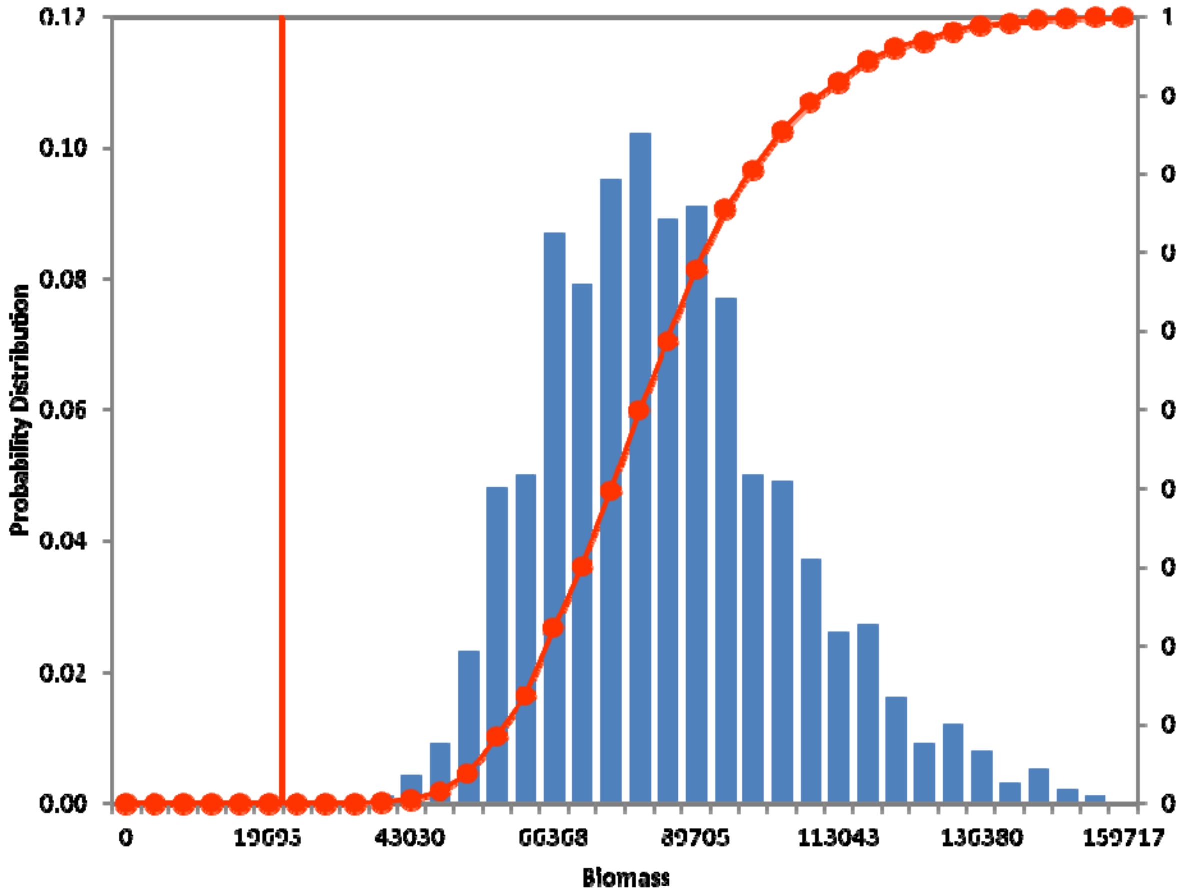
App. A4 Figure 22. Butterfish total catch (mt) and fishing mortality (F). Dashed blue line is the 2014 SAW/SARC F_{MSY} proxy = 0.81.



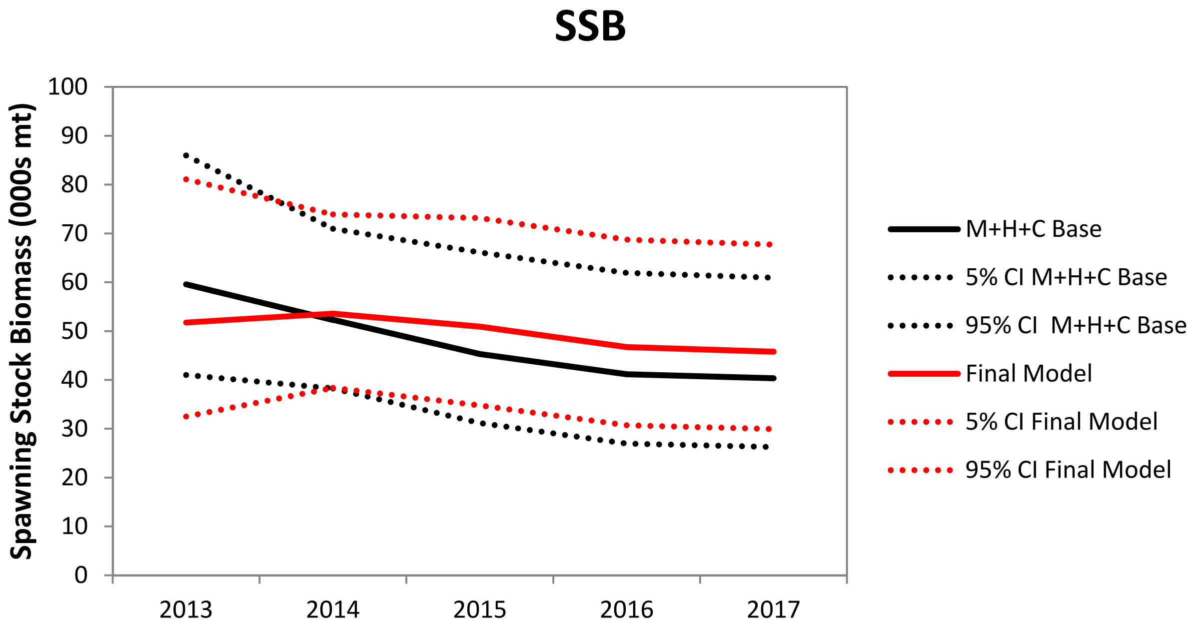
App. A4 Figure 23. Butterfish spawning stock biomass (SSB) and fishing mortality (F) relative to the 2014 SAW/SARC biological reference points $SSB_{threshold}$ = 22,808 mt, SSB_{MSY} proxy = 45,616 mt (100.6 million lb), and F_{MSY} proxy = 0.81 (upper left panel). Plot is expanded for clarity in lower right panel.



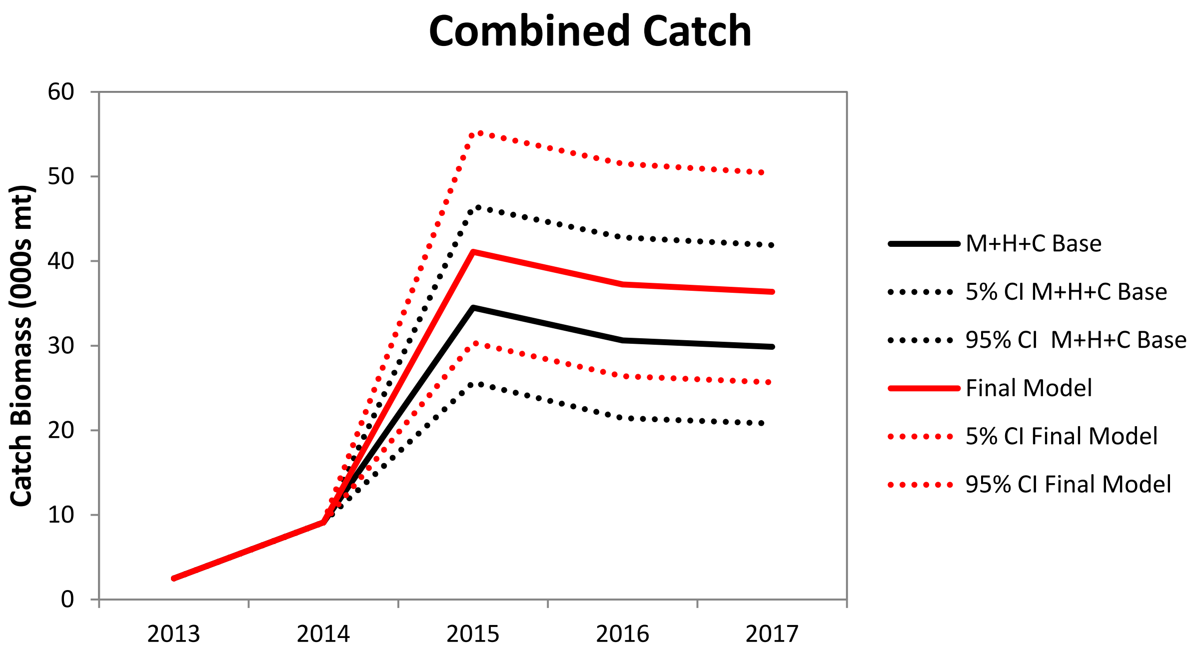
App. A4 Figure 24. Markov Chain Monte Carlo distribution plots for annual total F. Vertical line shows F_{MSY} proxy = 0.81.



App. A4 Figure 25. Markov Chain Monte Carlo distribution plots for annual total SSB. Vertical line shows $SSB_{threshold}$ = 22,808 mt (50.3 million lb).



App. A4 Figure 26. Projection of median butterfish spawning stock biomass and 95% confidence interval with preliminary 2013 catch (2,489 mt), 2014 ABC (9,100 mt), and F_{MSY} proxy = 0.81 in 2015 and beyond. Projected SSB from the M+H+C base model is shown for comparison.



App. A4 Figure 27. Projection of median butterfish catch and 95% confidence interval with preliminary 2013 catch (2,489 mt), 2014 ABC (9,100 mt), and F_{MSY} proxy = 0.81 in 2015 and beyond. Projected total catch from the M+H+C base model is shown for comparison

B. STOCK ASSESSMENT OF TILEFISH IN THE MID-ATLANIC/SOUTHERN NEW ENGLAND REGION FOR 2014

Executive Summary

The SAW Demersal Working Group prepared this report. The Working Group met December 2-5, 2013 at the NEFSC in Woods Hole, MA to conduct a stock assessment of Golden Tilefish for review by SARC 58 in January 2014. The following scientists, managers, and fishermen participated in the meeting:

Jon Deroba	NMFS NEFSC
Dan Farnham	MAFMC Industry Advisory Panel
Chris Legault	NMFS NEFSC
Richard McBride	NMFS NEFSC
Jose´ Montañez	MAFMC Staff
Paul Nitschke	NMFS NEFSC, Lead Assessment Scientist
John Nolan	MAFMC Industry Advisory Panel
Lauri Nolan	MAFMC Member
Loretta O'Brien	NMFS NEFSC
Michael Palmer	NMFS NEFSC
Douglas Potts	NMFS NERO
Katherine Sosebee	NMFS NEFSC
Mark Terceiro	NMFS NEFSC, SAW Working Group Chair
Douglas Vaughn	MAFMC SSC Member
Susan Wigley	NMFS NEFSC

B. Tilefish

Terms of Reference (TOR)

1. Estimate catch from all sources including landings and discards. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the magnitude of uncertainty in these sources of data.

2. Characterize commercial LPUE as a measure of relative abundance. Consider the utility of recreational data for this purpose. Characterize the uncertainty and any bias in these sources of data.

3. For the depth zone occupied by tilefish, examine the relationship between bottom temperature, tilefish distribution and thermal tolerance.

4. Use assessment models to estimate annual fishing mortality and stock size for the time series, and estimate their uncertainty. Include a historical retrospective to allow a comparison with previous assessment results.

5. State the existing stock status definitions for "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; point estimates for B_{MSY}, $B_{THRESHOLD}$, F_{MSY} and MSY or for their proxies) and provide estimates of their uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.
6. Evaluate stock status with respect to the existing ASPIC model (from previous peer reviewed accepted assessment) and with respect to a new model developed for this peer review. In both cases, evaluate whether the stock is rebuilt.
    a. When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.
    b. Then use the newly proposed model and evaluate stock status with respect to "new" BRPs and their estimates (from TOR-4).

7. Develop approaches and apply them to conduct stock projections and to compute the statistical distribution (e.g., probability density function) of the OFL (overfishing level) and candidate ABCs (Acceptable Biological Catch; see Appendix to the SAW TORs).
    a. Provide numerical annual projections (2-3 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment).
    b. Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.

c. Describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming overfished, 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 most recent SARC reviewed assessment and review panel reports. Identify new research recommendations.

Summary by TOR

1. Estimate catch from all sources including landings and discards. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the magnitude of uncertainty in these sources of data.

Total commercial landings (live weight) increased from less than 125 metric tons (mt) during 1967-1972 to more than 3,900 mt in 1979 and 1980 during the development of the directed longline fishery. Landing pior to the mid 1960s was landed as a bycatch through the trawl fishery. Annual landings have ranged between 666 and 1,838 mt from 1988 to 1998. Landings from 1999 to 2002 were below 900 mt (ranging from 506 to 874 mt). An annual quota of 905 mt was implemented in November of 2001. Landings in 2003 and 2004 were slightly above the quota at 1,130 mt and 1,215 mt respectively. Landing from 2005 to 2009 have been at or below the quota. Landings in 2010 were slightly above the quota at 922 mt. Landings in 2011 and 2012 were 864 mt ant 834 mt respectively.

During the late 1970s and early 1980s Barnegat, NJ was the principal tilefish port; more recently Montauk, NY has accounted for most of the landings. Most of the commercial landings are taken by the directed longline fishery. Discards in the trawl and longine fishery are a minor component of the catch. Recreational catches also appears to be a minor component of the total removals.

2. Characterize commercial LPUE as a measure of relative abundance. Consider the utility of recreational data for this purpose. Characterize the uncertainty and any bias in these sources of data.

A fishery independent index of abundance does not exist for tilefish. Three different series of longline effort data were analyzed. The first series was developed by Turner (1986) who used a general linear modeling approach to standardize tilefish effort during 1973-1982 measured in kg per tub (0.9 km of groundline with a hook every 3.7 m) of longline fished obtained from logbooks of tilefish fishermen. Two additional CPUE series were calculated from the NEFSC Weighout (1979-1993) and the VTR (1995-2013) systems. The NEFSC Weighout and VTR CPUE series were standardized using a general linear model (GLM) incorporating year and individual vessel effects (Appendix B1). The number of vessels targeting tilefish has declined over the time series; during 1994-2003, five vessels accounted for more than 70 percent of the total tilefish landings. The length of a targeted tilefish trip had been generally increasing until the mid 1990s. At the time of the 2005 assessment trip lengths have shorten to about 5 days. Trip length has increased slightly until 2008 and has subsequently declined until 2011. There was a slight increase in the trip length in 2012 to about 7 days.

Seven market categories exist in the database. They are: small-kitten, small, kitten, medium, large and extra large as well as an unclassified category. The proportion of landings in the kittens and small market categories increased in 1995 and 1996. Evidence of several strong recruitment events can be seen tracking through the market category proportions. The proportion of the large market category has been relatively low in the 1990s until around 2004. The proportion of larges has increase since 2005. Commercial length sampling has been inadequate over most of the time series. However some commercial length sampling occurred in the mid to late 1990s. More recently there has been a substantial increase in the commercial length sampling from 2003 to 2013.

More recently changes in the CPUE can be generally explained with evidence of strong incoming year classes that track through the landings size composition over time. Since the SARC 48 assessment there appear to be increases in CPUE due to a strong 2004 year class. In general, strong year classes appear to persist longer in the fishery after the FMP and after the constant quota management came into effect which is evident in both the CPUE and size composition data. The decrease in the CPUE in 2012 and 2013 is consistent with the ageing of the last strong year class.

3. For the depth zone occupied by tilefish, examine the relationship between bottom temperature, tilefish distribution and thermal tolerance.

There is very limited data to address this term of reference. Only a few fish per survey are caught during NEFSC bottom trawl surveys. The working group examined spatial distribution plots and bottom temperatures where tilefish were caught during the spring, winter, and fall NEFSC bottom trawl surveys. The probability of occurrence was also calculated for tilefish from the spring and fall surveys. Examination of temporal changes is not possible with the limited numbers of tilefish caught in the surveys. The literature states that tilefish have a narrow temperature preference of 9 to 14 C. The temperature distribution from the surveys also suggests the species is limited to this narrow temperature range. However, there were several tows which did catch tilefish at temperatures lower than 9 degrees C. The working group also found some evidence of small amounts of tilefish being caught in a non directed tilefish longline fishery in the Gulf of Maine.

4. Use assessment models to estimate annual fishing mortality and stock size for the time series, and estimate their uncertainty. Include a historical retrospective to allow a comparison with previous assessment results.

In this SARC 58 assessment the working group updated the ASPIC surplus production model and explored the use of forward projecting size (SCALE) and age (ASAP) structured models. The SARC 58 working group concentrated on the development of size/age structure models due to the continued concerns with process error issues from year class effects within the surplus production model and to include more realistic life history information on size and growth within the model. In general, all models show increases in biomass and decreases in fishing mortality since the implementation of the fishery management plan in 2001. However, the working group concluded that the ASPIC production model no longer adequately characterize the recent population and tilefish fishery trends, and therefore the ASPIC results are no longer sufficient to evaluate the status of the stock. There was relatively little difference in the results among the different SCALE and ASAP model configurations. Comparisons were also done to past assessments. Flattop selectivity runs showed an unrealistic truncation in the population age structure in comparison to the number of tilefish aged for both the SCALE and ASAP models at the end of the time series. In addition, there were reasons to believe that a dome-shaped selectivity pattern is appropriate for the directed tilefish longline fishery. Further development of the SCALE model was not persuaded due to the inability in modeling dome shaped selectivity patterns. The ASAP model that estimated dome shaped selectivity patterns was used as the best model for stock status determination. However general concerns still remain with the lack of data and reliance on commercial CPUE in this assessment.

5. State the existing stock status definitions for "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; point estimates for B_{MSY}, $B_{THRESHOLD}$, F_{MSY} and MSY or for their proxies) and provide estimates of their uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.

The existing stock status determination is based on the ASPIC surplus production model from SARC 48. SARC 48 concluded overfishing was not occurring and the stock was not overfished. In SARC 48 the ASPIC model indicated that the stock was above B_{MSY}. However, SARC 48 concluded that the stock was not yet rebuilt based on concerns with the catch size distributions and process error cause by year class effects within the ASPIC model.

Biological reference points were redefined in this assessment based on the ASAP model. The working group did not develop stock recruitment based biological based reference points due to the uncertainty in the recruitment and SSB estimates during the 1980s and 1990s. Therefore the working group based biological reference points on a percent SPR proxy. The long life span and relatively low M would suggest that a fishing mortality rate reference point of F40% or higher %MSP would be appropriate. However, information provided by fishing industry advisors and ASAP model results indicate that it is likely that the fishery selection curve for tilefish is strongly dome-shaped. Further, under the constant landings quota of 905 mt since implementation of the FMP in 2002, the stock has increased to the new estimate of SSB_{MSY}. In general, improvements to the stock have occurred under the 905 mt quota implemented in November of 2001 which is evident in the raw catch size and fishery CPUE data. Fishing mortality rates have averaged 0.367 since 2002, and the new yield per recruit analysis shows that this fishing rate corresponds to about $F_{25\%}$. Given these factors, the WG recommends that F_{MSY} = $F_{25\%}$ = 0.370 and the corresponding SSB_{MSY} = 5,153 mt, $SSB_{THRESHOLD}$ = 2,577 mt, and MSY = 1,029 mt be adopted as the new biological reference point proxies for this assessment.

6. Evaluate stock status with respect to the existing ASPIC model (from previous peer reviewed accepted assessment) and with respect to a new model developed for this peer review. In both cases, evaluate whether the stock is rebuilt.

a. When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.

b. Then use the newly proposed model and evaluate stock status with respect to "new" BRPs and their estimates (from TOR-4).

The reference points from the previous 2009 SAW 48 assessment are based on the ASPIC surplus production model and cannot be compared to the current assessment ASAP model results and reference points. The current assessment using an updated ASPIC model provides the following updated reference points: B_{MSY} = 12,950 mt, F_{MSY} = 0.139 and MSY = 1,800 mt. Based on the current ASPIC model results and updated reference points, F in 2012 is estimated to be 0.053, 38% of F_{MSY} and stock biomass in 2012 is estimated to be 15,150 mt, 17% above B_{MSY}. With respect to the existing reference points from the 2009 SAW 48 assessment, fishing mortality in 2012 was estimated to be 0.053, 33% of F_{MSY} = 0.16, and total biomass in 2012 was estimated to be 15,150 mt, 133% of B_{MSY} = 11,400 mt. With regards to this term of reference, note that for the ASPIC surplus production model it may not be appropriate to compare stock status relative to biological reference points from a different model run. All ASPIC model results suggest the stock is rebuilt. However, the SARC 48 review panel accepted the ASPIC model but concluded that the ASPIC model is likely over optimistic and that the stock has not rebuilt above B_{MSY}.

The SCALE model was not accepted for stock status determination in SARC 48. In addition the updated SCALE model for this assessment was also not used for status determination due to the inability for modeling a dome-shaped selectively pattern within the model.

The Golden Tilefish stock was not overfished and overfishing was not occurring in 2012 relative to the new biological reference points. The tilefish stock was slightly above the SSB_{MSY} estimate in 2012. A new model (ASAP statistical catch at age) is used in this assessment to incorporate newly available length and age data and better characterize the population dynamics of the stock. Comparison of ASAP model biological reference points to ASPIC model biological reference points was not done since the measure of fishing mortality (F_{MULT}) and biomass (SSB) has changed with the new model.

The fishing mortality rate was estimated to be 0.275 in 2012, below the new reference point F_{MSY} proxy = $F_{25\%}$ = 0.370. There is a 90% probability that the fishing mortality rate in 2012 was between 0.198 and 0.372. SSB was estimated to be 5,229 mt in 2012, about 101% of the new reference point SSB_{MSY} proxy = $SSB_{25\%}$ = 5,153 mt. There is a 90% chance that SSB in 2012 was between 3,275 and 7,244 mt. The average recruitment from 1971 to 2012 is 1.24 million fish at age-1. Recent large year classes have occurred in 1998 (2.35 million), 1999 (2.39 million) and 2005 (1.85 million).

7. Develop approaches and apply them to conduct stock projections and to compute the statistical distribution (e.g., probability density function) of the OFL (overfishing level) and candidate ABCs (Acceptable Biological Catch; see Appendix to the SAW TORs).

a. **Provide numerical annual projections (2-3 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment).**
b. **Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.**
c. **Describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming overfished, and how this could affect the choice of ABC.**

The 905 ACL was assumed for the removals in the two bridge years of the projections (2013-2014). The SARC 58 review panel concluded that there was no information to inform estimates of age-1 recruitment in the last three years of the final ASAP model (2010-2012) since fishery independent measure of abundance are lacking and since age-1 and -2 are not selected and age-3 possessing a low selection of 0.05 in the commercial fishery (Appendix B2). In the absence of information to inform recruitment at the end of the time series the SARC concluded that the model estimated geometric mean would be a better approximation of the recruitment from 2010 to 2012. Recruitment for the last three years (2010-2012) was adjusted to the time series geometric mean through the use of Mohn's rho adjustment within the AGEPRO projections. Projections were made at the constant 905 mt and at $F_{MSY} = F_{25} = 0.37$. The estimated fishing mortality assuming a 905 mt catch remain below F_{MSY} in the adjusted AGEPRO projections. The CV on the 2015 OFL was estimated at 30%. The adjusted recruitment projections done during the SARC meeting are shown in Appendix B2 which can be compared to the original unadjusted working group projections which are shown in the main report.

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

Two new research recommendations were developed by the working group (industry based survey and increase maturity sampling). Past research recommendations were reviewed and summarized as new, pending, or completed.

Introduction

Golden tilefish, *Lopholatilus chamaeleonticeps*, inhabit the outer continental shelf from Nova Scotia to South America, and are relatively abundant in the Southern New England to Mid-Atlantic region at depths of 80 to 440 m. Tilefish have a narrow temperature preference of 9 to 14 ºC. Their temperature preference limits their range to a narrow band along the upper slope of the continental shelf where temperatures vary by only a few degrees over the year. The middle Atlantic-Southern New England stock boundary is shown in Figure B1. They are generally found in and around submarine canyons where they occupy burrows in the sedimentary substrate. Tilefish are relatively slow growing and long-lived, with a maximum observed age of 46 years and a maximum length of 110 cm for females and 39 years and 112 cm for males (Turner 1986). At lengths exceeding 70 cm, the predorsal adipose flap, characteristic of this species, is larger in males and can be used to distinguish the sexes. Tilefish of both sexes are mature at ages between 5 and 7 years (Grimes et. al. 1988).

Golden Tilefish was first assessed at SARC 16 in 1992 (NEFSC 1993). The Stock Assessment Review Committee (SARC) accepted a non-equilibrium surplus production model (ASPIC). The ASPIC model estimated biomass-based fishing mortality (F) in 1992 to be 3-times higher than F_{MSY}, and the 1992 total stock biomass to be about 40% of B_{MSY}. The intrinsic rate of increase (r) was estimated at 0.22.

The Science and Statistical Committee (SSC) reviewed an updated tilefish assessment in 1999 based on a ASPIC surplus production model. Total biomass in 1998 was estimated to be 2,936 mt, which was 35% of B_{MSY} = 8,448 mt. Fishing mortality was estimated to be 0.45 in 1998, which was about 2-times higher than F_{MSY} = 0.22. The intrinsic rate of increase (r) was estimated to be 0.45. These results were used in the development of the Tilefish Fishery Management Plan (Mid-Atlantic Fishery Management Council 2000). The Mid-Atlantic Fishery Management Council implemented the Golden Tilefish Fishery Management Plan (FMP) in November of 2001. Rebuilding of the tilefish stock to B_{MSY} was based on a ten-year constant harvest quota of 905 mt.

SARC 41 reviewed a benchmark tilefish assessment in 2005. The surplus production model indicated that the tilefish stock biomass in 2005 has improved since the assessment in 1999. Total biomass in 2005 is estimated to be 72% of B_{MSY} and fishing mortality in 2004 is estimated to be 87% of F_{MSY}. Biological reference points did not change greatly from the 1999 assessment. B_{MSY} is estimated to be 9,384 mt and F_{MSY} is estimated to be 0.21. The SARC concluded that the projections are too uncertain to form the basis for evaluating likely biomass recovery schedules relative to B_{MSY}. The TAC and reference points were not changed based on the SARC 41 assessment.

The last benchmark tilefish stock assessment in SARC 48 (2009) was also based on the ASPIC surplus production model. The model is calibrated with CPUE series, as there are no fishery-independent sources of information on trends in population abundance. While the SARC expressed concern about the lack of fit of the model to the VTR CPUE index at the end of the time series, they agreed to accept the estimates of current fishing mortality and biomass and associated reference points. The instability of model results in the scenario projections was also a source of concern. It was noted that the bootstrap uncertainty estimates do not capture the true uncertainty in the assessment. The SARC concluded the overfishing was not occurring and the stock was not overfished. The ASPIC model indicated that the stock was rebuilt. However, SARC 48 concluded that the stock was not yet rebuilt due to concerns regarding the process error from year class effects within the ASPIC model.

In this SARC 58 assessment the working group updated the ASPIC surplus production model and explored the used of size and age structured forward projecting models. The working group put forward an age structured model in ASAP as the best estimate of stock status determination due to the continued concerns with process error within the surplus production model and to include more realistic life history information on size and growth into a single model framework.

TOR 1. Estimate catch from all sources including landings and discards. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the magnitude of uncertainty in these sources of data.

Data Sources

Commercial catch data

Total commercial landings (live weight) increased from less than 125 metric tons (mt) during 1967-1972 to more than 3,900 mt in 1979 and 1980 during the development of the directed longline fishery. Landing prior to the mid 1960s was landed as a bycatch through the trawl fishery. Annual landings have ranged between 666 and 1,838 mt from 1988 to 1998. Landings from 1999 to 2002 were below 900 mt (ranging from 506 to 874 mt). An annual quota of 905 mt was implemented in November of 2001. Landings in 2003 and 2004 were slightly above the quota at 1,130 mt and 1,215 mt respectively. Landing from 2005 to 2009 have been at or below the quota. Landings in 2010 were slightly above the quota at 922 mt. Landings in 2011 and 2012 were 864 mt ant 834 mt respectively (Table B1, Figure B2).

Over 75% of the landings came from Statistical Areas 537 and 616 since 1991 (Table B2, Figure B3). In the 1980s a greater proportion of the landings came from 526. It is not clear if the higher portion of the landings was partly an artifact of the low interview coverage in the Weighout system that was made up of mostly New Jersey vessels. Nevertheless perhaps a higher proportion of the landings were coming from 526 in the 1980s relative to 2000s. Since the 1980s, over 85% of the commercial landings of tilefish in the MA-SNE region have been taken in the longline fishery (Table B3, Figure B4). Over the last 4 years the percent of the landing coming from longline gear has increased to over 95%. During the development of the directed longline fishery in the late 1970s and early 1980s Barnegat, NJ was the principal tilefish port; more recently Montauk, NY has accounted for most of the landings (Figure B5). The shift in landings can be seen in the proportion of the landings by state in Table B4 and Figure B6. In the late 1970s and early 1980s a greater proportion of the landings were taken in quarters 1 and 2 (Table B5, Figure B7). Recent landings have been relatively constant over the year.

Commercial discard data

Discards were estimated following the SBRM approach (discard/kept all species ratio x kept all total) for small and large mesh trawl and for gillnet fisheries (Wigley et al. 2007). The number of observed trips, discard ratios, CVs, and estimated discards are summarized in Table B6. In general the discard of tilefish in other commercial fisheries appears to low (several metric tons per gear type). Very little discarding (< 1%) of tilefish was reported in the vessel trip report (VTR) from longline vessels that target tilefish (SARC 48). The small number of observed directed tilefish longline trips also suggest that discards of tilefish is minimal. The tilefish working group concluded that discarding of tilefish is a minor component of the total removals and was not included as a component of the total catch in the modeling.

Recreational catch data

A small recreational fishery occurred briefly in the mid 1970s (< 100 mt annually, Turner 1986) but subsequent recreational catches appear to have been low for the last 30 years in the Marine Recreational Information Program (MRIP) (Table B7). The tilefish catch in the MRIP survey is likely below detection levels of the survey judging from the sporadic estimates in the survey. However there a several party charter vessels which make on a few targeted tilefish trips a year. Party and charter boat vessel trip reports also show relatively low numbers of tilefish being caught although there is an increase in numbers of fish reported (6400 fish) at the end of the time series in 2012 (Table B8). However this increase may be more a reflection of recent increases in reporting rate. Most of the report landing was coming from New Jersey (Table B8). It appears that a greater proportion of the reported recreational catch and effort is further south in statistical area 622 relative to the commercial longline fleet that fishes more in 537 (Tables B9 and B10). The working group was not able to produce a reliable time series of recreational catches. However the working group also concluded that the recreational removals are likely a minor component of the catch.

TOR 2. Characterize commercial LPUE as a measure of relative abundance. Consider the utility of recreational data for this purpose. Characterize the uncertainty and any bias in these sources of data.

Only a few fish per survey are caught during NEFSC bottom trawl surveys. This survey time series is not useful as an index of abundance for tilefish. The tilefish stock assessment relies on a fishery dependent commercial CPUE as an index of abundance.

Commercial CPUE data

A fishery independent index of abundance does not exist for tilefish. Analyses of catch (landings) and effort data were confined to the longline fishery since directed tilefish effort occurs in this fishery (e.g. the remainder of tilefish landings are taken as bycatch in the trawl fishery). Most longline trips that catch tilefish fall into two categories: (a) trips in which tilefish comprise greater than 90% of the trip catch by weight and (b) trips in which tilefish accounted for less than 10% of the catch. Effort was considered directed for tilefish when at least 75% of the catch from a trip consisted of tilefish.

Three different series of longline effort data were analyzed. The first series was developed by Turner (1986) who used a general linear modeling approach to standardize tilefish effort during 1973-1982 measured in kg per tub (0.9 km of groundline with a hook every 3.7 m) of longline obtained from logbooks of tilefish fishermen. Two additional CPUE series were calculated from the NEFSC Weighout (1979-1993) and the VTR (1995-2012) systems. Effort from the Weighout data was derived by port agents' interviews with vessel captains whereas effort from the VTR systems comes directly from mandatory logbook data. In the SARC 48 assessment and in the 1998 and 2005 tilefish assessments we used Days absent as the best available effort metric. In the 1998 assessment an effort metric based on Days fished (average hours fished per set / 24 * number of sets in trip) was not used because effort data were missing in many of the logbooks and the effort data were collected on a trip basis as opposed to a haul by haul basis. For this assessment effort was calculated as:

Effort = days absent (time & date landed - time & date sailed) – one day per trip.

For some trips, the reported days absent were calculated to be a single day. This was considered unlikely, as a directed tilefish trip requires time for a vessel to steam to near the edge of the continental shelf, time for fishing, and return trip time. Thus, to produce a realistic effort metric based on days absent, a one day steam time for each trip (or the number of trips) was subtracted from days absents and therefore only trips with days absent greater than one day were used.

The number of vessels targeting tilefish has declined since the 1980s (Table B11, Figure B8); during 1994-2003 and 2005-2012, five vessels accounted for more than 70 percent of the total tilefish landings. The number of vessels targeting tilefish has remained fairly constant since the assessment in 2005. The length of a targeted tilefish trip had been generally increasing until the mid 1990s. At the time of the 2005 assessment trip lengths have shorten to about 5 days. Trip length has increased slightly until 2008 and has subsequently declined until 2011. There was a slight increase in the trip length in 2012 to about 7 days (Figure B8). In the Weighout data the small number of interview is a source of concern; very little interview data exists at the beginning of the time series (Table B11, Figure B9). The 5 dominant tilefish vessels make up most of the VTR reported landings (Table B12, Figure B10).

In some years there were higher total landings reported in the VTR data than the Dealer data for the 5 dominant tilefish vessels. After the FMP was implemented the IVR (Interactive Voice recorder) database was developed to monitor the quota. In 2005 the IVR database had the highest landings level despite that this system only applies to the limited access tilefish fishery (Figure B10). The IVR 2005 total was assumed to be a better estimate of the total landings in that year then the other data sources. The IVR total landing in 2005 was used as the total removals in all tilefish modeling. The IVR system was no longer used for monitoring after the development of a ITQ fishery in 2009 and was therefore not updated in this assessment.

The number of targeted tilefish trips declined in the early 1980s while trip length increased at the time the FMP was being developed in 2000 (Figures B11 and B12). During the last assessment in 2005 the number of trips became relatively stable as trip length decreased. Since the last assessment trip length has increased. The interaction between the number of vessels, the length of a trip and the number of trips can be seen in the total days absent trend in Figure B8. Total days absent remained relatively stable in the early 1980s, but then declined at the end of the Weighout series (1979-1994). In the beginning of the VTR series (1994-2004) days absent increased through 1998 but declined to 2005. Since 2005 total days absent has increase somewhat. Figure B11 also shows that a smaller fraction of the total landings in the Weighout series were included in the calculation of CPUE in comparison to the VTR series. Expanding effort to the total dealer landings shows a greater decline in effort (days absent and number of trips) over the time series (Figure B12).

Figure B13 illustrates difference between the nominal CPUE and vessel standardized (GLM) CPUE with the Weighout and VTR data combined. CPUE trends are very similar for most vessels that targeted tilefish (Figure B14). A sensitivity test of the GLM using different vessel combinations was done in SARC 41. The SARC 41 GLM was found not to be sensitivity to different vessels entering the CPUE series.

Very little CPUE data exist for New York vessels in the 1979-1994 Weighout series despite the shift in landing from New Jersey to New York before the start of the VTR series in 1994. The small amount of overlap between the Weighout and VTR series is illustrated in Figures B15 and B16 which were taken from SARC 48. Splitting the Weighout and VTR CPUE series can be justified by the differences in the way effort was measured and difference in the tilefish fleet between the series. In breaking up the series we omitted 1994 due to the lack of CPUE data for that year. The sparse 1994 data that existed came mostly from the Weighout system in the first quarter of the year. Very similar trends exist in the four years of overlap between Turner (1986) CPUE and the Weighout series (Figure B17). For this assessment additional logbook data for three New York vessels was collected from New York fishermen from 1991-1994 and added to the VTR series. This was done to provide more information (years of overlap) in the modeling between the Weighout and the VTR series (Figure B18).

Since 1979, the tilefish industry has changed from using cotton twine to steel cables for the backbone and from J hooks to circle hooks. The gear change to steel cable and snaps started on New York vessels in 1983. In light of possible changes in catchability associated with these changes in fishing gear, the working group considered that it would be best to use the three available indices separately rather than combined into one or two series. The earliest series (Turner 1986) covered 1973-1982 when gear construction and configuration was thought to be relatively consistent. The Weighout series (1979-1993) overlapped the earlier series for four years and showed similar patterns (Figure B17) and is based primarily on catch rates from New Jersey vessels. The VTR (1991-2013) series is based primarily on information from New York vessels using steel cable and snaps.

In SARC 41 a month vessel interaction was significant but explained only a small amount of the total sum of squares (6%*)*. Adding a month - vessel interaction term to the GLM model had very little influence on the results at SARC 41 and was not updated for this assessment. The GLM output for the Weighout and the VTR CPUE series standardized for individual vessel effects can be seen in Appendix B1.

In the SARC 48 assessment the sensitivity of the assumed error structure used in VTR GLM CPUE index was explored. The nominal VTR CPUE data distribution does appear over-dispersed relative to normal or lognormal distribution, suggesting that a model with poisson or negative binomial distribution may be more appropriate (SARC 48). However the GLM CPUE indices using different error assumptions showed very little differences in the CPUE trends. Therefore the lognormal error distribution was retained.

The NEFSC Weighout and VTR CPUE series were standardized using a general linear model (GLM) incorporating year and individual vessel effects. The CPUE was standardized to an individual longline vessel and the year 1984; the same year used in the last assessment. For the VTR series the year 2000 was used as the standard. Model coefficients were back-transformed to a linear scale after correcting for transformation bias. However, the updated GLM model that accounted of individual vessel effects appears to show more of an overall increasing trend in CPUE in comparison to the nominal series (figure B19). A similar pattern was seen when the additional New York logbook data from 1991-1994 was added to the VTR series (Figure B20).

More recently changes in the CPUE can be generally explained with evidence of strong incoming year classes that track through the landings size composition over time (See below). Since the SARC 48 assessment there appear to be increases in CPUE due to one or two new strong year classes. In general, strong year classes appear to persist longer in the fishery after the FMP and after the constant quota management came into effect which is evident in both the CPUE and size composition data. The small decrease in the CPUE in 2012 and 2013 is consistent with the ageing of the last strong year class.

Commercial market category and size composition data

Seven market categories exist in the database. They are: small-kitten (aka extra small, tiny or kk), small, kitten, medium, large and extra large as well as an unclassified category. Differences in the naming convention among ports tend to cause some confusion. For example small and kitten categories reflect similar size fish. Smalls is the naming convention used in New Jersey whereas the kitten market category is used primarily in New York ports. In 1996 and 1997, the reporting of tilefish by market categories increased, with the proportion of unclassified catch declining to less than 20% (Table B13, Figure B21). The proportion of landings in the small and kitten market categories increased in 1995 and 1996. However, the proportion of small fish in the catch may have increased prior to 1995. The size composition of the catch in the late 1980s and early 1990s is uncertain due to the high proportion of unclassified fish in the catch. Small and kitten market categories have similar length distributions and samples from 1995 to 1999 were combined. Evidence of several strong recruitment events can be seen tracking through the market category proportions (Figures B22). The proportion of the large market category has been relatively low in the 1990s until around 2004 (Figure B22). The proportion of larges has increase since 2005. The strong year class tracking through the small kitten and mediums in the late 1990s did not materialized into the large market category. However two strong year classes in the 2000s appear to have contributed to increases of the large market category since 2005.

Extensive size sampling was conducted in 1976-1982 (Grimes *et al.* 1980, Turner 1986) however that data are not available by market category (Figure B23). Since then commercial length sampling has been inadequate in most years (Table B14). However some commercial length sampling occurred in the mid to late 1990s which required some pooling of samples. More recently there has been a substantial increase in the commercial length sampling in 2003 to 2013. Commercial length sampling in New York has also increased since the last assessment in 2005 (Table B14). Expanded length frequency distributions from 1995 to 1999 are shown in Figure B24. In this assessment expanded length frequency distributions were estimated form 2002 to 2013 (Figures B25 through B27). The stratification used in the expansion can be seen in Table B14. The large market category length frequencies appear to have been relatively stable for years when more than 100 fish were measured. However the small market category exhibits shifts in the size distribution in certain years as a strong year class moves through the fishery (Figure B28). The tracking of a year classes can be seen as the cohort grows over the year in 2003 and 2004 (Figure B28). This strong 1998 and/or 1999 year class can be seen tracking over the years in the expanded commercial length frequency distributions (Figure B25).

Commercial length frequencies were expanded for years where sufficient length data exist (1995-1999 and 2002-2013) (Table B14). The large length frequency samples from 1996 to 1998 were used to calculate the 1995 to 1999 expanded numbers at length while the large length samples from 2001 and 2003 were used to calculate the 2002 expanded numbers at length. Evidence of strong 1992/1993, 1998/1999 and a 2005 year classes can be seen in the expanded numbers at length in the years when length data existed (1995-1999 and 2002-2013) (Figure B25). The matching of modes in the length frequency with ages was done using available growth information (Turner's (1986) and 2007-2013 catch at age). In 2004 and 2005 the 1998/1999 year class can be seen growing into the medium market category and in 2006 and 2007 the year class has entered the large market category. From 2002 to 2007 it appears that most of the landings were comprised of this year class. A similar pattern occurred with the 2005 year class from 2009-2013. An increase in the landings and CPUE can be seen when the 1992/1993, 1998/1999 and 2005 year classes recruit to the longline fishery. As the year classes gets older the catch rates decline (Figure B18). At this point the catch also gets more widely distributed over multiple year classes. This can be seen in 2007-2008 and 2012-2013. CPUE appear to decline as the strong year classes get older then about 6 years. However, biomass frequencies at length show that most of the biomass in the catch is still comprised of the larger heavier fish which is why the quota can still be taken (Figure B27).

There is additional market category in the fishery called large-mediums which makes up a relatively small component of the catch. A code does not exist for this market category which likely results in some error in several years in the expanded size distributions. Like the name suggests the large-medium category falls between the medium and the large sizes. Figure B29 compares medium and large length distributions with distributions that had a comment from the port sampler indicating that the sample came from a dealer large-medium category. Some of the samples are put into the large market code while some where coded as mediums. It is not clear how each dealer is reporting the catch from this category but it appears that most of these fish could be coded as unclassified. It can be seen that the proportion of unclassified tend to increase in years when we would expect the large year class to grow into the large-medium sizes (Figure B25). This does seem to cause some error in the expansions in those years (2005-2006, 2011-2012) since unclassified fish are distributed across all size categories (Figure B25). A database large-medium code is now being developed for commercial dealers and the biological port sampling. The working group acknowledges this issue and recommended continued work on developing a code but concluded that this additional error effect should be relatively minor.

Concern was expressed at SARC 48 with little evidence of an incoming year class, catch rates declining and the mismatch between the biomass trends predicted by the surplus production model in comparison to the observed CPUE at the end of the time series. However, since the last 2009 assessment there is evidence of a strong year class (2005) tracking through the landings size distributions. In 2012 that year class is entering the large market category and as expected there is a decline in the CPUE relative to 2011. However, there is also some evidence of a broader size distribution of the fish being caught from 2011to 2013 which suggests the fishery is less reliant on a single year class. Nevertheless, like in SARC 48 there are some concerns on whether another strong year class will increase CPUE and stock biomass in the future. Industry indicated that signs of another large year class has just recently entered the catch but are not yet reflected in the data or projections used for this assessment.

Commercial AGE data

For SARC 58 the Northeast Fisheries Science Center (NEFSC) aged commercial age samples (otoliths) from 2007-2012. The new age and growth data is summarized in table B15. Catch at age was estimated for 2007 and 2008 through 2012. Catch at age could not be developed for 2008 due to missing age data from the first half of the year which resulted in missing ages for smaller fish. A Pooled age length key was developed for all years combined and von Bertalanffy growth curve was also estimated using the NEFSC age data.

TOR 3. For the depth zone occupied by tilefish, examine the relationship between bottom temperature, tilefish distribution and thermal tolerance.

There is very limited data to address this term of reference. Only a few fish per survey are caught during NEFSC bottom trawl surveys. The working group examined spatial distribution plots and bottom temperatures where tilefish were caught during the spring, winter and fall NEFSC bottom trawl surveys (Figures B30 through B34). Examination of temporal changes is not possible with the limited numbers of tilefish caught in the surveys. In general, survey distributions seem to match information for the directed longline fishery (Figure B3). The fishery tends to be concentrated in an area in the Mid-Atlantic southern New England region where the stock is most abundant and where the stock is more widely distributed across the shelf break. The stock appears to occupy a narrower band to the north along the south edge of Georges Bank and to the south towards Cape Hatteras. The literature states that tilefish have a narrow temperature preference of 9 to 14 C. The temperature distribution from the surveys also suggests the species is limited to this narrow temperature range. However, there were several tows which did catch tilefish at temperatures lower than 9 C (Figure B30).

The probability of occurrence was calculated for tilefish from the spring and fall surveys (Figure B31). The confidence intervals tend to be wide due to the limited data but the analysis shows that tilefish occur at temperatures between 10-15 degrees C. The probability of occurrence is calculated as follows. The quotient analysis splits temperature into bins (1 degree C in this case). In each bin the following calculation is made:

$$Q_i = \frac{N_i n}{N\, n_i}$$

where Q is the quotient index for temperature bin i, N_i is the number of tilefish occurrences in the bin and N is the number of tilefish occurrences overall; n_i is the number of stations sampled in the bin and n is number of stations sampled overall). The following standardization is made:

$$Q_i^s = \frac{Q_i}{\sum Q_i}$$

which gives the probability of occurrence in each temperature bin. In essence this provides an empirical probability density function, which is corrected for potentially unequal sampling across temperature bins. Bootstrapping is used to estimate the confidence intervals. For tilefish, the confidence intervals are wide, because there are relatively few tilefish in the survey.

The probability of occurrence analysis gives a first-order analysis of the realized thermal niche of tilefish. This could be used as a starting point to see whether the tilefish stock could be impacted if bottom water temperatures change beyond this range. A critical dimension of tilefish realized niche is substrate suitability; tilefish construct burrows and require habitat with suitable substrate characteristics. This factor should be considered in future evaluations to determine whether shifts in distribution are possible if bottom temperatures do change beyond the range of estimated thermal niche.

In general, tilefish is a warm water species and are potentially quite vulnerable to cold water intrusions in their shelf break habitat. They principally occupy a relatively narrow temperature band at the shelf break bathed in relatively stable warm water influenced by the Gulf Stream. A massive tilefish die-off was recorded however in 1882 (Collins 1884; Bigelow and Schroeder 1953) and attributed to deep penetration of cold Labrador Current water into the region (Cushing 1982; Marsh et al. 1999). Collins (1884) estimated that as many as one billion tilefish may have perished in this massive ecological event. The deep water sea robin (*Peristedion miniatum*) was also affected. This cold water intrusion has in turn, been connected to the North Atlantic Oscillation which reached a very low point in the winters of 1880-1881 and 1881-1882 (Marsh et al. 1999). The affects of change in the NAO on the hydrography of the region is typically felt about 12-18 months later. A sharp drop in the NAO could provide an early-warning signal to look for strong input of Labrador Slope water with possible repercussions for the tilefish stock.

The working group also examined a distribution plot using point location data from the commercial fishery VTR (logbook) data for longline gear (Figure B35). This plot does show that most of the tilefish catch comes from the central part of the stock in 537 and 616 where the directed tilefish longline fishery occurs. Perhaps more interesting, the plot also suggests a small amount of non directed catch coming from the deep eastern part of the Gulf of Maine. Further investigation of some of these VTR trips and some limited observed trips did suggest that small amounts of tilefish are caught in the Gulf of Maine in other longline (non-tilefish directed) commercial fisheries. This is surprising since this tilefish population component was not detected in the bottom trawl surveys. The small Gulf of Maine population is likely below detection levels of the trawl surveys due to the low catch rates.

TOR 4. Use assessment models to estimate annual fishing mortality and stock size for the time series, and estimate their uncertainty. Include a historical retrospective to allow a comparison with previous assessment results.

In this SARC 58 assessment the working group updated the ASPIC surplus production model and explored the use of forward projecting size (SCALE) and age (ASAP) structured models. The SARC 58 working group concentrated on the development of size/age structure models due to the continued concerns with process error issues from year class effects within the surplus production model and to include more realistic life history information on size and growth within the model. However concerns with the general lack of data over the time series with more advance data hungry models remains a source of concern. All modeling was initially done through 2013 to make use of all available data. However carrying models through 2013 requires some assumption to be made for the terminal year. The working group assumed the calendar year removals would be at the quota of 905 mt in 2013. Landing in the past 10 years have been relatively close to the 905 mt quota. The working group also assumed the 2013 size at length distribution and the 2013 commercial CPUE estimate which included data through August

2013 would not change significantly when it is updated through the end of the calendar year. After all model exploration and examination was completed, the working group concluded that the final model terminal year should be 2012 to avoid questions regarding the incomplete 2013 data.

ASPIC Surplus production model

The ASPIC surplus production model (Prager 1994; 1995) was used to determine fishing mortality, stock biomass and biological reference points (F_{MSY}, and B_{MSY}) for the development of the tilefish FMP in 2001. SARC 41 in 2005 and SARC 48 in 2009 accepted the ASPIC model as a basis for stock status determination. However, the SARC 48 surplus production model suggested that the stock was rebuilt and SARC 48 concluded that the stock was not yet rebuilt due to process error concerns within the surplus production model caused by year class effects. The catch size distributions and reductions in CPUE as year classes age also suggested that the stock has not yet rebuilt.

The three commercial fishery CPUE index series (Turner 1973-1982; NEFSC Weighout 1982-1993; and VTR 1995-2013) as configured in the 2009 SAW 48 assessment were updated for the SARC 58 ASPIC model configuration in run 2. Comparison of the updated ASPIC model to historical assessments can be seen in Figure B36 and Table B16. The updated ASPIC model estimates higher biomass and lower F relative to models from SARC 41 and SARC 48. Biomass in 2014 was estimated to be 1.66 of B_{MSY} and F was estimated to be 0.28 of F_{MSY}. The updated model also suggests the stock was not overfished during the implementation of the fishery management plan (stock was above one half B_{MSY} in 1999 for this run). A retrospective analysis also reveals that the surplus production model tends to underestimate B_{MSY} and overestimates fishing mortality as years are omitted from the model (Figure B37). The updated ASPIC run maintained the same B1 ratio assumption as in the last assessment. The B1 ratio parameter is the ratio of biomass in the first year of the model to K (carrying capacity of the stock). In past assessments this ratio was fixed at B_{MSY} since the model tends to estimate biomass much higher than K in the first year. Sensitivity runs were made to further evaluate the impact of different model configurations (Table B17, Figures B37 and B39). The influence of the B1 assumption on the model results can be seen in the sensitivity analysis. Run 3 estimates the B1 ratio at 1.3 of k. This does lower the estimate of B/B_{MSY} at the end of the time series from 1.66 to 1.56. Run 4 used the nominal CPUE series for the VTR CPUE index and run 5 combine the Weighout and VTR series into a single series. Combining the two CPUE series also resulted in a lower B/B_{MSY} ratio in the terminal year. This suggests that in the separate series runs the fishery is becoming less efficient when comparing the VTR q to the Weighout q (Figure B40). It is the relative shift in the q between the two CPUE series which resulting in higher biomass as years get added to the model. Reasoning on why the fishery would be less efficient in the VTR series relative to the older Weighout series is difficult to justify.

Expanded landing length frequency distributions and trends in the VTR CPUE show recent strong year class effects tracking through the fishery. As in past assessments the strong 1998/1999 and 2005 year classes result in process error with the fit to the VTR series in the ASPIC model since the surplus production model does not consider changes in recruitment, or cohort effects (Figure B40). The increase in error is reflected in the residual pattern of the vtr series. All ASPIC sensitive runs suggest the stock is above B_{MSY}. Some runs suggest the biomass is closer to the carrying capacity where density depend processes should be occurring (Figure B41). However, in general catch at size and age distributions suggest the fishery relies on periodic strong year classes. The fishery is not fishing on a stable size distribution of mostly larger fish across years as expected when density dependent processes would be occurring.

The working group developed run 6 as the preferred run using ASPIC model (Table B17, Figure B42). Run 6 incorporated the 1991-1994 logbook data from NY vessels into the VTR series, had a terminal year of 2012 and fixed the B1 ratio at k. Fixing the B1 ratio at K seems to be more in line with the initial development of the longline fishery in the early 1970s. However the working group did not bring forward the surplus production model as the preferred model for stock status determination due to the concerns described above. The working group concluded that the ASPIC production model does not adequately characterize the recent population and tilefish fishery trends, and therefore the ASPIC results are no longer sufficient to evaluate the status of the stock.

SCALE Model

The working group investigated the use of an age and size structured forward projection model (SCALE) for assessing the tilefish stock due to the inability of the ASPIC surplus production model in fitting the observed year class effects. The SCALE model was first examined in the last assessment in SARC 48. The working group investigated the use of the SCALE model for this assessment using the new commercial age data available.

Incomplete or lack of age-specific catch and survey indices often limits the application of a full age-structured assessment (e.g. Virtual Population Analysis). Stock assessments will often rely on the simpler size/age aggregated models (e.g. surplus production models) when age-specific information is lacking. However the simpler size/age aggregated models may not utilize all of the available information for a stock assessment. Knowledge of a species growth and lifespan, along with total catch data, size composition of the removals, recruitment indices and indices on numbers and size composition of the large fish in a survey can provide insights on population status using a simple model framework.

SCALE Model Description

The Statistical Catch At LEngth (SCALE) model, is a forward projecting age-structured model tuned with total catch (mt), catch at length or proportional catch at length, recruitment at a specified age (usually estimated from first length mode in the survey), survey indices of abundance of the larger/older fish (usually adult fish) and the survey length frequency distributions (NOAA Fisheries Toolbox 2008a). The SCALE model was developed in the AD model builder framework. The model parameter estimates are fishing mortality and recruitment in each year, fishing mortality to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years and Qs for each survey index.

The SCALE model was developed as an age-structured model that does NOT rely on age-specific information on a yearly basis. The model is designed to fit length information, abundance indices, and recruitment at age which can usually be estimated by using survey length slicing. However a fishery independent survey does not exist for this tilefish stock. The model does require an accurate representation of the average overall growth of the population which is input to the model as mean lengths at age. Growth can be modeled as sex-specific growth and natural mortality or growth and natural mortality can be model with the sexes combined. The SCALE model will allow for missing data.

The SCALE model assumes growth follows the mean input length at age with predetermined input error in length at age. Therefore a growth model or estimates of mean length at age are essential for reliable results. The model assumes static growth and therefore population mean length/weight at age are assumed constant over time.

The SCALE model estimates logistic parameters for a flattop selectivity curve at length in each time block specified by the user for the calculation of population and catch age-length matrices or the user can input fixed logistic selectivity parameters. Presently the SCALE model cannot account for the dome shaped selectivity pattern.

The SCALE model computes an initial age-length population matrix in year one of the model as follows. First the estimated populations numbers at age starting with age-1 recruitment get normally distributed at one cm length intervals using the mean length at age with the assumed standard deviation. Next the initial population numbers at age are calculated from the previous age at length abundance using the survival equation. An estimated fishing mortality (Fstart) is also used to produce the initial population. This F can be thought of as the average fishing mortality that occurred before the first year in the model. Now the process repeats itself with the total of the estimated abundance at age getting redistributed according to the mean length at age and standard deviation in the next age (age+1).

This two step process is used to incorporate the effects of length specific selectivities and fishing mortality. The initial population length and age distribution is constructed by assuming population equilibrium with an initial value of F, called Fstart. Length specific mortality is estimated as a two step process in which the population is first decremented for the length specific effects of mortality as follows:

$$N^{*}_{a,len,y_1} = N_{a-1,len,y_1} e^{-\left(PR_{len}F_{start}+M\right)}$$

In the second step, the total population of survivors is then redistributed over the lengths at age *a* by assuming that the proportions of numbers at length at age *a* follow a normal distribution with a mean length derived from the input growth curve (mean lengths at age).

$$N_{a,len,y_1} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^*_{a,len,y_1}$$

where

$$\pi_{len,a} = \Phi\left(len + 1 \mid \mu_a, \sigma_a^2\right) - \Phi\left(len \mid \mu_a, \sigma_a^2\right)$$

where

$$\mu_a = L_\infty\left(1 - e^{-K(a-t_0)}\right)$$

Mean lengths at age can be calculated from a von Bertalanffy model from a prior study as shown in the equation above or mean lengths at age can be calculated directly from an age-length key. Variation in length at age a = σ_s^2 can often be approximated empirically from the growth study used for the estimation of mean lengths at age. If large differences in growth exist between the sexes then growth can be input as sex-specific growth with sex-specific natural mortality. However catch and survey data are still fitted with sexes combined.

This SCALE model formulation does not explicitly track the dynamics of length groups across age because the consequences of differential survival at length at age a do not alter the mean length of fish at age a+1. However, it does more realistically account for the variations in age-specific partial recruitment patterns by incorporating the expected distribution of lengths at age.

In the next step the population numbers at age and length for years after the calculation of the initial population use the previous age and year for the estimate of abundance. Here the calculations are done on a cohort basis. Like in the previous initial population survival equation the partial recruitment is estimated on a length vector.

$$N^*_{a,len,y} = N_{a-1,len,y-1} e^{-\left(PR_{len} F_{y-1} + M\right)}$$

second stage

$$N_{a,len,y} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^*_{a,len,y}$$

Constant M is assumed along with an estimated length-weight relationship to convert estimated catch in numbers to catch in weight. The standard Baranov's catch equation is used to remove the catch from the population in estimating fishing mortality.

$$C_{y,a,len} = \frac{N_{y,a,len} F_y PR_{len} \left(1 - e^{-\left(F_y PR_{len} + M\right)}\right)}{(F_y \; PR_{len}) + M}$$

Catch is converted to yield by assuming a time invariant average weight at length.

$$Y_{y,a,len} = C_{y,a,len} W_{len}$$

The SCALE model results in the calculation of population and catch age-length matrices for the starting population and then for each year thereafter. The model is programmed to estimate recruitment in year 1 and estimate variation in recruitment relative to recruitment in year 1 for each year thereafter. Estimated recruitment in year one can be thought of as the estimated average long term recruitment in the population since it produces the initial population. The residual sum of squares of the variation in recruitment $\sum(Vrec)^2$ is then used as a component of the total objective function. The weight on the recruitment variation component of the objective function (Vrec) can be used to penalize the model for estimating large changes in recruitment relative to estimated recruitment in year one.

The model requires an age-1 recruitment index for tuning or the user can assume relatively constant recruitment over time by using a high weight on Vrec. Usually there is little overlap in ages at length for fish that are one and/or two years of age in a survey of abundance. The first mode in a survey can generally index age-1 recruitment using length slicing. In addition numbers and the length frequency of the larger fish (adult fish) in a survey where overlap in ages at a particular length occurs can be used for tuning population abundance. The model tunes to the catch and survey length frequency data using a multinomial distribution. The user specifies the minimum size (cm) for the model to fit. Different minimum sizes can be fit for the catch and survey data length frequencies.

The number of parameters estimated is equal to the number of years in estimating F and recruitment plus one for the F to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years, and for each survey Q. The total likelihood function to be minimized is made up of likelihood components comprised of fits to the catch, catch length frequencies, the recruitment variation penalty, each recruitment index, each adult index, and adult survey length frequencies:

$$\mathrm{L_{catch}} = \sum_{years}\left(l\,\mathrm{n}(Y_{\mathrm{obs,y}} + 1) - \ln\left(\sum_{a}\sum_{len} \mathrm{Y_{pred,len,a,y}} + 1 \right)\right)^2$$

$$L_{catch\_lf} = -N_{eff} \sum_{y} \left(\sum_{inlen}^{L_\infty} \left(\left(C_{y,len} + 1\right) \ln\left(1 + \sum_{a} C_{pred,y,a,len} \right) - \ln\left(C_{y,len} + 1\right) \right) \right)$$

$$\mathrm{L_{vrec}} = \sum_{y=2}^{Nyears} \left(Vrec_y\right)^2 = \sum_{y=2}^{Nyears} \left(R_1 - R_y\right)^2$$

$$\sum L_{rec} = \sum_{i=1}^{Nrec} \left[\sum_{y}^{Nyears} \left(\ln\left(I_{rec_i, inage_i, y}\right) - \ln\left(\sum_{len}^{L_\infty} N_{y, inage_i, len} * q_{rec\,i} \right) \right)^2 \right]$$

$$\sum L_{adult} = \sum_{i=1}^{Nadult} \left[\sum_{y}^{Nyears} \left(\ln\left(I_{adult_i, inlen+_i, y}\right) - \left(\sum_{a} \sum_{inlen_i}^{L_\infty} \ln\left(N_{pred,y,a,len} * q_{adult\,i}\right) \right) \right)^2 \right]$$

$$\sum L_{lf} = \sum_{i=1}^{Nlf} \left[-N_{eff} \sum_{y} \left(\sum_{inlen_i}^{L_\infty} \left(\left(I_{lf_i,y,len} + 1\right) \ln\left(1 + \sum_{a} N_{pred,y,a,len} \right) - \ln\left(I_{lf_i,y,len} + 1\right) \right) \right) \right]$$

In equation L_{catch_lf} calculations of the sum of length are made from the user input specified catch length to the maximum length for fitting the catch. Input user specified fits are indicated with the prefix "in" in the equations. LF indicates fits to length frequencies. In equation L_{rec} the input specified recruitment age and in L_{adult} and L_{lf} the input survey specified lengths up to the maximum length are used in the calculation.

$$Obj\ fcn = \sum_{i=1}^{N} \lambda_i L_i$$

Lambdas represent the weights to be set by the user for each likelihood component in the total objective function.

Tilefish SCALE Model Configuration and results

Three growth studies are available for golden tilefish (Figure B36 and B37). Turner's aging study was done during the development of the longline fishery (1978-1982). Vidal growth study collected fish in 2008. Von Bertalanffy growth curves from Turner and Vidal were used in the SARC 48 SCALE model. For SARC 58 new age data from the 2007-2012 commercial fishery was used for the development of the updated SCALE model (Figure B43). Von Bertalanffy growth from the updated age information was very similar to the growth curve that Turner estimated (Figure B44). The lack of older fish (> 22 years) in Vidal study made the estimation of L-infinity more difficult. In SARC 48 sex specific models were examined since growth and longevity appears to differ between the sexes with males getting larger but not living as long as females. However, in general model results did not differ greatly between the sex specific and the combined sex models in SARC 48. A total of 3,579 fish were aged from 2007-2012 (Table B15, Figures B43). The estimated growth curve appears to be relatively stable. The estimated von Bertalanffy growth curve did not differ greatly when some of the oldest fish (> 26 year) were omitted from the growth model (Figure B45). However sex information is not available for commercial ages since the fish are landed dressed. Individual annual growth models also did not differ greatly (Figure B46).

Inferences on the assumed natural mortality were made using Turner's aging work since landings were relativity low before this period. Natural mortality may be higher on male than females judging from the number of older fish seen by sex in Turner's sample (Table B18). In general Turner saw fewer older males than females during his study. The oldest fish age in the recent 2007-2012 age data was a 76 cm 36 year old fish in 2008. Twenty-seven fish were aged older than 20 years when all years (2007-2012) were combined. At SARC 48 a natural mortality rate of 0.15 was assumed for males and 0.1 on females. For the south Atlantic stock and the Gulf of Mexico golden tilefish stock an assumption using the Lorenzen m scaled to 0.1 is done in the modeling. The SARC 58 working group concluded that natural mortality was between 0.1 and 0.15 for this assessment. Initial comparison of virgin length frequency distributions and length distributions from Turner's length distributions during the development of the directed fishery seem to suggest m is closer to 0.15 (Figure B47). The base runs were first developed using a natural mortality assumption of 0.15 with sensitivity runs done at 0.1.

The assumed variation around the mean lengths at age was also estimated from the pooled (2007-2012) age length data (Figure B48 and B49). A centered 5 year moving average was used to estimate the increase in the variation at age. The variation at age was held constant at age 17 where the lack of age data causes the estimated variation to decline.

The SCALE model was dimensioned from ages 1-45, lengths 1-140 cm from years 1971-2013 with a combined sex von Bertalanffy mean lengths at age from 2007-2012. The two selectivity blocks (1971-1981, 1982-2008) were initially retained from the SARC 48 assessment. A recruitment index does not exist for tilefish so a straight line index (constant recruitment index) was used as a proxy for the age index. A low penalty weight (0.05) on recruitment variation was use in fitting the recruitment. However with a straight line proxy for the index the weight on the index can also be thought of as a penalty on recruitment variation. The SCALE model did pick up a recruitment signal from the commercial expanded length frequency distributions. The CPUE indices were fit to fish sizes that were approximate according to the landing length frequency distributions. Turner's CPUE series was fit to 47+ cm fish and the Weighout and VTR series were fit to 37+ cm fish.

The working group discovered an error in the SARC 48 SCALE configuration. The NOAA toolbox SCALE model is designed to fit numbers at age indices. The model was recoded to fix biomass indices since commercial CPUE indices are in biomass. This did appear to aid in the model's ability in fitting the VTR CPUE trends cause by year class effects (Figure B50).

The catch length frequency distributions are an important component of the SCALE model. Turner collected landing length frequency information in 1974 and from 1976 to 1982. Note that Turner's length frequency data is only available in 5 cm blocks. NEFSC expanded landing size information exist from 1995 to 1999 and from 2002 to 2013. There appears to be a shift to smaller fish sizes between 1981 and 1982 in Turner's size distributions. Two selectivity blocks were assumed in the SCALE model (1971-1981, 1982-2008). The sensitivity of assuming a single selectivity block (run 3) over the time series was also tested. The working group also decided to shift the second selectivity block by one year so that the second block starts in 1983 (see ASAP model section below).

The SCALE model time series starts in 1971 at the beginning of the directed tilefish longline fishery. The SCALE model tends to estimate a low Fstart which is expected since this is the equilibrium F that is assumed to occur before the beginning the time series before the directed longline fishery started.

Relatively little differences are seen in the results among the different model configurations (Table B19, Figure B51). The models generally suggest the large decline in the biomass with the development of the directed longline fishery and then a small increase in the stock since the mid 1990s. Unlike the surplus production model the SCALE model results in a large shift in the q between the Weighout and VTR series which produces a large decline in the stock (Figure B52). This is likely the result of fitting the year class dynamics in the vtr series along with the tracking of cohorts information through the catch at length. Addition CPUE data from three vessels were collected from NY fishermen logbooks to extend the VTR series further in the past due to concerns that the model may be estimating a unrealistic increase in efficiency because of the lack of information during the mid-1990s. Adding this CPUE data from 1991-1994 did lower the change in q from the Weighout to the VTR series (Figure B53). In addition a sensitivity run which combines the Weighout and VTR series also prevents a change in q which results in higher biomass and lower F at the end of the time series.

Run 10 is the final working group run which was configured similar to the final ASPIC and final ASAP run (Table B19). Final runs had a terminal year of 2012 and included the additional 1991-1994 New York CPUE data in the VTR series. Results of the final SCALE runs are summarized in Figures B54 through B59. A comparison of the final SARC 48 and SARC 58 ASPIC and SCALE models and the new SARC 58 final ASAP model (see below) is shown in Figure B60. The size and age structure models result in similar estimates of biomass and fishing mortality relative to the more optimistic ASPIC model results.

There is a general concern with the lack of data and with the data independence used in the SCALE model. A general lack of tuning information may result in little difference between the sensitivity runs. The strongest evidence for the model estimating unrealistic low biomass and high fishing mortality came from a comparison of the estimated population numbers of older fish (10+ 15+ and 20+) with the actually number of fish aged in the commercial sampling program (Table B20). It seems unrealistic that the age sample accounted for over 25% of the entire population for age 20+ fish.

Tilefish fishing industry advisors participating in the working group meeting stated that large tilefish (in the extra large market category and larger, mainly larger/older than 75 cm/age 8) are not often targeted by the commercial longline fleet. The largest tilefish are worth a lower price than smaller fish, due mainly to lower relative meat yield per fish. The largest tilefish are known to occupy habitat that is a) difficult to fish due to bottom characteristics (e.g., burrows in canyon walls) or located in deeper water that is harder to fish efficiently and b) presents availability issues due to conflicts with lobster fishing gear. The largest tilefish also have an increased chance to escape the longline gear due to pulled hooks and leader breakage. All of these factors combine to make it likely that the fishery selection curve for tilefish is strongly dome-shaped. The current version of SCALE does not have the ability to incorporate a dome shape selection pattern. Therefore the working group did not accept the SCALE model basis for stock status determination and pursued the development of an ASAP model which directly fits the catch at age data.

ASAP Model

ASAP (Age Structured Assessment Program v2.0.20, Legault and Restrepo 1998) and the technical manual can be obtained from the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/). ASAP is an age-structured model that uses forward computations assuming separability of fishing mortality into year and age components to estimate population sizes given observed catches, catch-at-age, and indices of abundance. The separability assumption is partially relaxed by allowing for fleet-specific computations and by allowing the selectivity at age to change in blocks of years. Weights are input for different components of the objective function which allows for configurations ranging from relatively simple age-structured production models to fully parameterized statistical catch at age models. The objective function is the sum of the negative log-likelihood of the fit to various model components.

ASAP Model Inputs and Formulation

Maturity at age estimates came from McBride et al. (2013). Maturity at age was estimated using a logistic model from 58 female fish which that had maturation determined through histology (Figure B61). SARC 48 used at maturation curve based on macroscopic determination at length from Vidal. Conversion of the maturity at length curve to age was similar to the new update histological maturity at age curve (Figure B61). The A50 is slightly older the 5 years.

Four different ASAP formulation were initially developed, 1) catch at age to 20+ with year specific catch at age expansions for years where age data exists (2007, 2009-2012), 2) catch at age to 20+ with pooled age length key used for all years in the model, 3) catch at age to 10+ with year specific catch at age expansions for years where age data exists (2007, 2009-2012), 4) catch at age to 10+ with pooled age length key used for all years in the model. Relatively small differences in the catch at age exist between using the pool age length key and using year specific keys for years where age data exists (Figure B62). There is some evidence that year specific expansion show a slightly stronger 2005 year class tracking through the catch at age relative to using the pooled age length key. The marginal improvement in the tracking of the 2005 year class in the raw age data suggests that the uses of a pool age length key is not producing a large change in the model results. These may be partly a reflection of the difficultly in aging tilefish. Strong year class effects are seen in the catch at length and CPUE data but the error in the aging of tilefish plus or minus a year could result in the smearing of year class effects. Therefore there may not be a significant improvement in model results through production aging to produce a year specific catch at age for this stock.

Year specific expansion could not be estimated in 2008 due to missing age information for the smaller size fish in that year. Mean weight at age show variability increases for ages older than 20 due to the limit number of 20+ fish aged (Figures B63). Like the SCALE model the ASAP model time series was estimated from 1971 to 2013. For all four model formulations the average mean weights at age for years which possessed data was used in years which had missing information (1971-1973, 1975, 1983-1994, 2000-2001) (Table B21, Figures B64 and B65).

Initial runs assumed a flattop selectivity pattern (estimating selective at age while fixing 7+ fish at full selectivity 1971-1981 and 6+ for 1982-2013). Initial working group exploratory runs are shown in Table B22 and Figures B66 and B67. Runs 1 through 4 illustrate the effect of the 4 different initial model formulations describe above (Figure B66). There was very little difference between runs that used a pooled age length key for all years verse runs that used year specific keys when age exists. Comparison of 10+ verse 20+ formulations also show little difference between runs in years where length data exist at the end of the time series. However recruitment, SSB and fishing mortality did differ in the 1980s and early 1990s where significant data gaps exist. The working group was therefore concerned with a possible over interpretation of stock recruit based biological reference points that relied on unstable estimates of SSB and recruitment. Therefore the working group developed proxy based biological reference points.

Sensitivity runs 5 through 13 were developed from run 2 (20+ using year specific keys when data exists with m=0.15). Run 5 tested the effect of m=0.1. Run 6 combined the Weighout and VTR CPUE series and run 7 tested the effect of including the 1991 to 1994 data in the VTR series. The combing of the Weighout and VTR series had a similar effect as seen in the SCALE model which resulted in higher biomass at the end of the time series. The affects on the change in q was similar as observed with the SCALE model (Figure B68). However there is little justification for the combining of the Weighout and VTR series. The combining of the two series also results in some tension in the model which is reflected in the increase in the retrospective pattern of run 6 (Figures B69 and B70). Run 9 had a terminal year of 2012 and runs 10-12 tested the effect of three different fixed dome shaped selectivity patterns (Figure B71). Run 13 tested the effect of using a single selectivity block.

In general the ASAP model flattop selectivity results were very similar to the SCALE model results despite the different approaches for modeling growth. In addition, the fitting of catch at age data directly in the ASAP model did not result of in significantly more 20+ fish in the population at the end of the time series. Therefore flattop selectivity runs using ASAP also did not appear to be very believable when comparing the proportion of the population in the age sample (Table B23). Failure in passing this believability test and commercial fishing practice described above led the working group to the development of a dome shaped ASAP models.

The working group developed two different dome formulations using the pooled age length key for the catch at age in all years and a natural mortality rate of 0.15. One formulation (run 14, 17-22, 26-27) modeled the catch at age to 10+ with estimation of selectivity at each age for the older ages (7-10+) and the other formulation (run 16 and 25) expanded the catch at age out to 20+ and modeled selectivity as a double logistic curve (Table B24, Figure B72). Twelve of the working group dome shaped selectivity runs including the preferred working group final run 27b are summarized in table B24 and Figure B73. In general similar results were seen between the 10+ and 20+ runs. In general, the 20+ run tend to have more convergence issues then the 10+ formulation. Initial SSB was sensitive to changes in the selectivity blocks and to changes in fitting the length frequency data in 1974. Information on when the second selectivity block should start was lacking due to missing length data from 1983-1994. The last year in Turner's length data (1983) suggests a greater proportion of smaller fish in the catch. However information is lacking on whether this could have been due to an increase in recruitment or a shift in selectivity. The working group decided to put the second selectivity block after the last year of Turner's length data in 1983. The working group also decided not to fit the 1974 length data since this distribution was very different then the other years in the 1970s and since a limited sample size exists for this year with only 194 fish measured. Starting the model in 1995 (run 26) scaled the biomass lower at the end of the time series. Combining the Weighout and VTR series also did not produce as large an increase in biomass at the end of the time series as seen with the flattop SCALE and ASAP runs. This may be a function of the increased flexibility with the dome shape models through changes in selectivity between the blocks. The input, diagnostics, and results for the working group final ASAP model 27b are summarized in Figures B74 to B91. As expected the final dome shaped model did produce more older fish in the population relative to the fat-topped models (Table B25). A profile on m of the final ASAP model suggests an assume m=0.15 is appropriate (Figure B92).

Preferred ASAP Model Results

Fishing mortality (F_{MULT}) increased with the development of the directed longline fishing from near zero in 1971 to 1.2 in 1987. Fishing mortality was relatively high but fluctuated from 0.3 to 1.3 from 1987 to 1997. Fishing mortality has been decreasing since 1997 to 0.26 in 2011 and 0.27 in 2012. F_{MULT} MCMC 90% confidence intervals were 0.201 – 0.37 in 2012; (Table B26; Figures B93 and B94).

Mean recruitment was around 1.2 million for age-1 recruits. Recruitment was estimated to be relatively low at the end of the time series (mean recruitment of 0.7 million from 2009-2002). Several stronger year classes were produced in 1982, 1988, 1992-1993, 1998-1999, and 2005. Large uncertainty surrounds the strength of the model estimated 1982 year class since very little data exists in the model in the 1980s and early 1990s. Aging error due to the difficultly in aging tilefish and the use of a pooled age length key may also contribute to the estimation of two consecutive year classes in 1982-1983 and 1998-1999 instead of the estimation of single year class for each period.

Spawning stock biomass declined substantially early in the time series from 27,044 metric tons in 1974 to 1,221 metric tons in 1999, lowest in the time series. Thereafter, SSB has increased to 5,229 metric tons in 2012. Spawning stock biomass MCMC 90% confidence intervals were 3,275 mt to 7,244 mt in 2012; (Table B26; Figures B93 and B94).

Summary of Working Group Meeting Conclusions

Over the last twenty years, the commercial length and more recent age data indicate that increases in fishery CPUE and model estimated biomass are predominantly due to the influence of strong year classes in 1999 and 2005. The 2005 year class has now passed through the fishery, and recently fishery CPUE has started to decline. Process error in the ASPIC model associated with the recent large year classes has increased at the end of the time series due to an assumed constant recruitment/growth parameter. The WG concluded that the ASPIC production model does not adequately characterize the recent population and fishery trends of tilefish, and therefore the ASPIC results are not sufficient to evaluate the status of the stock.

The WG also examined results obtained from an alternative forward projecting age/size structured model (SCALE), in order to include length and age data in modeling the dynamics of the stock. The SCALE model incorporates population growth and length information into the model framework. This allows for the estimation of strong recruitment events which can be seen in the commercial length frequency distributions over time. However the overall lack of data and issues with independence of the data sources is a source of concern with the SCALE model results. The lack of a recruitment index, inability to estimate uncertainty using MCMC, and the inability of the current SCALE model to incorporate a dome-shaped selection curve, are also sources of uncertainty. The SCALE model results suggest that the ASPIC surplus production model may have overestimate the productivity of the stock.

Tilefish fishing industry advisors participating in the WG meeting stated that large tilefish (in the extra large market category and larger, mainly larger/older than 75 cm/age 8) are not often targeted by the commercial longline fleet. The largest tilefish generally are worth a lower price than smaller fish, due mainly to lower relative meat yield per fish. The largest tilefish are known to occupy habitat that is a) difficult to fish due to bottom characteristics (burrows in canyon walls) and b) presents availability issues due to conflicts with lobster fishing gear. The largest tilefish also have an increased chance to escape the longline gear due to pulled hooks and leader breakage. All of these factors combine to make it likely that the fishery selection curve for tilefish is strongly dome-shaped.

In response to these noted concerns with the ASPIC surplus production and SCALE age-length model, the WG used the ASAP statistical catch at age model for stock status determination, since the ASAP has the ability to model recruitment, incorporate annual fishery age compositions directly, estimate uncertainty using MCMC, and model dome-shaped fishery selectivity .

TOR 5. State the existing stock status definitions for "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; point estimates for B_{MSY}, $B_{THRESHOLD}$, F_{MSY} and MSY or for their proxies) and provide estimates of their uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.

The existing stock status determination is based on the ASPIC surplus production model from SARC 48. SARC 48 concluded overfishing was not occurring and the stock was not overfished. In SARC 48 the ASPIC model indicated that the stock was above B_{MSY}. However, SARC 48 concluded that the stock was not yet rebuilt based on concerns with the catch size distributions and process error cause by year class effects within the ASPIC model.

Biological reference points were redefined in this assessment based on the ASAP model. The working group did not develop stock recruitment based biological based reference points due to the uncertainty in the recruitment and SSB estimates during the 1980s and 1990s. Stock recruit based biological reference point would likely be sensitive to plus group decisions. Therefore the working group based biological reference points on a percent SPR proxy. Figure B95 shows yield per recruit and SPR curves for the final working group ASAP model run 27b. The long lifespan and relatively low M would suggest that a fishing mortality rate reference point of $F_{40\%}$ or higher %MSP would be appropriate. However, information provided by fishing industry advisors and ASAP model results indicate that it is likely that the fishery selection curve for tilefish is strongly dome-shaped. Further, under the constant landings quota of 905 mt since implementation of the FMP in November 2001, the stock has increased to the new estimate of SSB_{MSY}. In general, improvements to the stock have occurred under the 905 mt quota implemented in 2002 which is evident in the raw catch size and fishery CPUE data. Fishing mortality rates have averaged 0.367 since 2002, and the new yield per recruit analysis shows that this fishing rate corresponds to about $F_{25\%}$. Given these factors, the WG recommends that $F_{25\%}$ = 0.370 and the corresponding SSB_{MSY} = 5,153 mt, $SSB_{THRESHOLD}$ = 2,577 mt, and MSY = 1,029 mt be adopted as the new biological reference point proxies for this assessment. Working group dome-shaped run sensitivity runs, results and biological reference points are summarized in Table B27. Results for $F_{40\%}$ and $F_{30\%}$ associated reference points for the final run are also compared in Table B28. SSB_{MSY} was estimated from long term projections fishing at the F_{MSY} proxy and re-sampling from the CDF of recruitment using entire times series (1971-2013). The 90% confidence intervals from long term projections were 4,155 mt to 6,540 mt.

TOR 6. Evaluate stock status with respect to the existing ASPIC model (from previous peer reviewed accepted assessment) and with respect to a new model developed for this peer review. In both cases, evaluate whether the stock is rebuilt.

a. When working with the existing model, update it with new data and evaluate stock status (overfished and overfishing) with respect to the existing BRP estimates.

b. Then use the newly proposed model and evaluate stock status with respect to "new" BRPs and their estimates (from TOR-4).

The reference points from the previous 2009 SAW 48 assessment are based on the ASPIC surplus production model and cannot be compared to the current assessment ASAP model results and reference points. The current assessment using an updated ASPIC model provides the following updated reference points: B_{MSY} = 12,950 mt, F_{MSY} = 0.139 and MSY = 1,800 mt. Based on the current ASPIC model results and updated reference points, F in 2012 is estimated to be 0.053, 38% of F_{MSY} and stock biomass in 2012 is estimated to be 15,150 mt, 17% above B_{MSY}. With respect to the existing reference points from the 2009 SAW 48 assessment, fishing mortality in 2012 was estimated to be 0.053, 33% of F_{MSY} = 0.16, and total biomass in 2012 was estimated to be 15,150 mt, 133% of B_{MSY} = 11,400 mt. With regards to this term of reference, note that for the ASPIC surplus production model it may not be appropriate to compare stock status relative to biological reference points from a different model run. All ASPIC model results suggest the stock is rebuilt. However, the SARC 48 review panel accepted the ASPIC model but concluded that the ASPIC model is likely over optimistic and that the stock has not rebuilt above B_{MSY}.

The SCALE model was not accepted for stock status determination in SARC 48. In addition, the updated SCALE model for this assessment was also not used for status determination due to the inability for modeling a dome-shaped selectively pattern within the model. However flattop yield per recruit estimates were similar to flattop estimates using the ASAP model.

The Golden Tilefish stock was not overfished and overfishing was not occurring in 2012 relative to the new biological reference points. A new model (ASAP statistical catch at age) is used in this assessment to incorporate newly available length and age data and better characterize the population dynamics of the stock. Comparison of ASAP model biological reference points to ASPIC model biological reference points was not done since the measure of fishing mortality (F_{MULT}) and biomass (SSB) has changed with the new model.

The new model indicates that the stock was at high biomass and lightly exploited during the early 1970s. As the longline fishery developed during the late 1970s, fishing mortality rates increased and stock biomass decreased to a time series low by 1999. Since the implementation of constant landings quota of 905 mt in 2002, the stock has increased by 2012 to the new biomass reference point (SSB_{MSY} proxy).

The fishing mortality rate was estimated to be 0.275 in 2012, below the new reference point F_{MSY} proxy = $F_{25\%}$ = 0.370 (Figure B94). There is a 90% probability that the fishing mortality rate in 2012 was between 0.198 and 0.372. SSB was estimated to be 5,229 mt in 2012, about 101% of the new reference point SSB_{MSY} proxy = $SSB_{25\%}$ = 5,153 mt. $SSB_{THRESHOLD}$ was estimated to be 2,577 mt. There is a 90% chance that SSB in 2012 was between 3,275 and 7,244 mt. The average recruitment from 1971 to 2012 is 1.24 million fish at age-1. Recent large year classes have occurred in 1998 (2.35 million), 1999 (2.39 million) and 2005 (1.85 million).

TOR 7. Develop approaches and apply them to conduct stock projections and to compute the statistical distribution (e.g., probability density function) of the OFL (overfishing level) and candidate ABCs (Acceptable Biological Catch; see Appendix to the SAW TORs).

a. Provide numerical annual projections (2-3 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. Use a sensitivity analysis approach in which a range of assumptions about the most important uncertainties in the assessment are considered (e.g., terminal year abundance, variability in recruitment).

b. Comment on which projections seem most realistic. Consider the major uncertainties in the assessment as well as sensitivity of the projections to various assumptions.

c. Describe this stock's vulnerability (see "Appendix to the SAW TORs") to becoming overfished, and how this could affect the choice of ABC.

A five year average of stock and catch mean weights at age was used in the YRP and in all AGEPRO projections (Table B29). The 905 ACL was assumed for the removals in the two bridge years of the projections (2013-2014). Below is a description of the working group unadjusted recruitment projections. The SARC 58 panel concluded that projections should be done using 2010-2012 age-1 recruitment estimates adjusted to the time series geometric mean due to the lack of information to inform the estimate of recruitment at the end of the time series within the model. The adjusted projections from SARC 58 are described in Appendix B2.

In the unadjusted projections the fishing mortality in the bridge years increased to 0.28 in 2012 to 0.45 in 2013. Higher fishing morality in the bridge years and lower projected catches in 2014-2015 is a result of the assumed 905 catch in 2012-2013 and overall lower estimated recruitment at the end of the time series (2009-2012). The projected overfishing catch at F_{MSY} in 2015 is 759 mt. The estimated recruitment at the end of the times series is uncertain due to the lack of information to inform the recruitment estimate in the ASAP model (Figure B96). The 90% CI from projections assuming F_{MSY} = $F_{25\%}$ = 0.37 can be seen in Figure B97. The F_{MSY}

projection compared to a projections at F=0 and constant quota projections at 905 mt and 800 mt are summarized in Figure B98. A constant 905 mt projection suggests that overfishing would continue from 2013 to 2017.

ABC and OFL estimates that follow the Mid-Atlantic SSC p* approach from unadjusted projections are summarized in Table B30. The size of the uncertainty buffer between the OFL and the ABC is determined from the input uncertainty distribution on the OFL and the ratio of the SSB to SSB_{MSY}. Estimates assuming a 100% CV on the OFL and the model estimated 27% CV around the OFL in 2015 are also given in Table B30.

The new assessment model estimates a dome shaped selectivity based on probable refuge effects due to conflicts with lobster and trawl gear, unfished areas on the south flank of Georges Bank, effects of targeting incoming year classes, and avoiding the extra large fish due to price reductions. Uncertainty still surrounds the estimates of the extent of doming in the fishery selectivity since a fishery independent survey does not exist to help inform the shaped the selectivity curve. Unknown effects on tilefish CPUE due to competition/interference from increased dogfish abundance also introduce uncertainty in interpreting CPUE from this fishery as a measure of stock abundance.

The overall lack of data within the ASAP model and questions surrounding the estimates of selectivity are a general concern. However the ASAP model which incorporates the species lifespan, growth, and recruitment dynamics can more appropriately match the year class dynamics seen in the commercial size distributions and CPUE patterns which result in process error in the ASPIC model.

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

New SARC 58

1) Develop an industry based survey using two or three designated fishing trips per year. Industry based survey trips would follow a design similar to a fishery independent survey and collect more intensive size and catch information on a haul by haul basis. However a reduction in catch rates likely occur on these survey trips relative to normal fishing operation. The benefits of a survey design to the stock assessment will likely surpass a more intensive and burdensome haul by haul data collection on trips during normal fishing operation. The WG suggests this science could be funded through the Cooperative Research Program, the habitat assessment improvement plan, or MAFMC research set-aside (RSA).

2) Increase the sampling of maturity at size and age and commercial landings at size and age.

Pending research recommendations from the 2013 MAFMC SSC, 2009 SARC 48, 2005 SARC 41, and 1999 MAFMC SSC Reviews

1). For the study fleet project and any potential semi fishery independent survey, include additional information on conflicts with lobster and trawl gear, the possibility of unknown effects on tilefish CPUE due to competition/interference from an increased abundance of dogfish, the unknown effects of bait type on tilefish CPUE (e.g., substitutes for the preferred squid).

No progress.

2). Develop protocols to ensure consistency between dealer, VTR, and IVR reports of the tilefish landings.

Work in progress. The IVR is no longer the principle data source for monitoring this fishery. The dealer reports are used to monitor the fishery and are consistent with the VTR data. The NERO has been working to integrate tilefish into the expanding QA/QC process, and inconsistencies between dealer and VTR reports are being identified and addressed more consistently. Removing the IVR requirement could however require a FMP amendment, as the IVR is not specifically mentioned in the list of framework-able issues. The NERO has discussed moving the IVR report to an online report through the Fish-Online webpage. So that might be another option if there is interest in keeping some form of dedicated IFQ report.

3). Develop protocols to ensure consistency in market category designation among fishing ports.

Work in progress in development of a large medium code in the dealer data and in the collection of biological information from the large medium market category. These changes are expected to be implemented in 2014. NERO should follow up with dealers regarding accurate and consistent market category reporting across all sizes. For example, industry noted inconsistency in the categorization of the smallest landed tilefish into different categories in NY (KK or tiny, meaning smaller than a kitten) and NJ (extra small).

4) Conduct a hook selectivity study to determine partial recruitment changes with hook size. Determine catch rates by hook size. Update data on growth, maturity, size structure, and sex ratios at length.

Hook selectivity study was not done. Funding was initially available, but subsequently rescinded. Updated growth, maturity, and size structure studies were completed during the 2009 SARC 48 assessment.

5) Develop a bioeconomic model to calculate maximum economic yield per recruit.

No progress.

6) Incorporate auxiliary data to estimate r independent of the ASPIC model.

No progress. The 2005 SARC 41 questioned if this can be done or should be done. However the 2009 SARC 48 SCALE results suggest that r is overestimated in the ASPIC model. The WG does not consider the ASPIC model to be sufficient to evaluate the status of the stock and has explored other models in this SARC 58 assessment.

7) Understand the role of tilefish in creating secondary habitats through their burrowing activity, thereby increasing diversity and the extent to which this diversity is compromised by the removal of these ecosystem engineers by the fishery.

No progress.

8) Understand the causes in the pattern and variability in recruitment.

No progress.

9) Quantify and understand the spatial dynamics of the stock and the fishery (specifically, assess historical changes in the distribution of fishing effort, develop haul-by-haul information on the spatial and temporal distribution of catch, and evaluate the potential of a rigorously-designed study fleet program).

Work in progress, through examination of the 2008 study fleet data and ongoing use of the VTR as the source of information for the fishery dependent CPUE index of stock abundance.

10) Assess the potential for and extent of local population structure.

No recent progress. The work of Katz et al. (1983) used significant differences in allelic frequencies to identify distinct stocks between mid-Atlantic and South Atlantic tilefish. Those authors also felt that certain aspects of golden tilefish distribution, life history and ocean circulation patterns supported their two stock hypothesis for the United States Atlantic.

11) Assess coherence between north and south Atlantic stocks and evaluate the effects of climate indices in driving stock dynamics.

No progress.

12) Evaluate the potential effect of time-varying catchability on assessment models that rely on commercial CPUE data.

Work in progress, through examination of catchability trends in SCALE and ASAP models developed for the SARC 58 assessment.

13) Evaluate the potential for a stakeholder survey to assess extent of population outside of normal fishing area.

No progress.

14). Explore the influence of water temperature and other environmental factors on trend in the commercial fishery CPUE index of stock abundance.

Work in progress, but note that extremely limited catch and temperature data are available to address this RR. Available data was examined in the SARC 58 assessment in TOR 3.

Completed Research Recommendations

1) Collect data on spatial distribution and population size structure. This can help answer the question of the existence of a possible dome shaped partial recruitment pattern where larger fish are less vulnerable to the fishery due to spatial segregation by size.

This research recommendation was completed in the study fleet data during the 2009 SARC 48 assessment.

2) Continue to develop the forward projecting catch-length model as additional length data becomes available. Investigate the influence of adding a tuning index of abundance and model estimated partial recruitment (logistic) to the catch-length model.

This research recommendation was completed during the 2009 SARC 48 assessment. The improved catch-length model was renamed as the SCALE model.

3) Collect appropriate effort metrics (number and size of hooks, length of main line, soak time, time of day, area fished) on a haul basis to estimate commercial CPUE.

This research recommendation was completed with the study fleet analysis during the 2009 SARC 48 assessment.

4) Initiate a study to examine the effects of density dependence on life history parameters between the 1978-82 period and present.

This research recommendation was completed with the updated growth and maturity study during the 2009 SARC 48 assessment.

5) Increased observer coverage in the tilefish fishery to obtain additional length data.

Consider completed due to increased port sampling to obtain sufficient lengths from the landings. Discards in the fishery are relatively small and adequately sampled.

6) Ensure that market category distributions accurately reflect the landings. Sampling of the commercial lengths has improved over the last six years. Small, kitten, and medium market category distributions can shift from one year to the next due to the growth of a strong year class. Intensive length sampling of the landings by market categories is needed to account for possible shifts in the distribution within a market category over time. Similar landings distributions were seen among the observer, study fleet, and commercial port sampling data sources.

Consider completed as progress has been made to address this research recommendation; superseded by new SARC 58 research recommendation 2.

7) Ensure that length frequency sampling is proportional to landings by market category.
Commercial length sampling has been sporadic during the beginning of the time series. In particular length samples from the large market category have been lacking. However commercial length sampling has greatly improved over the last six years with a higher proportion of the sampling coming from Montauk where most of the fish are landed.

Consider completed as progress has been made to increase port sampling intensity. Recommend that sampling remain at least at current levels in the future. See current research recommendations.

8) Increase and ensure adequate length sampling coverage of the fishery.

Consider completed, superseded by new SARC 58 research recommendations 1 and 2.

9) Update age- and length- weight relationships.

Consider completed for SARC 58.

10) Update the maturity-at-age, weight-at-age, and partial recruitment patterns.

Consider completed for SARC 58.

11) Develop fork length to total length conversion factors for the estimation of total length to weight relationships.

This work was completed in SARC 41.

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Tables

Table B1. Landings of tilefish in live metric tons from 1915-2008. Landings in 1915-1972 are from Freeman and Turner (1977), 1973-1989 are from the general canvas data, 1990-1993 are from the Weighout system, 1994-2003 are from the dealer reported data, and 2004-2012 is from Dealer electronic reporting. - indicates missing data.

year	mt	year	mt	year	mt
1915	148	1960	1,064	2005	676
1916	4,501	1961	388	2006	907
1917	1,338	1962	291	2007	749
1918	157	1963	121	2008	737
1919	92	1964	596	2009	864
1920	5	1965	614	2010	922
1921	523	1966	438	2011	864
1922	525	1967	50	2012	834
1923	623	1968	32		
1924	682	1969	33		
1925	461	1970	61		
1926	904	1971	66		
1927	1,264	1972	122		
1928	1,076	1973	394		
1929	2,096	1974	586		
1930	1,858	1975	710		
1931	1,206	1976	1,010		
1932	961	1977	2,082		
1933	688	1978	3,257		
1934	-	1979	3,968		
1935	1,204	1980	3,889		
1936	-	1981	3,499		
1937	1,101	1982	1,990		
1938	533	1983	1,876		
1939	402	1984	2,009		
1940	269	1985	1,961		
1941	-	1986	1,950		
1942	62	1987	3,210		
1943	8	1988	1,361		
1944	22	1989	454		
1945	40	1990	874		
1946	129	1991	1,189		
1947	191	1992	1,653		
1948	465	1993	1,838		
1949	582	1994	786		
1950	1,089	1995	666		
1951	1,031	1996	1,121		
1952	964	1997	1,810		
1953	1,439	1998	1,342		
1954	1,582	1999	525		
1955	1,629	2000	506		
1956	707	2001	874		
1957	252	2002	851		
1958	672	2003	1,130		
1959	380	2004	1,215		

Table B2. Percent landings by statistical area. Landings before 1990 are taken from the general canvas data. Percent landings after 1993 are estimated from the AA tables. Most of the other category comes from statistical area 613.

year	unknown	626	622	616	537	526	525	other
1962	100%	0%	0%	0%	0%	0%	0%	0%
1963	65%	0%	0%	0%	4%	28%	0%	3%
1964	83%	0%	0%	0%	4%	14%	0%	0%
1965	83%	0%	0%	0%	1%	16%	0%	0%
1966	97%	0%	0%	0%	0%	1%	1%	0%
1967	96%	0%	0%	0%	0%	4%	0%	0%
1968	96%	0%	0%	0%	1%	0%	0%	3%
1969	93%	0%	0%	0%	2%	4%	0%	1%
1970	87%	0%	0%	0%	8%	5%	0%	0%
1971	99%	0%	0%	0%	0%	0%	0%	0%
1972	92%	0%	0%	1%	1%	0%	0%	6%
1973	0%	0%	0%	62%	16%	0%	0%	21%
1974	0%	0%	0%	51%	27%	0%	0%	22%
1975	0%	0%	0%	48%	34%	8%	0%	10%
1976	0%	0%	0%	58%	28%	13%	0%	1%
1977	1%	0%	0%	44%	32%	22%	0%	1%
1978	0%	0%	0%	29%	40%	31%	0%	0%
1979	0%	0%	0%	18%	37%	45%	0%	0%
1980	0%	0%	0%	22%	34%	44%	0%	0%
1981	0%	0%	0%	28%	37%	35%	0%	0%
1982	0%	0%	0%	19%	52%	27%	0%	2%
1983	0%	1%	0%	22%	54%	23%	0%	0%
1984	0%	1%	3%	9%	53%	34%	0%	1%
1985	0%	0%	2%	25%	33%	38%	2%	1%
1986	0%	0%	1%	28%	44%	25%	3%	1%
1987	0%	0%	0%	12%	53%	32%	1%	2%
1988	0%	1%	2%	21%	41%	32%	0%	2%
1989	0%	0%	1%	63%	9%	26%	1%	1%
1990	0%	2%	0%	15%	14%	36%	0%	33%
1991	0%	0%	1%	64%	25%	1%	0%	10%
1992	0%	0%	1%	22%	70%	5%	1%	1%
1993	0%	0%	2%	14%	72%	7%	3%	2%
1994	0%	0%	3%	12%	32%	2%	25%	26%
1995	0%	0%	0%	8%	74%	4%	7%	7%
1996	0%	0%	0%	45%	40%	11%	0%	5%
1997	0%	0%	0%	39%	57%	0%	0%	3%
1998	0%	0%	0%	10%	78%	1%	2%	9%
1999	0%	0%	0%	39%	51%	0%	1%	9%
2000	0%	0%	0%	65%	31%	3%	1%	1%
2001	0%	0%	0%	59%	34%	6%	0%	1%
2002	0%	0%	0%	41%	43%	10%	1%	5%
2003	0%	0%	0%	42%	49%	2%	2%	5%
2004	0%	0%	0%	35%	56%	4%	2%	3%
2005	0%	27%	0%	24%	47%	1%	0%	1%
2006	0%	18%	0%	44%	31%	2%	0%	5%
2007	0%	0%	1%	33%	48%	0%	0%	17%
2008	0%	0%	5%	42%	32%	0%	0%	21%
2009	0%	0%	3%	35%	42%	0%	0%	20%
2010	0%	0%	1%	47%	43%	0%	0%	10%
2011	0%	0%	0%	41%	52%	0%	0%	7%
2012	0%	0%	0%	44%	52%	0%	0%	4%

Table B3. Landings of tilefish (mt, live) by gear. Number of length measurements are in parentheses. Landing before 1990 are from the general canvas data. Percent by gear per year are also given.

	Gear				Percent by Gear		
Year	longli	traw	othe	Total	longline	trawl	other
1962	0	167	2	169	0%	99%	1%
1963	0	121	0	121	0%	100%	0%
1964	0	596	0	596	0%	100%	0%
1965	0	614	0	614	0%	100%	0%
1966	0	437	0	437	0%	100%	0%
1967	0	51	0	51	0%	100%	0%
1968	0	30	0	30	0%	100%	0%
1969	0	30	0	30	0%	100%	0%
1970	0	57	1	58	0%	99%	1%
1971	0	62	1	62	0%	99%	1%
1972	93	26	2	121	77%	21%	2%
1973	370	24	1	394	94%	6%	0%
1974	531	33	22	586	91%	6%	4%
1975	588	111	11	710	83%	16%	2%
1976	950	58	1	1,010	94%	6%	0%
1977	1,772	309	1	2,082	85%	15%	0%
1978	2,938	309	10	3,257	90%	9%	0%
1979	3,362	449	156	3,968	85%	11%	4%
1980	3,794	94	0	3,889	98%	2%	0%
1981	3,366	128	5	3,499	96%	4%	0%
1982	1,935	49	6	1,990	97%	2%	0%
1983	1,857	8	11	1,876	99%	0%	1%
1984	2,003	6	1	2,009	100%	0%	0%
1985	1,929	31	0	1,961	98%	2%	0%
1986	1,874	76	0	1,950	96%	4%	0%
1987	3,029	180	0	3,210	94%	6%	0%
1988	1,319	42	0	1,361	97%	3%	0%
1989	421	33	0	454	93%	7%	0%
1990	852	22	0	874	98%	2%	0%
1991	1164	25	0	1,189	98%	2%	0%
1992	1497	155	0	1,653	91%	9%	0%
1993	1597	241	0	1,838	87%	13%	0%
1994	764	22	0	786	97%	3%	0%
1995	618	47	1	666	93%	7%	0%
1996	1005	111	4	1,121	90%	10%	0%
1997	1724	79	7	1,810	95%	4%	0%
1998	1198	134	10	1,342	89%	10%	1%
1999	486	28	11	525	92%	5%	2%
2000	461	38	7	506	91%	7%	1%
2001	822	52	0	874	94%	6%	0%
2002	767	83	2	851	90%	10%	0%
2003	1004	124	2	1,130	89%	11%	0%
2004	905	211	99	1,215	75%	17%	8%
2005	495	20	160	676	73%	3%	24%
2006	717	32	158	907	79%	3%	17%
2007	700	9	40	749	94%	1%	5%
2008	652	13	72	737	88%	2%	10%
2009	848	15	1	864	98%	2%	0%
2010	888	29	5	922	96%	3%	1%
2011	849	13	2	864	98%	2%	0%
2012	823	10	1	834	99%	1%	0%

Table B4. Landings of tilefish (mt, live) by state. Number of length measurements are in parentheses. Landings before 1990 are from general canvas data. Percent by state per year are also given.

														Percent by State					
Year	ME		MA		RI		NY		NJ		other	Total		ME	MA	RI	NY	NJ	other
1962	0		28		31		57		42		12	169		0%	16%	18%	34%	25%	7%
1963	0		42		46		13		14		6	121		0%	35%	38%	10%	12%	5%
1964	0		102		424		37		30		2	596		0%	17%	71%	6%	5%	0%
1965	0		106		478		20		9		2	614		0%	17%	78%	3%	1%	0%
1966	0		13		366		55		3		2	437		0%	3%	84%	13%	1%	0%
1967	0		2		27		8		8		5	51		0%	4%	54%	16%	17%	9%
1968	0		1		23		3		3		0	30		0%	4%	76%	9%	11%	0%
1969	0		2		13		4		10		0	30		0%	7%	44%	15%	35%	0%
1970	0		8		36		3		10		1	58		0%	13%	62%	5%	17%	2%
1971	0		0		21		25		15		1	62		0%	1%	34%	40%	24%	2%
1972	0		2		3		6		111		0	121		0%	1%	2%	5%	92%	0%
1973	0		51		17		3		323		0	394		0%	13%	4%	1%	82%	0%
1974	0		163		21		22		380		0	586		0%	28%	4%	4%	65%	0%
1975	0		174		101		2		434		0	710		0%	24%	14%	0%	61%	0%
1976	0		212		56		23		718		0	1,010		0%	21%	6%	2%	71%	0%
1977	0		84		354		314		1,331		0	2,082		0%	4%	17%	15%	64%	0%
1978	0		95		292		969		1,900		0	3,257		0%	3%	9%	30%	58%	0%
1979	0		22		432		1,365		2,148		0	3,968		0%	1%	11%	34%	54%	0%
1980	0		1		87	(37)	1,451		2,348		2	3,889	(37)	0%	0%	2%	37%	60%	0%
1981	0		6		126		1,284	(25)	2,083		1	3,499		0%	0%	4%	37%	60%	0%
1982	6		5		42	(87)	643		1,288		6	1,990	(87)	0%	0%	2%	32%	65%	0%
1983	0		12		7		844	(158)	1,001		12	1,876		0%	1%	0%	45%	53%	1%
1984	0		1		5		1,094		898	(116)	11	2,009	(116)	0%	0%	0%	54%	45%	1%
1985	2		10		207	(247)	958		777	(163)	6	1,961	(410)	0%	0%	11%	49%	40%	0%
1986	3		1		183	(70)	1,076	(107)	687		1	1,950	(177)	0%	0%	9%	55%	35%	0%
1987	0		7		269	(380)	1,996		924	(203)	9	3,205	(583)	0%	0%	8%	62%	29%	0%
1988	0		33		101	(98)	868		353		5	1,359	(98)	0%	2%	7%	64%	26%	0%
1989	0		1		28		249		174		1	454		0%	0%	6%	55%	38%	0%
1990	7		7		20		606		232		2	874		1%	1%	2%	69%	27%	0%
1991	4		1		19		720		444		1	1,189		0%	0%	2%	61%	37%	0%
1992	8		3		148		963	(36)	530		0	1,653	(36)	0%	0%	9%	58%	32%	0%
1993	59		14		276	(100)	1,003		485		1	1,838	(100)	3%	1%	15%	55%	26%	0%
1994	25		3		51		580		127		0	786		3%	0%	6%	74%	16%	0%
1995	8		1		20		560	(432)	76		1	666	(432)	1%	0%	3%	84%	11%	0%
1996	6	(108)	0		88	(219)	924		98	(328)	5	1,121	(655)	1%	0%	8%	82%	9%	0%
1997	13	(244)	0		54	(422)	1,577	(159)	82	(1,154)	82	1,810	(1,979)	1%	0%	3%	88%	5%	4%
1998	15		4		82	(320)	1,073	(74)	123	(606)	45	1,342	(1,000)	1%	0%	6%	80%	9%	3%
1999	3		2		75	(212)	377		40	(161)	29	525	(373)	1%	0%	15%	74%	8%	2%
2000	7		0		57		423	(143)	14		5	506	(143)	1%	0%	11%	84%	3%	1%
2001	0		0		33	(103)	833	(217)	4		4	874	(320)	0%	0%	4%	96%	0%	0%
2002	4		9		59	(482)	740	(850)	23		16	851	(1,332)	0%	1%	7%	88%	3%	1%
2003	2	(330)	12		104	(168)	848	(1,862)	157	(1,205)	7	1,130	(3,565)	0%	1%	9%	75%	14%	1%
2004	0	(31)	117	(19)	142	(388)	596	(789)	323	(2,159)	37	1,215	(3,386)	0%	10%	12%	49%	27%	3%
2005	0	(9)	3		12		454	(1,108)	122	(2,307)	85	676	(3,424)	0%	0%	2%	67%	18%	13%
2006	0	(14)	52	(446)	8	(55)	524	(2,176)	226	(3,076)	96	907	(5,767)	0%	6%	1%	58%	25%	11%
2007	1	(6)	0	(5)	5	(133)	615	(5,257)	124	(2,018)	3	749	(7,419)	0%	0%	1%	84%	14%	0%
2008	2		1		42	(579)	510	(3,752)	180	(1,469)	2	737	(5,800)	0%	0%	6%	69%	24%	0%
2009	0		1		6	(186)	651	(2,621)	204	(2,462)	2	864	(5,269)	0%	0%	1%	75%	24%	0%
2010	0		1		16		719	(6,353)	180	(4,997)	6	922	(11,350)	0%	0%	2%	78%	19%	1%
2011	0		3	(31)	7	(93)	690	(7,203)	162	(3,149)	2	864	(10,476)	0%	0%	1%	80%	19%	0%
2012	0		1		4		642	(4,860)	185	(2,583)	3	834	(7,443)	0%	0%	0%	77%	22%	0%

Table B5. Landings of tilefish (mt, live) by quarter. Number of length measurements are in parentheses. General canvas data are not included. Percent by quarter per year are also given.

	Quarter								
Year	1	2	3	4	Total	1	2	3	4
1977	1,017	961	93	12	2,082	49%	46%	4%	1%
1978	905	1,128	432	793	3,257	28%	35%	13%	24%
1979	1,351	1,055	538	1,024	3,968	34%	27%	14%	26%
1980	1,524	1,263	505	596	3,889	39%	32%	13%	15%
1981	1,352	1,091	474	581	3,499	39%	31%	14%	17%
1982	1,028	433	239	289	1,990	52%	22%	12%	15%
1983	577	726	289	284	1,876	31%	39%	15%	15%
1984	1,032	491	293	193	2,009	51%	24%	15%	10%
1985	551	632	496	281	1,961	28%	32%	25%	14%
1986	542	597	437	374	1,950	28%	31%	22%	19%
1987	1,048	873	723	565	3,210	33%	27%	23%	18%
1988	737	292	160	172	1,361	54%	21%	12%	13%
1989	147	61	78	167	454	32%	13%	17%	37%
1990	258	243	184	189	874	30%	28%	21%	22%
1991	326	437	182	244	1,189	27%	37%	15%	21%
1992	426	433	401	393	1,653	26%	26%	24%	24%
1993	634	664	267	273	1,838	34%	36%	15%	15%
1994	301	275	72	138	786	38%	35%	9%	18%
1995	214	148	108	195	666	32%	22%	16%	29%
1996	366	215	231	308	1,121	33%	19%	21%	28%
1997	442	574	373	421	1,810	24%	32%	21%	23%
1998	541	363	229	209	1,342	40%	27%	17%	16%
1999	163	146	120	96	525	31%	28%	23%	18%
2000	143	141	77	144	506	28%	28%	15%	28%
2001	190	236	224	224	874	22%	27%	26%	26%
2002	289	201	173	188	851	34%	24%	20%	22%
2003	314	314	242	260	1,130	28%	28%	21%	23%
2004	530	272	187	226	1,215	44%	22%	15%	19%
2005	178	119	170	209	676	26%	18%	25%	31%
2006	281	200	188	238	907	31%	22%	21%	26%
2007	192	172	169	216	749	26%	23%	23%	29%
2008	317	188	108	125	737	43%	25%	15%	17%
2009	190	286	226	161	864	22%	33%	26%	19%
2010	253	259	209	200	922	27%	28%	23%	22%
2011	234	260	185	185	864	27%	30%	21%	21%
2012	183	222	248	181	834	22%	27%	30%	22%

Table B6. Number of observed trips, discard ratios (discard/ sum all species kept), estimated CVs, and estimated discards in metric tons for large and small mesh trawl and gillnet gear.

	Observed trips			Discard Ratio			CV			Metric Tons		
	trawl			trawl			trawl			trawl		
year	lg mesh	sm mesh	gillnet	lg mesh	sm mesh	gillnet	lg mesh	sm mesh	gillnet	lg mesh	sm mesh	gillnet
1989	30	82	23	0.000227	0.000204	0.000000	0.54	0.74	-	14	11	0
1990	33	55	31	0.000000	0.000023	0.000000	-	0.68	-	0	1	0
1991	37	103	164	0.000017	0.000288	0.000000	1.38	0.68	-	1	15	0
1992	42	68	286	0.000010	0.000352	0.000000	1.13	0.82	-	1	18	0
1993	38	36	208	0.000000	0.000086	0.000000	-	0.43	-	0	5	0
1994	44	23	228	0.000016	0.000034	0.000000	0.63	0.60	-	1	2	0
1995	81	57	247	0.000061	0.000015	0.000019	1.05	1.97	0.99	3	1	0
1996	46	74	218	0.000035	0.000094	0.000000	1.22	0.91	-	2	5	0
1997	31	60	206	0.000004	0.000075	0.000045	1.88	2.42	0.87	0	4	1
1998	17	35	179	0.000016	0.000138	0.000000	1.32	0.69	-	1	8	0
1999	23	35	83	0.000117	0.000014	0.000000	0.76	0.94	-	6	1	0
2000	46	49	100	0.000057	0.000065	0.000000	1.22	0.70	-	3	2	0
2001	64	63	83	0.000654	0.000134	0.000000	0.68	0.71	-	36	5	0
2002	86	60	77	0.000000	0.000009	0.000000	-	0.80	-	0	0	0
2003	173	104	184	0.000012	0.000418	0.000018	0.62	0.59	0.87	1	11	0
2004	407	315	316	0.000130	0.000023	0.000143	0.50	0.42	0.42	8	1	3
2005	1033	328	339	0.000004	0.000626	0.000179	0.58	0.64	0.63	0	19	3
2006	517	179	121	0.000016	0.000147	0.000105	0.50	0.71	1.17	1	7	1
2007	601	234	206	0.000014	0.000010	0.000205	0.77	0.54	1.04	0	0	4
2008	663	166	147	0.000004	0.000203	0.000024	0.46	0.54	0.78	0	7	0
2009	651	379	132	0.000060	0.000060	0.000101	0.55	0.39	0.64	2	2	2
2010	731	480	636	0.000005	0.000098	0.000025	0.65	0.44	0.78	0	3	0
2011	949	426	608	0.000084	0.000034	0.000200	0.43	0.37	0.31	3	1	4
2012	719	296	502	0.000002	0.000058	0.000085	0.77	0.62	0.37	0	2	2

Table B7. Recreational Golden tilefish data from the Marine Recreational Information Program (MRIP).

year	number fish measured	landed number A and B1 party/charter	landed number A and B1 private	Released B2 private
1982	0	0	984	0
1983	0	0	0	0
1984	0	0	0	0
1985	0	0	0	0
1986	0	0	0	0
1987	0	0	0	0
1988	0	0	0	0
1989	0	0	0	0
1990	0	0	0	0
1991	0	0	0	0
1992	0	0	0	0
1993	0	0	0	0
1994	0	608	0	0
1995	0	0	0	0
1996	0	6,842	0	0
1997	0	0	0	0
1998	0	0	0	0
1999	0	0	0	0
2000	0	0	0	0
2001	0	148	0	0
2002	0	0	20,068	1,338
2003	18	721	0	0
2004	3	62	0	0
2005	0	0	0	0
2006	0	541	0	0
2007	2	1,329	0	0
2008	0	0	0	0
2009	0	177	0	0
2010	3	2,812	27514	0
2011	0	0	0	0
2012	0	0	0	0
2013	0	0	0	0

Table B8. Number of tilefish reported in the Party/charter vessel trip reports.

year	ME	NH	MA	RI	NY	NJ	DE	MD	VA	NC	Other	total
1994	275	636	0	0	0	0	0	0	0	0	0	911
1995	0	0	0	541	176	0	0	0	0	0	0	717
1996	0	0	0	0	81	0	0	0	0	0	0	81
1997	0	0	0	0	380	0	0	0	0	0	20	400
1998	0	0	0	102	121	0	0	0	0	52	20	295
1999	0	0	0	1	88	0	0	6	0	34	0	129
2000	0	0	0	0	108	39	0	0	0	139	0	286
2001	0	0	0	0	122	101	0	0	0	1,164	0	1,387
2002	0	0	0	0	439	423	0	0	0	0	0	862
2003	0	0	0	3	86	905	0	0	0	0	0	994
2004	0	0	0	0	12	631	0	0	254	0	0	897
2005	0	0	0	72	82	364	14	0	16	25	0	573
2006	0	0	0	0	265	66	2	133	12	30	0	508
2007	0	0	0	0	447	457	88	5	138	313	0	1,448
2008	0	0	0	3	488	545	22	32	10	60	0	1,160
2009	0	0	0	0	720	675	18	7	31	0	0	1,451
2010	0	0	0	0	586	1,194	19	23	48	0	0	1,870
2011	0	0	496	0	720	1,643	60	5	14	9	0	2,947
2012	0	0	0	1	1,116	5,144	42	23	98	12	0	6,436
2013	0	0	0	0	970	2,163	16	12	20	0	0	3,181

Table B9. Number of tilefish reported in the Party/charter vessel trip reports by statistical area.

year	631	632	626	621	622	616	537	526	525	other	total
1994	0	0	0	0	0	0	0	0	0	911	911
1995	0	0	0	0	0	32	144	0	0	541	717
1996	0	0	0	0	0	0	15	66	0	0	81
1997	0	0	0	0	0	20	200	0	0	180	400
1998	52	0	0	0	0	1	102	120	0	20	295
1999	0	0	6	0	0	0	85	0	0	38	129
2000	0	0	0	0	0	46	0	83	0	157	286
2001	27	242	0	0	0	101	122	0	0	895	1,387
2002	0	0	0	0	0	472	40	160	0	190	862
2003	0	0	0	0	4	868	64	0	0	58	994
2004	3	251	0	3		626	0	0	0	14	897
2005	0	13	3	0	17	357	60	75	0	48	573
2006	30	12	30	20	87	273	50	0	3	3	508
2007	313	58	80	22	92	433	67	300	0	83	1,448
2008	1	0	18	99	21	574	3	380	0	64	1,160
2009	0	2	36	166	26	588	0	625	0	8	1,451
2010	0	6	37	169	97	968	150	416	17	10	1,870
2011	0	0	14	339	587	676	369	607	0	355	2,947
2012	1	0	120	466	4,282	538	0	356	0	673	6,436
2013	0	0	32	18	1,815	706	0	110	0	500	3,181

Table B10. Number of trips that caught tilefish reported in the Party/charter vessel trip reports by statistical area.

year	631	632	626	621	622	616	537	526	525	other	total
1994	0	0	0	0	0	0	0	0	0	4	4
1995	0	0	0	0	0	2	2	0	0	2	6
1996	0	0	0	0	0	0	1	1	0	0	2
1997	0	0	0	0	0	1	1	0	0	1	3
1998	3	0	0	0	0	1	2	1	0	1	8
1999	0	0	3	0	0	0	3	0	0	5	11
2000	0	0	0	0	0	10	0	2	0	4	16
2001	2	7	0	0	0	15	2	0	0	10	36
2002	0	0	0	0	0	31	3	2	1	2	39
2003	0	0	0	0	2	17	3	0	0	3	25
2004	1	7	0	1	0	26	0	0	0	1	36
2005	0	2	1	0	4	20	3	1	0	4	35
2006	1	1	1	2	6	12	1	0	0	3	27
2007	12	1	3	2	10	29	2	2	1	2	64
2008	1	0	6	9	5	24	2	3	0	5	55
2009	0	2	12	9	7	18	0	5	0	2	55
2010	0	1	14	3	4	26	3	3	0	3	57
2011	0	0	3	10	13	14	4	5	0	7	56
2012	1	0	26	5	39	29	0	3	0	13	116
2013	0	0	9	2	26	9	0	1	0	3	50

Table B11. Total commercial and vessel trip report (VTR) landings in live mt and the commercial catch-per-unit effort (CPUE) data used for tilefish. Dealer landings before 1990 are from the general canvas data. CPUE data from 1979 to the first half of 1994 are from the NEFSC Weighout database, while data in the second half of 1994 to 2004 are from the vtr system (below the dotted line). Effort data are limited to longline trips which targeted tilefish (= or >75% of the landings were tilefish) and where data existed for the days absent. Nominal CPUE series are calculated using landed weight per days absent minus one day steam time per trip. Da represents days absent. * 2013 are preliminary estimates based on data retrieval in October 2013.

	Weighout		Commerical CPUE data subset								
year	& Dealer landings	vtr landings	interview landings	No. interviews	% interview trips	No. vessels	subset landings	days absent	No. trips	da per trip	nominal cpue
1979	3,968		0.0	0	0.0%	20	1,807	1,187	330	3.6	1.93
1980	3,889		0.8	1	0.3%	18	2,153	1,390	396	3.5	1.99
1981	3,499		35.0	4	1.2%	21	1,971	1,262	333	3.8	1.95
1982	1,990		90.7	13	5.7%	18	1,267	1,282	229	5.6	1.10
1983	1,876		85.8	16	8.9%	21	1,013	1,451	179	8.1	0.73
1984	2,009		140.1	25	18.2%	20	878	1,252	138	9.1	0.72
1985	1,961		297.1	64	30.6%	25	933	1,671	209	8.0	0.59
1986	1,950		120.7	31	16.5%	23	767	1,186	188	6.3	0.71
1987	3,210		198.5	38	18.5%	30	1,014	1,343	206	6.5	0.82
1988	1,361		148.2	30	19.4%	23	422	846	154	5.5	0.56
1989	454		92.8	11	15.7%	11	165	399	70	5.7	0.46
1990	874		32.4	8	11.9%	11	241	556	68	8.2	0.45
1991	1,189		0.8	3	2.8%	7	444	961	107	9.0	0.48
1992	1,653		58.0	9	8.6%	13	587	969	105	9.2	0.62
1993	1,838		71.9	11	10.5%	10	571	959	105	9.1	0.61
1994	-		0	0	0.0%	7	127	385	42	9.2	0.34
1994	786	30				4	53	150	18	8.3	0.37
1995	666	547				5	466	954	99	9.6	0.50
1996	1,121	865				8	822	1,318	134	9.8	0.64
1997	1,810	1,439				6	1,427	1,332	133	10.0	1.09
1998	1,342	1,068				9	1,034	1,517	158	9.6	0.70
1999	525	527				10	516	1,185	133	8.9	0.45
2000	506	446				11	421	932	110	8.5	0.47
2001	874	705				8	691	1,046	116	9.0	0.68
2002	851	724				8	712	951	114	8.3	0.78
2003	1,130	790				7	788	691	101	6.8	1.22
2004	1,215	1,153				12	1,136	811	134	6.1	1.54
2005	676	808				11	802	470	93	5.1	1.95
2006	907	870				12	852	682	105	6.5	1.35
2007	749	710				12	691	727	101	7.2	1.01
2008	737	675				14	672	1,119	124	9.0	0.62
2009	864	812				12	800	1,106	130	8.5	0.75
2010	922	871				11	853	694	108	6.4	1.33
2011	864	822				9	781	517	89	5.8	1.68
2012	834	799				12	795	651	100	6.5	1.32
*2013	-	-				9	481	449	64	7.0	1.15

Table B12. Dealer, VTR, and IVR tilefish total landings (live metric tons) compared to the total landings from the five dominant tilefish vessels. Percent of five dominant vessels to the total are also shown. IVR could not be updated from the SARC 48 assessment.

year	Dealer total (live mt)	Dealer top 5 vessels	Dealer % landing of top 5 vessels to total	VTR total (live mt)	VTR top 5 vessels	VTR % landing of top 5 vessels to total	IVR total (live mt)	IVR top 5 vessels	IVR % landing of top 5 vessels to total
1994	786	485	62%	31	17	57%	-	-	-
1995	666	522	78%	549	538	98%	-	-	-
1996	1,121	803	72%	865	799	92%	-	-	-
1997	1,810	1,292	71%	1,439	1,416	98%	-	-	-
1998	1,342	948	71%	1,068	1,003	94%	-	-	-
1999	525	399	76%	527	486	92%	-	-	-
2000	504	459	91%	446	428	96%	-	-	-
2001	871	817	94%	705	684	97%	-	-	-
2002	843	733	87%	724	687	95%	766	727	95%
2003	1,130	784	69%	790	732	93%	894	779	87%
2004	1,215	561	46%	1,153	688	60%	944	687	73%
2005	676	473	70%	808	596	74%	868	670	77%
2006	907	555	61%	870	569	65%	901	595	66%
2007	751	609	81%	710	601	85%	762	651	85%
2008	737	539	73%	675	502	74%	709	542	76%
2009	864	644	75%	812	617	76%	-	-	-
2010	922	711	77%	871	711	82%	-	-	-
2011	864	687	80%	822	664	81%	-	-	-
2012	833	642	77%	799	633	79%	-	-	-

Table B13. Tilefish Landing (metric tons) by market category from 1990-2012.

year	sm-kittens	small	kittens	medium	large	xl	unclassified	total
1990	0	24	14	103	46	0	687	874
1991	0	43	16	154	85	0	891	1189
1992	0	193	136	88	86	0	1,149	1653
1993	0	237	131	206	66	4	1,193	1838
1994	0	8	11	89	54	7	617	786
1995	0	26	73	88	91	2	386	666
1996	0	169	423	149	156	2	221	1121
1997	0	252	878	260	111	2	307	1810
1998	0	100	375	700	103	6	58	1342
1999	0	38	143	201	106	8	29	525
2000	0	17	193	153	115	8	20	506
2001	0	11	553	161	124	6	19	874
2002	0	28	341	311	128	3	40	851
2003	0	132	644	171	144	5	35	1130
2004	20	169	228	523	129	9	137	1215
2005	0	6	12	335	149	1	173	676
2006	1	8	8	233	369	1	287	907
2007	3	19	77	142	397	4	106	749
2008	17	49	100	195	299	17	60	737
2009	35	55	279	179	226	28	61	864
2010	16	28	240	373	166	17	81	922
2011	6	6	136	339	216	10	152	864
2012	8	10	84	308	285	17	121	834

Table B14. Number of lengths (1995-2013), samples (2002-2013), and metric tons landed per sample (2002-2013) for Golden tilefish. Number of lengths includes borrowing across years in bold. Trawl lengths were not used in the expansion. Large lengths used from 1995 to 1999 were taken from years 1996, 1997, and 1998. Large lengths in 2002 also used large lengths from 2003. Unclassified were redistributed according to market and quarter proportions.

Number of lengths.

year	half	sm	ki	med	lg	xl	total
1995	1		244	208	**332**		
	2						784
1996	1		312	100	**332**		
	2						744
1997	1		958	688	**332**		
	2						1978
1998	1		202	407	**332**		
	2						941
1999	1		211	155	**332**		
	2						698

Number of lengths.

year	half	sm	ki	med	lg	xl	total
2002	1		353	206	**492**		
	2						1051
2003	1	735	385	396	467	32	
	2		522	958			3495
2004	1	788	115	882	432		
	2	106	197	427			2947
2005	1		393	1378	825		
	2			763			3359
2006	1	112	346	1856	1284		
	2	218		1079	752		5647
2007	1	396	379	1128	898	25	
	2	220	1152	1871	1316		7385
2008	1	192	964	1456	1540	20	
	2		581	726			5479
2009	1	508	650	731	658	5	
	2	402	470	1024	322		4770
2010	1	1122	858	2363	1995	43	
	2	213	1081	2031	1140		10846
2011	1	852	1236	2682	2011	35	
	2		1104	1626	851		10397
2012	1	520	900	1342	1709	252	
	2		531	1100	1010		7364
2013	1	400	1200	1823	2575	369	
	2						6367

Number of samples

year	half	sm	ki	med	lg	xl	total
2002	1		6	2	**8**		
	2				↑		16
2003	1	5	4	3	7	2	
	2		6	5			32
2004	1	4	1	6	7		
	2	1	2	4			25
2005	1		6	10	12		
	2			8			36
2006	1	3	6	14	11		
	2	2		11	8		55
2007	1	4	4	12	12	1	
	2	1	5	9	8		56
2008	1	2	12	17	31	3	
	2		10	11			86
2009	1	5	11	13	11	2	
	2	4	8	17	11		82
2010	1	11	13	30	29	3	
	2	2	11	23	27		149
2011	1	10	17	32	29	3	
	2		12	18	11		132
2012	1	5	9	15	17	12	
	2		6	12	11		87
2013	1	6	12	19	32	13	
	2						82

mt/samples

year	half	sm	ki	med	lg	xl	total
2002	1		61	156	**19**		
	2						54
2003	1	26	98	22	21	3	
	2		42	21			34
2004	1	37	209	50	20		
	2	23	20	55			43
2005	1		3	19	12		
	2			18			14
2006	1	2	1	9	19		
	2	2		9	21		11
2007	1	1	6	6	18	4	
	2	12	11	8	23		12
2008	1	25	6	7	10	6	
	2		5	6			8
2009	1	9	8	8	14	14	
	2		25	5	6		9
2010	1	2	10	7	3	6	
	2		10	8	3		6
2011	1	1	4	6	4	3	
	2		6	8	9		5
2012	1	2	3	10	9	1	
	2		10	13	13		8
2013	1	2	8	11	7	1	
	2						7

Table B15. SARC 58 NEFSC commercial raw age data from 2007-2012.

Age	Year						Total
	2007	2008	2009	2010	2011	2012	
1	1					1	2
2	17		6	8	1	12	44
3	5		38	4	5	26	78
4	119	27	163	51	26	121	507
5	45	115	135	133	60	295	783
6	90	75	75	96	134	220	690
7	41	83	36	68	116	127	471
8	14	21	11	32	44	51	173
9	13	7	11	14	22	27	94
10	19	20	16	32	30	15	132
11	10	8	24	13	22	12	89
12	16	26	26	42	23	8	141
13	10	19	15	32	18	16	110
14	12	11	12	17	7	6	65
15	13	14	11	24	6	4	72
16	6	7	10	13	6	6	48
17	5	5	4	3	2	7	26
18	2	1	7	3	4	2	19
19	1		1	1	1	4	8
20	2		1	2		2	7
21	2	1		1			4
22			1		1		2
23		2				2	4
24			1				1
25		1	2				3
26		1				1	2
28		1		1			2
30					1		1
36		1					1
Total	443	446	606	590	529	965	3579

Table B16. Historical retrospective comparison of Golden tilefish assessments (ASPIC model).

				Run2 update	Run7 Final
assessment	SSC 2000	SARC 41	SARC 48	SARC 58	SARC 58
terminal year	1999	2004	2008	2013	2012
BMSY	8,448	9,384	11,400	10,620	10,420
FMSY	0.22	0.21	0.16	0.18	0.16
MSY	1,858	1,988	1,868	1,921	1,632
r	0.45	0.42	0.33	0.36	0.31
Turner q	0.009	0.010	0.009	0.009	0.007
Weightout q	0.222	0.225	0.175	0.180	0.156
VTR q	-	0.392	0.260	0.191	0.251
Biomass terminal yr	3,064	6,712	13,030	17,660	14,410
F terminal yr	0.450	0.184	0.059	0.052	0.059
B/Bmsy	0.36	0.72	1.14	1.66	1.38
F/Fmsy	2.05	0.88	0.37	0.29	0.38

Table B17. ASPIC surplus production model run comparison and sensitivity.

Run ID	0	1	2	3	4	5	6	7 (Final)
Description	SARC 48 Fix b1-ratio	Fix b1-ratio to Bmsy	Fix b1-ratio to Bmsy	Estimate b1-ratio	Estimate b1-ratio, nominal vtr series	Estimate b1-ratio, combine weighout-VTR series	Estimate b1-ratio, add 91-94 data to VTR series	Fix b1-ratio to K, add 91-95 data to VTR series, terminal year 2012
Terminal Year	2008	2012	2013	2013	2013	2013	2013	2012
Diagnostics								
RMSE	0.350	0.353	0.352	0.339	0.337	0.344	0.331	0.330
turner r2	0.22	0.22	0.15	0.60	0.63	0.61	0.61	0.53
Weighout r2	0.65	0.61	0.61	0.65	0.66	na	0.65	0.65
vtr r2	0.20	0.30	0.32	0.30	0.23	0.51	0.35	0.36
Turner q	0.009	0.009	0.009	0.007	0.006	0.006	0.007	0.007
Weighout q	0.175	0.169	0.180	0.166	0.094	na	0.152	0.156
VTR q	0.260	0.202	0.191	0.224	0.103	0.317	0.241	0.251
Results								
B1:K ratio	0.50	0.50	0.50	1.30	1.41	1.40	1.36	1.00
MSY (mt)	1,868	1,879	1,921	1,658	1,430	1,515	1,580	1,632
r	0.33	0.33	0.36	0.34	0.26	0.30	0.31	0.313
FMSY	0.16	0.17	0.18	0.17	0.13	0.15	0.16	0.16
K (mt)	22,790	22,700	21,240	19,290	22,430	20,480	20,210	20,840
BMSY (mt)	11,400	11,350	10,620	9,643	11,210	10,240	10,110	10,420
B2013/BMSY	na	1.56	1.65	1.54	1.19	1.13	1.41	1.38
F2012/FMSY	na	0.29	0.27	0.33	0.50	0.49	0.38	0.38
B2014/BMSY	na	na	1.66	1.56	1.23	1.19	1.44	na
F2013/FMSY	na	na	0.28	0.35	0.52	0.51	0.40	na

Table B18. Empirical mean lengths (top) at age and sample size from Turner et. al. (1983). Oldest fish aged (bottom) from Turner's PHD dissertation (1986) and Vidal's MS (2008).

	Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
female	empirical mean length	-	-	38	47	52	58	64	65	66	68		90	-	-	84	77	-	84	82	-	-	-	-	-	-	-	-	-	92	89	91	89	95	-	88
	n	-	-	14	47	61	40	65	52	11	1		1	-	-	1	1	-	1	1	-	-	-	-	-	-	-	-	-	1	1	1	3	1	-	2
male	empirical mean length	-	-	40	50	53	60	71	74	79	86	89	93	-	-	99	102	104	-	96	109	-	108	-	-	108	96	-	-	-	-	-	-	-	-	-
	n	-	-	4	51	55	17	44	41	23	5	1	1	-	-	5	1	1	-	2	2	-	1	-	-	1	1	-	-	-	-	-	-	-	-	-

Dissertation 1986 S Turner		Number of females younger than 31	Number of females older than 31
oldest male: 39	1978	234	7
oldest female: 46	1979	87	4
	1980	177	3
	1982	194	21

	Number of males younger than 31	Number of males older than 31
1978	216	0
1979	148	1
1980	91	0
1982	187	1

T. Vidal (2008)
oldest male: 23
oldest female: 21

Table B19. Ten SCALE sensitivity runs. Under each run is a column for the weight or the input effective sample size, estimated q or input model fit at size and larger, and the residual or model estimates. resid = residuals, par = parameters.

Run		1			2			3			4			5	
Description		fit numbers			fit biomass			lower wt on age index			lower wt on catch			lower variation on len@age	
m		0.15			0.15			0.15			0.15			0.15	
selecivity		start 2nd block in 82			start 2nd block in 82			start 2nd block in 82			start 2nd block in 82			start 2nd block in 82	
	weight	q or fit	resid or par	weight	q or fit	resid or par	weight	q or fit	resid or par	weight	q or fit	resid or par	weight	q or fit	resid or par
Total Objective function			89.10			82.34			71.03			83.34			81.98
total catch	4		1.86	4		1.80	4		1.40	8		1.10	4		1.73
catch len freq 1+	400		49.87	400		47.07	400		43.77	400		47.39	400		47.32
Penalty of recruitment variation	0.05		0.42	0.05		0.51	0.05		0.99	0.05		0.52	0.05		0.48
Age 4	1	2.9E-06	8.37	1	3.0E-06	9.13	0.1	3.3E-06	1.92	1	3.0E-06	9.48	1	2.9E-06	8.76
Turner 47+ (1973-1982)	2	2.6E-02	1.31	2	6.6E-03	0.71	2	6.7E-03	0.72	2	6.5E-03	0.72	2	6.8E-03	0.76
Weighout 37+ (1979-1993)	2	3.5E-02	1.89	2	1.5E-02	1.09	2	1.5E-02	1.02	2	1.5E-02	1.14	2	1.5E-02	1.09
VTR 37+ (1995-2008)	4	8.9E-02	8.18	4	6.9E-02	4.08	4	7.2E-02	3.92	4	6.9E-02	4.99	4	6.7E-02	4.14
Turner (1973-1982) size fit		47			47			47			47			47	
Weighout (1979-1993) size fit		37			37			37			37			37	
VTR (1995-2008) size fit		37			37			37			37			37	
survey/catch len freq 65+	100		17.20	100		17.95	100		17.28	100		18.00	100		17.71
survey/catch len freq size fit		65			65			65			65			65	
Fstart			0.01			0.01			0.00			0.01			0.02
Recruitment year 1 (1971, 000s)			1106			1000			927			1011			1050
Selectivity Alpha (L50) 71-81			53.16			53.41			53.70			53.42			53.67
Selectivity Beta (slope) 71-81			0.36			0.35			0.32			0.35			0.33
Selectivity Alpha (L50) 82-08			40.87			40.92			41.10			40.91			40.74
Selectivity Beta (slope) 82-08			1.00			1.00			1.00			1.00			1.00
2012 F			0.16			0.24			0.25			0.24			0.23
2012 Biomass (000s mt)			6658			4767			4560			4772			4928
2013 F			0.16			0.24			0.26			0.24			0.23
2013 Biomass (000s mt)			7106			4860			4602			4870			5028

Table B19 cont.

Run		6			7			8			9			10 (final)	
Description		combine wo-vtr series			add 91-94 data to vtr			lower m to 0.1			increase wt on vtr			2012, 1974 off, 91-94 vtr	
m		0.15			0.15			0.1			0.15			0.15	
selecivity		start 2nd block in 82			start 2nd block in 82			start 2nd block in 82			start 2nd block in 82			start 2nd block in 83	
	weight	q or fit	resid or par	weight	q or fit	resid or par	weight	q or fit	resid or par	weight	q or fit	resid or par	weight	q or fit	resid or par
Total Objective function			87.82			86.06			83.16			80.06			81.81
total catch	4		3.21	4		2.51	4		1.98	4		1.09	4		2.74
catch len freq 1+	400		48.36	400		47.66	400		47.64	400		47.54	400		43.54
Penalty of recruitment variation	0.05		0.61	0.05		0.51	0.05		0.59	0.05		0.50	0.05		0.47
Age 4	1	2.8E-06	8.85	1	2.9E-06	8.61	1	3.6E-06	8.87	1	3.0E-06	9.04	1	2.8E-06	9.06
Turner 47+ (1973-1982)	2	8.3E-03	0.78	2	7.2E-03	0.72	2	7.5E-03	1.01	2	6.6E-03	0.71	2	8.3E-03	0.88
Weighout 37+ (1979-1993)	4	5.3E-01	6.98	2	1.8E-02	0.98	2	1.6E-02	1.11	2	1.5E-02	1.09	2	2.0E-02	0.94
VTR 37+ (1995-2008)			-	4	5.7E-01	6.14	4	7.8E-02	4.00	2	6.8E-02	2.57	4	5.7E-01	5.71
Turner (1973-1982) size fit		47			47			47			47			47	
Weighout (1979-1993) size fit		37			37			37			37			37	
VTR (1995-2008) size fit					37			37			37			37	
survey/catch len freq 65+	47		19.04	100		18.91	100		17.96	100		17.51	100		18.48
survey/catch len freq size fit		140			65			65			65			65	
Fstart			0.03			0.01			0.08			0.01			0.08
Recruitment year 1 (1971, 000s)			928			974			630			1002			1102
Selectivity Alpha (L50) 71-81			1.00			53.59			52.84			53.40			52.55
Selectivity Beta (slope) 71-81			140.00			0.34			0.37			0.35			0.24
Selectivity Alpha (L50) 82-08			1.00			40.84			40.89			40.89			40.83
Selectivity Beta (slope) 82-08			1.00			1.00			1.00			1.00			1.00
2012 F			0.17			0.19			0.28			0.23			0.17
2012 Biomass (000s mt)			6318			5752			4108			4815			6204
2013 F			0.17			0.19			0.28			0.24			-
2013 Biomass (000s mt)			6580			5959			4209			4932			-

Table B20. Comparison of final SCALE model run 10 estimated population numbers with the raw numbers of fish aged for 10+, 15+, and 20+ fish. Percent of the population numbers aged are also calculated.

	10+			15+			20+		
	population numbers	raw age data	percent pop aged	population numbers	raw age data	percent pop aged	population numbers	raw age data	percent pop aged
2007	29,714	98	0.3%	222	31	14.0%	13	4	30.8%
2008	38,190	118	0.3%	1,038	34	3.3%	11	7	63.6%
2009	139,478	131	0.1%	965	38	3.9%	10	5	50.0%
2010	124,552	184	0.1%	1,706	48	2.8%	12	4	33.3%
2011	105,129	121	0.1%	2,303	21	0.9%	15	2	13.3%
2012	95,116	85	0.1%	3,262	28	0.9%	23	5	21.7%
total	532,179	737	0.1%	9,496	200	2.1%	84	27	32.1%

Table B21. Input mean weight example for 20+ catch at age using a pool age length key for all years. Shaded cells indicated cells where missing data was filled in with the average from years where data exists.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1971	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1972	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1973	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1974	0.107	0.225	0.639	1.257	2.109	2.707	3.311	4.851	6.412	7.390	7.971	8.550	9.491	9.391	10.125	10.139	12.098	11.788	15.007	15.749
1975	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1976	0.166	0.387	0.659	1.021	2.830	3.404	3.785	4.305	5.247	5.911	6.594	7.399	8.350	8.553	9.678	10.381	13.024	12.142	15.433	17.312
1977	0.166	0.387	0.802	1.068	2.427	3.400	3.780	4.271	5.137	5.811	6.562	7.409	7.967	8.236	8.641	9.028	10.275	11.339	13.064	17.578
1978	0.166	0.387	0.790	1.308	2.132	3.139	3.772	4.349	5.207	5.789	6.365	7.252	7.925	8.260	8.991	9.502	11.352	10.834	14.071	15.807
1979	0.166	0.387	0.766	1.440	2.278	2.880	3.381	3.786	5.164	5.867	6.284	7.290	7.636	7.991	8.711	9.216	10.931	9.685	13.820	15.238
1980	0.107	0.287	0.768	1.395	2.385	3.042	3.508	3.818	4.939	5.663	6.186	7.342	7.816	8.128	8.820	9.240	10.613	9.907	13.142	14.970
1981	0.225	0.342	0.723	1.128	2.403	3.294	3.796	4.297	5.105	5.656	6.257	7.189	7.911	8.165	8.919	9.402	10.706	10.609	13.078	14.416
1982	0.225	0.301	0.703	1.098	1.774	2.736	3.462	4.065	5.236	5.850	6.420	7.214	7.760	7.991	8.466	8.886	9.862	10.419	12.300	13.506
1983	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1984	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1985	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1986	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1987	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1988	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1989	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1990	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1991	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1992	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1993	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1994	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
1995	0.166	0.363	0.785	1.036	1.645	2.413	2.848	3.129	5.102	5.962	6.058	7.529	7.934	7.857	8.488	8.637	8.999	10.027	10.974	11.300
1996	0.166	0.378	0.929	0.981	1.398	1.890	2.441	2.817	4.731	5.596	5.823	7.529	7.935	7.857	8.488	8.637	8.999	10.029	10.976	11.304
1997	0.166	0.529	0.999	1.112	1.430	1.799	1.977	2.166	3.618	5.107	5.595	7.526	7.934	7.857	8.488	8.637	9.001	10.025	10.973	11.296
1998	0.166	0.378	1.185	1.416	1.809	2.136	2.356	2.360	3.339	4.287	3.897	7.514	7.933	7.857	8.486	8.636	8.997	10.026	10.974	11.300
1999	0.166	0.378	1.129	1.193	1.697	2.231	2.488	2.769	4.788	5.866	6.397	7.529	7.935	7.857	8.488	8.637	8.998	10.029	10.976	11.304
2000	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
2001	0.166	0.378	0.893	1.228	1.908	2.553	3.062	3.495	4.729	5.452	5.763	7.152	7.754	7.937	8.507	8.831	9.868	10.084	11.991	13.253
2002	0.166	0.435	0.768	0.929	1.360	2.069	2.938	3.465	4.394	4.915	5.672	6.972	7.936	8.015	8.649	8.983	11.801	9.904	12.487	17.259
2003	0.166	0.372	0.939	1.258	1.519	1.949	2.454	2.762	3.475	4.530	4.717	6.952	7.918	8.059	8.734	9.022	11.960	9.898	13.083	17.566
2004	0.166	0.378	1.285	1.548	1.796	2.093	2.473	2.725	3.804	4.276	3.664	6.742	7.802	7.995	8.492	8.722	9.089	9.563	10.788	12.644
2005	0.166	0.378	1.155	1.791	2.109	2.537	3.044	3.244	4.601	4.941	4.630	6.258	6.866	7.022	7.347	7.737	8.474	8.738	7.980	9.256
2006	0.166	0.318	0.736	1.243	2.307	2.951	3.532	3.943	4.891	5.253	5.459	5.890	6.315	6.836	6.989	7.138	7.515	8.146	9.490	10.679
2007	0.166	0.359	0.885	1.095	1.789	2.766	3.413	4.062	5.241	5.697	6.017	6.437	6.626	6.978	7.176	7.428	7.998	7.830	9.430	10.355
2008	0.166	0.396	0.636	0.988	1.655	2.561	3.263	3.839	5.069	5.690	6.157	6.997	7.356	7.518	7.896	8.394	8.169	8.788	11.967	11.792
2009	0.166	0.327	0.877	1.088	1.478	2.062	2.658	3.267	4.939	5.722	6.195	7.402	7.856	8.105	8.591	8.930	9.165	12.233	10.850	13.031
2010	0.166	0.378	1.060	1.300	1.716	2.138	2.516	2.753	3.763	4.836	5.056	7.530	8.139	8.404	8.864	9.165	9.667	10.592	11.001	10.866
2011	0.166	0.384	1.029	1.413	1.909	2.513	2.980	3.139	4.360	5.014	5.039	7.066	7.901	8.134	8.801	9.101	9.504	10.320	12.566	10.840
2012	0.166	0.468	1.034	1.264	1.902	2.595	3.235	3.592	4.724	5.185	5.292	6.782	7.701	8.016	8.639	9.005	10.187	10.109	12.416	12.808
2013	0.166	0.529	1.052	1.333	1.845	2.533	3.130	3.590	4.934	5.473	5.760	6.491	6.902	7.337	7.705	8.186	9.327	9.125	12.935	13.136

Table B22. Initial ASAP model sensitivity runs.

	Run	1	2	3	4	5	6	7	8	9	10	11	12	13
Description	plus group	20	20	10	10	20	20	20	20	20	20	20	20	20
	age data	pooled	actual	pooled	actual	actual	actual	actual	actual	actual	actual	actual	actual	actual
	m	0.15	0.15	0.15	0.15	0.1	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	Description		base				combine wo-vtr cpue	add 91-94 to vtr cpue	wt vtr 91-13	terminal-yr 2012	fixed dome 1	fixed dome 2	fixed dome 3	1 selectivity block
	Total Objective function	1709.1	1726.0	1257.5	1278.7	1720.8	1840.2	1762.1	1851.3	1660.9	1717.0	1718.0	1729.6	1808.8
components of the objective function	catch fit	243.1	243.2	242.7	242.8	243.9	253.4	245.8	271.2	237.8	243.1	243.3	243.7	243.9
	index fit	10.1	10.5	-4.8	-4.7	10.9	72.4	37.2	78.3	9.8	9.1	8.3	8.8	7.0
	catch age comp	1006.8	1022.9	620.6	641.2	1023.7	1062.3	1029.1	1052.6	970.4	1017.0	1017.4	1016.9	1110.2
	N year 1	110.9	110.7	69.0	68.8	120.0	114.7	111.5	111.9	110.9	111.3	113.6	123.1	111.4
	recruit devs	338.3	338.7	330.0	330.6	322.3	337.3	338.5	337.3	332.0	336.5	335.4	337.1	336.3
RMSE	catch	0.41	0.42	0.39	0.39	0.45	0.81	0.54	1.22	0.43	0.41	0.42	0.44	0.45
	Turner 47+ (1973-1982)	0.71	0.70	0.61	0.60	0.77	0.59	0.68	0.65	0.70	0.66	0.61	0.57	0.61
	Weighout 37+ (1979-1993)	1.28	1.28	0.79	0.79	1.23	2.27	1.26	1.26	1.28	1.27	1.27	1.32	1.14
	VTR 37+ (1995-2008)	1.46	1.48	1.20	1.20	1.51	-	2.07	3.04	1.51	1.45	1.43	1.42	1.46
	index total	1.26	1.27	0.96	0.96	1.28	2.02	1.63	2.24	1.28	1.24	1.23	1.24	1.21
	stock numbers 1st year	0.41	0.41	0.99	0.99	0.95	0.54	0.42	0.44	0.41	0.44	0.63	1.14	0.51
	recruit devs	1.24	1.25	0.98	1.00	1.24	1.09	1.22	1.18	1.26	1.20	1.16	1.16	1.22
Results	SSB first year	17,721	17,901	20,039	20,205	12,090	15,910	17,579	17,010	17,931	22,571	30,773	65,208	22,952
	SSB terminal year	2,989	3,004	2,613	2,622	2,588	7,320	4,187	4,374	3,157	2,968	3,003	3,208	2,874
	F terminal year	0.31	0.31	0.37	0.36	0.36	0.12	0.22	0.21	0.26	0.31	0.30	0.29	0.33

Table B23. Comparison of ASAP flattop run 2 estimated population numbers with the raw numbers of fish aged for 10+, 15+, and 20+ fish. Percent of the population numbers aged are also calculated.

	10+			15+			20+		
	population numbers	raw age data	percent pop aged	population numbers	raw age data	percent pop aged	population numbers	raw age data	percent pop aged
2007	40,110	98	0.2%	1,170	31	2.6%	60	4	6.7%
2008	62,940	118	0.2%	2,040	34	1.7%	40	7	17.5%
2009	75,260	131	0.2%	1,970	38	1.9%	30	5	16.7%
2010	67,200	184	0.3%	2,090	48	2.3%	20	4	20.0%
2011	52,150	121	0.2%	2,130	21	1.0%	30	2	6.7%
2012	41,240	85	0.2%	2,660	28	1.1%	80	5	6.3%
total	338,900	737	0.2%	12,060	200	1.7%	260	27	10.4%

Table B24. Working group dome shaped ASAP model sensitivity runs. Run 27b is the final working group preferred run for stock status determination.

	Run	14	16	17	18	20	21	22	24	25	26	27	27b (final)
	plus group	10	20	10	10	10	10	10	20	20	10	10	10
	age data	pooled	pooled	pooled	pooled	pooled	pooled	pooled	pooled	pooled	pooled	pooled	pooled
	m	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	selectivity	at age	double log	at age	at age	at age	at age	double log	double log	double log	at age	at age	full 7 1st blk
Discription		full at 6		full at 6	full at 6	full at 6	full at 6				full at 6	full at 6	full 5 2nd bl
	Selectivity start 2nd block	82	82	82	82	82	83	95	83	95	95	83	83
	terminal year	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2012
	Fit to LF 1974	yes	yes	No	yes	yes	yes	yes	yes	yes	yes	yes	no
	LF Effective Sample size	150	150	150	150	75	75	75	75	75	75	75	75
	Discription			add 91-94	add 91-94	add 91-94	add 91-94	add 91-94	add 91-94	add 91-94	Model start in 1995	combine wo - vtr	add 91-94
	Total Objective function	1170.0	1544.9	1057.6	1087.0	971.4	980.2	975.7	Did not converge	1303.9	553.1	993.1	932.4
components of the objective function	catch fit	242.3	242.4	241.8	241.8	240.8	240.9	241.2		242.1	104.2	240.9	235.2
	index fit	-8.3	-3.2	-10.0	-9.7	-17.1	-15.1	-16.4		-6.1	10.9	-2.6	-16.9
	catch age comp	537.5	862.0	432.2	457.1	351.0	356.8	356.2		625.7	246.4	356.7	325.4
	N year 1	68.7	115.8	65.4	69.8	68.7	68.5	69.0		114.5	51.7	68.8	66.0
	recruit devs	329.8	327.9	328.2	328.1	328.0	329.0	325.9		327.8	139.8	329.2	322.7
RMSE	catch	0.36	0.37	0.33	0.33	0.25	0.26	0.28		0.35	0.40	0.26	0.23
	Turner 47+ (1973-1982)	0.57	0.58	0.57	0.58	0.58	0.72	0.65		0.71	1.04	0.73	0.65
	Weighout 37+ (1979-1993)	0.71	0.67	0.40	0.40	0.50	0.68	0.58		0.83	1.04	0.90	0.63
	VTR 37+ (1995-2008)	1.09	1.33	1.08	1.09	1.01	0.99	0.99		1.27	0.69	0.87	0.98
	index total	0.87	0.99	0.83	0.83	0.80	0.85	0.81		1.04	0.00	0.86	0.82
	stock numbers 1st year	0.96	0.58	0.21	1.02	0.88	0.83	1.03		0.49	0.00	0.00	0.18
	recruit devs	0.97	0.84	0.85	0.86	0.85	0.86	0.91		0.86	0.86	0.86	0.84
Results	SSB first year	30,291	36,492	22,646	31,216	33,763	25,977	47,602		31,904	777	26,506	21,895
	SSB terminal year	2,913	2,948	3,974	3,806	3,993	3,963	2,682		3,883	2,249	4,342	5,229
	F terminal year	0.39	0.36	0.33	0.34	0.35	0.35	0.41		0.30	0.47	0.33	0.27

Table B25. Comparison of ASAP dome 20+ run 16 estimated population numbers with the raw numbers of fish aged for 10+, 15+, and 20+ fish. Percent of the population numbers aged are also calculated.

	10+			15+			20+		
	population numbers	raw age data	percent pop aged	population numbers	raw age data	percent pop aged	population numbers	raw age data	percent pop aged
2007	92,570	98	0.1%	18,610	31	0.2%	11,560	4	0.0%
2008	128,130	118	0.1%	21,400	34	0.2%	9,890	7	0.1%
2009	153,160	131	0.1%	21,420	38	0.2%	8,500	5	0.1%
2010	153,160	184	0.1%	21,420	48	0.2%	8,500	4	0.0%
2011	127,910	121	0.1%	22,910	21	0.1%	6,750	2	0.0%
2012	109,870	85	0.1%	25,240	28	0.1%	6,980	5	0.1%
total	764,800	737	0.1%	131,000	200	0.2%	52,180	27	0.1%

Table B26. Time series of fishing mortality (F), spawning stock biomass (SSB), and age-1 recruitment from the final working group run 27b.

year	F	SSB (mt)	Recruitment (000s)
1971	0.006	21,895	1,074
1972	0.012	21,540	1,011
1973	0.040	20,870	1,098
1974	0.048	27,044	1,657
1975	0.079	19,364	1,729
1976	0.089	23,744	1,135
1977	0.212	19,902	655
1978	0.375	17,106	880
1979	0.529	13,950	1,638
1980	0.639	10,941	1,165
1981	0.836	7,871	1,307
1982	0.715	5,476	1,110
1983	0.672	4,550	4,489
1984	0.863	3,828	1,106
1985	1.022	3,001	831
1986	0.773	2,657	831
1987	1.165	2,740	799
1988	0.829	2,246	1,219
1989	0.307	2,087	1,933
1990	0.577	2,157	998
1991	0.801	2,089	676
1992	0.956	2,047	1,052
1993	1.267	1,756	2,192
1994	0.722	1,486	2,161
1995	0.615	1,389	770
1996	0.828	1,307	736
1997	1.195	1,264	854
1998	1.067	1,250	1,191
1999	0.517	1,221	2,346
2000	0.403	1,453	2,390
2001	0.570	1,666	1,297
2002	0.497	1,777	561
2003	0.429	2,318	435
2004	0.395	3,039	624
2005	0.292	3,914	1,051
2006	0.379	4,378	1,847
2007	0.428	4,240	1,484
2008	0.418	4,241	973
2009	0.365	4,489	694
2010	0.302	4,540	661
2011	0.258	4,989	717
2012	0.275	5,229	751

Table B27. Summary of the working group meeting's dome shaped selectivity ASAP runs for tilefish. n/c = not calculated, selec yr is the start of 2nd selectivity block.

Run	SSB_{1971}	SSB_{2013}	F_{1971}	F_{2013}	R1971	R_{2013}	F_{40}	SSB_{40}	MSY_{40}	Median R	$SSB2013/SSB_{40}$	$F2013/F_{40}$	Comment
Run 21-10+, Selec 83	25,977	3,963	0.005	0.35	1,034	691	0.198	6,121	700	782	0.65	1.77	Acceptable Diagnostics, good retro
Run 22-10+, Selec 95	47,602	2,682	0.005	0.409	863	618	0.164	4,636	870	780	0.58	2.49	Acceptable Diagnostics, good retro
Run25-20+, Selec 95	31,904	3,883	0.004	0.299	1,120	661	0.174	7,963	730	851	0.49	1.67	Estimation issues, worse retro
Run 27a	22,057	5,186	0.006	0.351	1,070	746	0.236	8,189	893	1,060	0.63	1.49	Best diagnostics, best retro
							F_{30}	SSB_{30}	MSY_{30}	Median R	$SSB2012/SSB_{30}$	$F2012/F_{30}$	
							0.319	6,138	984	1,060	0.85	1.1	

Run	SSB1983/1995	SSB2013	F1983/1995	F2013	R1983/1995	R2013	F_{40}	SSB_{40}	MSY_{40}	Median R	$SSB2013/SSB_{40}$	$F2013/F_{40}$	Comment
Start in 1983	3,643	4,778	0.43	0.28	1,195	1,363	n/c	n/c	n/c	n/c	n/c	n/c	No advantage to shortening series, start up issues
run26, Start in 1995	777	2,249	0.75	0.47	710	514	n/c	n/c	n/c	n/c	n/c	n/c	Retro problems

Run 27b - Final WG run	SSB1971	SSB2012	F1971	F2012	R1971	R2012	F_{40}	SSB_{40}	MSY_{40}	Median R	$SSB2012/SSB_{40}$	$F2012/F_{40}$	Comment
	21,895	5,229	0.006	0.275	1,074	751	0.233	8,280	900	1,070	0.63	1.18	Run 27 B through 2012

F_{30}	SSB_{30}	MSY_{30}	Median R	$SSB2012/SSB_{30}$	$F2012/F_{30}$
0.315	6,208	993	1,070	0.87	0.84

F_{25}	SSB_{25}	MSY_{25}	Median R	$SSB2012/SSB_{25}$	$F2012/F_{25}$
0.37	5,153	1029	1,070	1.01	0.74

Final Run 27b Properties

age 10+ , m=0.15
years 1971 - 2012
two selectivity blocks: 1971-1982 and 1983-2012
fix age 7 at 1 in sel block 1, fix age 5 at 1 in sel block 2
dropped 1974 catch at age proportions due to low sample size
survey CVs 0.4, 0.2, 0.2
catch input ESS 75
landings only (discards assumed minimal - zero actually)
recruitment years 1971-2012

Table B28. Biological Reference Points from the final working group ASAP run 27b.

Final Working Group Run 27b

SSB_{2012}	5229 mt
F2012	0.275 (S= 1 at age 5)
R2012	751 (000s)

Proxy	**F40%**	**F30%**	**F25%**
SSB_{MSY}	8278	6208	5153
$SSB_{Threshold}$	4139	3104	2577
MSY	899	993	1029
FMSY	0.233	0.315	0.37
SSB/SSB_{MSY}	0.63	0.84	1.01
F/F_{MSY}	1.18	0.87	0.74

Table B29. Yield per recruit and AGEPRO projection inputs from the final ASAP run 27b. The five year average (2008-2012) was used for input mean weights. Rivard catch mean weights to Jan-1 were used for stock mean weights. Terminal year + 1 stock size at age is also shown.

age	Stock Size on 1 Jan 2012	Selectivity	Proportion Mature	Mean Weights Stock	Mean Weights Catch & SSB
1	751,400	0.000	0.000	0.101	0.166
2	617,010	0.004	0.000	0.262	0.417
3	489,370	0.045	0.010	0.627	1.010
4	436,610	0.479	0.110	1.088	1.280
5	464,710	1.000	0.570	1.463	1.770
6	460,170	0.775	0.930	2.024	2.368
7	373,920	0.527	0.990	2.622	2.904
8	141,320	0.245	1.000	3.092	3.268
9	59,750	0.115	1.000	3.877	4.544
10+	341,570	0.280	1.000	7.110	7.110

Table B30. Mid-Atlantic SSC OFL and ABC calculation using unadjusted projections and an assumed 100% CV on the OFL and a model estimated 27% CV on the OFL. Probability of overfishing or being overfished is also given.

	100% CV					probability	
year	OFL	ABC	SSB/SSB_{MSY}	ABC/OFL	F	overfishing	overfished
2015	759	552	0.89	0.73	0.26	0.13	0.04
2016	867	650	0.92	0.75	0.27	0.15	0.03
2017	973	744	0.94	0.76	0.28	0.13	0.03
rebuilt	1,029	833	1.00	0.81			

	27% CV					probability	
year	OFL	ABC	SSB/SSB_{MSY}	ABC/OFL	F	overfishing	overfished
2015	759	686	0.89	0.90	0.33	0.35	0.04
2016	844	767	0.91	0.91	0.33	0.37	0.04
2017	932	847	0.91	0.91	0.33	0.35	0.05
rebuilt	1,029	962	1.00	0.94			

Figures

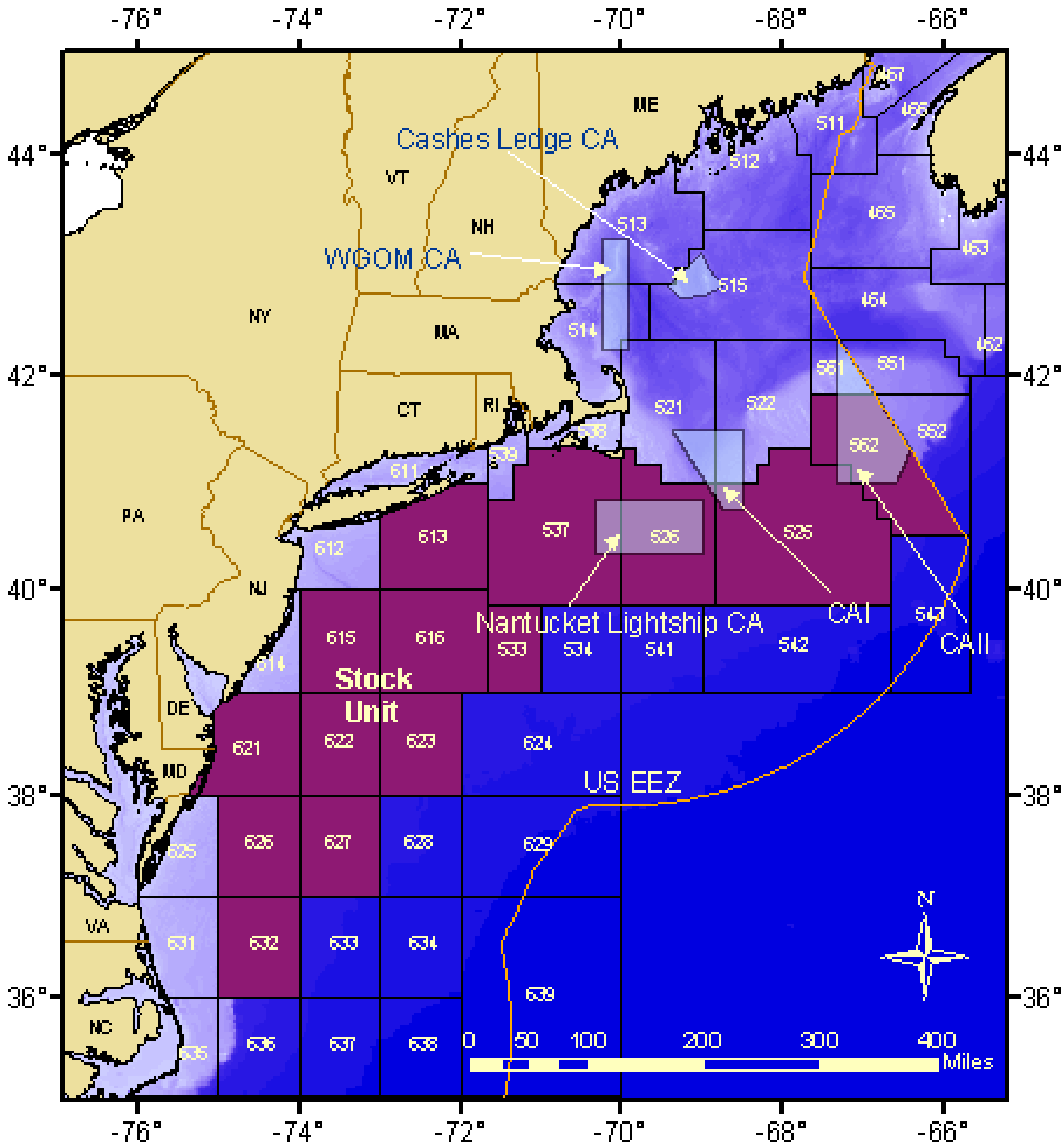


Figure B1. Middle Atlantic-Southern New England Golden tilefish stock boundary by statistical area.

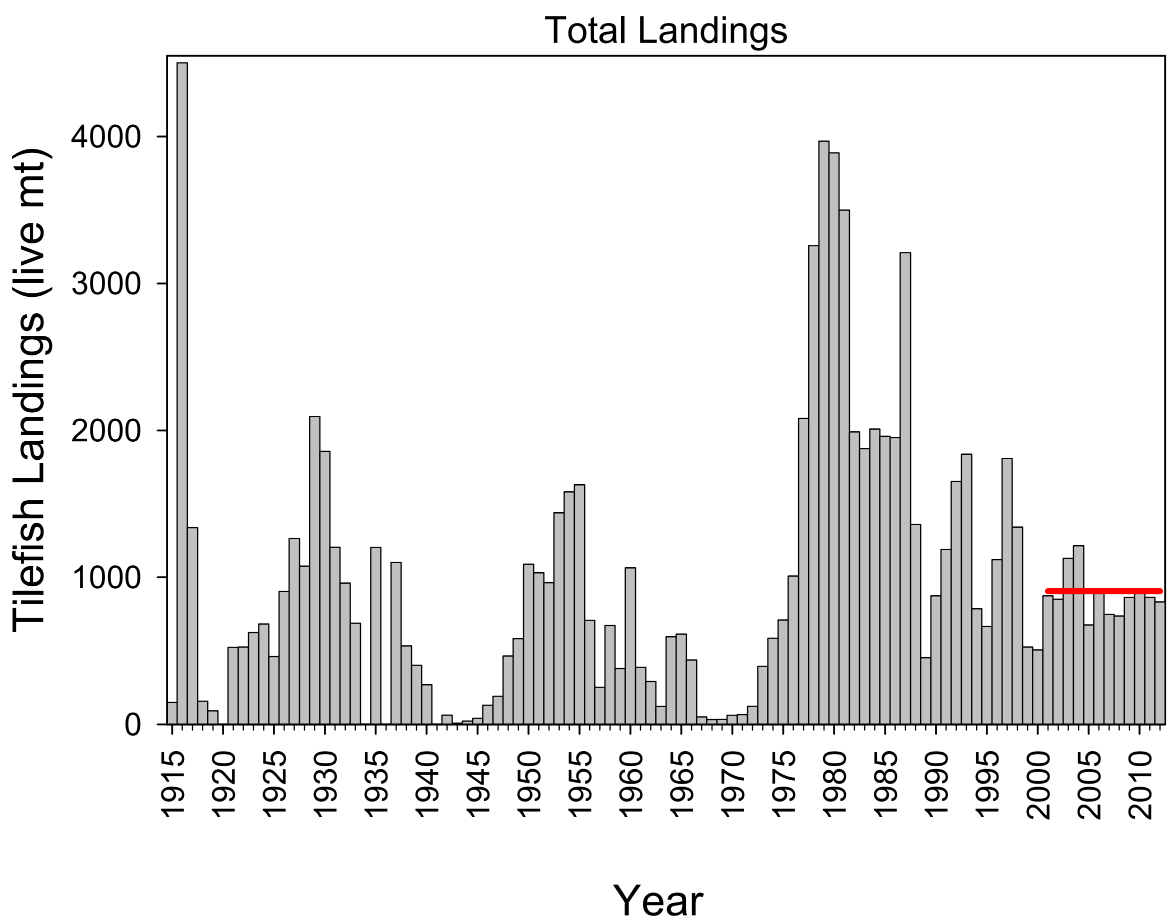


Figure B2. Landings of tilefish in metric tons from 1915-2004. Landings in 1915-1972 are from Freeman and Turner (1977), 1973-1989 are from the general canvas data, 1990-1993 are from the Weighout system, 1994-2003 are from the dealer reported data, and 2004-2012 is from dealer electronic reporting.

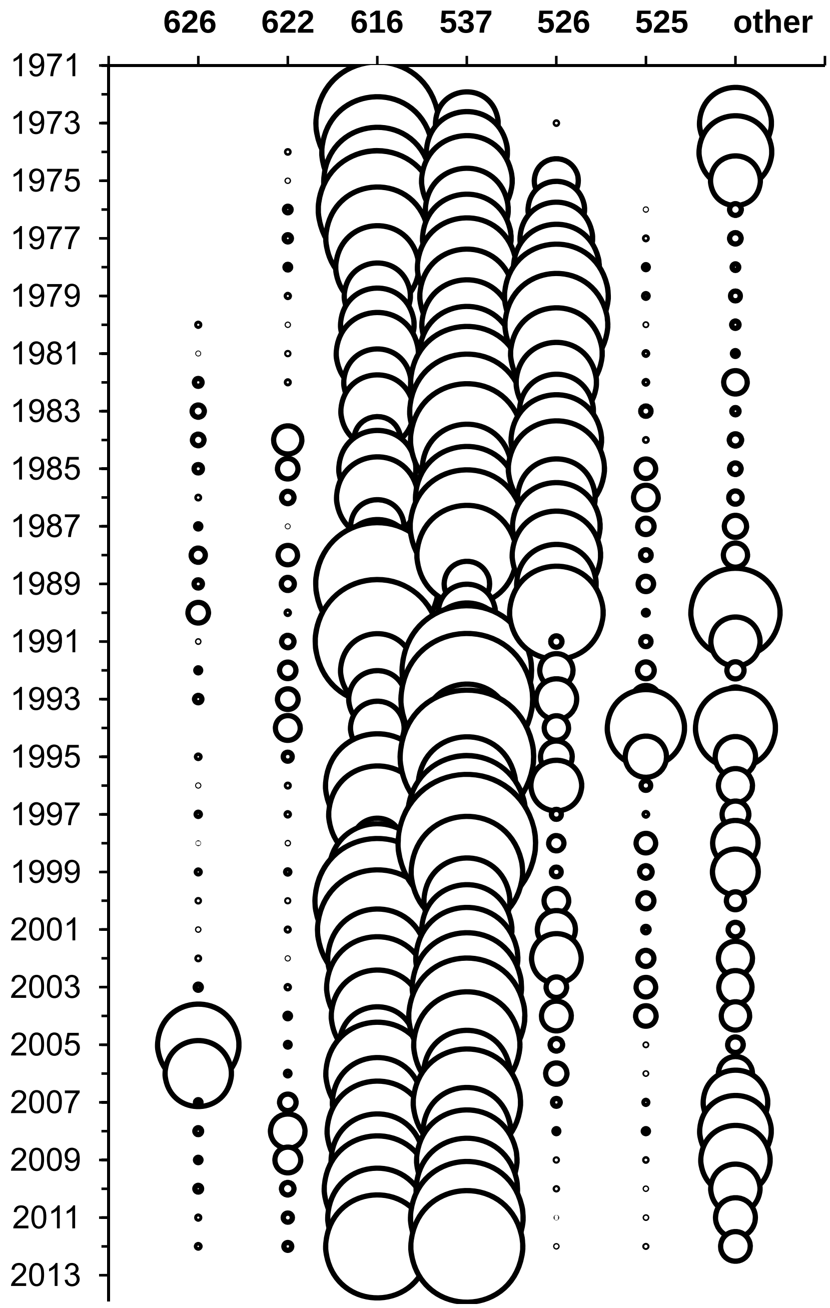


Figure B3. Bubble plot of Golden tilefish landings by statistical area.

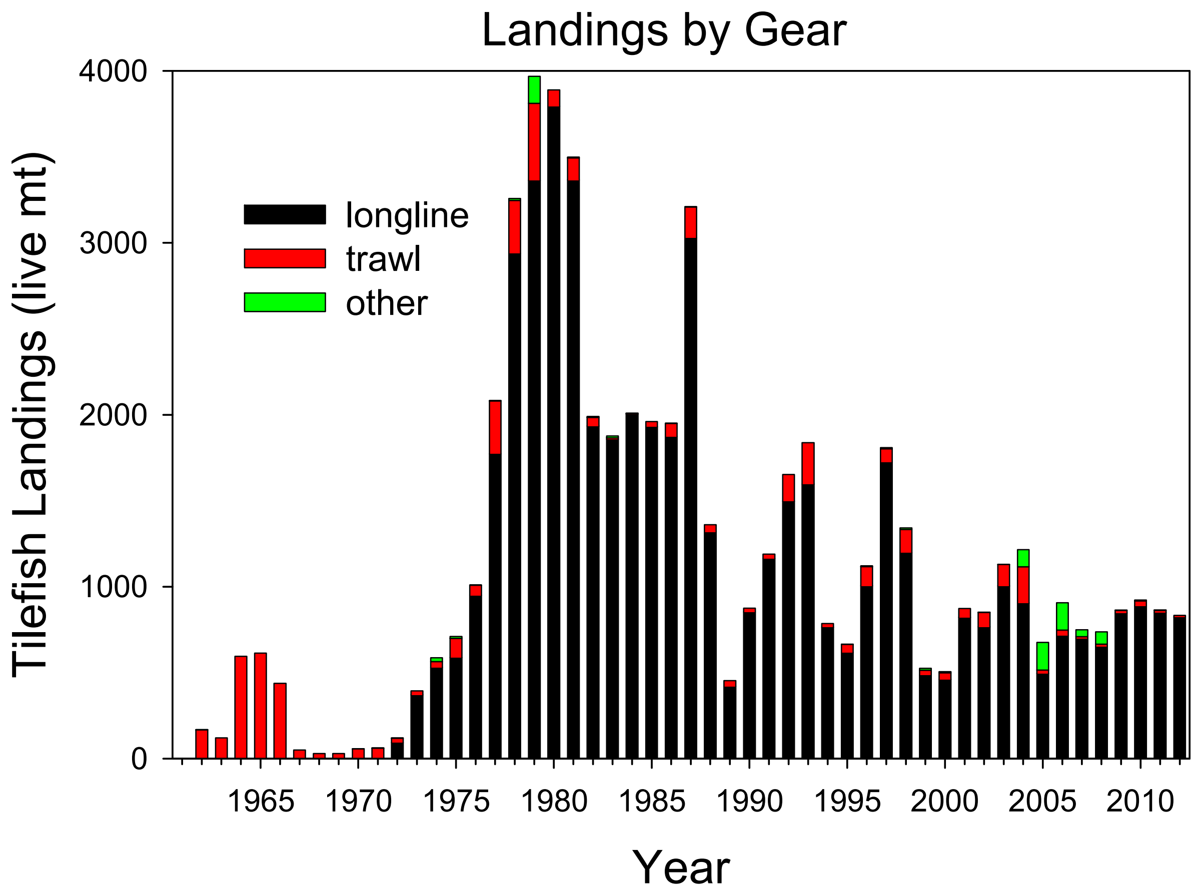


Figure B4. Landings of tilefish (mt, live) by gear. Landing before 1990 are from the general canvas data.

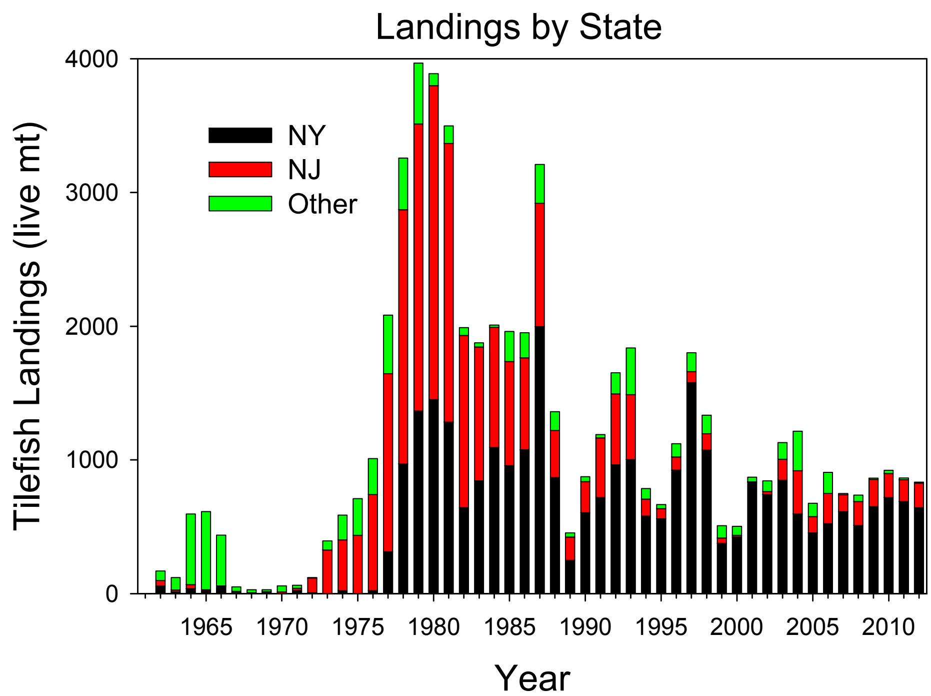


Figure B5. Landings of tilefish (mt, live) by State. Landings before 1990 are from the general canvas data.

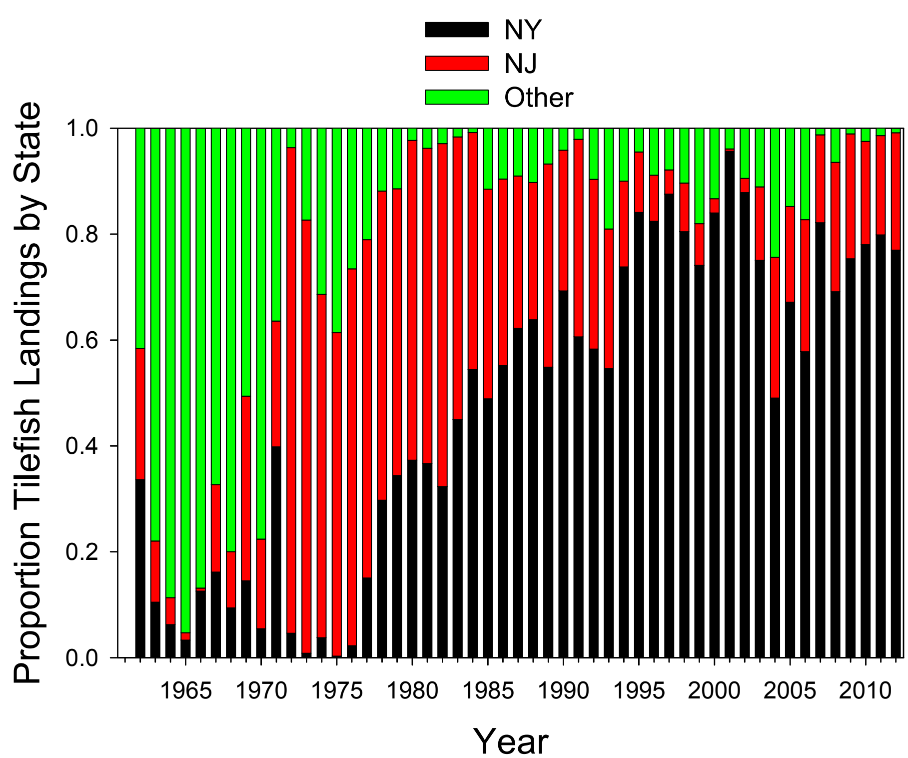


Figure B6. Landings of tilefish proportion by State. Landings before 1990 are from the general canvas data.

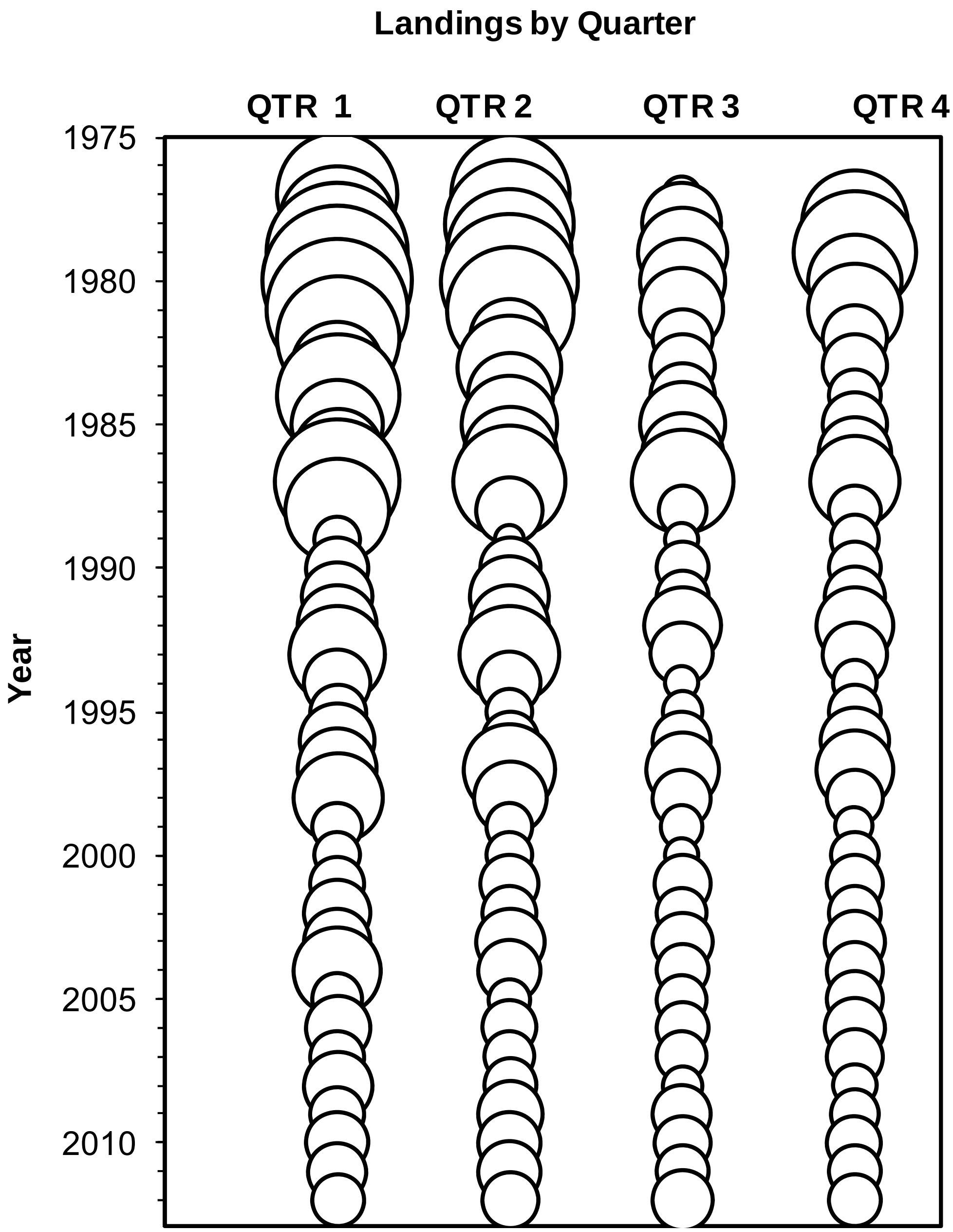


Figure B7. Bubble plot of Golden tilefish landings by quarter.

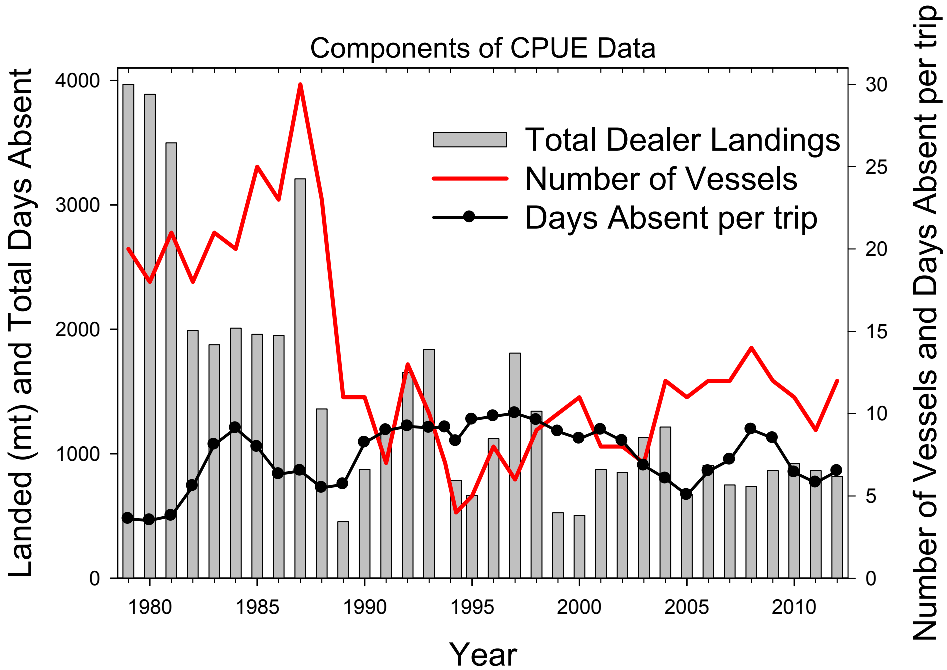


Figure B8. Number of vessels and length of trip (days absent per trip) for trips targeting tilefish (= or >75% tilefish) from 1979-2012. Total Dealer landings are also shown.

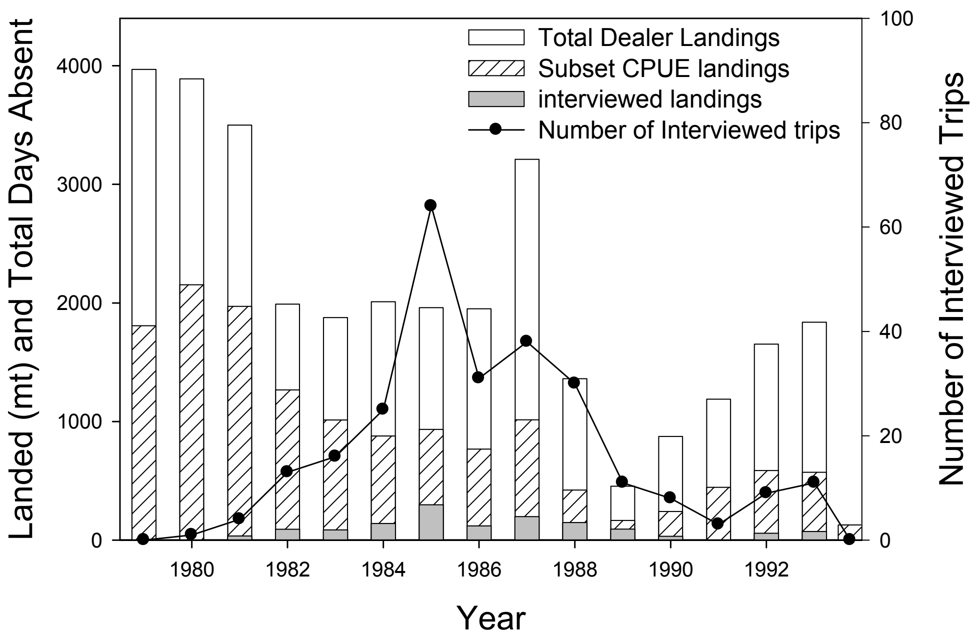


Figure B9. Number of interviewed trips and interviewed landings for trips targeting tilefish (= or >75% tilefish) for the Weighout data from 1979-1994. Total Weighout landings and the subset landings used in CPUE estimate are also shown.

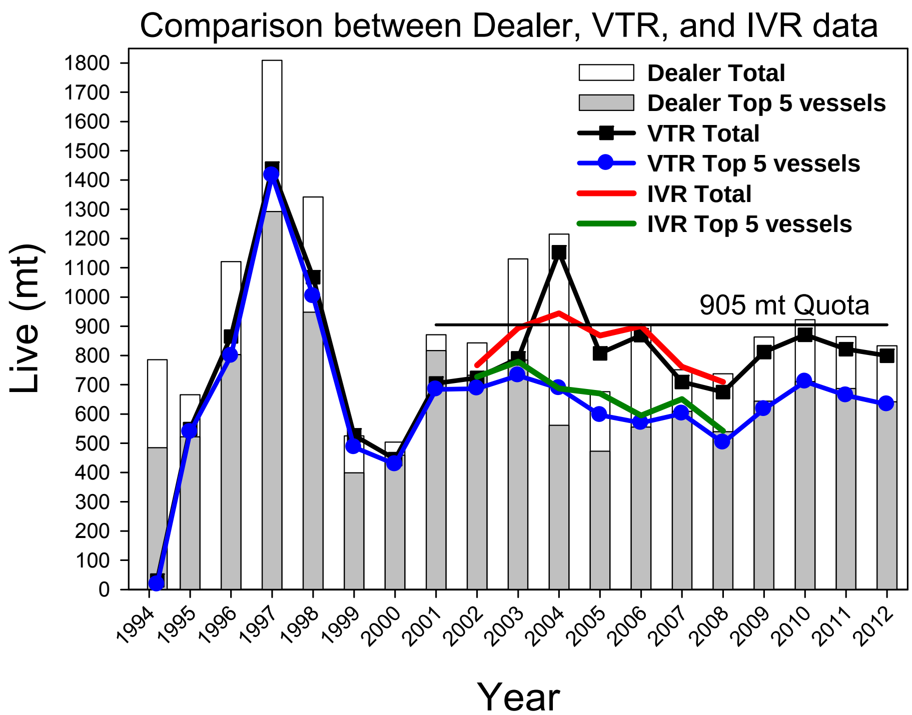


Figure B10. Comparison of dealer, VTR, and IVR total landings in live metric tons. Total landings limited to the top five dominant tilefish vessels are also shown.

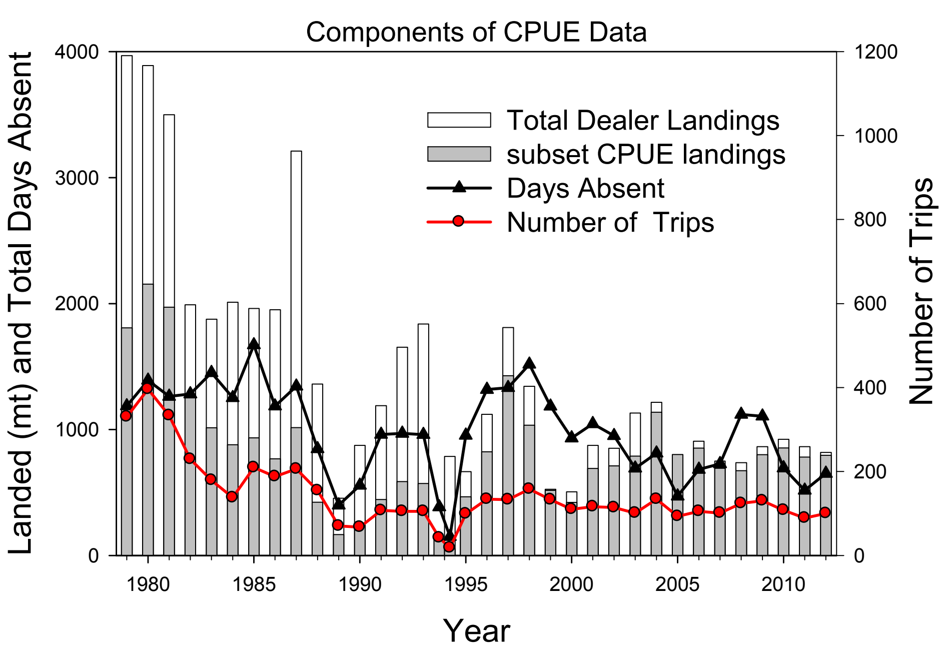


Figure B11. Total number of trips and days absent for trips targeting tilefish (= or >75% tilefish) from 1979-2012. Total Dealer and CPUE subset landings are also shown.

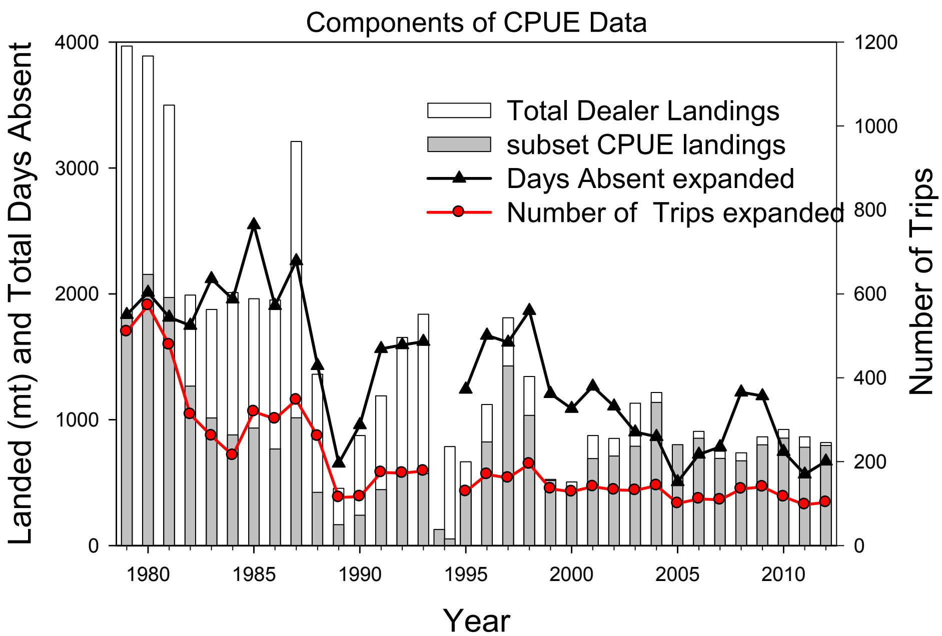


Figure B12. Total number of trips and days absent expanded to the total dealer landings from 1979-2012. Total Dealer and CPUE subset landings are also shown.

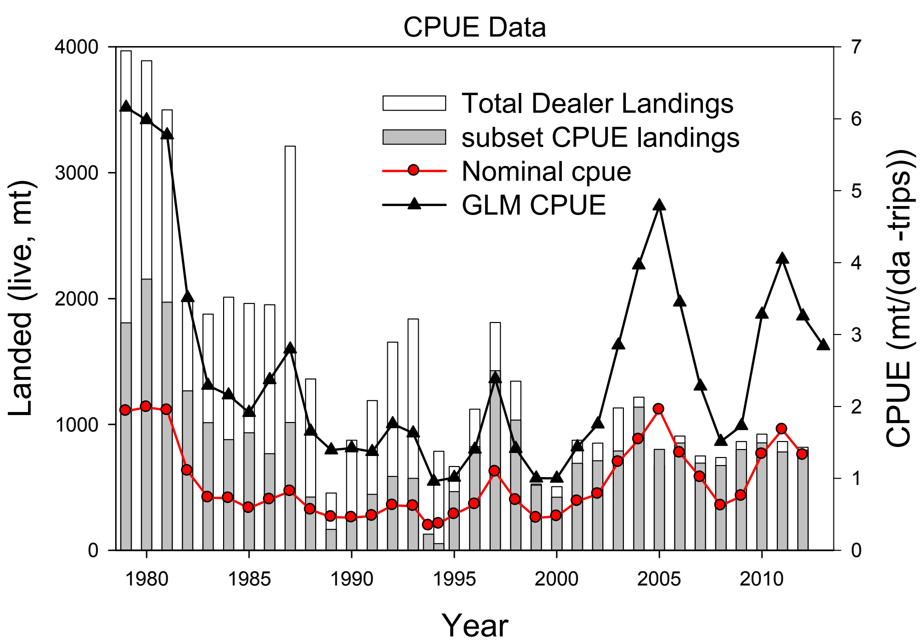


Figure B13. Nominal CPUE (1994 split by Weighout and VTR series) and vessel standard CPUE (GLM) for trips targeting tilefish (= or >75% tilefish) from 1979-2008. Total Dealer and CPUE subset landings are also shown.

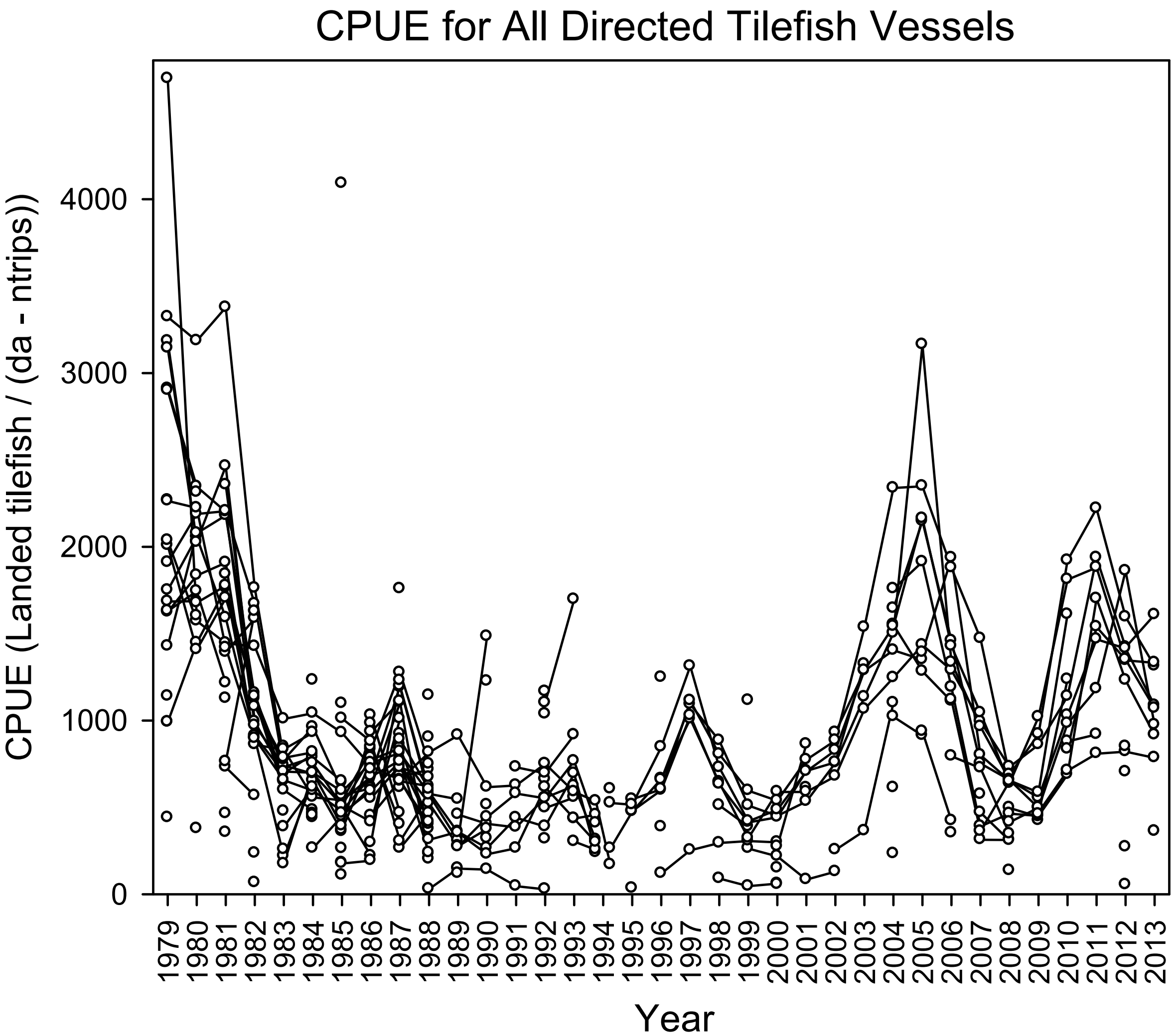


Figure B14. All individual tilefish vessel CPUE data for trips targeting tilefish (= or >75% tilefish) from 1979-2013.

Figure B15. Depiction of individual vessels (rows) targeting tilefish over the Weighout and VTR series. Year 1994 is split by the two series. Below the horizontal line are vessels which are predominantly found in the VTR series.

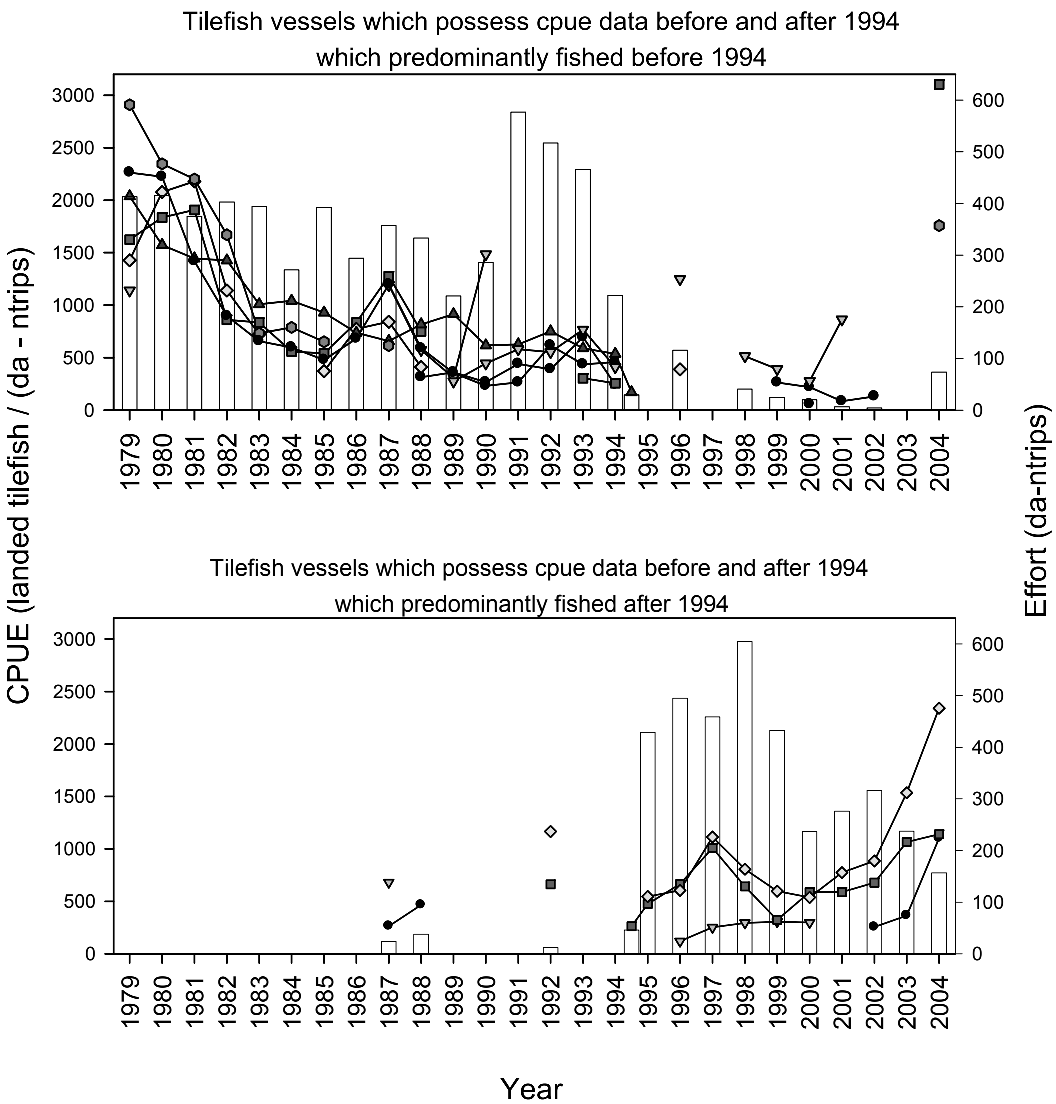


Figure B16. Individual tilefish vessel CPUE and effort data (Bars) for trips targeting tilefish (= or >75% tilefish) from 1979-2004 which are found in both the Weighout and VTR series. Top graph are vessels found predominantly in the Weighout series. Bottom graph are vessels found predominantly in the VTR series.

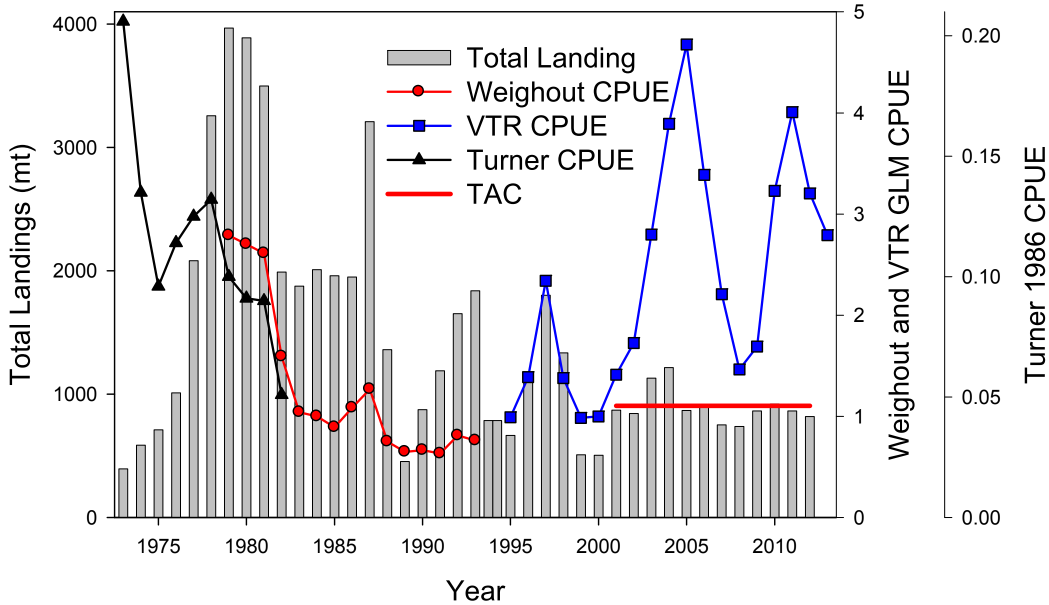


Figure B17. GLM CPUE for the Weighout and VTR data split into two series. Four years of overlap between Turner's and the Weighout CPUE series can be seen. Assumed total landings are also shown. Landing in 2005 was taken from the IVR system.

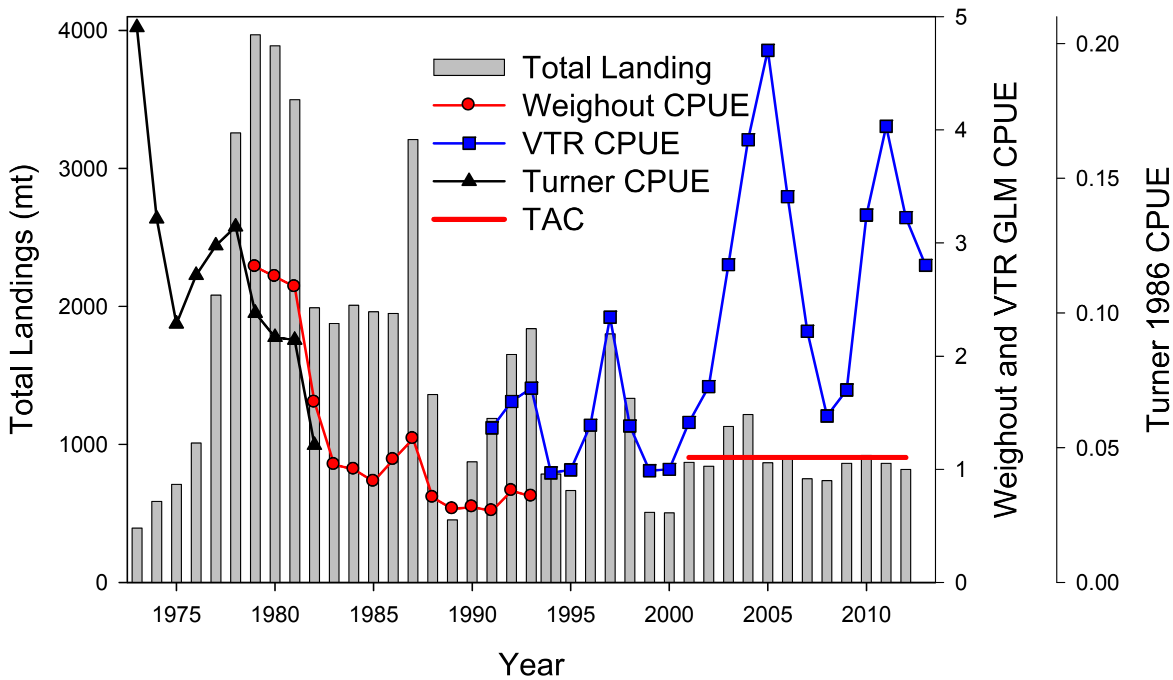


Figure B18. GLM CPUE for the Weighout and VTR data split into two series with additional New York logbook CPUE data from three vessels (1991-1994) added to the VTR series.

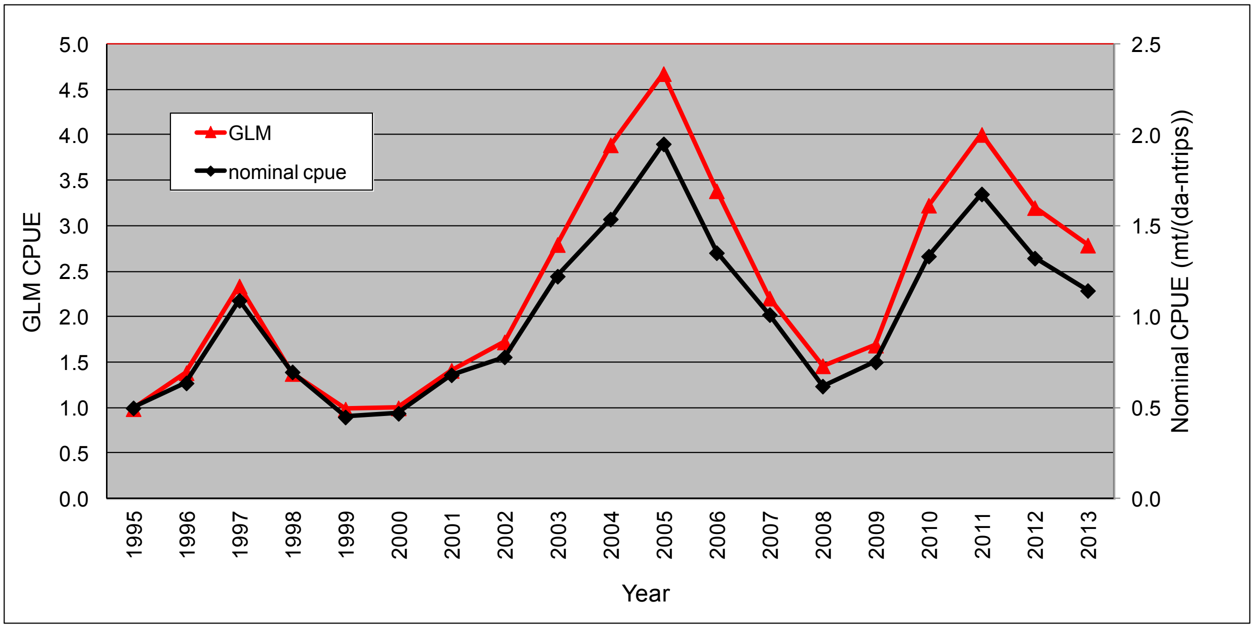


Figure B19. Comparison of nominal and GLM (vessel standardized) CPUE series from the VTR series.

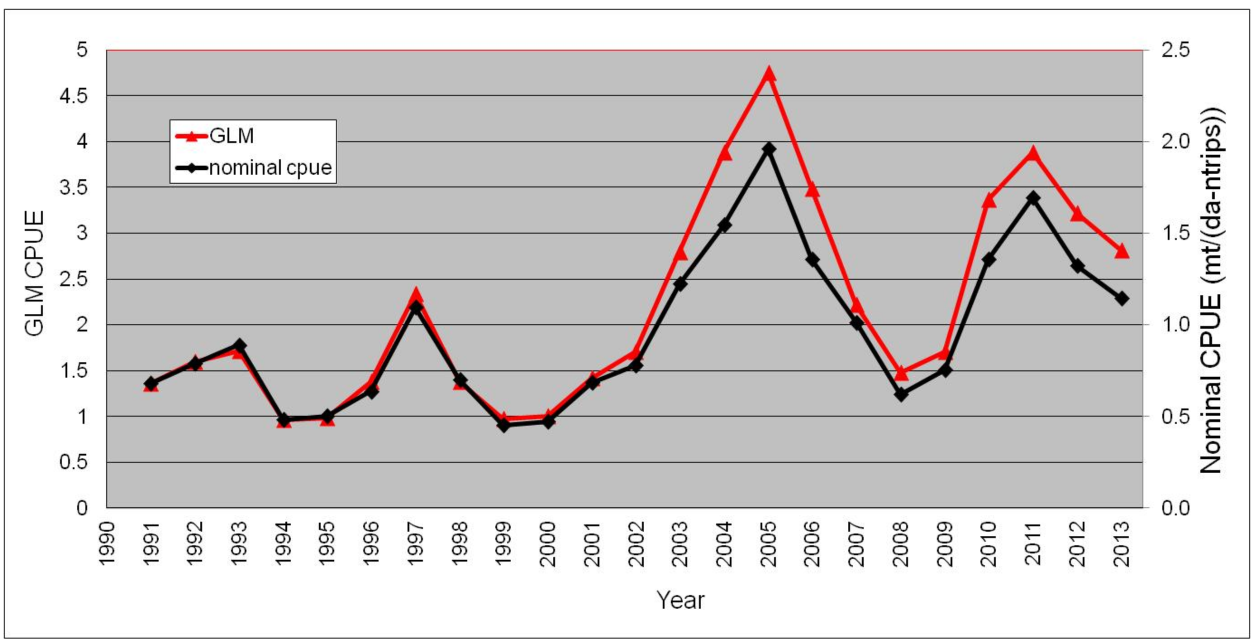


Figure B20. Comparison of nominal and GLM (vessel standardized) CPUE series from the VTR series with the additional 1991-1994 New York logbook CPUE data added to the series.

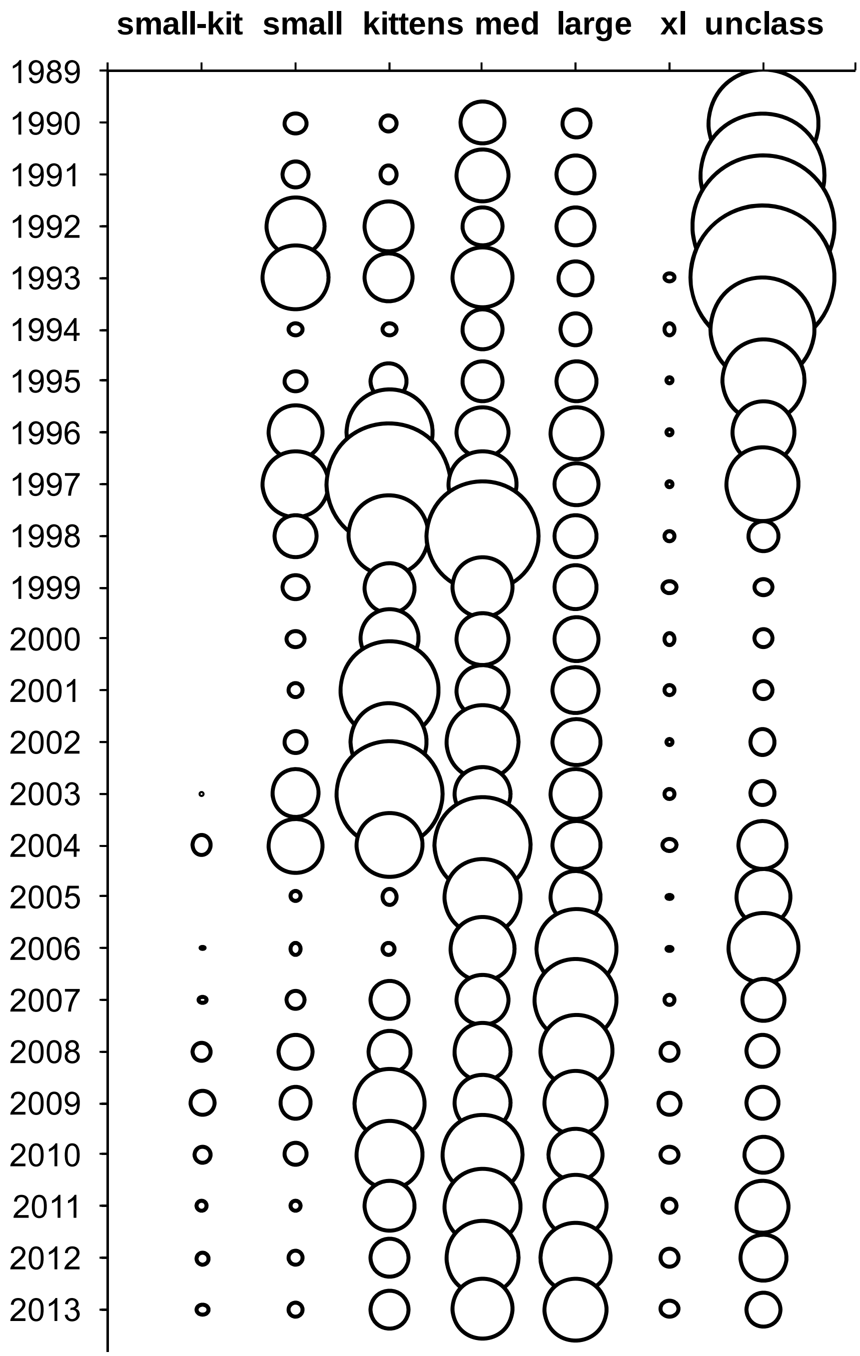


Figure B21. Bubble plot of Golden tilefish landings by market category.

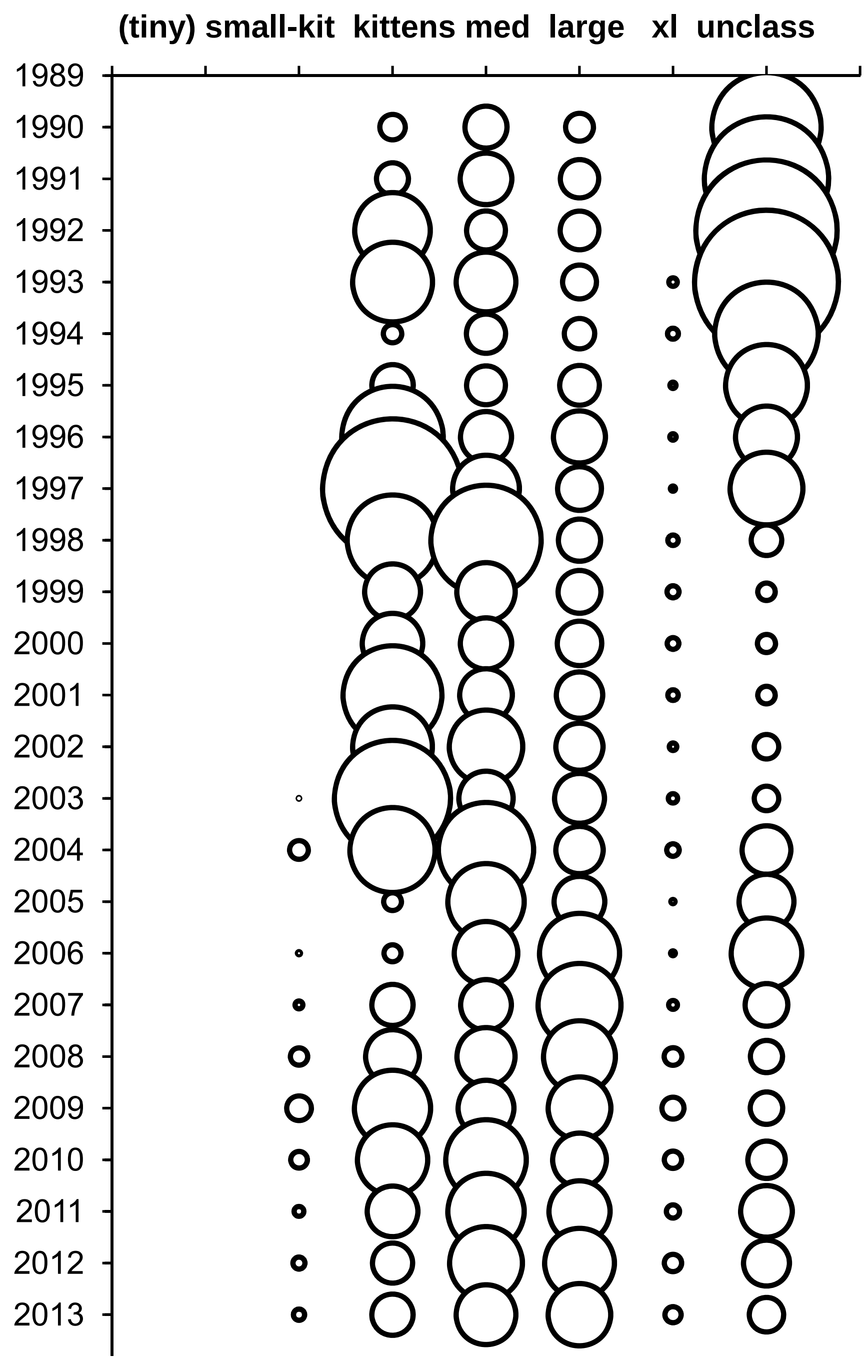


Figure B22. Bubble plot of Golden tilefish landings by market category where similar sized smalls and kittens market categories are combined into the kittens category.

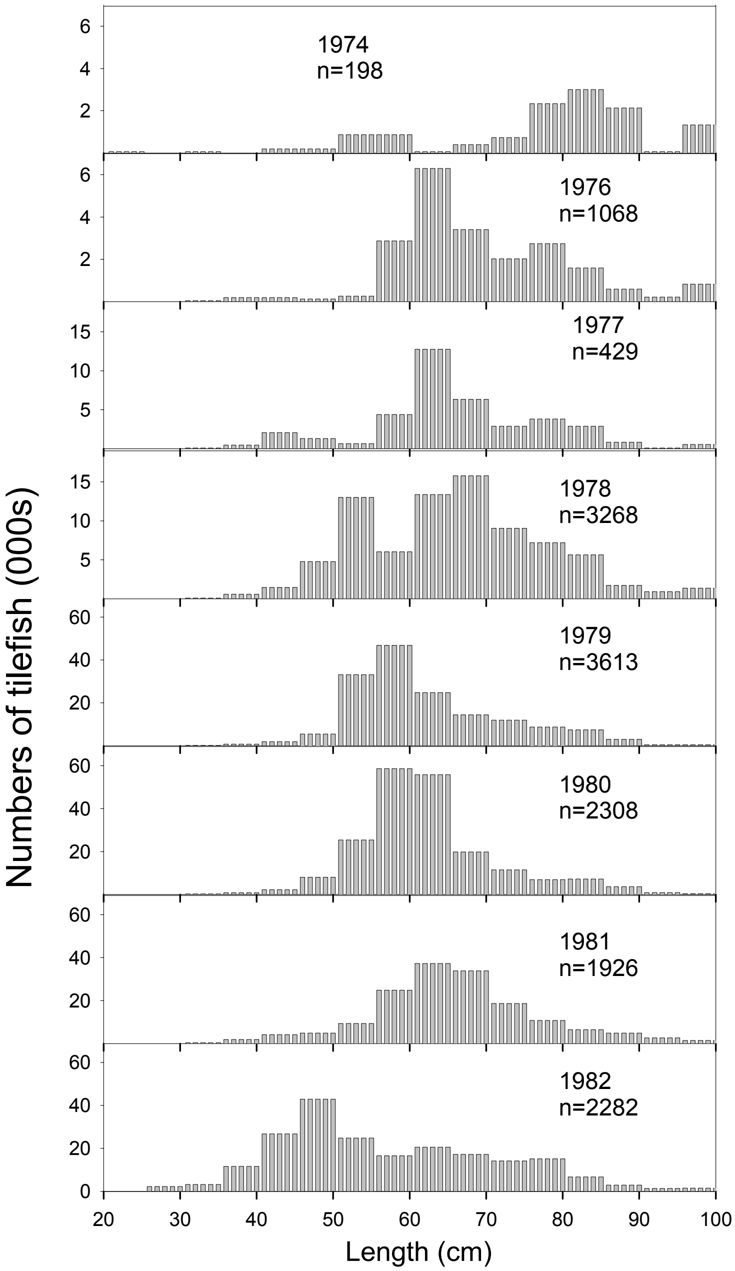


Figure B23. Expanded length frequency distributions using Turner (1986) length samples by 5 cm intervals. Hudson Canyon and Southern New England samples were combined.

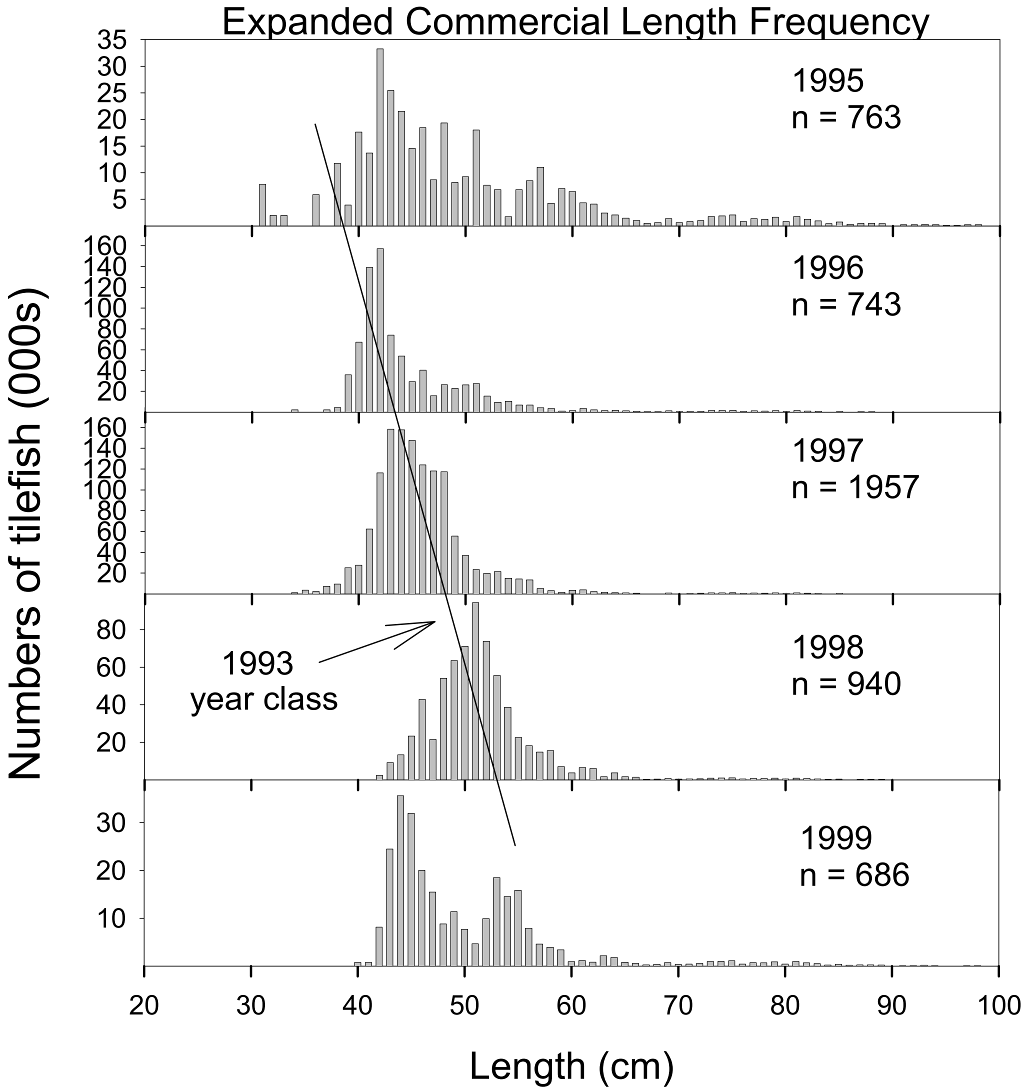


Figure B24. Expanded length frequency distributions by year. Large market category length used from 1995 to 1999 were taken from years 1996, 1998, and 1998. Smalls and kittens were combined and large and extra large were also combined.

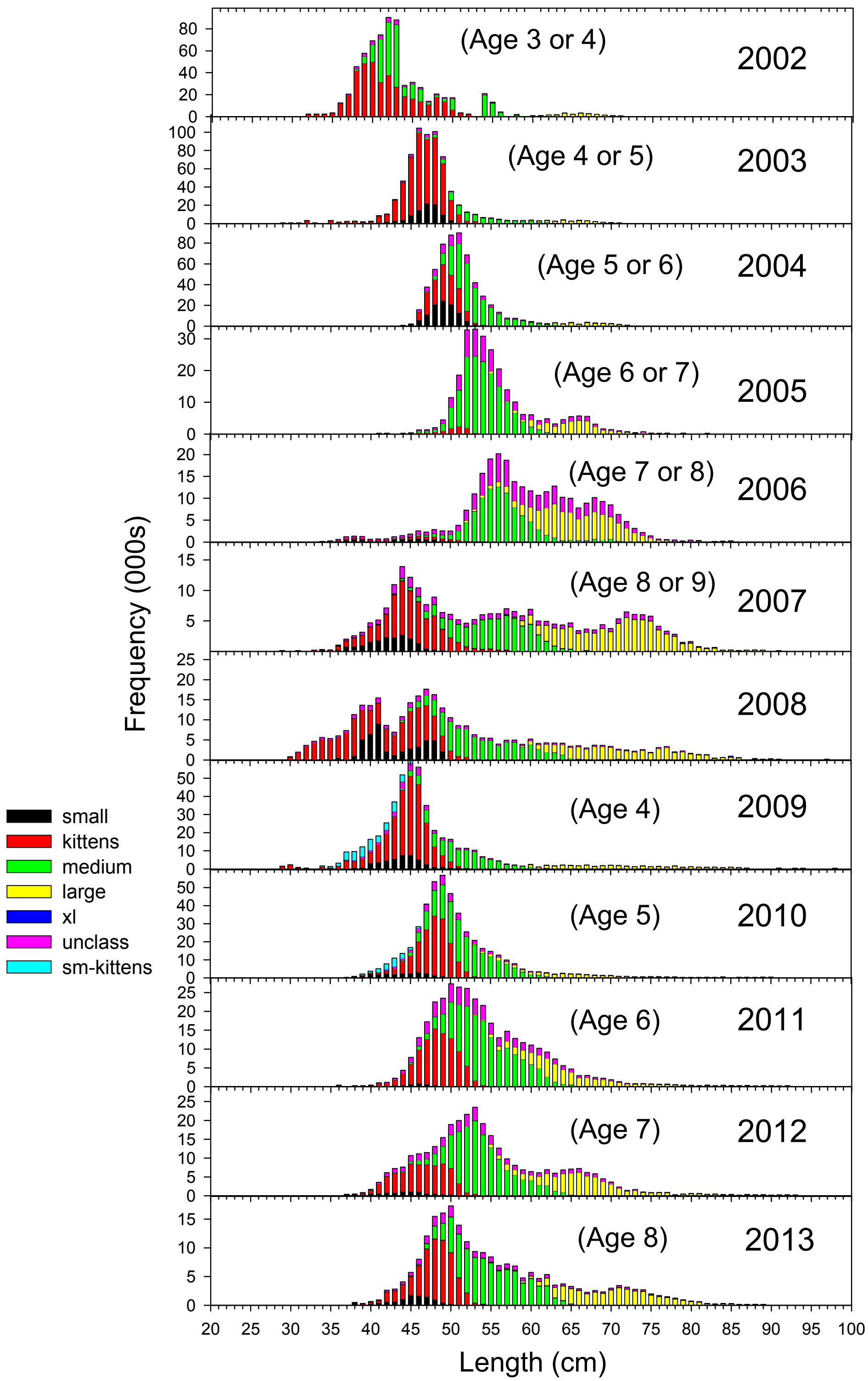


Figure B25. Expanded numbers length frequency distributions by year. Y-axis is allowed to rescale.

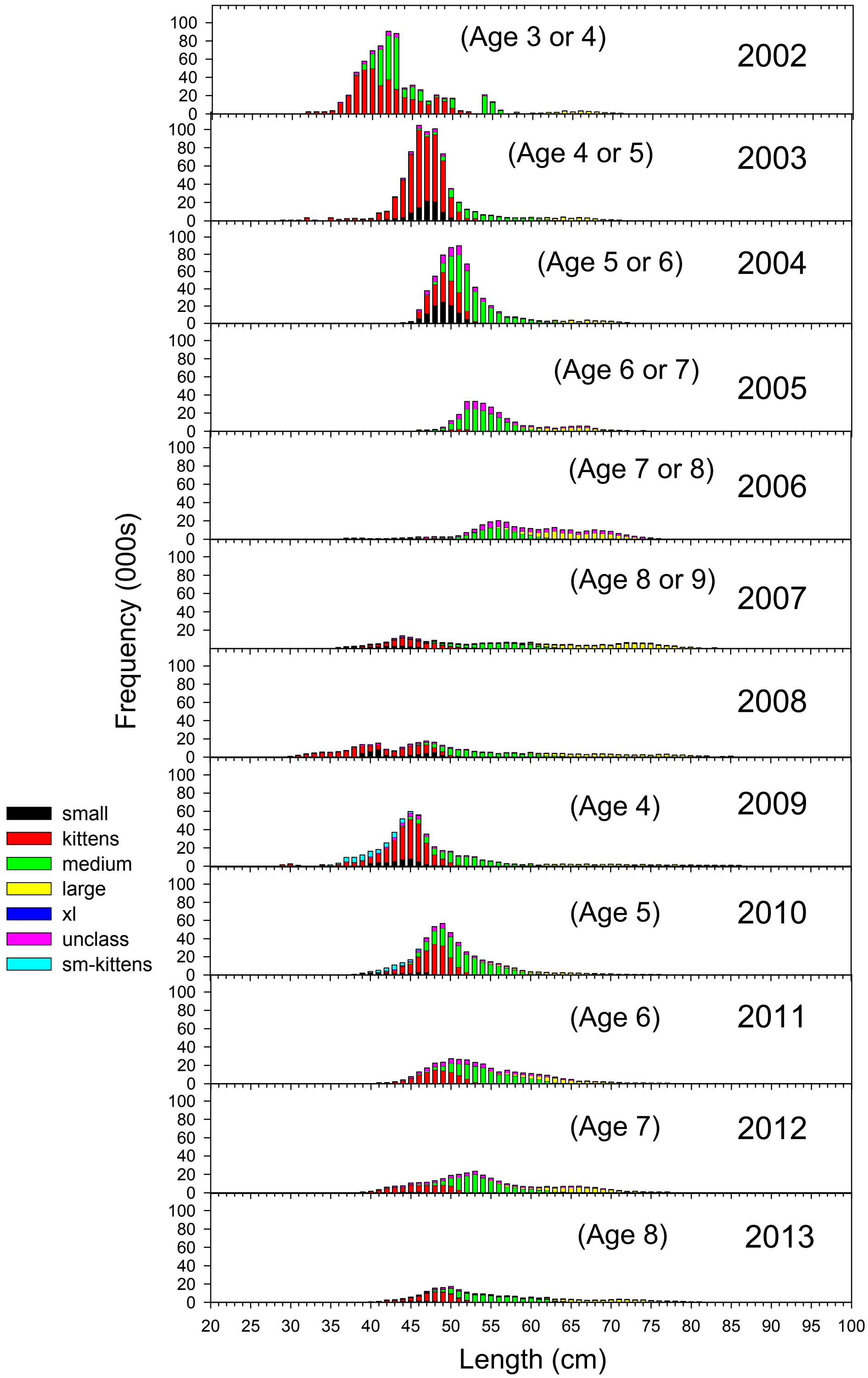


Figure B26. Expanded numbers length frequency distributions by year. Y-axis scale is fixed.

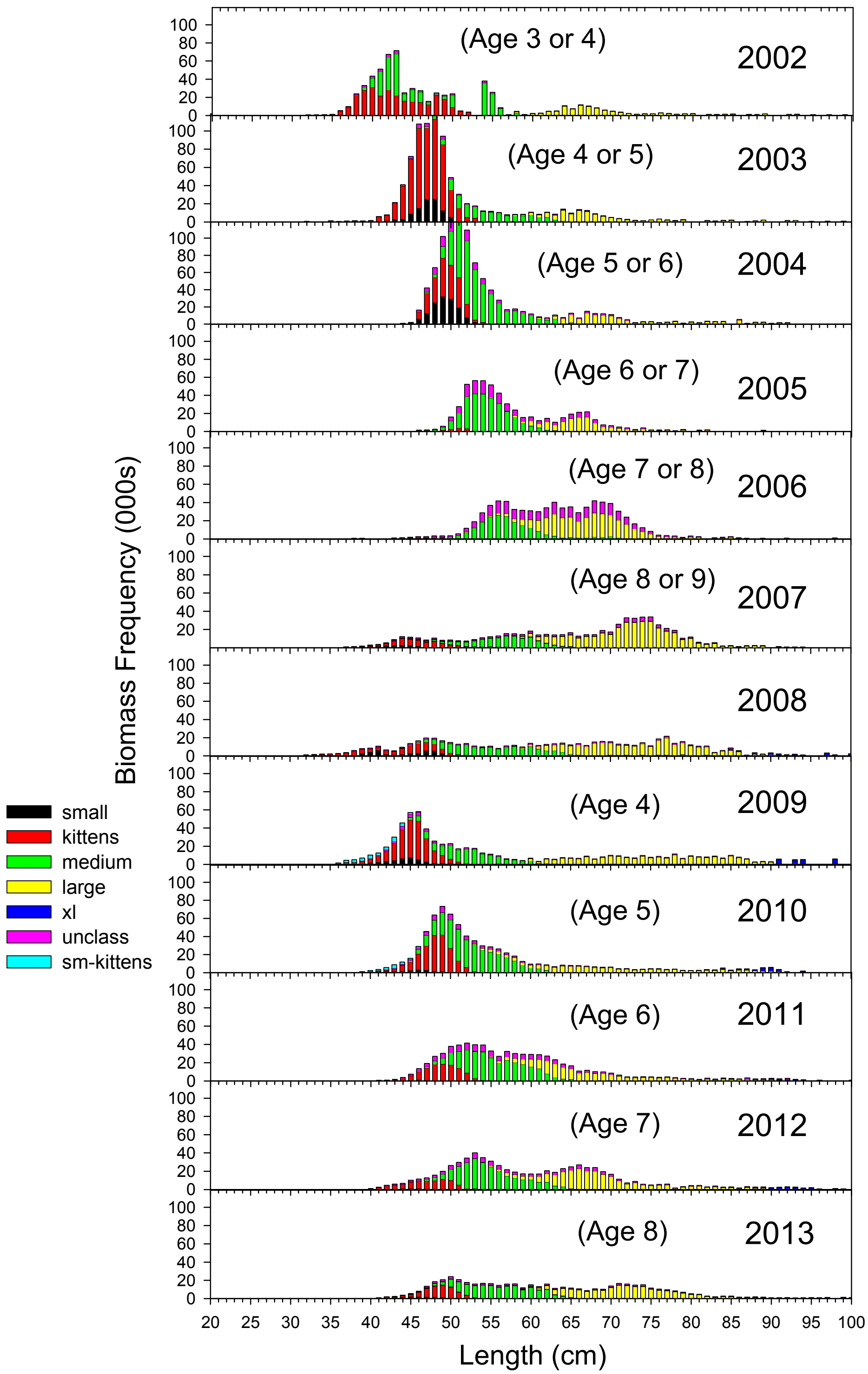


Figure B27. Expanded biomass length frequency distributions by year. Y-axis scale is fixed.

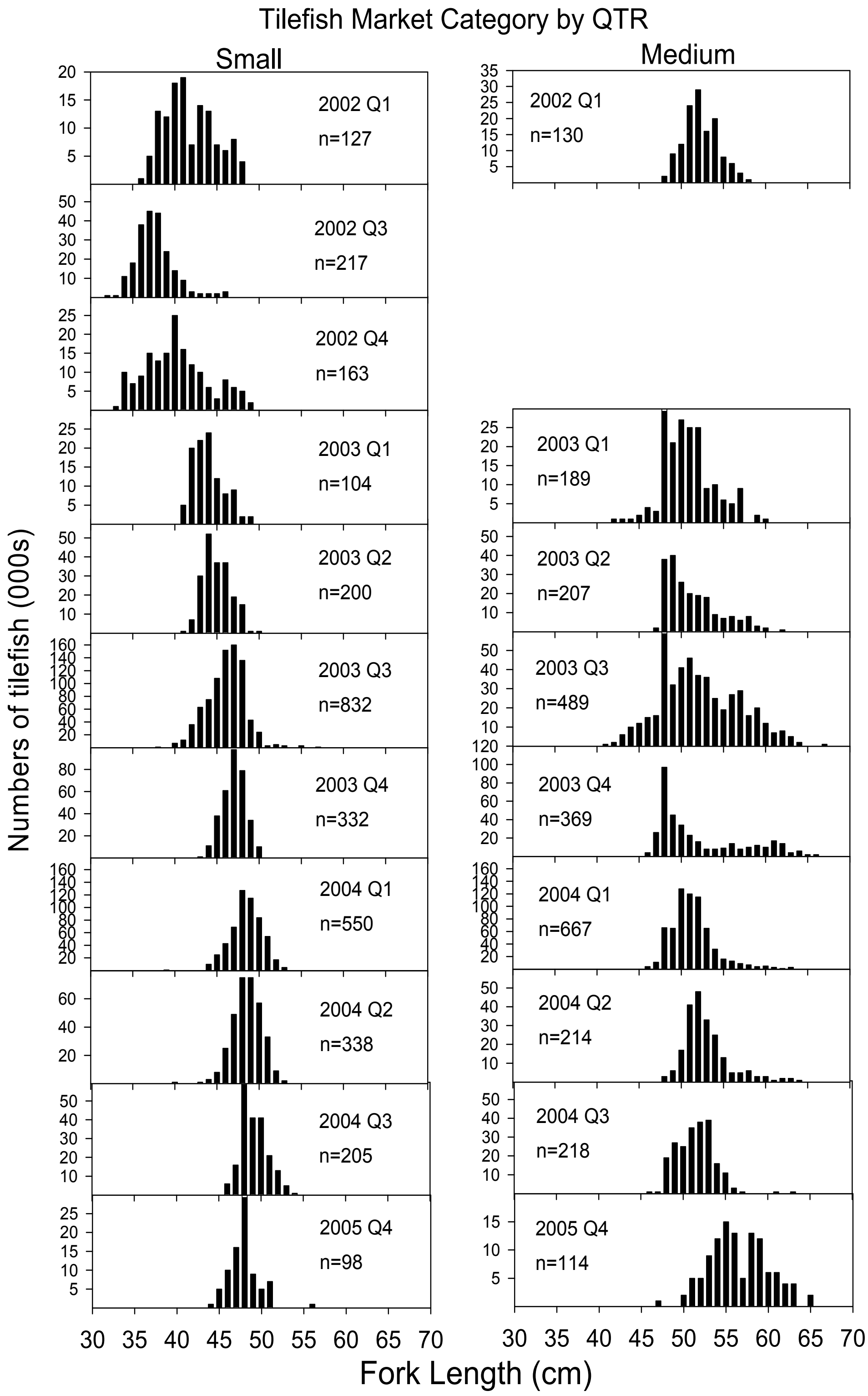


Figure B28. Small and medium tilefish market category length frequency distributions by quarter.

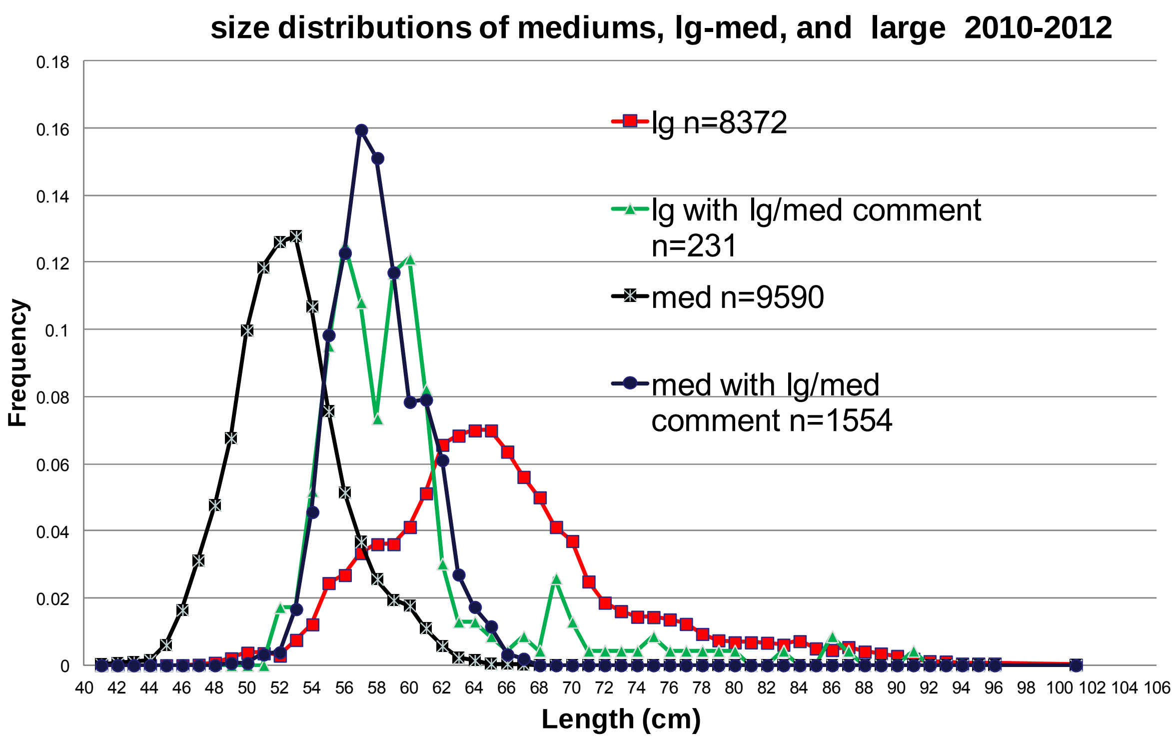


Figure B29. Comparison of medium and large length distributions with distributions that had a comment from the port sampler indicating that the sample came from a dealer large-medium category.

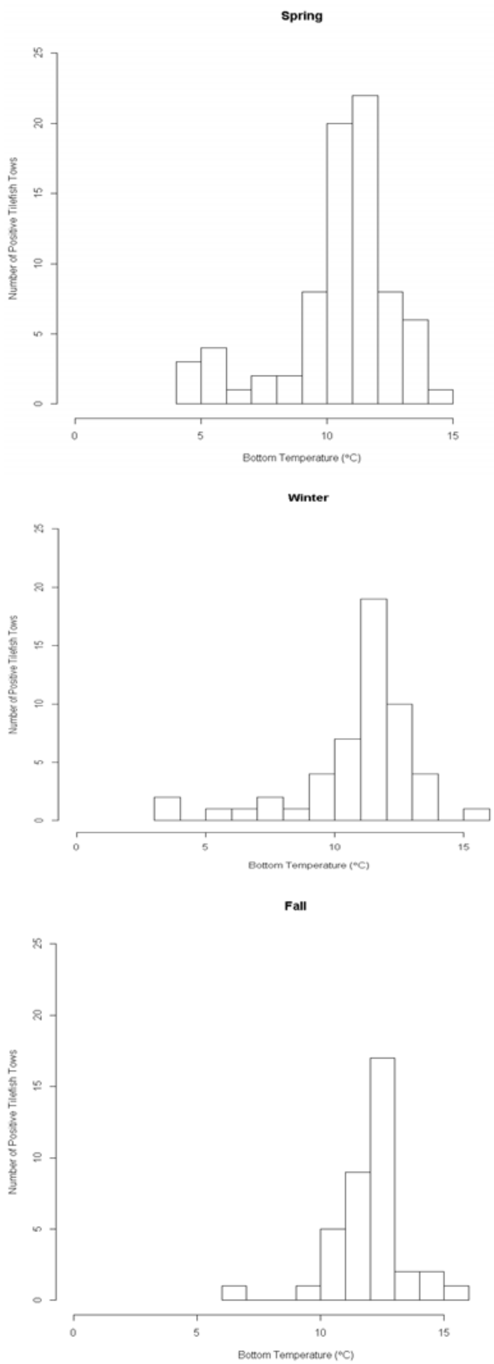


Figure B30. Temperature distributions from survey tows which caught tilefish over the entire time series for the NEFSC spring, winter and fall bottom trawl surveys.

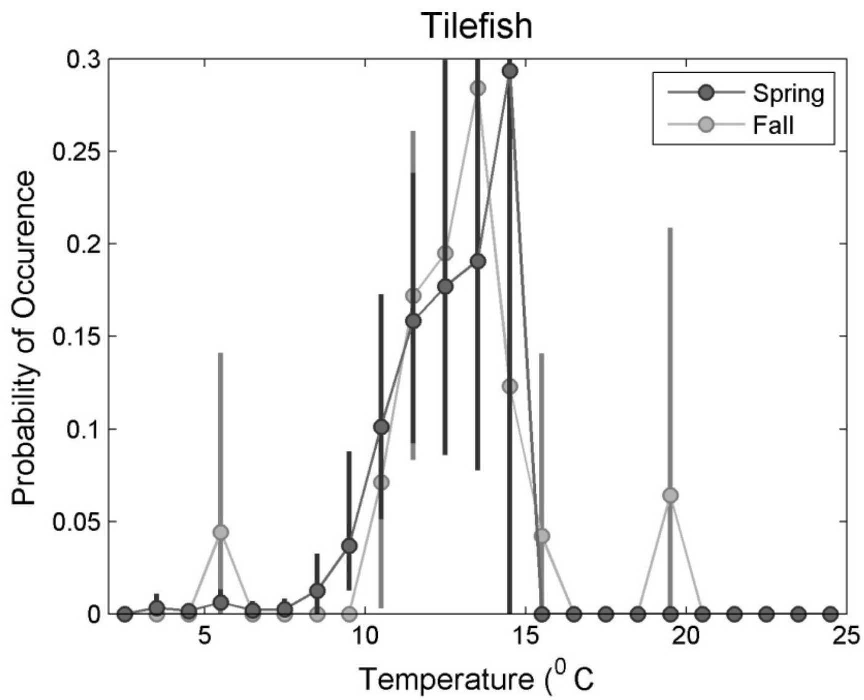


Figure B31. The probability of occurrence with temperature for tilefish from the spring and fall surveys. Confidence intervals were calculated from bootstrapping.

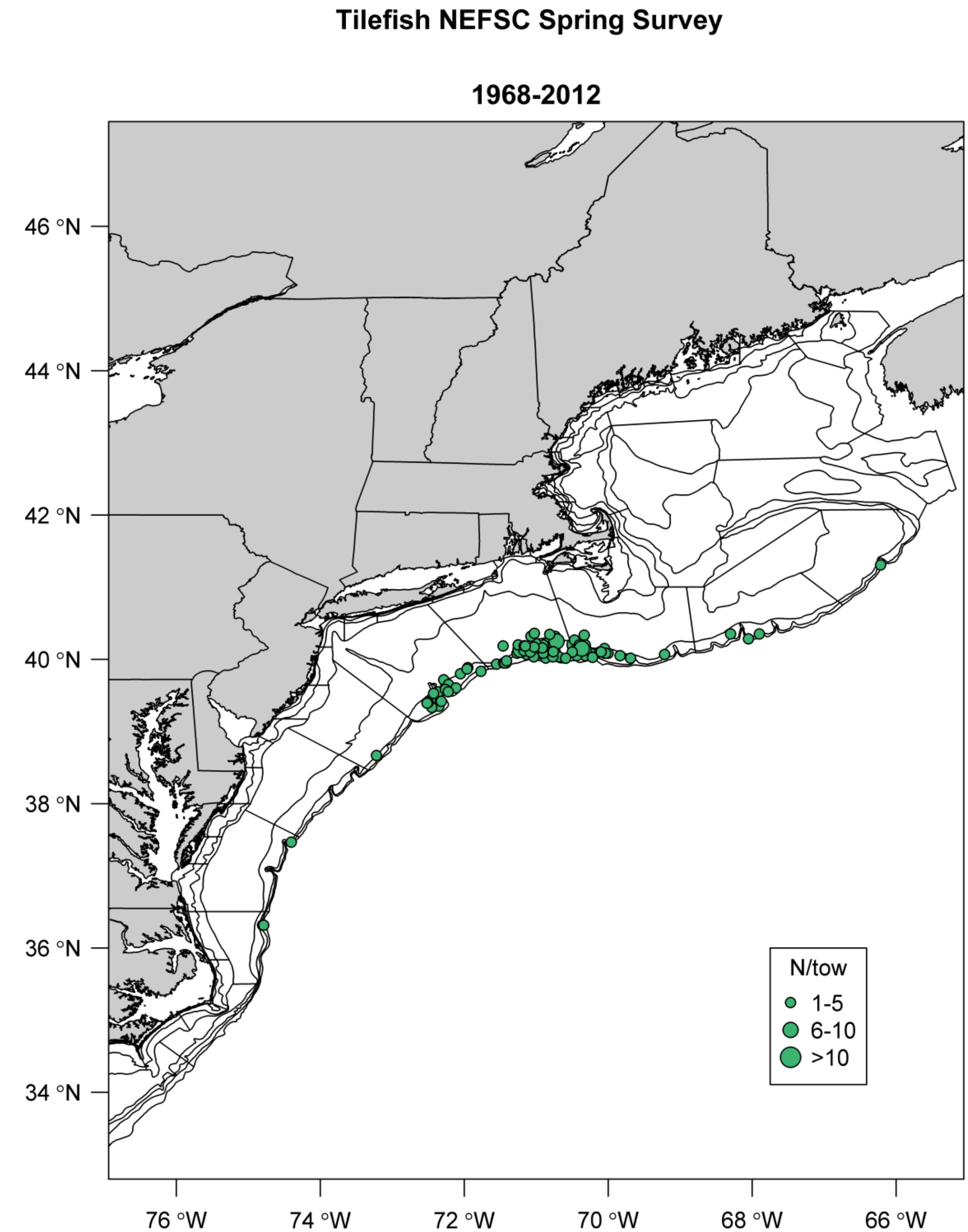


Figure B32. Spatial distribution for 138 tilefish caught in the Spring NEFSC bottom trawl survey over the entire 1968-2012 time series.

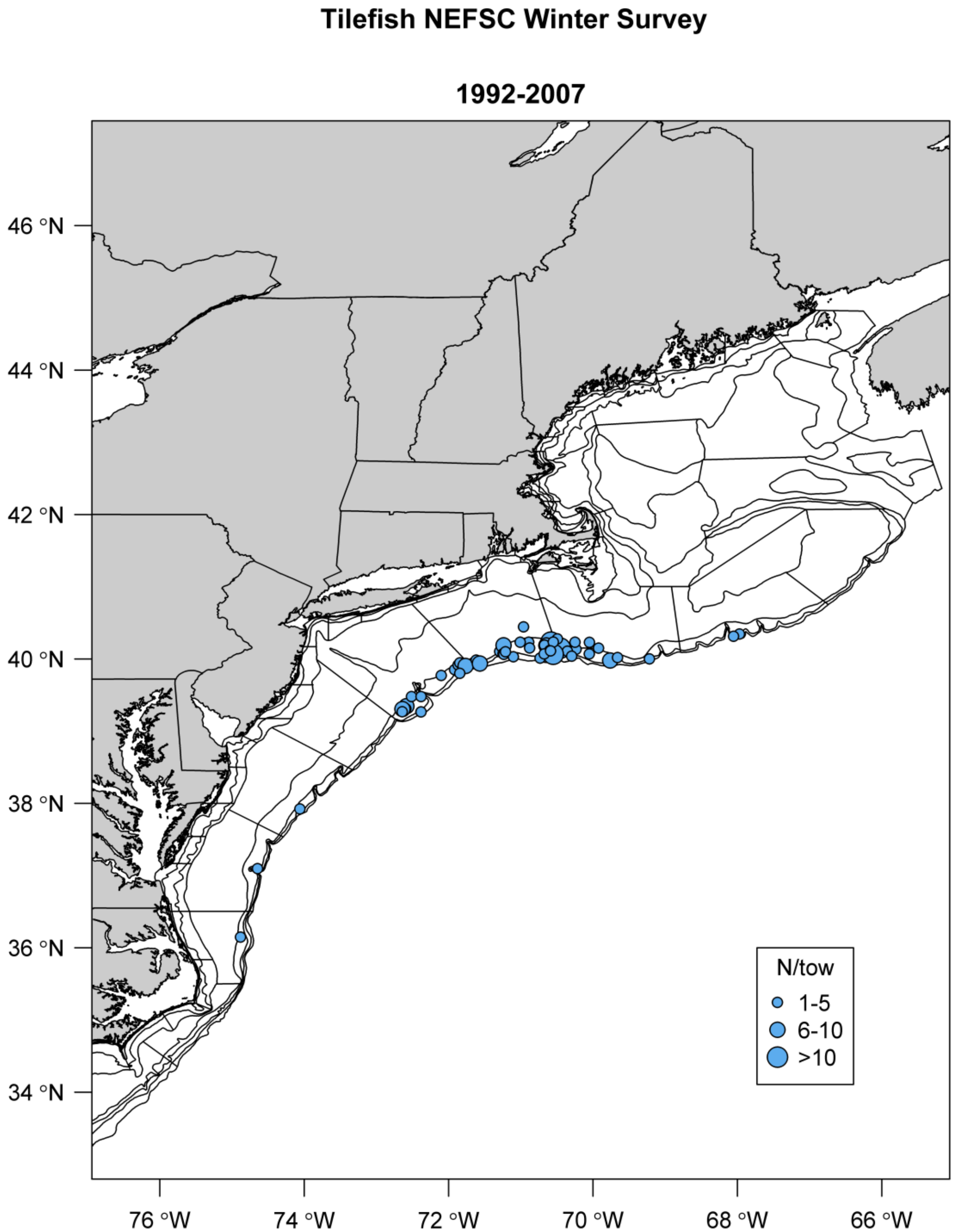


Figure B33. Spatial distribution for tilefish caught in the Winter NEFSC bottom trawl survey (flatfish net) over the entire 1992-2007 time series.

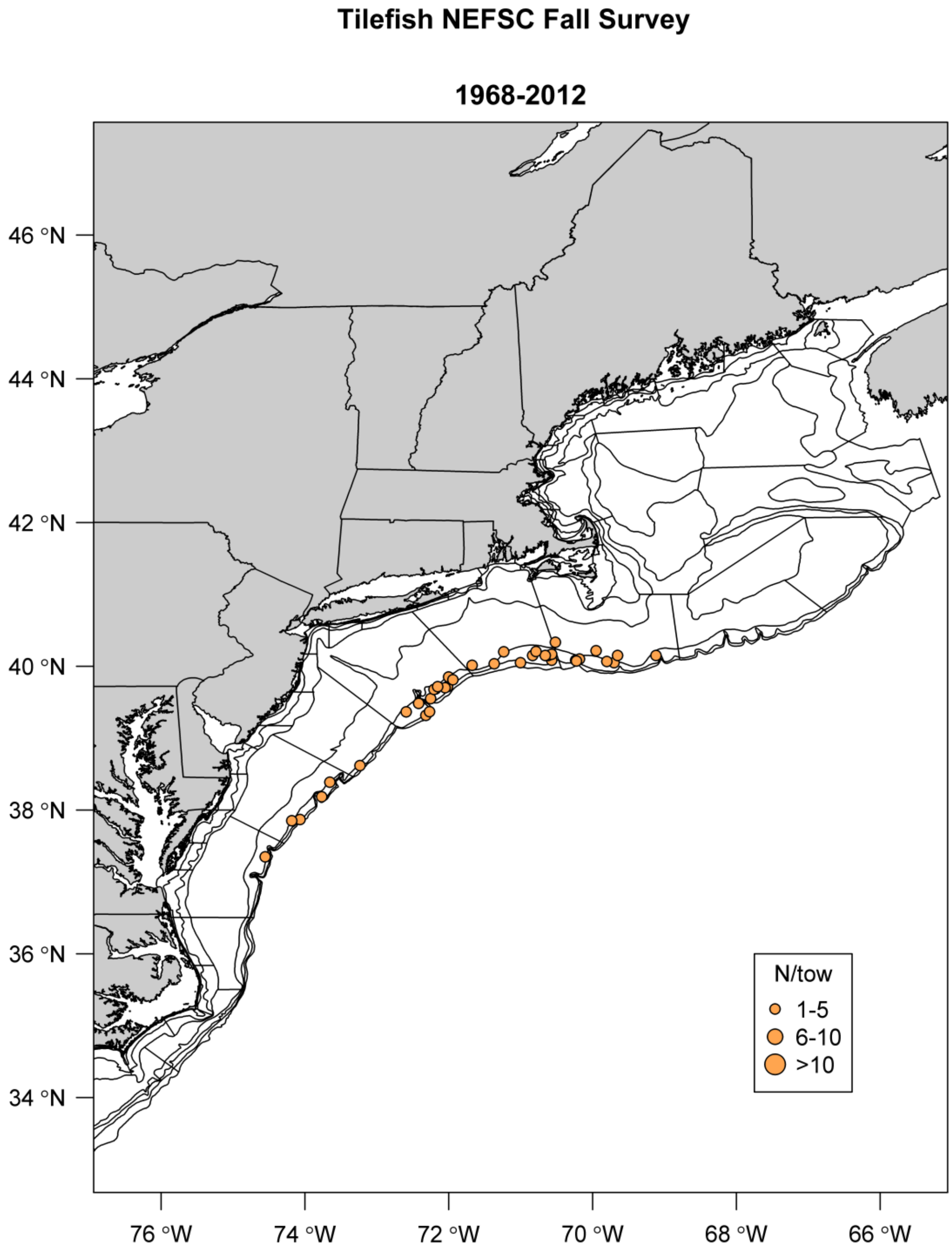


Figure B34. Spatial distribution for 47 tilefish caught in the Fall NEFSC bottom trawl survey over the entire 1963-2012 time series.

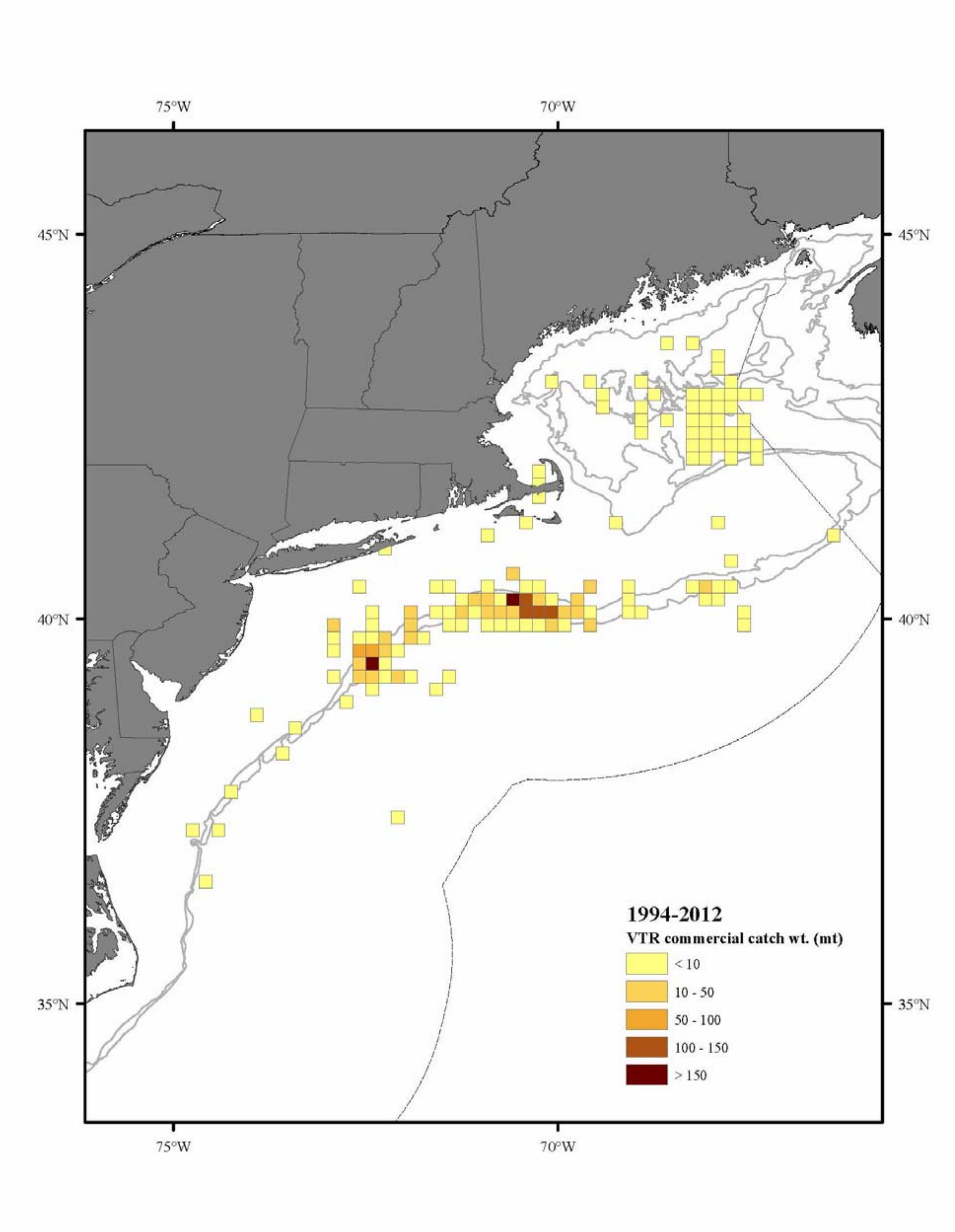


Figure B35. Spatial distribution for tilefish caught in all longline gear reported in the commercial VTR data from 1994-2012.

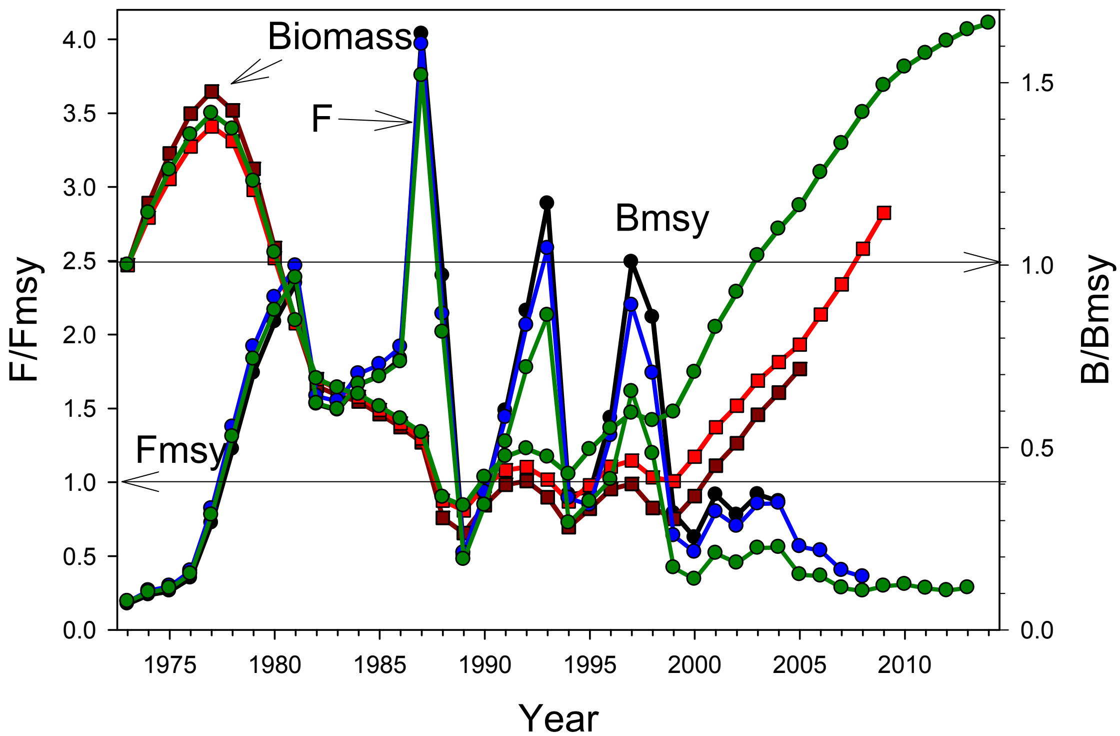


Figure B36. Comparison of the 2005 SAW 41, 2009 SARC 48 estimates of fishing mortality (F/FMSY) ratios and biomass (B/BMSY) ratios to the update model using the same configuration (run2 green).

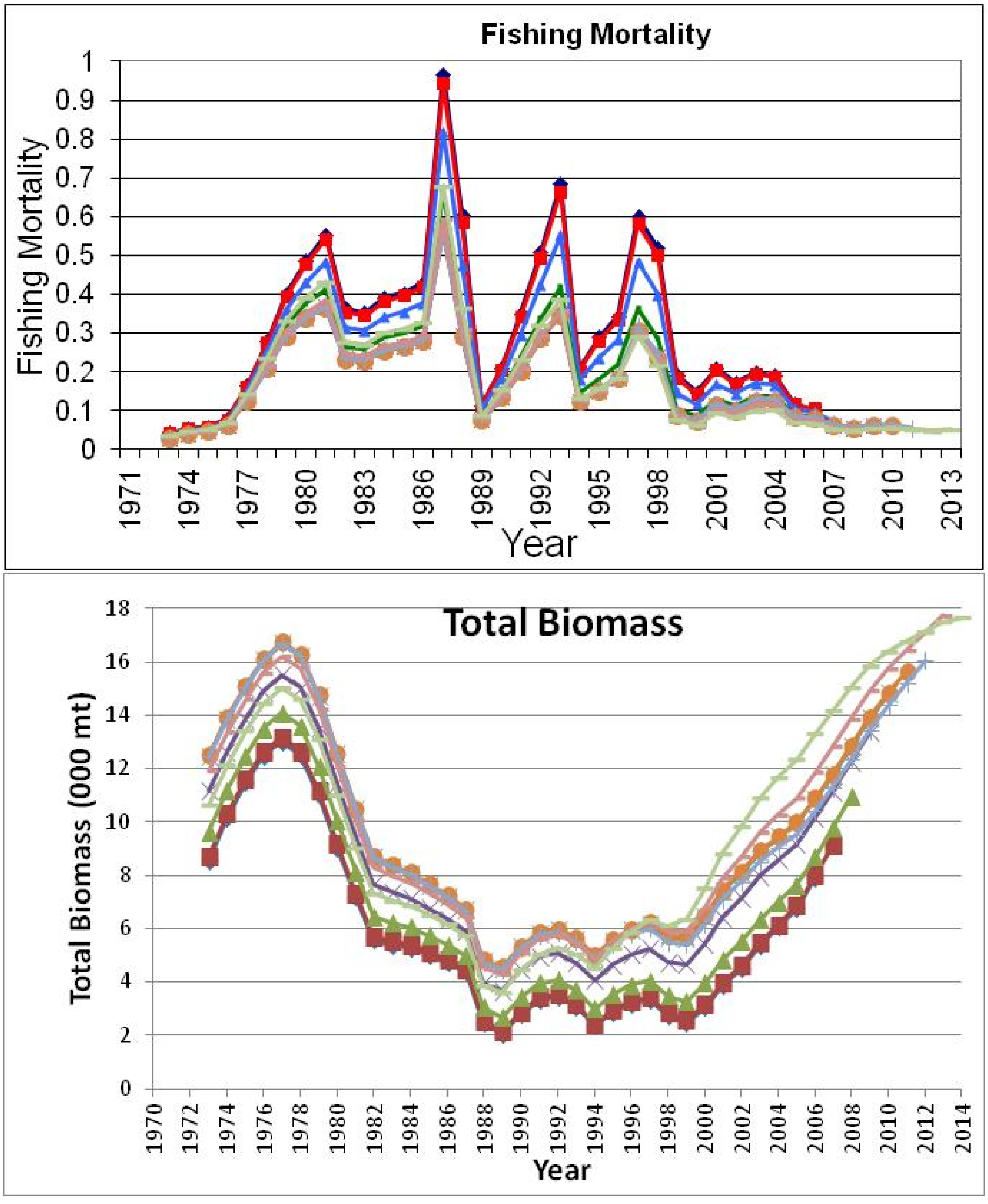
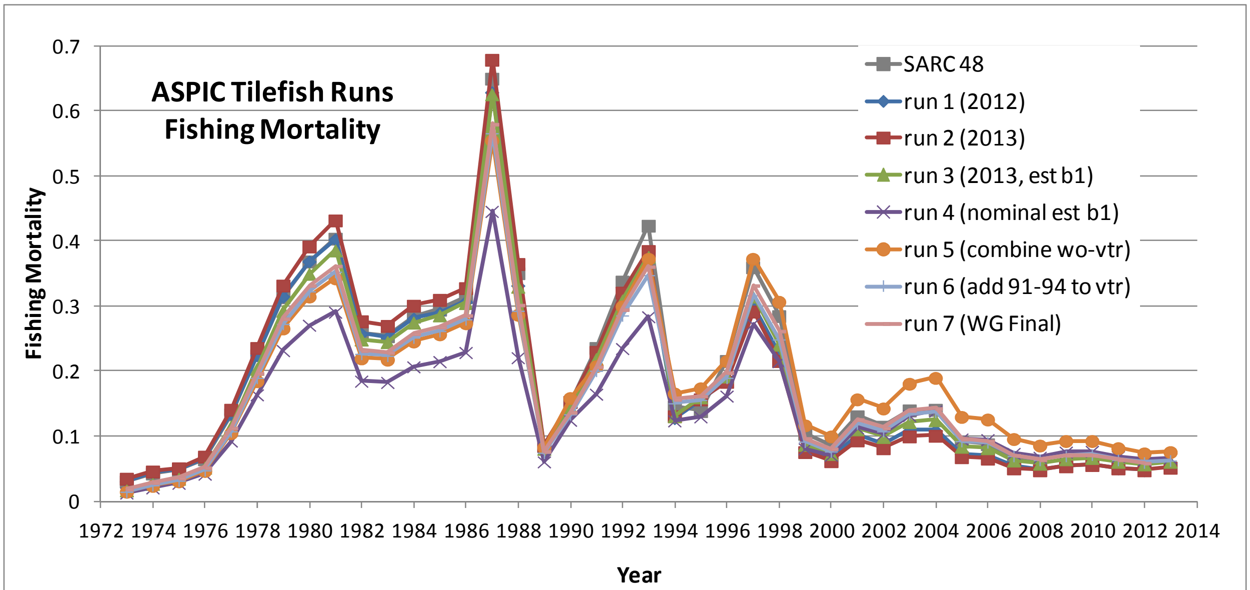


Figure B37. Retrospective analysis results for fishing mortality and biomass for the updated ASPIC run 2.



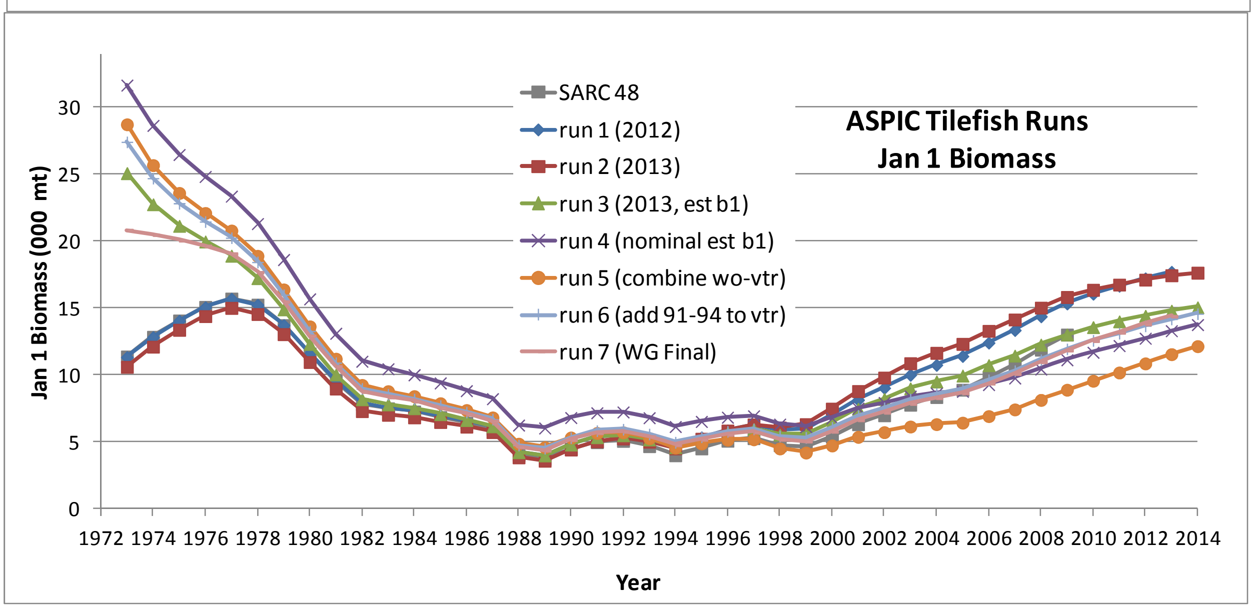


Figure B38. Sensitivity ASPIC runs for fishing mortality and total biomass.

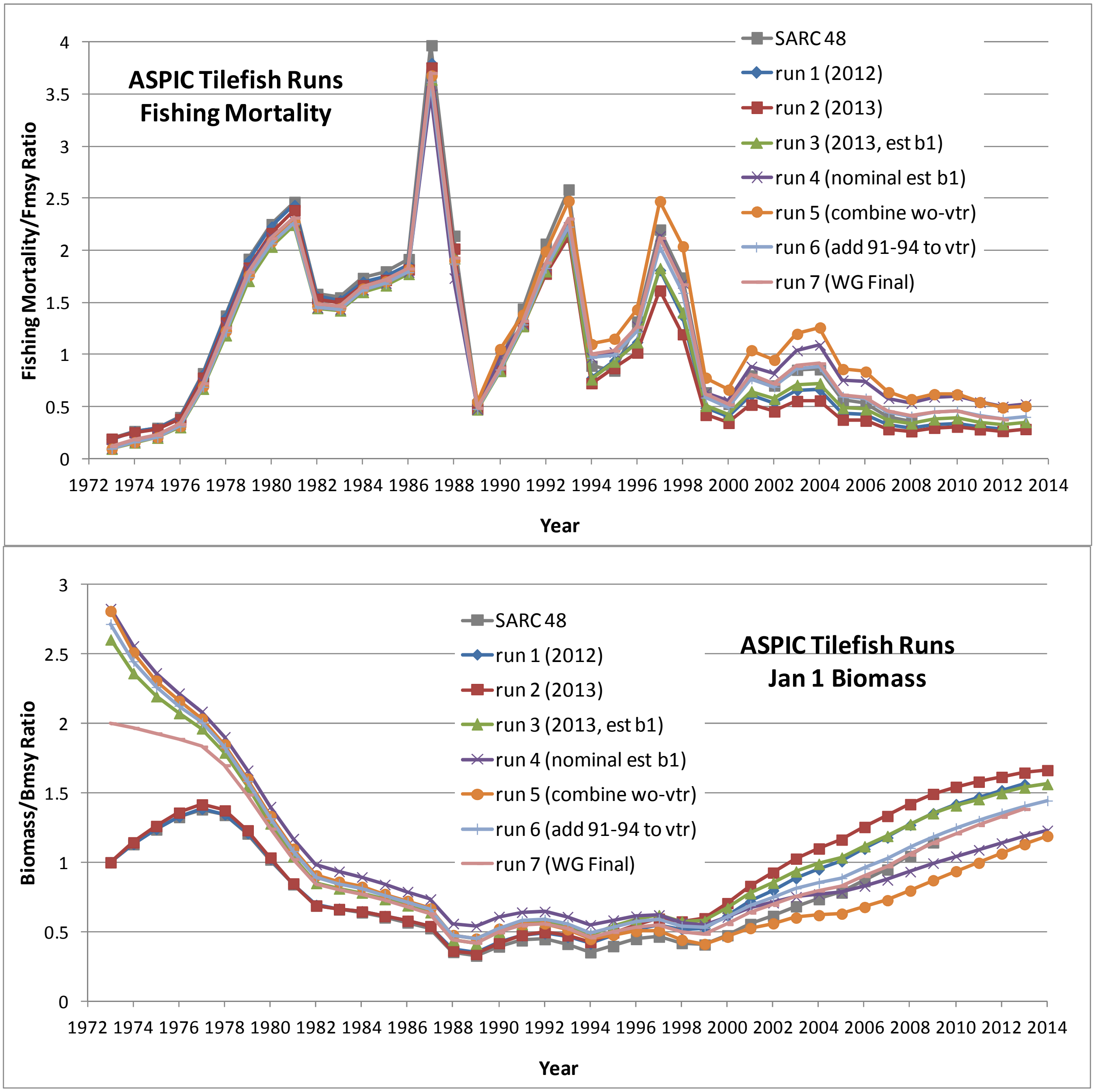
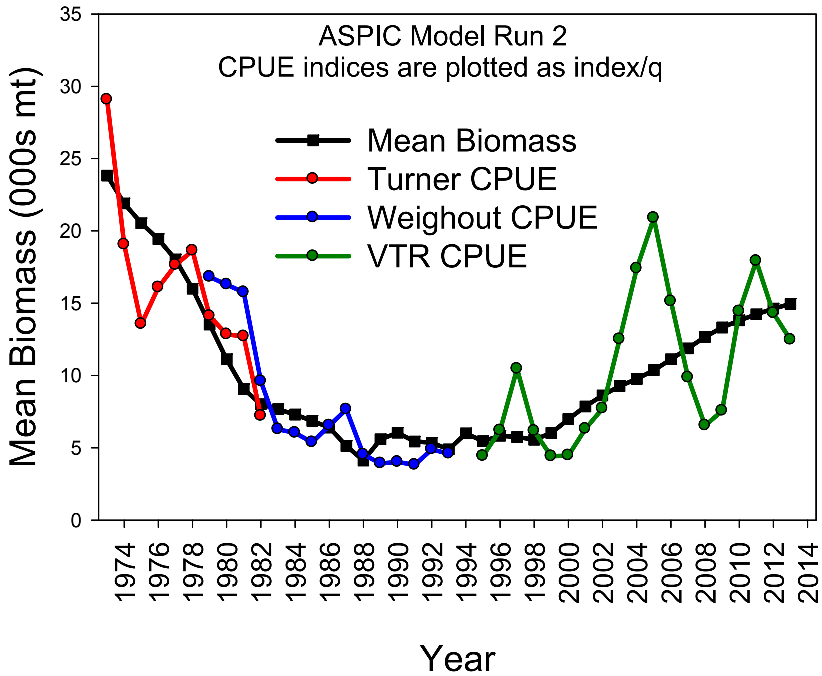


Figure B39. Sensitivity ASPIC runs for relative fishing mortality to F_{MSY} and relative biomass to B_{MSY}.



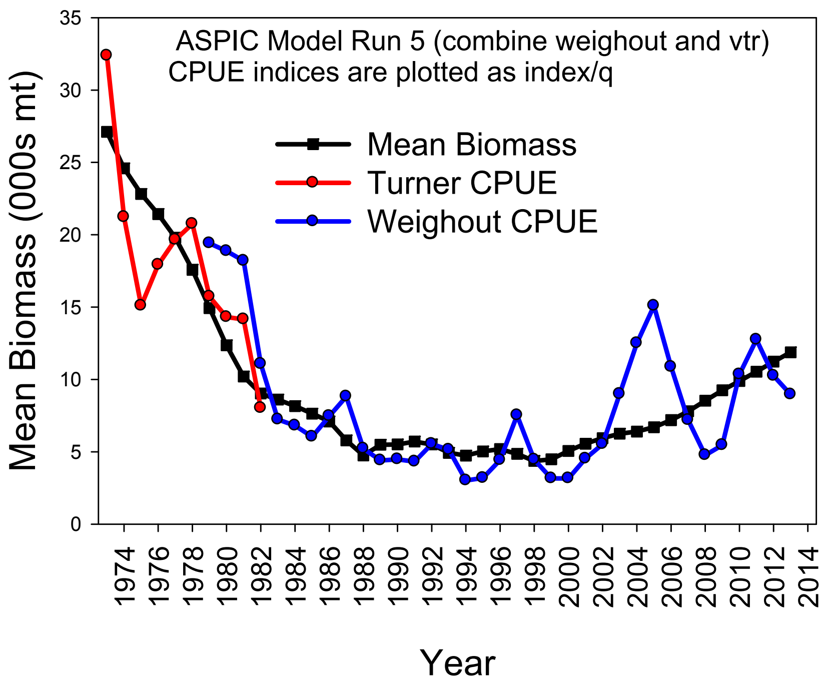


Figure B40. Fit of the ASPIC base run 1 with the three separate (Turner's, Weighout, and VTR) cpue series (top) and the fit of the ASPIC model to Turner's and the Weighout and VTR series combined.

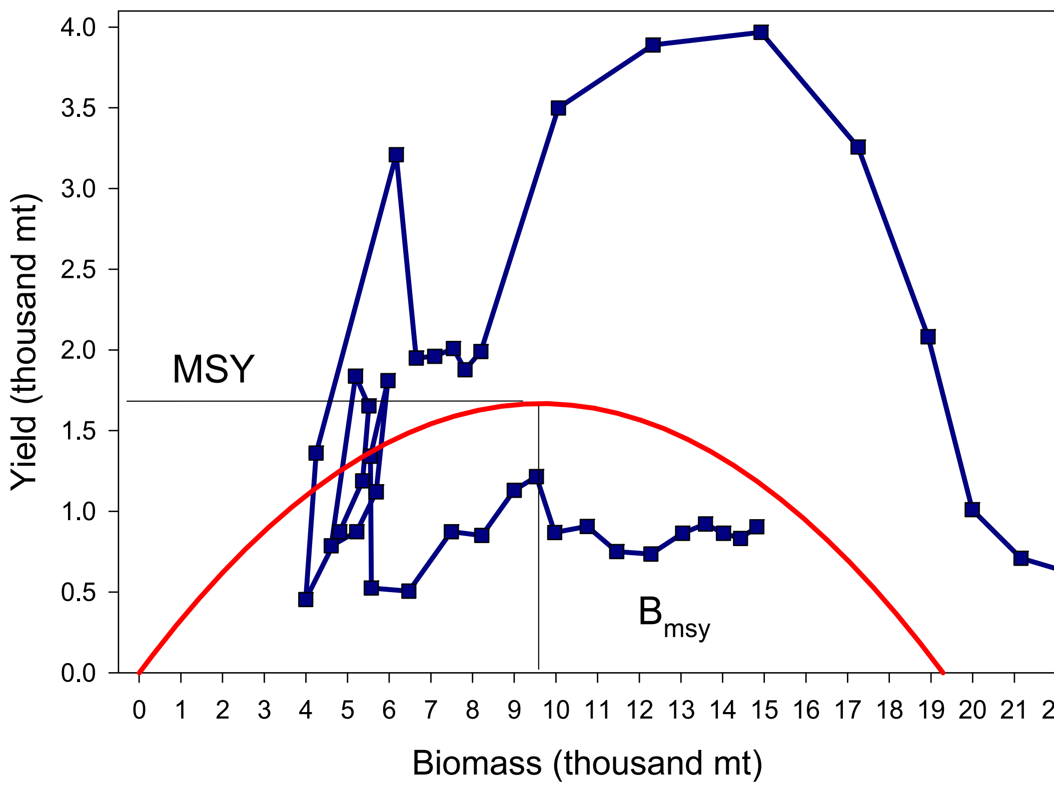


Figure B41. Time series of biomass and yield for ASPIC run 3. The beginning of the time series (1973) start at the right higher than the model estimated K and ends in 2013 above B_{MSY}.

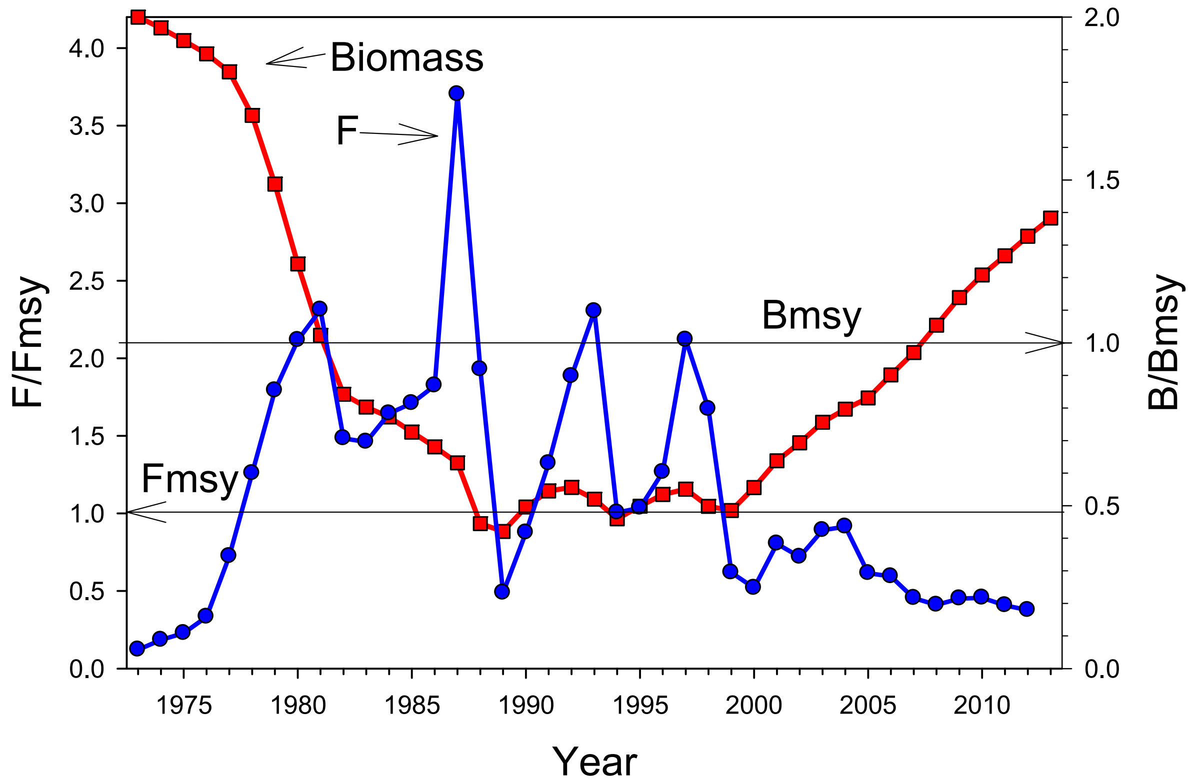


Figure B42. Working group final ASPIC model run which had a terminal year of 2012, added 1991-1994 data to the VTR series and fix the B1 ratio at K.

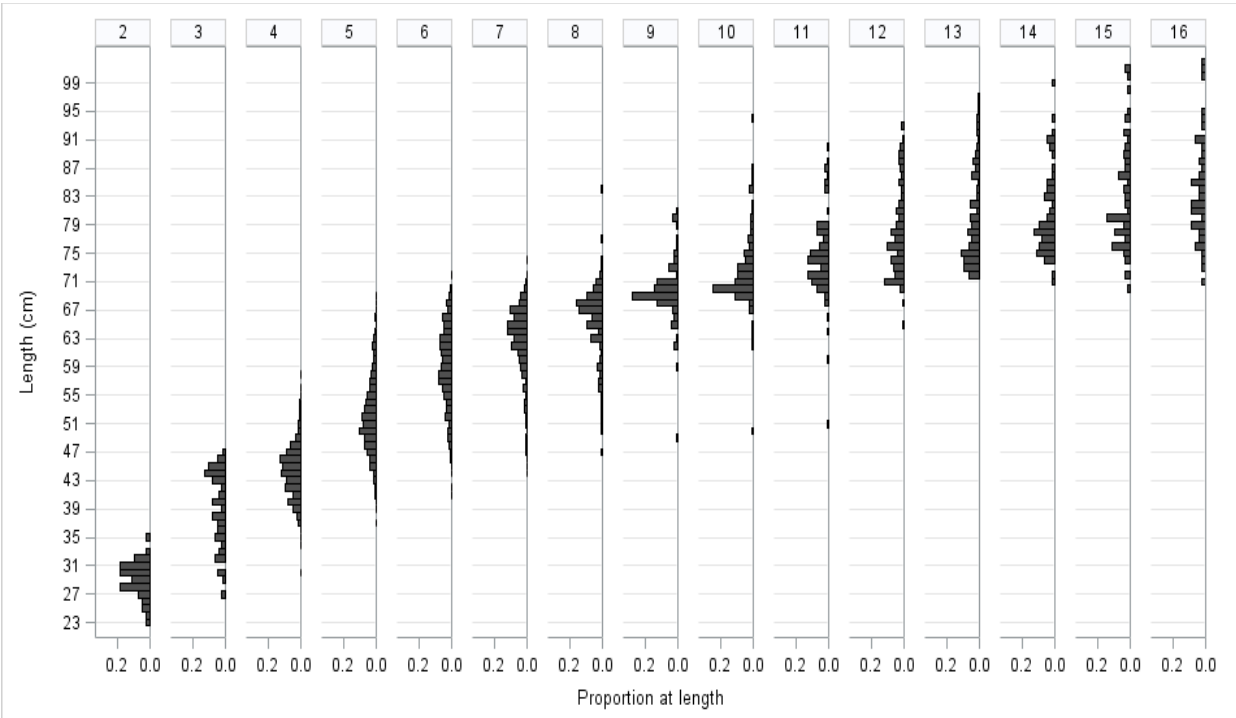


Figure B43. Distribution of lengths at age with all years combined.

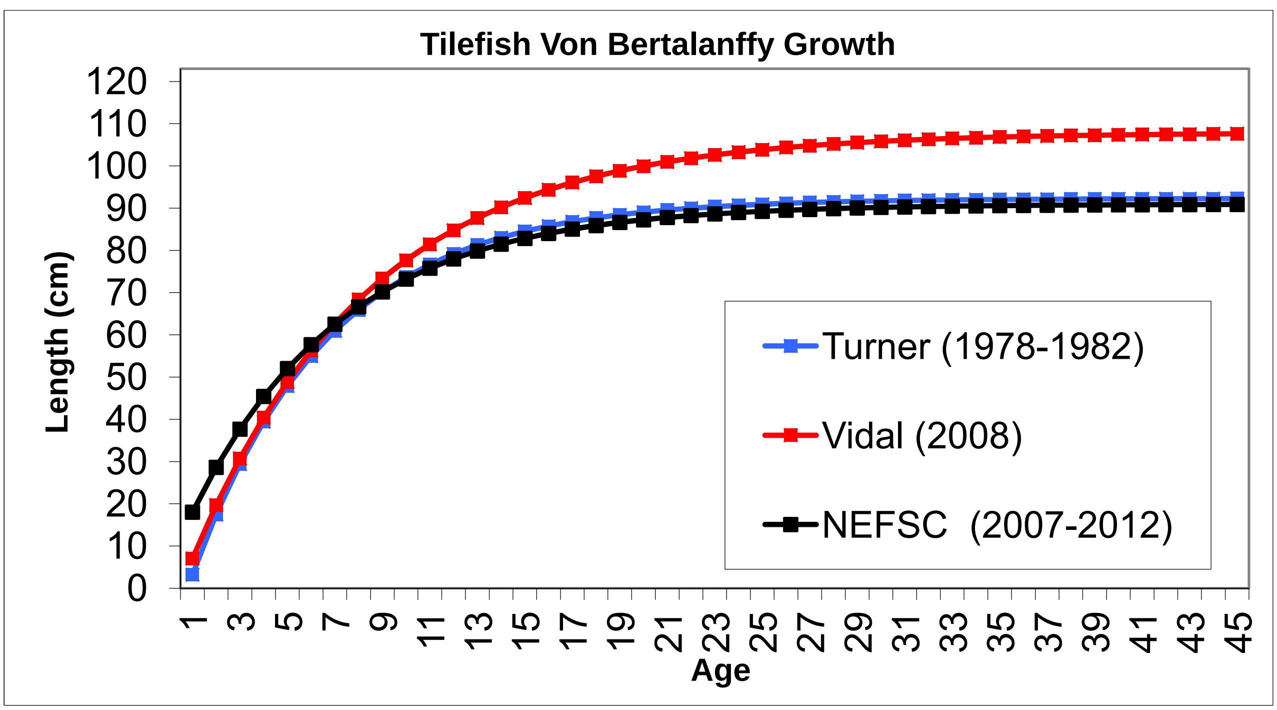


Figure B44. Comparison of von Bertalanffy growth curves from the three different growth studies.

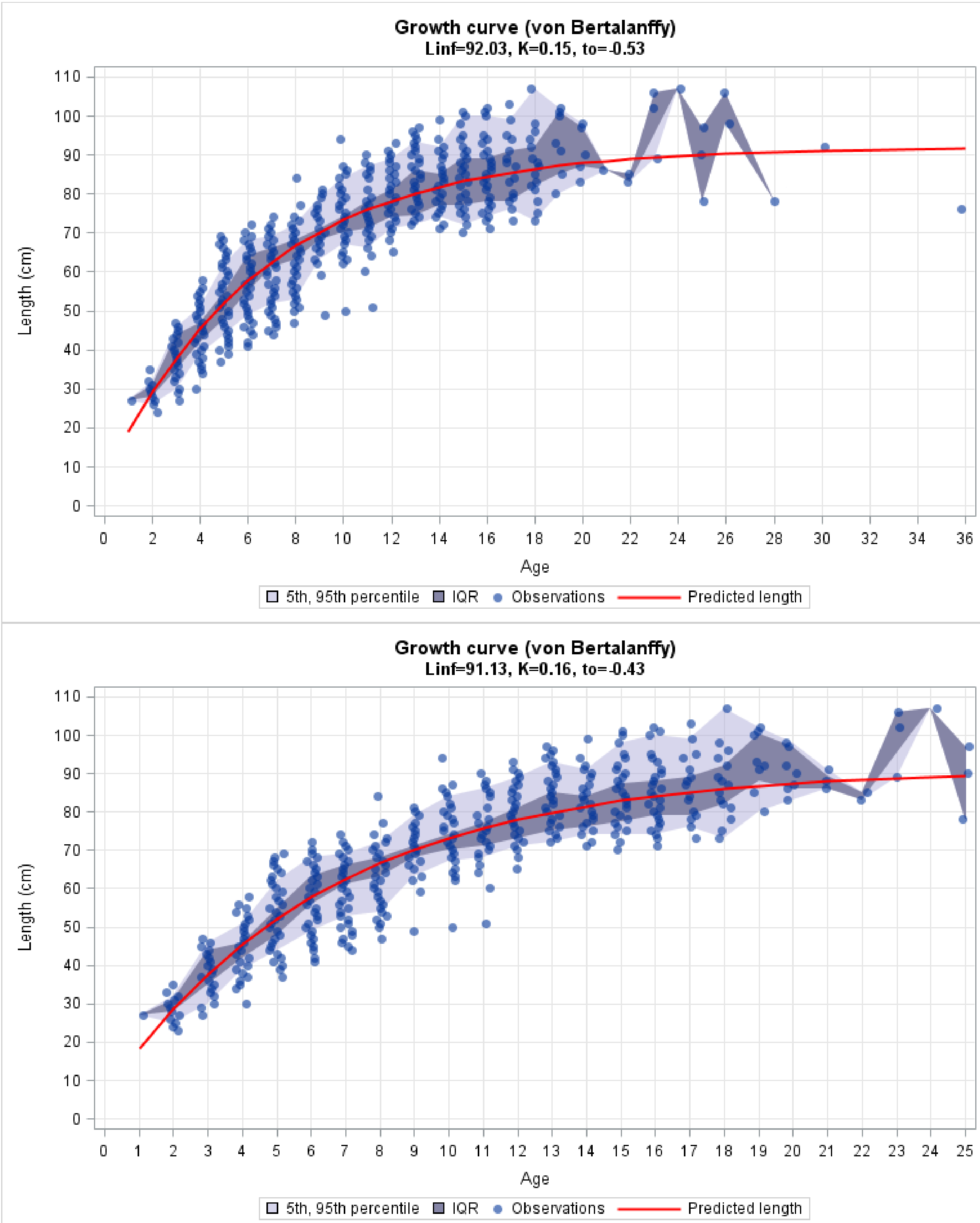


Figure B45. Estimated von Bertalanffy growth using all data (top) and data limited to fish younger the age 26 (bottom).

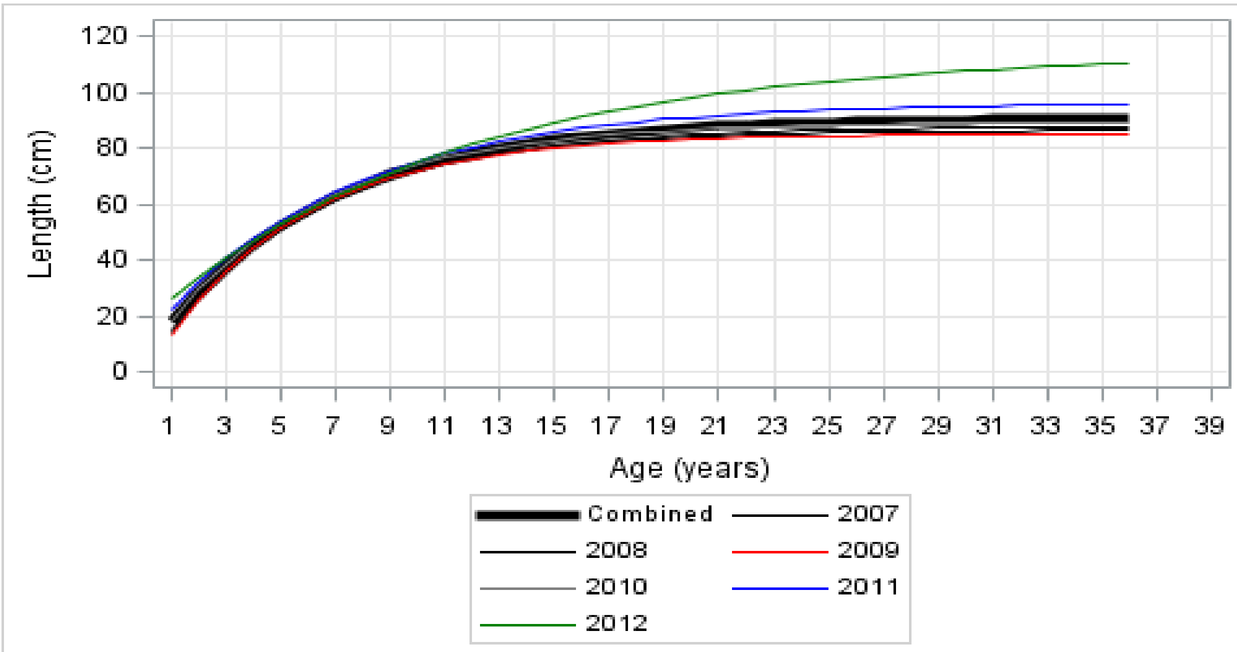


Figure B46. Comparison of annual von Bertalanffy growth curves.

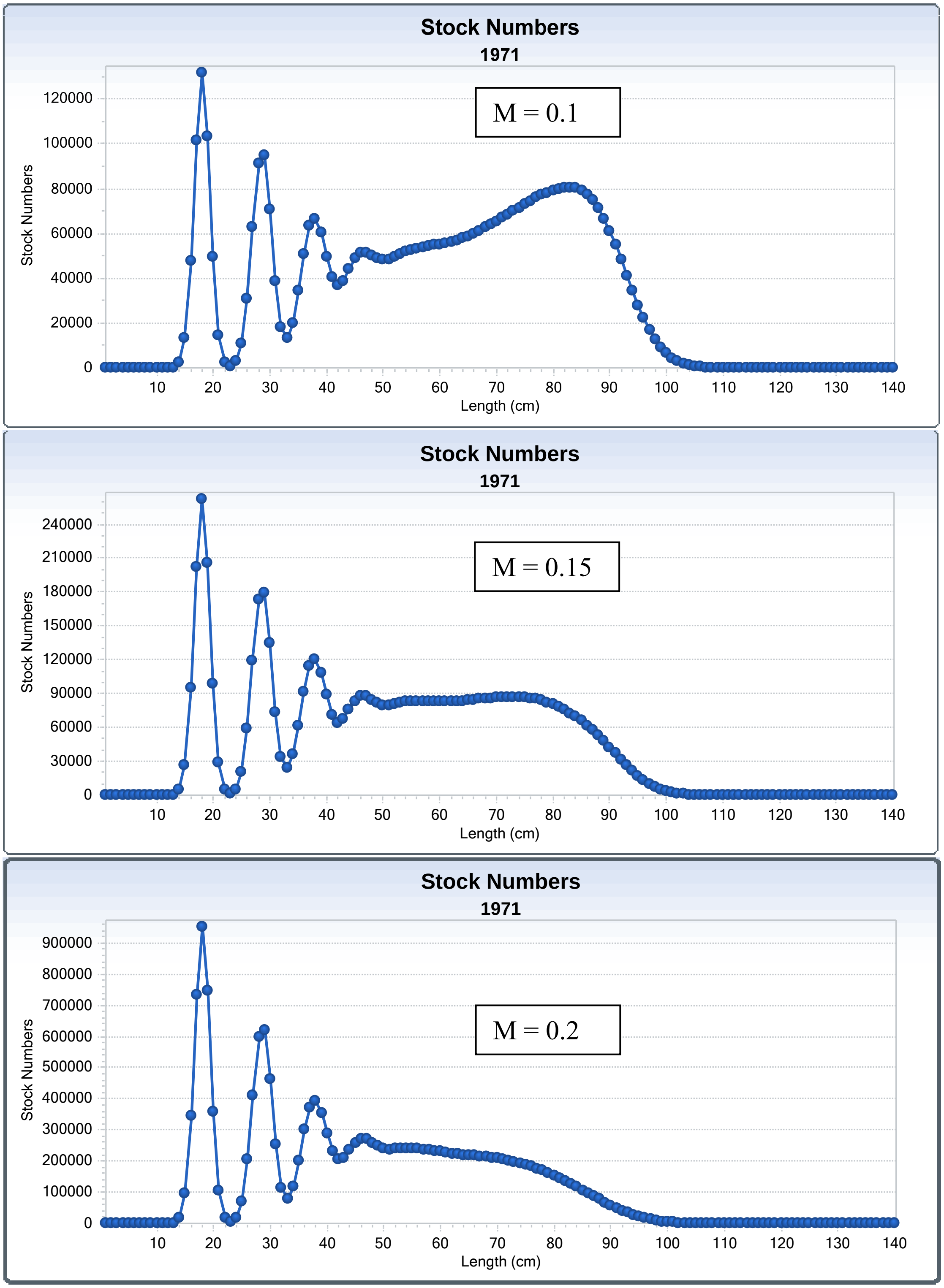


Figure B47. Equilibrium predicted virgin length distributions assuming no fishing and m=0.1, 0.15 and 0.2.

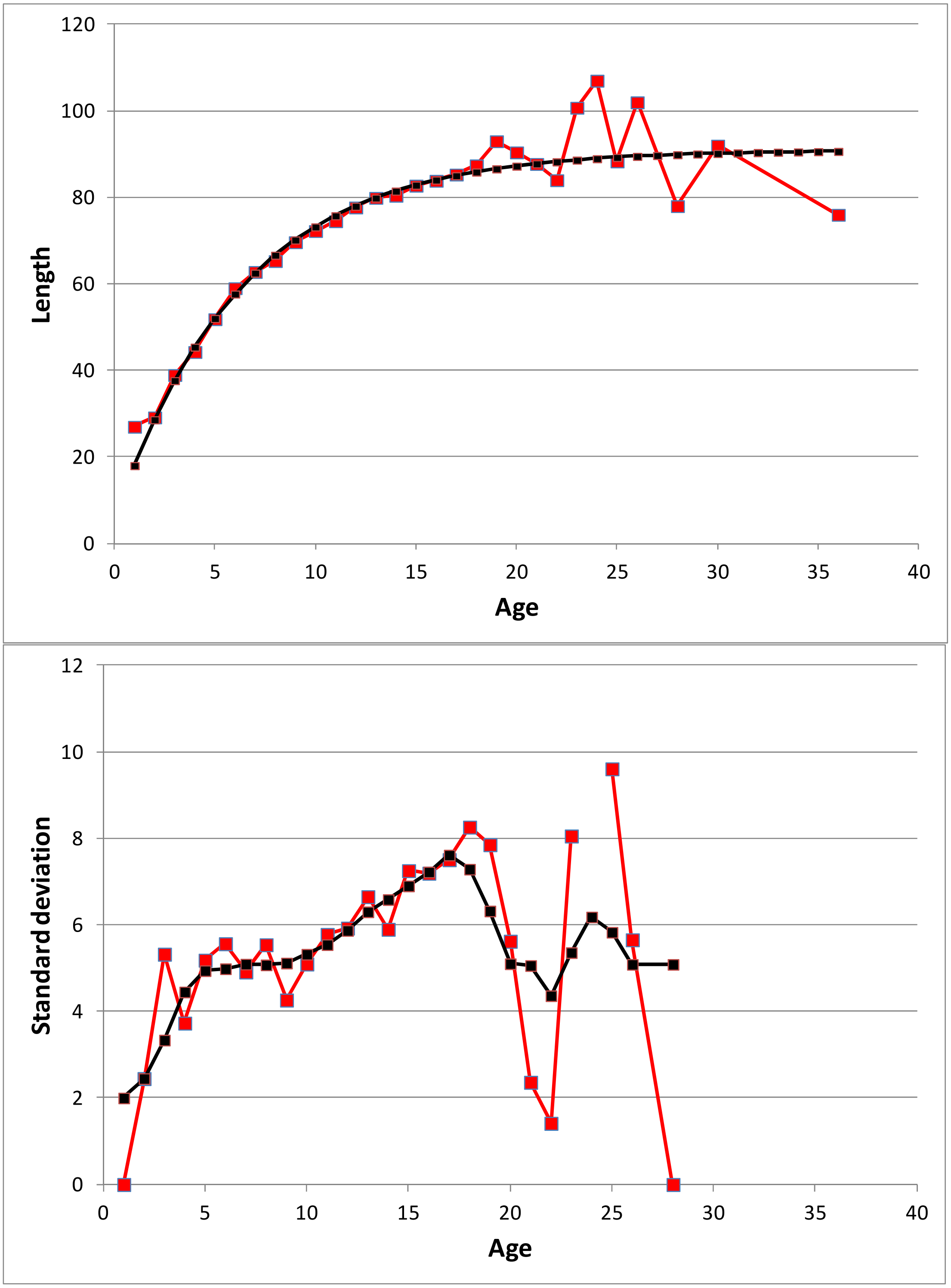


Figure B48. Comparison of the von Bertalanffy curve with the raw mean lengths at age (top) and the standard deviation at age with a centered 5 age moving average (bottom) for all years combined.

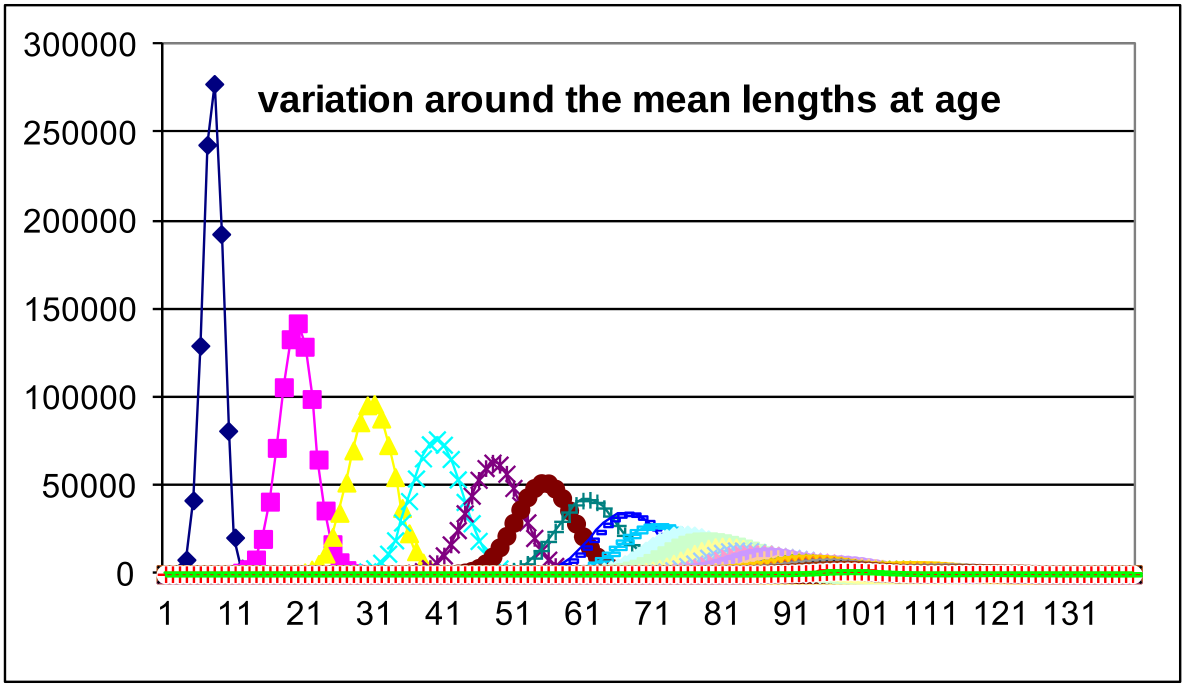


Figure B49. Resulting distributions at age from input variation on the mean lengths at age used in the SCALE model.

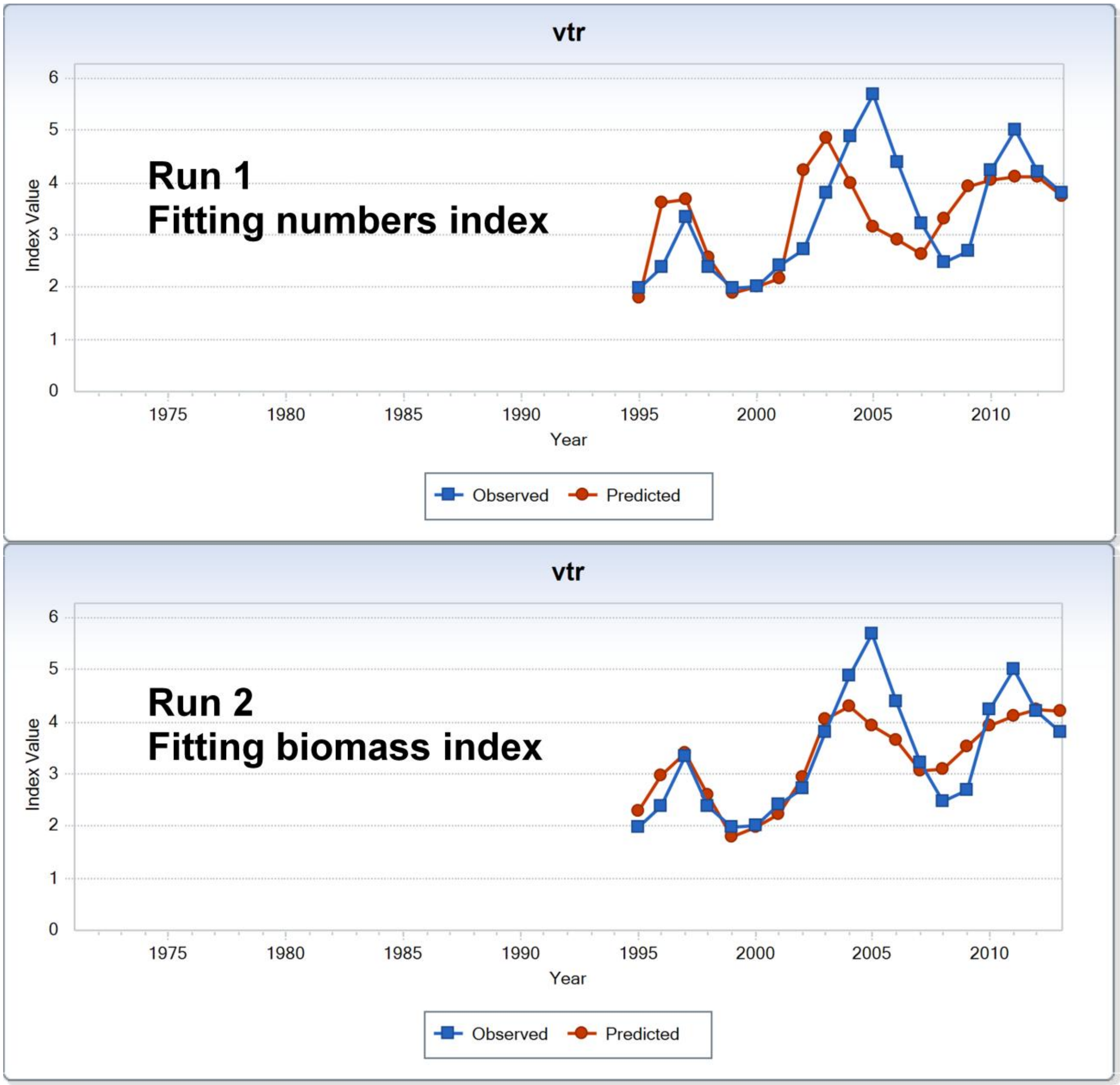


Figure B50. Comparison of fits using the incorrect numbers fit to the VTR biomass CPUE index (top) vs the correct fit to predicted biomass (bottom).

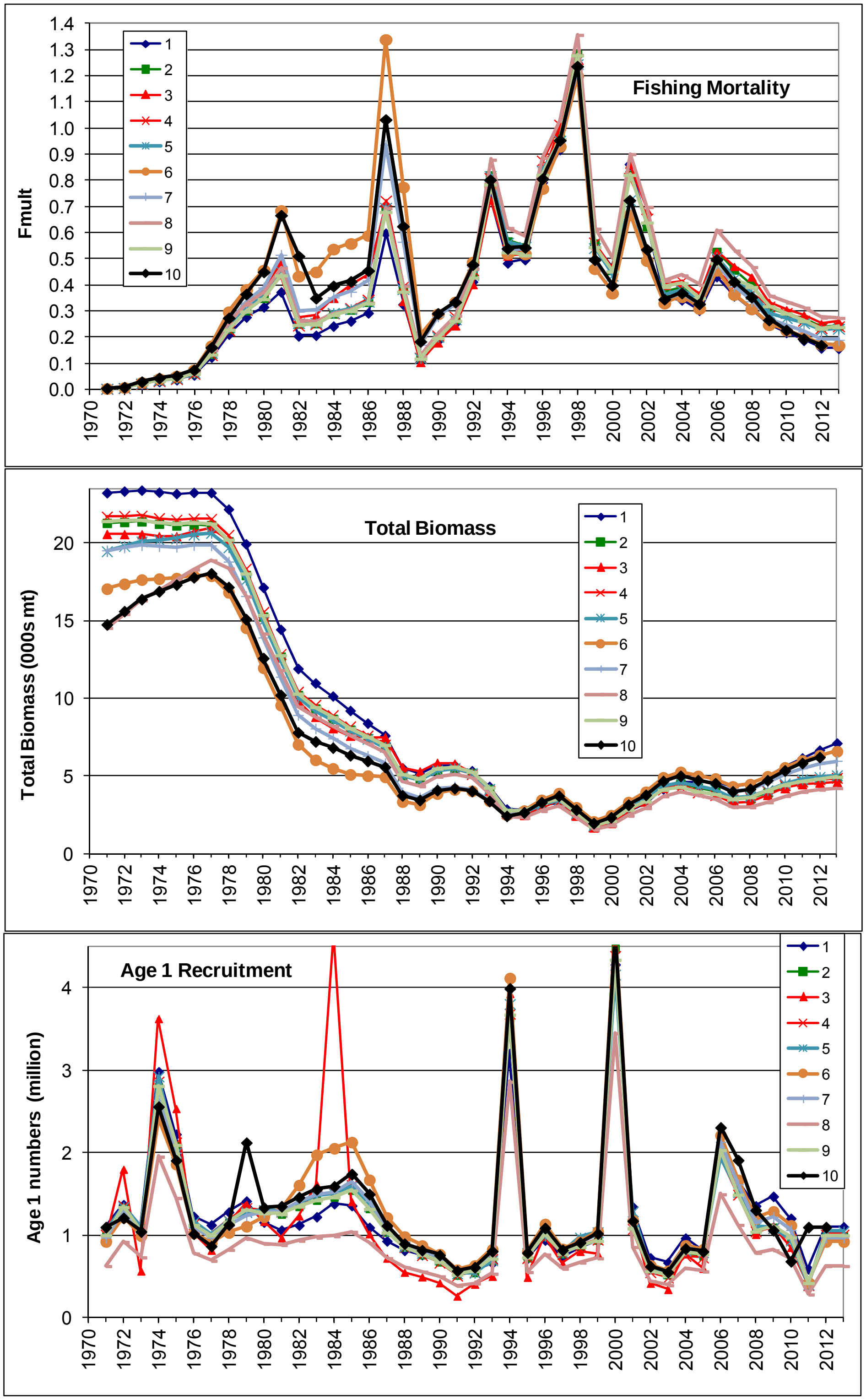


Figure B51. Sensitive SCALE runs comparing fishing mortality, total biomass, and age-1 recruitment.

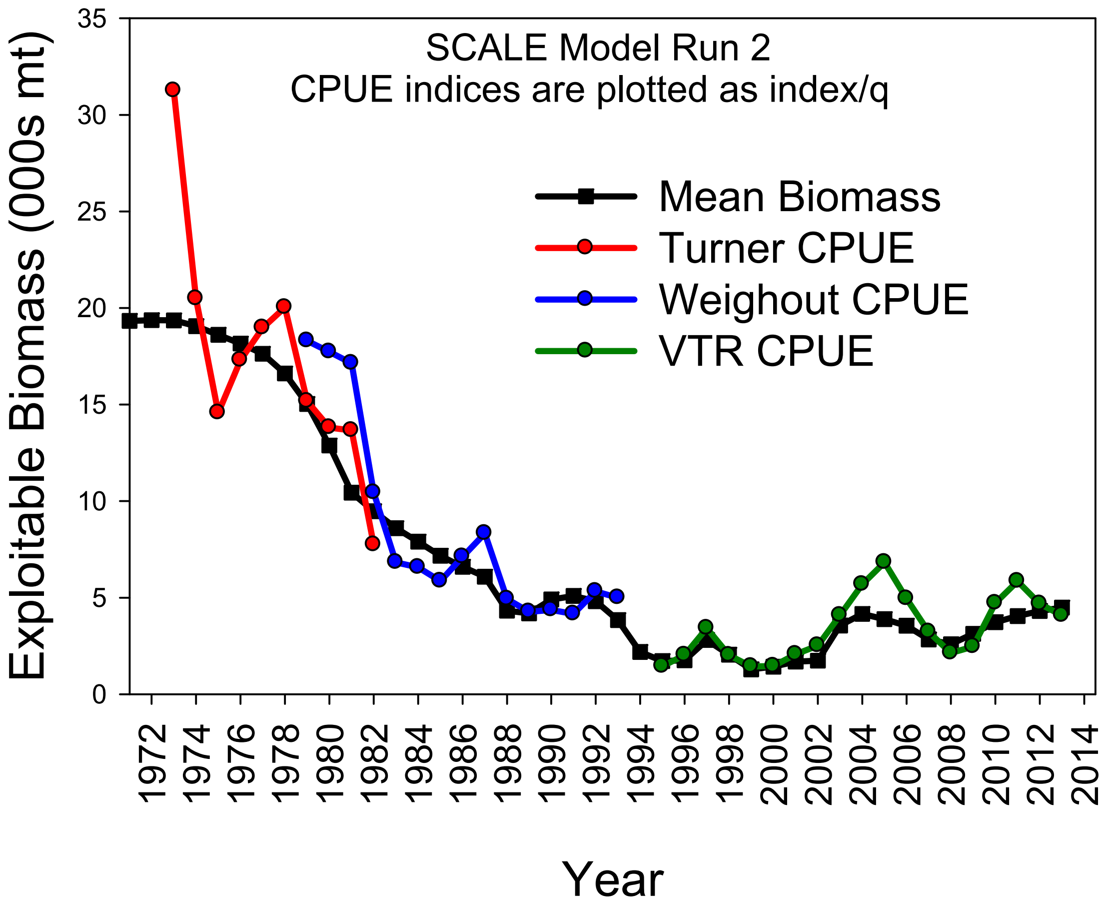


Figure B52. Comparison of the estimated exploitable biomass with the CPUE index / q for SCALE run2. A large change in q occurs between the Weighout and VTR series which results in lower biomass.

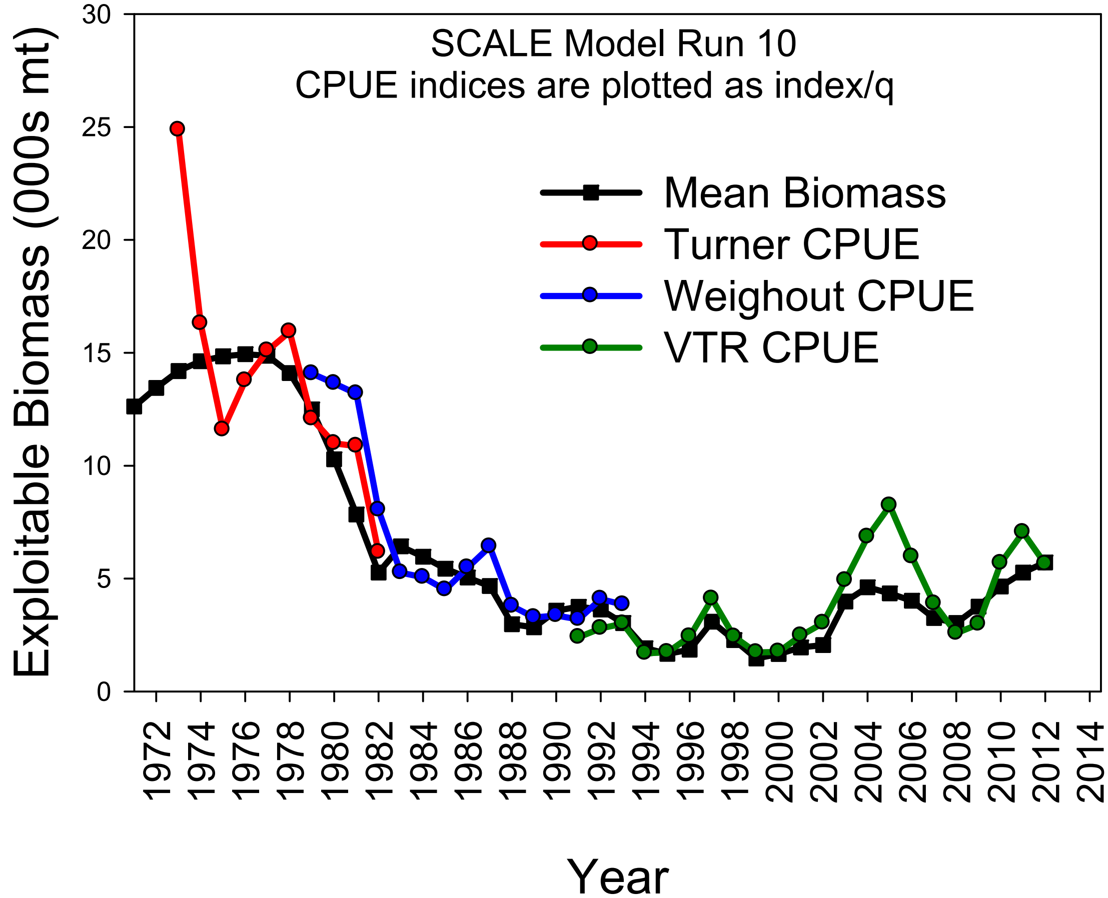


Figure B53. Comparison of the estimated exploitable biomass with the CPUE index / q for SCALE run10. The additional CPUE data form 1991-1994 results in less change in the q between the Weighout and VTR series.

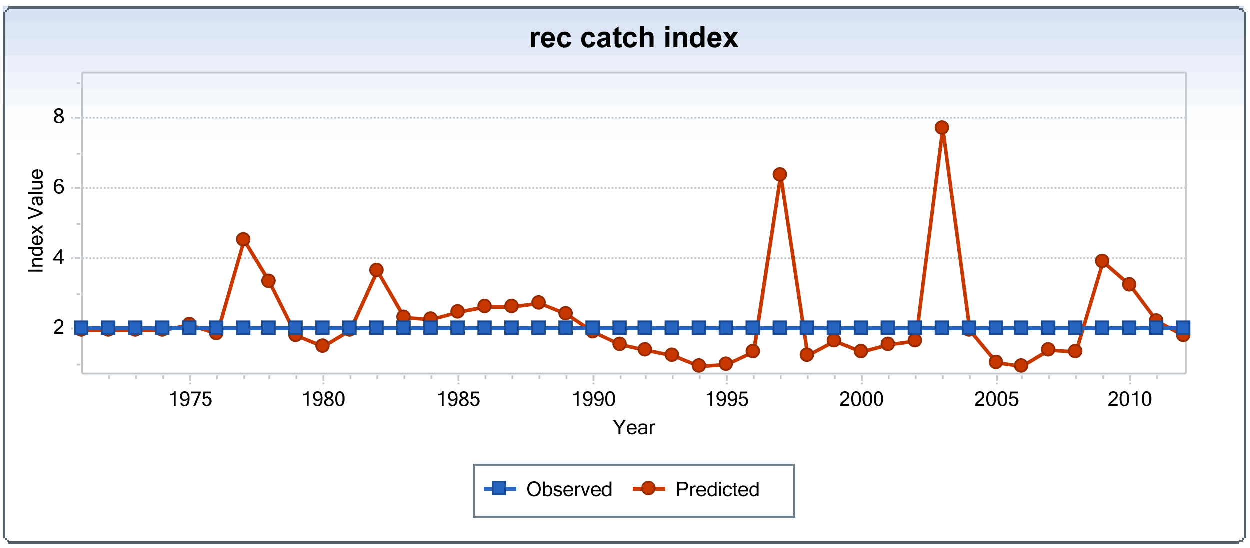


Figure B54. Working group final SCALE run 10 straight line age (recruitment) index which was used since an age index does not exist for this stock.

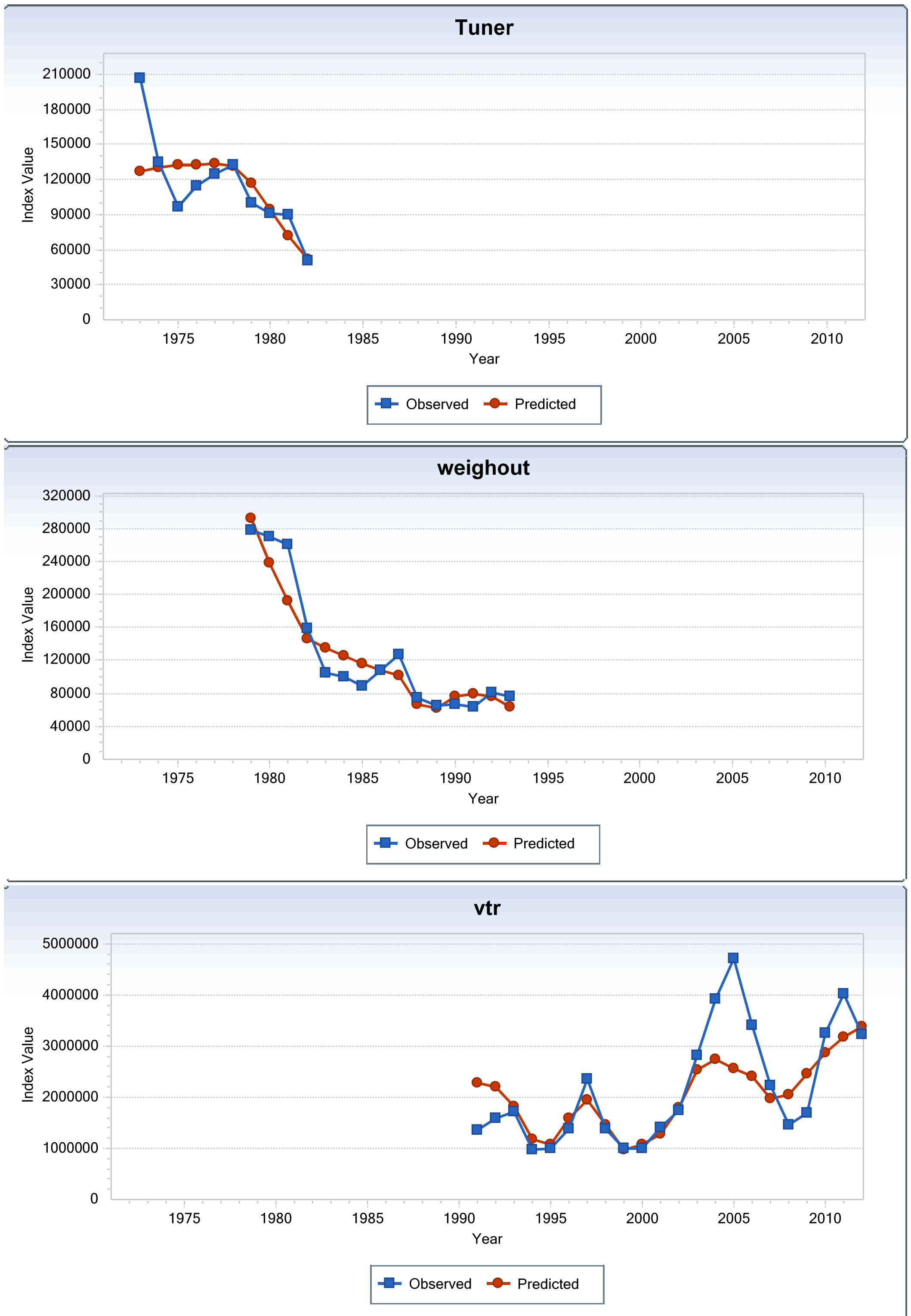
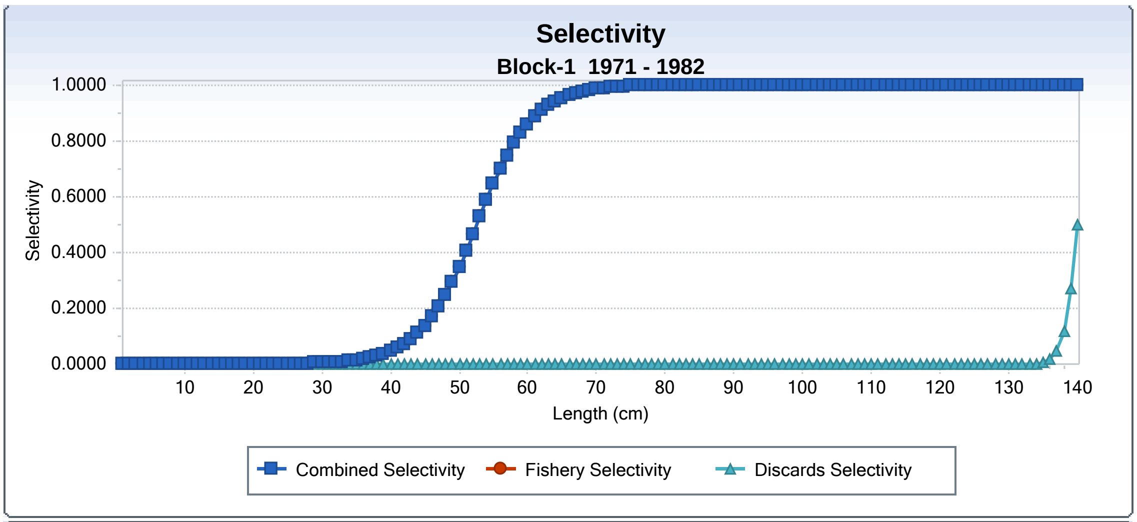


Figure B55. Working group final SCALE run 10 fit to the three CPUE indices.



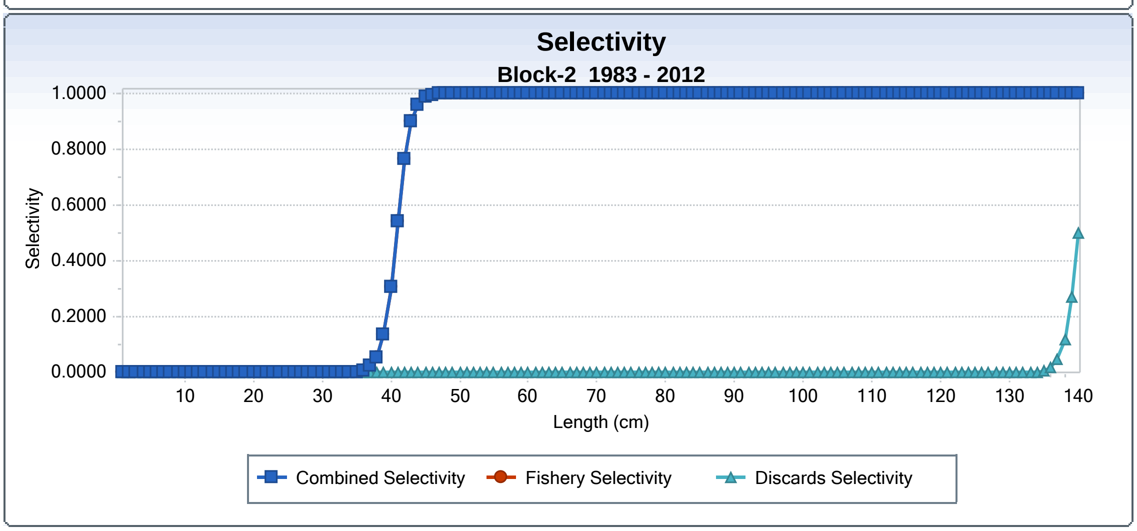


Figure B56. Working group final SCALE run 10 flattop estimated selectivity at length curves.

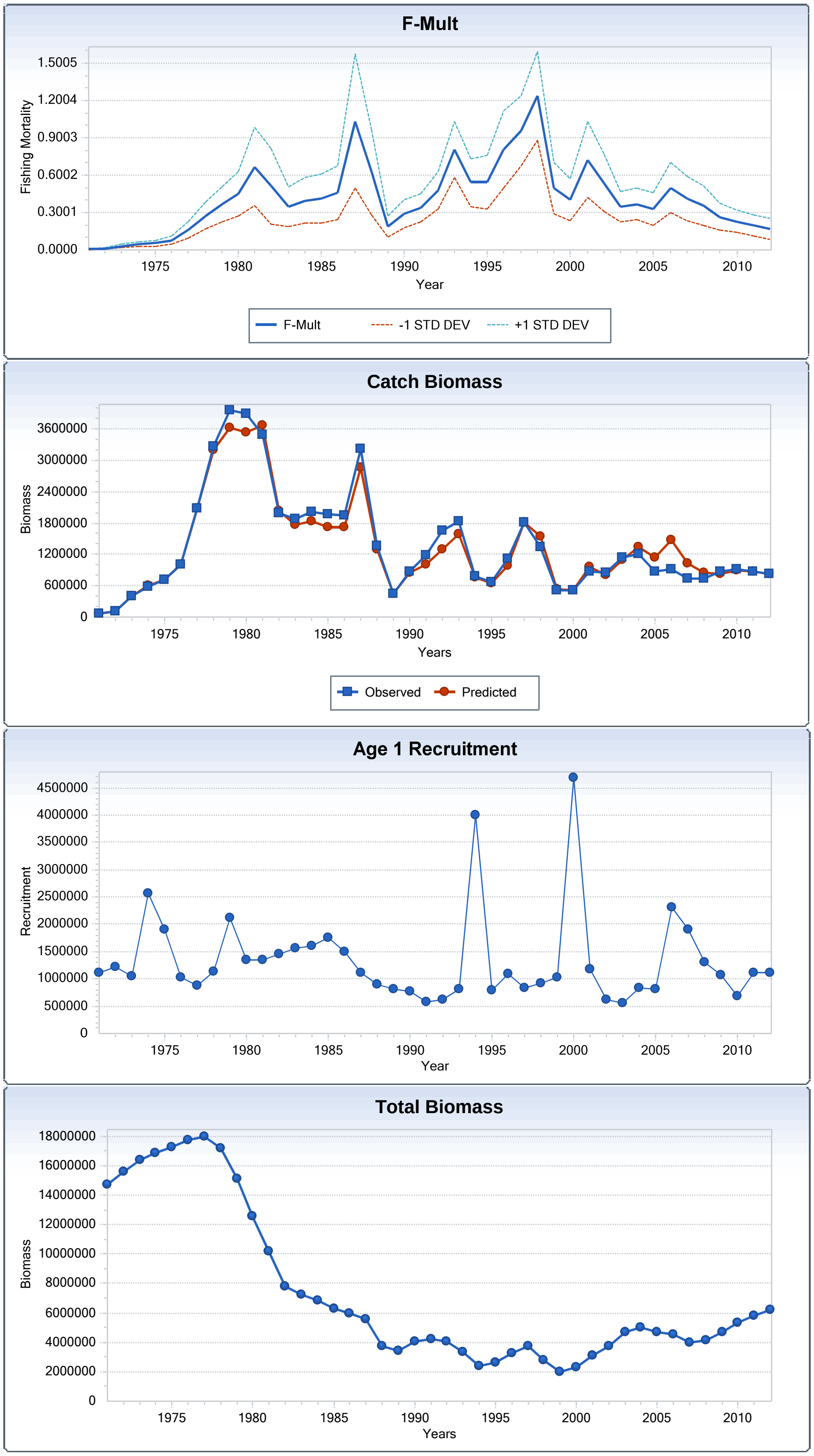


Figure B57. Working group final SCALE run 10 estimated F, fit to the catch, estimated recruitment, and total biomass.

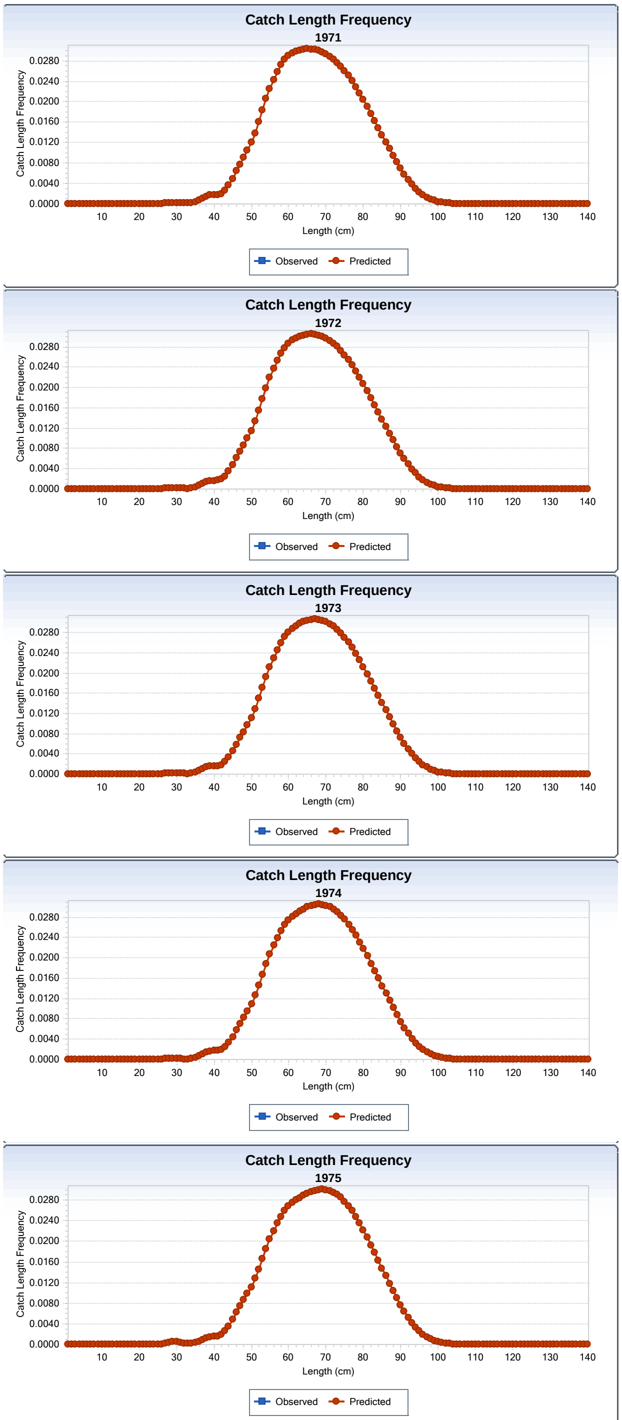


Figure B58. Working group final SCALE run 10 predicted (red) and observed (blue) catch distributions by year. Years which do not have data are also shown.

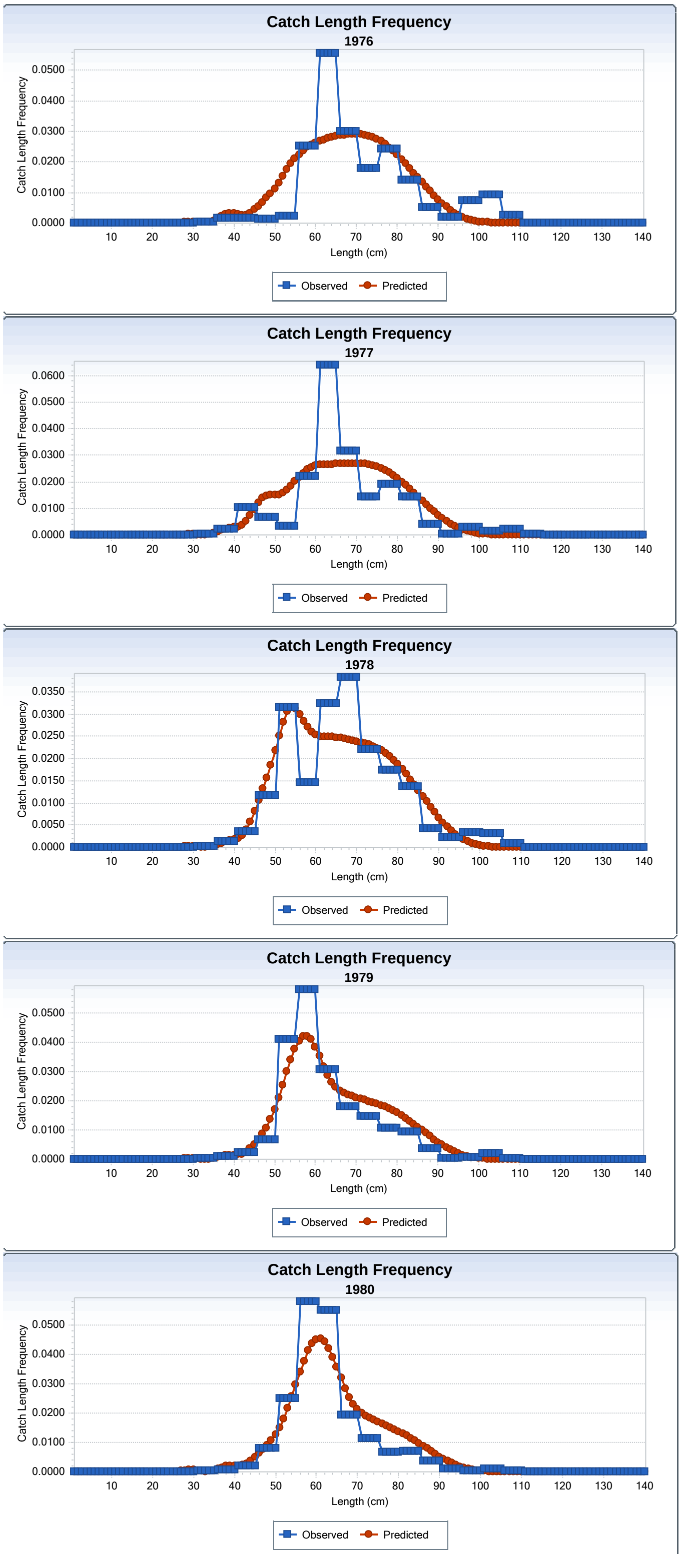


Figure B58. cont.

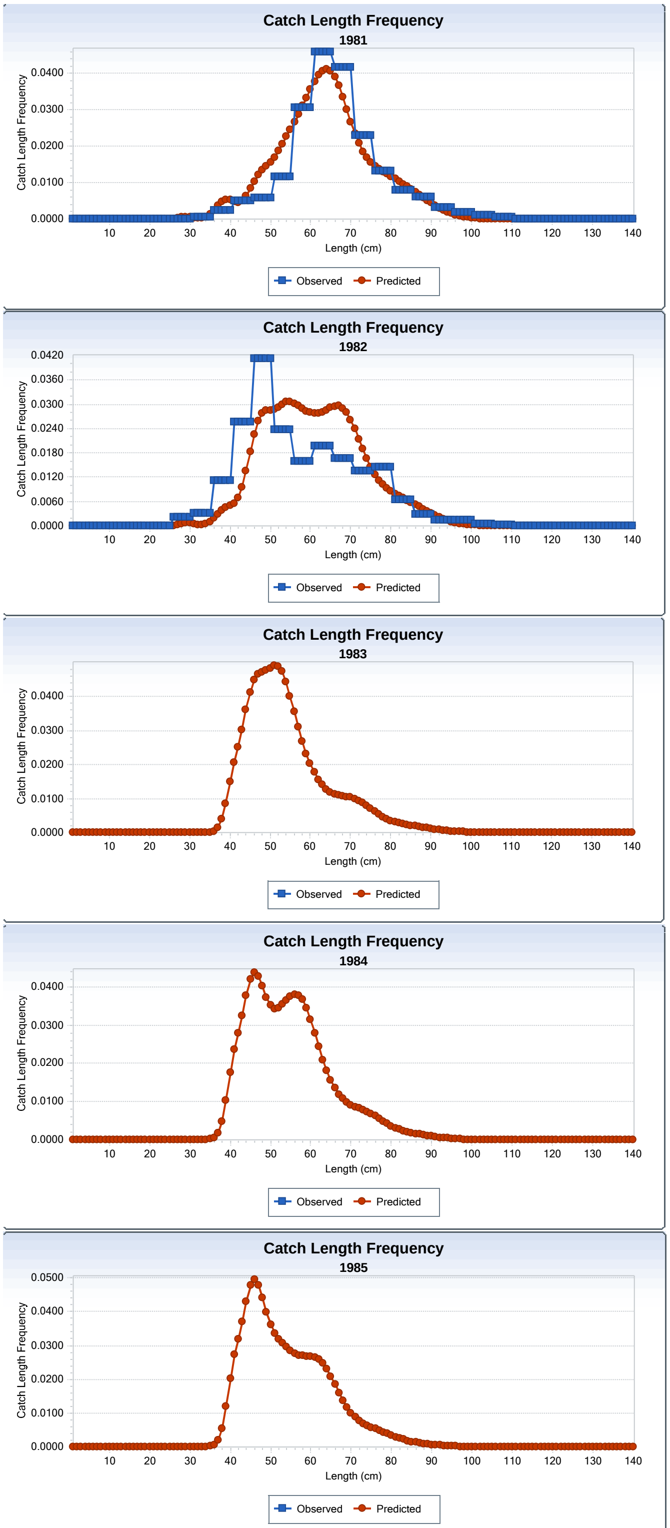


Figure B58. cont.

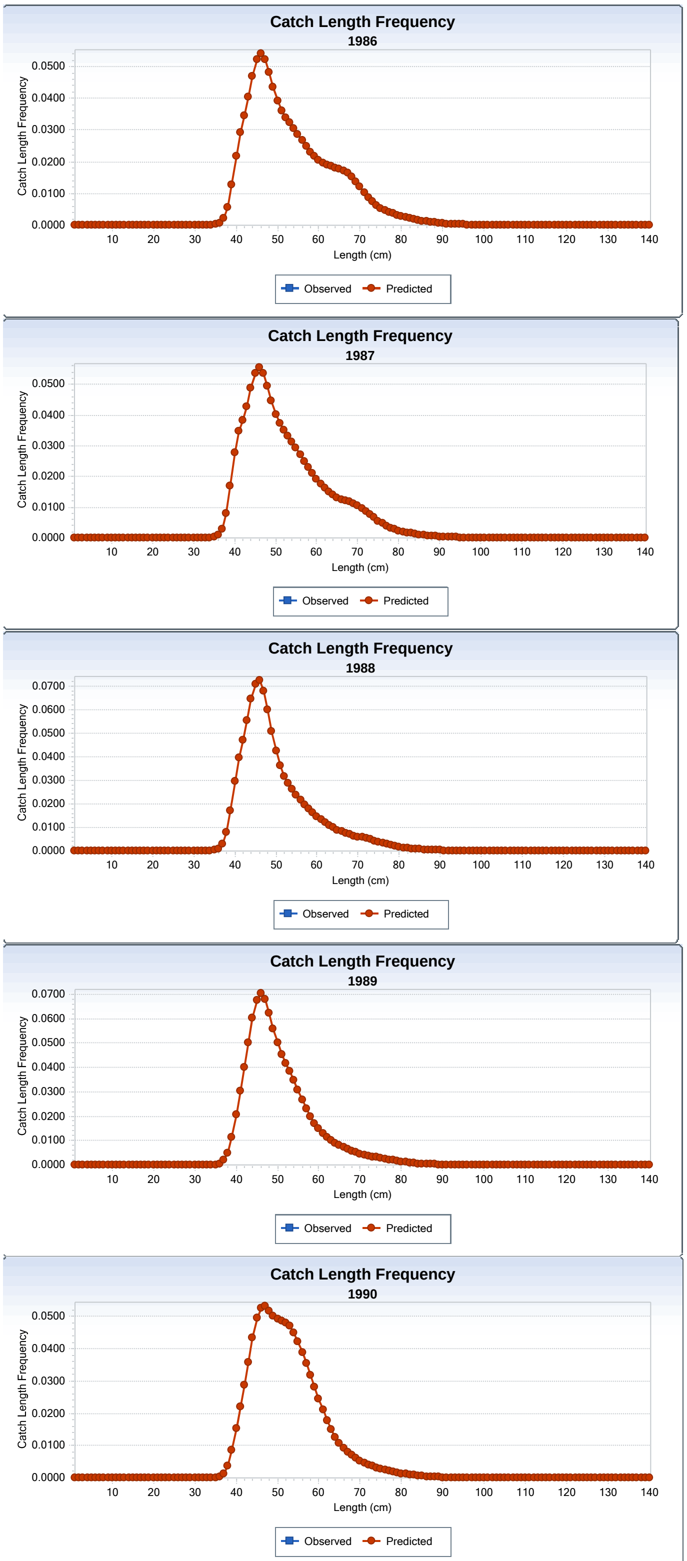


Figure B58. cont.

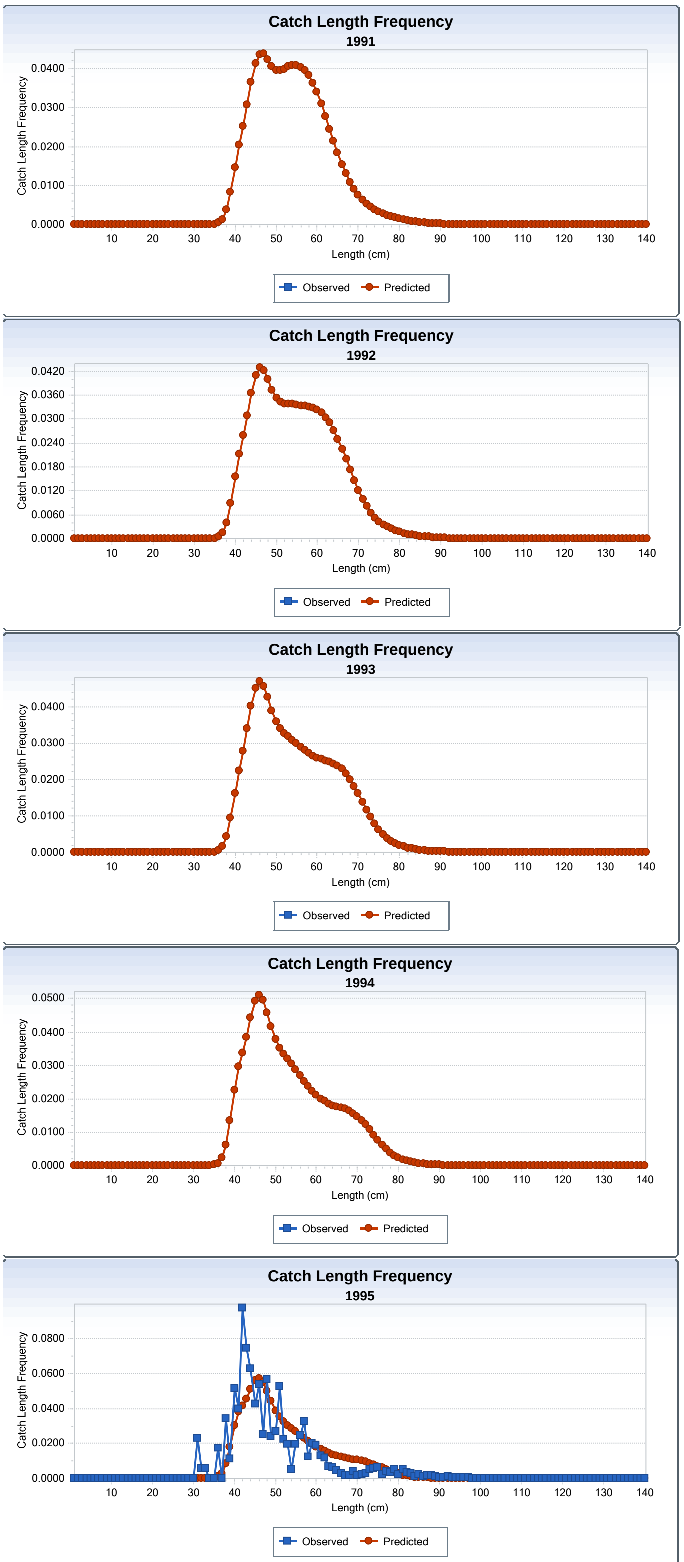
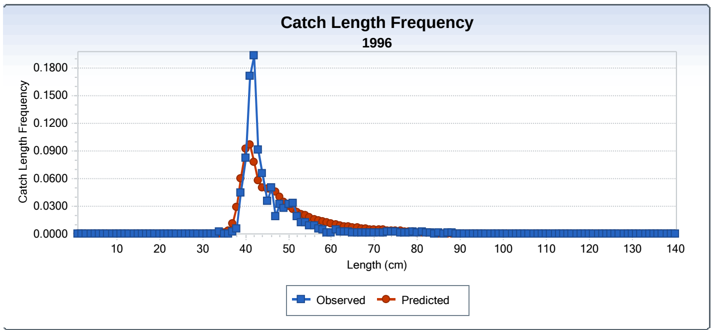
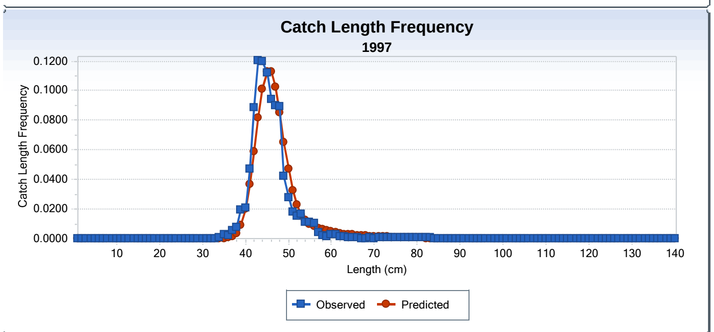
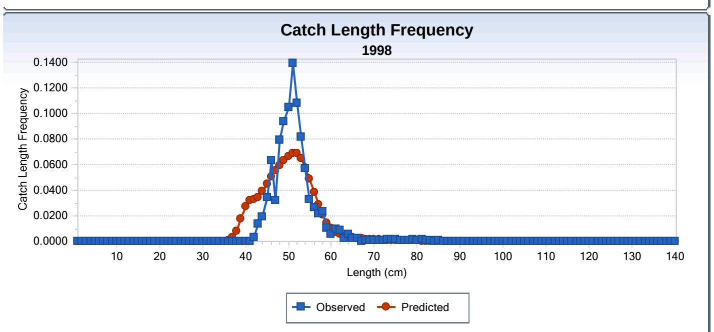
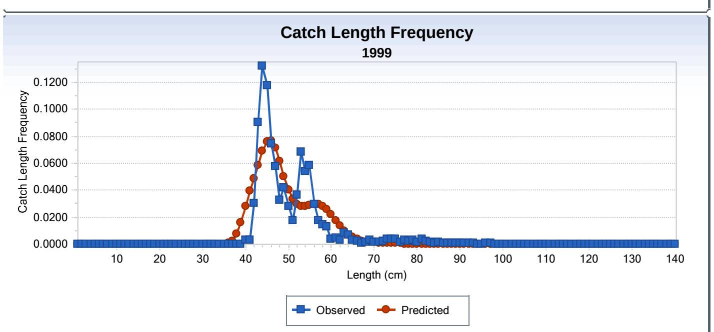


Figure B58. cont.









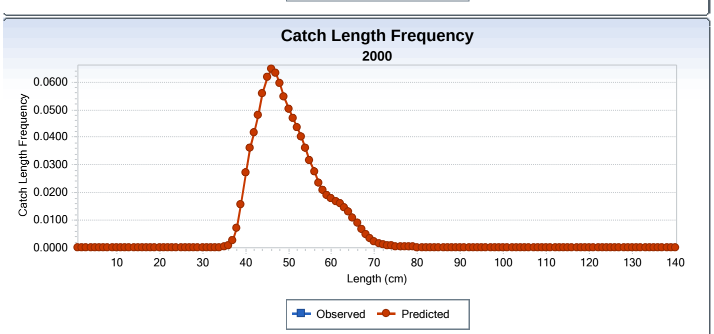


Figure B58. cont.

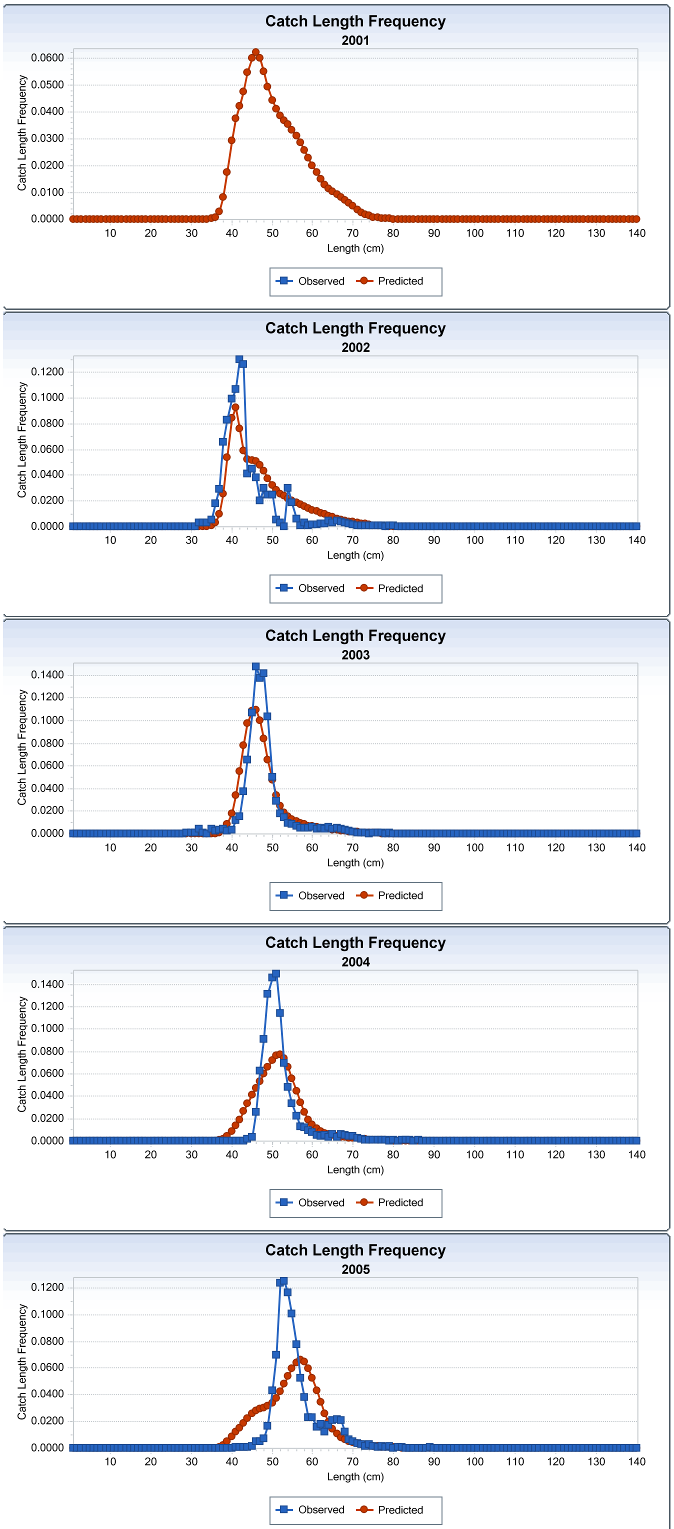


Figure B58. cont.

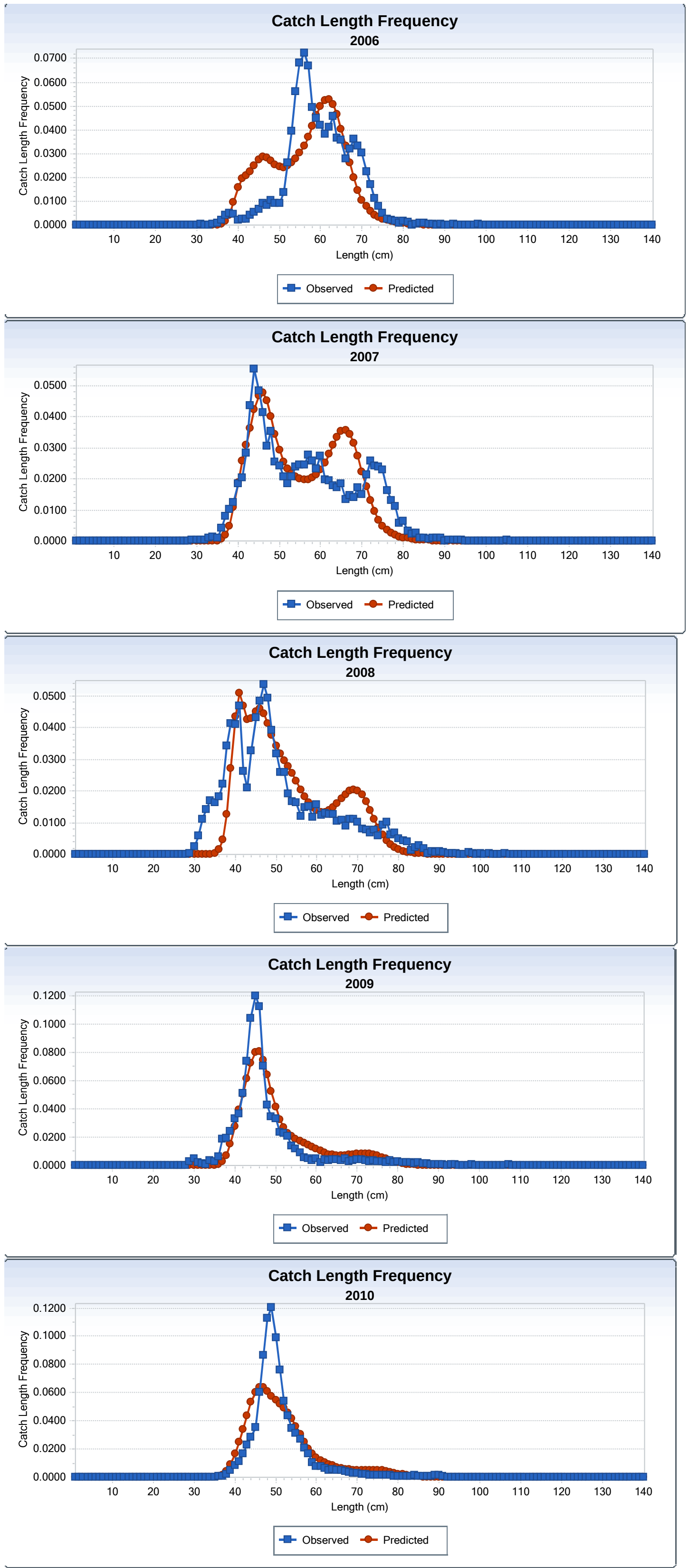
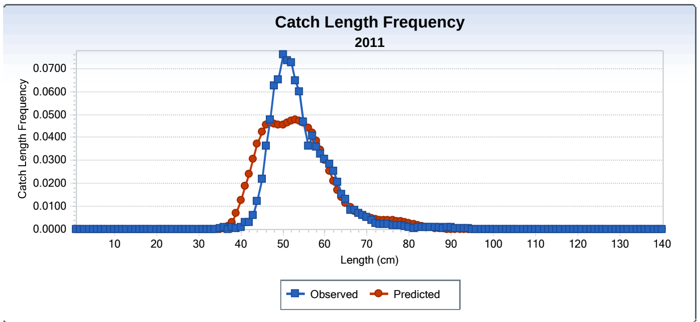


Figure B58. cont.

Catch Numbers Length Frequency, Year 1993



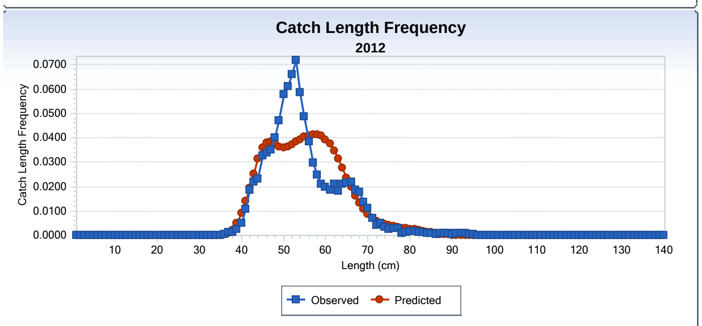


Figure B58. cont.

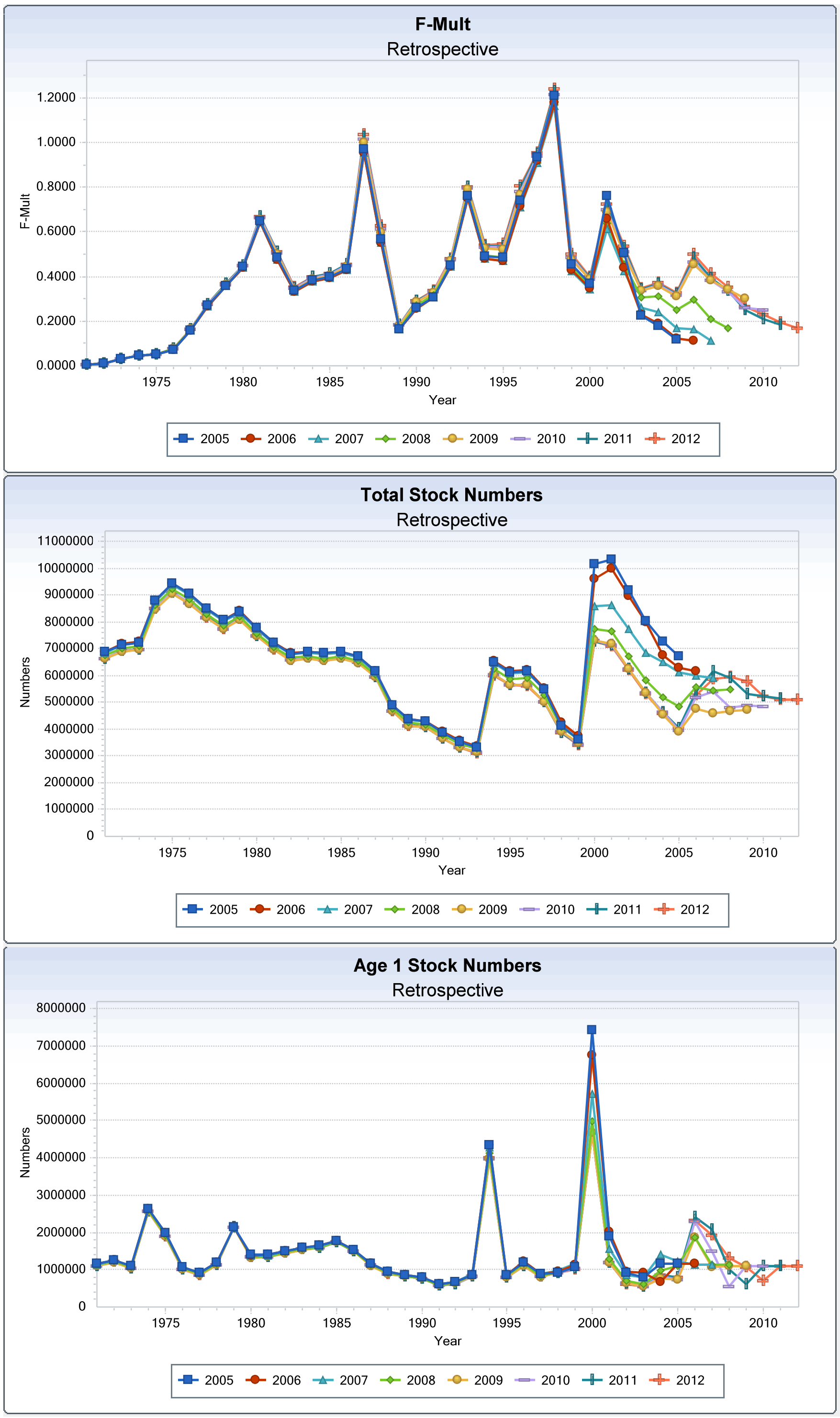


Figure B59. Working group final SCALE run 10 retrospective pattern.

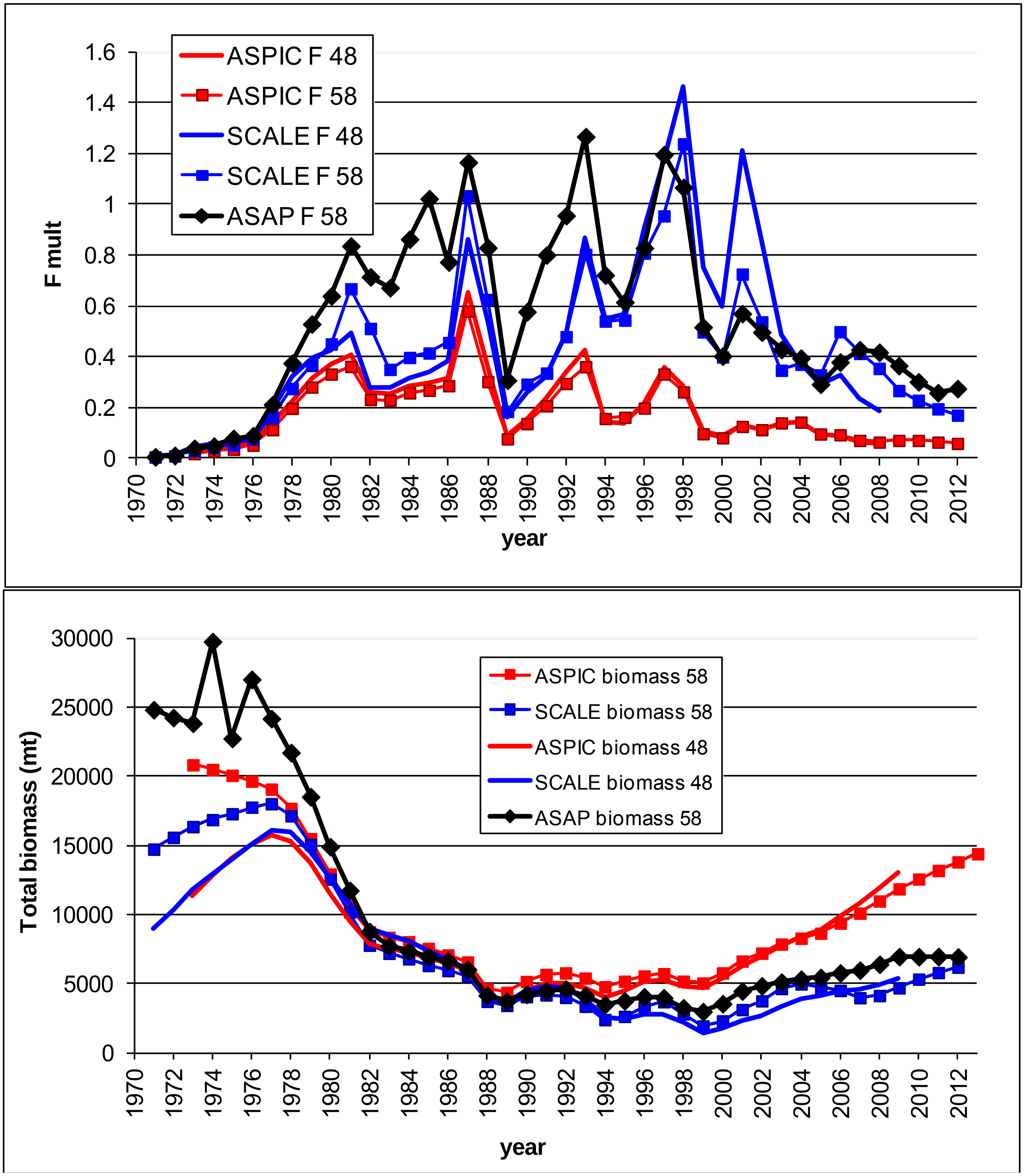


Figure B60. Comparison of the final SARC 48 and SARC 58 ASPIC and SCALE models and the new SARC 58 final ASAP model for total biomass and fishing mortality.

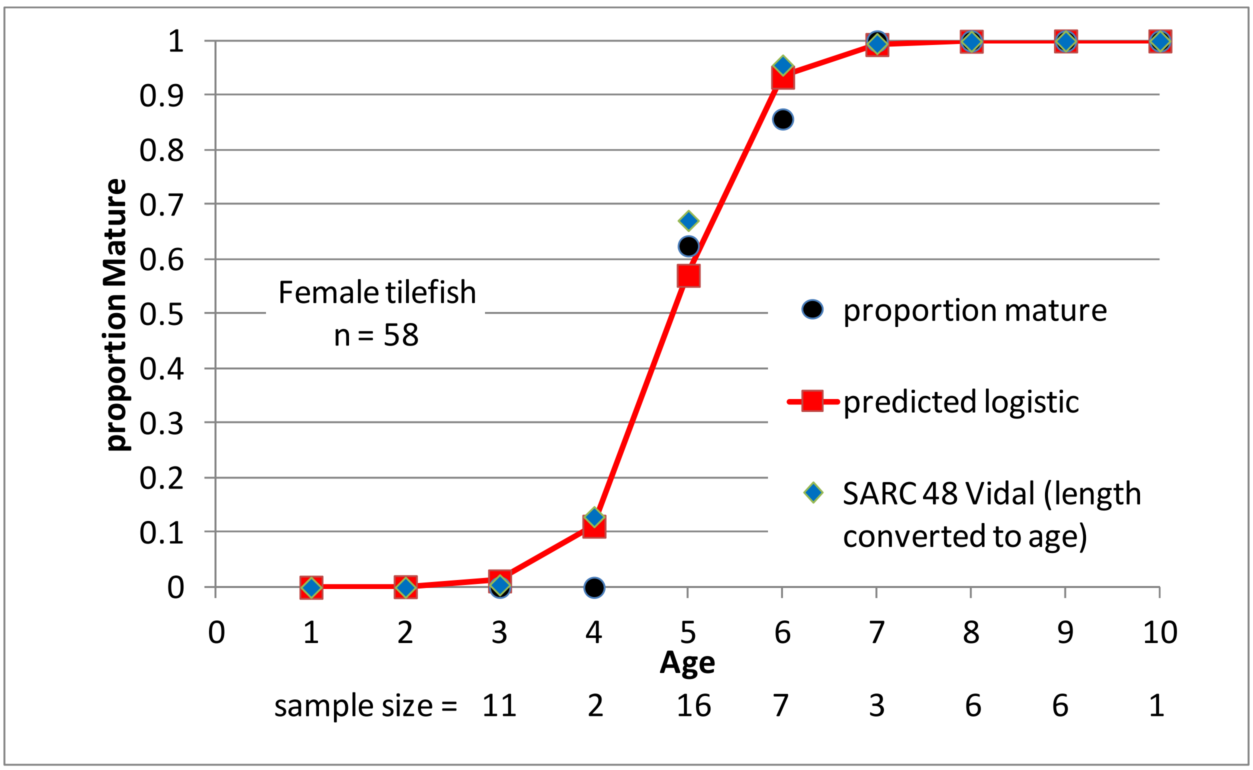


Figure B61. Maturity at age curves from Vidal (SARC 48) and McBridge et al. (2013).

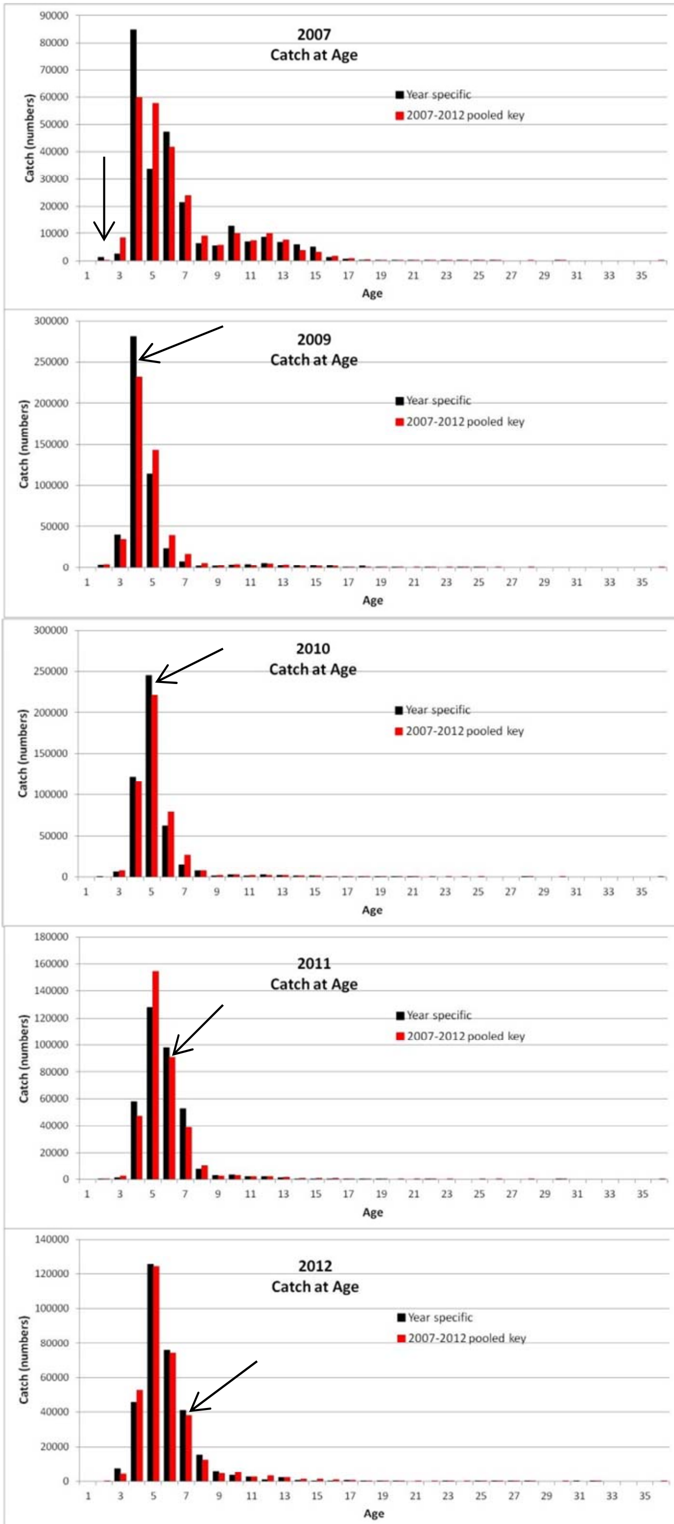


Figure B62. Comparison of catch at age using the pool age length key and using year specific keys for years where age data exists. 2008 did not have enough small fish aged to estimate a year specific catch at age. Arrows show the tracking of the 2005 year class.

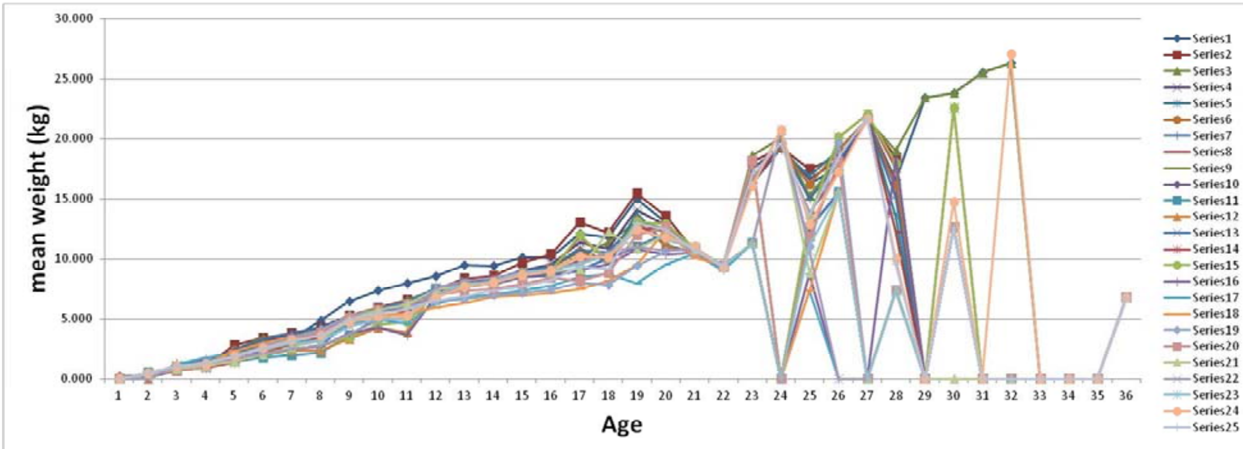
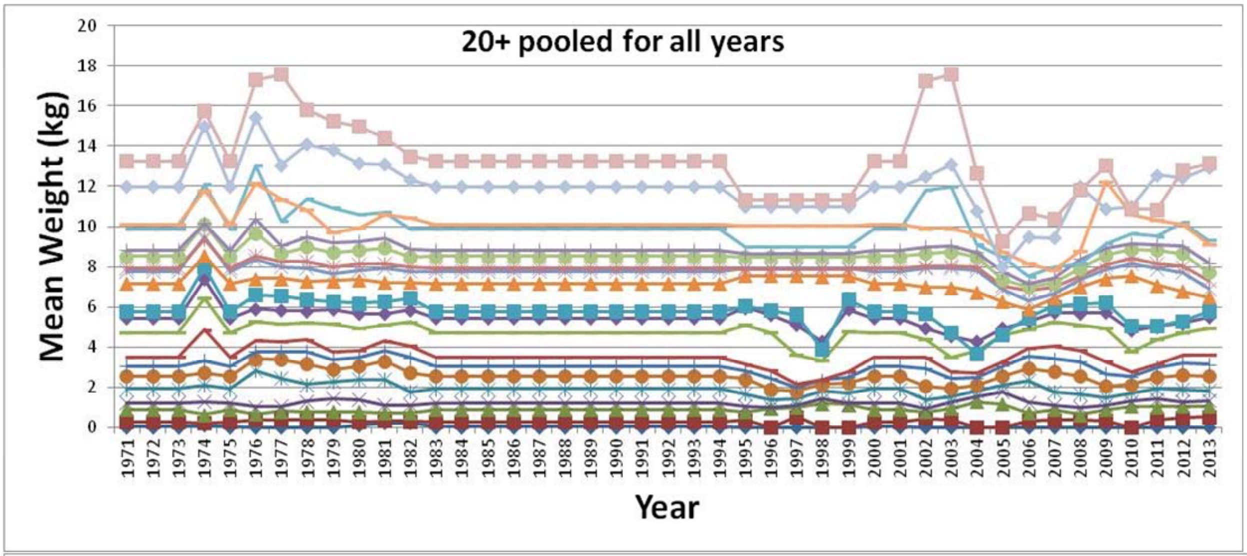


Figure B63. Mean weight at age. Each series represents a year in the time series. Estimates become variable at ages older than 20 where there is limited information.



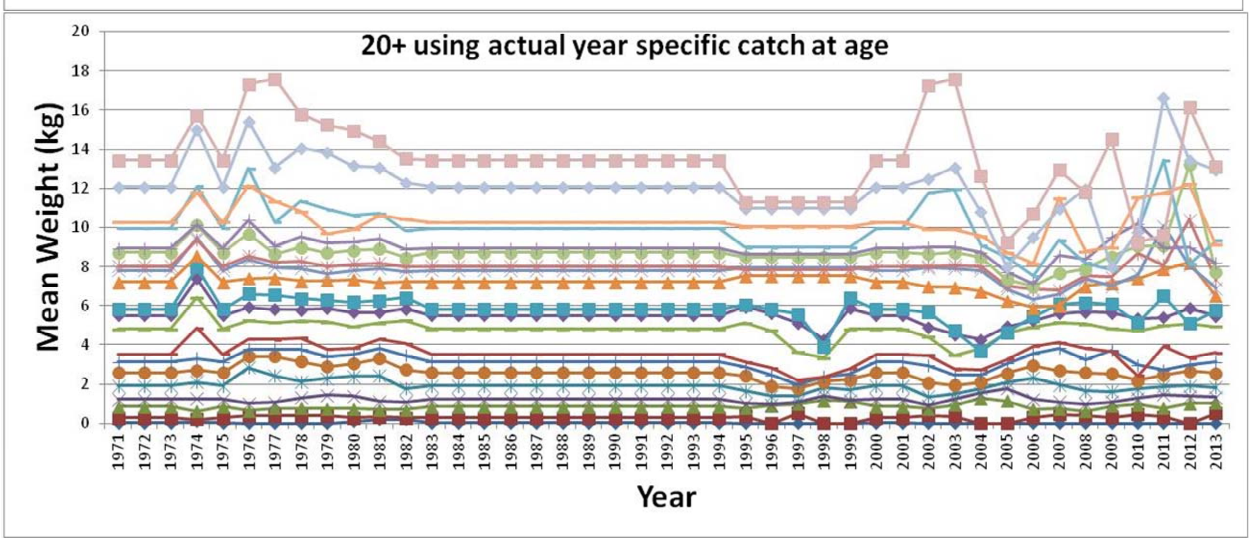
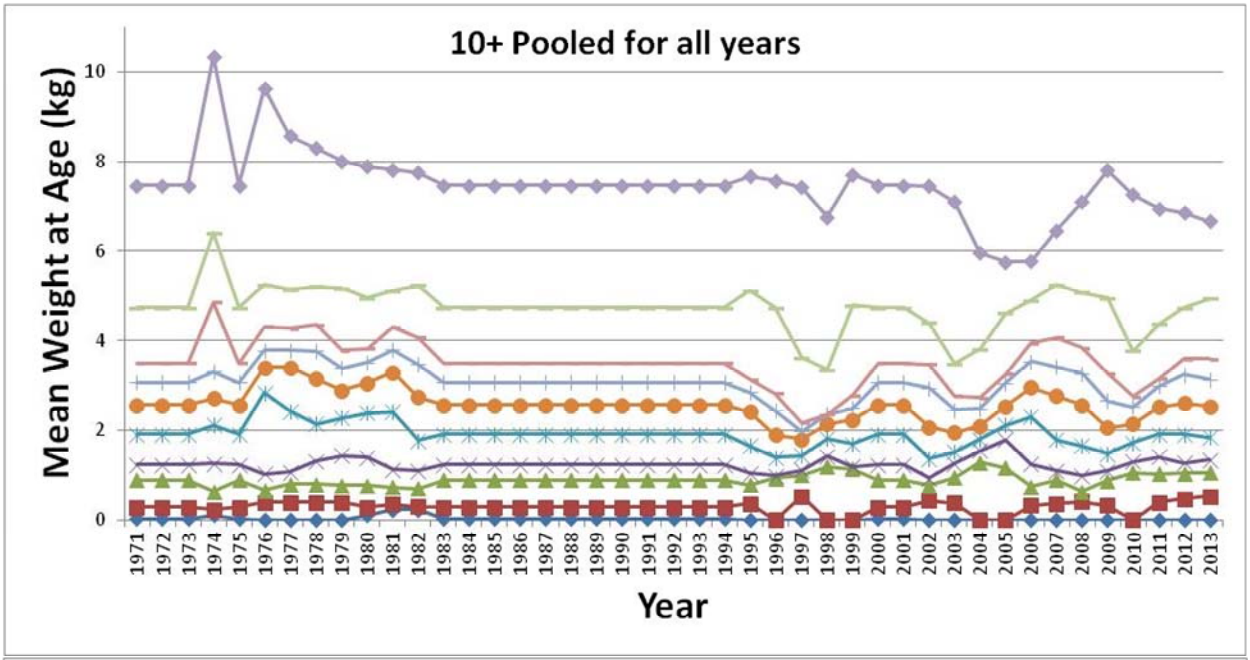


Figure B64. Mean weights at age of the 20+ formulation using a pool age length key for all years (top) and using year specific key in years were data exists (2007,2009-2012) (bottom). The average of years which have data was used for years with missing information.



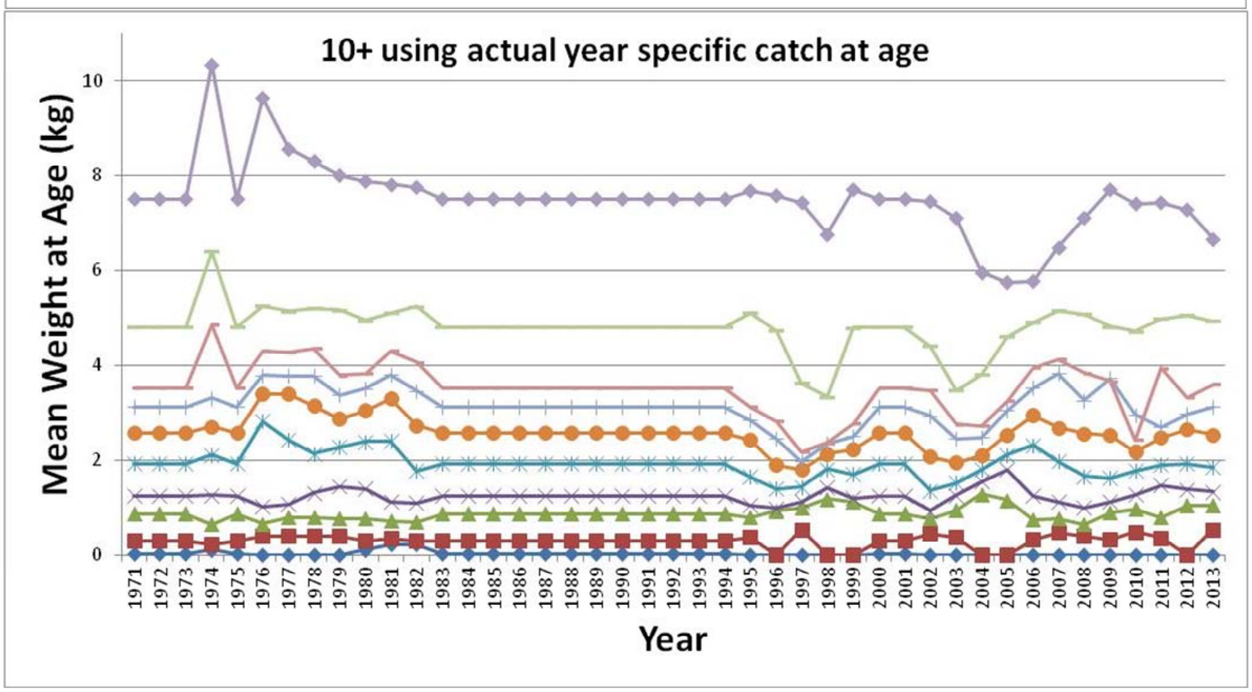


Figure B65. Mean weights at age of the 10+ formulation using a pool age length key for all years (top) and using year specific key in years were data exists (2007,2009-2012) (bottom). The average of years which have data was used for years with missing information.

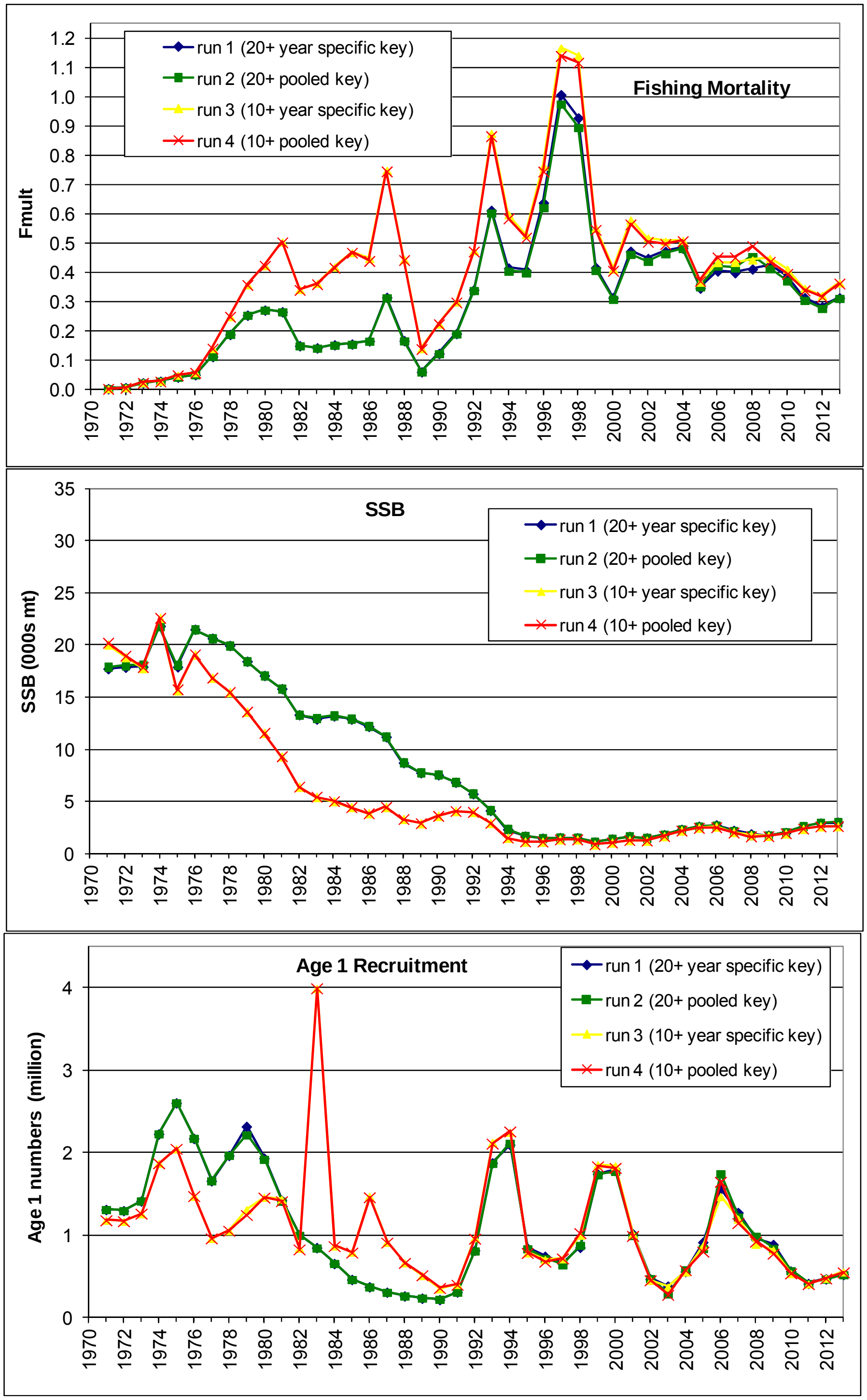


Figure B66. Results of initial four tilefish ASAP formulations for fishing mortality, SSB, and recruitment.

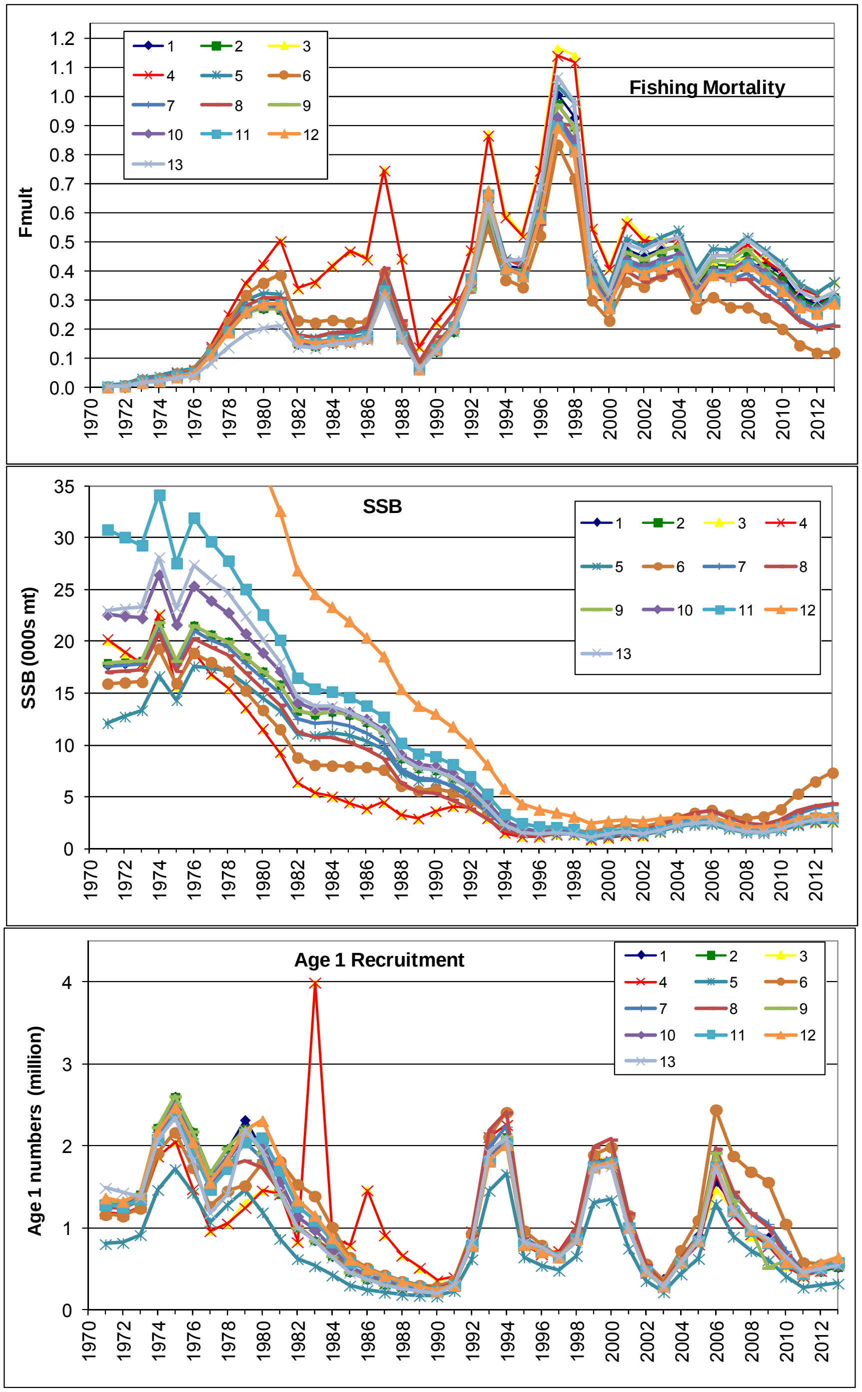


Figure B67. Initial tilefish sensitivity runs for fishing mortality, SSB, and recruitment.

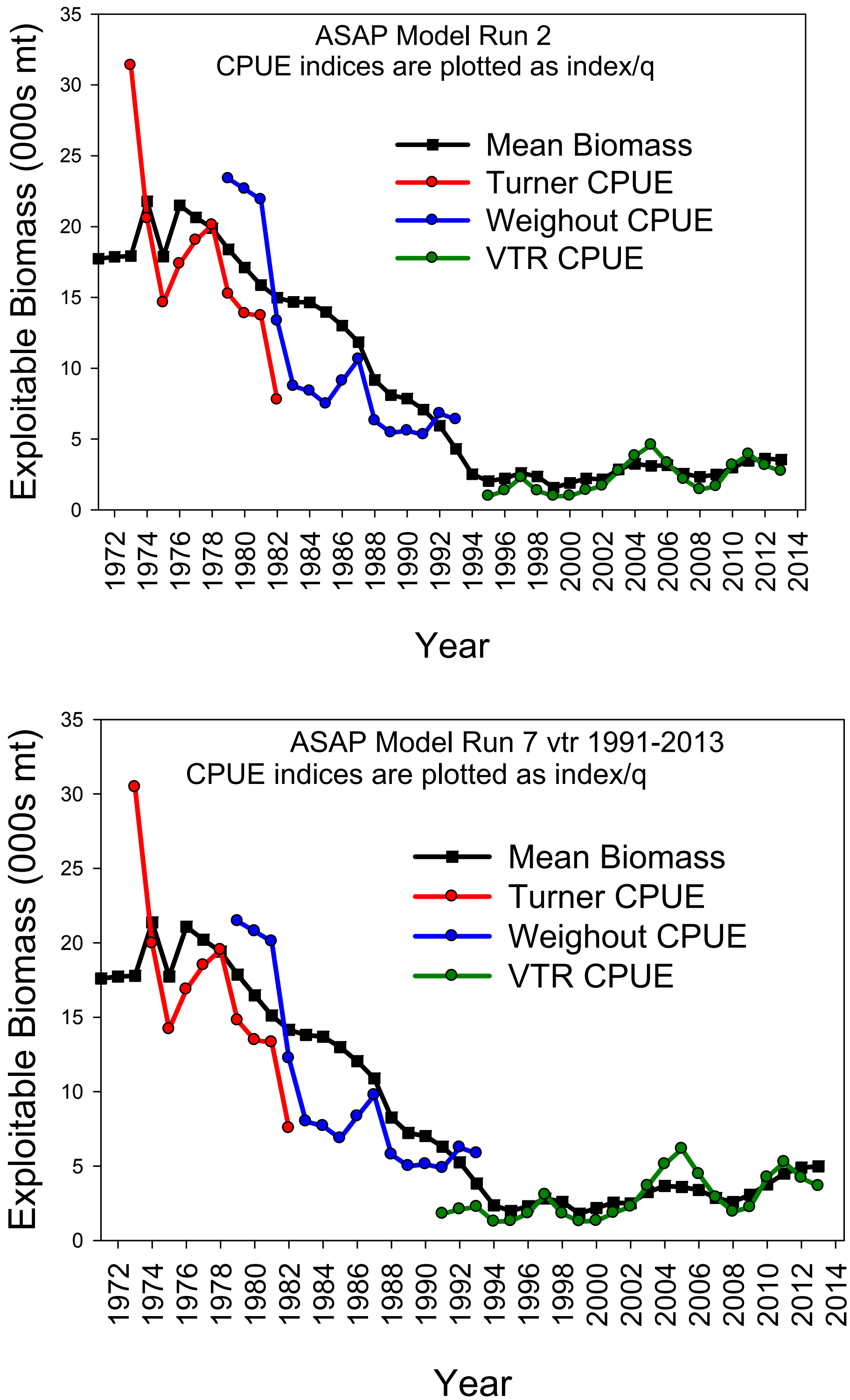


Figure B68. Depiction of the change in q between ASAP run 2 and ASAP run 7 which added the 1991-1994 New York CPUE data to the VTR series. Adding the 1991-1994 CPUE information in the past results in less change between the series.

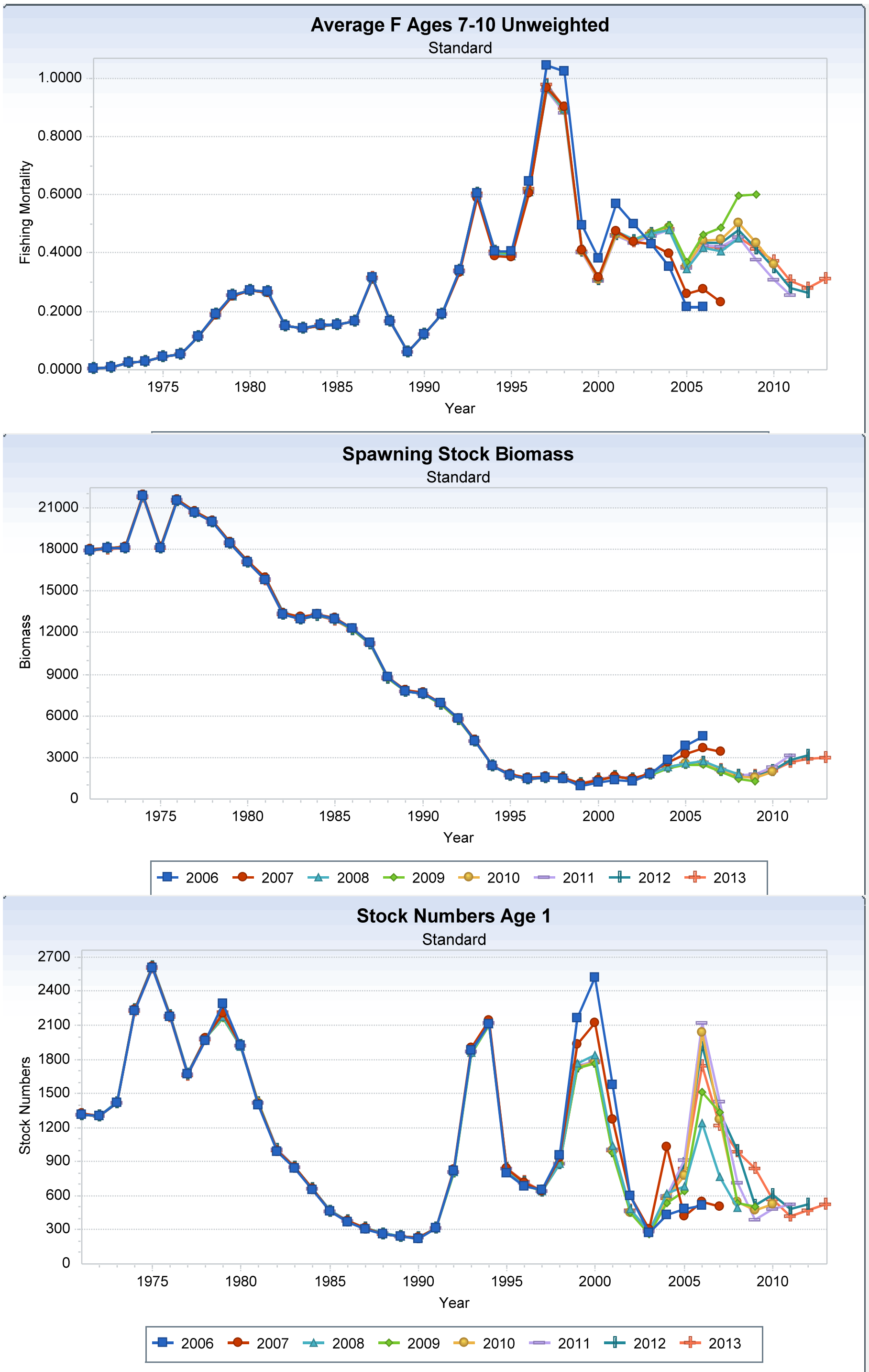


Figure B69. Tilefish ASAP run 2 retrospective analyses with 7 year peel.

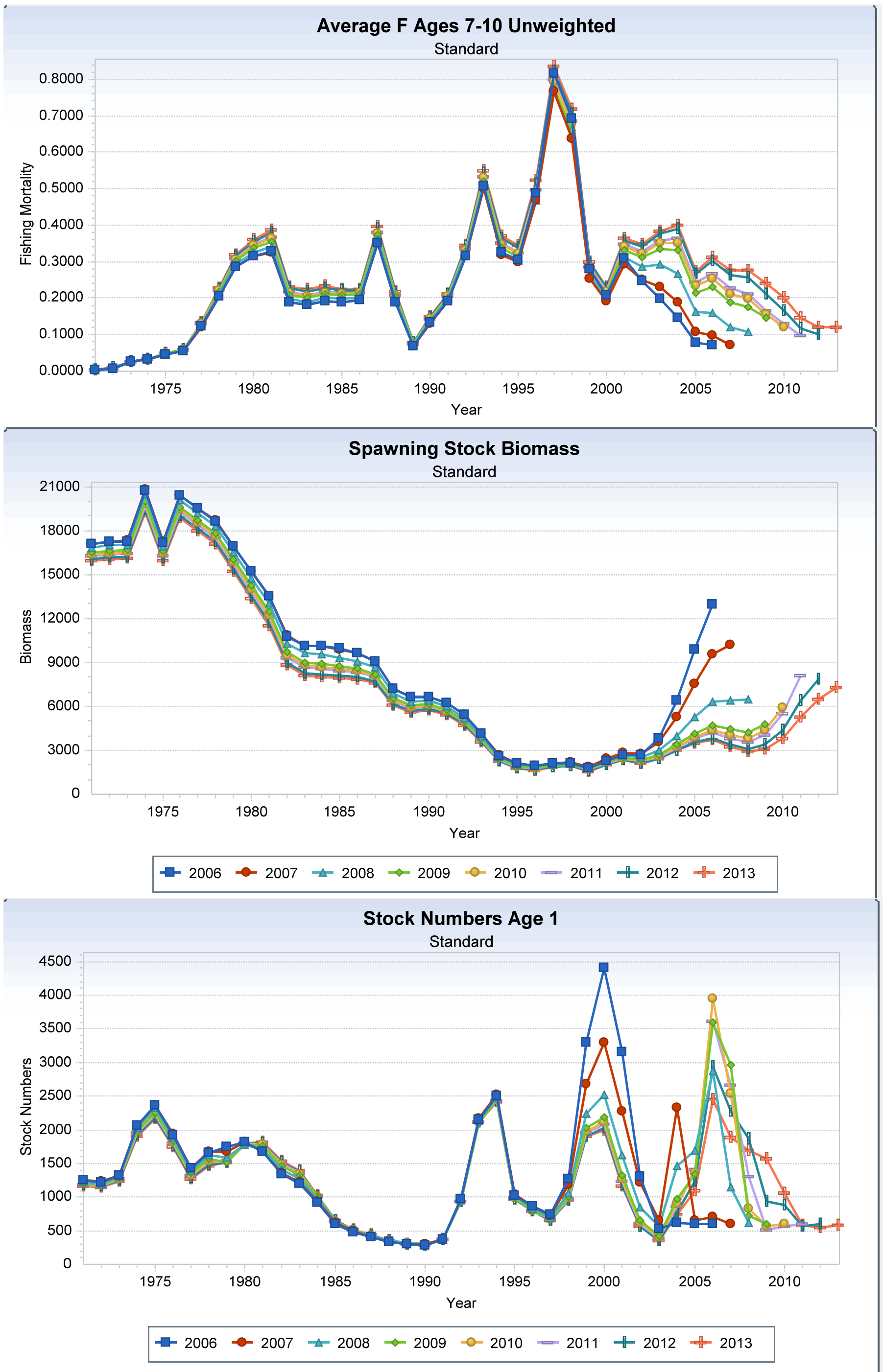


Figure B70. Tilefish ASAP run 6 (combine Weighout and VTR series) retrospective analyses with 7 year peel.

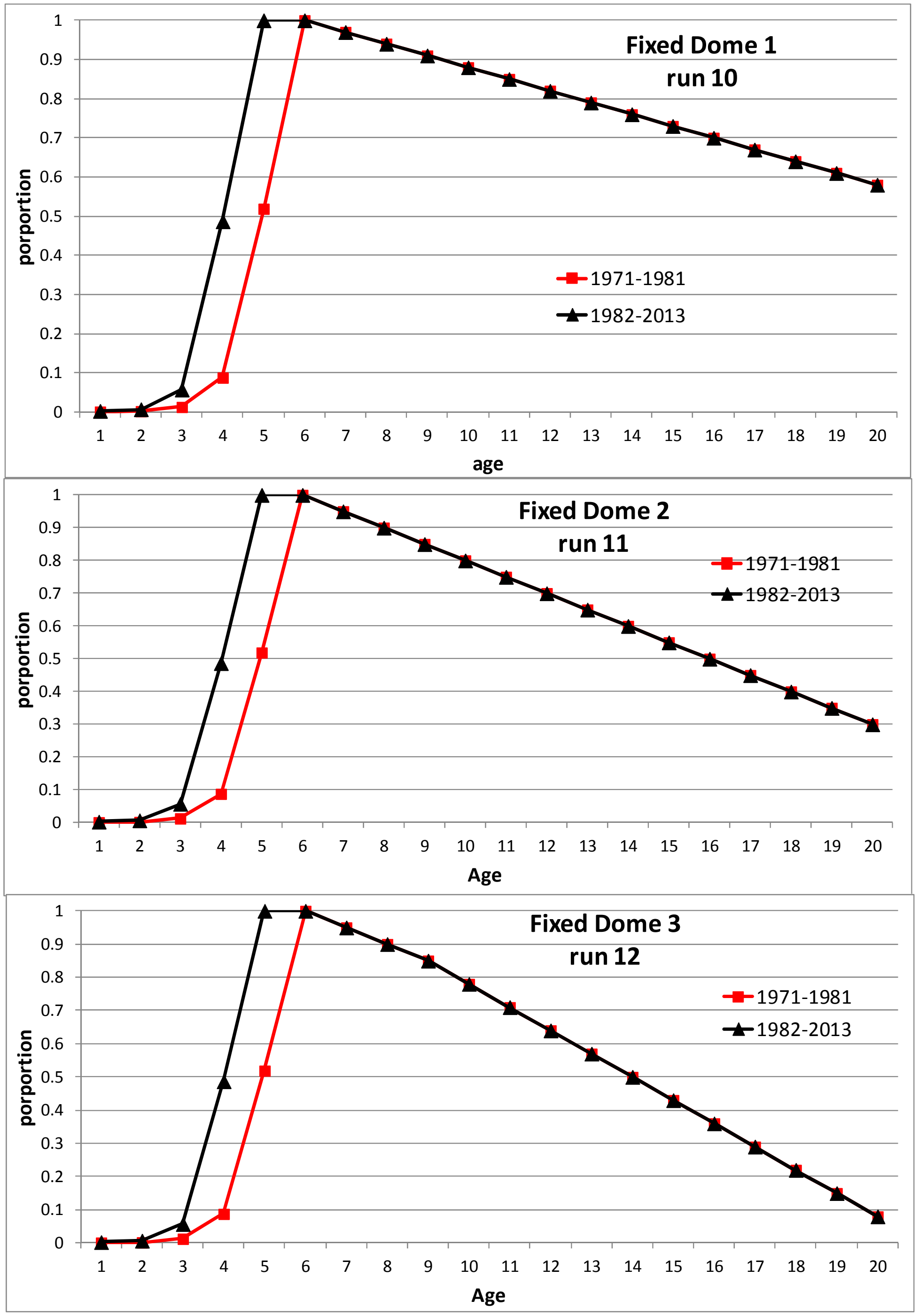


Figure B71. Fixed ASAP dome shaped (> age 5) selectivity which were used in sensitivity runs 10-12.

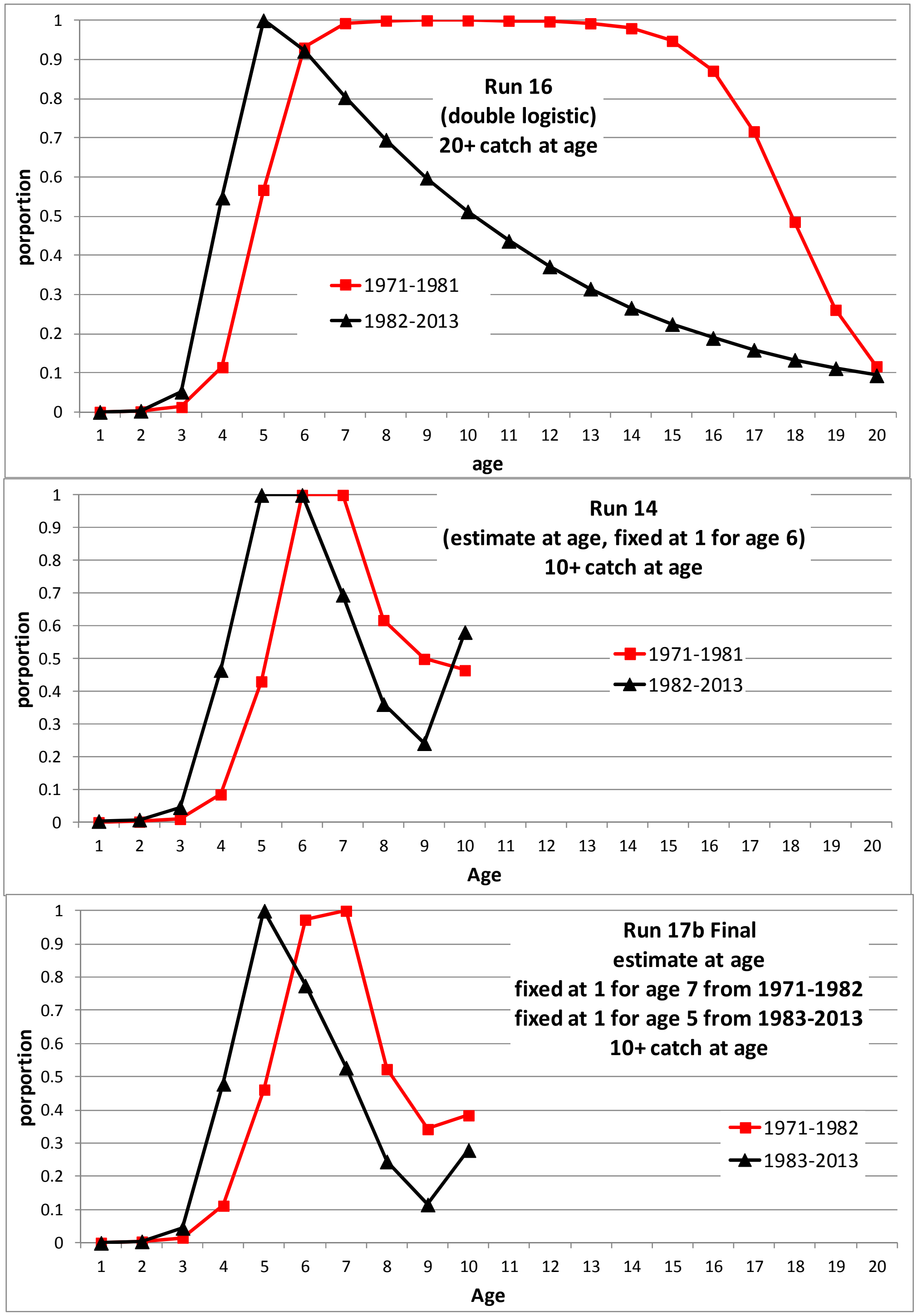


Figure B72. Estimated ASAP dome shaped selectivity from sensitivity runs 16 (20+ double logistic), run 14 (10+ at age), and the final run 27b (10+ at age).

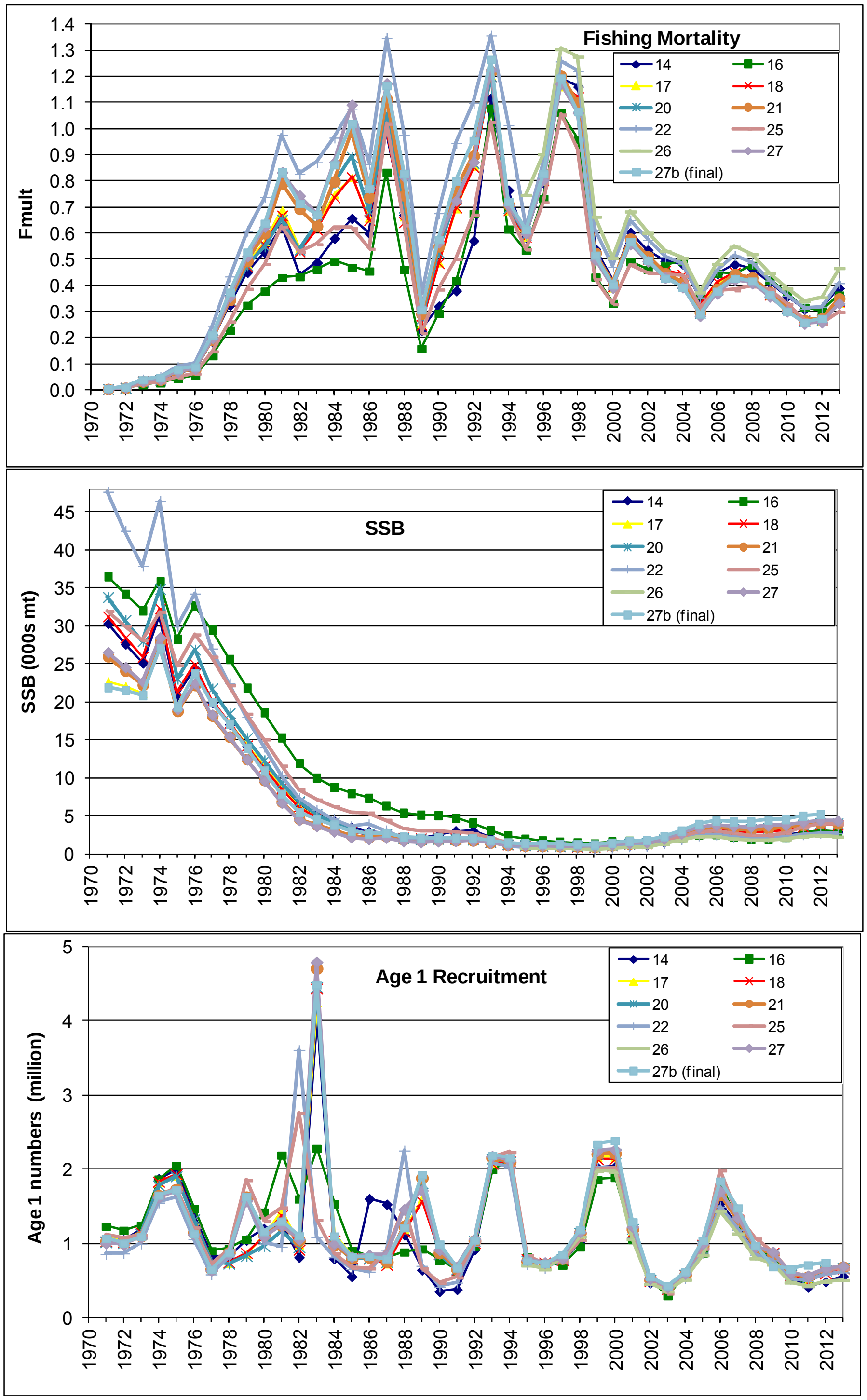


Figure B73. Working group tilefish dome shaped sensitivity runs for fishing mortality, SSB, and recruitment.

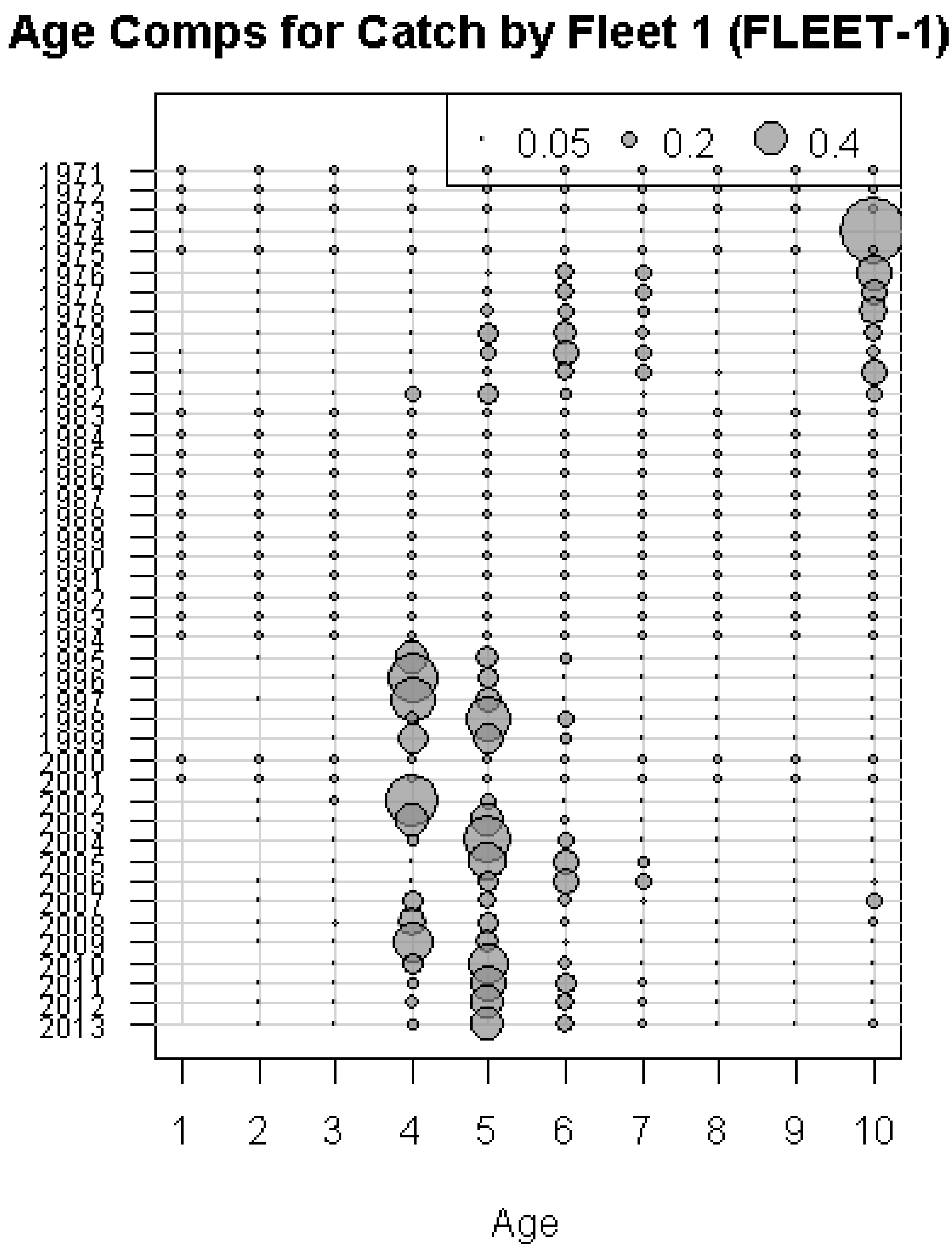


Figure B74. Working group final ASAP run 27b catch at age.

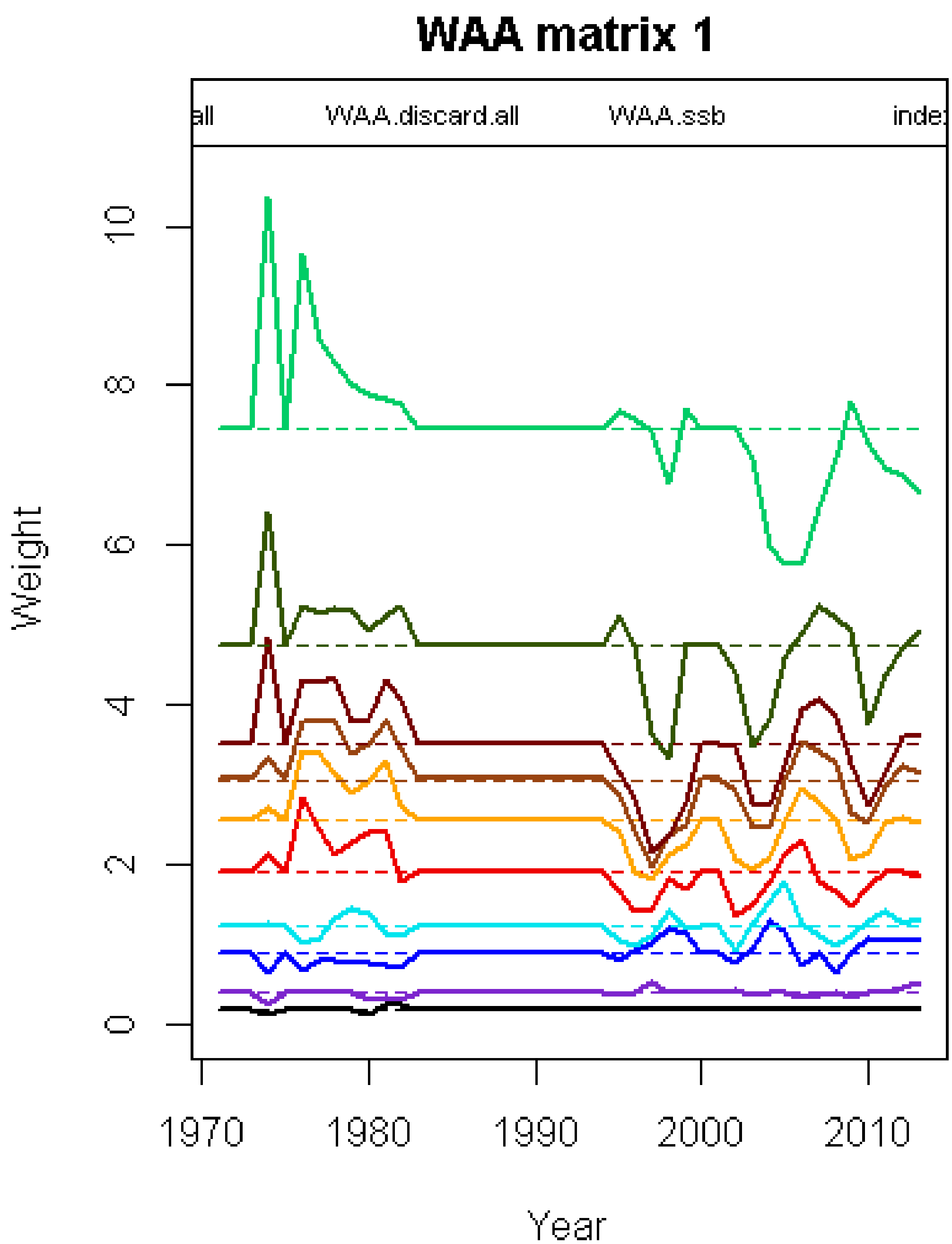


Figure B75. Working group final ASAP run 27b input mean weights at age.

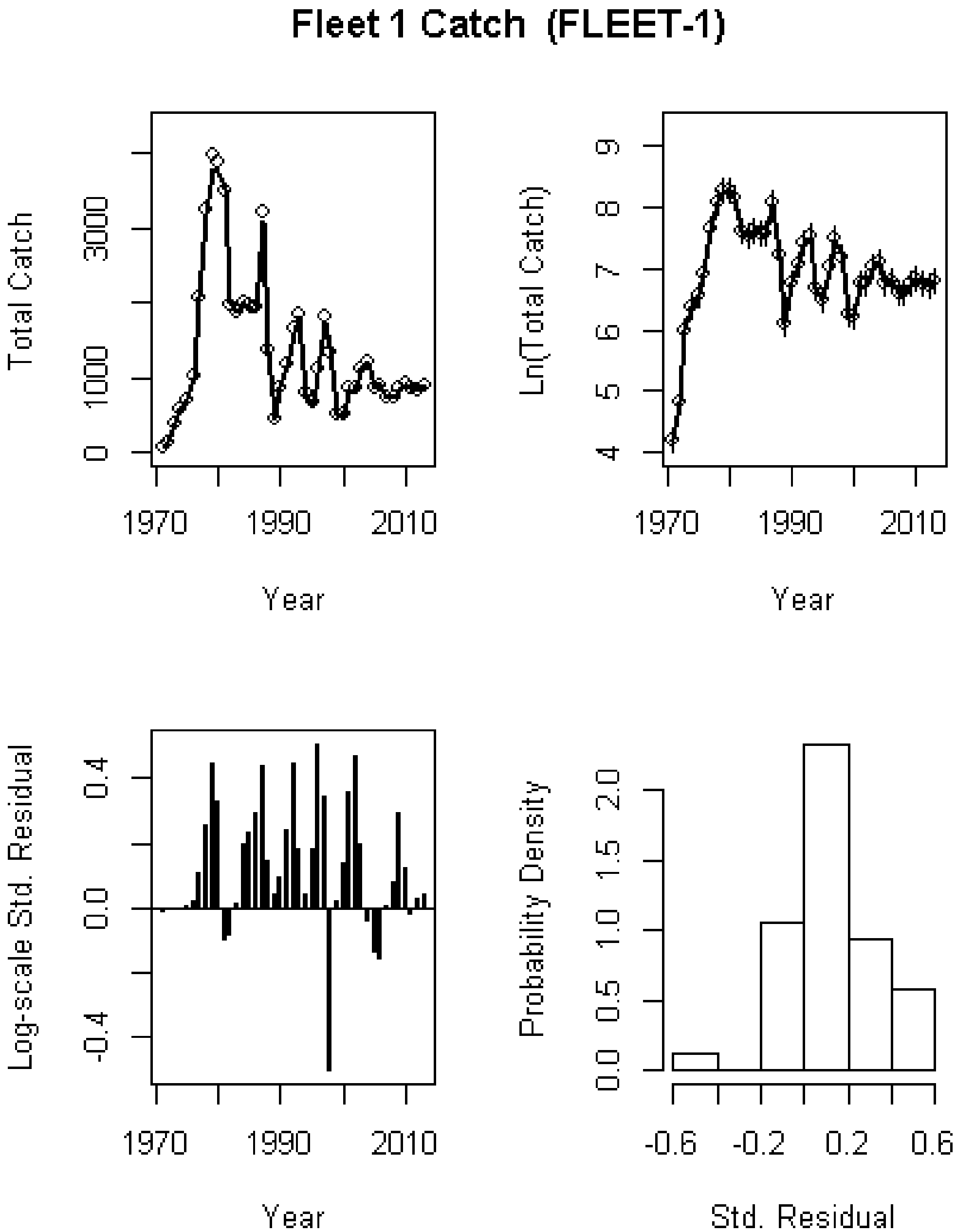


Figure B76. Working group final ASAP run 27b fit to the total catch.

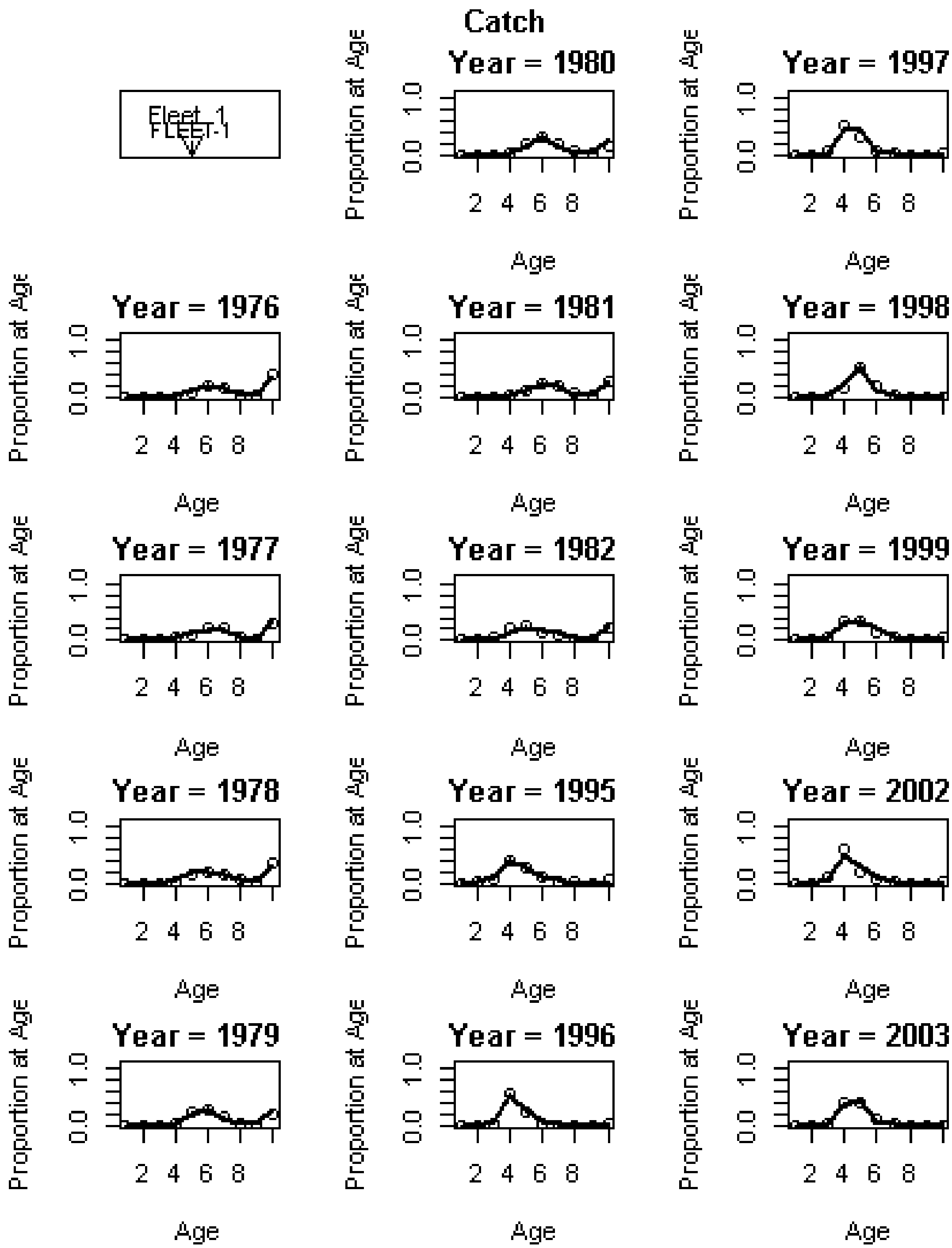


Figure B77. Working group final ASAP run 27b fit to catch at age.

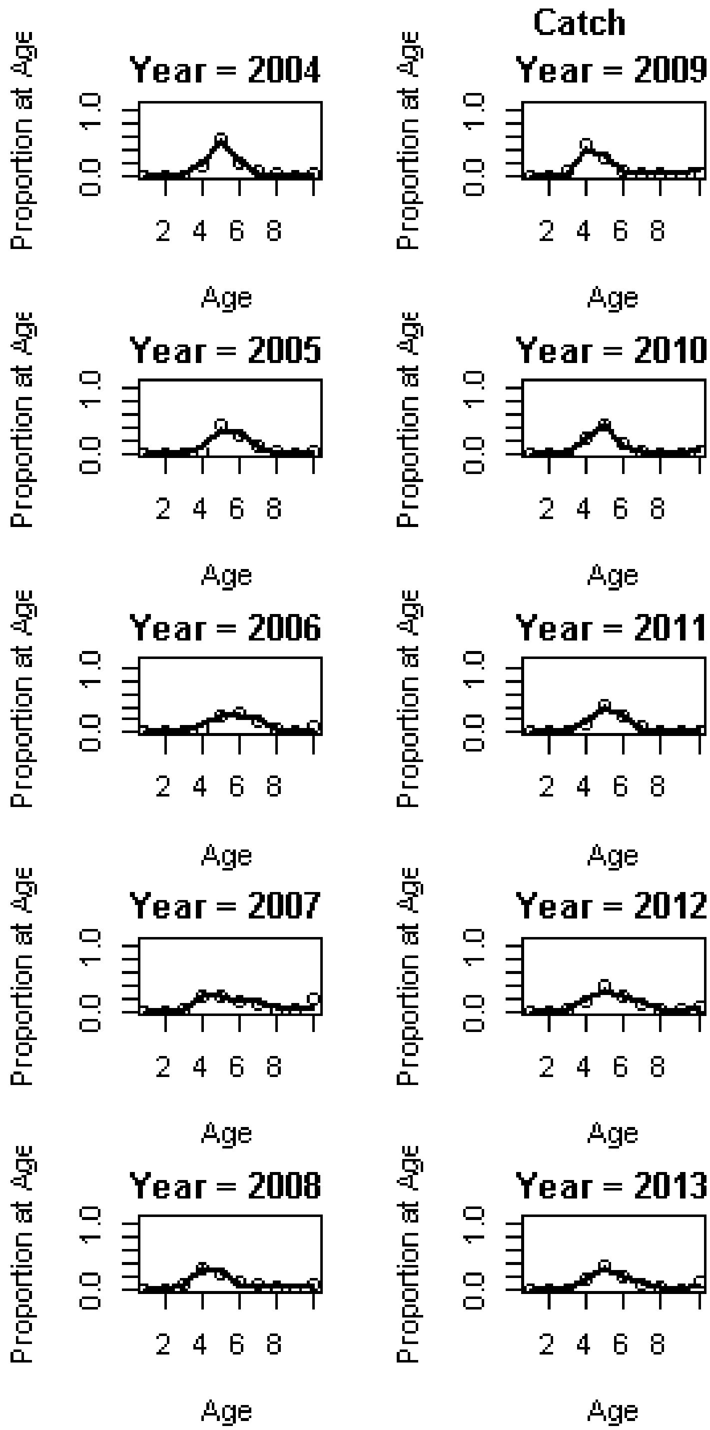


Figure B77. Cont.

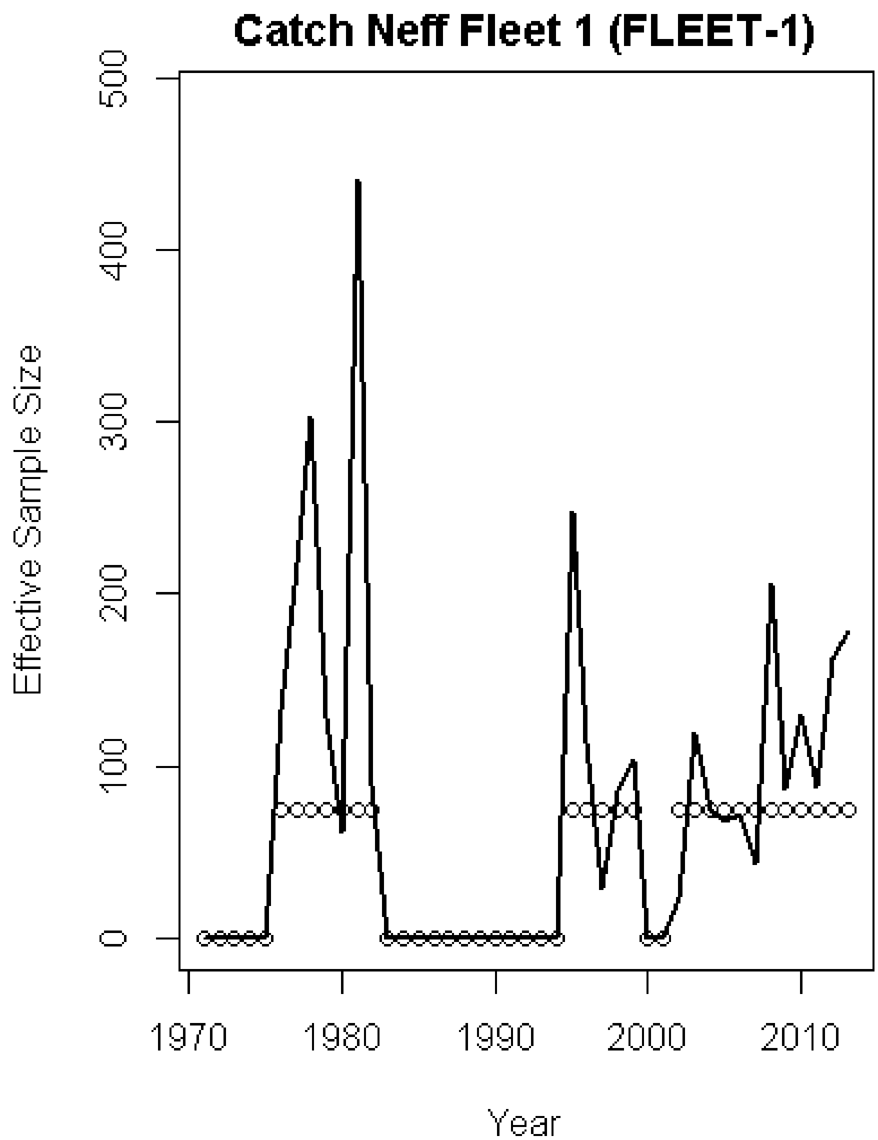


Figure B78. Working group final ASAP run 27b input and model estimated effective sample size on the catch at age.

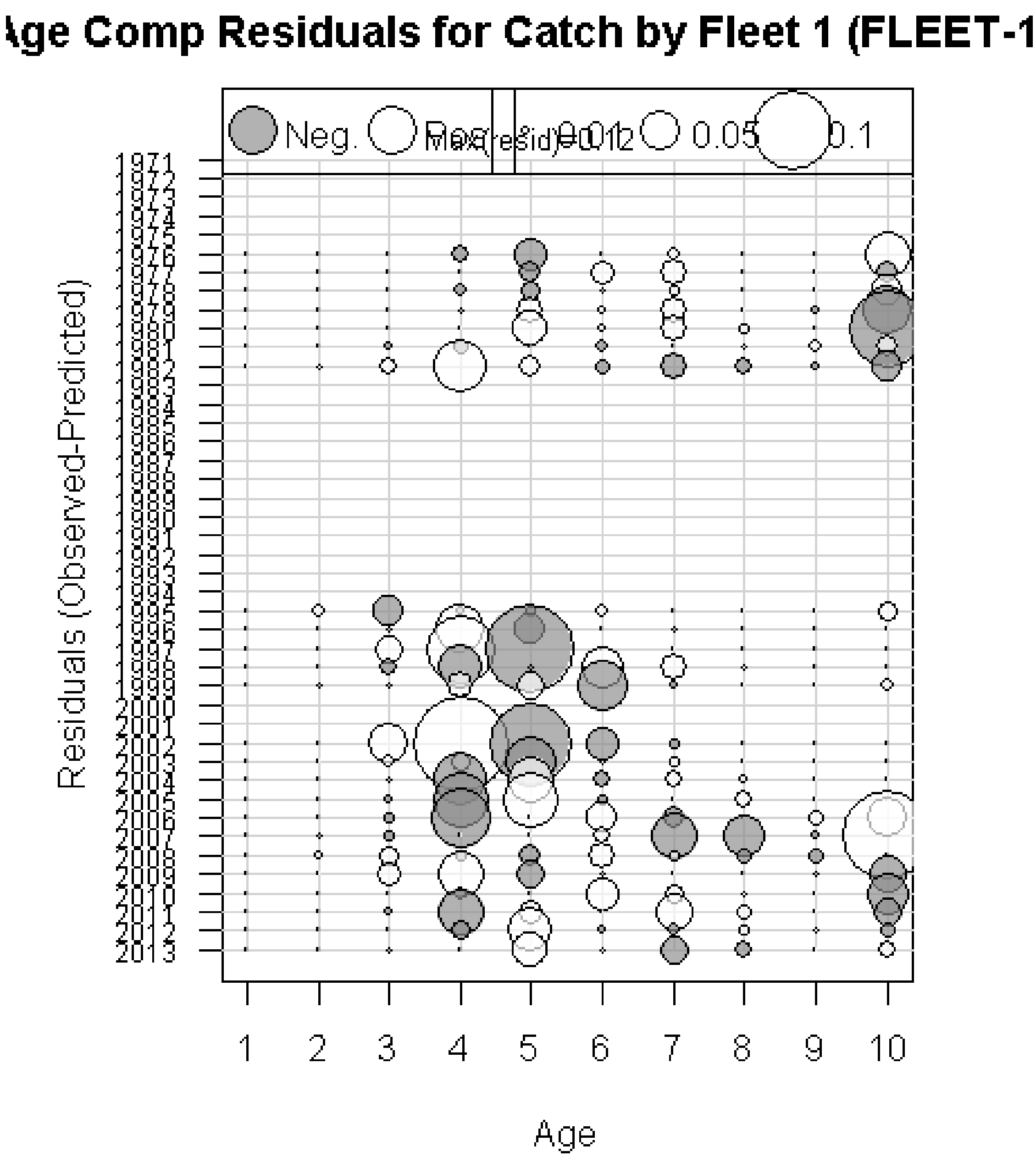


Figure B79. Working group final ASAP run 27b catch at age comp residuals.

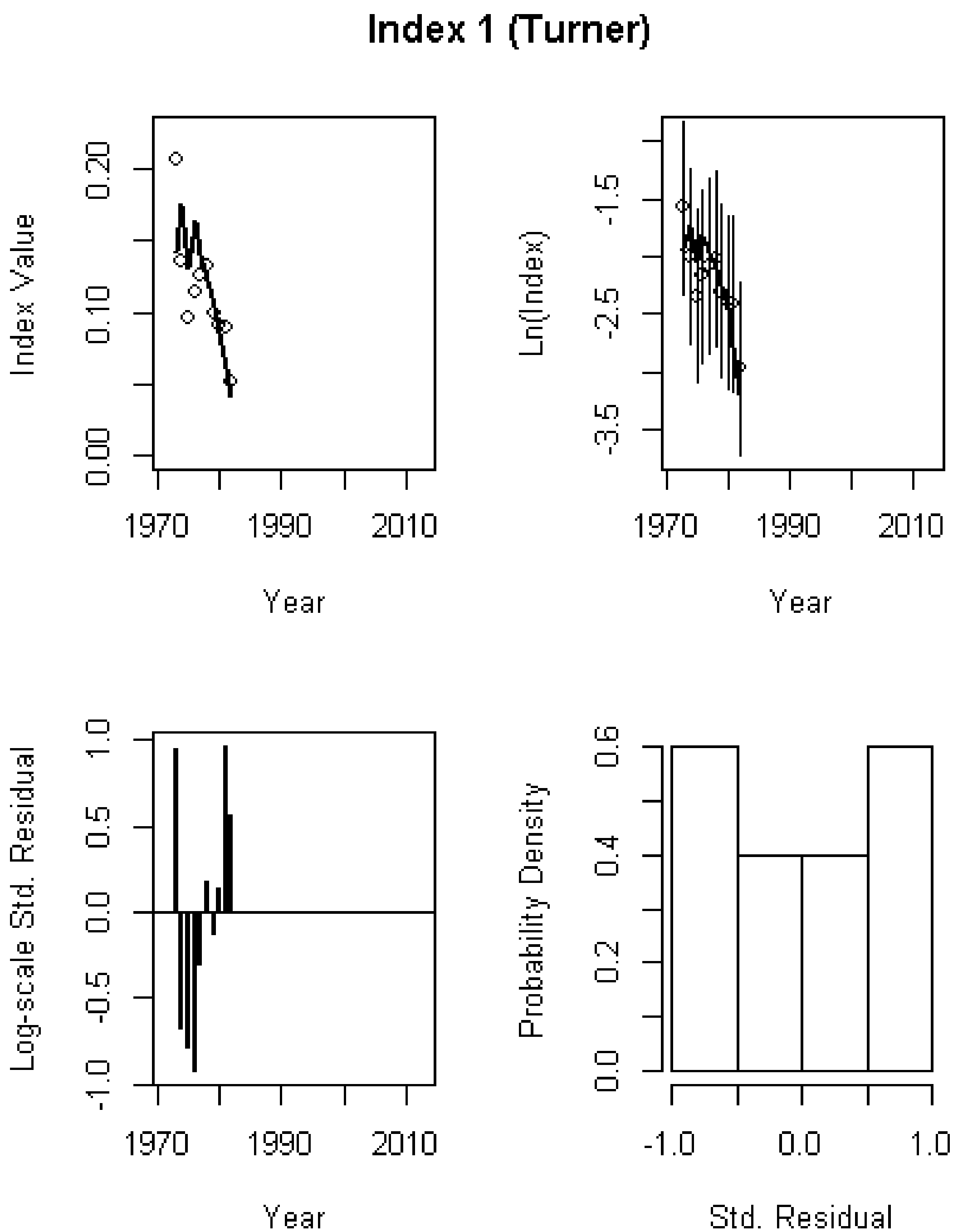


Figure B80. Working group final ASAP run 27b fit to Turner's CPUE index.

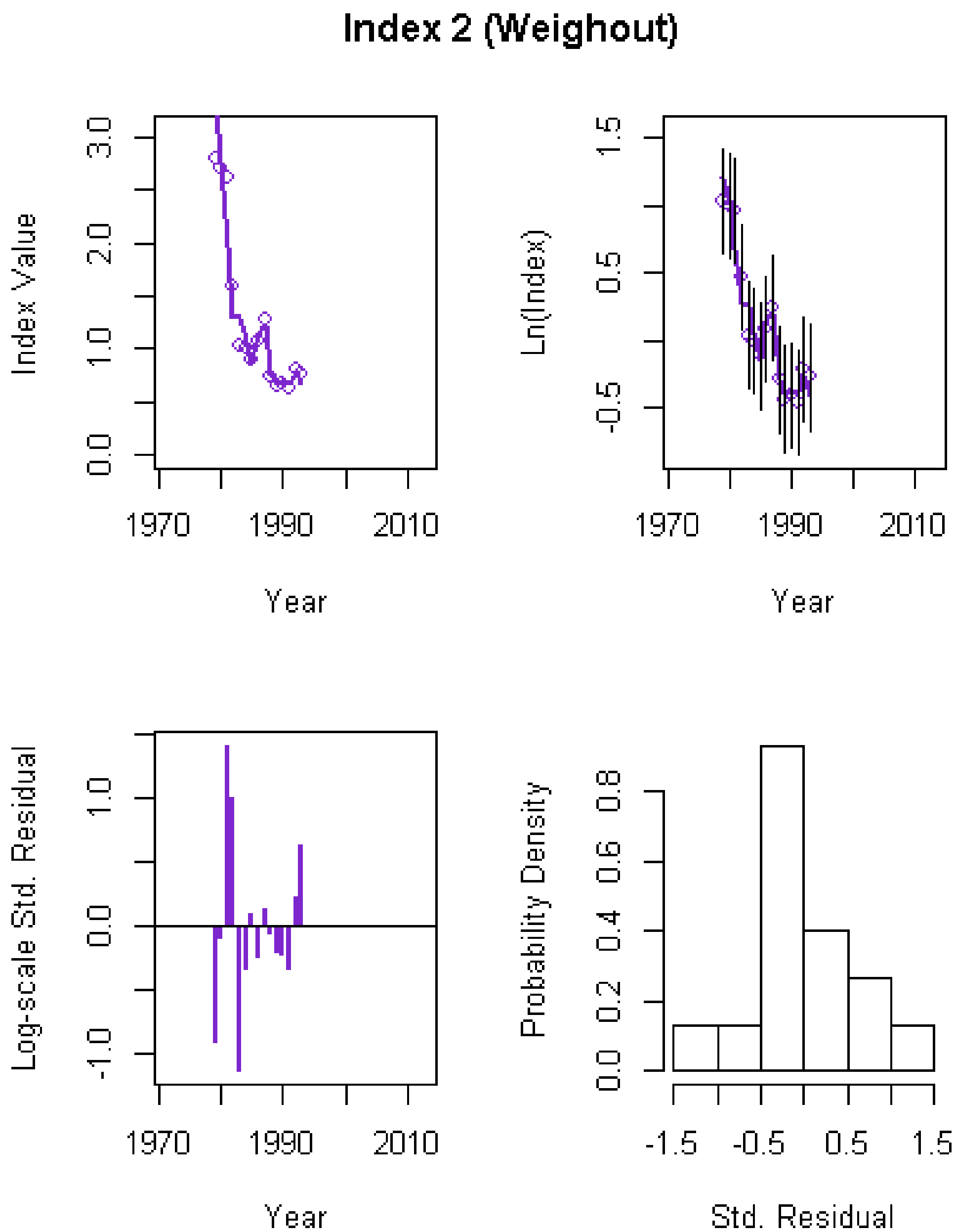


Figure B81. Working group final ASAP run 27b fit to the Weighout CPUE index.

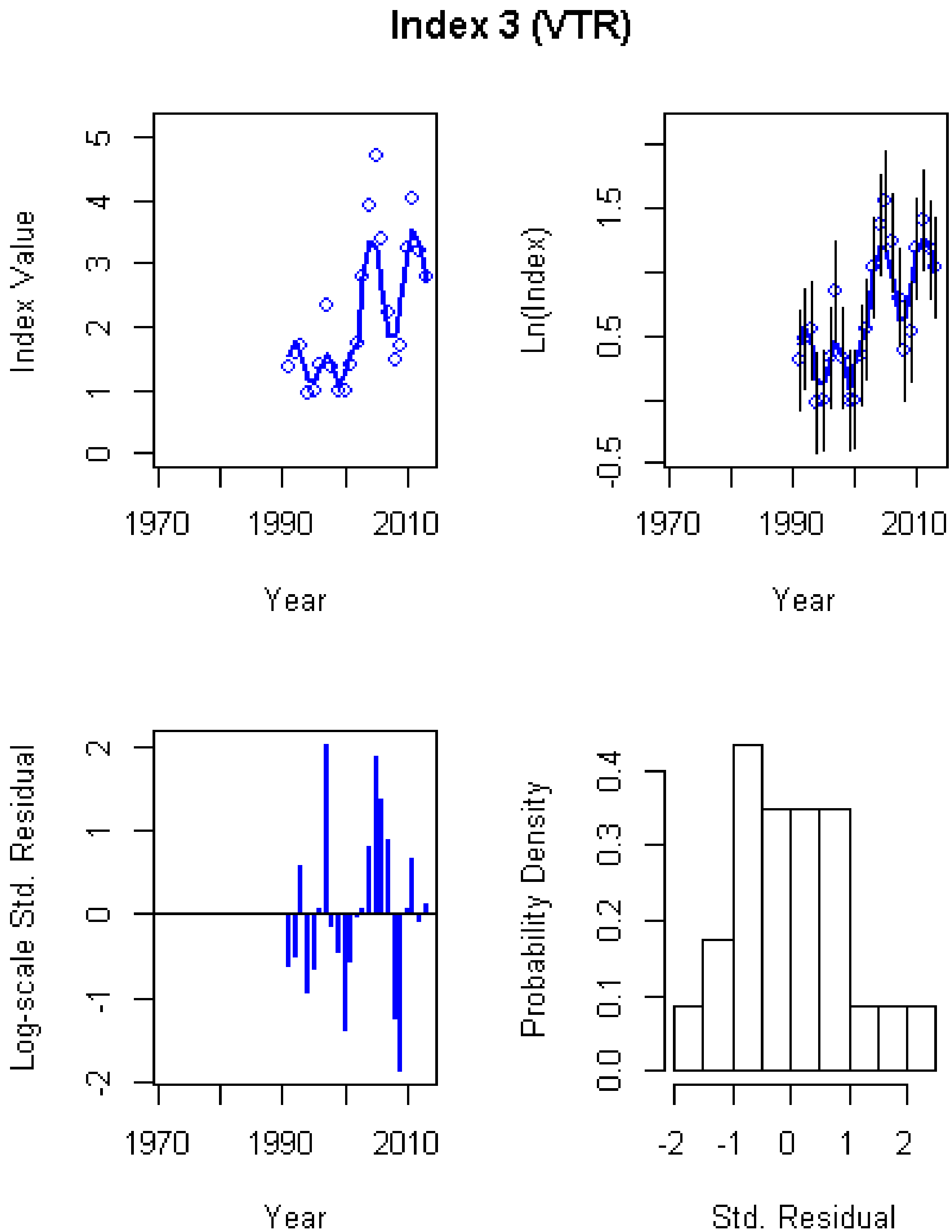


Figure B82. Working group final ASAP run 27b fit to VTR CPUE index.

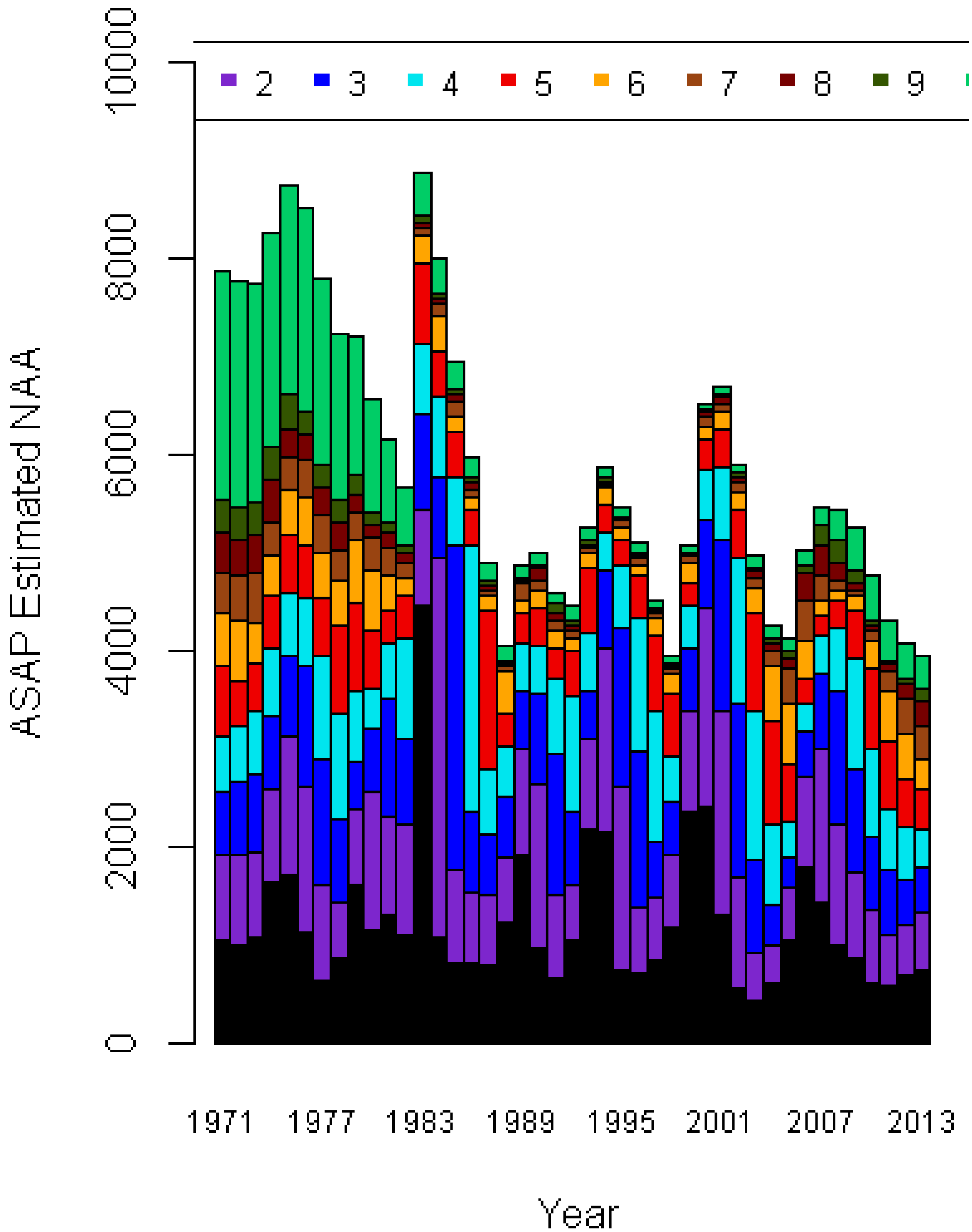


Figure B83. Working group final ASAP run 27b estimated numbers at age over the 1971-2012 time series.

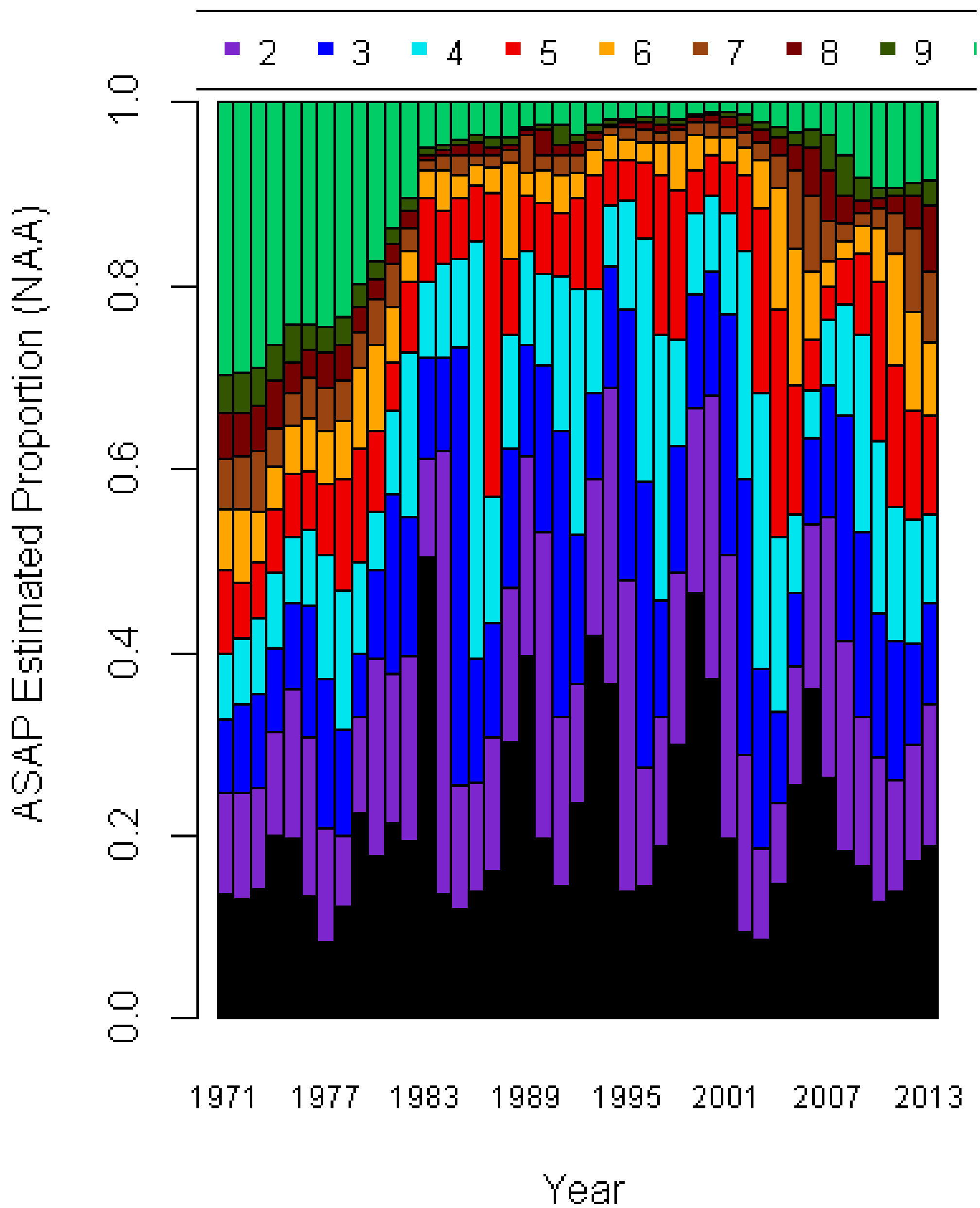


Figure B84. Working group final ASAP run 27b proportion of the numbers at age over the 1971-2012 time series.

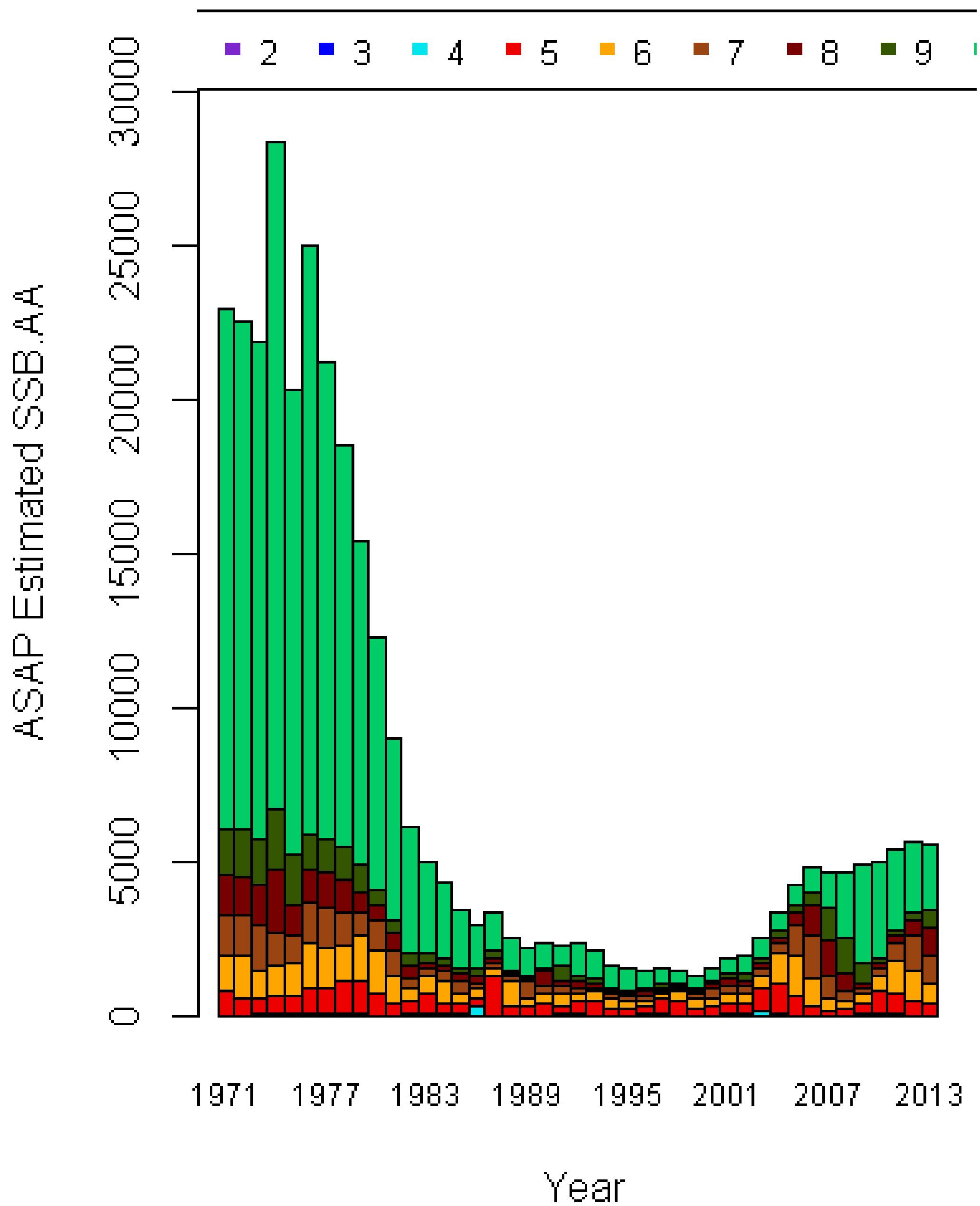


Figure B85. Working group final ASAP run 27b estimated SSB at age over the 1971-2012 time series.

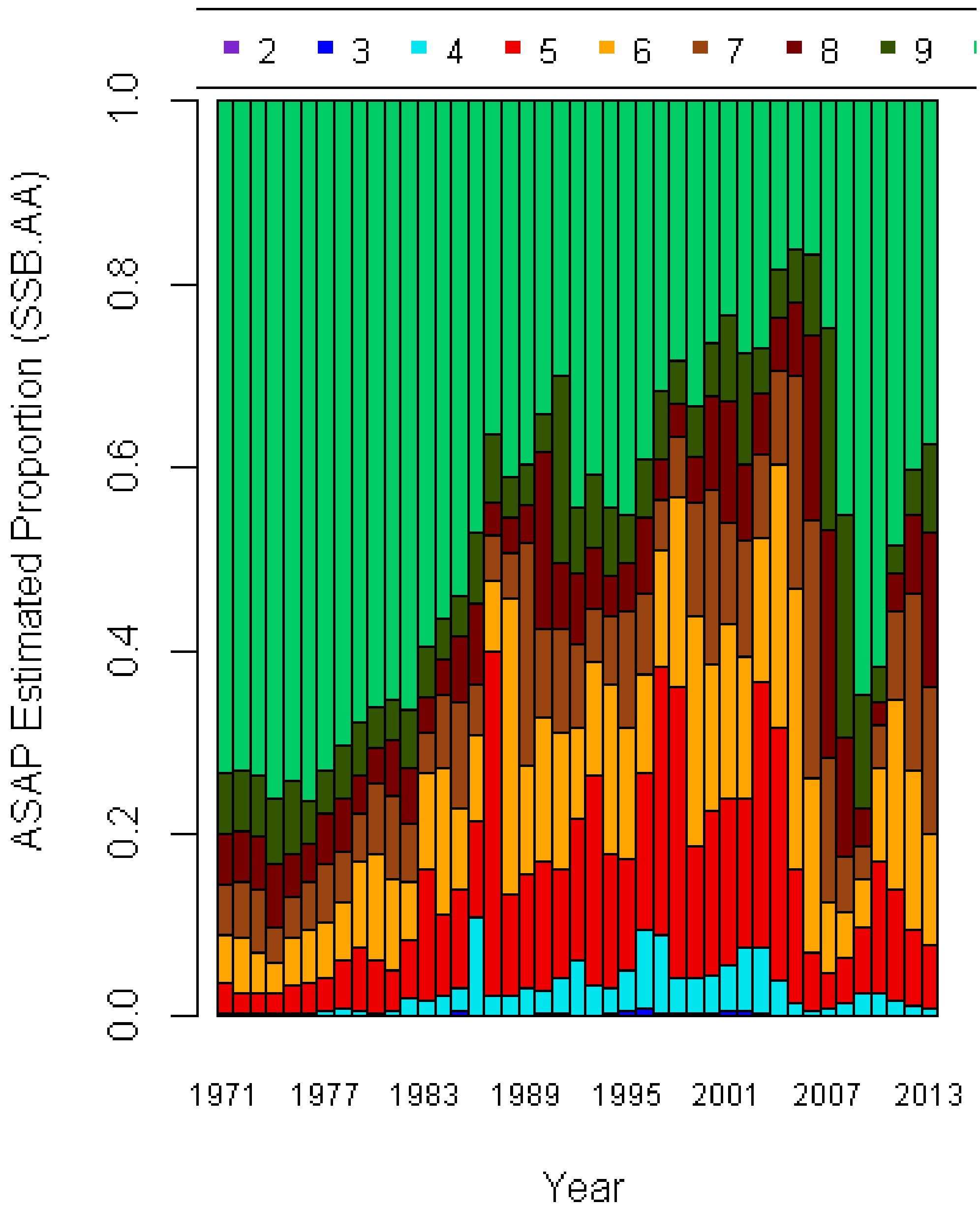


Figure B86. Working group final ASAP run 27b proportion of the SSB at age over the 1971-2012 time series.

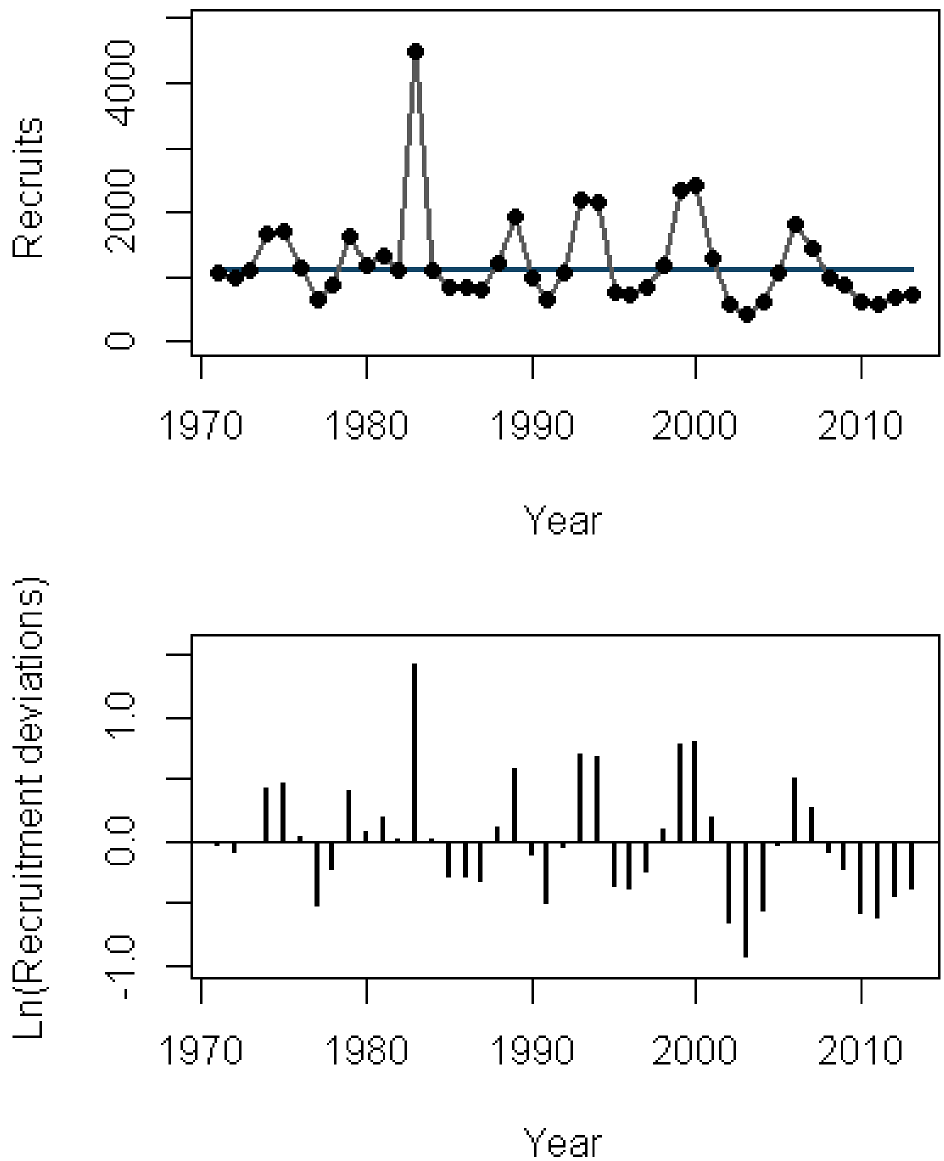


Figure B87. Working group final ASAP run 27b estimated age-1 recruitment deviations.

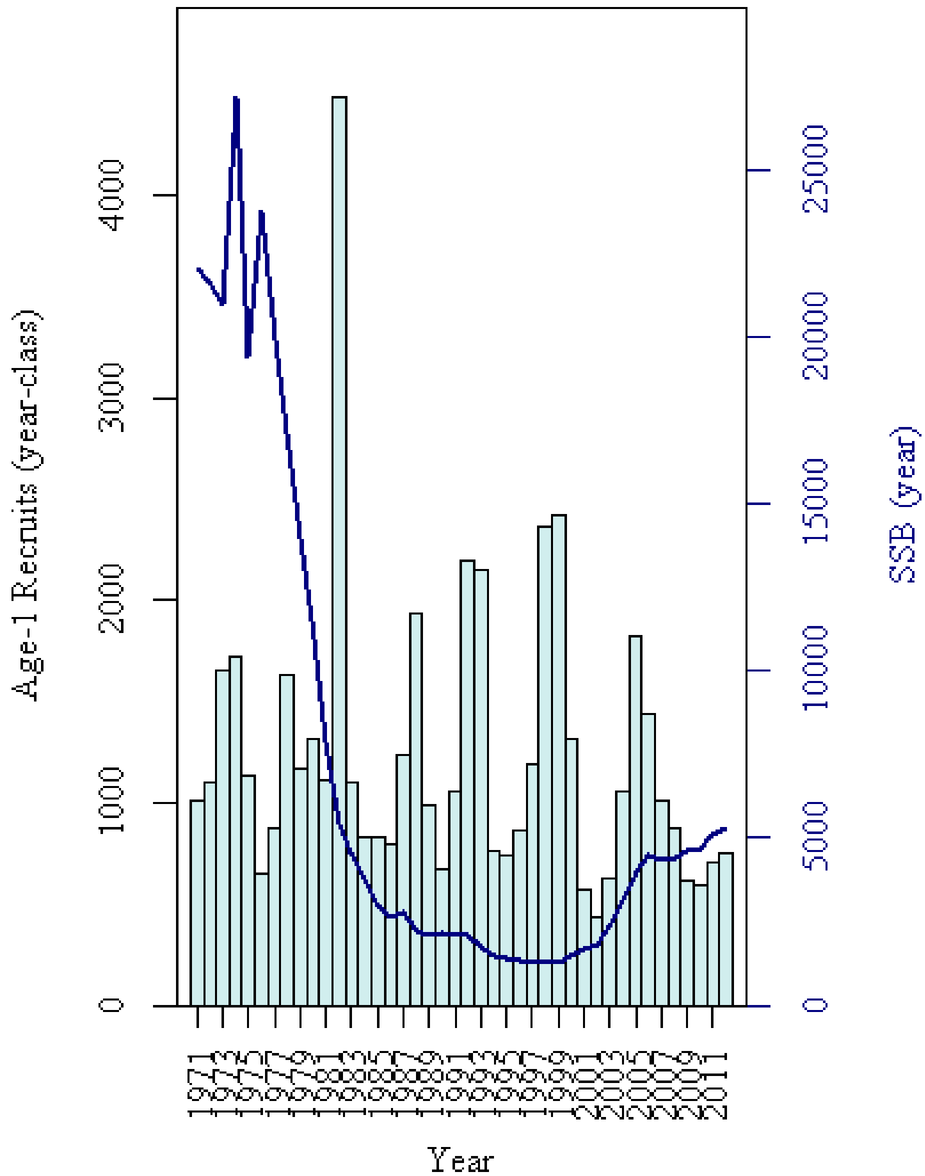


Figure B88. Working group final ASAP run 27b estimated age-1 recruitment and SSB.

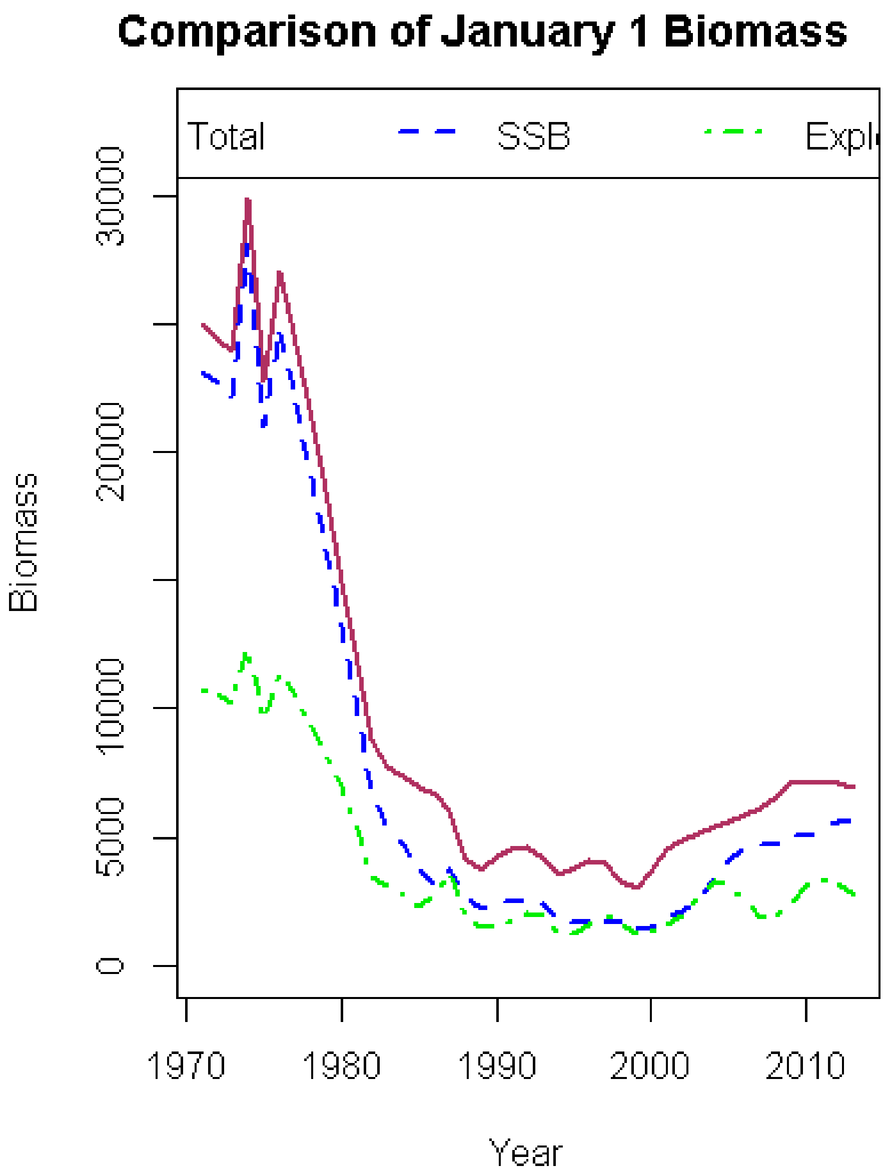


Figure B89. Working group final ASAP run 27b estimated total Jan-1 biomass, SSB, and exploitable biomass.

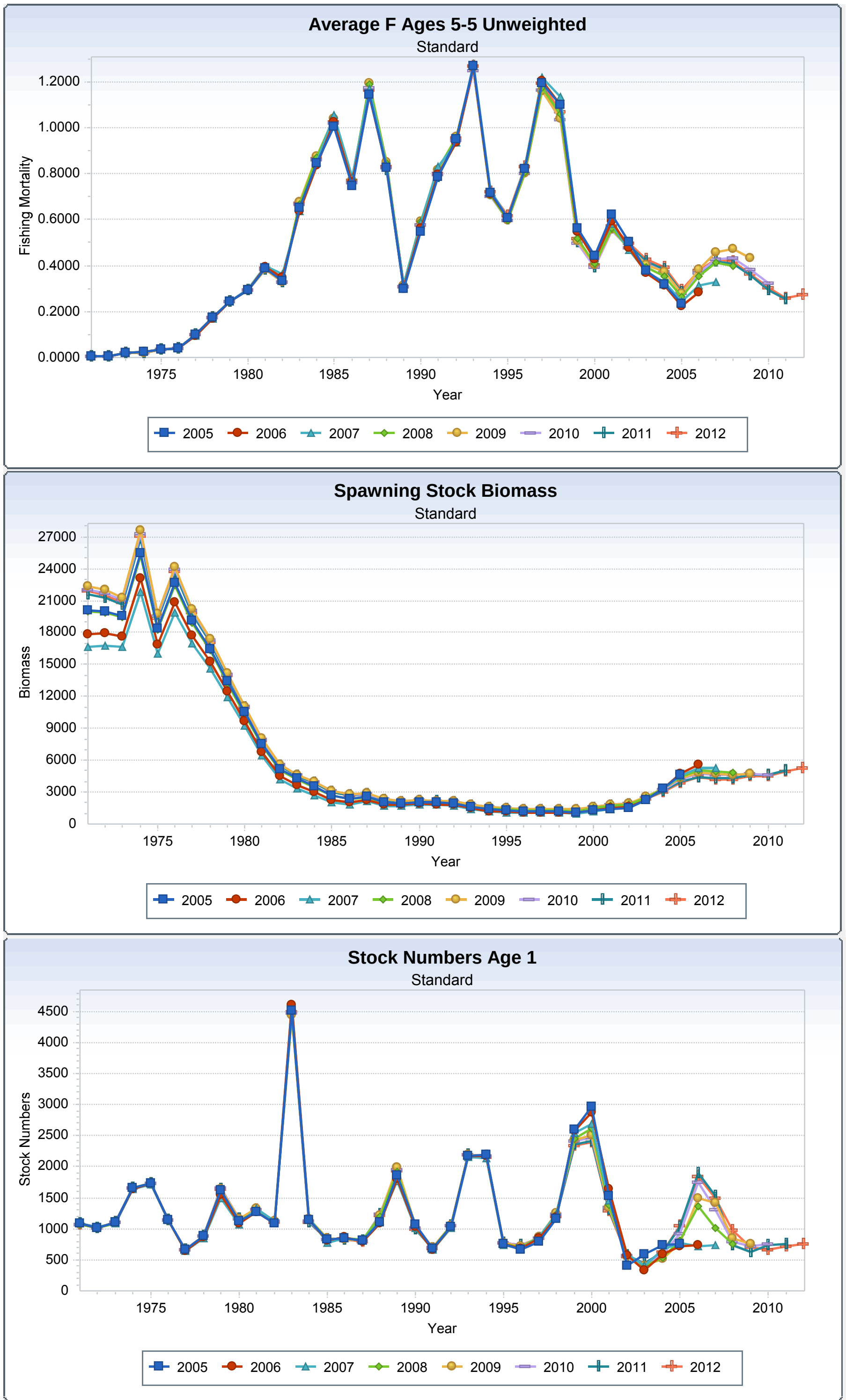


Figure B90. Working group final ASAP run 27b retrospective analysis using 7 year peel.

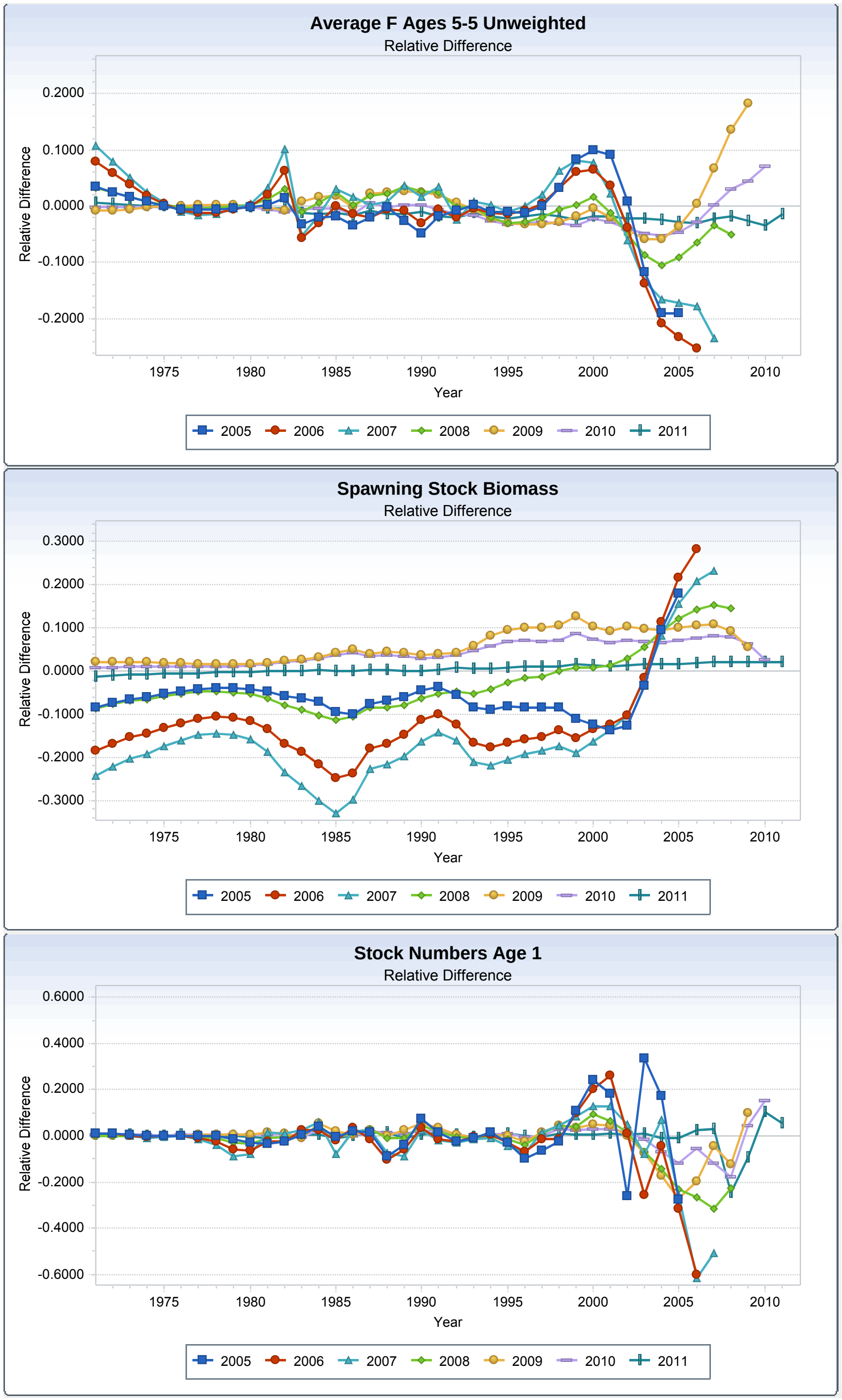


Figure B91. Working group final ASAP run 27b relative retrospective analysis using 7 year peel.

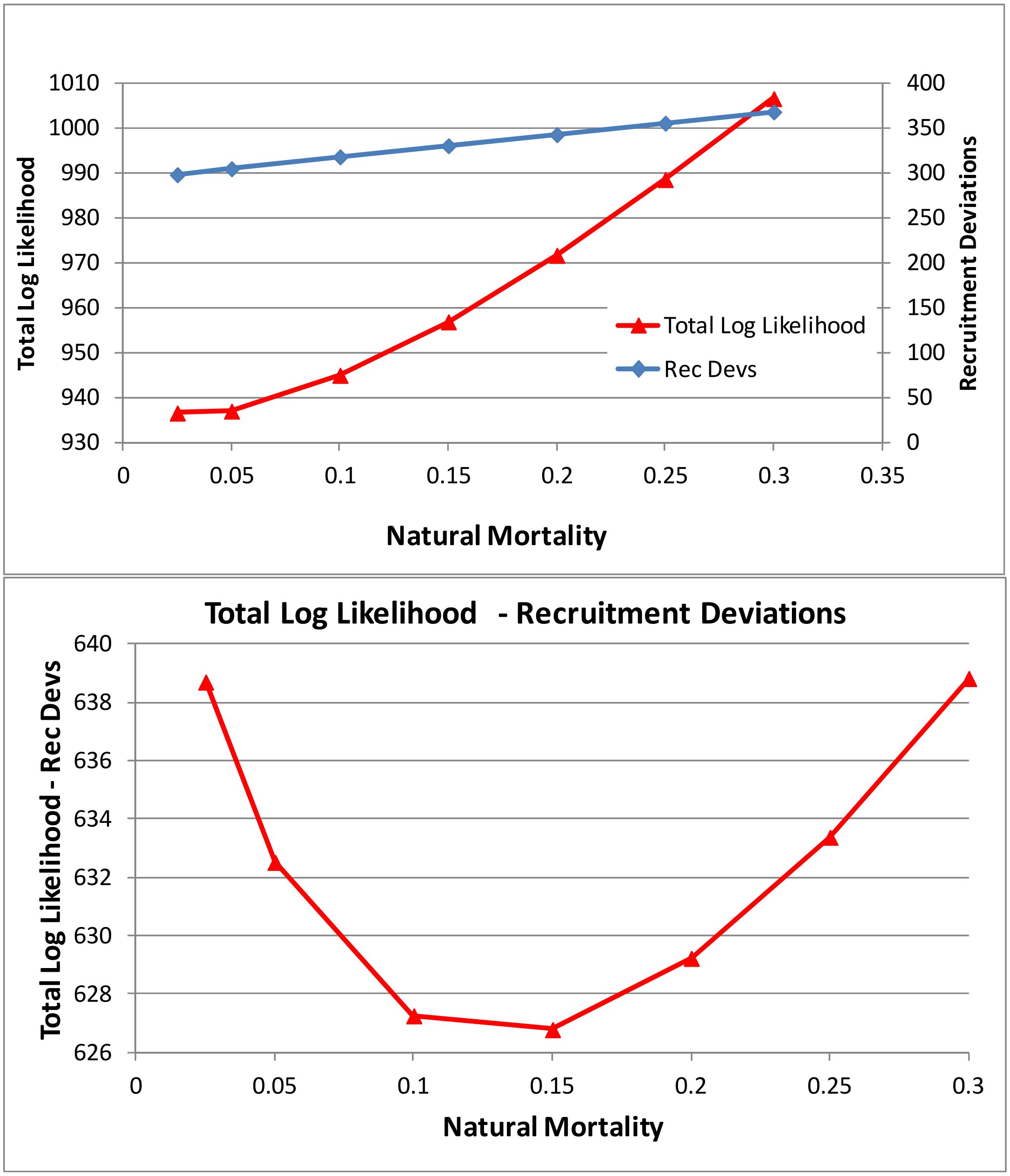


Figure B92. Working group final ASAP run 27b profile on natural mortality. Recruitment deviation residuals were subtracted from the total likelihood.

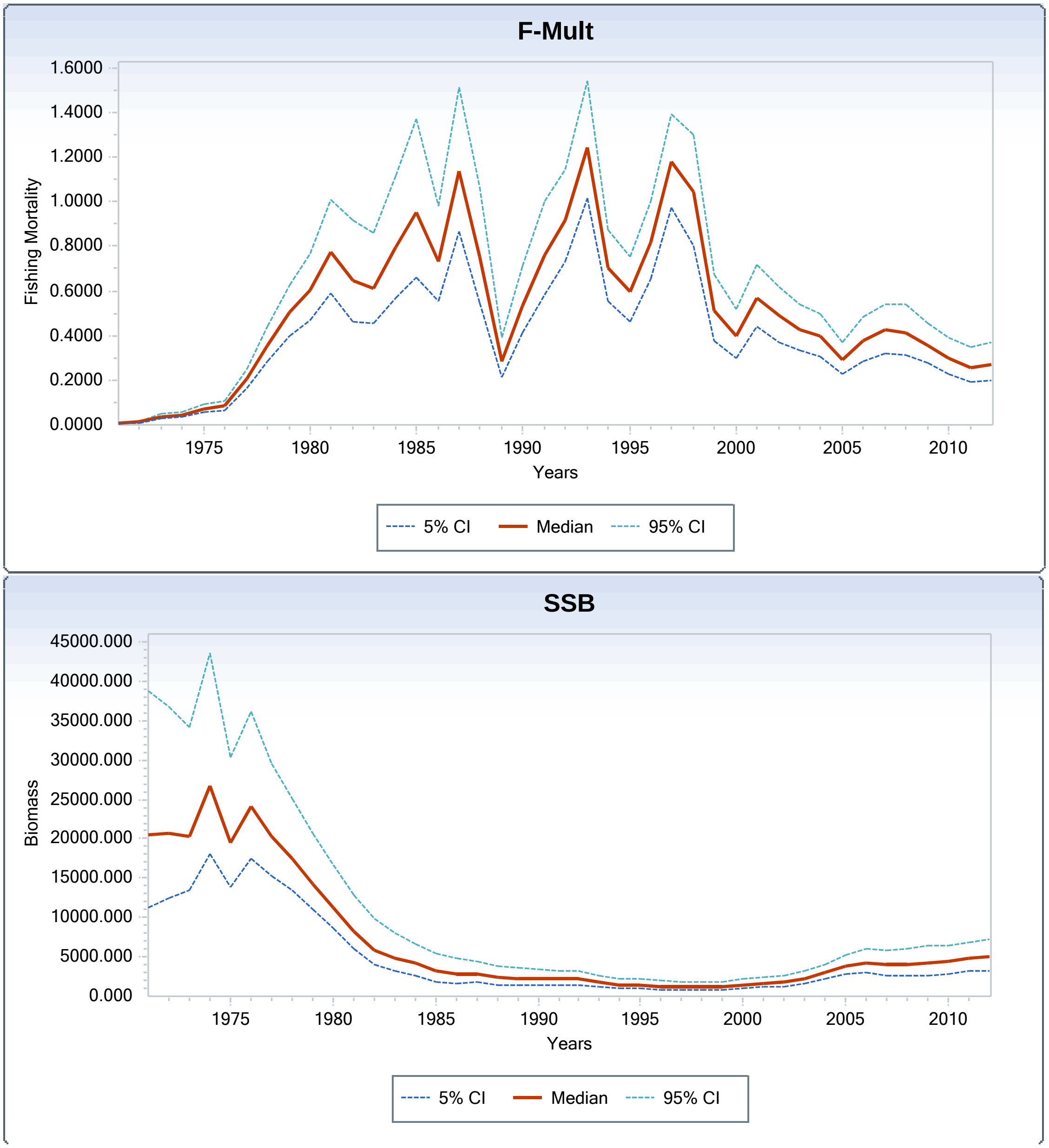


Figure B93. Working group final ASAP run 27b fishing mortality and SSB. 90% CI from NCMC are also shown.

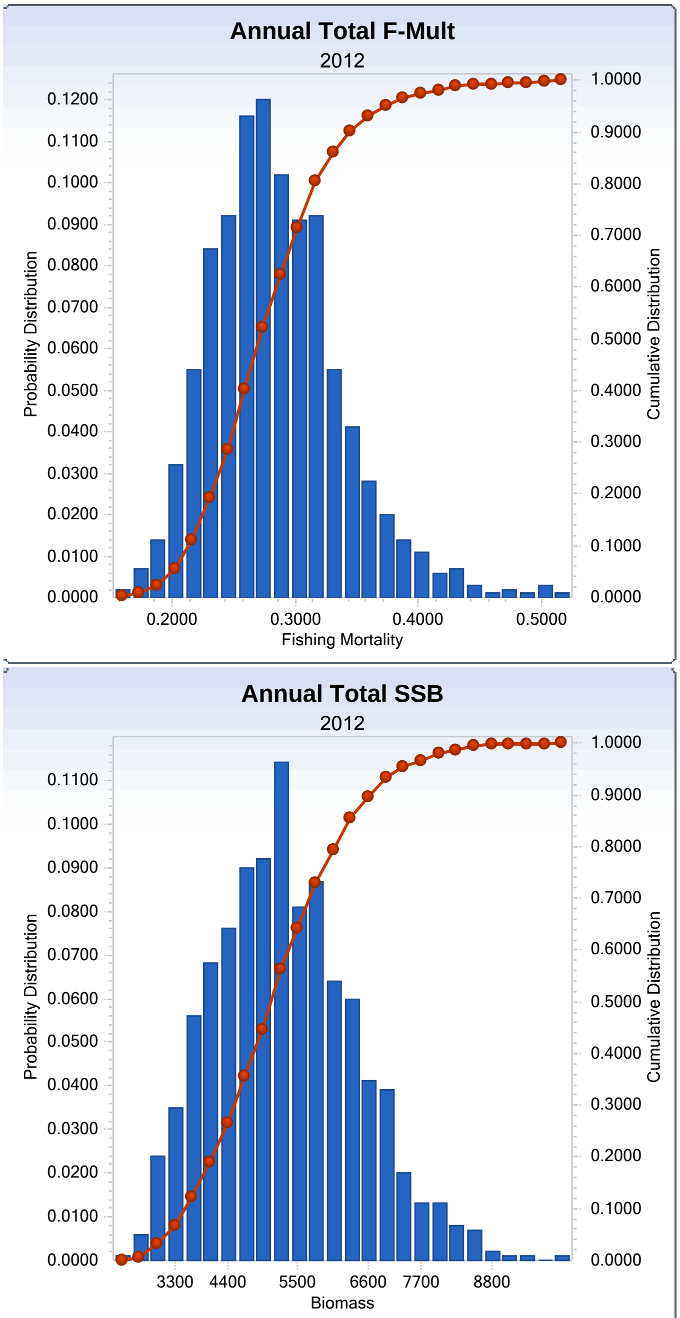


Figure B94. Working group final ASAP run 27b 2012 fishing mortality and SSB.

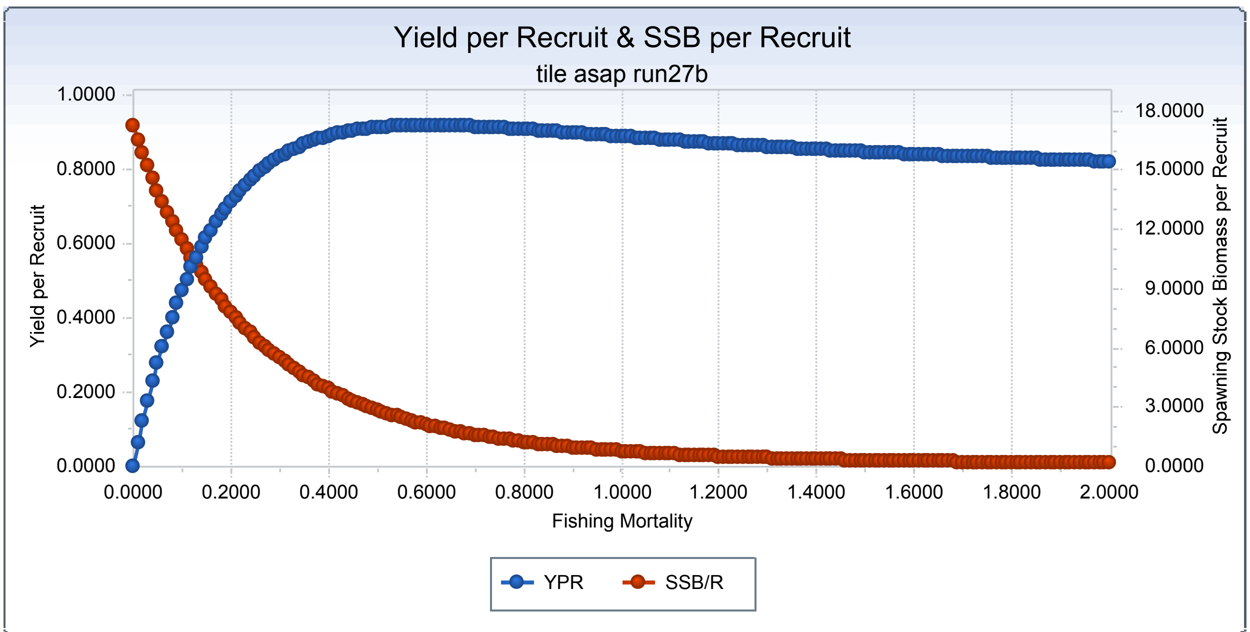


Figure B95. Yield per recruit and SPR curves for the final working group ASAP model run 27b.

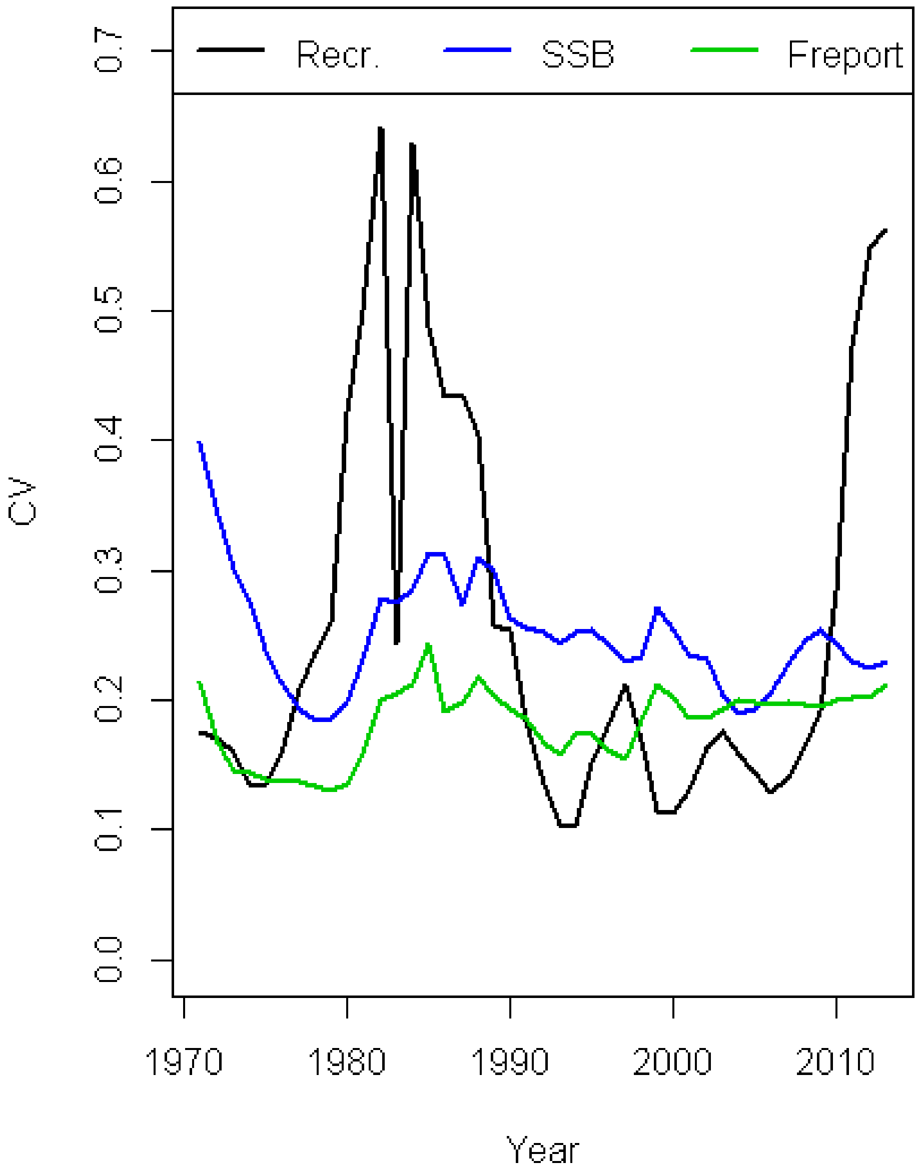


Figure B96. Estimated CVs from the final ASAP run 27b for age-1 recruitment, SSB, and fishing mortality.

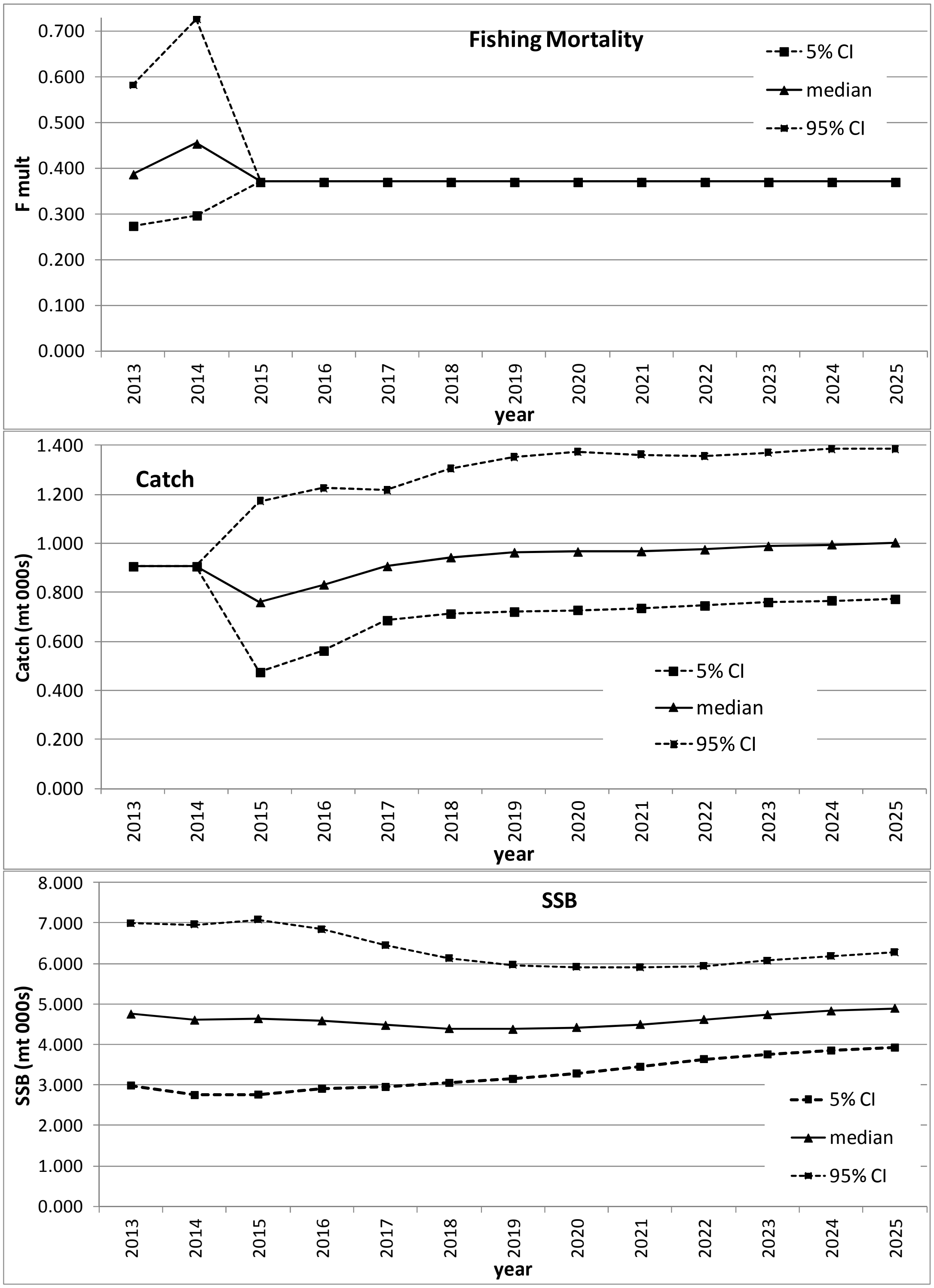


Figure B97. Final ASAP run 27b unadjusted AGEPRO $F_{MSY} = F_{25} = 0.37$ projections with 90% CIs. Removals of 905 mt was assumed in 2013 and 2014.

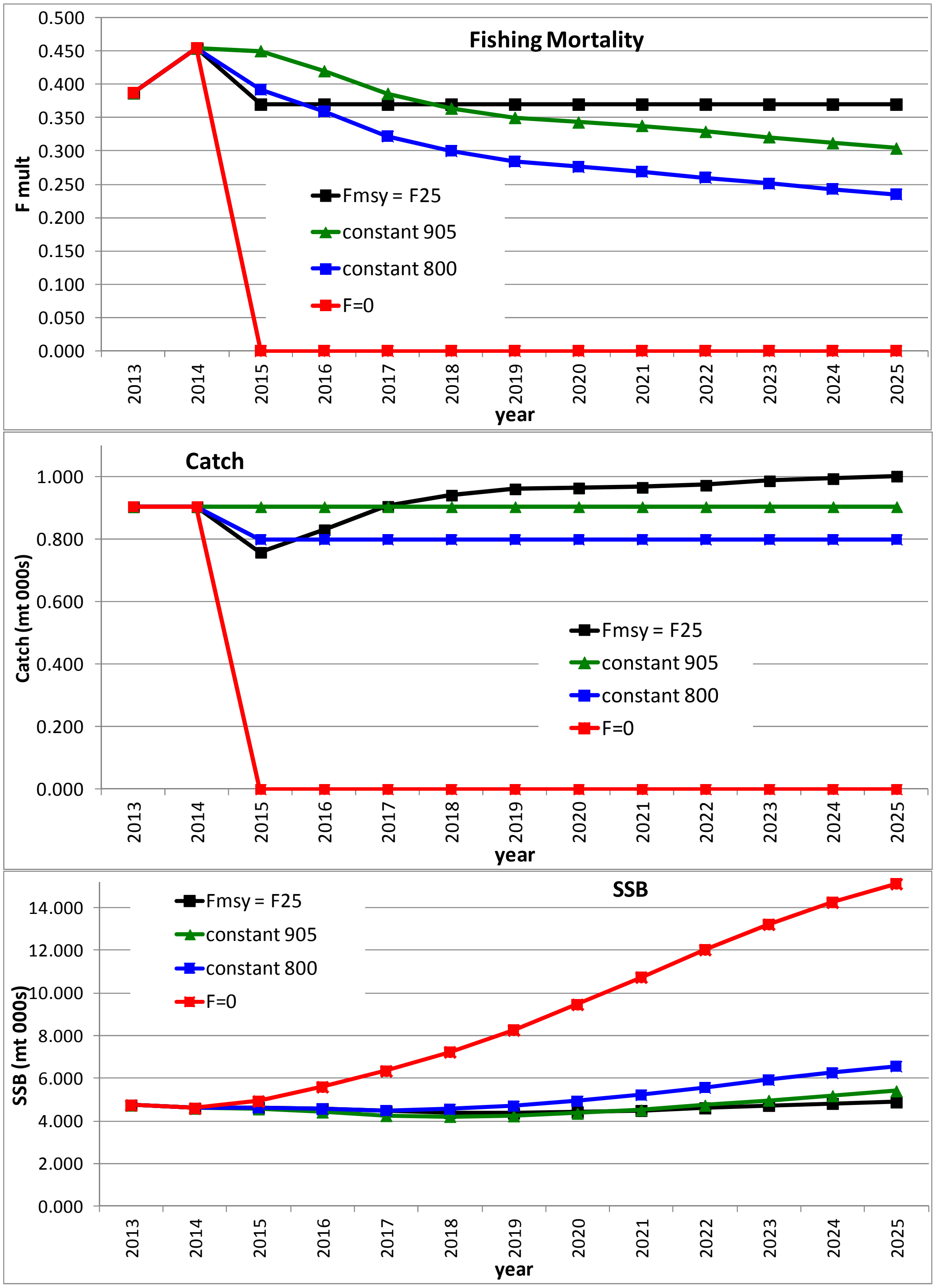


Figure B98. Final ASAP run 27b unadjusted AGEPRO projections at $F_{MSY} = F_{25} = 0.37$, constant catch of 905 mt, constant catch of 800 mt and F=0. A Catch of 905 mt was assumed in 2013 and 2014 bridge years.

NEFSC Weighout CPUE GLM model

The SAS System
14:00 Thursday, March 31, 2005 1
The GLM Procedure

Class Level Information

Class	Levels	Values
lndyear	15	1979 1980 1981 1982 1983 1985 1986 1987 1988 1989 1990 1991 1992 1993 9999
permit	92	(delete permit numbers)

Number of observations 1897

The SAS System
14:00 Thursday, March 31, 2005 2

The GLM Procedure
Dependent Variable: LNCPUE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	105	743.569869	7.081618	23.67	<.0001
Error	1791	535.787323	0.299155		
Corrected Total	1896	1279.357192			

R-Square	Coeff Var	Root MSE	LNCPUE Mean
0.581206	8.116663	0.546951	6.738619

Source	DF	Type I SS	Mean Square	F Value	Pr > F
lndyear	14	566.9637531	40.4974109	135.37	<.0001
permit	91	176.6061156	1.9407265	6.49	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
lndyear	14	281.1521083	20.0822934	67.13	<.0001
permit	91	176.6061156	1.9407265	6.49	<.0001

Parameter		Estimate		Standard Error	t Value	Pr > |t|
Intercept		6.232567267	B	0.11429828	54.53	<.0001
lndyear	1979	1.022878443	B	0.07430951	13.77	<.0001
lndyear	1980	0.991305758	B	0.07181247	13.80	<.0001
lndyear	1981	0.957632235	B	0.07168379	13.36	<.0001
lndyear	1982	0.461931590	B	0.07359297	6.28	<.0001
lndyear	1983	0.036989477	B	0.07511938	0.49	0.6225
lndyear	1985	-0.116577906	B	0.07301030	-1.60	0.1105
lndyear	1986	0.078237855	B	0.07992860	0.98	0.3278
lndyear	1987	0.235247667	B	0.07689409	3.06	0.0023
lndyear	1988	-0.290869711	B	0.08580020	-3.39	0.0007
lndyear	1989	-0.437414680	B	0.11355219	-3.85	0.0001
lndyear	1990	-0.412418009	B	0.10524248	-3.92	<.0001
lndyear	1991	-0.462210977	B	0.09637704	-4.80	<.0001
lndyear	1992	-0.213720208	B	0.09349023	-2.29	0.0224
lndyear	1993	-0.277906028	B	0.09113548	-3.05	0.0023
lndyear	9999	0.000000000	B	.	.	.
permit	-	0.053877941	B	0.39953947	0.13	0.8927
permit	-	0.290799259	B	0.40217631	0.72	0.4697
permit	-	2.200653904	B	0.55660933	3.95	<.0001
permit	-	-0.720065816	B	0.33062733	-2.18	0.0295
permit	-	1.204048080	B	0.23673422	5.09	<.0001
permit	-	-0.918838210	B	0.55660933	-1.65	0.0990
permit	-	0.884977111	B	0.55660933	1.59	0.1120
permit	-	0.089186369	B	0.13030426	0.68	0.4938
permit	-	0.351073875	B	0.55660933	0.63	0.5283

permit	-	-0.474685588	B	0.40127024	-1.18	0.2370
permit	-	-1.051239079	B	0.55796370	-1.88	0.0597
permit	-	0.883791874	B	0.55876605	1.58	0.1139
permit	-	0.042036558	B	0.15197217	0.28	0.7821
permit	-	-2.501448583	B	0.55827964	-4.48	<.0001
permit	-	0.450272193	B	0.12822212	3.51	0.0005
permit	-	0.471191134	B	0.55809344	0.84	0.3986
permit	-	-0.050060896	B	0.14723604	-0.34	0.7339
permit	-	-0.138317903	B	0.24734699	-0.56	0.5761
permit	-	0.288864363	B	0.40301160	0.72	0.4736
permit	-	-0.719753788	B	0.55856606	-1.29	0.1977
permit	-	0.539895149	B	0.20257954	2.67	0.0078
permit	-	0.200325406	B	0.14810284	1.35	0.1764
permit	-	0.166798650	B	0.13012707	1.28	0.2001
permit	-	0.171959971	B	0.11302093	1.52	0.1283
permit	-	0.231976547	B	0.12244851	1.89	0.0583
permit	-	0.024125664	B	0.13432034	0.18	0.8575
permit	-	0.094051267	B	0.16446785	0.57	0.5675
permit	-	0.371090946	B	0.17507191	2.12	0.0342
permit	-	0.068525060	B	0.15621988	0.44	0.6610
permit	-	0.291237884	B	0.55606608	0.52	0.6005
permit	-	0.250774748	B	0.19444954	1.29	0.1973
permit	-	-1.365464039	B	0.19254217	-7.09	<.0001
permit	-	0.202892095	B	0.11692497	1.74	0.0829
permit	-	-0.150565146	B	0.55660933	-0.27	0.7868
permit	-	-1.227887492	B	0.55827964	-2.20	0.0280
permit	-	-1.316984788	B	0.55796370	-2.36	0.0184
permit	-	0.055682092	B	0.55606608	0.10	0.9202
permit	-	0.476788308	B	0.56089822	0.85	0.3954
permit	-	-1.513147475	B	0.22407363	-6.75	<.0001
permit	-	0.925030445	B	0.56089822	1.65	0.0993
permit	-	-0.260880622	B	0.40623775	-0.64	0.5208
permit	-	0.277147040	B	0.11033921	2.51	0.0121
permit	-	-0.894403775	B	0.26894018	-3.33	0.0009
permit	-	-0.087797738	B	0.21953680	-0.40	0.6893
permit	-	0.002668324	B	0.19877790	0.01	0.9893
permit	-	0.496364007	B	0.10872728	4.57	<.0001
permit	-	-0.163600190	B	0.55796370	-0.29	0.7694
permit	-	0.467983305	B	0.12033347	3.89	0.0001
permit	-	0.024708856	B	0.13276574	0.19	0.8524
permit	-	-1.665756882	B	0.40275435	-4.14	<.0001
permit	-	-0.008289609	B	0.21203679	-0.04	0.9688
permit	-	0.422212817	B	0.56253472	0.75	0.4530
permit	-	-0.994541917	B	0.41068120	-2.42	0.0155
permit	-	0.640814312	B	0.17122800	3.74	0.0002
permit	-	0.289229697	B	0.11245469	2.57	0.0102
permit	-	0.232020794	B	0.11406216	2.03	0.0421
permit	-	0.435287696	B	0.23285239	1.87	0.0617
permit	-	-0.093362255	B	0.55876605	-0.17	0.8673
permit	-	0.565119319	B	0.29382393	1.92	0.0546
permit	-	0.185883996	B	0.10864670	1.71	0.0873
permit	-	0.383628924	B	0.26777330	1.43	0.1521
permit	-	-0.429338431	B	0.15476255	-2.77	0.0056
permit	-	0.941153790	B	0.26751142	3.52	0.0004
permit	-	-0.144900138	B	0.55876605	-0.26	0.7954
permit	-	-0.018365360	B	0.39831869	-0.05	0.9632
permit	-	0.233109656	B	0.24325318	0.96	0.3380
permit	-	0.579583698	B	0.55656992	1.04	0.2979
permit	-	0.280357477	B	0.14815327	1.89	0.0586
permit	-	-0.220190021	B	0.33549831	-0.66	0.5117
permit	-	0.477244382	B	0.17126647	2.79	0.0054
permit	-	0.586558492	B	0.29544304	1.99	0.0473
permit	-	1.003951166	B	0.55606608	1.81	0.0712
permit	-	0.882877530	B	0.33498687	2.64	0.0085
permit	-	0.191509700	B	0.24286878	0.79	0.4305
permit	-	0.297364159	B	0.29099874	1.02	0.3070
permit	-	0.283495433	B	0.12957609	2.19	0.0288
permit	-	1.042813481	B	0.56089822	1.86	0.0632
permit	-	-0.065468315	B	0.19188028	-0.34	0.7330
permit	-	-0.153684912	B	0.40328873	-0.38	0.7032
permit	-	0.036432483	B	0.15621610	0.23	0.8156

permit	-	0.099929826 B	0.29223882	0.34	0.7324
permit	-	0.224377910 B	0.11753056	1.91	0.0564
permit	-	0.334472400 B	0.29263852	1.14	0.2532
permit	-	0.346528767 B	0.39933585	0.87	0.3856
permit	-	0.131354900 B	0.17613902	0.75	0.4559
permit	-	0.056859718 B	0.15272950	0.37	0.7097
permit	-	-1.420176111 B	0.55660933	-2.55	0.0108
permit	-	-1.054505031 B	0.33062733	-3.19	0.0015
permit	-	1.290671749 B	0.56253472	2.29	0.0219
permit	-	-0.545675103 B	0.55660933	-0.98	0.3270
permit	-	0.722755358 B	0.12789264	5.65	<.0001
permit	-	0.000000000 B	.	.	.

NEFSC VTR CPUE GLM model

The GLM Procedure

Class Level Information

Class	Levels	Values
lndyear	19	1995 1996 1997 1998 1999 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 9999
permit	36	(delete permit numbers)

Number of Observations Read 2146
Number of Observations Used 2146

14:00 Friday, November 8, 2013 2

The GLM Procedure

Dependent Variable: LNCPUE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	53	648.075178	12.227834	58.58	<.0001
Error	2092	436.644890	0.208721		
Corrected Total	2145	1084.720068			

R-Square	Coeff Var	Root MSE	LNCPUE Mean
0.597458	6.805228	0.456860	6.713372

Source	DF	Type I SS	Mean Square	F Value	Pr > F
lndyear	18	452.2524125	25.1251340	120.38	<.0001
permit	35	195.8227654	5.5949362	26.81	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
lndyear	18	400.8695114	22.2705284	106.70	<.0001
permit	35	195.8227654	5.5949362	26.81	<.0001

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		5.073759644 B	0.27110831	18.71	<.0001
lndyear	1995	-0.010840525 B	0.06456189	-0.17	0.8667
lndyear	1996	0.325454976 B	0.06062010	5.37	<.0001
lndyear	1997	0.848643292 B	0.05958290	14.24	<.0001
lndyear	1998	0.318906222 B	0.05795507	5.50	<.0001
lndyear	1999	-0.016218797 B	0.05978930	-0.27	0.7862
lndyear	2001	0.343345263 B	0.06155312	5.58	<.0001
lndyear	2002	0.543557316 B	0.06193521	8.78	<.0001
lndyear	2003	1.026699630 B	0.06420643	15.99	<.0001
lndyear	2004	1.357155069 B	0.06265746	21.66	<.0001
lndyear	2005	1.540431534 B	0.06664663	23.11	<.0001
lndyear	2006	1.217942412 B	0.06591796	18.48	<.0001
lndyear	2007	0.789623034 B	0.06544416	12.07	<.0001

lndyear	2008	0.378445974 B	0.06286125	6.02	<.0001
lndyear	2009	0.523148894 B	0.06381061	8.20	<.0001
lndyear	2010	1.170092352 B	0.06483635	18.05	<.0001
lndyear	2011	1.386115179 B	0.06781105	20.44	<.0001
lndyear	2012	1.161758259 B	0.06787520	17.12	<.0001
lndyear	2013	1.023305566 B	0.07686102	13.31	<.0001

November 8, 2013
The GLM Procedure

Dependent Variable: LNCPUE

Parameter		Estimate	Standard Error	t Value	Pr > |t|
lndyear	9999	0.000000000 B	.	.	.
permit	-	1.000240081 B	0.53108744	1.88	0.0598
permit	-	-1.021792024 B	0.33616119	-3.04	0.0024
permit	-	-0.179783079 B	0.42173492	-0.43	0.6699
permit	-	0.518893867 B	0.28755105	1.80	0.0713
permit	-	0.648328200 B	0.28668452	2.26	0.0238
permit	-	1.078960128 B	0.53066901	2.03	0.0422
permit	-	0.004834108 B	0.29663146	0.02	0.9870
permit	-	0.207649348 B	0.29312039	0.71	0.4788
permit	-	-0.253254364 B	0.35683079	-0.71	0.4779
permit	-	0.807880459 B	0.28104760	2.87	0.0041
permit	-	0.830907462 B	0.32758196	2.54	0.0113
permit	-	0.331394774 B	0.35509381	0.93	0.3508
permit	-	0.478936831 B	0.27731798	1.73	0.0843
permit	-	0.088150844 B	0.27771544	0.32	0.7510
permit	-	0.955828220 B	0.26860601	3.56	0.0004
permit	-	-0.019828893 B	0.28588920	-0.07	0.9447
permit	-	0.722948931 B	0.27614561	2.62	0.0089
permit	-	0.530397700 B	0.31049062	1.71	0.0877
permit	-	0.305959594 B	0.32044878	0.95	0.3398
permit	-	0.363977510 B	0.31161281	1.17	0.2429
permit	-	0.758052492 B	0.27401682	2.77	0.0057
permit	-	1.960291509 B	0.53091498	3.69	0.0002
permit	-	0.948976026 B	0.26858505	3.53	0.0004
permit	-	-2.225412900 B	0.53163198	-4.19	<.0001
permit	-	-0.538962670 B	0.53096245	-1.02	0.3102
permit	-	0.386452271 B	0.29935630	1.29	0.1969
permit	-	-1.059762130 B	0.53124475	-1.99	0.0462
permit	-	0.221800322 B	0.28682561	0.77	0.4394
permit	-	0.988179949 B	0.26926685	3.67	0.0002
permit	-	0.884573839 B	0.27816892	3.18	0.0015
permit	-	1.197314834 B	0.26788469	4.47	<.0001
permit	-	0.583851859 B	0.29268642	1.99	0.0462
permit	-	-1.541423130 B	0.53145158	-2.90	0.0038
permit	-	0.843729584 B	0.27471313	3.07	0.0022
permit	-	1.108586125 B	0.26793094	4.14	<.0001
permit	-	0.000000000 B	.	.	.

SAW/SARC 58 Golden Tilefish
APPENDIX B2: Final recruitment adjusted projections

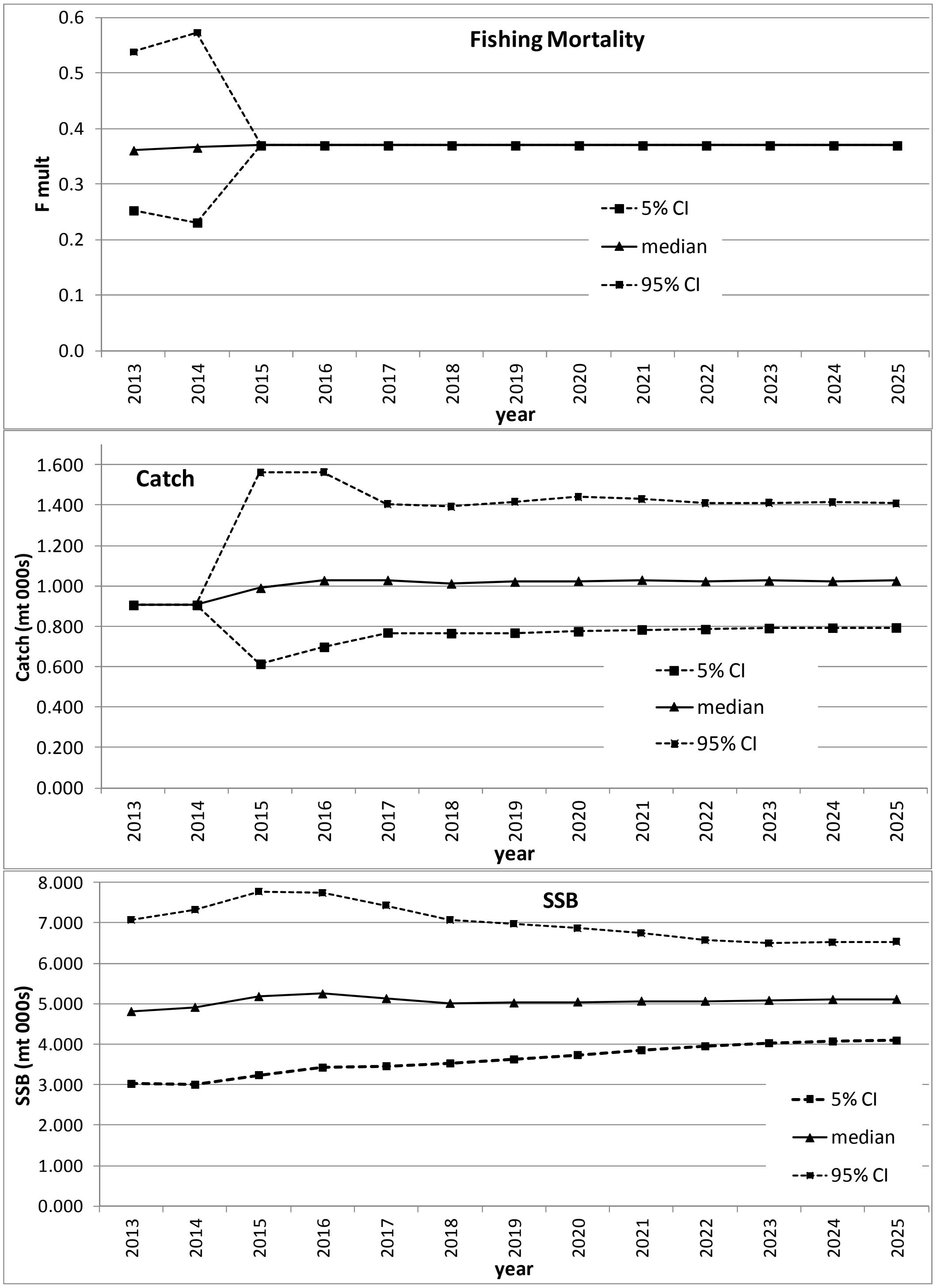
The SARC 58 review panel concluded that there was no information to inform estimates of age-1 recruitment in the last three years of the final ASAP model (2010-2012) because fishery independent measure of abundance are lacking, and bacause age-1 and 2 are not selected and selection of age-3 fish is low, 0.05, in the commercial fishery. Selection at age-4 was estimated at 0.479 which should provide some information on recruitment in 2009. Based on these considerations, recruitment estimates for the last three years of the time series, which are low, are likely underestimated. In the absence of information to inform recruitment at the end of the time series the SARC concluded that the model estimated geometric mean would be a better approximation of the recruitment from 2010 to 2012. To make this adjustment without affecting the underlying model results the SARC choose to make the adjustment in the AGRPRO projections using the Mohn's rho adjustment at age. The age-1 recruitment adjustment to the geometric mean (1.1 million fish) was calculated as 1.67 in 2010, 1.54 in 2011, and 1.47 in 2012. This corresponds to an age-4 (2010 recruitment) to an age-2 (2012 recruitment) adjustment for the t+1 numbers at age in the projections. Year t+1 age-1 recruitment was already configured to use the geometric mean from the time series of recruitment in the final ASAP model. As expected making this recruitment adjustment prevents the estimated decline in biomass at the beginning of the projection relative to unadjusted projections. Differences between the original unadjusted projections with the final adjusted projections can be seen when comparing Figures B97 and B98 to Appendix Figures B2.1 and B2.2. A similar result can be obtained within the model and projections by lowering the CVs on the recruitment deviations in the last three years of the ASAP model in which case a Mohn's rho adjustment is not needed. However this option was not used because it would result in a small change in model parameter estimates in the final model and would likely artificially lower the estimated uncertainty for age-1 at the end of the time series. All projections assume the 905 mt ACL will be taken in the 2013 and 2014 bridge years. Final ASAP run 27b adjusted AGEPRO $F_{MSY} = F_{25\%} = 0.37$ projections with 90% CIs and projections that assume a constant 905 mt catch can be seen in Appendix Tables B2.1 and B2.2 and Appendix Figures B2.1 and B2.2. The CV on the 2015 OFL was estimated as 30% in the recruitment adjusted projections.

Appendix Table B2.1. Landings (mt), fishing mortality (F) and spawning stock biomass (SSB) for the final ASAP run 27b AGEPRO $F_{MSY} = F_{25} = 0.37$ projections using an age-1 recruitment adjustment to the geometric mean for 2010-2012. Removals of 905 mt was assumed in 2013 and 2014 bridge years. Probability of overfishing or being overfished is also given.

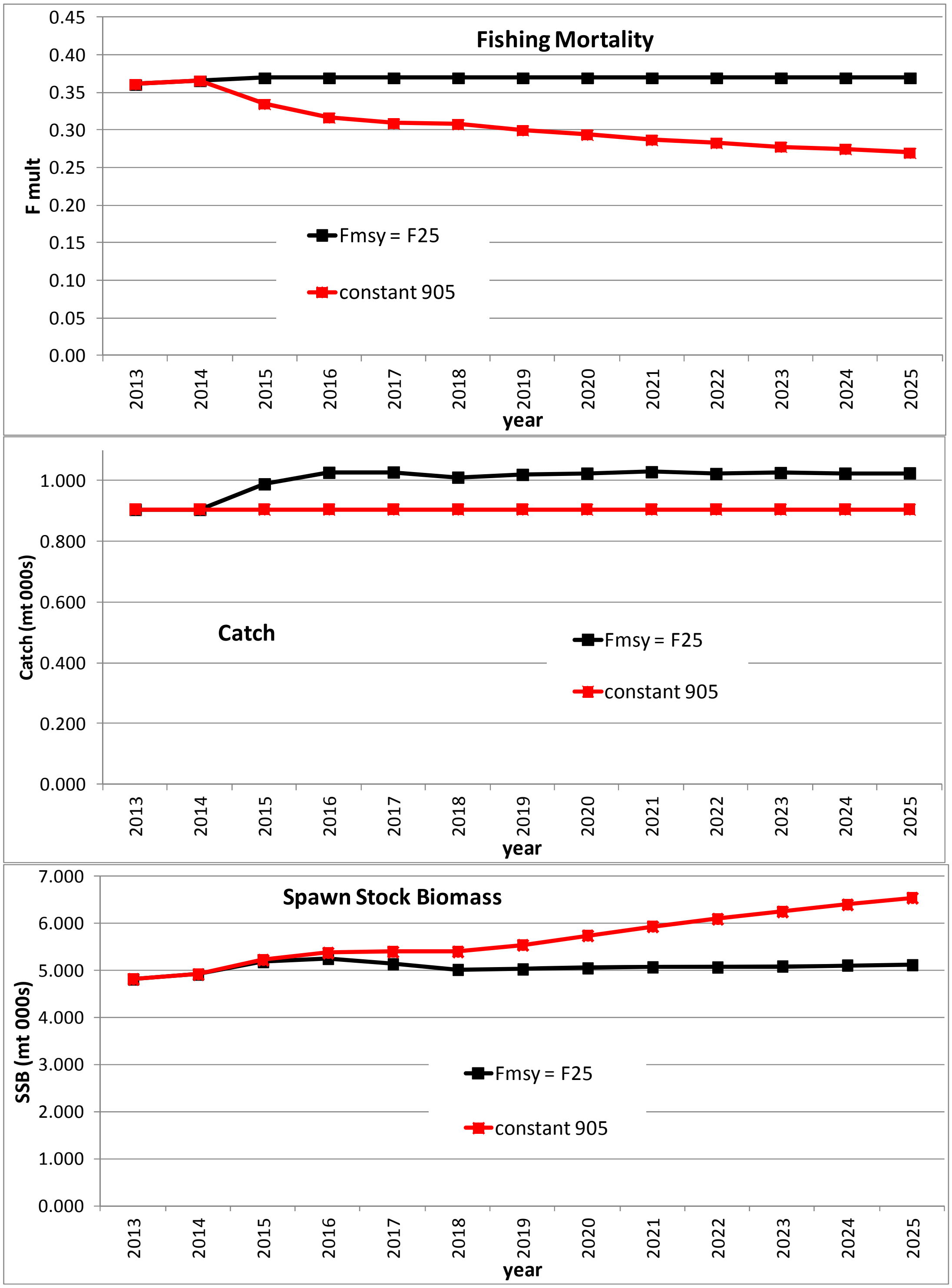
Year	Landings	F	SSB	P(F>Fmsy)	P(SSB<SSBmsy/2)
2013	905	0.361	4,811	0.463	0.010
2014	905	0.366	4,914	0.489	0.013
2015	989	0.370	5,180	-	0.012
2016	1,027	0.370	5,246	-	0.010
2017	1,028	0.370	5,132	-	0.005

Appendix Table B2.2. Landings (mt), fishing mortality (F) and spawning stock biomass (SSB) for the final ASAP run 27b AGEPRO projections assuming a constant catch of 905 mt using an age-1 recruitment adjustment to the geometric mean for 2010-2012. Removals of 905 mt was assumed in 2013 and 2014 bridge years. Probability of overfishing or being overfished is also given.

Year	Landings	F	SSB	P(F>Fmsy)	P(SSB<SSBmsy/2)
2013	905	0.361	4,811	0.463	0.010
2014	905	0.366	4,914	0.489	0.013
2015	905	0.335	5,219	0.371	0.017
2016	905	0.317	5,370	0.323	0.020
2017	905	0.309	5,392	0.273	0.025



Appendix Figure B2.1. Final ASAP run 27b AGEPRO $F_{MSY} = F_{25} = 0.37$ projections with 90% CIs using an age-1 recruitment adjustment to the geometric mean for 2010-2012. Removals of 905 mt was assumed in 2013 and 2014 bridge years.



Appendix Figure B2.2. Comparison of final ASAP run 27b AGEPRO projections using an age-1 recruitment adjustment to the geometric mean for 2010-2012 at $F_{MSY} = F_{25\%} = 0.37$ and a constant catch of 905 mt. A Catch of 905 mt was assumed in 2013 and 2014 bridge years.

C. NORTHERN SHRIMP STOCK ASSESSMENT FOR 2014

[SAW58 Editor's Note: The SARC58 peer review panel concluded that the northern shrimp stock assessment models presented to them were not acceptable to serve as a basis for fishery management advice. Specifically, the SARC58 concluded that shrimp assessment Terms of Reference #2, #3, #4, and #5 were not met. These particular sections are included in this report to document the analyses that were done for the peer review, but they are not recommended by SARC58 as a basis for management.]

C1.0 CONTRIBUTORS

ASMFC Northern Shrimp Technical Committee
Kelly Whitmore, Technical Committee Chair (Massachusetts Division of Marine Fisheries)
Dr. Anne Richards, Stock Assessment Subcommittee Chair (National Marine Fisheries Service)
Jessica Carloni, (New Hampshire Fish and Game Department)
Margaret Hunter (Maine Department of Marine Resources)
Marin Hawk and Dr. Katie Drew (ASMFC)

With
Dr. Larry Jacobson (NMFS)
Dr. Yong Chen and Jie Cao (University of Maine)

C2.0 TERMS OF REFERENCE (TOR) FOR NORTHERN SHRIMP

1. Present the Gulf of Maine northern shrimp landings, discards, effort, and fishery-independent data used in the assessment. Characterize the precision and accuracy of the data and justify inclusion or elimination of data sources.

2. Estimate population parameters (fishing mortality, biomass, and abundance) using assessment models. Evaluate model performance and stability through sensitivity analyses and retrospective analysis, including alternative natural mortality (M) scenarios. Include consideration of environmental effects where possible. Discuss the effects of data strengths and weaknesses on model results and performance.

3. Update or redefine biological reference points (BRPs; point estimates or proxies for BMSY, SSBMSY, FMSY, MSY). Evaluate stock status based on BRPs.

4. Characterize uncertainty of model estimates of fishing mortality, biomass and recruitment, and biological reference points.

5. Review the methods used to calculate the annual target catch and characterize uncertainty of target catch estimates.

6. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made before the next benchmark assessment.

7. Based on the biology of species, and potential scientific advances, comment on the appropriate timing of the next benchmark assessment and intermediate updates.

C3.0 EXECUTIVE SUMMARY

C3.1 Major findings for TOR #1 - Gulf of Maine Northern shrimp landings, discards, effort, and fishery independent surveys.

Landings in the Gulf of Maine northern shrimp fishery since the mid-1980s have fluctuated between 306-9,500 mt, reflecting variations in year class strength as well as regulatory measures, participation, and market conditions in the fishery. A peak of 9,500 mt was reached in 1996, after which landings declined steadily to a low in 2002 (450 mt). After 2002, landings generally increased, reaching another peak of around 6,000 mt in 2010 and 2011. Preliminary landings (not accounting for late reporting) in 2013 declined to 306 mt, which was 48% of the TAC set by ASMFC for 2013 (625 mt) despite the 2013 TAC being the lowest set since 1984. Observer sampling indicates discards in the shrimp fishery and in other Gulf of Maine fisheries is negligible. There is no recreational fishery for northern shrimp.

The number of fishing vessels participating in the northern shrimp fishery dropped from a high in 1996 (347 vessels) to an average below 200 vessels during 2002-2007. In 2013, an estimated 198 vessels participated (152 trawl, 46 trap). Trap catches accounted for about 12% of Maine's landings during 2001 to 2007, 18% during 2008 to 2011, and 8% since then. Catch-per-unit-effort (pounds per trap and trawl pounds per trip) was the lowest on record since 1991.

Trends in biomass of Gulf of Maine northern shrimp were monitored during 1968-1983 using data collected in Northeast Fisheries Science Center (NEFSC) autumn bottom trawl surveys and in summer surveys by the State of Maine. Since 1984, two surveys have been used to monitor population trends: the NEFSC fall survey and a summer shrimp survey conducted by the Atlantic States Marine Fisheries Commission (ASMFC). The summer survey was designed specifically for monitoring northern shrimp in the western Gulf of Maine and is considered to provide the highest quality data for this population. The NEFSC fall survey is split into two time periods due to a change in survey protocol in 2009. A Maine-New Hampshire inshore trawl survey conducted each spring since 2001 catches northern shrimp (Sherman et al. 2005), but is not used in the assessment because its results may be influenced by inter-annual variation in the timing of the offshore migration of post-hatch females. The average coefficients of variation for abundance (biomass) for the surveys were: fall survey before 2009 27% (25%), fall survey 2009-2013 36% (36%). summer shrimp survey 21% (14%), Abundance and biomass indices from the ASMFC summer shrimp survey fluctuate widely, reflecting the highly variable recruitment of northern shrimp. The 2013 indices were the lowest on record at 27 shrimp/tow and 1.0 kg/tow. The stratified mean catch per tow in numbers of 1.5-year old shrimp represents a recruitment index. The 2012 index for age 1.5 was the lowest in the time series (until 2013), with only 7 individuals per tow, signifying a very weak 2011 year class. The 2013 age 1.5 index dropped even further to 1 individual per tow, signifying a very weak 2012 year class and an unprecedented three consecutive years of poor recruitment. The indices from the new NEFSC fall survey (2009-2012, 2013 not yet available) have declined since 2009, parallel to recent trends in the summer shrimp survey and the ME-NH survey.

C3.2 Major findings for TOR #2 - Estimate population parameters using assessment models.

The proposed model for Northern shrimp was a forward-projecting size-structured model (UME model) developed by the University of Maine in conjunction with the Northern Shrimp Technical Committee. As complements, a Collie-Sissenwine Analysis (CSA) and a surplus production model (ASPIC) were also developed to estimate biomass and fishing mortality.

None of the proposed models were accepted for management use. The UME size structured model did not fit catch and survey length composition and survey indices sufficiently well. The CSA was sensitive to the data weighting schemes, but the model diagnostics did not clearly indicate the optimal weightings. This resulted in inconsistent determination of overfishing status depending on the weighting scheme. The ASPIC model was unable to respond to the highly variable recruitment of northern shrimp, resulting in an extreme retrospective pattern and making estimates of F and B in the terminal year unreliable.

C3.3 Major findings for TOR #3 - Update or redefine biological reference points and evaluate stock status.

Biological reference points for northern shrimp have been defined using historical proxies of average model-estimated F and exploitable biomass during a stable period in the fishery (1985-1994).

Because none of the models used to estimate F and B during the stable period were accepted, the updated estimates of the reference points were not approved for management use, and stock status could not be determined according to these definitions. However, all fishery-independent and fishery-dependent indices were at or near time-series lows in 2013, suggesting that the Northern shrimp stock is currently at a very low level of abundance.

C3.4 Major findings for TOR #4 - Characterize the uncertainty of model estimates.

Uncertainty in model parameters was estimated through several different methods. For the UME model, asymptotic standard errors were estimated internally by the model. For the CSA model, an MCMC approach was used to estimate error (see Appendix C3 for more details). For the ASPIC model, residuals were bootstrapped to estimate error around the estimated and calculated parameters. In addition, uncertainty was assessed qualitatively through retrospective and sensitivity analyses.

Sensitivity analyses showed that the UME model is most sensitive to assumptions about the growth model used to develop the growth transition matrix. Choice of M scaled the population and fishing mortality estimates as expected for both the UME and the CSA model. Including a time-varying M, scaled to predation, improved the retrospective pattern for the CSA but not the UME. The ASPIC model was not very sensitive to the surveys included, but had a strong retrospective pattern of underestimating F and overestimating biomass, indicating that the terminal year estimates are highly uncertain.

In addition, both the UME and the CSA model were sensitive to the weighting of data input sources. When the catch data were weighted more heavily than the survey data, the CSA model estimated that F was low in 2013 and overfishing was not occurring. When the survey data were weighted more heavily than the catch data, the model estimated a high terminal F and indicated overfishing was occurring in 2013. See Appendix C6 for the details of additional sensitivity runs that were conducted at the review workshop.

C3.5 Major findings for TOR #5 - Review methods to calculate the annual target catch.

To determine the TAC options for each fishing season, the NSTC uses Pope's approximation (Pope 1972) to the Baranov catch equation (Baranov 1918) to estimate the yield in numbers of shrimp for a given value of F (F_{target} or a proportion of it). The number of shrimp is then converted to weight using the predicted mean weight of an individual northern shrimp based on survey size composition.
Sources of uncertainty of the target catch estimates include uncertainty around (1) model estimates of the numbers of exploitable shrimp, (2) the selected value of M, (3) timing of the upcoming fishing season, and (4) the estimate of mean weight of shrimp in the upcoming season's landings.

Because the model estimates of abundance required for the quota calculations were not accepted, the estimates of total allowable catch were not approved for management use.

C3.6 Major findings for TOR #6 - Research recommendations.

The NSTC identified a number of high priority research needs: (1) improve monitoring and estimates of discards, (2) evaluate the effectiveness of the summer shrimp survey statistical design and its geographic coverage, (3) explore direct ageing methods to evaluate assumptions about the timing of growth and transition, (4) incorporate predation and temperature effects in the size-structured model, (5) develop BRPs appropriate to changing environmental and ecological conditions.

In addition, the NSTC emphasized the primary importance of continuing the summer shrimp survey despite the current low abundance of northern shrimp.

C3.7 Major findings for TOR #7 - Timing of next benchmark assessment and assessment updates.

The NSTC recommended that the Northern shrimp stock assessment be updated annually to incorporate the most recent information on recruitment, size composition, and landings into the quota/specification setting process. Annual specifications are important for a short-lived species with environmentally-driven recruitment like Northern shrimp.

In addition, the NSTC recommends that a full benchmark assessment be conducted sooner than the standard five year interval, ideally in the next two to three years. This will give the NSTC time to evaluate the performance of the new size-structured model through simulation work and resolve the data-weighting and fit issues identified by the Panel. This will also give the NSTC time to incorporate additional information on the Gulf of Maine's changing environmental conditions.

C4.0 INTRODUCTION

C4.1 Management History

The Gulf of Maine fishery for northern shrimp (Pandalus borealis Krøyer) is managed through interstate agreement between the states of Maine, New Hampshire and Massachusetts. The management framework evolved during 1972-1979 under the auspices of the State/Federal Fisheries Management Program. In 1980, this program was restructured as the Interstate Fisheries Management Program (ISFMP) of the Atlantic States Marine Fisheries Commission (ASMFC). The Fishery Management Plan (FMP) for Northern Shrimp was approved under the ISFMP in October 1986 (McInnes 1986). Amendment 2, which entirely replaced the original FMP and Amendment 1 in 2011, provides flexible management options including a clarification of fishing mortality reference points, a timely and comprehensive reporting system, trip limits, trap limits, and days out of the fishery.

Addendum I to Amendment 2 (2012) includes provisions to set an annual TAC that may range between the fishing mortality target and threshold values, inclusive; allocate 87% of the TAC to the trawl fishery and 13% to the trap fishery; and close each fishery when a certain percentage of the TAC is projected to be reached. The percentage, ranging between 80 and 95%, will be established by the Section during the annual specification process. The Addendum also provides flexibility to transfer unused TAC between gear types; set aside a portion of the TAC for research purposes; and allow for the optional use of a size sorting grate system (compound grate or double Nordmore) to minimize the retention of small shrimp.

Within the ISFMP structure, the Northern Shrimp Technical Committee (NSTC) provides annual stock assessments and related information to the ASMFC Northern Shrimp Section. Annually, the Section decides on management regimes after thorough consideration of the NSTC stock assessment, input from the Northern Shrimp Advisory Panel, and comment from others knowledgeable about the shrimp fishing industry. In the first five years (1987 – 1991) after the passage of the 1986 FMP, the NSTC generally recommended full fishing seasons (182 days) and the Section followed the committee's recommendations (Table A.4.1). Nearly every year from 1992 to 1999, the NSTC recommended restricted seasons. The managers set seasons that were less than the full 182 days but more than the seasons recommended by its scientific advisors. With the exception of 2001, the NSTC recommended no fishery from 2000 to 2004. The managers set limited fishing seasons during that time, with the shortest (25 days) in 2002. The NSTC has taken a new approach to its recommendation to the Section since 2005. It recommends a maximum landings amount for the fishing season. The Section used that number and recommendations from the Advisory Panel to establish seasons. In the past two years, the NSTC has recommended a moratorium on northern shrimp. For the 2014 fishing season, a moratorium was implemented by the Section.

C4.2 Assessment History

C4.2.1 Past Assessments

Stock assessments initially consisted of total landings estimates, indices of abundance from Northeast Fisheries Science Center (NEFSC) groundfish surveys, fishing mortality estimates from the application of cohort slicing of length frequencies from the State of Maine survey, and yield per recruit modeling (Clark and Anthony 1980; Clark 1981, 1982).

The NSTC unified individual state port sampling programs in the early 1980s to better characterize catch at length and developmental stage (sex and maturity), and established a dedicated research trawl survey for the species in the summer of 1983 to monitor relative abundance, biomass, size structure and demographics of the stock annually. Subsequent stock assessments provided more detailed description of landings, size composition of catch, patterns in fishing effort, catch per unit effort, relative year class strength and survey indices of total abundance and biomass. Length distributions from the summer shrimp survey have been used for size composition analysis to estimate mortality rates, but the early length-based models did not fit well because of variable recruitment and growth (Terceiro and Idoine 1990, Fournier et al. 1991).

Beginning in 1997, the northern shrimp stock in the Gulf of Maine has been evaluated more quantitatively using three analytical models that incorporate much of the available data (Cadrin et al. 1999):

- Preferred: Collie-Sissenwine analysis (CSA) that tracks removals of shrimp using summer survey indices of recruits and fully-recruited shrimp scaled to total catch in numbers, and provides estimates of F (instantaneous fishing mortality rate) and B (exploitable biomass);

- Supportive: A surplus production analysis (ASPIC) that models the biomass dynamics of the stock with a longer times series of total landings and three survey indices of stock abundance;

- A yield-per-recruit (YPR) model and an eggs-per-recruit (EPR) model that simulate the life history of northern shrimp (including growth rates, transition rates, natural mortality, and fecundity) and fishing mortality on recruited shrimp. It uses estimates of trawl selectivity to estimate yield and egg production at various levels of fishing mortality, providing guidance on the selection of biological reference points (Cadrin et al. 1999).

In 2004, Amendment 1 to the ASMFC Interstate Fishery Management Plan for Northern Shrimp was adopted. This was the first time formal biological reference points were defined for this fishery. The assessment model configuration reviewed by SARC 45 (2007) is updated annually in October to provide a recommended quota for the winter season.

C4.2.2 Current Assessment and Changes from Past Assessments

For this assessment, a statistical catch-at-length model was developed by Yong Chen and Jie Cao of the University of Maine in conjunction with the NSTC. This model uses catch-at-length data, total catch, and fishery independent indices of abundance to estimate fishing mortality, total abundance, spawning female abundance and biomass, and recruitment. It also provides biological reference points in the form of yield-per-recruit and spawning stock biomass-per-recruit reference points.

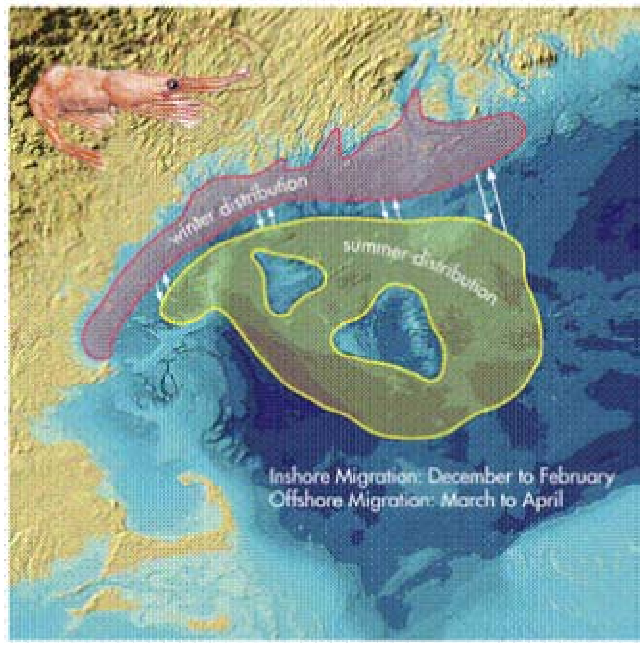
As complements to the length-structured model, the CSA model and the ASPIC model were also used. The CSA model (NMFS Toolbox v. 4.2.2) was updated to use a formal likelihood framework and to allow the use of multiple indices of abundance.

The new length-structured model and the changes to the CSA allow us to make better use of the available data and improve our understanding of stock dynamics.

C4.3 BIOLOGY

C4.3.1 Life History

Northern shrimp (*Pandalus borealis*) inhabit boreal waters of the North Atlantic, North Pacific and Arctic Oceans (Figure C4.1). In the Gulf of Maine, they are at the southern extent of their range. Northern shrimp are protandric hermaphrodites, usually maturing first as males at approximately 2.5 years of age and then transforming to females at approximately 3.5 years of age in the Gulf of Maine (Figure C4.2). Spawning takes place in offshore waters beginning in late July. By early fall, most adult females extrude their eggs onto the abdomen. Egg-bearing females move inshore in late autumn and winter, where the eggs hatch. The planktonic larvae pass through six larval stages and settle to the bottom in inshore waters after metamorphosing to a juvenile state (Berkeley 1930; Haynes and Wigley, 1969; Apollonio and Dunton 1969; Stickney and Perkins 1977; Stickney 1980). Juveniles remain in coastal waters for a year or more before migrating to deeper offshore waters, where they mature as males. The males pass through a series of transitional stages before maturing as females. Some females may survive their first egg hatch to repeat the spawning process. Females that have never extruded eggs are referred to here as "female I". Non-ovigerous females that have carried eggs in the past are "female II". Female I's and II's can be distinguished by the presence or absence of sternal spines (McCrary 1971). The females are the individuals targeted in the Gulf of Maine fishery. It is believed that most *P. borealis* in the Gulf of Maine do not live past age 5 (Haynes and Wigley 1969; Apollonio and Dunton 1969).



Distribution of adult female northern shrimp, from *Ecosystem Relationships in the Gulf of Maine-Combined Expert Knowledge of Fishermen and Scientists.* **NAMA collaborative report 1:1-16, 2006.**

The extent, location, and timing of the transitions and migrations are variable. Several factors may influence the size and age at sex transition (Bergström 2000). Several year classes in recent decades show some percentage of 2.5-year old shrimp maturing first as females instead of males (early-maturing females) (Figure C4.3). This presents both sexes in the same year class and may be a reaction to stress in the population as predicted by sex allocation theory (Charnov et al. 1978), or temperature (Apollonio et al. 1986; Hansen and Aschan 2000) or density dependent growth (Koeller et al. 2000), or could be the result of fishery removals of larger females selecting for smaller females (Marliave et al. 1993; Bergström 2000). Other year classes have exhibited some late sex transition. In the 2001 year class, there was evidence of both very early- and late-maturing females, with early-maturing females appearing at assumed age 1.5, but also males remaining as males at assumed age 3.5 (Figure C4.3).

Growth, as in other crustaceans, is a discontinuous process associated with molting of the exoskeleton (Hartnoll 1982). Information on growth of Gulf of Maine northern shrimp has been reported by Haynes and Wigley 1969; Apollonio et al. 1986; Terceiro and Idoine 1990; and

Fournier at al. 1991. Differences in size at age by area and season can be ascribed in part to temperature effects, with more rapid growth rates at higher temperatures (Apollonio et al. 1986).

C4.3.2 Habitat

In the Gulf of Maine, northern shrimp populations comprise a single stock (Clark and Anthony 1981), which is concentrated in the southwestern region of the Gulf (Haynes and Wigley 1969; Clark et al. 1999). Water temperature, salinity, depth, and substrate type have all been cited as important factors governing shrimp distribution in the Gulf of Maine (Haynes and Wigley 1969; Apollonio et al. 1986; Shumway et al. 1985). In the Gulf of Maine, northern shrimp are most frequently found in depths ranging from 10 m to over 300 m (30-1000 ft) (Haynes and Wigley 1969), with juveniles and immature males occupying shallower, inshore waters and mature males and females occupying cooler, deeper offshore waters for most of the year (Apollonio and Dunton 1969, Haynes and Wigley 1969, Apollonio et al. 1986). During the summer months, adult shrimp inhabit water from 93-183 m (300-600 ft) (Clark et al. 1999); ovigerous female shrimp are found in shallower near-shore waters during the late winter and spring (Apollonio and Dunton 1969, Clark et al. 1999) when their eggs are hatching.

Northern shrimp most commonly inhabit organic-rich, mud bottoms or near-bottom waters (Hjort and Ruud 1938; Bigelow and Schroeder 1939; Wigley 1960; Haynes and Wigley 1969), where they prey on benthic invertebrates; however, shrimp are not limited to this habitat and have been observed on rocky substrates (Schick 1991). Shrimp distribution in relation to substrate type determined by trawl surveys clearly show northern shrimp primarily occupy areas with fine sediments (sand, silt, and clay) (ASMFC 2004). Shrimp are often associated with biotic or abiotic structures such as cerianthid anemone (Langton and Uzmann 1989) and occasional boulders in these fine sediment habitats (Daniel Schick, Maine Department of Marine Resources, pers. comm.).

Male and non-ovigerous female shrimp exhibit diurnal vertical migration, from bottom and near-bottom during the day, up into the water column to feed at night. Egg-bearing females are less likely to exhibit vertical diurnal migration, and are more likely to stay on the bottom (Apollonio and Dunton 1969; Apollonio et al. 1986).

C4.3.3 Temperature

The most common temperature range for this species is 0-5 °C (Shumway et al. 1985). The Gulf of Maine marks the southern-most extent of this species' range in the Atlantic Ocean, and it is thought that seasonal water temperatures in many areas regularly exceed the upper physiological limit for northern shrimp. This environmental limitation restricts the amount of available habitat occupied by this species to the western region of the Gulf (west of 680 W) where bottom topography and oceanographic conditions create submarine basins protected from seasonal warming by thermal stratification. The deep basins act as cold water refuges for adult shrimp populations

(Apollonio et al. 1986). In the northeastern region of the Gulf, it is hypothesized that large shrimp populations do not persist because bottom waters are not protected from seasonal warming, due to continual mixing from intense tidal currents nearer to the Bay of Fundy (Apollonio et al. 1986).

Ocean temperature has an important influence on northern shrimp in the Gulf of Maine (Apollonio et al. 1986; Richards et al. 1996; Richards et al. 2012). During the warm period of the 1950s, northern shrimp catches declined to zero despite continued fishing effort (Dow 1964), suggesting a population collapse. Several studies have found a significant negative correlation between annual mean temperatures and recruitment of northern shrimp (Dow, 1977; Richards et al. 1996). Spring ocean temperatures during the larval period are particularly important for recruitment, with cooler temperatures favoring higher recruitment (Richards et al. 2012). Spawner abundance also influences recruitment strength, with more recruits resulting from higher spawner abundance (Richards et al. 2012 and Figure C4.3). Timing of the larval hatch is influenced by temperature during late spring through early winter (Richards 2012).

Sea surface temperature (SST) has been measured since 1905 at Boothbay Harbor, Maine, near the center of the inshore nursery areas for northern shrimp. Annual average SST at Boothbay has increased (Figure C5.9) from an average of 7.9º C during 1906-1948 to an average of 10.4º C during 2000-2012. SST has exceeded the 1953 high point three times in the past decade, and 2012 was the warmest year in the 108 years of record. Similar trends have been seen during March-April, a critical time for determining recruitment strength (Figure C5.9). During 2013, the March-April average SST (5.0º C) was cooler than in 2012 (6.9º C), but still well above the 20th century average (3.4º C) (Figure C5.9).

Spring temperature anomalies (deviations measured relative to a standard time period) in offshore shrimp habitat areas were the highest on record during 2012 (surface temperature) and 2011-2012 (bottom temperature) (NEFSC trawl survey data, 1968-2012; Figure C5.9). Spring surface temperature in 2013 was only slightly below the record high 2012 anomaly, while bottom temperatures declined but were still relatively high. The start of the hatch period has become earlier as temperatures have increased, with the hatch now beginning more than a month earlier than before 2000 (10% line in Figure C5.9). The midpoint of the hatch period has changed less than the hatch start, but has trended earlier since 2008 (50% line in Figure C5.9).

C4.3.4 Predators and Prey

Northern shrimp are an important component of marine food chains, preying on both plankton and benthic invertebrates, and being consumed by many commercially important fish species, such as cod, redfish, silver and white hake, and pollock (Shumway et al. 1985, ASMFC 2004, Link and Iodoine 2009; Appendix C2, this document). *P. borealis* diet was documented by Wienberg (1981) and Apollonio and Dunton (1969).

C4.3.5 Natural Mortality

The natural mortality rate (M) used in US Gulf of Maine northern shrimp assessments (M=0.25) is one of the lowest assumed for northern shrimp in the North Atlantic (NEFSC 2007). The assumption of M=0.25 is based on direct estimates from the Gulf of Maine northern shrimp population and fishery data, as approximated from the intercept of a regression of total mortality by year class in 1968-1972 on effort (Rinaldo 1973, Rinaldo 1976, Shumway et al. 1985) and from catch curve analysis of survey data for age 2+ shrimp during a fishery closure in 1978 (Clark 1981, 1982). In other *Pandalus* stocks, the assumed M ranges from 0.2 to 1.0 (ICES 1977, Abramson 1980, Frechette and Labonte 1980, Shumway et al. 1985). During SAW 45, estimated consumption of *P. borealis* in the Gulf of Maine was compared to model estimates of population size (NEFSC 2007, Link and Idoine 2009). The review panel concluded that M must be higher than 0.25 because the model estimates of abundance were lower than estimated consumption. The panel suggested that a higher M, around M=0.6, was likely more realistic for this population.

The NSTC examined alternative M values to better integrate life history knowledge, survey data, and predation information. Several approaches underlying natural mortality assumptions were explored including ratios of assumed age class abundance, age-constant (Table C4.2), age-varying using Lorenzen's (1996) mortality-weight model (Table C4.3), and age-varying using Gislason et al.'s (2010) mortality-growth model (Table C4.4). Ratios from assumed age-class abundance from survey data suggest an average annual total mortality (Z) of 0.43 for assumed ages 2.5 to 3.5, and Z of 0.53 for assumed ages 3.5 to 4.5 (1984-2011 summer survey data). The age-constant and age-varying methods produced a range of instantaneous M values from 0.38 to 5.36. The Lorenzen calculation results in an exponentially declining M-at-age, where M = 0.71 in the first year, 0.34 in middle years, and 0.30 for later ages, when scaled so that 1.5% of the population remains at the oldest age class.

These explorations provide support for an assumed M higher than 0.25 for this stock. Several alternative values for natural mortality were considered for the CSA and UME assessment models. Constant values of M included 0.25, 0.5 based on the 3/M rule (where M is equal to 3/max age of the species (6) =0.5), and 0.6 as suggested by SARC 45. Length- and time-varying estimates of M were also considered, where M is U-shaped M over the life span of the shrimp (UME model) or where M changes annually. To determine values for the U-shape over the life span of the shrimp, M was calculated by weight for the smallest size/weight bins (Lorenzen 1996), then reduced to 0.25 for the mid-weight classes as measured for age 2+ shrimp (Rinaldo 1973), and for the largest size classes, M was increased so that only 1.5% of the population would remain at age six (Hoenig 1983) (Table C4.5). Time-varying (but not length-varying)M was also tested in the UME and CSA models. A baseline M=0.5 was scaled by an annual predation pressure index (PPI, Appendix C2), which incorporated the occurrence of Pandalids in fish stomachs and predator biomass to derive an annual estimate of M.

C4.3.6 Other Pandalid Species

The striped shrimp, *Pandalus montagui,* and the bristled long-beak shrimp, *Dichelopandalus leptocerus,* both smaller and less frequently-caught than *Pandalus borealis,* are also common in Gulf of Maine commercial and survey catches, but are not targeted by the fishery.

C4.4 Fishery Description

Northern shrimp support important commercial fisheries in boreal and sub-arctic waters throughout the North Atlantic and North Pacific. In the western North Atlantic, commercial concentrations occur off Greenland, Labrador, and Newfoundland, in the Gulf of St. Lawrence, and on the Scotian Shelf. The Gulf of Maine marks the southernmost extent of its Atlantic range (Parsons and Fréchette, 1989). In the Gulf of Maine, primary concentrations occur in the western Gulf where bottom temperatures are coldest. In summer, adults are most common at depths of 90-180 meters (Clark *et al*. 2000).

The fishery formally began as a large-scale fishery in 1938; during the 1940s there were a few landings in Massachusetts, but most of the landings were by Maine vessels from Portland and smaller Maine ports further east. This was an inshore winter trawl fishery, directed towards egg-bearing females in inshore waters (Scattergood 1952). Landings declined from the late 1940's until the fishery stopped altogether from 1954 through 1957. Reports from fishers at the time indicate that this decline was associated with low shrimp abundance. The fishery resumed in 1958 (McInnes 1986).

New Hampshire vessels entered the fishery in 1966, but throughout the 1960s and 1970s New Hampshire landings were minor. New Hampshire currently accounts for about 8% of the total catch for the Gulf of Maine (Table C5.1).

Landings by Massachusetts vessels were insignificant until 1969, but in the early 1970s the fishery developed rapidly, with Massachusetts landings increasing from 14% of the Gulf of Maine total in 1969 to over 40% in 1974-1975. Massachusetts landings have declined to about 2% of total during the past 10 years, while Maine vessels have accounted for about 90% (Table C5.1)

The Gulf of Maine fishery has been seasonal in nature, peaking in late winter when egg-bearing females move into inshore waters and terminating in spring under regulatory closure (ASMFC 2011 and Table C4.1). Northern shrimp have been an accessible and important resource to fishermen working inshore areas in smaller vessels who otherwise have few winter options due to seasonal changes in availability of groundfish, lobsters and other species (Clark *et al*. 2000).

A summer fishery, which existed in the 1970s, caught shrimp of all ages, including age 1 and 2. These immature and male shrimp made up 40-50% of the catch by numbers in April-June, increasing to 70-80% for July-September, during 1973-1974 (Clark *et al*. 2000). Since 1976, fishing has been restricted to months within a December to May timeframe. (Throughout this document, references to a particular fishing year will include the previous December unless otherwise indicated – *e.g*. the 2006 season includes December 2005 but not December 2006, which will belong to the 2007 season.) Since 2000, the months of January and February have accounted for about 80% of landings, and there has not been a significant spring fishery (April-May) since 1999 (Table C5.2) due to management or market constraints.

Maps of the areas fished in 2010 and 2013 are shown in Figure C5.4 (preliminary data).

A wide variety of vessels have been used in the fishery (Bruce 1971; Wigley 1973). The predominant type during the 1960s and 1970s appears to have been side-rigged trawlers in the 14-23 m (45-75 ft) range. During the 1980s and 1990s, side trawlers either re-rigged to stern trawling, or retired from the fleet. Currently, the shrimp fleet is comprised of lobster vessels in the 9-14 m (30-45 ft) range that re-rig for shrimping, small to mid-sized stern trawlers in the 12-17 m (40-55 ft) range, and larger trawlers primarily in the 17-24 m (55-80 ft) range (ASMFC 2011). The number of vessels participating in the fishery in recent years varied from a high of about 347 in 1997 to a low of about 144 in 2006 (Table C5.6).

The otter trawl remains the primary gear employed and is typically roller rigged. There has been a trend in recent years towards the use of heavier, larger roller and/or rock hopper gear. These innovations, in concert with substantial improvements in electronic equipment, have allowed for much more accurate positioning and towing in formerly unfishable grounds, thus greatly increasing the fishing power of the Gulf of Maine fleet. Legal restrictions on trawl gear require a minimum 44.5 mm (1.75 inch) stretch mesh net and the use of a finfish separator device known as the "Nordmore grate" with a maximum grate spacing of 25.4 mm (1 inch) (ASMFC 2011). Some trawlers are voluntarily using a combination grate, which includes a section that performs as a finfish separator and a second section that selects for larger shrimp. Additional restrictions on trawlers include the closure of Maine territorial waters from April 1 through December 31, a limit on the length of the bottom legs of the trawl bridle (Maine DMR Regulations, Chapter 45), and limitations on chafing gear and liners (ASMFC 2011).

Inshore trawl trips during the winter months are usually of only one day's duration. A typical fishing day consists of about four tows of about two hours each (from port interviews). In April and May, two- and three-day offshore trips are common for Maine boats.

A small pot fishery has also existed in mid-coastal Maine since the 1970s, where in many areas bottom topography provides favorable shrimp habitat that is too rough or restricted for trawling. The trapped product is of good quality, as the traps target only female shrimp once they have migrated inshore (ASMFC 2011; and see Figure C5.6). Trappers use baited rectangular wire mesh traps with a V-shaped trough opening on top, set in single, double, or triple trap strings (Moffett *et al* 2012). In 2010, trappers hauled an average of 114 traps on an average of three-day sets (from port interviews). Most shrimp trappers also trap lobsters at other times of the year. Trappers accounted for about 13% of Maine's landings in 2000-2013 (Table C5.3).

Since the trap fishery is dependent on the inshore availability of shrimp in a specific area, the fishing season is naturally shorter for trappers than for draggers (e.g. see 2010 in Table C5.3, and ASMFC 2011). There is some indication that trap fishing for shrimp has grown in a few areas such as South Bristol and Boothbay Harbor (mid-coast Maine) and might continue to grow if stock conditions were favorable.

C5.0 - TOR #1: PRESENT THE GULF OF MAINE NORTHERN SHRIMP LANDINGS, DISCARDS, EFFORT, AND FISHERY-INDEPENDENT DATA USED IN THE ASSESSMENT. CHARACTERIZE THE PRECISION AND ACCURACY OF THE DATA AND JUSTIFY INCLUSION OR ELIMINATION OF DATA SOURCES.

C5.1 Landings

C5.1.1 Commercial Data Sources

Commercial landings by state, month, and gear (trawl vs. trap) were compiled by NMFS port agents from dealer reports until the mid-late 1990's, and are available electronically back to 1964. A dealer reporting system became mandatory in 1982 but was repealed in 1991, and NMFS began collecting the data again. In 2004, shrimp reporting for federally permitted dealers buying from federally permitted harvesters became mandatory, but "state-only" dealers, mostly in Maine, continued to report voluntarily. Trip level reporting became mandatory for all licensed Maine shrimp dealers in 2008, although "peddlers" selling directly to the public only were not required to have a license, so catches sold in the peddler market were mostly unreported on the dealer side. This was remedied in 2013, and during the next shrimp season, anyone buying shrimp for resale will need to be licensed in Maine and report landings.

In 1994, a Vessel Trip Report (VTR) system was implemented for many federally permitted harvesters and in 1999 (but not implemented until the 2000 season), reporting became mandatory for all shrimp harvesters landing in Maine. Harvesters report "hail" weights, which are estimates of the caught weight.

The time series used in the current Gulf of Maine northern shrimp stock assessment begins with 1968, when survey data became available. For the period 1968 through 1999, the assessment uses landings data from the NMFS commercial fisheries database, based on dealer reports. For the period 2000-2012, the assessment uses the more complete mandatory harvester report data. When the 2013 data were compiled in September 2013, the dealer report data for 2013 seemed to be more complete (higher total shrimp landings) than the harvester report data, likely due to late reporting on the part of harvesters, so dealer data were used to characterize landings for the 2013 season. Late reporting has been a chronic problem with the terminal year of the annual assessment, and each year the landings from the previous two seasons are re-calculated. However, an effort in Maine to improve dealer reporting compliance in 2012 resulted in only a 2% increase in 2012 landings when they were recalculated in 2013 based on 2012 harvester reports.

It is likely that landings are most completely reported in the 2001-2012 period and are less complete in the 1968-2000 period, but there is no way to be certain of this or of the extent of the problem. Model sensitivity runs described in section C.6.2 address this issue. It is also difficult to separate trawl and trap landings before 2000. For this reason, the length-based model discussed in section C6.1 uses a mixed fleet before 2000, and separate trawl and trap fleets for 2000-2013.

C5.1.2 Commercial Landings

Landings data for the Gulf of Maine northern shrimp fishery are presented in Tables C5.1-C5.3 and Figures C5.1, C5.2, and C5.4.

Annual landings declined from an average of 11,400 metric tons (mt) (25.2 million lbs) during 1969-1972 to about 400 mt (0.84 million lbs) in 1977, culminating in a closure of the fishery in 1978 (Table C5.1). The fishery reopened in 1979 and landings increased steadily to over 5,000 mt (11.1 million lbs) by 1987. Landings ranged from 2,100 to 6,500 mt (5.1 to 14.2 million lbs) during 1988-1995, and then rose dramatically to 9,500 mt (21.0 million lbs) in 1996, the highest since 1973. Landings declined to an average of 2,000 mt (4.4 million lbs) for 1999 to 2001, and dropped further in the 25-day 2002 season to 450 mt (1.0. million lbs), the lowest northern shrimp landings since the fishery was closed in 1978. Landings then increased steadily, averaging 2,100 mt (4.6 million lbs) during the 2003 to 2006 seasons, then jumping to 4,900 mt (10.8 million lbs) in 2007 and 5,000 mt (10.9 million lbs) in 2008. In 2009, 2,500 mt (5.5 million lbs) were landed during a season that was market-limited. The proposed 180-day season for 2010 was closed after 156 days with 6,100 mt (13.5 million lbs) landed, due to the industry exceeding the NSTC recommended upper limit of 4,900 mt (10.8 million lbs), and concerns about small shrimp. As in 2010, the 2011 season was closed early due to landings in excess of the NSTC recommended limit, of 4,000 mt (8.8 million lbs). A total of 6,400 mt (14.1 million lbs) of shrimp were landed. In 2012, the season was further restricted by having trawlers begin on January 2 with 3 landings days per week and trappers begin on February 1 with a 1,000 pound (0.45 mt) limit per vessel per day. The season was closed on February 17 and trawlers had a 21-day season and trappers had a 17-day season. Preliminary landings for 2012 were 2,500 mt (5.5 million lbs), exceeding the total allowed catch (TAC) of 2,211 mt (4.9 million lbs). In 2013, the TAC was set at 625 mt (1.38 million lbs); the trawl fishery was allocated 539.02 mt (1.19 million lbs) and the trap fishery was allocated 80.54 mt (0.18 million lbs). Trawlers fished for 54 days and trappers fished 62 days culminating with 307.1 mt (0.68 million lbs) landed (preliminary), which is 312.5 mt (0.69 million lbs) below the TAC. The average price per pound was $1.81 ($3.98/kg) (USD) and is the highest observed in the Gulf of Maine northern shrimp fishery (Table C5.1).

Maine landed 83% of the 2013 season total, New Hampshire followed with 10% and Massachusetts landed 7% of the season total (preliminary data, Table C5.1). The proportional distribution of landings among the states was similar to 2000-2013, but has shifted gradually since the 1980's when Massachusetts accounted for about 30% of the catch (Table C5.1 and Figure C5.1).

The relative proportion of landings by month in 2013 (Table C5.2 and Figure C5.2b), preliminary data) remained generally similar to past years (compare with 2010 in Figure C5.2a), except for the absence of landings in December and May since the fishery did not begin until January 23 and ended April 12. The month of February yielded the highest proportion of the catch (62%) followed by January (23%) and March (14%) and April (1%).

Most northern shrimp fishing in the Gulf of Maine is conducted by otter trawls, although traps are also employed off the central Maine coast. According to federal and state of Maine VTRs, trappers averaged 12% of Maine's landings during 2001 to 2007, 18% during 2008 to 2011 (preliminary data), and 9% (preliminary data) in 2012 (Table C5.3). Trapping effort has been increasing in recent years, accounting for 22% of Maine's landings in 2010. After 2010, the trapping season was cut short by management actions in 2011 and 2012 that curtailed the season before the month of March, which can be an important month for the trap fishery (e.g. 2005 and 2008 in Table C5.3). In 2013, trap catch rates were very low (from port interviews), possibly because the season started when egg hatch was already well underway (see Figures C5.5-C5.6) and stock conditions were poor. Preliminary dealer reports indicate that trappers accounted for about 6% of Maine's landings in 2013 (Table C5.3).

C5.2 Discards

Discard rates of northern shrimp in the northern shrimp fishery are thought to be near zero because no size limits are in effect and most fishing effort occurs in areas where only the larger females are present. Data from a study which sampled the northern shrimp trap fishery indicated overall discard/kept ratios (kg) for northern shrimp of 0.2% in 2010 and 0.1% in 2011 (Moffett et al. 2012). Sea sampling data from Gulf of Maine shrimp trawlers in the 1990s indicated no discarding of northern shrimp (Richards and Hendrickson 2006). The Northeast Pelagic Observer Program sampled 89 trips targeting Pandalid shrimp from 2001-2012; over that time period, 0.03% of the observed catch was discarded. On an anecdotal level, port samplers in Maine reported seeing manual shakers (used to separate the small shrimp) on a few trawl vessels during April 2010, but made no similar observations in 2011 through 2013. Discarding of northern shrimp in other Gulf of Maine fisheries is also low (Table C5.4). For these reasons and because detailed data for estimating potential discards are lacking, shrimp discards from the shrimp and other fisheries are assumed zero in this assessment.

C5.3 Effort and Catch per Unit Effort

C5.3.1 Vessel Data

The approximate number of vessels participating in the fishery is listed in Table C5.5. Data for fishing seasons before 2000 were gleaned from NSTC annual assessment documents, were probably derived from the NMFS dealer weightout database, and must be considered approximations. Data from 2000 forward are from harvester VTRs, except 2013, which is from dealer reports as described in C5.1.1. Since 2000, the number has varied from a low of 144 in 2006 to a high of 342 in 2011. In the 2013 fishery, there were 16 vessels from Massachusetts (the most since 2001), 168 from Maine (122 trawling, 46 trapping), and 14 from New Hampshire for a total of 198 (preliminary data).

C5.3.2 Trip Data

Prior to 1994, effort (numbers of trips by state and month) was estimated from landings data collected from dealers, and landings per trip information (LPUE) from dockside interviews of vessel captains:

$$Effort = \frac{Landings}{LPUE}$$

Beginning in the spring of 1994, a vessel trip reporting system (VTR) supplemented the collection of effort information from interviews. From 1995 to 1999, landings per trip (LPUE) from these logbooks were expanded to total landings from the dealer weighouts to estimate the total trips:

$$Total.Trips = VTR.Trips\frac{Total.Landings}{VTR.Landings}$$

Since 2000, VTR landings have exceeded dealer weighout landings, and the above expansion is no longer necessary. The 1996 NSTC assessment report (Schick *et al*. 1996) provides a comparison of 1995 shrimp catch and effort data from both the interview and logbook systems and addresses the differences between the systems at that time. It showed a slightly larger estimate from the logbook system than from the interview system. Thus trip estimates reported through 1994 are not directly comparable to those collected after 1994. However, patterns in effort can be examined if the difference between the systems is taken into account. An additional complication of the logbook system is that one portion of the shrimp fishery may not be adequately represented by the logbook system during 1994-1999. Smaller vessels fishing exclusively in Maine coastal waters are not required to have federal groundfish permits and were not required to submit shrimp vessel trip reports until 2000. In the 1994-1999 time series, effort from unpermitted vessels is characterized by catch per unit effort of permitted vessels.
Beginning in 2000, landings, vessels, and trips are calculated from vessel trip reports (VTRs) only, except for 2013, which used dealer trip-level report data as discussed in C5.1.1 above.

C5.3.3 Hours Towing from Port Interviews, Port Sampling Program

A port sampling program was established in the early 1980s to characterize catch at length and developmental stage, as well as to collect effort (hours towing or numbers of traps hauled and numbers of set-over-days) and fishing depth and location data. Samplers strive to achieve representative sampling (but see Moffett *et al* 2011) by maintaining up-to-date lists of active buyers and visiting ports in proportion to their estimated landings activity. Sampling consists of interviewing boat captains and collecting a 1 kg (2.2 lbs) sample of shrimp from each catch. The samples are separated and weighed in the lab by species, sex (male, transitional, or female) and development stage, where females are described as: ovigerous, female I (have not carried eggs yet), or female II (have carried eggs). Female stage I or II are determined by the presence (stage I) or absence (stage II) of pronounced sternal spines (McCrary 1971). Measurements are made of all shrimp dorsal carapace lengths, to the nearest 0.5 mm prior to 1994, and to the nearest 0.01 mm since 1994. The numbers of interviews conducted, shrimp measured, and the total weight of samples collected each season since 1985 are summarized in Table C5.6.

C5.3.4. Effort and Catch per Unit Effort Results

Estimated numbers of trips for 1985-2013 are reported in Tables C5.7-C5.8 and Figure C5.3. Locations of 2010 and 2013 fishing trips from federal and state VTRs (preliminary) are plotted by 10-minute square in Figure C5.4. Note that landings and effort in 2010 were relatively high, with some offshore trips in the spring, while 2013 was characterized by low landings and low effort with very few offshore trips.

Catch per unit effort for the shrimp fishery is typically measured in catch per hour (from Maine interview data) or catch per trip. A trip is a less precise measure of effort, because: 1) trips (as presented in Figure C5.3) from interviews and logbooks include both trawl and trap trips (difficult to separate before 2000 as discussed above); 2) there are single day trawl trips and multiple day trawl trips (in the spring), and the proportion of such trips can vary from season to season; 3) in some years, buyers imposed trip limits on their boats; and 4) in 2012 and 2013, Maine DMR imposed day-length limits.

Average pounds landed per trip (lbs/trip; 1 lb = 2.2 kg) was calculated by dividing each season's landings (Table C5.1) by the total number of trips (Table C5.7) and is presented in Table C5.9 and Figure C5.3. It averaged 1,410 pounds during 1995-2000, dropped to 752 pounds in 2001, the lowest since 1994, and remained low in 2002. During 2003-2005 it averaged 1,407 lbs/trip. The increasing trend continued in 2006 and in 2007 the highest pounds per trip of the time series was observed with 2,584 pounds. During 2008-2011, pounds per trip averaged 2,012, with a value of 2,264 in 2010, which is the second highest in the time series. There was a large decrease in 2012 to 1,497 lbs/trip (preliminary). In 2013, the average pounds landed per trip was 512, with 579 lbs per trawl trip (preliminary), both the lowest of their time series.

More precise CPUE estimates from port interviews (pounds landed per hour trawling) were calculated by dividing the pooled landings from interviewed Maine catches by the pooled hours towing for those catches, and agree well with the (less precise) catch per trip data (see Table C5.9 and Figure C5.3). Maine's season average for 2013 was 110 lbs/hr, less than half the time series average of 250 lbs/hr (Table C5.9 and Figure C5.3).

Because catch rates for this fishery can be affected by many factors in addition to stock abundance, such as possible increasing trawler efficiency (discussed in C.4.4 above), the timing of the season (catch rates are generally highest in January and February), attrition of less successful harvesters, and, most importantly, the inshore/offshore migrating and aggregating behavior of northern shrimp in the Gulf of Maine, catch rates have not historically been reliable indices of shrimp abundance or biomass, and are not used as such in this assessment. See Figure C5.3, in which annual Maine trawler catch rates are plotted against the summer survey biomass index from the previous summer. Note that, in particular, catch rates were very stable during the 2008-2012 seasons, before plummeting in 2013, while the summer survey index dropped steadily after the summer of 2008.

C5.4 Size, Sex, and Stage Composition of Landings

Size and sex-stage composition data were collected from port samples of commercial catches from each of the three states. One-kilogram samples were collected from randomly selected catches, and all northern shrimp in each sample were measured, sexed, and staged as described in C5.3.3 above. Sampled northern shrimp counts were grouped in 0.5 mm carapace length intervals by sex-stage, expanded from the sample to the catch, and then from all sampled catches to landings, for each gear type, state, and month. These expanded counts were then summed for the fishing season to give an estimate of the total number of shrimp landed, and the total number landed in each length bin and sex-stage.

Size composition data (Figures C5.5-C5.8) collected from catches since the early 1980s indicate that trends in landings have been influenced by recruitment of strong (dominant) year classes.

Landings more than tripled with recruitment to the fishery of a strong assumed 1982 year class in 1985 – 1987 and then declined sharply in 1988. A strong 1987 year class was a major contributor to the 1990-1992 fisheries. A strong 1992 year class, supplemented by a moderate 1993 year class, partially supported large annual landings in 1995 – 1998 (Figure C5.8). Low landings in 1999 – 2003 were due in part to poor 1994, 1995, 1997, 1998, and 2000 year classes with only moderate 1996 and 1999 year classes. A very strong 2001 year class supported higher landings in 2004 – 2006. In the 2007 fishery, landings mostly comprised assumed 4 year-old females from the moderate to strong 2003 year class, and possibly 6 year-olds from the 2001 year class. Landings in 2008 were mostly composed of the assumed 4 year-old females from the strong 2004 year class, and the 2003 year class (assumed 5 year–old females, which first appeared as a moderate year class in the 2004 survey).

In the 2009 fishery, catches were comprised mainly of assumed 5-year old females from the strong 2004 year class. Catches in the 2010 fishery consisted of assumed 5 year-old females from the 2005 year class and possibly some 4-year-old females from the weak 2006 year class. The 2011 fishery consisted mainly of 4-year-old females from the assumed 2007 year class. Numbers of 5-year-old shrimp were limited likely due to the weak 2006 year class. The 2011 catch included transitionals and newly-transformed females from the assumed 2008 year class, and some males and juveniles from the assumed 2009 year class, especially in the Massachusetts and New Hampshire catches and Maine's December and January trawl catches. Trawl catches in the 2012 fishery were likely 4-year-olds from the moderate 2008 year class, but they were small for their age (compare with 2011 in Figure C5.8). Low percentages of males and juveniles were caught in 2012 likely due to the later start date of January 2 and early closure on February 17. In the 2013 fishery, catches were limited but likely comprised 4- and 5-year-olds from the moderate 2009 and 2008 year classes, however, these shrimp were small for their assumed age (Figure C5.8). Limited numbers of males and transitionals were observed in catches, in Massachusetts and New Hampshire in samples from January through March (Figure C5.7), and in Maine in April (Figure C5.6).

Maine trappers generally were more likely to catch females after egg hatch, than trawlers, as in previous years, and, as in past years, there were fewer small (male) shrimp in Maine trap catches than in trawl catches (Figure C5.6).

Historically, landings from January to March have consisted primarily of mature female shrimp (presumably age 3 and older) and December, April, and May landings have included higher proportions of males (assumed ages 1 and 2). These patterns reflect shifts in distribution of fishing effort in response to seasonal movements of mature females: inshore in mid-winter and offshore after egg-hatch. Spatial and temporal differences in the timing of egg-hatch can be estimated by noting the relative abundance of ovigerous females to females that have borne eggs in the past but are no longer carrying them (female stage II) (Figures C5.5-C.7).

Pre-season research tows were conducted in winter 2013, to obtain information on catch rates and egg hatch. Three shrimp trawlers from Maine (from Stonington, South Bristol, and Sebasco, east to west, Figure C5.10) and one from Portsmouth, New Hampshire conducted short experimental tows for one day during the week of January 13, 2013. They provided samples of the shrimp from each tow for analysis by Maine DMR and New Hampshire Fish & Game. Catch rates were much lower than the 1991-2013 Maine commercial trawl fishery average of 250 lbs/hr (Table C5.9). Counts per pound (1 pound=2.2 kg) varied greatly, generally from east to west, with 34 for the Stonington boat (downeast Maine), 38 for the South Bristol boat (midcoast Maine), 51 for the Sebasco boat (Casco Bay, mid to southern Maine area), and 48 for the Portsmouth boat (New Hampshire). Egg hatch also varied from east to west, with almost no hatch in Stonington, 7% hatched near South Bristol, to 26% hatched near Sebasco, to 88% hatched near Portsmouth, NH (Figure C5.5).

Pre-season research traps were also set. Five shrimp trappers from midcoast Maine (from Boothbay to Vinalhaven, Figure C5.10) set experimental pre-season shrimp traps between January 24 and February 2, 2013. Each trapper was allowed to set and haul up to 6 traps. Catch rates were poor, less than 1 pound per trap (1 lb=2.2kg). One sample was collected from the Boothbay Harbor area (Figure C5.10), with 16% of shrimp carrying eggs and 84% hatched off (Figure C5.5).

According to port samples collected from the 2013 season's commercial catches, in January, in Maine, 22.5% of the trawled catch was female stage II; in February this increased to 45% (Figure C5.6). These percentages are higher in 2010 through 2013 than in past seasons, suggesting that egg hatch is occurring somewhat earlier than in 2008 and 2009 (2008: 5.4% in January, 13.5% in February and 2009: 5.8% in January, 17.8% in February).

In New Hampshire trawl catches, the percentage of female stage II shrimp for the 2013 season was 95.6% in January, and 88% in February (Figure C5.7). In Massachusetts trawl catch samples, the percentage of female stage II shrimp was 75.6% in January, and 81.2% in February. Egg hatch was well underway when compared to 2012 (NH: 60.2% in January, 94.6% in February, MA: 17.9% in January, 49.2% in February). New Hampshire and Massachusetts percentage of stage II shrimp in the catch were higher than Maine for the same months (compare Figure C5.6 with C.7), probably reflecting the eastern Gulf lagging the west in the timing of egg hatch.

C5.4.1 Estimated Number and Mean Weight of Northern Shrimp in Landings

Size composition data were collected from port samples of commercial catches from each of the three states as described in C5.3.3 above and Table C5.6. Sampled northern shrimp counts were grouped in 0.5 mm carapace length intervals for each sample, expanded from the sample to the catch, and then from all sampled catches to landings, for each gear type, state, and month, which were then summed for the fishing season by gear to give an estimate of the total number of shrimp landed, and the total number landed in each length bin. If there were landings (usually small amounts) but no samples for a given gear, state, and month, the size composition from samples from an adjacent state or month were used. The results are reported in Tables C5.10-C5.12 for 1985-2013. Total numbers of shrimp landed by season are shown in Figure C5.8 and are used in the CSA model below in Section C6.1. Total numbers of shrimp landed by season, gear (fleet), and length interval are used in the length-based model below at C6.11

General patterns in size composition of landings are reflected in the mean weight of individual shrimp landed by season, state, month, and gear: the mean weight of a landed shrimp generally increases from December to January as fewer small males are caught, peaks in February, and decreases through the spring as the fleet fishes further offshore on mixed sizes. Mean shrimp size is often larger in Maine landings than in those of the other states, and larger in Maine trap catches than trawl catches. The mean weights of individual shrimp (*P. borealis*) from the 2010 fishery are given below, as an example to illustrate these trends. Note that these weights are calculated by dividing the landed weight by the estimated number of shrimp in the landed weight. Since the landings may also contain water, detritus, and other species of shrimp and other bycatch, these "mean weights" are actually estimates of the amount of catch that contains exactly one *P. borealis.* There is further discussion of these estimates in section C9.

Mean weights (grams, g) of individuals (and numbers of samples) of *P. borealis* in 2010 landings. 1 g = 0.0022 lb

	Maine		Massachusetts	New Hampshire
Month	**Trawls**	**Traps**	**Trawls**	**Trawls**
December	10.96g (28)	No samples; use January	No samples; use NH Dec.	10.94g (3)
January	11.76g (52)	14.01g (17)	8.77g (3)	9.69g (3)
February	12.70g (63)	13.52g (33)	9.03g (3)	10.15g (3)
March	11.59g (15)	13.38g (16)	No samples; use ME March	No samples; use ME March
April	7.94g (24)	No samples; use March	No samples; use NH April	8.91g (2)
May	8.54g (1)	No landings	No landings	No samples; use ME May

C.5.4.2 Estimated Time of Egg Hatch

Probit analysis of the proportion of reproductive females (ovigerous or female stage II) whose eggs had hatched, from Maine port samples, was used to define metrics of hatch timing. The start of the hatch period has become earlier as temperatures have increased (Figure C4.3). See Richards (2012) and Section C4.3.3 for methods and further discussion.

C5.5 Fishery Independent Surveys

Trends in abundance of Gulf of Maine northern shrimp have been monitored since 1968 from data collected in Northeast Fisheries Science Center (NEFSC) autumn bottom trawl surveys and in summer shrimp surveys by the State of Maine (discontinued in 1983). A dedicated shrimp survey has been conducted annually since 1983 by the ASMFC in the resource area in the western Gulf of Maine. An inshore trawl survey has been conducted each spring and fall since fall 2000 by the states of Maine and New Hampshire (Sherman *et al*. 2005). The NSTC has placed primary dependence on the ASMFC summer shrimp survey for fishery-independent data used in stock assessments, although the other survey data are also considered (see survey locations in Figure C5.10).

C5.5. 1 State-Federal (ASMFC) Summer Survey

The ASMFC NSTC shrimp survey, or "summer survey", has been conducted offshore (depths > 50 m or 164 ft) each summer since 1983 aboard the *R/V Gloria Michelle* employing a stratified random sampling design and gear specifically designed for Gulf of Maine conditions (Blott *et al*. 1983, Clark 1989). The summer survey is considered to provide the most reliable information available on abundance, distribution, age and size structure and other biological parameters of the Gulf of Maine northern shrimp resource because all adult life history stages are aggregated during the summer and because the gear is designed specifically for capturing northern shrimp. Indices of abundance and biomass are based on catches in the strata that have been sampled most intensively and consistently over time (strata 1, 3, 5, 6, 7, and 8; Figure C5.10). Survey catches have been highest in strata 1, 3, 6, and 8 – the region from Jeffreys Ledge and Scantum Basin eastward to Penobscot Bay. The 1983 survey did not sample strata 6-8 and is not used in the assessment. Survey sites for 2013 are shown in Figure C5.11.

The statistical distribution of the summer survey catch per tow (in numbers) was investigated to determine the best estimator of relative abundance (Cadrin et al. 1999). Catches within strata were distributed with significant positive skew, and arithmetic stratum means were correlated to stratum variances. Log-transformed catches (Ln[n+1]) were more normally distributed, therefore, stratified geometric mean catch per tow was used to estimate relative abundance (Cadrin *et al*. 1999).

The CV of geometric mean indices from the summer survey during 1984-2013 averaged 21% for abundance (range 11-46%) and 14% for weight (range 7-13%). Indices with 95% confidence intervals are shown in Figure C5.12. Bias is thought to be relatively low in this survey because year classes can generally be tracked over time (Figure C5.13), and the survey has performed well in predicting availability of harvestable shrimp to the upcoming fishery (Figure C5.3c)). The smallest size mode, assumed to be age 1.5 recruits, may not be fully selected to the survey gear.

Shrimp summer survey catches by length and developmental stage (Figure C5.13) reflect the predominance of strong cohorts in the stock. Although size at age-1.5 varies from year to year, discrete length modes indicate the relative abundance of assumed age-1.5 shrimp (generally around 12-18 mm carapace length (CL)) and assumed age-2.5 shrimp (generally 18.5-23 mm CL). Length modes for older cohorts overlap extensively, but female shrimp that have carried eggs in the past (female stage II) can be separated from those that have not (female stage I). Age

1.5 shrimp are not fully recruited to the survey, probably because of variation in the timing of their migration from inshore to offshore, and also because they are not fully retained by the survey net.

Abundance and biomass indices for 2013 were the lowest on record in this series, with a $\log_e$ transformed mean weight per tow of 1.0 kg/tow (Table C5.14, Figure C5.12). The series averaged 15.8 kg/tow from 1984 through 1990. Beginning in 1991, this index began to decline and averaged 10.2 kg/tow from 1991 through 1996. The survey mean weight per tow then declined further, averaging 6.5 kg/tow from 1997 through 2003, and reaching a low of 4.3 kg/tow in 2001. Between 2003 and 2006 the index increased markedly, reaching a new time series high in 2006 (66.0 kg/tow). Although 2006 was a high abundance year, as corroborated by the fall survey index, the 2006 summer survey index should be viewed with caution because it was based on 29 survey tows compared with about 40 tows in most years (Table C5.13). The summer survey index was 16.8 kg/tow in 2008, and has dropped steadily since then to 8.6 kg/tow in 2011, 2.5 kg/tow in 2012, and 1.0 kg/tow in 2013. These most recent values are well below the time series average of 12.9 kg/tow (Table C5.13). The total mean number of shrimp per tow demonstrated the same general trends over the time series (Table C5.13 and Figure C5.13).

The stratified mean catch per tow in numbers of 1.5-year old shrimp (Table C5.13, Figure C5.13, and graphically represented as the total number in the first (left-most) size modes in Figure C5.13) represents a recruitment index. Although these shrimp are not fully recruited to the survey gear, this index appears sufficient as a preliminary estimate of year class strength. This survey index indicated strong (more than 700 per tow) assumed 1987, 1992, 2001, and 2004 year classes. The assumed 1983, 2000, 2002, and 2006 age classes were weak (less than 100 per tow), well below the time series mean of 367 individuals per tow. From 2008 to 2010, the age 1.5 index varied around 500 individuals per tow (506, 555, and 475 individuals per tow, respectively), indicating moderate but above average assumed 2007, 2008, and 2009 year classes. The age 1.5 index dropped markedly to 44 individuals per tow in 2011, signifying a weak 2010 year class. The 2012 index for age 1.5 was the lowest in the time series (until 2013), with only 7 individuals per tow, signifying an extremely weak 2011 year class. The 2013 age 1.5 index dropped even further with only 1 individual per tow, signifying a very weak 2012 year class and an unprecedented three consecutive years of poor recruitment.

Individuals >22 mm will be fully recruited to the upcoming winter fishery (primarily age 3 and older) and thus survey catches of shrimp in this size category provide indices of harvestable numbers and biomass for the coming season (Table C5.13 and Figure C5.13). The harvestable biomass index exhibited large peaks in 1985 and 1990, reflecting the very strong assumed 1982 and 1987 year classes respectively. This index has varied from year to year but generally trended down until 2004. The 2001 index of 1.5 kg/tow represented a time series low, and is indicative of poor assumed 1997 and 1998 year classes. In 2002 the index increased slightly to 2.9 kg/tow, reflecting recruitment of the moderate 1999 year class to the index. The index subsequently dropped to the second lowest value in the time series (1.7 kg/tow) in 2003. From 2003 to 2006, the fully recruited index increased dramatically, reaching a time series high in 2006 (29.9 kg/tow). This increase may have been related to the continued dominance of the record 2001 year class, some of which may have survived into the summer of 2006, and to an unexplained increase in the number of female stage 1 shrimp (Figure C5.13), probably the 2003 year class. Note that the 2006 summer survey indices (Table C5.13), which are almost all well above historical norms for this survey, are based on 29 tows, compared with about 40 tows in other years. However, the NEFSC fall survey also recorded very high indices in 2006.

In 2007 the index declined to 4.1 kg/tow with the passing of the 2001 year class and the diminishing of the 2003 year class. The 2008 index increased to 10.8 kg/tow, reflecting the strong 2004 and moderate 2005 year classes. The >22 mm weight index declined slightly in 2009 to 8.5 kg/tow, still above the time series mean of 6.0 kg/tow. The moderate 2005 and 2007 year classes and perhaps a remnant of the strong 2004 year class contributed to the composition of the 2009 summer survey >22 mm index. Since 2009, the index has been below the time-series mean and has declined steadily to new time-series lows of 0.9 kg/tow in 2012 and 0.3 kg/tow in 2013 (Table C5.13 and Figure C5.12). The low values in 2012 and 2013 are most likely due to weak recruitment of the 2010 and 2011 year classes, poor survival of the moderate 2008 and 2009 year classes, and overall small size (carapace length) of female shrimp from those year classes.

The low values in the state-federal summer survey in the most recent years have raised concerns that the survey is no longer adequately tracking abundance. The NSTC examined some of the potential hypotheses to explain the changes. One hypothesis is that the bulk of the northern shrimp population has moved northeast, outside of the area covered by the summer survey. The NEFSC bottom trawl survey samples the entire US Gulf of Maine, and although 2013 fall survey data are not yet available, the 2009-2012 survey data do not suggest a significant shift in distribution of shrimp that would explain the recent decline in abundance indices in the summer survey. Patchiness in the distribution of shrimp in the summer survey appears to have increased slightly since 2008 (Figure C5.15) and shrimp are more concentrated in slightly cooler temperatures relative to the temperature at all stations in the past several years (Figure C5.16). Indices based on randomly selected stations show the same trends in abundance as indices based on fixed stations (Figure C5.17). Three additional fixed stations were added to the 2013 summer survey in Stratum 10 (stations 28-30 in Figure C5.11), based on harvester recommended sites. These stations caught an average of 3.7 kg/tow (32 lbs/hr, untransformed). This does not provide support for the theory that the shrimp have moved northeastward.

C.5.5.2 NEFSC Fall Trawl Survey

The NEFSC autumn survey has been conducted in the northern shrimp resource area since 1963; however, shrimp were not identified to species until 1977 and detailed data on northern shrimp (length, sex, life history stage) were not consistently collected until 1994. The survey is based on a stratified random design. During 1963-2008, the survey was conducted using the *FRV Albatross IV*. In 2009 the *Albatross IV* was replaced by the *FRV Henry Bigelow* and the sampling gear was re-designed. No conversion coefficients were developed for northern shrimp because none of the experimental tows were conducted in the shrimp resource area. Thus the NEFSC fall survey was treated as two time series in the assessment (1984-2008, 2009-2012). Figure C5.18).

The NEFSC fall survey indices during Albatross years 1994-2008 had CVs averaging 25% for biomass and 27% for abundance. For the first 3 years of the Bigelow survey (2009-2011), CVs averaged 25% (biomass) and 27% (abundance). However in 2012, the indices showed a steep decline and CVs increased to 68% (biomass) and 64% (abundance). NEFSC fall survey data for 2013 are not yet available. Biomass trends in the NEFSC fall survey have generally corresponded to biomass trends in the summer shrimp surveys (Clark et al. 2000).

The fall survey biomass index fluctuated around all-time highs in the late 1960's and early 1970's (Clark et al. 2000). In the mid 1970's the index declined precipitously and the fishery collapsed; this was followed by a substantial increase in the middle 1980's to early 1990's, with peaks in 1986, 1990 and 1994 (Figure C5.18). This reflects recruitment and growth of the strong presumed 1982, 1987 and 1992 year classes and the above average 1993 year class. After declining to 0.90 kg/tow in 1996, the index rose sharply in 1999 to 2.32 kg per tow, well above the time series mean of 1.77 kg/tow. This was likely due to recruitment of the 1996 year class to the survey gear. Beginning in 2000, the fall survey index declined precipitously for two consecutive years reaching a low of 0.63 kg/tow in 2001, indicating very poor 1997 and 1998 year classes. From 2002 to 2006, the index generally increased, reaching unprecedented time series highs in 2006 and 2007 of 6.64 kg/tow and 4.13 kg/tow, respectively. From 2005 to 2008, the fall survey index was well above the time series mean of 1.77 kg/tow.

The NEFSC fall survey indices since 2009 are not directly comparable to earlier years because of the change of survey platform. However, the indices from the new NEFSC fall survey aboard the *FRV Bigelow* have declined since 2009 (Figure C5.18) similar to recent trends in the summer shrimp survey and the ME-NH survey.

C5.5.3 Maine-New Hampshire Inshore Trawl Survey

The Maine-New Hampshire inshore trawl survey (Sherman *et al*. 2005) takes place semi-annually, during spring and fall, in five regions and three depth strata (1 = 5-20 fa, 2 = 21-35 fa, 3 = 36-55 fa) (1 fa = 1 fathom = 6 feet = 1.9 meters). A deeper stratum (4 = > 55 fa out to about 12 miles) was added in 2003. The survey consistently catches shrimp in regions 1-4 (NH to Mt. Desert) and depths 3-4 (> 35 fa), and more are caught in the spring than the fall (Table C5.14). The $\log_e$-transformed stratified mean weights per tow for *P. borealis* for the spring and fall surveys using regions 1-4 and depths 3-4 only are presented in Table C5.14 and Figure C5.19, with 80% confidence intervals. Because the fall indices for northern shrimp are lower and more variable than spring, only the spring survey was considered for inclusion in the assessment.

The Maine-New Hampshire spring index rose from 4.16 kg/tow (1 kg = 2.2 lbs) during 2003 to 15.42 kg/tow during 2008. In 2009, the index dipped to 9.65 kg/tow. This was followed by an increase to 15.95 kg/tow in 2010 and to 17.86 kg/tow in 2011. However, this upward trend dropped abruptly in 2012 to 7.50 kg/tow and then declined further in 2013 to only 1.69 kg/tow. The 2013 index is well below the time-series average of 9.60 kg/tow (Table C5.14 and Figure C5.15).

In 2007-2011, the spring ME-NH inshore trawl survey data did not match the declining trend in the summer survey data. However, the low 2012 and 2013 values in the ME-NH survey are consistent with the 2012 and 2013 summer survey results in showing a severe drop in abundance. This survey also has not provided any evidence of a shift in shrimp populations to the northeast.

Because trends in the spring ME/NH survey may be affected by inter-annual variation in the timing of the offshore migration of post-hatch females, the NSTC did not use this survey as model input below, but included it as a sensitivity run in the length-based model (Section C.6). However, the spring ME/NH size-frequency distributions (Figure C5.16) generally confirm the characterization of strong and weak year classes from the summer survey.

C5.5.4 State of Maine Shrimp Survey

The State of Maine conducted summer shrimp surveys in the Gulf of Maine from 1967 to 1983. Fixed stations were sampled with an otter trawl during daylight at locations where shrimp abundance was historically high (Schick *et al*. 1981; Figure C5.10). The Maine survey biomass index began declining in about 1970, and remained low for the rest of the time series (Clark 1981, 1982; Schick *et al*. 1981). Survey biomass indices with 95% confidence intervals are shown in Figure C5.21. The average CV for biomass indices was 92.0%. The benchmark assessment models did not include this survey because of its high variability and because accurate catch data were not available for this earlier time period.

C6.0 - TOR #2: Estimate population parameters (fishing mortality, biomass, and abundance) using assessment models. Evaluate model performance and stability through sensitivity analyses and retrospective analysis, including alternative natural mortality (M) scenarios. Include consideration of environmental effects where possible. Discuss the effects of data strengths and weaknesses on model results and performance.

[SAW58 Editor's Note: The SARC58 peer review panel concluded that the northern shrimp stock assessment models presented to them were not acceptable to serve as a basis for fishery management advice. Specifically, the SARC58 concluded that shrimp assessment Terms of Reference #2, #3, #4, and #5 were not met. These particular sections are included in this report to document the analyses that were done for the peer review, but they are not recommended by SARC58 as a basis for management.]

C6.1 University of Maine Size-Structured Assessment Model (UME Model)

Life history and fisheries processes are more likely size-dependent than age dependent, and as such size-structured models may be more appropriate than age-structured models in quantifying the dynamic processes of a fish population (Chen et al. 2005; Kanaiwa et al. 2005). Another benefit of using a size-structured model for a species that is difficult to age (e.g., northern shrimp), is that it avoids the need for age composition data (e.g., catch at age) required by age-structured models.

A size-structured population dynamic model was developed for the assessment of northern shrimp in the Gulf of Maine. This model has the capacity to account for (1) the unique biology and life history of the shrimp including changes in sex, natural mortality varying with environmental variables (e.g., temperature and predator abundances), variability in growth among individuals, uncertainty in stock-recruitment relationship which may be greatly influenced by environmental variables; (2) the uniqueness of the fishery including strong seasonality of the fishery (winter only), multiple gears targeting different fishing grounds and catching different sizes of shrimp; (3) multiple data sources (multiple surveys and multiple CPUEs); (4) temporal changes in management regulations which could result in changes in catchability and selectivity; (5) different sources of uncertainty; (6) the estimation of biological reference points inside the model to make the estimated stock and fishery indicators comparable with the reference points; and (7) the capacity to project how the population may respond to alternative management regulations (e.g., changes in TAC and fishing seasons).

C6.1.1 Model Structure and Configuration

The size-structured model consists of the following five components: (1) size-structured population models to quantify the dynamics of the northern shrimp population in GOM; (2) observational models linking state-space variables in the population models with observations made in the fishery and fishery-independent survey programs; (3) statistical estimators (maximum likelihood and Bayesian) for parameter estimation; (4) models for estimating biological reference points using the parameters estimated in the above; and (5) projection models for risk analysis to evaluate alternative management strategies. The Bayesian estimators and projection model were not used in this stock assessment.

The detailed description of the model and relevant computer program can be found in the technical documentation and user manual included in Appendix C1.

The following input data are required in the UME model for the GOM northern shrimp:

- Survey indices, survey catch length compositions;
- Proportion female at size for each year;
- Weight-at-size matrix (by year if posssible, can be calculated from length-weight relationship if not);
- Maturity-at-size matrix (by year if possible);
- Annual (seasonal) commercial catch and CV for catch;
- Commercial catch length composition and associated effective sample size (ESS);
- Survey catch CV; and

- Effective sample sizes related to survey size compositions.

In addition to the above input data, we also need to specify and/or estimate growth parameters for development of a growth transition matrix which describes the probability of shrimp of a given size staying in the same size class or growing into other size classes in a given time step. An algorithm based on the von Bertalanffy growth function (VBGF) (Chen et al. 2003) is used to develop the growth transition matrix. This approach requires information on the VBGF parameters (i.e., L_∞ and K) and their variances. These parameters can be all or partially estimated in modeling and/or entered as part of the inputs.

The ASMFC Northern Shrimp Technical Committee (NSTC) developed a base case for the UMaine size-structured model (Table C6.1). The time period covered was from 1984 to 2013 with year as the model time step. Two sexes were defined: females and non-females. The range of carapace length (CL) was defined from 10 to 35 mm with the width of the size bin being 1 mm.

Based on an evaluation of temporal variability in fishing gear, three commercial fishing fleets were defined in the model: mixed gear from 1984 to 1999, trawl from 2000 to 2013, and trap from 2000 to 2013. Accordingly, three logistic functions were used to quantify fishing selectivity curves with the model parameters being estimated in by the model. Three sets of survey data were considered in the assessment: NEFSC fall survey (Albatross) with abundance index from 1984 to 2008 and CL composition data from 1991 to 2008; ASMFC summer survey with both abundance index and length frequency data from 1984 to 2013; and NEFSC fall survey (Bigelow); and three separate selectivity logistic functions were used to quantify the selectivity of the three sets of survey data with the parameters being estimated in the assessment.

Natural mortality was assumed to vary with CL with small (young) and large (old) shrimp subject to higher natural mortality than medium sizes of shrimp (Fig. C6.1). The proportion of females at CL was defined by a logistic model with the parameters being estimated in modeling. Recruitments are estimated without a functional relationship being assumed for the spawner-recruit relationship. Annual recruitment is defined as the total number f shrimp growing into the CL range of 10 to 18 mm in a given year. Two sets of growth transition matrices were developed for two time periods when the climate conditions were considered different: cold period from 1984 to 1999 and warm period from 2000 to 2013. One set of K and L_∞ values from McInnes (1986) were used for both the periods, but the variances for K and L_∞ were assumed to be different between the two time periods, and were estimated by the model.

The initial size composition (i.e., in 1984) was assumed to be the same as the size composition data from the ASMFC summer survey length composition data. For the base case, likelihood functions for all the data (i.e., catch, catch size compositions, survey abundance indices, survey catch compositions, and sex ratio) were assumed to be the same in their importance.

In addition to the base case run, we ran 12 alternative scenarios to evaluate the sensitivity of the assessment results with respect to various settings hypothesized in the base case (Table C6.2). These scenarios evaluated if the assessment results are sensitive to the hypothesized settings of natural mortality (Scenarios 1, 2, and 3), misreporting of landings (Scenarios 4, 5, and 6), importance of survey data in modeling (Scenarios 7 and 8), number of time periods for the growth transition matrix (Scenario 9 for which the shrimp growth was assumed to be the same from 1984 to 2013 in comparison of two time periods of different growth for the base case), growth parameters (Scenario 10), number of fishing fleets (Scenario 11 for which four fishing fleets were defined), and time step (Scenario 12 for which season was used as time step in modeling). Detailed differences between the base case and alternative scenarios were outlined in Table C6.2.

C6.1.2 Results and Discussion for the Base Case Run

The plots of mean weight versus dorsal carapace length (CL) and the proportion of maturity versus CL were derived from the input parameters (Fig. C6.2). Two growth curves were plotted for the two time periods defined in the base case (Fig. C6.3). These plots describe the two growth transition matrices with K and L_∞ values from Mclnnes (1986) and their variances estimated in the model. The difference in growth between the two time periods was small (Fig. C6.3). The UME-estimated fisheries selectivity curves for the three fishing fleets defined showed some differences with traps more likely selective for larger shrimps (Fig. C6.4). The UME-estimated survey selectivity also differed among the three survey programs with the ASMFC summer survey program more likely capturing small individuals and the NEFSC Bigelow survey being more likely to catch larger individuals (Fig. C6.5).

The UME-estimated fishing mortality varied greatly over time (Table C6.3), and traps resulted in much lower fishing mortality than trawl (Fig. C6.6). The UME-estimated recruitment also varied greatly over time (Table C6.3), and recruits had the lowest values in years 2000, 2012 and 2013 (Fig. C6.7). Recruitment showed continued decline from 2009 to 2012 (Table C6.3). Although the recruitment estimated for 2013 increased compared to that for 2012 (Table C6.3), it is still one of the lowest recruitment values in the history (3rd lowest from 1984 to 2013; Fig. C6.7, Table C6.3). The SSB estimates varied more than six-fold from 1984 to 2013 (Table C6.3, Fig. C6.8). The SSB had the highest value in 1995 (8652 mt; (Table C6.3) and lowest value in 2013 (1334 mt; Table C6.3). After reaching a high level in 2007 (2nd highest level of SSB at 8148 mt; Table C6.3; Fig. C6.8), SSB started to decline and had a continuous and substantial decrease over the last three years (Fig. C6.8, Table C6.3), probably resulting from declining recruitment (Fig. C6.7). The downward trends over the last three years occurred across all size classes (Fig. C6.9).

The base-case model fit trends in the NEFSC fall survey but did not capture the exceptionally high value in 2006 (Fig C6.10). Similar to NEFSC, fits to the ASMFC summer survey also failed to capture the exceptionally large value in 2006. The increasing trends from 2009 to 2011 shown in the ME-NH inshore spring survey was not captured by the model which predicted a downturn trend (Fig. C6.10).

Overall, the model fit the average size composition data well for the three survey programs, but the model predictions tended to be lower than observed values for large size classes and higher than observed data for medium size classes (Fig. C6.11). For the NEFSC fall survey, the model fit observed size compositions well for most of the years, but tended to under-estimate the first peak in small size classes in some years (e.g., 1993, 2000, 2002, and 2005; Fig. C6.12). The estimated effective sample sizes differed from input effective sample sizes in many years (Fig. C6.13), suggesting that the model considered the importance of size composition data differently. For those years with under-estimated first peaks (i.e., 1993, 2000, 2002, and 2005), the model predicted effective sample sizes were much smaller than the input value of 40 (Fig. C6.12). For the ASMFC summer survey, the model predictions captured the observed size compositions well for most of the years, but under-estimated or missed peaks for some years (Fig. C6.14). For those years with relatively poor fit, the model-estimated effective sample sizes were much smaller than the input values, suggesting that the model considered these data less reliable (Fig. C6.14). For the NEFSC Bigelow survey, the observed peaks in 2011 and 2012 were not fit well, with model-estimated effective sample sizes smaller than the input effective sample sizes (Fig. C6.15).

Temporal trends in total landings (in numbers) were fit well by the model (Fig. C6.16), and so were landings of individual fisheries (Fig. C6..17). For the mixed-gear fishery defined from 1984 to 1999, the peaks were under-estimated by the model for most years (Fig. C6.18), suggesting the fishery selectivity curve might not be well defined. The same results could be seen for the trawl fishery (Fig. C6.19) and trap fishery (Fig. C6.20). Commercial size composition data averaged over all the years could be captured well by the model for all the three fisheries, although the peaks of observed distribution were still under-estimated (Fig. C6.21).

The model could predict observed proportion of females well (Fig. C6.22). The predicted abundance of females and non-females for each size class at the beginning of each year was shown in Fig. C6.23) For almost all the years from 1984 to 2013, non-females tended to have two peaks, most likely representing two age groups (Fig. C6.23). This suggests that most northern shrimp became females at age 3. The estimated size at which 50% of individuals become females ($L_{50\%}$) varied over time with the highest and lowest $L_{50\%}$ occurring in 2008 and 2002, respectively (Fig. C6.24). The estimated size at which 50% of individuals were female had a significant positive correlation with the estimated non-female biomass (p=0.035).

Temporal variability in biomass of females and non-females was shown in Table C6.3 and Figure C6.25. The biomass of both females and non-females was fairly stable from 1984 to

1993, reached the highest level in 1995 and then decreased continuously from 1995 to 2001 (Table C6.3). The biomass bounced back to a high level from 2001 to 2007, followed by a large decline after 2010. The biomass in 2013 was the lowest (Fig. C6.25). The model-predicted exploitation rates, calculated as the ratio of predicted landings (in number/weight) and total abundance/biomass, were shown in Table C6.3 and Figure C6.26. The highest exploitation rates occurred in 2011 and 2012 (Table C6.3; Fig. C6.26). During the time period from 1984 to 2013, more than 50% of females were removed in the fishery for 15 out of 30 years. Of these 15 years, 11 years occurred after 1996 (Table C6.3). More than 50% of the females were caught in the fishery in every year from 2007 to 2012 except for 2009 (Table C6.3). In 2010, 2011 and 2012, 64%, 77% and 74% of females were removed by the fishery, respectively (Table C6.3).

The annual estimates of recruitment, SSB, female biomass, non-female biomass, female abundance, non-female abundance, abundance-based exploitation rate (i.e., ratio of landings in number versus stock abundance), biomass-based exploitation rate (i.e., ratio of landings in weight versus stock biomass), and biomass-based exploitation rate for females (i.e., ratio of female landings in weight versus female biomass) are shown in Table 3.

The retrospective analysis suggests that estimated SSB tended to have a low retrospective error with SSB being likely to have a slight overestimation (Fig. C6.27, C6.28). The recruitment and exploitation rates also had small retrospective errors with the recruitment being under-estimated (Fig. C6.29, C6.30) and exploitation rate being over-estimated (Fig. C6.31, 6.32).

A phase plot for the fishing mortality of fully-recruited shrimp and spawning stock biomass is presented in Figure C6.33.

C6.1.3 Sensitivity Analyses

The total negative log-likelihood (NLL) value and NLL values of each component are shown in Table C6.4. We could not get scenario 12 (using season as time step) converged. The only scenario that had a smaller NLL value than the base case is scenario 10, which used different growth parameters for the derivation of the growth transition matrices. The other alternative scenarios had larger NLL values, suggesting that the configuration of these models is less optimal than the base case. The NLL for the proportion of females had the same NLL value for all the scenarios, suggesting it is not sensitive to the model configuration. Size composition data of both surveys and fisheries had the largest NLL values, resulting from a large number of observations in these data sets. Overall, differences in the NLL values and compositions among the scenarios were not surprising (Table C6.4).

The key population and management parameter estimates for the base case and other alternative scenarios were shown in Table C6.5. Scenario 7 (survey indices were weighted five times in modeling; Table C6.2) yielded least optimistic conclusions about the status of the fishery in 2013 with low SSB and low recruitment, and scenario 10 (alternative growth parameters; Table C6.2) was most optimistic. Most alternative scenarios yielded the results similar to those for the base case (Table C6.5). The base case and most alternative scenarios suggested that the SSB was less than 30% of B_{MSY} in 2013, which may suggest that the shrimp stock is overfished. However, the exploitation rates, calculated in three different ways (i.e., ratio of catch in number versus the total stock abundance, ratio of catch in weight versus total stock biomass, and ratio of female catch in weight versus female biomass; Table C6.5; Fig. C6.26), were low for most scenarios including the base case, suggesting that overfishing might not occur in 2013. The retrospective errors existed in the estimation of SSB, recruitments and exploitation rates, but were not serious for most scenarios (see Mohn's rho values in Table C6.5).

C6.1.4 Summary

The UME assessment fit the GOM northern shrimp data reasonably well. Retrospective errors were not serious in the assessment (Table C6.5). Sensitivity analysis suggests that the assessment results were most sensitive to alternative hypotheses on growth parameters used in quantifying growth transition matrix (Tables C6.4 and C6.5).

The UME assessment suggests that the GOM northern shrimp stock biomass and recruitment fluctuated greatly from 1984 to 2013 (Table C6.3). The shrimp SSB and recruitment decreased greatly from 2010 to 2013, in parallel with substantially high rates of removal of females during 2010 to 2012 (i.e., 64%, 77%, and 74%, respectively; Table C6.3). The SSB in 2013 was the lowest for the time period from 1984 to 2013, and the recruitment in 2013 was one of the lowest (Table C6.3).

C6.2 Collie-Sissenwine Analysis (CSA)

C6.2.1 Model Structure and Configuration

Collie-Sissenwine Analysis (CSA) is a two-stage stock assessment model that estimates abundance, fishing mortality and recruitment to the fishery using total catch numbers and survey data (Collie and Sissenwine 1983; Conser 1995). The "recruit" stage group consists of animals that will recruit during the current time step. The "post-recruit" animals are those that were fully recruited before the start of the time step. The two stages may correspond to age groups, length groups or any other natural division (e.g. genders in hermaphroditic species). The initial application of CSA to Gulf of Maine northern shrimp is described in Cadrin et al. (1999).

The software for CSA was updated in 2013; the 2013 benchmark assessment used CSA version 4.2.2 from the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/). Technical documentation is provided in Appendix C3 of this report. Changes to the software are summarized in Table C1. The most significant improvements are the use of maximum likelihood methods rather than weighted sums of squares to estimate parameters, and the capability to incorporate more than one survey index in fitting the model.

The surveys in CSA ver. 4.2.2 can be of two types. "Recruit/post-recruit" surveys consist of two indices (one for recruits and the other for post-recruits) usually derived from the same survey; aggregate surveys are not divided into recruits and post-recruits. For recruit/post-recruit surveys, the user must specify annual selectivity parameters (sometimes called q-ratios) which cannot be estimated and which measure catchability of recruits relative to post-recruits in each year. It is inadvisable to include multiple recruit/post-recruit surveys because fixed selectivity parameters for the two surveys are likely to conflict.

The model may include any number of "aggregate" surveys. The aggregate surveys involve a single selectivity parameter for recruits that may be fixed or estimated. The selectivity of post-recruits is assumed to be one; the parameter for recruits measures selectivity relative to the selectivity of post-recruits. In the current application to northern shrimp, selectivity of the aggregate surveys was estimated within the model rather than fixed.

The user must specify the time of year (as a fraction) that each survey observation was collected. The model uses this information in comparing the observed survey observation to predicted abundance at the time the observation was collected. This facilitates use of multiple surveys collected at different times of the year and surveys with variable start dates, particularly when mortality rates are high. In the benchmark application, the summer survey was considered the start of the year, the fall survey occurred 0.25 year later, and the ME-NH survey 0.625 year later.

The effects of the new software and model configuration were tested using the final CSA run (ver 3.1.1) from the 2013 annual assessment for northern shrimp (Whitmore et al. 2013) as a base. Subsequent runs were done to include additional surveys (aggregated) and to explore different values of natural mortality (M). Aggregate surveys considered were the NEFSC autumn surveys (Albatross years (1984-2008), Bigelow years (2009-2012)) and the ME-NH spring inshore survey. The ME-NH survey was not included in the base run because of concerns about inter-annual variability in availability of shrimp to this survey (due to timing of migration). The model time period was survey years 1984-2013; however, fall survey data were only available through 2012.

Annual survey CVs were adjusted prior to performing the benchmark model runs to bring the assumed CV values close to that implied based on the model residuals (see Appendix C3 Table 2 and Figure 1). Catch CV for the final runs was assumed equal to 0.05 to match the CV assumed in the UME model. Confidence limits for final model estimates were generated using Markov chain Monte Carlo (MCMC) calculations using 1000 iterations with a thinning rate of 10.

C.6.2.2 Results

Estimates of fishing mortality from the CSA peaked at 1.12 in 1997, with the second and third highest values in the time-series occurring in 2011 and 2012 (0.48 and 0.55, respectively). F subsequently dropped in 2013, to 0.13.

Estimates of 2013 recruit abundance (82 million shrimp), post-recruit abundance (238 million shrimp), and exploitable biomass (3,000 mt) were the lowest values in the time-series. Recruit abundance and exploitable biomass peaked in 2007 (5,790 million shrimp and 62,000 mt, respectively), while post-recruit abundance peaked the following year.

C6.2.4 Sensitivity Runs

Sensitivity runs were done to examine the influence of assumed natural mortality, estimated recruit selectivity, the assumed CV on catch, and possible catch under-reporting.

Three scenarios for M were examined (Figure C2). The first scenario was constant M=0.25 with an ad hoc adjustment in 2006 of M=1.0 to account for the sudden disappearance of an unusually strong year class. Previous assessments assumed a constant M=0.25, but this was considered too low by SARC 45 because consumption estimates were higher than model estimates of shrimp abundance (NEFSC 2007). However empirical estimates of M for Gulf of Maine northern shrimp in the exploitable size range have been relatively low (Rinaldo 1976, regression of Z on effort, M=0.25; Clark 1982, catch curve Z during fishery closure, M=0.17), suggesting there may be some merit in assuming a relatively low M for CSA.

The other two M scenarios incorporated estimates of interannual variation in predation pressure on shrimp using as a baseline either the Rinaldo (1976) empirical estimates (M=0.25) or M=0.5 based on the 3/M rule of thumb (maximum age of shrimp=6 years). In these runs, the baseline M values were adjusted annually according to an index of predation pressure (PPI, Figure C3) developed from food habits sampling and predator biomass data from NEFSC surveys (Appendix C2). The adjustment to M was proportional to the long term average of the PPI, so that M was scaled up in years with above average PPI and down in years with below average PPI:

$$M_i = M_b * \frac{PPI_i}{\overline{PPI}}$$

where i=year and M_b=baseline M. In the 'Rinaldo' scenario (M=0.25), M was scaled relative to the average PPI during 1968-1972, the time period when M was estimated. This resulted in an average M during the assessment time period (1984-2013) of M=0.20 under the Rinaldo scenario.

Figure C4 shows the estimates that resulted from incremental changes made to extend the CSA ver 3.1.1 model. The software change had no observable effect on the population estimates (Figure C4, A-D). Adding the fall surveys had some effect in the early part of the time series, but little effect since around 2000 (Figure C4, E-H). Using the adjusted survey CVs smoothed out some of the spikes in the estimates (Figure C4, I-L). Using a constant M=0.5 (vs. constant M=0.25) decreased the estimates of F and increased the estimates of abundance and biomass, as would be expected (Figure C4, M-P). Applying the PPI-adjusted M (base M=0.5) reduced recruit abundance since 2001 (fishing year) and increased F during the same time period. This reflects the generally higher PPI (and thus higher M) since about 2000 (Figure C3). In the CSA, 6 months of natural mortality is applied to the starting population before the catch is removed, thus years with higher PPI have fewer shrimp at the start of the fishery than would be predicted from models with constant M. A comparison of the cumulative difference between the original CSA ver. 3.1.1 model vs. the ver. 4.2.2 model using PPI-adjusted M (M=0.5 base) is shown in Figure C4, U-X.

Goodness of fit was evaluated for 3 assumptions regarding M as described above (Table C3). The PPI-adjusted 3/M scenario had the lowest overall objective function, although the ad hoc M fit the post-recruits more closely than the other options. The fit to the 3/M-PPI model improved as catch CV was decreased (Table C3). The 3/M model was selected as the base model for further development.

The value of including additional surveys (as aggregate indices) was evaluated by examining likelihood components and AIC scores for each model (Table C4). The models that included the ME-NH inshore spring survey performed most poorly. The models that excluded the ME-NH survey had equivalent objective functions but the model that included both shrimp and fall surveys had a higher AIC because it had more parameters. Based on these results and concerns discussed above, the ME-NH survey was dropped from further consideration. The fall surveys were retained despite the somewhat higher AIC.

The final model used the 3/M PPI-scaled M and included the summer shrimp survey (recruits and post-recruits) and the NEFSC fall surveys (Albatross and Bigelow, aggregate indices). Results and comparison to the 2013 annual assessment model are shown in Figures C5-C8 and Table C5. The strong retrospective patterns seen in the 2013 model are improved when annual M is scaled by the predation pressure index (Figure C6). Mohn's rho is given in Table C6. The improvement in the retrospective pattern compared to the 2013 annual assessment is due primarily to scaling M by the PPI (Figure. C7). The PPI model also better accommodates the large spike in abundance observed in the 2006 surveys (Figure C5). Confidence limits (90%) based on MCMC are shown in Figure C7.

We examined sensitivity of the final model to the annual estimates of recruit selectivity, to hypotheses re. catch under-reporting, and to variation in the assumed baseline M. Recruit selectivity estimated from survey data during 1984-2013 averaged 0.91 (range 0.63-1.0). We varied selectivity by multiplying the annual estimated selectivity by a constant ranging from 0.25 to 0.9, or set selectivity in all years equal to 1 (100% selected, Table C7). The base model (=estimated selectivity) and models with 0.75*base or 0.9*base had similar overall fits based on the objective function and likelihood components. Setting selectivity below 0.75*base resulted in poorer fits, and setting it equal to 1 also resulted in a poorer fit than using the base (estimated) selectivity.

Increasing catch numbers to account for possible under-reporting particularly prior to 2001 did not significantly affect the model fit (Table C8), but had some effect on the resulting estimates (Figure C9). The final model used the catch data as reported and did not adjust for suspected under-reporting.

Using baseline M lower than 0.5 (as multiplier for PPI) resulted in poorer fits of the model; using higher baseline M did not significantly improve the model fit (Table C9).

A final set of runs was done using an alternative formulation of the PPI (PPI2) based on the annual percent of the diet that comprised Pandalids (vs. average frequency over time in the diet of each predator) (Appendix C2). This formulation had slightly poorer goodness of fit and a slightly worse retrospective pattern than the final 3/M-PPI model, and was not considered further.

C6.3 Surplus Production Model (ASPIC)

C6.3.1 Model Structure and Configuration

An alternative method of estimating stock size and F was compared to results from the CSA analysis. A nonequilibrium surplus production model (ASPIC ver. 5.34.9 NOAA/NMFS, Prager 1994, 1995, 2004) was fit to seasonal catch and survey biomass indices from 1968 to 2013 (summarized in Table C6-3; Figure C6-10). The model assumes logistic population growth, in which the change in stock biomass over time (dB_t/dt) is a quadratic function of biomass (B_t):

$$dB_t/dt = rB_t - (r/K)B_t^2$$

where r is the intrinsic rate of population growth, and K is carrying capacity. For a fished stock, the rate of change is also a function of F:

$$dB_t/dt = (r-F_t)B_t - (r/K)B_t^2$$

For discrete time increments, such as annual fishing seasons, the difference equation is:

$$B_{t+1} = B_t + (r-F_t)B_t - (r/K)B_t^2$$

Initial biomass (B_1), r, and K were estimated using nonlinear least squares. The NEFSC R/V Albatross fall groundfish survey catch per unit effort (CPUE) contributed to the total sum of squares as a series of observed effort (E=CPUE/C); the Maine summer survey, the ASMFC summer shrimp survey, and the NEFSC R/V Bigelow fall groundfish survey contributed as independent indices of biomass at the start of the fishing season.

C6.3.2 Results

Estimates of F and B from the biomass dynamics model generally confirm the pattern and magnitude of estimates from the size-structured models (Figure C6-10). Biomass estimates have been rapidly declining since 2007 (Tables C6-2 and C6-3; Figure C6-10). Recruitment of the strong 1982, 1987, 1992, 2001, and 2004 cohorts is not as pronounced in the biomass trajectory from the production model. Estimates of biomass from the base model run of ASPIC, which includes four available fishery independent indices, were below B_{MSY} in 2013 indicating the stock is overfished (Table C6-3; Figure C6-11). Estimates of F from the production model were below F_{MSY} in 2013, but above it in 2011 and 2012, indicating the stock has experienced overfishing for two of the last three years (Table C6-3). The biomass dynamics model suggests that a maximum sustainable yield (MSY) of 4,430 mt can be produced when stock biomass is approximately 22,800 mt (B_{MSY}) and F is approximately 0.19 (F_{MSY}). However, estimated biomass was only above B_{MSY} during the first five years in the analysis, which are not reliable (Prager 1994, 1995).

The model struggled to fit two observations from the NEFSC fall groundfish survey conducted on the R/V Albatross (2006 and 2007) and one observation from the ASMFC summer shrimp surveys. The pattern of residuals from the Maine and ASMFC Summer surveys suggest autocorrelation (Figure C6-12). The model did not account for peaks in biomass from 2005 to 2008 that resulted from strong recruitment.

Survey residuals were randomly resampled 1000 times to estimate precision and model bias. Bootstrap results suggest that B_1/B_{MSY}, K, MSY, B_{MSY} and F_{MSY} were relatively well estimated (relative interquartile ranges were <7%, and bias was ≤1%). Estimates of the survey *q*'s were moderately precise (relative IQs were 5-18%, bias was ≤1%). The ratio of F/F_{MSY} in 2013 was estimated with moderate precision (relative IQ = 15%, bias was -10%). B/B_{MSY} in 2013 was estimated with lower precision (relative IQ = 74%, bias 23%).

C6.3.3 Sensitivity Runs and Retrospective Analysis

Estimates of fishing mortality and biomass derived from the biomass dynamics model (ASPIC) were examined for sensitivity to potential uncertainty and biases by excluding and including certain survey indices (NEFSC R/V Bigelow fall survey and Maine-New Hampshire shrimp inshore survey. Two continuity runs were completed. For the first run (Cont. 1), the NEFSC R/V Albatross fall survey catch per unit effort (CPUE) contributed to the total sum of squares as a series of observed effort (E=CPUE/C); while the Maine summer survey, and the ASMFC summer shrimp survey contributed as independent indices of biomass at the start of the fishing season. This represented the ASPIC input used in the 2007 SAW Assessment update. The second run (Cont. 2) represented indices used in more recent assessment updates. For this run, the NEFSC R/V Albatross fall survey catch per unit effort (CPUE) contributed to the total sum of squares as a series of observed effort (E=CPUE/C); while the Maine summer survey, the

ASMFC summer shrimp survey, and the Maine-New Hampshire spring inshore survey contributed as independent indices of biomass at the start of the fishing season.

Estimates of fishing mortality and starting biomass from ASPIC were slightly sensitive to the exclusion of the NEFSC R/V Bigelow fall groundfish survey. For Cont. 1, the average annual starting biomass was 10% higher than the base run estimate, and the average annual F was 10% lower than the base run (Figure C9-2.1). Fishing mortality and biomass estimates were less sensitive to the inclusion of the Maine-New Hampshire spring inshore survey (with the exclusion of the NEFSC R/V Bigelow fall survey). For Cont. 2, the average annual starting biomass was 0.05% higher than the base run estimate, while the average annual F was 1.8% higher than the base run F (Figure C9-2.2).

A total of five retrospective ASPIC runs were completed and examined to assess the stability of model estimates of biomass and fishing mortality in the terminal year, and to assess the sensitivity of time series trends of biomass and fishing mortality to terminal values of survey and catch time series. The analysis was performed by sequentially removing the last year of survey and catch data (for five years) to create retrospective time series of surplus production fishing mortality and biomass estimates.

Retrospective analyses of results indicate that stock size has been considerably overestimated and the fishing mortality rate has been underestimated by the ASPIC model in recent years (Figure C6-14). F values have been underestimated and B values overestimated since the late 1990's, and the degree of retrospective bias for F and B has increased in recent years. The optimistic bias in estimated biomass is notable since 2007, where the trajectory of the stock has changed from increasing to declining (Figure C6-14).

C6.4 Model Comparisons

All three models show similar trends, with fishing mortality spiking in 2010-2012 and then declining in 2013 (Figure C6.50). Biomass and abundance peak earlier, in 2007/2008 and have declined since then, with 2013 being the lowest value in the time-series for all models (Figure C6.51).

The UME model predicts a much higher full F than the ASPIC and CSA models do; however, the UME model assumes F is separable, and uses a model-estimated selectivity pattern to apply that full F to each size class in the population. When the full F is averaged across all size classes, weighted by the abundance at size, the N-weighted F is similar in magnitude to the F estimated by the CSA and ASPIC.

C7.0 - TOR #3: UPDATE OR REDEFINE BIOLOGICAL REFERENCE POINTS (BRPs; POINT ESTIMATES OR PROXIES FOR B_{MSY}, SSB_{MSY}, F_{MSY}, MSY). EVALUATE STOCK STATUS BASED ON BRPs.

[SAW58 Editor's Note: The SARC58 peer review panel concluded that the northern shrimp stock assessment models presented to them were not acceptable to serve as a basis for fishery management advice. Specifically, the SARC58 concluded that shrimp assessment Terms of Reference #2, #3, #4, and #5 were not met. These particular sections are included in this report to document the analyses that were done for the peer review, but they are not recommended by SARC58 as a basis for management.]

The current fishing mortality reference points as established by Amendment 2 and re-estimated during the 2013 assessment update by the NSTC are F_{target} =0.38 and $F_{threshold}$= 0.48. The F_{target} is defined as the average F estimated by the CSA model during a period in the fishery when biomass and landings were considered stable (1985-1994). The $F_{threshold}$ is the maximum F estimated during this time period. Amendment 2 also specifies an F_{limit} = $F_{20\%SSPR}$ = 0.6, which was exceeded in the early 1970s when the stock collapsed.

The stock biomass threshold of $B_{Threshold}$ = 9,000 mt (19.8 million lbs) and limit of B_{Limit} = 6,000 mt (13.2 million lbs) are based on historical abundance estimates and response to fishing pressure. The limit was set 2,000 metric tons higher than the lowest observed biomass – 4,000 mt in 1976 from ASPIC analysis (ASMFC 2001).

C7.1 Historical Proxies

Current management of Northern shrimp relies on historical proxies to establish fishing mortality targets and thresholds. Earlier efforts to develop model-based reference points resulted in values that were not consistent with estimates of F derived from the CSA model and suggested the stock could sustain levels of F and harvest much higher than had been estimated by the CSA model. In addition, uncertainty about natural mortality and the spawner-recruit relationship made model-based reference points and quota calculations less reliable. The historical proxy was chosen in part because the allowable catch and stock status determinations were not sensitive to assumptions about M.

C7.1.1 UME model

Because the selectivity of the fleet during the stable time period is different than the current fishery, the F_{target} and $F_{threshold}$ are based on the numbers-weighted value of F. The numbers-weighted value of F in the terminal year is calculated to compare to those reference points. The N-weighted F is calculated as the average partial F experienced by each length class, weighted by the numbers of shrimp in that length class:

$$\overline{F_y} = \frac{\sum_1^{Lmax} F_y \cdot selectivity_L \cdot N_{L,y}}{N_{total,y}}$$

The annual N-weighted Fs for 1985-1994 were averaged to produce the F_{target} = 0.22. The maximum N-weighted F for this time period was $F_{threshold}$ = 0.39.

The N-weighted F in 2013 was 0.04, below both the threshold and the target, indicating overfishing was not occurring (Figure C7.1).

The biomass threshold defined in Amendment 2 was used as the historical proxy for the UME model. One-half of the average SSB during the stable period (1985-1994) was defined as the SSB threshold, resulting in $SSB_{threshold}$ = 2,335 mt.

SSB_{2013} was estimated as 1,334 mt, below the $SSB_{threshold,}$ indicating the stock is overfished.

The historical biomass limit for Northern shrimp was derived from the ASPIC model and thus cannot be used to compare to the estimates from the size-structured UME model. Thus, a biomass limit reference point was not defined for this assessment.

Amendment 2 to the Northern shrimp FMP does not employ a biomass target because the Section did not want to set unlikely goals for a species whose biomass can easily be affected by environmental conditions. Shrimp management is focused on achieving the target F while keeping the biomass above the threshold level. Because historical proxy reference points were used, the NSTC did not estimate MSY. Shrimp recruitment is driven in part by temperature, and since environmental conditions in the Gulf of Maine are currently in a state of flux, model-based estimates of MSY would not be biologically meaningful or useful for management purposes.

C7.1.2 CSA model

The average F for the stable period from the updated CSA model was F_{target} = 0.20, with a maximum of $F_{threshold}$ = 0.27. The estimate of F_{2013} was 0.13, below both the threshold and the target, indicating overfishing was not occurring (Figure C7.2).

The average exploitable biomass for the stable period from the updated CSA model was 16,600 mt, resulting in a $B_{threshold}$ = 8,300 mt. The estimate of B_{2013} was 300 mt, well below the B threshold, indicating the stock is overfished.

C7.1.3 ASPIC model

The average F for the stable period from the updated ASPIC model was F_{target} = 0.23, with a maximum of $F_{threshold}$ = 0.35. The estimate of F_{2013} was 0.16, below both the threshold and the target, indicating overfishing was not occurring (Figure C7.3).

The average biomass for the stable period from the updated ASPIC model was 16,230 mt, resulting in a $B_{threshold}$ = 8,115 mt. The estimate of B_{2013} was 1,270 mt, below the B threshold, indicating the stock is overfished.

C7.2 Model-Based Reference Points

C7.2.1 Spawner-per-recruit Reference Points

Spawner-per-recruit reference points (F_{305SPR} and $F_{40\%SPR}$) were calculated from the selectivity and growth parameters estimated by the UME model. Setting $F_{40\%SPR}$ = 0.78 as the target and $F_{30\%SPR}$ = 1.17 as the threshold results in a similar assessment of stock status. The total full F from the trawl and trap fisheries in 2013 was 0.26, indicating overfishing was not occurring (Figure C7.4).

Because of the strong environmental effects on recruitment, and the fact that the environmental conditions in the Gulf of Maine are in a state of flux, the NSTC did not feel any SSB reference points based on a stock-recruitment relationship would be reliable.

C7.2.2 MSY Reference Points

MSY-based reference points were calculated from the ASPIC surplus production model. F_{MSY} was estimated as 0.19, and B_{MSY} was estimated as 22,800 mt. F_{2013} was 0.16, less than F_{MSY}, indicating overfishing was not occurring (Figure C7.5). B_{2013} was estimated to be 1,270 mt, well below B_{MSY} and $0.5B_{MSY}$, indicating the stock is overfished.

C7.3 Stock Status

Regardless of whether model based or historical reference points are chosen, all three models agree that overfishing was not occurring in 2013, but did occur in 2010-2012. In addition, stock biomass and abundance are at time-series lows and the stock is overfished when compared to historical proxy reference points .

BRP	F reference points	Biomass reference points
UME historical proxy	$F_{target} = 0.22$ $F_{threshold} = 0.39$	$SSB_{threshold} = 2{,}335$ mt
UME SPR	$F_{40\%SPR} = 0.78$ $F_{30\%SPR} = 1.17$	n.a.
CSA historical proxy	$F_{target} = 0.20$ $F_{threshold} = 0.27$	$B_{threshold} = 8{,}300$ mt
ASPIC MSY	$F_{MSY} = 0.19$	$B_{MSY} = 22{,}800$ mt

C7.4 BRPs and Changing Environmental Conditions

There is strong evidence that recruitment strength is driven by both spawning stock size and environmental conditions, particularly temperature (Richards *et al*. 2012). Unfortunately, environmental conditions in the Gulf of Maine are currently in flux. Model-based reference points that assume equilibrium conditions and historical reference points calculated from a different temperature regime may not be appropriate for the future dynamics of this stock. As temperatures in the Gulf of Maine continue to rise, levels of fishing mortality and biomass that were sustainable in the past may become unsustainable as the productivity of the stock declines.

C8.0 - TOR #4: CHARACTERIZE UNCERTAINTY OF MODEL ESTIMATES OF FISHING MORTALITY, BIOMASS AND RECRUITMENT, AND BIOLOGICAL REFERENCE POINTS.

[SAW58 Editor's Note: The SARC58 peer review panel concluded that the northern shrimp stock assessment models presented to them were not acceptable to serve as a basis for fishery management advice. Specifically, the SARC58 concluded that shrimp assessment Terms of Reference #2, #3, #4, and #5 were not met. These particular sections are included in this report to document the analyses that were done for the peer review, but they are not recommended by SARC58 as a basis for management.]

Uncertainty in model parameters was estimated through several different methods. For the UME model, asymptotic standard errors were estimated internally by the model. For the CSA model, an MCMC approach was used to estimate error (see Appendix C3 for more details). For the ASPIC model, residuals were bootstrapped to estimate error around the estimated and calculated parameters.

In addition, uncertainty was assessed qualitatively through retrospective and sensitivity analyses.

The coefficient of variation and Mohn's rho for fishing mortality, biomass, and recruitment for each model are presented in Table C8.1. Because all three models use different methods to calculate the CVs, they are not directly comparable. In particular, the asymptotic standard error calculated internally for the UME model is most likely an underestimate of what would be calculated from a bootstrap or Monte Carlo method.

Sensitivity analyses showed that the UME model is most sensitive to assumptions about the growth model used to develop the growth transition matrix (Figure C6.34). Changes in M did not strongly affect the model estimates in recent years, although they had a stronger effect on estimates of F and SSB in the early time period, which would affect the historical proxy reference points. Underestimating catch by 10% or 25% in the early years, before mandatory reporting, and underreported catch in the terminal year did not have a large effect on estimates of SSB and F. Increasing the likelihood weight on the survey did have an effect on estimates of F and SSB in the most recent years, predicting a higher F and lower SSB. The model showed a slight retrospective pattern in overestimating SSB and underestimating F in the terminal year.

Results from the CSA sensitivity analyses were similar (Figures C6.39-C6.41). Choice of M scales the population and fishing mortality estimates as expected. Including a time-varying M, scaled to predation, improved the retrospective pattern for the CSA but not the UME. The ASPIC model was not very sensitive to the surveys included, but had a strong retrospective pattern of underestimating F and overestimating biomass, indicating that the terminal year estimates are highly uncertain.

Absolute values of biological reference points were sensitive to choices of M as well as choice of model, but regardless of BRP calculation or model choice, stock status remained the same.

See Appendix C6 for additional sensitivity runs that were conducted at the review workshop.

C9.0 - TOR #5: REVIEW THE METHODS USED TO CALCULATE THE ANNUAL TARGET CATCH AND CHARACTERIZE UNCERTAINTY OF TARGET CATCH ESTIMATES.

[SAW58 Editor's Note: The SARC58 peer review panel concluded that the northern shrimp stock assessment models presented to them were not acceptable to serve as a basis for fishery management advice. Specifically, the SARC58 concluded that shrimp assessment Terms of Reference #2, #3, #4, and #5 were not met. These particular sections are included in this report to document the analyses that were done for the peer review, but they are not recommended by SARC58 as a basis for management.]

C.9.1 Background

In recent years, as part of the annual stock assessment update each autumn, the NSTC has been recommending a target catch level (TAC) for the upcoming GOM shrimp fishing season. In the past, this was done informally, and the NSTC's recommendation took the form of recommending the length of the fishing season, since season length was the most important, or most relied-upon, management tool to limit fishing effort. In 2005, the committee began recommending an annual TAC and leaving it up to the Section, with advice from industry and the NSTC, to craft a season that might achieve the TAC. From 2006 to 2009, the recommended TAC was not reached, probably because of low effort and poor market conditions. 2010 was the first season in which the Section took emergency action to close the season early when it became apparent that the recommended TAC had been exceeded. Since then, the Section has relied more heavily on the TAC as a management tool, requiring more careful monitoring of landings. For 2012, mandatory landings reporting by dealers became weekly instead of monthly, and the timely enforcement of a TAC became more attainable.

C.9.2 Annual target catch specification, as described in the FMP

Amendment 2 to the northern shrimp FMP, implemented in 2011 (ASMFC 2011), specifically requires the NSTC to recommend a target TAC annually. The Section can manage to the TAC by adjusting the fishing season length, as well as trip limits, trap limits, and days out, at any time during the season through emergency action. Other management tools are available, but must be implemented through the ASMFC addendum process.

Addendum 1 to Amendment 2 (ASMFC 2012) further specifies the methodology to be used to establish a "hard" TAC, and also addresses allocation by gear type, transferability, projecting the season closure, and research set asides. Addendum 1 also allows the ASMFC to close the fishery automatically (without a Section meeting or public input) when the NSTC projects that the TAC (or a percentage chosen beforehand by the Section at its annual season specifications meeting) will be reached. This process has not been utilized yet, because the 2013 TAC (625 mt) was never reached.

Addendum 1 describes the TAC calculation and specification process thusly:

"**Total Allowable Catch (TAC) Specification**

"The Section has the flexibility to set a hard TAC annually, that is associated with managing the Northern shrimp fishery,

- At the F_{target} [$F_{target} = F_{1985\text{-}94}$ from Amendment 2]
- At the $F_{threshold}$ [$F_{threshold} = F_{1987}$ from Amendment 2]
- Between the F_{target} and $F_{threshold}$

"The NSTC will estimate a TAC associated with the above management flexibility using results from the most recent stock assessment.

"**The methodology used to establish the TAC is described below.**

…"Catch in numbers (C) is a function of abundance (N) and exploitation rate (μ, which is a function of fishing mortality F and natural mortality M).

"Using this relationship, it is possible to estimate projected landings (in numbers) for a given year at various levels of F, using population estimates and an assumption of M.

"To convert landings in numbers to landings in weight, an assumption must be made about the mean weight of the shrimp caught in the upcoming fishery. The NSTC uses the relationship between the mean carapace length (mm) of female shrimp during the summer survey, and the mean weight (g) of an individual shrimp in the next fishing season, to predict the fishery mean weight." (ASMFC 2012)

Note that the committee estimates yield for various levels of F and reports these to the Section as possible TAC options; it is the Section which chooses and sets the TAC. For the 2014 season, the Section selected a TAC of 0 mt (fishery moratorium).

C9.3 Determining the target catch – estimating catch in numbers

To determine the TAC options for the 2014 season, the NSTC used the following relationship, based on Pope's approximation (Pope 1972) to the Baranov catch equation (Baranov 1918), which estimates the yield in numbers of shrimp for a given value of F, and then converts numbers to weight:

$$Yield_{2014} = F * (\text{exploitable abundance}) * e^{-p*M}$$

Where F = fishing mortality rate

p = proportion of year before start of fisheries (e.g., 52/365 for a fishery with a mid-point of Feb. 14.

M=natural mortality

For the CSA, which starts the year when the summer survey occurs, instead of on January 1:

N = CSA-estimated abundance of new and fully-recruited shrimp at time of survey

p =proportion of year between mean survey date and mean fishery date

For the UME model, exploitable abundance was calculated as the sum of the numbers in each size class in 2013 multiplied by a catch-weighted selectivity-at-length function. For the CSA model, exploitable abundance was calculated as the sum of new recruits and post-recruits in 2014.

This required making some assumptions about the timing of the potential 2014 season. Based on the poor stock conditions, the NSTC assumed a 2014 fishing season would be short and relatively late, to limit catch and allow maximum egg hatch. The results of calculations using these parameters and the formula above are in Table C.9.1.

C.9.4 Converting the catch in numbers to weight (metric tons)

Since specifying a TAC in numbers of shrimp caught is not particularly useful for the managers or for the administration of the TAC, the estimated yield from the process described above must be converted from numbers to weight. For this, the NSTC predicts the mean weight of one individual northern shrimp ("w" in the formula above) in the upcoming fishery, and multiplies the catch in numbers by this weight to estimate the catch in weight. Note that since the catch contains other species of shrimp, water, detritus, and other bycatch, this conversion factor is not actually the mean weight of one northern shrimp, but rather, the amount of catch that contains exactly one northern shrimp. However, it will be referred to here as the mean weight of one shrimp.

The mean weight of one shrimp for past seasons can be easily estimated by dividing each season's landings by the estimated number of northern shrimp in each of those landings. The estimated number of shrimp is obtained from port samples; the number of northern shrimp in a sample is expanded to that sample's catch, summed over samples by month, state, and gear, and expanded to that month-state-gear's landings as described in section C5.4.1 above. The mean weights of shrimp for the 1985-2013 fishing seasons are shown in Table C.9.2. Note that they have varied from 8.9g in 2006 to 13.78g in 1988.

The NSTC has struggled with predicting the size of shrimp in an upcoming fishing season. The previous summer survey provides useful information on stock size structure, but there are a number of complicating factors:

1. Shrimp will grow between the summer survey (late July to August) and the next fishery.
    a. The timing of the start, middle, and end of that fishery may vary and may be unknown to the NSTC ahead of time.
    b. The female shrimp will grow very little. Once they have extruded eggs (generally by late September (Clark et al 2000)) they stop molting and growing, as shown in Figure C.9.
2. Fishery gear selectivity is different from the survey gear selectivity. However, the selectivity of the fishing gear is not as important as the natural size selection that occurs when the female shrimp migrate inshore, leaving most of the smaller shrimp offshore.
3. The proportions of males (small) and females (large) in the catch, and the sizes of the males and females, vary from year to year, based on:
    a. The relative strength of the male and female year classes
    b. Whether there is good separation of males and females during the female migration.
    c. Whether the fishery is conducted before (December) and after (April and May) the female inshore migration.
    d. Fishers' choices of where (inshore vs. offshore) and when (early, middle, or late) to fish, and what gear to use (trawl vs. trap).

The NSTC has found that there is a strong relationship between the mean size (carapace length) of female shrimp from the summer survey (from data displayed in Figure C5.15 [the summer survey lfs]) and the mean size (weight) of a shrimp in the following fishery. This can be seen by eye when viewing Figure C.9.1. There is also a linear correlation when the fishery mean weights are plotted against the previous summer survey mean female lengths, for 1985 through 2013 (r^2 =0.43, Table C.9.2 and Figure C.9.2). When the mean fishery weights were smaller than predicted (see turquoise outliers in Figure C.9.2), it was often because there was a relatively strong year class of small, 3-year-old shrimp that the fishery was unable to avoid. For instance, in the 2005 survey, the assumed age 1.5 shrimp (2004 year class) were very abundant, and were caught as age 3 in the 2007 fishery (2006 survey year outlier in Figure C.9.2). The fit of the linear regression was improved (r^2 =0.52) if each year's mean survey female length was corrected downward by subtracting 0.001 x the age 1.5 index (no. per tow) from the previous survey (see method in Table C.9.3 and fit in Figure C.9.3). The fit was further improved (r^2 =0.82) if only recent years were used (survey years 2001 through 2012, Table C.9.3 and Figure C.9.4). Note that an exponential relationship, which might be expected to provide a better fit when correlating weight with length, did not improve the fit (r^2 =0.80, Figure C.9.4).

The mean length of the females in the 2013 summer survey was 26.45 mm. Inserting this value into the linear formula in Table C.9.3 and Figure C.9.4 gives an estimate of 11.64 g for the mean weight of shrimp in a 2014 fishery. This was the value used for "w" in the yield calculation in section C.9.3 above.

For the UME model, exploitable biomass can also be calculated from the numbers-at-length multiplied by the predicted weight-at-length from the length-weight relationship. The TAC from this method is also shown in Table C9.1. Results are similar. However, it should be noted that the length-weight relationship is for non-ovigerous females, and as a result will underestimate the mean size of a shrimp in the catch when egg-bearing females make up a non-trivial component of the catch. The proportion of egged females in the catch varies annually, and the NSTC favors using the predicted mean weight of the shrimp based on historical data over the L-W relationship.

C.9.5 Uncertainty of target catch estimates

Sources of uncertainty of the target catch estimates include:

1. Uncertainty around the model estimates of the exploitable abundance and biomass. Uncertainty around p, based on guessing the timing of the upcoming fishing season.

2. Uncertainty around the estimate of w, the mean weight of one shrimp in the upcoming season's landings. The difference between observed and predicted weights for 2001-2012 are given in Table C9.3.

C10.0 - TOR #6: DEVELOP DETAILED SHORT AND LONG-TERM PRIORITIZED LISTS OF RECOMMENDATIONS FOR FUTURE RESEARCH, DATA COLLECTION, AND ASSESSMENT METHODOLOGY. HIGHLIGHT IMPROVEMENTS TO BE MADE BEFORE THE NEXT BENCHMARK ASSESSMENT.

Improvements to be made before the next benchmark assessment are underlined.

In addition to the recommendations listed below, the NSTC emphasized the importance of continuing the summer shrimp survey despite the current low abundance of shrimp and the closure of the shrimp fishery in 2013.

C10.1 Fishery-Dependent Priorities

C10.1.1 Short-term

High

- Improve separator and excluder devices to reduce bycatch and discard of non-targeted species and small shrimp in the shrimp fishery and fisheries targeting other species.
- Evaluate selectivity of shrimp by traps and trawls.

Moderate

- <u>Evaluate commercial fishery sampling design. Increase and/or redistribute sampling of commercial catches as necessary, ensuring good allocation of samples among ports and months, to provide better estimates of size composition.</u>

C10.1.2 Long-term

High

- Continue to quantify the magnitude of bycatch of other species in the shrimp fishery by area and season and take steps necessary to limit negative impacts.

Moderate

- Continue sea sampling efforts.
-

C10.2 Fishery-Independent Priorities

C10.2.1 Short-term

High

- <u>Evaluate effectiveness of summer shrimp survey statistical design, including geographic coverage.</u>

Moderate

- Explore ways to sample age 1 and younger shrimp.

C10.2.2 Long-term

Low

- Verify that summer shrimp survey tow bottom tending times have been consistent.

C10.3 Modeling / Quantitative Priorities

C10.3.1 Short-term

High

- Continue research to refine annual estimates of consumption by predators, and include in models as appropriate.

Moderate

- Explore explicit inclusion of temperature effects in stock assessment models.
- Expand the time series of stock and recruitment data using catchability estimates from the production model.

C10.3.2 Long-term

Moderate

- Continue examination of methods for age determination to develop the possibility of using age based assessment methods.
- Develop a bio-economic model to study the interactions between four variables: movements of shrimp, catchability of shrimp, days fished, and market price.

C10.4 Life History, Biological, and Habitat Priorities

C10.4.1 Long-term

High

- Investigate application of newly developed direct ageing methods to ground truth assumed ages based on size and stage compositions.
- Evaluate larval and adult survival and growth, including frequency of molting and variation in growth rates, as a function of environmental factors and population density.
- Study the effects of oceanographic and climatic variation (i.e., North Atlantic Oscillation) on the cold water refuges for shrimp in the Gulf of Maine.
- Explore the mechanisms behind the stock-recruitment and temperature relationship for Gulf of Maine northern shrimp.

Moderate

- Determine the short and long-term effects of mobile fishing gear on shrimp habitat.
- Study specific habitat requirements and develop habitat maps for early life history stages.
- Evaluate effects of potential habitat loss/degradation on northern shrimp.
- Identify migration routes of immature males offshore and ovigerous females inshore.
- Evaluate maturation, fecundity, and lifetime spawning potential. Estimates of fecundity at length should be updated and the potential for annual variability should be explored. Examine variability of egg quality with female size and stage over time.

- Investigate changes in transition and maturation as a function of stock size and individual size and temperature.
    - Investigate diet of northern shrimp for different life history stages.

C10.5 Management, Law Enforcement, and Socioeconomic Priorities

C10.5.1 Short-term

High

- Explore new markets for Gulf of Maine shrimp, including community supported fisheries.
- Develop a framework to aid evaluation of the impact of limited entry proposals on the Maine fishing industry.

10.5.2 Long-term

High

- Characterize demographics of the fishing fleet by area and season. Perform comparative analysis of fishing practices between areas.
- Develop an understanding of product flow and utilization through the marketplace. Identify performance indicators for various sectors of the shrimp industry. Identify significant variables driving market prices and how their dynamic interactions result in the observed intra-annual and inter-annual fluctuations in market price for northern shrimp.
- Develop a socioeconomic analysis assessing the importance of the northern shrimp fishery in annual activities of commercial fishing.
- Determine the relative power relationships between the harvesting and processing sector and the larger markets for shrimp and shrimp products.
- Develop an economic-management model to determine the most profitable times to fish, how harvest timing affects markets, and how the market affects the timing of harvesting.

Moderate

- Perform cost-benefit analyses to evaluate management measures.

C11.0 - TOR #7: BASED ON THE BIOLOGY OF SPECIES, AND POTENTIAL SCIENTIFIC ADVANCES, COMMENT ON THE APPROPRIATE TIMING OF THE NEXT BENCHMARK ASSESSMENT AND INTERMEDIATE UPDATES.

The NSTC recommends that the Northern shrimp stock assessment be updated annually to incorporate the most recent information on recruitment, size composition, and landings into the quota/specification setting process. Annual specifications are important for a short-live species with highly environmentally-driven recruitment like Northern shrimp.

Initially, the NSTC recommended that a full benchmark assessment be conducted in five years.

In light of the peer review outcome, the NSTC recommends a benchmark assessment be carried out sooner, ideally in the next two to three years. This will give the NSTC time to evaluate the performance of the new size-structured model through simulation work and resolve the data-weighting and fit issues identified by the Panel, as well as incorporate additional information on the Gulf of Maine's changing environmental conditions.

C12.0 REFERENCES

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Table C4.1. Shrimp Section for management of the Gulf of Maine northern shrimp fishery, 1987 – 2014 (adapted from Clark et al. 2000)

Fishing Season	Recommendations	Actions Taken
1987	• Extension of season to maximum allowed • Continuation of mesh regulations	• Open season (182 days) • Continuation of mesh regulations
1988	• Restriction of season to winter and spring • Continuation of mesh regulations	• Open season (183 days) • Continuation of mesh regulations, except 0.25 inch tolerance in codend eliminated
1989	• Extension of season to maximum allowed • Continuation of mesh regulations	• Open season (182 days) • Continuation of mesh regulations • Shrimp separator trawls required in April and May
1990	• Extension of season to maximum allowed • Continuation of mesh regulations	• Open season (182 days) • Continuation of mesh regulations • Shrimp separator trawls required in December, April, and May
1991	• Extension of season to maximum allowed • Continuation of mesh regulations	• Open season (182 days) • Continuation of mesh regulations • Shrimp separator trawls required throughout season
1992	• Restriction of season from January – March • Continuation of mesh regulations	• Open season (153 days). December 16, 1991 – May 15, 1992. • No fishing on Sundays • Continuation of mesh regulations • Shrimp separator trawls required throughout season • Finfish excluder devices required April 1 – May 15
1993	• Restriction of season from January – March • Continuation of mesh regulations	• Open season (138 days). December 14, 1992 – April 30, 1993 • No fishing on Sundays • Continuation of mesh regulations • Finfish excluder devices and separator panels required
1994	• Restriction of season from January – March • Continuation of mesh regulations	• Open season (122 days) December 15, 1993 – April 15, 1994. • Continuation of mesh regulations • Finfish excluder devices
1995	• Restriction of season from January – March • Continuation of mesh regulations	• Open season (128 days). December 1, 1994 – April 30, 1995. • No fishing Fridays or Sundays (state choice) • Continuation of mesh regulations • Finfish excluder devices required
1996	• Extension of season to maximum allowed • Continuation of mesh regulations	• Open season (152 days). December 1, 1995 – May 31, 1996 for mobile gear; no fishing one day per week. • Open season (121 days). January 1 – May 31, 1996 for fixed gear (traps) • Continuation of mesh regulations • Finfish excluder devices required
1997	• Restriction of effort in December, April, and May • Continuation of mesh regulations	• Open season (156 days). December 1, 1996 – May 31. Two 5-day and four 4-day blocks of no fishing. Trap gear may be left untended. • Continuation of mesh regulations

		• Finfish excluder devices required
1998	• Restriction of effort in February – March • Continuation of mesh regulations	• Open season (105 days). December 1, 1997 – May 22, 1998 for mobile gear; no fishing weekends except March 14 – 15 and December 25-31 and March 16 – 31. • Open season (65 days). January 1 – March 15 for trap gear. No fishing on Sundays except March 15. • Continuation of mesh regulations • Finfish excluder devices required
1999	• Restriction of season to 40 days during February – March • Continuation of mesh regulations	• Open season (90 days). December 15, 1998 – May 25, 1999 for mobile gear. No fishing on weekends plus December 24-25, December 28 – January 1, January 27-29, February 24-26, March 17-31, and April 29-30. • Open season (61 days). January 10 – March 10 for trap gear. • Continuation of mesh regulations • Finfish excluder devices required
2000	• No fishing; closed season	• Open season (51 days). January 15 – March 15. No fishing on Sundays. • Continuation of mesh regulations • Finfish excluder devices required
2001	• Restriction of season to 61 days • Continuation of mesh regulations	• Open season (83 days). January 9 – April 30. March 18-April 15 no fishing. Experimental offshore fishery in May. • Continuation of mesh regulations • Finfish excluder devices required
2002	• No fishing; closed season	• Open season (25 days). February 15 – March 11. • Continuation of mesh regulations • Finfish excluder devices required
2003	• No fishing; closed season	• Open season (38 days). January 15 – February 27. No fishing on Fridays. • Continuation of mesh regulations • Finfish excluder devices required
2004	• No fishing; closed season	• Open season (40 days). January 19 – March 12. No fishing on weekends. • Continuation of mesh regulations • Finfish excluder devices required • No mechanical shaking of net on vessel
2005	• Landings should not exceed 2,500 metric tons • Continuation of mesh regulations	• Open season (70 days). December 19 – 30, no fishing on Friday and Saturday; January 3 – March 25, no fishing on weekends. • Continuation of mesh regulations • Finfish excluder devices required • No mechanical shaking of net on vessel
2006	• Landings should not exceed 5,200 metric tons • Continuation of mesh regulations	• Open season (140 days). December 12 – April 30. • 2007 fishing season tentatively set at 140 days. • Continuation of mesh regulations • No mechanical shakers allowed on vessel
2007	• No recommendation against 140-day season • Continuation of mesh regulations	• Open season (151 days). December 1 – April 30. • 2008 fishing season tentatively set at 151 days. • Continuation of mesh regulations • No mechanical shakers allowed on vessel

2008	• No recommendation against 152-day season • Maintain fishing mortality at or below the target/threshold	• Open season (152 days). December 1 – April 30. • 2009 fishing season tentatively set from December to April • Continuation of mesh regulations • No mechanical shakers allowed on vessel
2009	• Landings should not exceed 5,103 metric tons • Maintain fishing mortality at or below the target/threshold	• Open season (180 days). December 1 – May 29. • Continuation of mesh regulations • No mechanical shakers allowed on vessel
2010	• Landings should not exceed 4,400 to 4,900 metric tons • Maintain fishing mortality at or below the target/threshold	• Open season (180 days). December 1 – May 29. Closed early on May 5, 2010. • Continuation of mesh regulations • No mechanical shakers allowed on vessel
2011	• Based on favored fishing mortality rate, landings should not exceed 3,200 metrics tons (F = 0.22) or 4,000 metric tons (F = 0.29)	• Open season (136 days). December 1 – April 15. Closed early on February 28, 2011. • Continuation of mesh regulations • No mechanical shakers allowed on vessel
2012	• Maintain fishing mortality at or below the target value (F = 0.32) • Landings should not exceed 1,834 metric tons	• Total allowable catch (TAC) of 2,000 metric tons; increased to 2,211 metric tons on January 20, 2012 • Trap season start on February 1 with a 1,000 pound landing limit per vessel per day • Trawl season start on January 2, 2012 with three landing days a week
2013	• Moratorium on fishing • If fishing is allowed, start season after 50% of shrimp have hatched their brood	• TAC of 625 metric tons; divided 17% to trap fishery and 83% to trawl fishery • Trawl fishery start on January 22, 2013with two landings days • Trap fishery start on February 5, 2013 with 6 landings days and an 800 lb limit • Landings days modified throughout season
2014	• Moratorium on fishing; the stock has collapsed	• Moratorium on fishing

Table C4.2. Age-constant estimates of natural mortality for Northern shrimp.

ESTIMATORS OF AGE-CONSTANT NATURAL MORTALITY

INPUT	Type	von B age-length		longevity		maturity		environ.
	Parameter	L_inf	K	t_max	P	a_50	GI	Temp
	Units	*mm*	*year -1*	*years*		*years*		° *C*
	Value	35.2	0.360	6	0.015	1.5	NA	3

ESTIMATES

Method	Note	Equation	Required Parameters L_inf	K	t_max	P	a_50	GI	temp	M *instantaneous*	M *annual*
Alverson and Carney 1975		**M** = 3**K**/(exp[0.38***K*****t_max**) − 1]		X	X					0.85	0.57
Rikhter and Efanov 1977		**M** = [1.521/(**a_50**^0.720)] − 0.155					X			0.98	0.63
Gunderson 1980		**M** = −0.370 + 4.64**GI**						X		NA	NA
Pauly 1980	1	**M** = exp[−0.0152 + 0.6543*ln(**K**) − 0.279*ln(**L_inf**/10) + 0.4634*ln(**Temp**)]	X	X					X	0.59	0.45
Hoenig 1983 (regression)	2	**M** = exp[1.44 − 0.982*ln(**t_max**)]			X					0.73	0.52
Hoenig 1983 (rule-of-thumb)	3	**M** = −ln(**P**)/**t_max**			X	X				0.70	0.50
Ralston 1987 (linear regression)	4	**M** = 0.0189 + 2.06***K**		X						0.76	0.53
Gunderson and Dygert 1988		**M** = 0.03 + 1.68***GI**						X		NA	NA
Jensen 1996 (theoretical)		**M** = 1.50***K**		X						0.54	0.42
Jensen 1996 (derived from Pauly 1980)		**M** = 1.60***K**		X						0.58	0.44
Gunderson 1997		**M** = 1.79***GI**						X		NA	NA
Hewitt and Hoenig 2005		**M** = 4.22/**t_max**			X					0.70	0.51
Beverton	5	**M** = 3***K**/[exp(**a_50*****K**) − 1]		X			X			1.51	0.78

Notes

1 Pauly's (1980) equation converted from base 10 to natural logarithms by Quinn and Deriso (1999); L_inf divided by 10 to adjust for mm
2 Values 1.44 (intercept) and -0.982 (slope) were those recommended by Hoenig (1983)
3 Equation ≈ 3/t_max when P = 0.05
4 Ralston's (1987) relationship was developed for snappers and groupers
5 Was not able to verify this equation or identify reference

Table C4.3. Age-varying estimates of natural mortality for Northern shrimp using Lorenzen's (1996) method, unscaled and scaled to the maximum observed age in the population.

ESTIMATOR OF AGE-VARYING NATURAL MORTALITY USING LORENZEN'S (1996) MORTALITY-WEIGHT MODEL

INPUT	Type	age range			von B age-length			len(mm)-wt(g)		mortality-weight *	
	Parameter	t_min	t_max	P	L_inf	K	t_0	alpha	beta	M_u	b
	Units	*years*	*years*		*mm*	*year -1*	*years*				
	Value	0	6	0.015	35.2	0.360	NA	5.93E-04	3.01	3.69	-0.305

ESTIMATES

Method	Equation	Age *years*	Length *mm*	Weight *g*	M(W) - unscaled *instantaneous*	M(W) - unscaled *annual*	M(W) - scaled** *instantaneous*	M(W) - scaled** *annual*
Lorenzen 1996	**M**(W) = **M_u** * W ^ **b**	**0**	8	0.3	5.224	0.99	1.33	0.74
Scaled estimate	**-M(a)* LN(%-at-max-age)/ΣM(a)**	**1**	16	2.6	2.752	0.94	0.70	0.50
		2	22	6.5	2.089	0.88	0.53	0.41
		3	26	10.7	1.793	0.83	0.46	0.37
		4	29	14.5	1.633	0.80	0.42	0.34
		5	31	17.6	1.538	0.79	0.39	0.32
		6	32	20.1	1.479	0.77	0.38	0.31

Table C4.4. Age-varying estimates of natural mortality for Northern shrimp using Gislason *et al.'s* (2010) method.

ESTIMATOR OF AGE-VARYING NATURAL MORTALITY USING GISLASON ET AL'S (2010) MORTALITY-GROWTH MODEL							
INPUT	Type	age range		von B age-length		
	Parameter	t_min	t_max	L_inf	K	t_0
	Units	*years*	*years*	*mm*	*year -1*	*years*
	Value	0	6	35.2	0.360	NA

ESTIMATES					
		Age	Length	M(L)	
Method	Equation	*years*	*mm*	*instantaneous*	*annual*
Gislason et al. (2010)	**M**(L)=exp[0.55 − 1.61*ln(L/10) + 1.44*ln(**L_inf**/10)+ln(**K**)]	**0**	8.1	5.36	1.00
		1	16	1.74	0.82
		2	22	1.07	0.66
		3	26	0.82	0.56
		4	29	0.70	0.50
		5	31	0.63	0.47
		6	32	0.59	0.44

Table C4.5. Length-varying U-shaped M for Northern shrimp.

Length (mm)	M	Source
10	1.10	Scaled Lorenzen (1996) estimate of M-at-length
11	1.00	
12	0.93	
13	0.86	
14	0.80	
15	0.76	
16	0.71	
17	0.67	
18	0.64	
19	0.61	
20	0.58	
21	0.25	Rinaldo (1976)
22	0.25	
23	0.25	
24	0.25	
25	0.25	
26	0.25	
27	0.25	
28	0.25	
29	0.75	Estimated to align with maximum observed age
30	0.75	
31	0.75	
32	0.75	
33	0.75	
34	0.75	

Table C5.1. U.S. Commercial landings (mt) of northern shrimp in the Gulf of Maine.
1 mt = 2,205 lbs

Year	Maine	Massachusetts	New Hampshire	Total	Price $/Lb	Value $
1958	2.2	0.0	0.0	2.2	0.32	1,532
1959	5.5	2.3	0.0	7.8	0.29	5,002
1960	40.4	0.5	0.0	40.9	0.23	20,714
1961	30.5	0.3	0.0	30.8	0.20	13,754
1962	159.5	16.2	0.0	175.7	0.15	57,382
1963	244.3	10.4	0.0	254.7	0.12	66,840
1964	419.4	3.1	0.0	422.5	0.12	112,528
1965	941.3	8.0	0.0	949.3	0.12	245,469
1966	1,737.8	10.5	18.1	1,766.4	0.14	549,466
1967	3,141.2	10.0	20.0	3,171.2	0.12	871,924
1968	6,515.2	51.9	43.1	6,610.2	0.11	1,611,425
1969	10,993.1	1,773.1	58.1	12,824.3	0.12	3,478,910
1970	7,712.8	2,902.3	54.4	10,669.5	0.20	4,697,418
1971	8,354.8	2,724.0	50.8	11,129.6	0.19	4,653,202
1972	7,515.6	3,504.6	74.8	11,095.0	0.19	4,586,484
1973	5,476.6	3,868.2	59.9	9,404.7	0.27	5,657,347
1974	4,430.7	3,477.3	36.7	7,944.7	0.32	5,577,465
1975	3,177.2	2,080.0	29.4	5,286.6	0.26	3,062,721
1976	617.3	397.8	7.3	1,022.4	0.34	764,094
1977	142.1	236.9	2.2	381.2	0.55	458,198
1978	0.0	3.3	0.0	3.3	0.24	1,758
1979	32.8	405.9	0.0	438.7	0.33	320,361
1980	69.6	256.9	6.3	332.8	0.65	478,883
1981	530.0	539.4	4.5	1,073.9	0.64	1,516,521
1982	883.0	658.5	32.8	1,574.3	0.60	2,079,109
1983	1,029.2	508.2	36.5	1,573.9	0.67	2,312,073
1984	2,564.7	565.4	96.8	3,226.9	0.49	3,474,351

Table C5.1 continued – U.S. commercial landings (metric tons, mt) of northern shrimp in the Gulf of Maine. 1 mt = 2,205 lbs
(*2012 and 2013 data are preliminary)

Season	Maine	Massachusetts	New Hampshire	Total	Price $/Lb	Value $
1985	2,946.4	968.8	216.7	4,131.9	0.44	3,984,562
1986	3,268.2	1,136.3	230.5	4,635.0	0.63	6,451,206
1987	3,680.2	1,427.9	157.9	5,266.0	1.10	12,740,581
1988	2,258.4	619.6	157.6	3,035.6	1.10	7,391,777
1989	2,384.0	699.9	231.5	3,315.4	0.98	7,177,659
1990	3,236.3	974.9	451.3	4,662.5	0.72	7,351,420
1991	2,488.6	814.6	282.1	3,585.3	0.91	7,208,838
1992	3,070.6	289.3	100.1	3,460.0	0.99	7,547,941
1993	1,492.5	292.8	357.6	2,142.9	1.07	5,038,053
1994	2,239.7	247.5	428.0	2,915.2	0.75	4,829,106
1995	5,013.7	670.1	772.8	6,456.6	0.90	12,828,030
1996	8,107.1	660.6	771.7	9,539.4	0.73	15,341,504
1997	6,086.9	366.4	666.2	7,119.5	0.79	12,355,871
1998	3,481.3	240.3	445.2	4,166.8	0.96	8,811,938
1999	1,573.2	75.7	217.0	1,865.9	0.91	3,762,043
2000	2,516.2	124.1	214.7	2,855.0	0.79	4,968,655
2001	1,075.2	49.4	206.4	1,331.0	0.86	2,534,095
2002	391.6	8.1	53.0	452.7	1.08	1,077,534
2003	1,203.7	27.7	113.0	1,344.4	0.87	2,590,916
2004	1,926.9	21.3	183.2	2,131.4	0.44	2,089,636
2005	2,270.2	49.6	290.3	2,610.1	0.57	3,261,648
2006	2,201.6	30.0	91.1	2,322.7	0.37	1,885,978
2007	4,469.3	27.5	382.9	4,879.7	0.38	4,087,120
2008	4,515.8	29.9	416.8	4,962.4	0.49	5,407,373
2009	2,315.7	MA-NH combined 185.6		2,315.7	0.40	2,051,987
2010	5,604.3	35.1	501.4	6,140.8	0.52	6,994,106
2011	5,569.7	196.4	631.5	6,397.5	0.75	10,625,533
*2012	2,211.4	77.8	187.8	2,476.9	0.95	5,212,137
*2013	255.5	20.3	31.3	307.1	1.81	1,223,045

Table C5.2. Distribution of landings (metric tons, mt) in the Gulf of Maine northern shrimp fishery by state and month.
1 mt = 2,205 lbs

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
1985 Season, 166 days, Dec 1 - May 15								
Maine	335.7	851.8	1,095.5	525.1	116.8	21.5	0.0	2,946.4
Mass.	91.7	283.9	238.3	239.3	57.8	57.0	0.8	968.8
N.H.	67.0	86.2	50.4	11.6	1.3		0.2	216.7
Total	494.4	1,221.9	1,384.2	776.0	175.9	78.5	1.0	4,131.9
1986 Season, 196 days, Dec 1 - May 31, June 8-21								
Maine	346.9	747.8	1,405.3	415.4	104.2	149.2	99.4	3,268.2
Mass.	154.3	213.4	221.2	200.7	111.2	84.8	150.7	1,136.3
N.H.	57.7	75.9	70.8	14.2	1.3	0.0	10.6	230.5
Total	558.9	1,037.1	1,697.3	630.3	216.7	234.0	260.7	4,635.0
1987 Season, 182 days, Dec 1 - May 31								
Maine	485.9	906.2	1,192.7	672.9	287.6	127.9	7.0	3,680.2
Mass.	103.5	260.0	384.9	310.2	180.8	182.8	5.7	1,427.9
N.H.	18.4	53.6	62.8	15.7	7.3	0.0	0.1	157.9
Total	607.8	1,219.8	1,640.4	998.8	475.7	310.7	12.8	5,266.0
1988 Season, 183 days, Dec 1 - May 31								
Maine	339.7	793.9	788.1	243.6	24.6	67.3	1.2	2,258.4
Mass.	14.4	225.8	255.0	104.9	8.6	10.9	0.0	619.6
N.H.	13.0	72.6	53.7	14.9	0.3	0.0	3.1	157.6
Total	367.1	1,092.3	1,096.8	363.4	33.5	78.2	4.3	3,035.6
1989 Season, 182 days, Dec 1 - May 31								
Maine	353.6	770.5	700.6	246.4	218.7	94.2		2,384.0
Mass.	26.2	197.5	154.9	104.8	160.9	55.6		699.9
N.H.	28.5	106.9	77.0	15.4	3.7	0.0		231.5
Total	408.3	1,074.9	932.5	366.6	383.3	149.8	0.0	3,315.4
1990 Season, 182 days, Dec 1 - May 31								
Maine	512.4	778.4	509.8	638.7	514.1	282.8	0.1	3,236.3
Mass.	75.6	344.5	184.8	100.2	159.0	110.0	0.8	974.9
N.H.	111.3	191.7	116.2	30.7	1.4			451.3
Total	699.3	1,314.6	810.8	769.6	674.5	392.8	0.9	4,662.5
1991 Season, 182 days, Dec 1 - May 31								
Maine	238.3	509.2	884.1	455.0	251.8	148.2	2.0	2,488.6
Mass.	90.6	174.7	176.0	131.2	93.3	133.8	15.0	814.6
N.H.	107.3	104.4	33.8	27.8	7.8	1.0		282.1
Total	436.2	788.3	1,093.9	614.0	352.9	283.0	17.0	3,585.3
1992 Season, 153 days, Dec 15 - May 15								
Maine	181.2	881.0	1,295.0	462.6	163.6	87.2		3,070.6
Mass.	17.1	148.3	73.3	47.6	2.9		0.1	289.3
N.H.	33.4	47.0	11.9	6.8	1.0			100.1
Total	231.7	1,076.3	1,380.2	517.0	167.5	87.2	0.1	3,460.0

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
1993 Season, 138 days, Dec 14 - April 30								
Maine	101.0	369.1	597.1	297.5	127.8			1,492.5
Mass.	19.6	82.0	81.9	62.3	42.0	5.0		292.8
N.H.	33.5	85.4	101.8	77.0	59.9			357.6
Total	154.1	536.5	780.8	436.8	229.7	5.0	0.0	2,142.9
1994 Season, 122 days, Dec 15 - Apr 15								
Maine	171.5	647.8	972.1	399.6	48.7			2,239.7
Mass.	27.1	68.0	100.8	38.8	12.8			247.5
N.H.	117.2	124.3	128.7	49.6	8.2			428.0
Total	315.8	840.1	1,201.6	488.0	69.7	0.0	0.0	2,915.2
1995 Season, 128 days, Dec 1 - Apr 30, 1 day per week off								
Maine	747.3	1,392.9	1,336.0	912.1	625.4			5,013.7
Mass.	160.6	154.0	104.1	111.0	139.5		0.9	670.1
N.H.	210.2	186.8	118.3	158.5	99.0			772.8
Total	1,118.1	1,733.7	1,558.4	1,181.6	863.9	0.0	0.9	6,456.6
1996 Season, 152 days, Dec 1 - May 31, 1 day per week off								
Maine	1,122.0	1,693.1	3,236.9	795.6	361.5	897.6	0.4	8,107.1
Mass.	167.9	106.7	190.7	67.2	66.5	60.3	1.3	660.6
N.H.	189.8	169.5	234.0	81.9	78.8	17.1	0.6	771.7
Total	1,479.7	1,969.3	3,661.6	944.7	506.8	975.0	2.3	9,539.4
1997 Season, 156 days, Dec 1 - May 27, two 5-day and four 4-day blocks off								
Maine	1,178.0	1,095.8	1,749.3	758.4	766.8	538.2	0.4	6,086.9
Mass.	90.2	110.4	111.4	49.0	1.2	0.5	3.7	366.4
N.H.	185.6	104.1	140.1	108.4	85.8	42.2	0.0	666.2
Total	1,453.8	1,310.3	2,000.8	915.8	853.8	580.9	4.1	7,119.5
1998 Season, 105 days, Dec 8 - May 22, weekends off except Mar 14-15, Dec 25-31 and Mar 16-31 off.								
Maine	511.1	926.8	1,211.1	401.0	228.7	202.6		3,481.3
Mass.	49.1	73.3	88.6	14.0	15.3			240.3
N.H.	89.4	106.9	143.5	54.3	49.0	2.1		445.2
Total	649.6	1,107.0	1,443.2	469.3	293.0	204.7	0.0	4,166.8
1999 Season, 90 days, Dec 15 - May 25, weekends, Dec 24 - Jan 3, Jan 27-31, Feb 24-28, Mar 16-31, and Apr 29 - May 2 off.								
Maine	79.9	192.7	599.3	247.9	205.3	248.1		1,573.2
Mass.	25.0	23.8	16.0	2.5	8.4			75.7
N.H.	46.5	63.2	52.2	10.0	36.5	8.6		217.0
Total	151.4	279.7	667.5	260.4	250.2	256.7	0.0	1,865.9
2000 Season, 51 days, Jan 17 - Mar 15, Sundays off								
Maine		759.9	1,534.4	221.9				2,516.2
Mass.		25.9	86.0	12.2				124.1
N.H.		40.6	133.7	40.4				214.7
Total	0.0	826.4	1,754.0	274.6	0.0	0.0	0.0	2,855.0

Table C5.2 continued – Landings by season, state, and month.

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
2001 Season, 83 days, Jan 9 - Apr 30, Mar 18 - Apr 16 off, experimental offshore fishery in May								
Maine		575.8	432.8	36.6	29.8	0.3		1,075.2
Mass.		38.5	9.0	1.9		0.002		49.4
N.H.		127.9	78.6	conf	conf			206.4
Total	0.0	742.2	520.3	38.4	29.8	0.3	0.0	1,331.0
2002 Season, 25 days, Feb 15 - Mar 11								
Maine			306.8	84.8				391.6
Mass.			8.1	conf				8.1
N.H.			38.6	14.4				53.0
Total	0.0	0.0	353.5	99.1	0.0	0.0	0.0	452.7
2003 Season, 38 days, Jan 15 - Feb 27, Fridays off								
Maine		534.7	668.0	0.4			0.6	1,203.7
Mass.		12.0	15.7					27.7
N.H.		30.9	82.1					113.0
Total	0.0	577.6	765.8	0.4	0.0	0.0	0.6	1,344.4
2004 Season, 40 days, Jan 19 - Mar 12, Saturdays and Sundays off								
Maine	1.8	526.2	945.1	446.4	4.7	2.7	0.04	1,926.9
Mass.		conf	21.3	conf				21.3
N.H.		27.3	94.8	61.1				183.2
Total	1.8	553.5	1,061.1	507.5	4.7	2.7	0.04	2,131.4
2005 Season, 70 days, Dec 19 - 30, Fri-Sat off, Jan 3 - Mar 25, Sat-Sun off								
Maine	75.0	369.4	903.2	922.6			0.01	2,270.2
Mass.	7.2	8.1	24.9	9.4				49.6
N.H.	17.3	53.5	175.4	44.1				290.3
Total	99.5	431.0	1,103.6	976.0	0.0	0.0	0.01	2,610.1
2006 Season, 140 days, Dec 12 - Apr 30								
Maine	144.1	691.7	896.9	350.8	118.0			2,201.6
Mass.	conf	conf	30.0	conf	conf			30.0
N.H.	3.4	27.9	9.6	50.3	conf			91.1
Total	147.5	719.6	936.5	401.1	118.0	0.0	0.0	2,322.7
2007 Season, 151 days, Dec 1 - Apr 30								
Maine	761.9	1,480.5	1,590.4	481.9	154.2	0.4	0.03	4,469.3
Mass.	conf	27.5	conf	conf				27.5
N.H.	52.5	222.6	81.6	26.1	conf			382.9
Total	814.4	1,730.6	1,672.0	508.1	154.2	0.4	0.0	4,879.7
2008 Season, 152 days, Dec 1 - Apr 30								
Maine	408.5	1,053.7	2,020.4	983.8	49.3		0.1	4,515.8
Mass.	conf	conf	15.4	14.5				29.9
N.H.	94.2	123.7	161.6	37.4	conf			416.8
Total	502.6	1,177.4	2,197.3	1,035.7	49.3	0.0	0.1	4,962.4

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
2009 Season, 180 days, Dec 1 - May 29								
Maine	134.6	595.9	988.2	560.1	34.9	1.8	0.2	2,315.7
Mass.& NH	conf	112.9	72.6	conf	conf			185.6
Total	134.6	708.8	1,060.8	560.1	34.9	1.8	0.2	2,501.2
2010 Season, 156 days, Dec 1 - May 5								
Maine	263.4	1,683.1	2,914.5	515.6	194.3	33.0	0.4	5,604.3
Mass.	conf	16.9	18.2	conf	conf			35.1
N.H.	107.3	152.4	200.0	14.2	27.4	conf		501.4
Total	370.7	1,852.5	3,132.7	529.8	221.7	33.0	0.4	6,140.8
2011 Season, 90 days, Dec 1 - Feb 28								
Maine	722.7	2,572.2	2,274.3	0.5				5,569.7
Mass.	20.8	100.9	74.7					196.4
N.H.	93.1	304.0	234.4					631.46
Total	836.6	2,977.0	2,583.4	0.5	0.0	0.0	0.0	6,397.5
***2012** Season, Trawling Mon,Wed,Fri, Jan 2 - Feb 17 (21days); Trapping Feb 1-17 (17 days)								
Maine	0.5	1,130.1	1,080.2	0.5				2,211.4
Mass.		58.4	19.4					77.8
N.H.		119.2	68.6					187.8
Total	0.5	1,307.7	1,168.2	0.5	0.0	0.0	0.0	2,476.9
***2013** Season, Trawling 3 to 7 days/wk, Jan 23 - Apr 12 (54 days); Trapping 6 or 7 days/wk, Feb 5 - Apr 12 (62 days)								
Maine		54.2	167.2	33.6	0.5			255.5
Mass.		4.3	8.9	7.2	conf			20.3
N.H.		14.5	13.5	3.3	conf			31.3
Total	0.0	72.9	189.5	44.1	0.5	0.0	0.0	307.1

conf = Confidential data were included in an adjacent month.
* Preliminary data

Table C5.3. Distribution of landings (metric tons, mt) in the Maine northern shrimp fishery by season, gear type, and month.
1 mt = 2,205 lbs

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total	% of total
2000 Season, 51 days, Jan 17 - Mar 15, Sundays off									
Trawl		731.1	1,354.8	163.6				2,249.47	89%
Trap		28.9	179.6	58.3				266.7	11%
Total	0.0	759.9	1,534.4	221.9	0.0	0.0	0.0	2,516.2	
2001 Season, 83 days, Jan 9 - Apr 30, Mar 18 - Apr 16 off, experimental offshore fishery in May									
Trawl		533.0	360.1	30.9	29.8	0.3		954.0	89%
Trap		42.9	72.6	5.7				121.2	11%
Total	0.0	575.8	432.8	36.6	29.8	0.3	0.0	1,075.2	
2002 Season, 25 days, Feb 15 - Mar 11									
Trawl			263.6	77.2				340.8	87%
Trap			43.2	7.6				50.8	13%
Total	0.0	0.0	306.8	84.8	0.0	0.0	0.0	391.6	
2003 Season, 38 days, Jan 15 - Feb 27, Fridays off									
Trawl		467.2	518.8	0.4			0.6	987.0	82%
Trap		67.5	149.2					216.7	18%
Total	0.0	534.7	668.0	0.4	0.0	0.0	0.6	1,203.7	
2004 Season, 40 days, Jan 19 - Mar 12, Saturdays and Sundays off									
Trawl	1.8	514.0	905.5	430.0	4.7	2.7	0.04	1858.7	96%
Trap		12.2	39.5	16.5				68.1	4%
Total	1.8	526.2	945.1	446.4	4.7	2.7	0.04	1926.9	
2005 Season, 70 days, Dec 19 - 30, Fri-Sat off, Jan 3 - Mar 25, Sat-Sun off									
Trawl	75.0	369.4	770.6	663.6			0.01	1878.5	83%
Trap		conf	132.6	259.0				391.6	17%
Total	75.0	369.4	903.2	922.6	0.0	0.0	0.01	2270.2	
2006 Season, 140 days, Dec 12 - Apr 30									
Trawl	144.1	675.0	733.8	256.9	117.1			1927.0	88%
Trap	conf	16.7	163.1	93.9	0.9			274.6	12%
Total	144.1	691.7	896.9	350.8	118.0	0.0	0.0	2201.6	
2007 Season, 151 days, Dec 1 - Apr 30									
Trawl	758.2	1,443.3	1,275.6	362.1	143.6	0.4	0.0	3,983.2	89%
Trap	3.7	37.2	314.7	119.8	10.6			486.1	11%
Total	761.9	1,480.5	1,590.4	481.9	154.2	0.4	0.0	4,469.3	
2008 Season, 152 days, Dec 1 - Apr 30									
Trawl	408.5	989.6	1,680.8	603.4	42.6		0.1	3,724.9	82%
Trap	conf	64.1	339.6	380.4	6.7			790.8	18%
Total	408.5	1,053.7	2,020.4	983.8	49.3	0.0	0.1	4,515.8	
2009 Season, 180 days, Dec 1 - May 29									
Trawl	134.3	579.7	780.9	405.4	33.6	1.8	0.2	1,935.9	84%
Trap	0.4	16.2	207.3	154.7	1.3			379.8	16%
Total	134.6	595.9	988.2	560.1	34.9	1.8	0.2	2,315.7	
2010 Season, 156 days, Dec 1 - May 5									
Trawl	263.4	1,488.3	2,091.1	326.3	194.3	33.0	0.4	4,396.7	78%
Trap	conf	194.8	823.4	189.3	conf			1,207.6	22%
Total	263.4	1,683.1	2,914.5	515.6	194.3	33.0	0.4	5,604.3	
2011 Season, 90 days, Dec 1 - Feb 28									
Trawl	720.8	2,194.5	1,728.5	0.5				4,644.4	83%
Trap	1.9	377.7	545.8					925.3	17%
Total	722.7	2,572.2	2,274.3	0.5	0.0	0.0	0.0	5,569.7	
***2012** Season, Trawling Mon,Wed,Fri, Jan 2 - Feb 17 (21 days); Trapping Feb 1-17 (17 days)									
Trawl	0.5	1,130.1	887.1	0.5				2,018.3	91%
Trap			193.1					193.1	9%
Total	0.5	1,130.1	1,080.2	0.5	0.0	0.0	0.0	2,211.4	
***2013** Season, Trawl 2-7 days/wk, Jan 23-Apr 12 (54 days); Trap 6-7 days/wk, Feb 5-Apr 12 (62 days)									
Trawl		54.2	154.6	31.4	0.5			240.7	94%
Trap			12.5	2.2	conf			14.8	6%
Total	0.0	54.2	167.2	33.6	0.5	0.0	0.0	255.5	

conf = Confidential data were included in an adjacent month.
* Preliminary data

Table C5.4. Discards of shrimp in pounds from NEFOP-observed trips by target species and year. Totals include both Northern shrimp and "unknown" shrimp that could not be identified to species by the observer.

Target Species	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
HERRING, ATLANTIC					1.6	200.5	16	54				5.4	90
GROUNDFISH, NK	1	15	20	13.7	28.4	18.8	12.7	15	10		25		4.3
HAKE, SILVER	3			1	0.2	1.5	31.5	18		0.1	2.4		2
SHRIMP, PANDALID					0.6		50		0.1		1		
COD				1	4.2	6.3	3.3	0.9		2.2	2	10.7	3
SHRIMP, NK								30					
HADDOCK						1.2	12			0.2			
FLOUNDER, NK		1		0.1	0.1	10			2.1				
FLOUNDER, YELLOWTAIL						2		5.6	3.1				
FLOUNDER, WINTER						8		1.4	0.5				
MONKFISH				2						6	0.7		
FLOUNDER, WITCH				0.5	2.5	2		0.1		2.2		0.1	0.5
POLLOCK					0.2	0.1		0.2	0.1	0.8		5.4	
FLOUNDER, AM. PLAICE				0.1						2	0.2		
FISH, NK													1
HERRING, NK					0.5								
LOBSTER, AMERICAN					0.2								
QUAHOG, OCEAN						0.1							
HAKE, WHITE										0.1			
HAGFISH, ATLANTIC									0.1				
Grand Total	4	16	20	18.4	38.5	250.5	125.5	125.2	16	13.6	31.3	21.6	100.8

Table C5.5. Estimated numbers of vessels in the Gulf of Maine northern shrimp fishery by fishing season and state.

Season	Maine			Massachusetts	New Hampshire	Total
	Trawl	Trap	Total			
1980			15-20	15-20		30-40
1981			~75	~20-25		~100
1982			>75	~20-25		>100
1983			~164	~25	~5-8	~197
1984			239	43	6	288
1985			~231	~40	~17	~300
1986						~300
1987			289	39	17	345
1988			~290	~70	~30	~390
1989			~230	~50	~30	~310
1990			~220			~250
1991			~200	~30	~20	~250
1992			~259	~50	16	~325
1993			192	52	29	273
1994			178	40	29	247
1995						
1996			275	43	29	347
1997			238	32	41	311
1998			195	33	32	260
1999			181	27	30	238
2000	207	68	265	17	27	304
2001	174	60	234	19	27	275
2002	117	52	168	7	23	198
2003	142	49	191	12	22	222
2004	114	56	170	7	15	192
2005	102	64	166	9	22	197
2006	68	62	129	4	11	144
2007	97	84	179	3	15	196
2008	121	94	215	4	15	234
2009	80	78	158	12 (MA and NH combined)		170
2010	124	112	236	6	14	256
2011	172	143	311	12	19	342
*2012	163	131	293	14	17	324
*2013	122	46	168	16	14	198

note that some boats reported both trapping and trawling

* preliminary

Table C5.6. The total weight of the northern shrimp catches that were sampled (mt), the number of samples and interviews collected, the total weight of the samples (kg), and the numbers of northern shrimp (P. borealis) measured, by fishing season, for the Gulf of Maine northern shrimp port sampling project. 1kg=2.205 lbs. 1 mt = 2,205 lbs.

Fishing Season	Catches sampled (mt)	Number of samples	Sample wts (kg)	Numbers measured
1985	42.09	66	65.3	6,032
1986	37.52	72	76.3	6,415
1987	33.83	81	67.2	5,699
1988	41.33	94	79.4	6,393
1989	60.47	106	102.6	8,885
1990	56.24	98	86.5	8,132
1991	120.93	215	174.7	15,058
1992	73.58	162	128.5	10,225
1993	61.42	160	147.1	12,852
1994	78.17	165	132.1	12,221
1995	98.66	131	143.8	14,270
1996	243.70	243	293.8	28,320
1997	251.69	323	351.2	35,033
1998	150.73	227	249.5	23,916
1999	130.60	222	196.1	22,529
2000	112.82	130	121.2	11,458
2001	53.54	146	140.5	14,714
2002	31.28	58	49.4	5,243
2003	63.57	128	121.5	11,805
2004	114.99	113	107.1	10,972
2005	166.22	214	209.9	19,539
2006	171.49	162	176.5	16,218
2007	301.78	207	222.4	25,409
2008	237.43	243	258.6	26,181
2009	130.49	152	152.2	12,804
2010	324.59	266	296.9	25,393
2011	272.52	286	328.1	30,590
2012	278.10	311	370.0	39,748
2013	39.01	115	124.2	11,370

Table C5.7. Distribution of fishing effort (number of trips) in the Gulf of Maine northern shrimp fishery by season, state, and month.

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
1985 Season, 166 days, Dec 1 - May 15								
Maine	552	1,438	1,979	1,198	260	35		5,462
Mass.	127	269	224	231	92	73		1,016
N.H.	118	135	78	26	22			379
Total	797	1,842	2,281	1,455	374	108	0	6,857
1986 Season, 183 days, Dec 1 - May 31								
Maine	590	1,309	2,798	831	224	133	68	5,953
Mass.	128	235	225	320	194	133	159	1,394
N.H.	156	163	165	51	3		17	555
Total	874	1,707	3,188	1,202	421	266	244	7,902
1987 Season, 182 days, Dec 1 - May 31								
Maine	993	2,373	3,073	2,241	617	340	16	9,653
Mass.	325	354	414	426	283	317	164	2,283
N.H.	67	164	175	95	28		32	561
Total	1,385	2,891	3,662	2,762	928	657	212	12,497
1988 Season, 183 days, Dec 1 - May 31								
Maine	972	2,183	2,720	1,231	193	122		7,421
Mass.	28	326	426	315	26	57		1,178
N.H.	72	231	236	99	3			641
Total	1,072	2,740	3,382	1,645	222	179	0	9,240
1989 Season, 182 days, Dec 1 - May 31								
Maine	958	2,479	2,332	936	249	84		7,038
Mass.	103	479	402	254	297	102		1,637
N.H.	120	369	312	69	16			886
Total	1,181	3,327	3,046	1,259	562	186	0	9,561
1990 Season, 182 days, Dec 1 - May 31								
Maine	1,036	1,710	1,529	1,986	897	238		7,396
Mass.	147	459	273	202	175	118		1,374
N.H.	178	363	284	157	6			988
Total	1,361	2,532	2,086	2,345	1,078	356	0	9,758
1991 Season, 182 days, Dec 1 - May 31								
Maine	568	1,286	2,070	1,050	438	139		5,551
Mass.	264	416	401	231	154	147		1,613
N.H.	279	285	135	82	22	1		804
Total	1,111	1,987	2,606	1,363	614	287	0	7,968
1992 Season, 153 days, Dec 15 - May 15								
Maine	411	1,966	2,700	1,222	318	141		6,758
Mass.	59	337	145	101	41			683
N.H.	96	153	76	29	3			357
Total	566	2,456	2,921	1,352	362	141	0	7,798

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
1993 Season, 138 days, Dec 14 - April 30								
Maine	249	1,102	1,777	1,032	227			4,387
Mass.	60	200	250	185	72			767
N.H.	76	246	275	256	151			1,004
Total	385	1,548	2,302	1,473	450	0	0	6,158
1994 Season, 122 days, Dec 15 - Apr 15								
Maine	265	1,340	1,889	1,065	122			4,681
Mass.	58	152	147	83	15			455
N.H.	169	228	266	173	18			854
Total	492	1,720	2,302	1,321	155	0	0	5,990
1995 Season, 128 days, Dec 1 - Apr 30, 1 day per week off								
Maine	879	2,341	2,641	1,337	694			7,892
Mass.	145	385	275	157	109			1,071
N.H.	189	331	279	359	344			1,502
Total	1,213	3,057	3,195	1,853	1,147	0	0	10,465
1996 Season, 152 days, Dec 1 - May 31, 1 day per week off								
Maine	1,341	2,030	3,190	1,461	444	457		8,923
Mass.	299	248	325	269	106	126		1,373
N.H.	331	311	389	248	155	61		1,495
Total	1,971	2,589	3,904	1,978	705	644	0	11,791
1997 Season, 156 days, Dec 1 - May 31, two 5-day and four 4-day blocks off								
Maine	1,674	1,753	2,737	1,178	793	530		8,665
Mass.	184	226	245	114	7	1		777
N.H.	277	245	301	218	189	62		1,292
Total	2,135	2,224	3,283	1,510	989	593	0	10,734
1998 Season, 152 days, Dec 1 - May 31, 1 day per week off								
Maine	852	1,548	1,653	725	346	189		5,313
Mass.	94	200	148	70	3	1		515
N.H.	141	216	182	134	83	22		778
Total	1,087	1,964	1,983	929	432	212	0	6,606
1999 Season, 152 days, Dec 1 - May 31, 1 day per week off								
Maine	190	556	1,125	553	324	172		2,920
Mass.	39	57	71	9	40			216
N.H.	82	192	213	44	123	21		675
Total	311	805	1,409	606	487	193	0	3,811
2000 Season, 51 days, Jan 17 - Mar 15, Sundays off								
Maine		897	2,494	647				4,038
Mass.		33	117	32	1			183
N.H.		45	201	87				333
Total	0	975	2,812	766	1	0	0	4,554

Table C5.7 continued – Trips by season, state, and month.

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
2001 Season, 83 days, Jan 9 - Apr 30, Mar 18 - Apr 15 off, experimental offshore fishery in May								
Maine		1,683	1,551	177	43	6		3,460
Mass.		111	48	10		1		170
N.H.		303	200	conf	conf			503
Total	0	2,097	1,799	187	43	7	0	4,133
2002 Season, 25 days, Feb 15 - Mar 11								
Maine			799	299				1,098
Mass.			31	conf				31
N.H.			119	56				175
Total	0	0	949	355	0	0	0	1,304
2003 Season, 38 days, Jan 15 - Feb 27, Fridays off								
Maine		1114	1,582	1			2	2,699
Mass.		41	50					91
N.H.		81	151					232
Total	0	1,236	1,783	1	0	0	2	3,022
2004 Season, 40days, Jan 19 - Mar 12, Saturdays and Sundays off								
Maine	7	647	1,197	482	13	14	6	2,366
Mass.		conf	56	conf				56
N.H.		46	147	66				259
Total	7	693	1,400	548	13	14	6	2,681
2005 Season, 70 days, Dec 19 - 30, Fri-Sat off, Jan 3 - Mar 25, Sat-Sun off								
Maine	140	667	1,305	1,255	0	0	1	3,368
Mass.	15	18	49	23				105
N.H.	24	76	216	77				393
Total	179	761	1,570	1,355	0	0	1	3,866
2006 Season, 140 days, Dec 12 - Apr 30								
Maine	148	585	947	530	101			2,311
Mass.	conf	conf	58	conf	conf			58
N.H.	5	23	19	62	conf			109
Total	153	608	1,024	592	101	0	0	2,478
2007 Season, 151days, Dec 1 - Apr 30								
Maine	437	1,102	1,514	669	136	1	3	3,862
Mass.	conf	45	conf	conf				45
N.H.	26	115	71	44	conf			256
Total	463	1,262	1,585	713	136	1	3	4,163
2008 Season, 152 days, Dec 1 - Apr 30								
Maine	418	1,291	2,076	1,286	102	0	9	5,182
Mass.	conf	conf	25	13				38
N.H.	63	141	125	38	conf			367
Total	481	1,432	2,226	1,337	102	0	9	5,587

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
2009 Season, 180 days, Dec 1 - May 29								
Maine	134	785	1,122	739	47	5	1	2,833
Mass.& NH	conf	107	62	conf	conf			169
Total	134	892	1,184	739	47	5	1	3,002
2010 Season, 156 days, Dec 1 - May 5								
Maine	241	1,561	2,593	911	185	29	1	5,521
Mass.	conf	26	23	conf	conf			49
N.H.	54	127	151	21	56	conf		409
Total	295	1,714	2,767	932	241	29	1	5,979
2011 Season, 90 days, Dec 1 - Feb 28								
Maine	599	2,880	2,875	1				6,355
Mass.	28	92	73	0	0			193
N.H.	108	241	198					547
Total	735	3,213	3,146	1	0	0	0	7,095
***2012** Season, Trawling Mon,Wed,Fri, Jan 2 - Feb 17 (21days); Trapping Feb 1-17 (17 days)								
Maine	1	1,302	2,000	1				3,304
Mass.		74	42					116
N.H.		129	99					228
Total	1	1,505	2,141	1	0	0	0	3,648
***2013** Season, Trawl 2-7 days/wk, Jan 23-Apr 12 (54 days); Trap 6-7 days/wk, Feb 5-Apr 12 (62 days)								
Maine		166	790	196	7			1,159
Mass.		8	30	30	conf			68
N.H.		21	59	15	conf			95
Total	0	195	879	241	7	0	0	1,322

conf = Confidential data were included in an adjacent month.
* Preliminary data

Table C5.8. Distribution of fishing trips in the Maine northern shrimp fishery by season, gear type, and month.

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total	%
2000									
Trawl		818	2,073	462				3,353	97%
Trap		79	421	185				685	20%
Total	0	897	2,494	647	0	0	0	4,038	
2001									
Trawl		1,500	1,214	112	43	6		2,875	83%
Trap		183	337	65				585	17%
Total	0	1,683	1,551	177	43	6	0	3,460	
2002									
Trawl			595	236				831	76%
Trap			204	63				267	24%
Total	0	0	799	299	0	0	0	1,098	
2003									
Trawl		850	1,081	1			2	1,934	72%
Trap		264	501					765	28%
Total	0	1,114	1,582	1	0	0	2	2,699	
2004									
Trawl	7	566	965	382	13	14	6	1,953	83%
Trap		81	232	100				413	17%
Total	7	647	1,197	482	13	14	6	2,366	
2005									
Trawl	140	647	953	778			1	2,519	75%
Trap		conf	372	477				849	25%
Total	140	647	1,325	1,255	0	0	1	3,368	
2006									
Trawl	145	490	563	273	88			1,559	67%
Trap	conf	98	384	257	13			752	33%
Total	145	588	947	530	101	0	0	2,311	
2007									
Trawl	425	977	921	349	119	1	3	2,795	72%
Trap	12	125	593	320	17			1,067	28%
Total	437	1,102	1,514	669	136	1	3	3,862	

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total	%
2008									
Trawl	414	1,062	1,393	661	51	0	9	3,590	69%
Trap	conf	233	683	625	51			1,592	31%
Total	414	1,295	2,076	1,286	102	0	9	5,182	
2009									
Trawl	130	705	673	381	32	5	1	1,927	68%
Trap	4	80	449	358	15			906	32%
Total	134	785	1,122	739	47	5	1	2,833	
2010									
Trawl	238	1,230	1,512	447	157	29	1	3,614	65%
Trap	conf	334	1,081	492	conf			1,907	35%
Total	238	1,564	2,593	939	157	29	1	5,521	
2011									
Trawl	577	2,068	1,692	1				4,338	68%
Trap	22	812	1,183					2,017	32%
Total	599	2,880	2,875	1	0	0	0	6,355	
***2012**									
Trawl	1	1,302	1,032	1				2,336	71%
Trap			968					968	29%
Total	1	1,302	2,000	1	0	0	0	3,304	
***2013**									
Trawl		166	621	164	conf			951	82%
Trap			169	39	conf			208	18%
Total	0	166	790	203	0	0	0	1,159	

conf = Confidential data were included in an adjacent month.
* Preliminary data

Table C5.9. Gulf of Maine northern shrimp trawl catch rates by season. Mean CPUE in lbs/hour towed is from Maine trawler port sampling. Mean catch in lbs/trip is from NMFS weighout and logbook data for all catches for all states. Trawl lbs/trip is trawler only catches per trawl trip for all states. 1 lb=0.45 kg.

Season	Maine pounds per hour towing			Pounds/trip	Trawl lbs/trip
	Inshore (<55F)	Offshore (>55F)	Combined		
1991	94	152	140	992	
1992	132	93	117	978	
1993	82	129	92	767	
1994	139	149	141	1,073	
1995	172	205	193	1,360	
1996	340	203	251	1,784	
1997	206	192	194	1,462	
1998	158	151	154	1,391	
1999	148	147	147	1,079	
2000	279	224	272	1,382	1,475
2001	100	135	109	710	752
2002	223	91	194	765	854
2003	174	215	182	981	1,102
2004	361	310	351	1,753	2,006
2005	235	212	228	1,488	1,621
2006	572	345	499	2,066	2,616
2007	531	477	507	2,584	3,129
2008	350	327	343	1,958	2,302
2009	400	315	370	1,837	2,231
2010	424	354	401	2,264	2,671
2011	334	435	347	1,988	2,376
*2012	407	313	399	1,497	1,879
*2013	118	78	110	512	579

Table C5.10 Estimated numbers of northern shrimp in Gulf of Maine landings, by season and carapace length (mm).
Mixed fleet (all gears), 1985-1999.

Fishing Season	Total Catch (Millions)	Catch (Millions) at Size (mm)																								
		<=10.0	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5	21	21.5	22
1985	355.57	1.06	0.50	0.31	0.19	0.33	0.35	0.81	0.16	0.31	0.11	0.19	0.49	0.80	1.09	1.33	1.19	1.26	1.96	2.11	4.60	8.22	7.47	8.21	15.28	19.44
1986	369.32	0.06	0.07	0.01	0.12	1.20	0.60	1.41	1.64	3.07	1.09	0.89	1.19	1.17	1.88	2.45	1.92	3.16	2.90	3.88	5.10	5.69	4.97	3.30	2.63	3.17
1987	424.41	0.17	0.05	0.68	0.17	1.08	0.96	2.70	0.98	1.23	0.56	1.35	1.04	1.33	2.21	3.51	6.71	3.67	4.95	4.35	5.36	4.04	4.49	6.42	8.22	8.94
1988	220.30	0.85	0.12	0.18	0.02	0.24	0.22	0.41	0.10	0.23	0.29	0.57	0.24	0.73	1.24	2.36	1.39	1.53	1.22	0.81	0.86	1.42	1.88	2.81	3.17	3.92
1989	295.73	0.06	0.01	0.05	0.04	0.28	0.18	0.04	0.20	0.05	0.04	0.14	0.37	0.73	1.20	3.20	6.75	7.94	8.89	7.83	7.56	7.36	7.88	7.49	5.78	6.46
1990	437.17	0.07	0.02	0.05	0.06	0.10	0.00	0.09	0.05	0.30	0.18	0.49	1.18	2.75	2.70	6.65	8.92	12.49	10.40	17.34	18.84	15.90	10.30	14.85	13.00	18.95
1991	334.78	0.62	0.55	0.76	0.51	0.85	1.08	2.68	1.79	2.32	1.69	1.18	0.52	1.14	1.39	3.75	4.70	6.59	7.50	7.49	8.79	8.11	6.73	5.88	6.85	9.84
1992	267.74	1.21	1.10	0.70	0.74	0.20	0.50	0.52	0.16	0.09	0.51	0.45	0.77	1.07	2.86	3.35	4.49	6.19	5.34	3.24	3.85	3.17	1.83	1.74	1.21	2.06
1993	186.69	0.75	0.44	0.70	1.05	1.32	1.11	1.16	1.19	0.45	0.23	0.26	0.29	0.66	0.94	2.12	2.85	5.02	4.12	5.46	3.67	4.20	3.11	3.83	4.15	5.19
1994	263.22	1.12	0.40	0.57	0.69	0.37	0.29	0.38	0.47	0.32	0.88	2.63	3.17	6.27	7.40	7.27	7.34	7.93	6.77	4.84	4.23	3.23	2.46	2.66	5.20	5.91
1995	627.47	2.16	0.67	0.90	1.40	1.20	0.98	1.13	1.22	1.13	1.30	3.11	4.34	7.53	7.06	12.42	10.57	14.04	12.43	10.46	10.01	12.24	11.78	20.04	17.03	23.95
1996	865.44	0.31	0.48	0.46	0.32	0.78	0.97	1.47	1.32	1.77	2.31	2.63	2.06	5.37	4.05	5.79	6.08	6.90	7.03	7.65	9.72	12.45	13.27	14.31	15.22	17.21
1997	716.34	6.02	3.76	3.83	4.07	3.73	3.76	3.61	3.22	1.65	1.98	2.62	3.55	5.92	8.01	10.51	15.46	17.14	16.84	16.89	17.62	17.91	15.40	16.87	17.93	21.97
1998	361.46	1.42	0.60	0.93	0.66	0.73	0.61	1.13	1.75	2.46	2.99	4.35	4.95	6.22	5.42	6.78	5.97	5.77	6.19	5.03	4.20	3.58	3.38	3.96	3.91	5.72
1999	207.17	0.30	0.41	0.47	0.64	0.70	0.77	0.58	0.48	0.48	0.77	1.02	1.34	2.74	3.20	3.49	4.14	4.03	3.75	4.90	5.90	7.49	7.71	9.06	9.14	10.81

Fishing Season	22.5	23	23.5	24	24.5	25	25.5	26	26.5	27	27.5	28	28.5	29	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34
1985	18.39	24.55	26.15	30.63	25.06	25.46	27.16	28.40	23.82	19.35	11.27	5.73	5.70	2.53	1.98	1.05	0.25	0.25	0.02	0.04	0.00	0.00	0.00	0.00
1986	2.87	4.42	7.45	14.28	28.10	36.89	50.83	54.70	39.62	29.37	12.49	13.97	9.34	5.88	3.37	1.72	0.19	0.15	0.06	0.05	0.01	0.00	0.00	0.00
1987	10.77	8.56	10.15	9.06	9.98	19.40	21.60	41.88	49.36	59.53	46.37	30.99	14.11	8.35	4.76	3.61	0.44	0.31	0.00	0.00	0.00	0.00	0.00	0.00
1988	2.52	4.86	4.16	6.33	9.83	15.24	12.08	18.57	18.23	27.83	21.32	20.50	15.63	9.44	4.82	1.47	0.51	0.11	0.03	0.00	0.00	0.00	0.00	0.00
1989	6.24	8.13	7.20	8.15	7.66	11.60	14.26	24.58	23.86	27.81	23.42	20.62	12.70	7.87	6.10	2.85	1.08	0.56	0.29	0.16	0.02	0.00	0.00	0.00
1990	22.41	24.84	21.56	21.79	26.93	24.80	26.30	26.15	23.65	19.59	14.00	11.63	7.11	5.50	2.85	0.94	0.82	0.47	0.07	0.10	0.00	0.00	0.00	0.00
1991	10.11	6.76	7.55	9.07	13.23	22.91	32.55	38.71	34.47	27.32	14.93	9.03	5.46	4.42	2.57	1.33	0.41	0.37	0.23	0.01	0.00	0.07	0.00	0.00
1992	2.37	2.79	2.72	3.73	5.20	8.93	12.65	15.28	33.83	42.86	40.24	27.24	11.59	7.33	2.08	1.01	0.35	0.14	0.02	0.02	0.00	0.00	0.00	0.00
1993	7.12	9.16	8.93	8.54	8.71	9.67	10.57	11.12	9.85	11.94	9.96	9.95	7.85	4.71	2.67	1.06	0.32	0.12	0.17	0.00	0.00	0.00	0.00	0.00
1994	8.75	10.94	10.50	14.89	19.10	22.41	20.85	19.82	15.02	9.78	7.34	6.12	4.95	4.14	2.75	1.82	0.91	0.29	0.06	0.00	0.00	0.00	0.00	0.00
1995	35.07	35.80	40.87	33.68	38.11	36.39	36.51	39.01	36.65	34.80	24.73	18.38	9.95	8.31	4.03	2.56	1.65	1.00	0.49	0.33	0.01	0.04	0.00	0.00
1996	20.75	32.62	36.10	50.97	73.33	98.40	106.27	92.96	77.93	54.61	29.52	19.86	11.46	8.30	6.26	3.21	1.54	0.46	0.75	0.16	0.01	0.00	0.03	0.00
1997	19.26	20.26	16.88	20.60	33.13	43.73	54.08	52.89	55.27	47.60	39.38	30.86	18.19	12.35	5.65	2.99	1.99	0.53	0.27	0.13	0.01	0.01	0.01	0.00
1998	6.66	8.65	12.48	15.19	17.79	25.57	30.10	32.41	31.39	23.50	22.08	18.82	11.66	8.29	4.34	2.27	0.92	0.37	0.19	0.03	0.03	0.04	0.00	0.00
1999	10.81	11.66	12.29	11.71	11.23	11.50	11.12	10.32	7.86	7.01	4.89	3.95	2.96	2.20	1.65	0.92	0.39	0.26	0.10	0.01	0.01	0.00	0.00	0.00

Table C5.11 Estimated numbers of northern shrimp in Gulf of Maine landings, by season and carapace length (mm). Trawl fleet, 2000-2013.

Fishing Season	Total Catch (Millions)	Catch (Millions) at Size (mm)																								
		<=10.0	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5	21	21.5	22
2000	240.38	2.81	2.01	3.05	2.91	2.52	2.23	1.36	0.78	0.79	0.26	0.13	0.16	0.15	0.09	0.30	0.67	0.95	1.61	2.01	1.79	1.35	1.20	1.96	3.39	5.69
2001	132.90	0.13	0.01	0.05	0.08	0.04	0.03	0.14	0.29	0.31	0.94	1.23	2.92	5.08	6.40	6.85	6.25	6.05	4.02	3.08	1.96	1.41	0.92	1.32	1.91	2.69
2002	42.12	0.02	0.06	0.16	0.16	0.31	0.26	0.50	0.32	0.22	0.17	0.13	0.04	0.06	0.03	0.05	0.09	0.09	0.15	0.15	0.19	0.27	0.64	1.49	2.90	3.33
2003	110.66	0.01	0.00	0.01	0.01	0.05	0.01	0.04	0.06	0.24	0.17	0.73	1.08	2.70	3.11	3.81	3.06	2.83	2.29	3.12	2.76	1.90	1.76	1.36	0.95	0.72
2004	214.58	0.38	0.39	0.25	0.16	0.18	0.01	0.04	0.03	0.08	0.11	0.04	0.12	0.14	0.25	0.17	0.37	0.58	0.84	1.10	1.53	2.68	4.29	8.14	15.58	23.62
2005	208.30	2.52	0.79	0.98	0.82	0.53	0.34	0.14	0.13	0.10	0.43	1.07	2.00	3.32	4.25	4.39	4.81	3.34	2.08	1.29	0.73	0.62	0.55	0.64	0.80	1.91
2006	182.76	0.15	0.01	0.02	0.02	0.02	0.03	0.06	0.05	0.11	0.27	1.01	1.82	3.23	3.97	4.06	3.75	3.20	2.08	1.22	0.91	0.81	1.26	1.94	3.04	4.22
2007	501.10	0.08	0.08	0.02	0.17	0.17	0.23	0.51	1.69	2.32	4.53	6.27	5.40	6.19	4.28	3.06	3.79	5.66	7.98	11.94	15.62	16.56	14.22	13.63	15.52	19.59
2008	417.54	1.11	0.87	0.94	1.20	1.39	0.98	0.58	0.38	0.34	0.42	0.28	0.76	0.94	1.31	1.51	1.76	2.26	2.62	2.95	3.46	4.36	5.11	6.49	10.27	16.80
2009	192.33	0.62	0.30	0.42	0.45	0.15	0.26	0.12	0.18	0.06	0.03	0.06	0.27	0.84	2.13	2.02	2.94	2.77	2.20	1.81	1.53	0.95	0.58	0.67	1.12	1.76
2010	425.34	2.10	0.57	0.70	0.58	0.40	0.44	0.29	0.35	0.44	1.24	2.34	4.26	5.85	4.98	6.08	4.37	4.51	3.78	3.52	2.94	3.57	3.76	4.01	5.12	5.78
2011	529.15	0.90	0.69	0.55	0.54	0.64	0.63	0.86	0.76	1.38	3.09	6.72	9.51	12.19	14.38	10.84	7.71	4.81	2.38	2.28	3.95	5.95	8.39	10.65	9.37	9.77
2012	246.98	0.26	0.09	0.12	0.11	0.07	0.10	0.06	0.11	0.23	0.32	0.79	1.00	1.38	1.59	1.19	1.17	1.51	2.37	2.61	2.58	2.68	3.15	4.78	6.35	10.08
2013	26.41	0.01	0.00	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.05	0.05	0.06	0.08	0.08	0.07	0.05	0.05	0.04	0.05	0.08	0.09	0.07	0.18	0.34	0.56

Fishing Season	22.5	23	23.5	24	24.5	25	25.5	26	26.5	27	27.5	28	28.5	29	29.5	30	31	31	31.5	32	32.5	33	33.5	34
2000	8.63	10.19	11.48	16.77	23.25	27.96	28.39	25.33	14.47	11.80	8.49	4.86	3.27	2.13	1.64	0.72	0.41	0.27	0.12	0.01	0.00	0.00	0.00	0.00
2001	3.18	4.30	5.23	6.54	8.75	9.18	10.83	9.61	8.28	5.57	3.19	2.04	1.08	0.50	0.36	0.07	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.00
2002	4.71	4.50	4.16	2.93	2.66	2.28	1.91	1.91	1.70	1.41	1.05	0.54	0.37	0.13	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.69	1.53	3.85	8.05	12.83	14.89	13.27	10.20	5.10	2.98	2.03	1.13	0.54	0.46	0.16	0.10	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00
2004	31.54	34.67	27.14	17.13	9.12	4.40	4.24	5.33	6.23	5.69	3.44	2.06	1.44	0.59	0.25	0.17	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00
2005	3.20	6.19	12.34	20.36	28.19	32.97	27.18	17.20	9.00	4.77	2.92	2.20	1.65	1.05	0.22	0.15	0.09	0.00	0.01	0.03	0.00	0.00	0.00	0.00
2006	4.83	5.28	4.54	4.18	3.91	5.91	10.79	18.63	26.92	27.06	18.94	9.06	3.62	1.09	0.42	0.23	0.02	0.05	0.04	0.00	0.00	0.00	0.00	0.00
2007	24.40	29.52	37.34	47.12	53.97	48.23	33.58	17.24	11.40	9.32	9.28	9.59	5.96	3.07	1.14	0.23	0.12	0.00	0.03	0.00	0.00	0.00	0.00	0.00
2008	28.29	37.28	47.32	52.45	46.52	39.51	36.24	23.62	16.23	8.95	4.88	3.39	2.04	1.00	0.44	0.22	0.06	0.01	0.01	0.00	0.00	0.00	0.00	0.00
2009	2.60	3.19	3.44	6.77	10.08	17.19	23.00	27.21	26.83	20.85	13.39	6.92	3.60	1.87	0.85	0.17	0.06	0.02	0.07	0.00	0.00	0.00	0.00	0.00
2010	5.35	7.12	7.78	10.86	14.66	21.29	30.26	45.42	54.14	53.07	45.38	29.49	17.01	7.57	2.81	0.77	0.27	0.06	0.05	0.00	0.00	0.00	0.00	0.00
2011	10.91	14.12	18.17	27.81	39.88	55.13	63.16	56.32	40.73	25.28	16.73	13.03	8.63	5.21	3.34	1.18	0.37	0.16	0.06	0.00	0.01	0.00	0.00	0.00
2012	17.76	29.45	37.86	39.43	28.63	18.56	12.00	8.36	5.20	2.89	1.24	0.49	0.24	0.12	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2013	0.81	1.38	1.87	2.71	3.32	3.42	3.22	2.91	2.17	1.30	0.71	0.31	0.12	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table C5.12 Estimated numbers of northern shrimp in Gulf of Maine landings, by season and carapace length (mm). Trap fleet, 2000-2013.

Fishing Season	Total Catch (Millions)	Catch (Millions) at Size (mm)																								
		<=10.0	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5	21	21.5	22
2000	20.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03
2001	9.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.06
2002	4.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.08	0.16	0.28
2003	17.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.15	0.20	0.19	0.15	0.14	0.07	0.05
2004	6.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.16	0.49	0.62
2005	32.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.00	0.00	0.02	0.00	0.02	0.00	0.01	0.03	0.02	0.05	0.10
2006	20.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.04	0.00	0.03	0.09
2007	46.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.11	0.35	0.45	1.00	2.06
2008	72.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.10	0.12	0.31	0.82	1.62
2009	28.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03
2010	88.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.06	0.01	0.00	0.00	0.00	0.02	0.02	0.03	0.18	0.36
2011	75.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.00	0.02	0.04	0.05	0.02	0.01	0.06	0.03	0.06	0.12	0.17	0.50	0.72
2012	19.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.09	0.16	0.28	0.65
2013	1.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00

Fishing Season	22.5	23	24	24	24.5	25	25.5	26	26.5	27	27.5	28	29	29	30	30	31	31	32	32	33	33	34	34
2000	0.37	0.39	0.70	1.49	2.32	3.02	3.22	2.72	2.50	0.76	0.90	0.61	0.62	0.31	0.38	0.36	0.02	0.03	0.06	0.00	0.05	0.00	0.00	0.00
2001	0.08	0.23	0.39	0.54	0.81	1.14	1.58	1.35	1.33	0.71	0.48	0.31	0.08	0.05	0.05	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.41	0.62	0.43	0.32	0.21	0.30	0.28	0.23	0.35	0.26	0.30	0.16	0.11	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.07	0.19	0.68	1.61	2.78	3.22	3.27	1.97	1.12	0.57	0.25	0.34	0.38	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	1.35	1.44	0.82	0.74	0.41	0.09	0.11	0.12	0.10	0.10	0.06	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.49	0.85	1.69	3.12	4.86	5.92	5.67	4.06	1.90	0.90	0.82	0.59	0.29	0.28	0.17	0.03	0.04	0.02	0.03	0.00	0.00	0.00	0.00	0.00
2006	0.19	0.20	0.39	0.32	0.40	0.71	1.38	2.72	3.77	4.43	3.34	1.59	0.58	0.15	0.10	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
2007	2.97	3.58	4.02	4.35	5.60	6.13	4.27	2.49	1.62	1.66	2.07	1.61	1.26	0.69	0.17	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	2.93	4.96	7.66	9.01	10.46	9.12	7.13	5.70	4.28	3.13	1.98	1.27	0.85	0.53	0.23	0.15	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	0.05	0.14	0.18	0.52	1.01	2.05	3.44	5.09	5.59	3.93	2.73	2.03	0.94	0.53	0.27	0.08	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.58	0.68	0.96	1.03	2.07	3.25	5.59	8.30	12.79	15.47	14.92	11.16	6.94	2.94	0.96	0.30	0.30	0.02	0.00	0.00	0.00	0.00	0.00	0.00
2011	1.48	2.30	2.92	4.00	6.49	11.18	13.09	12.25	7.93	4.69	2.79	2.19	1.16	0.89	0.38	0.11	0.11	0.01	0.00	0.00	0.01	0.00	0.00	0.00
2012	1.11	2.37	3.31	3.76	3.19	2.06	1.14	0.60	0.45	0.12	0.13	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2013	0.02	0.06	0.08	0.14	0.16	0.20	0.16	0.16	0.10	0.07	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table C13. Stratified* retransformed mean numbers and weights per tow of northern shrimp collected during *R/V Gloria Michelle* state/federal summer surveys.
1 kg=2.2 lbs.

		Log$_e$ retransformed				
Year	**N Tows**	**Age-1.5 Number**	**>22 mm** Number**	**>22 mm Weight (kg)**	**Total Number**	**Total Weight (kg)**
1984	37	18	316	3.4	1,152	10.5
1985	44	332	1,169	11.5	1,825	17.7
1986	40	358	860	10.0	1,695	19.6
1987	41	342	854	9.5	1,533	15.4
1988	41	828	298	3.4	1,269	12.8
1989	43	276	564	6.1	1,884	17.0
1990	43	142	1,127	12.0	1,623	18.1
1991	43	482	657	8.0	1,256	11.7
1992	45	282	397	4.8	955	9.4
1993	46	757	250	2.8	1,157	9.1
1994	43	368	243	2.7	984	8.7
1995	35	292	628	7.0	1,449	13.3
1996	32	232	358	4.0	776	8.8
1997	40	374	245	2.8	762	7.7
1998	35	134	170	1.9	583	6.3
1999	42	114	174	1.9	398	5.8
2000	35	450	283	3.2	808	6.4
2001	36	18	146	1.5	451	4.3
2002	38	1,164	261	2.9	1,445	9.2
2003	37	11	173	1.7	564	5.5
2004	35	286	519	5.3	887	10.3
2005	46	1,752	871	10.3	3,661	23.4
2006	29	374	2,773	29.9	9,998	66.0
2007	43	28	412	4.1	887	11.5
2008	38	506	995	10.8	1,737	16.8
2009	49	555	702	8.5	1,627	15.4
2010	49	475	413	4.8	1,373	13.9
2011	47	44	316	3.2	830	8.6
2012	49	7	81	0.9	138	2.5
2013	40	1	24	0.3	27	1.0
Mean	41	367	543	6.0	1,458	12.9
Median	41	312	377	4	1154	10
1984-93 Mean	42	382	649	7.1	1,435	14.1
Median	43	337	611	7.0	1,401	14.1

***Based on strata 1, 3, 5, 6, 7 and 8.**
****Will be fully recruited to the winter fishery.**

Table C5.14. Stratified retransformed mean weights (kg) per tow of northern shrimp collected during the Maine - New Hampshire inshore trawl surveys by year, regions 1-4 (NH to Mt. Desert) and depths 3-4 (> 35 fa or 117 m) only, with number of tows (n) and 80% confidence intervals. 1 kg=2.2 lbs.

	Spring				Fall			
	kg/tow	n	80% CI		kg/tow	n	80% CI	
2003	**4.16**	40	3.40	5.05	**1.91**	33	1.35	2.60
2004	**3.87**	42	3.31	4.51	**1.53**	38	1.04	2.14
2005	**7.81**	40	6.60	9.21	**3.59**	25	2.46	5.10
2006	**10.99**	46	8.50	14.13	**2.06**	38	1.43	2.84
2007	**10.70**	43	7.93	14.33	**4.04**	45	3.15	5.13
2008	**15.42**	45	12.72	18.64	**3.59**	37	2.32	5.36
2009	**9.65**	45	7.67	12.09	**2.73**	41	2.27	3.27
2010	**15.95**	48	12.60	20.12	(samples lost)			
2011	**17.86**	50	14.88	21.40	**4.20**	32	3.24	5.38
2012	**7.50**	50	6.07	9.23	**1.89**	42	1.53	2.30
***2013**	**1.69**	46	1.09	2.46				

*2013 data are preliminary.

Table C5.15. Stratified mean number and weight (kg) per tow from NEFSC fall surveys. New survey methods began in 2009.

	Arithmetic				Re-transformed geometric			
Year	Mean Weight	CV	Mean number	CV	Mean Weight	CV	Mean number	CV
1984					1.7	18.2	710.1	12.7
1985					1.6	19.1	853.0	12.5
1986	2.5		252.65		2.5	13.6	1318.8	7.8
1987	1.7		149.49		1.4	21.8	370.9	12.6
1988	1.2		197.07		1.1	24.6	603.3	16.6
1989	2.1		259.82		2.0	16.9	1763.2	10.8
1990	1.8		164.36		1.7	16.6	788.9	13.3
1991	1.0		103.84		0.9	15.9	323.7	13.4
1992	0.6		56.33		0.6	22.5	157.2	14.3
1993	1.9		361.99		1.7	19.2	2009.4	13.8
1994	2.3	29.3	297.06	28.8	2.2	21.0	2213.9	12.9
1995	1.6	21.2	162.60	22.2	1.7	14.2	755.1	8.4
1996	1.2	16.5	114.92	16.2	1.1	11.7	257.6	5.7
1997	1.4	32.6	181.71	41.2	1.3	19.7	495.0	11.3
1998	2.3	14.6	330.23	15.3	2.3	9.4	2561.4	6.4
1999	2.4	20.4	334.10	21.8	2.3	13.3	1984.0	8.4
2000	1.4	27.5	235.96	27.3	1.4	19.2	1398.6	12.2
2001	0.6	27.2	96.77	24.6	0.6	22.0	268.0	11.0
2002	1.7	26.4	323.66	28.2	1.7	18.9	1976.8	10.9
2003	1.1	32.6	128.12	30.5	1.0	24.8	345.1	12.0
2004	1.6	41.6	262.27	47.9	1.4	23.5	1062.4	14.1
2005	2.8	24.6	585.03	32.4	2.6	12.4	4253.2	8.9
2006	6.6	20.2	1191.32	20.5	7.5	13.2	45950.6	10.9
2007	4.1	25.3	650.40	29.7	4.1	12.6	4228.2	7.4
2008	3.1	17.5	404.75	22.0	3.4	13.8	3807.6	10.5
2009	7.8	25.8	804.0	26.8	8.0	12.3	8054.1	7.8
2010	5.0	28.4	660.3	29.7	4.6	16.1	8561.0	10.9
2011	5.6	21.6	685.8	22.9	5.8	11	11814.9	8.0
2012	1.2	67.6	118.8	63.9	0.8	32.7	124.5	18.4

Table C6.1. Comparison of various aspects of all the UMaine model runs. Model run B is the base case run, and greyed texts are settings different from those hypothesized in the base run scenario.

TI=Terminal year incomplete; PPI=Predation-scaled time-varying, B = base case

#	Time step	Years covered	# of fishery selectivity	Catch	# of survey	Natural mortality	Growth time blocks	Growth parameters	Weights	Initial values
B	Year	1984-2013	3	Standard	3	U-shaped	2	McInnes	Equal	Guess
1	Year	1984-2013	3	Standard	3	0.25	2	McInnes	Equal	Guess
2	Year	1984-2013	3	Standard	3	0.5	2	McInnes	Equal	Guess
3	Year	1984-2013	3	Standard	3	PPI	2	McInnes	Equal	Guess
4	Year	1984-2013	3	Under 10%	3	U-shaped	2	McInnes	Equal	Guess
5	Year	1984-2013	3	Under 25%	3	U-shaped	2	McInnes	Equal	Guess
6	Year	1984-2013	3	TI	3	U-shaped	2	McInnes	Equal	Guess
7	Year	1984-2013	3	Standard	3	U-shaped	2	McInnes	Survey*5	Guess
8	Year	1984-2013	3	Standard	3	U-shaped	2	McInnes	Survey*0.5	Guess
9	Year	1984-2013	3	Standard	3	U-shaped	1	McInnes	Equal	Guess
10	Year	1984-2013	3	Standard	3	U-shaped	2	Fournier	Equal	Guess
11	Year	1984-2013	4	Standard	3	U-shaped	2	McInnes	Equal	Guess
12	Season	1984-2013	3	Standard	3	U-shaped	2	McInnes	Equal	Guess

Table C6.2. Summary of UMaine model base run configuration for Northern shrimp.

Item	Descriptor	Note
Years covered	1984-2013	All years with survey data
Seasons	1	
Number sexes	2	Female/Non-female
Lengths	10-35 mm	
Length bins	1 mm	
Commercial fleets	3	Mixed gear (1984-1999), Trawl (2000-2013), Trap (2000-2013)
Commercial selectivity at length	Mixed fleet inshore (1984-1999) Trawl fleet (2000-2013) Trap fleet (2000-2013)	Logistic Logistic Logistic
Fishing mortality	Instantaneous rates	
Survey data	NEFSC fall ASMFC summer NEFSC Bigelow	1984-2008 (length composition data 1991-2008) 1984-2013 with length frequency data for all years 2009-2012 (length composition data 2009-2012)
Survey selectivity at length	NEFSC fall ASMFC summer NEFSC Bigelow	Logistic Logistic Logistic
Natural mortality	Natural mortality rate at length used in the model	U-shaped
Maturity at length	Proportion of female at length	Data from ASMFC summer survey, incorporate a likelihood function to estimated the proportion of female
Spawner-recruit relationship	No functional relationship	Recruitments freely estimated
Recruitment lengths	10-18 mm	
Growth	Growth transition matrix used in the model	K and L_{inf} from Mclnnes 1986; sd of K and L_{inf} were estimated; Two time blocks were used according to climate condition (cold period: 1984-1999; warm period: 2000-2013)
Initial condition	First-year length composition assumed in the model	ASMFC summer survey length composition
Likelihood weights	All one (1.0)	Used to weight each term in the negative log likelihood

Table C6.3. Population estimates from the UMaine model base run
R=Recruitment; SSB=Spawning stock biomass; Abundance in millions and the unit for biomass is metric ton.

Year	R	SSB	Female biomass	Non-female biomass	Female abundance	Non-female abundance	Exploitation of numbers	Exploitation of biomass	Exploitation of female biomass
1984	1162.66	4573.30	4904.62	6657.34	515.53	2101.60	0.12	0.15	0.36
1985	1323.60	5399.92	5857.45	6593.19	509.59	2014.78	0.14	0.19	0.41
1986	1075.40	5444.76	6011.84	5760.44	468.03	1736.35	0.16	0.24	0.46
1987	929.56	4470.17	5144.31	4832.92	399.38	1477.49	0.21	0.31	0.60
1988	2167.14	3001.92	3283.76	6414.14	265.10	2622.16	0.08	0.14	0.42
1989	1374.76	4442.63	4819.41	6487.84	445.60	2180.44	0.11	0.16	0.39
1990	765.87	4410.49	4929.54	6153.24	405.25	1549.99	0.21	0.24	0.53
1991	980.21	4088.51	4575.85	4499.44	362.47	1428.48	0.18	0.27	0.53
1992	867.41	3624.77	4053.21	3540.76	340.91	1255.42	0.16	0.27	0.51
1993	2930.36	3055.79	3304.41	7115.95	285.09	3302.89	0.05	0.11	0.36
1994	2175.08	4784.64	5097.04	9193.93	489.14	3247.10	0.07	0.10	0.28
1995	1501.03	8652.18	9436.02	7178.61	885.16	2377.56	0.16	0.25	0.44
1996	1041.55	7117.38	8203.73	6094.29	677.92	1785.38	0.27	0.36	0.63
1997	1335.54	4275.42	5184.54	4805.94	440.87	1789.97	0.24	0.39	0.74
1998	947.12	2859.55	3263.28	3700.44	335.72	1370.91	0.20	0.29	0.61
1999	560.07	2543.97	2799.27	2962.13	270.52	937.64	0.18	0.24	0.50
2000	439.79	2696.34	3159.94	1895.06	290.35	658.39	0.26	0.43	0.69
2001	581.25	1713.32	1988.35	1676.45	203.74	717.78	0.17	0.35	0.65
2002	945.04	1734.67	1822.41	2289.89	215.62	1085.59	0.04	0.09	0.21
2003	1389.47	2926.90	3144.54	3667.24	344.70	1653.37	0.07	0.16	0.36
2004	1101.87	2645.16	2917.25	5504.20	259.30	1742.79	0.12	0.17	0.49
2005	2178.10	4002.42	4356.33	6493.55	401.77	2669.08	0.08	0.17	0.43
2006	2468.09	5714.91	6070.82	8065.55	605.42	3221.13	0.05	0.12	0.28
2007	1353.13	8148.37	9076.44	7214.25	867.57	2292.29	0.18	0.29	0.52
2008	1146.42	5126.37	5776.52	7571.39	475.79	2008.13	0.20	0.25	0.57
2009	2011.51	4740.12	5111.07	7147.10	414.93	2619.76	0.07	0.15	0.35
2010	1256.81	5324.56	6191.20	6955.74	515.15	2132.55	0.19	0.30	0.64
2011	711.86	5146.51	6330.91	3311.32	645.38	1128.24	0.34	0.51	0.77
2012	306.91	2240.65	2666.08	2077.99	268.89	596.72	0.32	0.42	0.74
2013	542.15	1334.27	1388.38	1915.08	128.32	705.96	0.03	0.06	0.15

Table C6.4. Likelihood components for all the UMaine model runs (Run number is identical to Table C6.1)

Run #	Total	C1	C2	C3	CC1	CC2	CC3	I1	I2	I3	I4	IC1	IC2	IC3	IC4	R-penalty	F-prop
B	12951.5	-27.2	-36.7	-41.9	934.3	1362.6	1784.9	55.2	43.7	37.7	-	2012.0	3387.9	421.1	-	51.8	2966
1	12984.5	-25.9	-31.6	-41.9	933.7	1361.8	1786.4	56.7	46.6	36.6	-	2018.0	3396.8	423.7	-	57.6	2966
2	12981.5	-28.1	-37.2	-41.9	934.4	1362.4	1788.6	52.1	44.6	39.6	-	2015.7	3413.1	421.9	-	50.2	2966
3	12979.1	-32.0	-39.4	-41.8	930.6	1356.8	1780.0	47.8	31.9	36.4	-	2017.3	3429.0	419.8	-	76.6	2966
4	12962.1	-25.5	-36.5	-41.9	935.3	1363.5	1786.0	57.5	44.5	38.3	-	2012.3	3387.8	421.3	-	53.6	2966
5	12978.5	-23.0	-36.1	-41.9	936.9	1364.9	1787.5	60.4	45.9	39.1	-	2012.8	3387.7	421.6	-	56.8	2966
6	12951.6	-27.2	-36.7	-41.9	934.3	1362.6	1785.0	55.2	43.7	37.8	-	2012.0	3388.0	421.1	-	51.7	2966
7	13078.0*	-16.6	-28.3	-41.8	947.9	1374.3	1803.5	144.7	26.7	51.2	-	2027.1	3425.3	427.9	-	148.2	2966
8	13223.5*	-30.1	-37.3	-41.9	933.2	1360.1	1782.1	31.5	31.4	24.3	-	2011.0	3386.5	419.4	-	38.5	2966
9	12955.5	-27.1	-36.5	-41.9	934.7	1362.3	1786.1	56.9	43.4	37.8	-	2012.6	3389.0	421.4	-	51.0	2966
10	12690.4	-34.6	-41.7	-41.9	914.7	1304.3	1701.2	42.7	50.0	43.9	-	1979.1	3348.2	419.4	-	39.1	2966
11	12957.8*	-26.6	-35.9	-41.9	934.4	1361.1	1785.1	56.5	45.5	41.7	5.7	2010.1	3378.9	420.3	1163.1	62.6	2966
12									NOT CONVERGED								

* Adjusted likelihood values for weighting factors used in order to make them comparable

Notes: C1, C2, C3: total catch of fishery 1, 2, and 3;
CC1, CC2, CC3: catch size composition of fishery 1, 2, and 3;
I1, I2, I3, I4: index of survey 1, 2, 3, and 4;
IC1, IC2, IC3, IC4: survey size composition of survey 1, 2, 3, and 4;
R-penalty: recruitment penalty term;
F-prop: proportion of females

Table C6.5. Key estimates for all UMaine model runs (Run number is identical to Table C6.1). *Model exhibited problems converging in one or some retrospective runs.

Run #	Terminal SSB (mt)	Terminal Recruitment (millions)	Mean recruitment (millions)	Terminal exploitation rates (numbers/biomass/ female biomass)	Mohn's rho for SSB/recruitment/ exploitation rate	F_{max}	F_{MSY}	MSY (mt)	B_{MSY} (mt)	Terminal SSB/B_{MSY}
B	1334.27	542.15	1104.00	0.03/0.06/0.15	0.22/0.93/-0.47	1.77	1.77	2556.1	5643.4	0.236
1	1226.87	257.12	494.36	0.05/0.08/0.16	0.20/1.07/-0.48	0.97	0.97	2541.0	7017.7	0.175
2	1578.72	508.17	965.99	0.03/0.05/0.13	0.25/0.83/-0.53	6.02	6.02	2736.7	4634.9	0.341
3	1330.91	508.64	1029.00	0.03/0.06/0.14	1.27/2.10/-2.11	-	-	-	-	-
4	1388.60	567.20	1151.84	0.03/0.06/0.15	0.00/0.78/-0.26	1.78	1.78	2667.5	5880.6	0.236
5	1464.94	603.38	1219.58	0.03/0.06/0.14	-0.95/0.52/0.37	1.78	1.78	2825.2	6233.7	0.235
6	1342.16	541.75	1104.34	0.04/0.07/0.17	0.22/0.93/-0.47	1.77	1.77	2557.0	5646.2	0.238
7	290.82	194.79	966.74	0.11/0.19/0.56	0.17/1.01/-0.51	1.77	1.77	2233.6	4905.1	0.059
8	2176.42	701.02	1145.67	0.03/0.05/0.11	0.52/1.01/-0.78	1.75	1.75	2650.7	5834.5	0.373
9	1341.11	536.62	1104.72	0.03/0.06/0.15	0.18/0.96/-0.43	1.78	1.78	2563.7	5623.2	0.239
10	3438.66	843.68	1541.13	0.02/0.03/0.06	*	2.78	2.78	2575.5	5951.5	0.578
11	1566.19	411.75	1080.17	0.04/0.07/0.14	0.26/0.91/-0.20	1.78	1.78	2501.4	5526.3	0.283
12				NOT CONVERGED						

Table C6.6. Summary of major changes to CSA software. Version 3 was used for 2013 annual assessment update, version 4 was used for 2014 benchmark assessment.

	CSA Version 3	CSA Version 4.2.2
Fitting method	Nonlinear least squares	Maxiumum likelihood
Survey inputs	1 series only	mulitple surveys can be used
Catch	assumed known, no error	cv can be varied (but not time depend
Survey cv	assumed 1 for recruits and post-recruits	time-varying
Catch model	option for Pope's approximation	Baranov's catch equation

Table C6.7. Average CV for each series before and after adjusting CV based on preliminary runs. Catch CV assumed=0.20.

		After adjustment		
	Initial	Ad hoc	3/M rule	Rinaldo
Shrimp survey recruits	0.15	0.40	0.34	0.44
Shrimp survey post-recruits	0.15	0.42	0.55	0.55
ME-NH spring survey	0.03	1.64	1.34	1.51
NEFSC fall Albatross	0.26	0.55	0.53	0.48
NEFSC fall Bigelow	0.36	0.34	0.37	0.31

Table C6.8. Comparison of goodness of fit for 3 scenarios for M. Runs used adjusted cv's for each scenario.

	Assumed catch cv	0.2	0.2	0.2	0.1	0.05
		Ad hoc	Rinaldo (M=0.25)	3/M rule, PPI	3/M rule, PPI	3/M rule, PPI
Objective function		-69.7	-62.2	-75.2	-95.3	-115.9
Component	Shrimp survey recruits	-15.7	-10.1	-23.3	-23.1	-23.0
	Shrimp survey post-recruits	-10.4	-2.3	-2.9	-2.4	-2.3
	ME-NH spring	7.0	6.1	5.5	5.4	5.4
	Fall Albatross	-3.2	-8.0	-4.3	-4.1	-4.0
	Fall_Bigelow	-2.1	-3.1	-2.3	-2.2	-2.1
	Catch	-45.3	-44.7	-47.8	-69.0	-89.8

Table C6.9. Comparison of goodness of fit for models which included different surveys. All models estimated under 3/M –PPI scenario for M. Catch CV=0.20.

		All surveys	Drop ME_NH (keep shrimp, fall)	Drop Fall (keep shrimp, ME-NH)	Shrimp only
Objective function		-75.24	-81.11	-74.23	-81.46
Component	Shrimp survey recruits	-23.33	-23.04	-28.08	-27.54
	Shrimp survey post-recruits	-2.90	-4.14	-4.17	-5.81
	ME-NH spring	5.48		6.31	
	Fall Albatross	-4.34	-4.47		
	Fall_Bigelow	-2.31	-1.73		
	Catch	-47.84	-47.74	-48.29	-48.11
	# parameters	68	66	64	62
	AIC	-14.47	-30.22	-20.46	-38.93

Table C6.10. Estimates of fishing mortality, recruit abundance, post-recruit abundance and total biomass from final CSA run.

	Fishing mortality			Recruit Abundance (millions)			Post-recruit Abundance (millions)			Exploitable Biomass (kt)		
Fishing Year	Median	Lower 5%	Upper 5%	Median	Lower 5%	Upper 5%	Median	Lower 5%	Upper 5%	Median	Lower 5%	Upper 5%
1985	0.23	0.15	0.38	1,001	606	1,663	963	531	1,694	15	9	22
1986	0.21	0.14	0.31	1,167	733	1,742	1,211	656	1,877	20	14	29
1987	0.27	0.18	0.40	836	527	1,359	1,289	837	2,009	20	14	29
1988	0.15	0.10	0.22	703	474	1,117	1,121	697	1,793	17	12	25
1989	0.18	0.12	0.25	835	564	1,225	1,223	816	1,942	15	11	21
1990	0.24	0.18	0.34	1,162	817	1,584	1,245	878	1,849	18	14	25
1991	0.22	0.15	0.31	765	525	1,110	1,335	908	1,853	20	15	27
1992	0.20	0.13	0.29	572	348	1,000	1,128	776	1,611	16	12	23
1993	0.15	0.10	0.22	512	352	736	1,004	672	1,542	14	10	20
1994	0.19	0.13	0.27	816	520	1,308	965	655	1,462	12	9	17
1995	0.41	0.30	0.57	1,004	682	1,505	1,078	725	1,668	15	12	20
1996	0.73	0.51	0.97	1,028	716	1,410	1,019	673	1,489	17	13	22
1997	1.12	0.76	1.68	615	412	869	600	389	946	10	8	13
1998	0.47	0.30	0.73	822	554	1,329	285	133	518	7	5	10
1999	0.20	0.14	0.30	812	452	1,290	491	278	850	9	7	13
2000	0.35	0.24	0.53	294	195	482	802	514	1,166	9	7	13
2001	0.20	0.13	0.33	562	304	963	475	288	738	8	5	11
2002	0.07	0.05	0.10	388	227	695	440	245	687	6	4	9
2003	0.13	0.07	0.19	1,196	762	2,341	475	326	745	9	6	16
2004	0.26	0.16	0.40	759	406	1,326	527	340	1,009	9	6	14
2005	0.14	0.09	0.19	1,768	1,197	2,575	512	303	836	17	13	24
2006	0.05	0.03	0.06	4,176	3,033	5,688	1,325	958	2,001	34	26	46
2007	0.09	0.06	0.12	5,790	4,299	8,201	3,156	2,354	4,275	62	49	84
2008	0.16	0.12	0.21	635	327	1,092	3,948	3,033	5,496	39	31	55
2009	0.11	0.08	0.15	903	520	1,483	1,898	1,442	2,791	26	19	35
2010	0.32	0.22	0.45	1,098	740	1,768	1,440	1,045	2,026	22	17	30
2011	0.48	0.34	0.69	1,287	843	1,808	897	596	1,367	16	12	21
2012	0.55	0.35	0.81	292	148	449	617	387	938	7	5	10
2013	0.13	0.08	0.20	82	51	146	238	135	404	3	2	5
2014				16	8	30	144	87	231			

Table C6.11. Mohn’s rho for estimates from final CSA model.

Relative Change in Estimate				
Terminal Year	F	Recruit	Post-Recruit	Total B
2013	-0.56	0.26	1.60	1.26
2012	-0.74	4.58	0.59	1.65
2011	-0.25	0.15	0.43	0.27
2010	-0.21	0.03	0.40	0.27
2009	-0.29	0.39	0.37	0.38
Mohn's Rho	-0.41	1.08	0.68	0.77

Table C6.12. Likelihood profile on selectivity of recruits. Base is annual selectivity estimated from shrimp survey data.

		Base	All sel=1.0	0.25*base	0.50*base	0.75*base	0.9*base
Objective function		-121.6	-117.5	-109.6	-118.6	-121.3	-121.7
Component	Shrimp sv recruits	-22.7	-21.5	-7.5	-16.4	-20.5	-22.1
	Shrimp sv post-rcrt	-3.4	-0.7	-2.1	-4.5	-4.3	-3.8
	Fall Albatross	-4.1	-3.8	-7.3	-5.7	-4.9	-4.4
	Fall_Bigelow	-1.5	-1.6	-3.4	-2.3	-1.7	-1.6
	Catch	-89.84	-89.85	-89.34	-89.6	-89.8	-89.8

Table C6.13. Likelihood profile on catch under-reporting. Base assumes no under-reporting.

		Base	10% before 2001	25% before 2001	50% before 2001	25% before 2001, 10% after
Objective function		-121.6	-121.4	-121.1	-120.6	-121.3
Component	Shrimp sv recruits	-22.7	-22.8	-23.0	-23.3	-22.9
	Shrimp sv post-rcrt	-3.4	-3.1	-2.6	-1.8	-2.9
	Fall Albatross	-4.1	-4.2	-4.2	-4.2	-4.2
	Fall_Bigelow	-1.5	-1.5	-1.5	-1.5	-1.5
	Catch	-89.8	-89.8	-89.8	-89.8	-89.8

Table C6.14. Likelihood profile on baseline M for PPI run. Base assumes average M=0.5.

		M=0.3	M=0.4	Base M=0.5	M=0.6	M=0.7
Objective function		-111.5	-117.7	-121.6	-123.4	-123.4
Component	Shrimp sv recruits	-16.4	-20.4	-22.7	-23.7	-24.1
	Shrimp sv post-rcrt	-0.8	-2.3	-3.4	-3.9	-3.5
	Fall Albatross	-4.8	-4.5	-4.1	-3.8	-3.4
	Fall_Bigelow	0.1	-0.8	-1.5	-2.1	-2.6
	Catch	-89.6	-89.8	-89.8	-89.9	-89.9

Table C6.15. ASPIC model inputs.

	ASPIC Model Input					ASPIC Model Results			
Fishing Season	NEFSC Fall R/V Albatross (kg/tow)	ME Summer (kg/tow)	ASMFC Summer Shrimp (kg/tow)	NEFSC Fall R/V Bigelow (kg/tow)	Catch (mt)	Biomass	ASPIC F	B/Bmsy	F/Fmsy
1968	3.20	45.80			6,610	62.58	0.12	2.75	0.61
1969	2.70	31.20			12,824	50.88	0.29	2.23	1.50
1970	3.70	40.80			10,670	38.53	0.31	1.69	1.59
1971	3.00	9.40			11,130	31.09	0.41	1.36	2.09
1972	3.30	7.00			11,095	24.17	0.54	1.06	2.78
1973	1.90	7.80			9,405	17.43	0.65	0.76	3.36
1974	0.80	4.90			7,945	11.83	0.89	0.52	4.56
1975	0.90	6.70			5,287	6.67	1.16	0.29	5.97
1976	0.60	4.80			1,022	2.96	0.34	0.13	1.76
1977	0.20	1.60			381	3.03	0.11	0.13	0.57
1978	0.40	3.20			3	3.88	0.00	0.17	0.00
1979	0.50	4.40			439	5.50	0.07	0.24	0.36
1980	0.50	2.70			333	7.17	0.04	0.31	0.21
1981	1.50	3.00			1,074	9.46	0.10	0.42	0.53
1982	0.30	2.00			1,574	11.52	0.13	0.51	0.65
1983	1.00	4.20			1,574	13.46	0.11	0.59	0.56
1984	1.90		10.47		3,227	15.74	0.20	0.69	1.03
1985	1.60		17.69		4,132	16.57	0.25	0.73	1.29
1986	2.50		19.61		4,635	16.53	0.29	0.73	1.47
1987	1.70		15.40		5,266	15.95	0.35	0.70	1.78
1988	1.20		12.76		3,036	14.63	0.20	0.64	1.04
1989	1.81		16.95		3,315	15.52	0.21	0.68	1.08
1990	2.04		18.12		4,663	16.22	0.29	0.71	1.51
1991	0.44		11.68		3,585	15.58	0.23	0.68	1.17
1992	0.41		9.43		3,460	16.01	0.21	0.70	1.09
1993	1.85		9.14		2,143	16.61	0.12	0.73	0.63
1994	2.24		8.69		2,915	18.67	0.15	0.82	0.77
1995	1.22		13.29		6,457	20.08	0.34	0.88	1.75
1996	0.90		8.77		9,539	17.93	0.64	0.79	3.31
1997	1.12		7.73		7,120	12.25	0.71	0.54	3.65
1998	1.99		6.33		4,167	8.17	0.58	0.36	2.97
1999	2.32		5.78		1,866	6.35	0.29	0.28	1.48
2000	1.28		6.39		2,855	6.65	0.46	0.29	2.35
2001	0.63		4.33		1,331	5.90	0.21	0.26	1.09
2002	1.70		9.16		453	6.67	0.06	0.29	0.30
2003	1.08		5.45		1,344	8.69	0.14	0.38	0.73
2004	1.58		10.27		2,131	10.25	0.20	0.45	1.02
2005	2.77		23.38		2,610	11.32	0.22	0.50	1.15
2006	6.64		65.99		2,323	12.09	0.18	0.53	0.94
2007	4.13		11.51		4,880	13.33	0.39	0.58	1.99
2008	3.05		16.77		4,962	11.99	0.45	0.53	2.30
2009			15.44	7.96	2,501	10.29	0.24	0.45	1.21
2010			13.94	4.65	6,141	10.96	0.67	0.48	3.44
2011			8.47	5.79	6,398	7.66	1.30	0.34	6.70
2012			2.50	0.76	2,477 *	2.95	1.22	0.13	6.25
2013			1.00	N/A	307 *	1.27	0.16	0.06	0.82
2014						1.58		0.07	
Average:	1.77	11.22	12.88	4.79	4,165	14.14	0.35		
1971-74 ave:						21.13	0.62		
1985-94 ave:						16.23	0.23		
2011-2013 (3-yr) ave:						3.96	0.89		

*Catch data are preliminary

Table C7.1. Biological reference points and terminal year estimates for Northern shrimp models.

Fishing Mortality					
	Historical Proxy			Model Based	
	F_{target}	$F_{threshold}$	F_{2013}*		
UME	0.22	0.39	0.04 (N-weighted), 0.26 (full F)	$F_{40\%SPR}$ = 0.78	$F_{30\%SPR}$ = 1.17
CSA	0.20	0.27	0.13	n.a.	n.a.
ASPIC	0.23	0.35	0.16	F_{MSY}=0.19	

*For the UME model, the N-weighted F_{2013} should be compared to the historical proxies, and the full F should be compared to the model-based reference points.

Biomass*			
	Historical Proxy		Model Based
	$B_{threshold}$/ $SSB_{threshold}$	B_{2013} SSB_{2013}	
UME	2,335 mt	1,334 mt	n.a.
CSA	16,600 mt	3,000 mt	n.a.
ASPIC	16,200 mt	1,270 mt	B_{MSY}=22,800 mt

*UME biomass reference points and terminal year estimates are for spawning stock biomass; CSA and ASPIC estimates are for exploitable biomass.

Table C7.2 Comparison of current management reference points (approved through SARC 45) and proposed new reference points.

Reference Point	SARC 45 Definition	SARC 45 Value	SARC 58 Definition	SARC 58 Value
$F_{Threshold}$	Maximum F during stable period (1985-94)	0.48[3]	Maximum F during stable period (1985-94)	0.39
F_{Target}	Average F during stable period (1985-94)	0.38[3]	Average F during stable period (1985-94)	0.22
$B_{Threshold}$	0.5*Average B during stable period (1985-1994)	9,000 mt	0.5*Average SSB during stable period (1985-1994)	2,335 mt
B_{Limit}	2,000 mt less than lowest value estimated by ASPIC model	6,000 mt	Not defined in this assessment	n.a.

[3]: The F reference points are updated at each annual assessment update; these values are from the 2013 update.

Table C8.1. Uncertainty of model estimates and Mohn's rho.

Model	Average CV (%)	Mohn's Rho %
UME		
Recruitment	19.0	93.0
Spawning stock biomass	8.4	22.0
Fishing Mortality	11.4	-47.0
CSA		
Recruit Numbers	27.5	108.0
Post-recruit Numbers	27.0	68.0
Biomass	21.5	77.0
Fishing Mortality	26.9	-41.0
ASPIC		
Biomass	11.6	760.0
Fishing Mortality	9.2	220.0

Table C9.1 Yield calculation and input values for determining target catch levels for several values of fishing mortality, for 2014.

CSA	F	Yield (mt)
25% F_{target}	0.05	64
50% F_{target}	0.1	127
F_{target}	0.2	255

UME	F_{target} = $F_{40\%SPR}$	Yield (mt) avg. weight of shrimp	Yield (mt) calc. weight of shrimp
25% F_{target}	0.195	286	244
50% F_{target}	0.39	572	488
F_{target}	0.78	1144	976

	F_{target} = avg F	Yield (mt) avg. weight of shrimp	Yield (mt) calc. weight of shrimp
25% F_{target}	0.055	78	67
50% F_{target}	0.11	157	134
F_{target}	0.22	314	267

Table C9.2 Mean size (carapace length in mm) of shrimp in summer surveys and mean weights (g) of a shrimp in the GOM northern shrimp fishery landings the following season.

Survey year	Mean survey female length (mm)	Fishing season	Observed mean wt of shrimp in fishery (g)
1984	24.78	1985	11.62
1985	26.06	1986	12.55
1986	26.71	1987	12.41
1987	26.30	1988	13.78
1988	26.65	1989	11.21
1989	25.34	1990	10.67
1990	26.42	1991	10.71
1991	26.98	1992	12.92
1992	26.71	1993	11.48
1993	25.80	1994	11.07
1994	25.49	1995	10.29
1995	25.49	1996	11.02
1996	26.21	1997	9.94
1997	26.11	1998	11.53
1998	24.95	1999	9.01
1999	25.33	2000	10.93
2000	25.54	2001	9.36
2001	23.82	2002	9.70
2002	24.37	2003	10.49
2003	23.20	2004	9.63
2004	25.34	2005	10.86
2005	26.33	2006	11.43
2006	24.72	2007	8.91
2007	24.31	2008	10.13
2008	26.42	2009	11.945
2009	26.91	2010	11.940
2010	26.52	2011	10.57
2011	23.99	2012	9.30
2012	25.09	2013	11.10
2013	26.45		

Table C9.3 Mean size (carapace length in mm) of shrimp in summer surveys and mean weights (g) of shrimp in the GOM northern shrimp fishery landings the following season, with the 3-year-old weighting factor X, and the linear regression coefficients used to predict the mean weight (g) of a shrimp in the 2014 fishery.

MS Excel Solver was used to find the best 3yo weighting factor "X" and the linear regression coeffients a and b by minimizing the sum of the Difference^2 between Observed and Predicted.

X= 0.0016

a= 0.5445
b= -2.7376

Survey year	Mean survey female length (mm)	3yo index (age 1.5 no. per tow in prevous survey year)	Mean survey female length - X*3yo	Fishing season	Observed mean wt of shrimp in fishery (g)	Predicted =a(survey len-X*3yo)+b	Difference^2
2001	23.82	450.33	23.08	2002	9.70	9.83	0.018
2002	24.37	17.62	24.34	2003	10.49	10.52	0.001
2003	23.20	1164.45	21.30	2004	9.63	8.86	0.587
2004	25.34	10.72	25.32	2005	10.86	11.05	0.035
2005	26.33	286.39	25.86	2006	11.43	11.34	0.007
2006	24.72	1752.49	21.87	2007	8.91	9.17	0.066
2007	24.31	374.31	23.70	2008	10.13	10.16	0.001
2008	26.42	28.27	26.38	2009	11.95	11.62	0.104
2009	26.91	505.74	26.09	2010	11.94	11.47	0.222
2010	26.52	582.42	25.58	2011	10.57	11.19	0.377
2011	23.99	474.75	23.22	2012	9.30	9.90	0.371
2012	25.09	43.68	25.01	2013	11.10	10.88	0.050
2013	26.45	6.67	26.44	2014	??	**11.66**	
							1.838

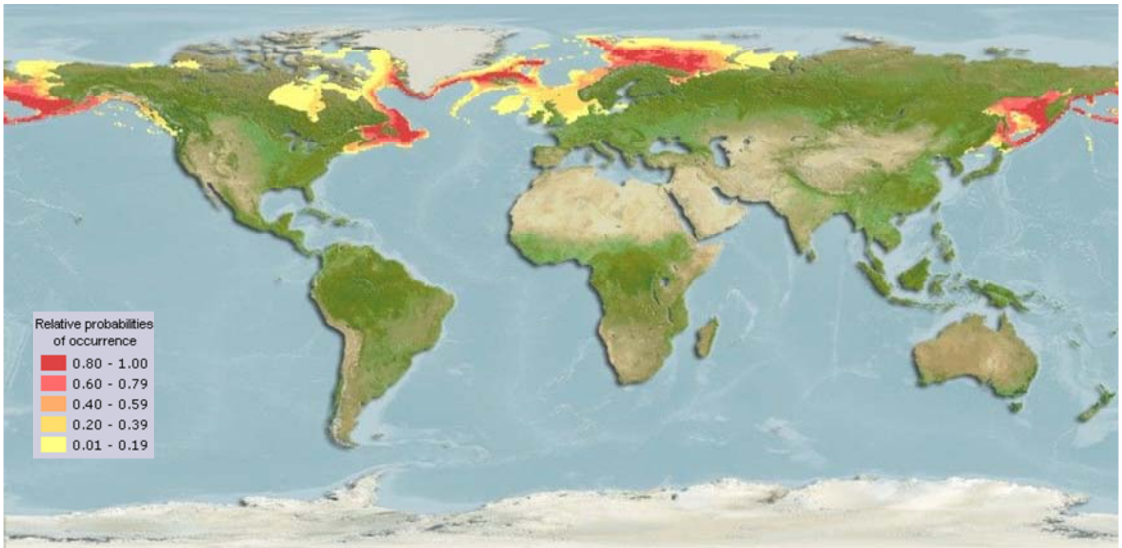


Figure C4.1. Range distribution of northern shrimp with relative probabilities of occurrence (www.aquamaps.org).

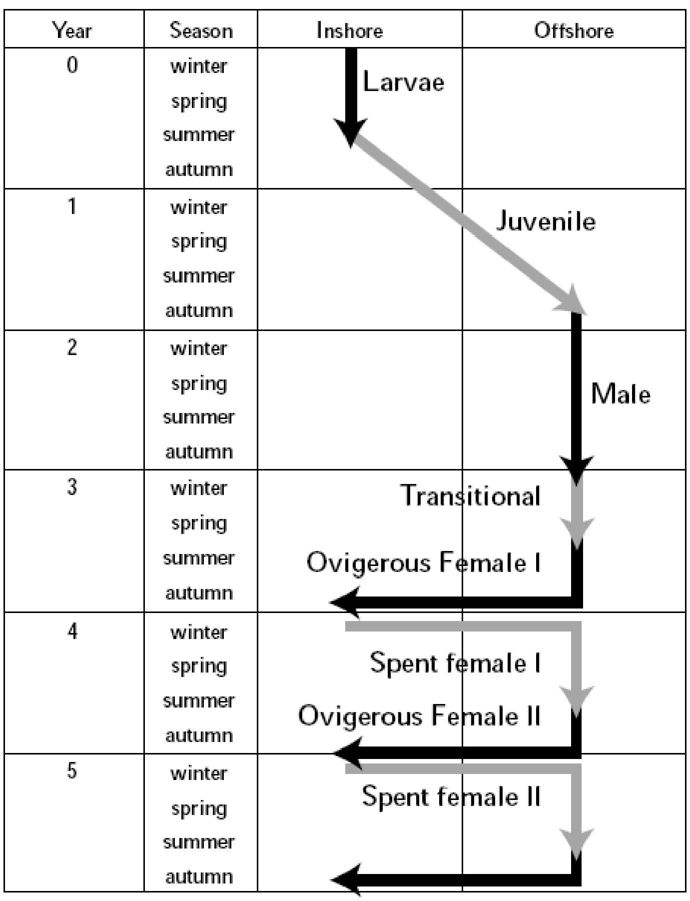


Figure C4.2. Life cycle of northern shrimp in the Gulf of Maine (Clark et al. 2000).

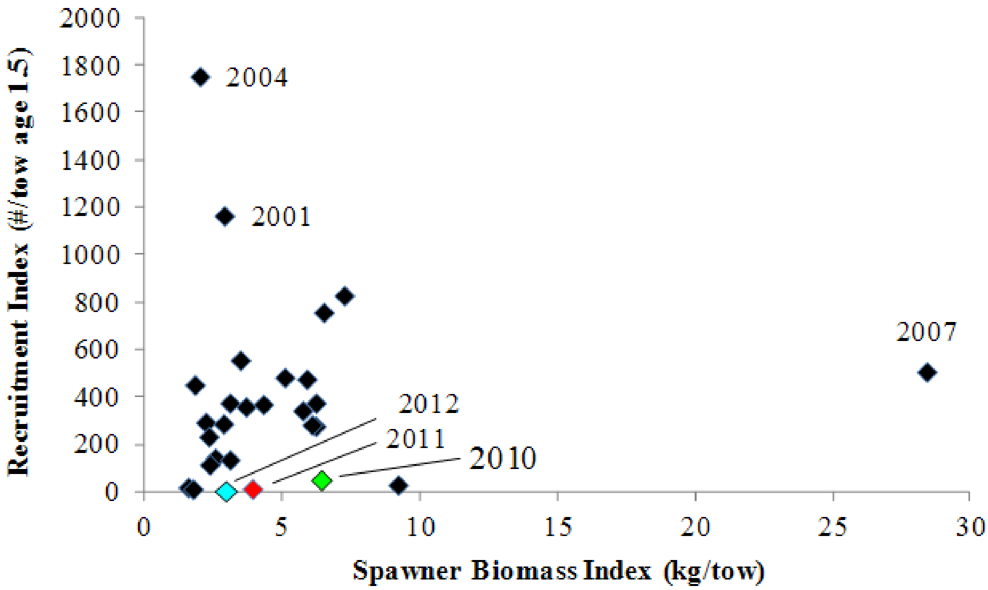


Figure C4.3. Relationship between summer survey index of Gulf of Maine female northern shrimp biomass the summer before spawning to age 1.5 abundance two years later. Year labels indicate the assumed age 1.5 year class.

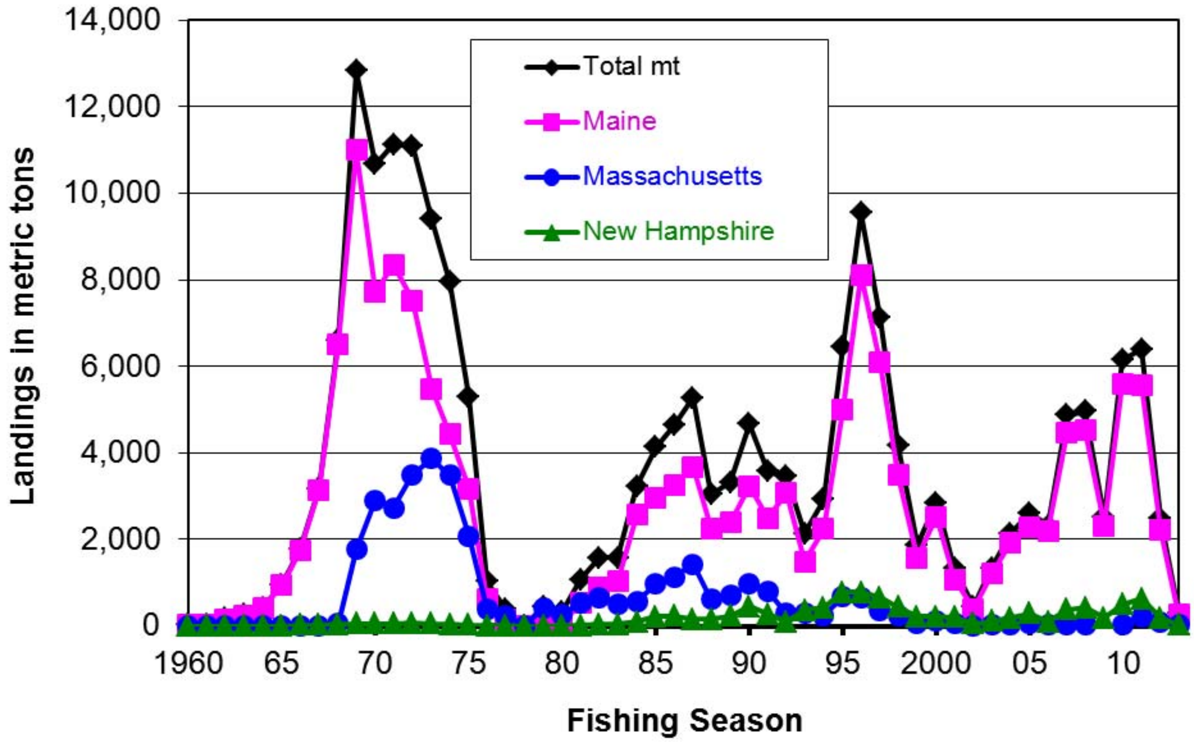
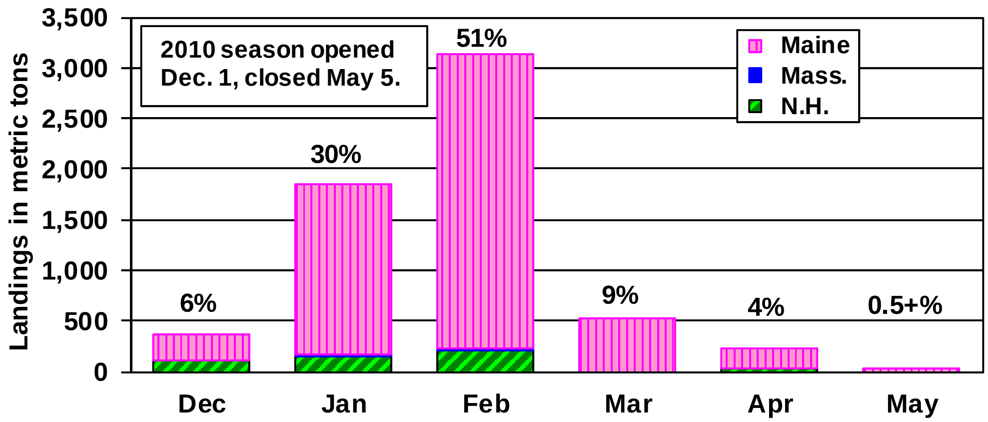


Figure C5.1. Gulf of Maine northern shrimp landings (metric tons, mt) by season and state. MA landings are combined with NH landings in 2009 to preserve confidentiality. 1 mt = 2,205 pounds.



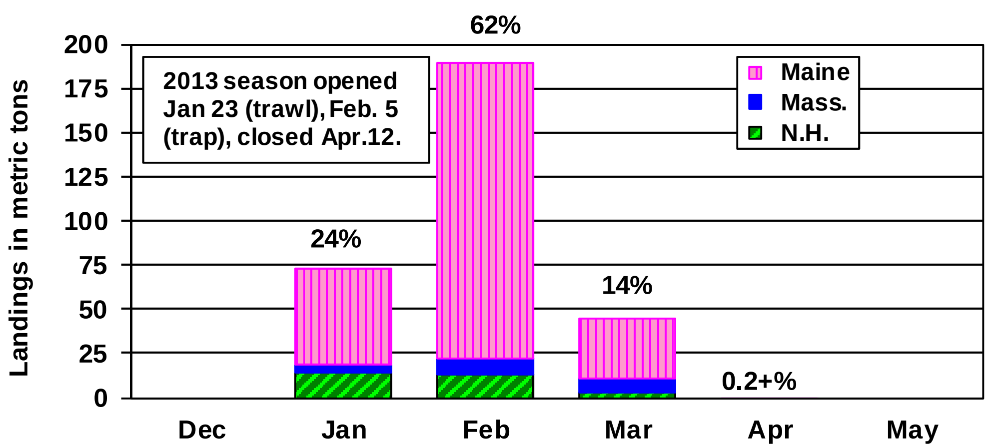


Figure C5.2. Gulf of Maine northern shrimp landings by state and month in the 2010 season (above) and the 2013 season (below) (preliminary data). Landings are in metric tons. 1 mt = 2,205 lbs.

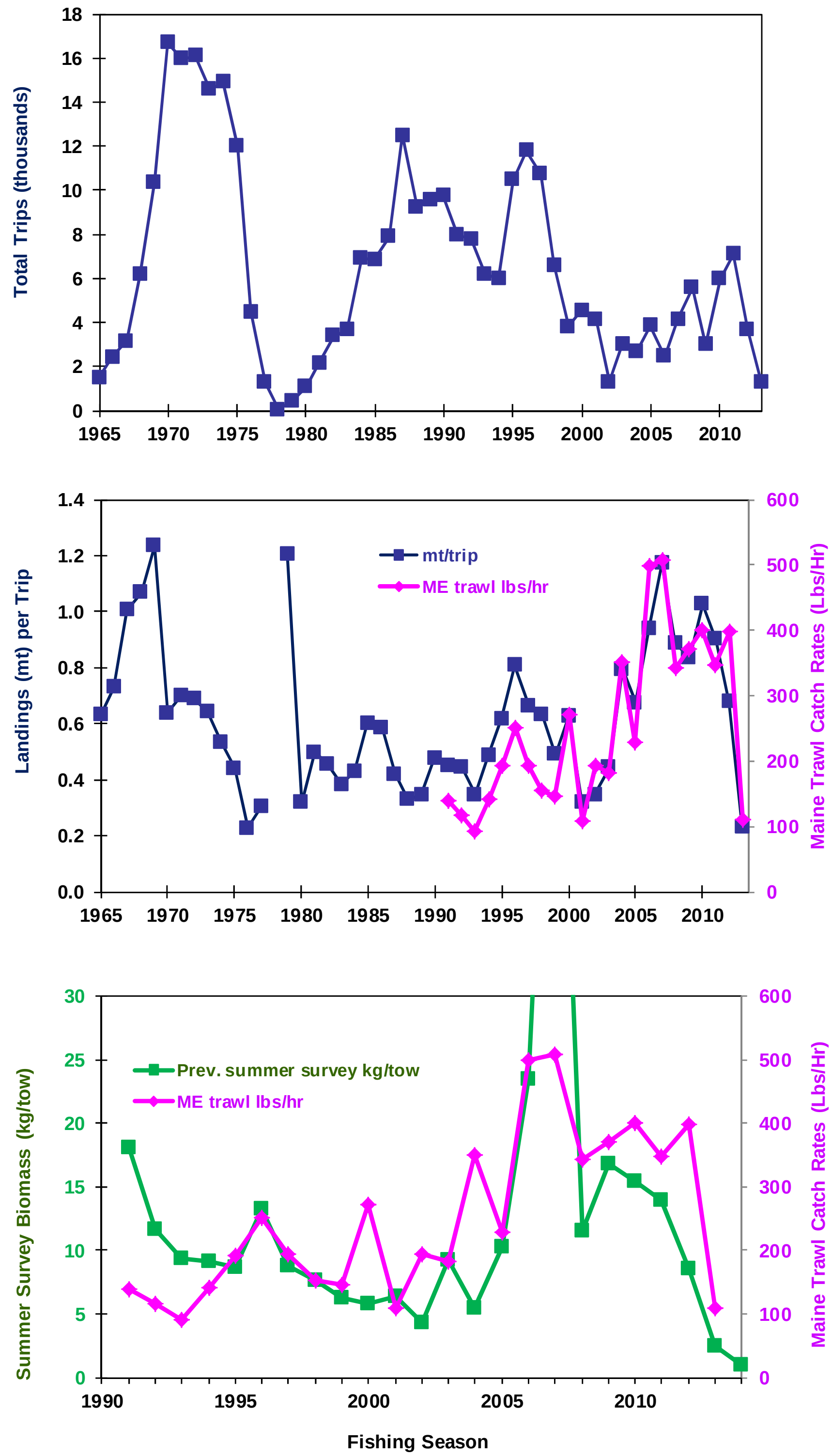


Figure C5.3. Nominal fishing effort (trips) in the Gulf of Maine northern shrimp fishery by season above, catch per unit effort in mt/trip and Maine trawl lbs/hr (middle), and Maine trawl lbs/hr and the previous summer survey index (kg/tow) (below). 2012 and 2013 trip data are preliminary.

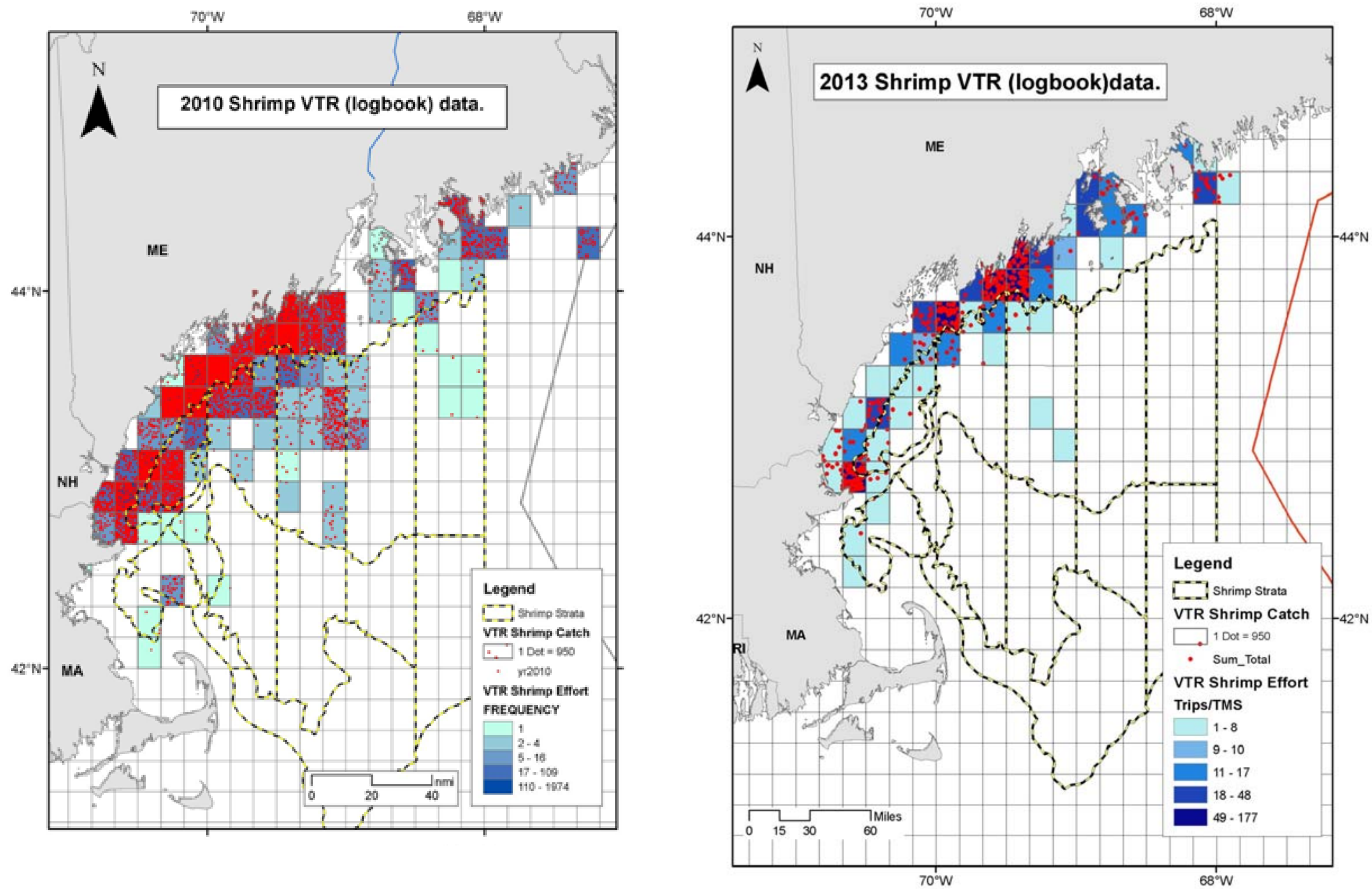


Figure C5.4. Pounds caught and numbers of trips during the 2010 (left) and 2013 (right) northern shrimp fishing seasons by 10-minute-square. Each red dot represents 950 lbs caught; locations of dots within squares are random and do not reflect the actual location of the catch. Number of trips is indicated by the blue palette for the squares. From preliminary state and federal harvester logbook (VTR) data.

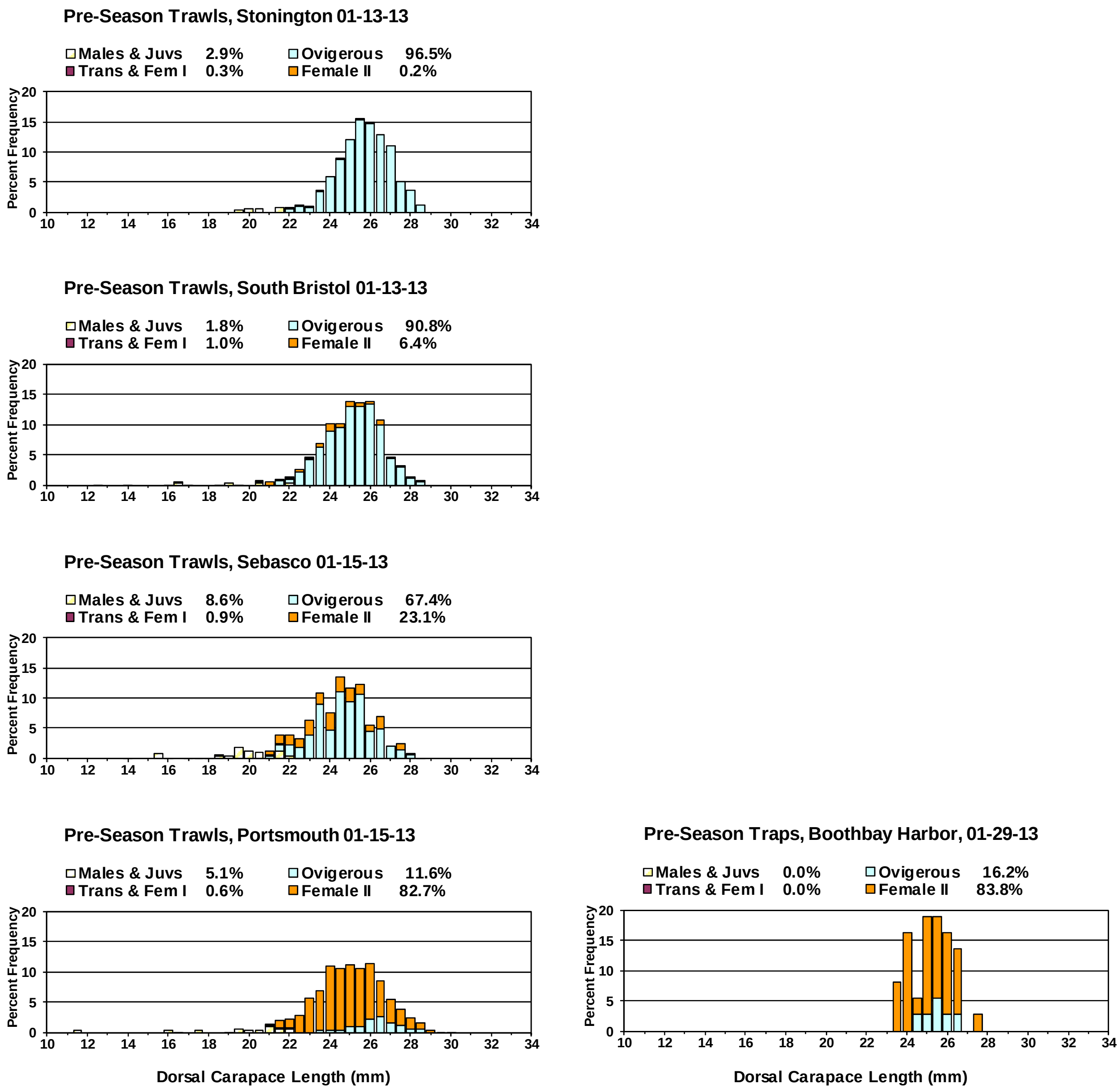


Figure C5.5. Relative length-frequency distributions from samples of northern shrimp from pre-season tows (left) and traps (right), from north (top) to south (bottom).

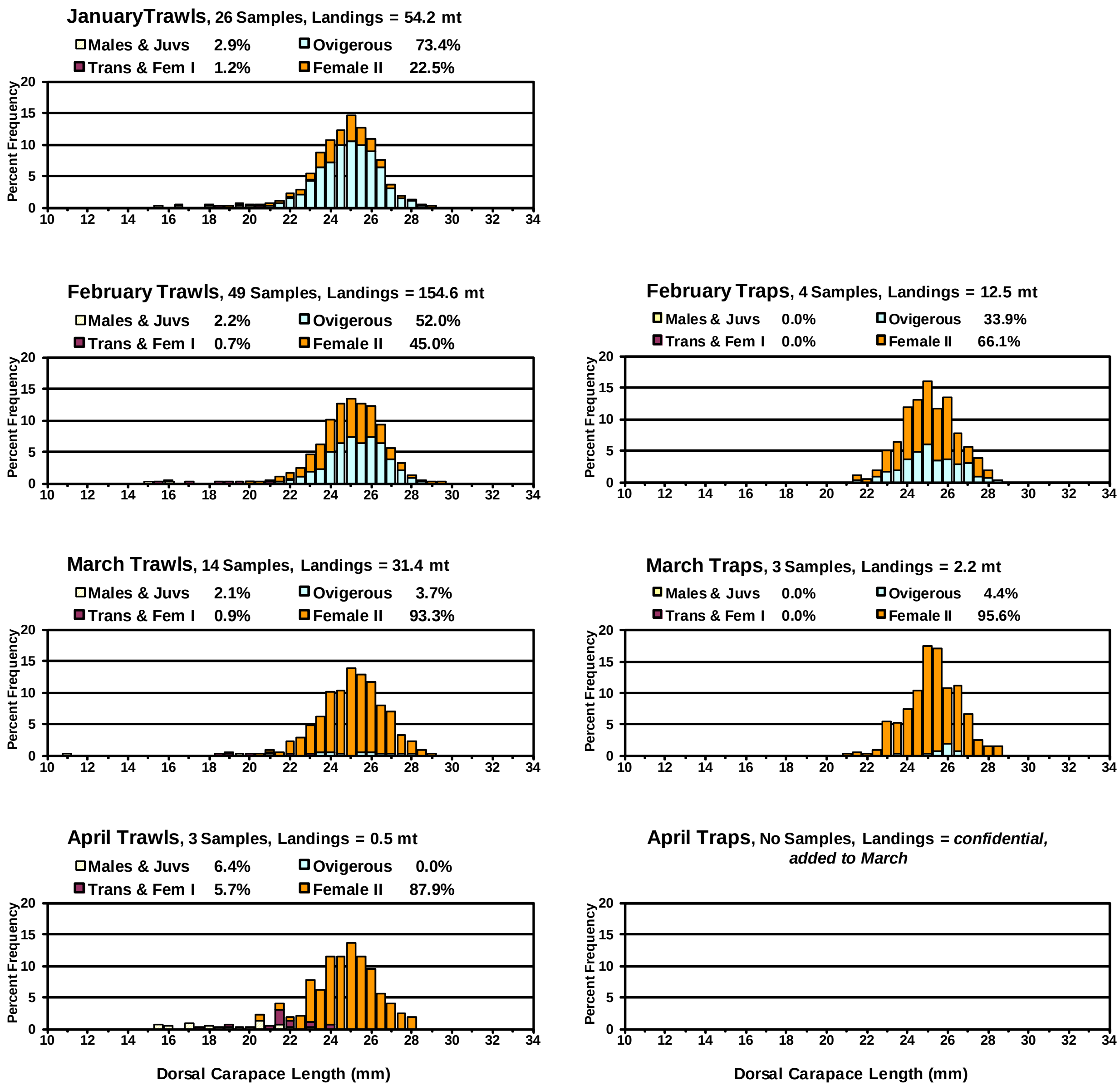


Figure C5.6. Relative length-frequency distributions from samples of Maine northern shrimp catches during the 2013 season by month (top to bottom) and gear, trawls (left) and traps (right). Landings are preliminary. 1 mt = 2,205 lbs.

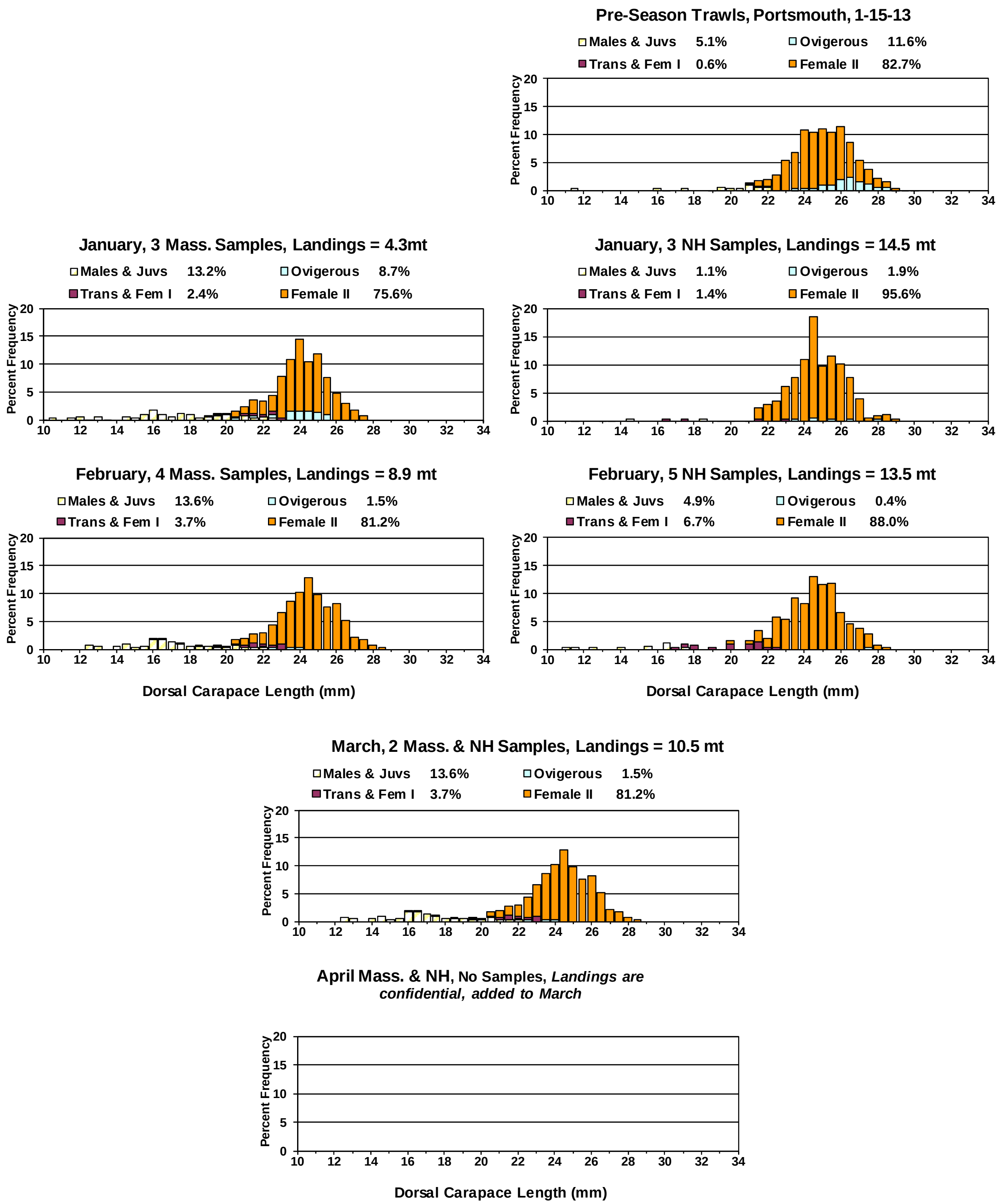


Figure C5.7. Relative length-frequency distributions from samples of Massachusetts (left) and New Hampshire (right) northern shrimp catches during the 2013 season by month (top to bottom). Landings are preliminary. 1 mt = 2,205 lbs.

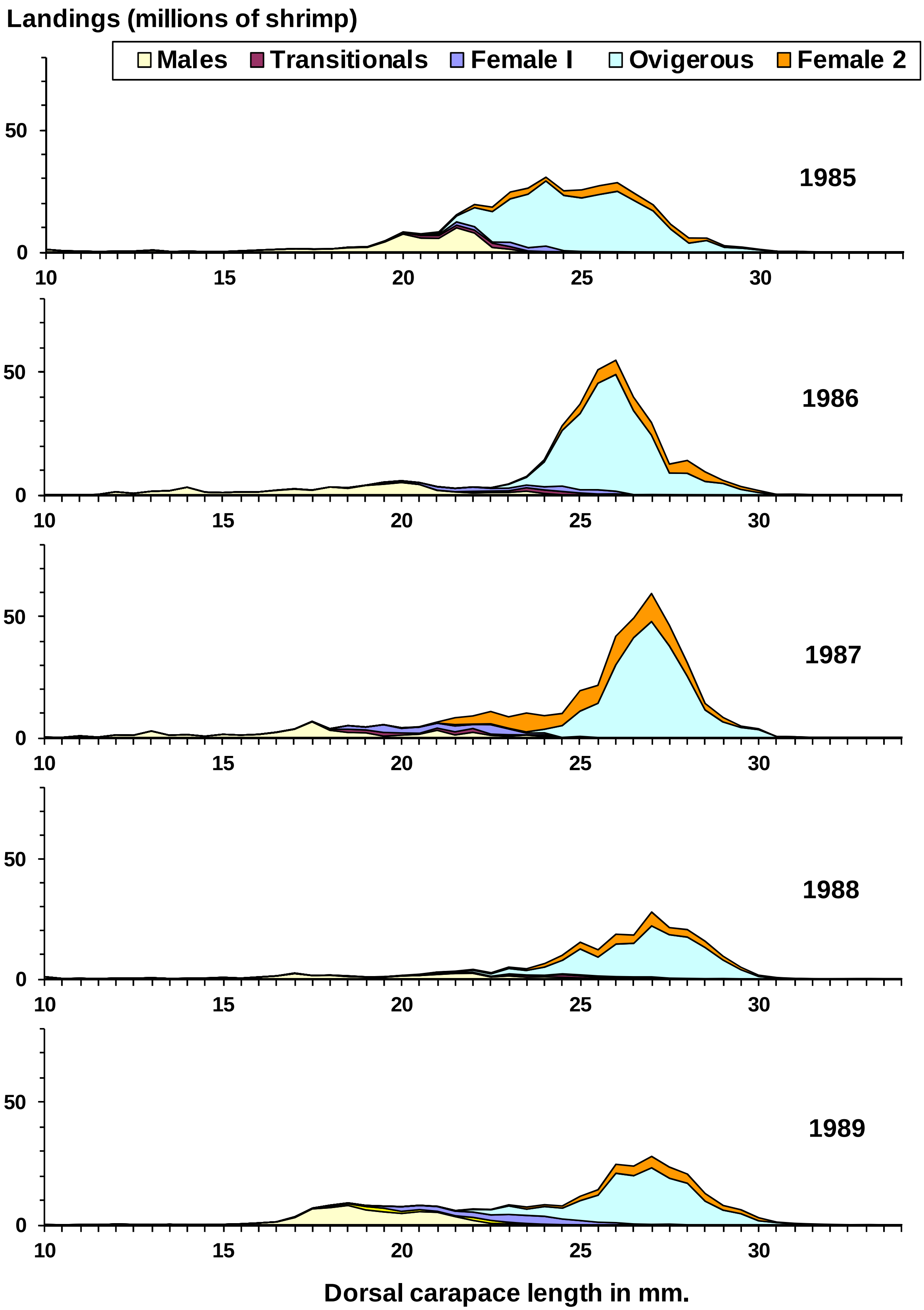


Figure C5.8. Gulf of Maine northern shrimp landings in estimated numbers of shrimp (millions), by length, development stage, and fishing season.

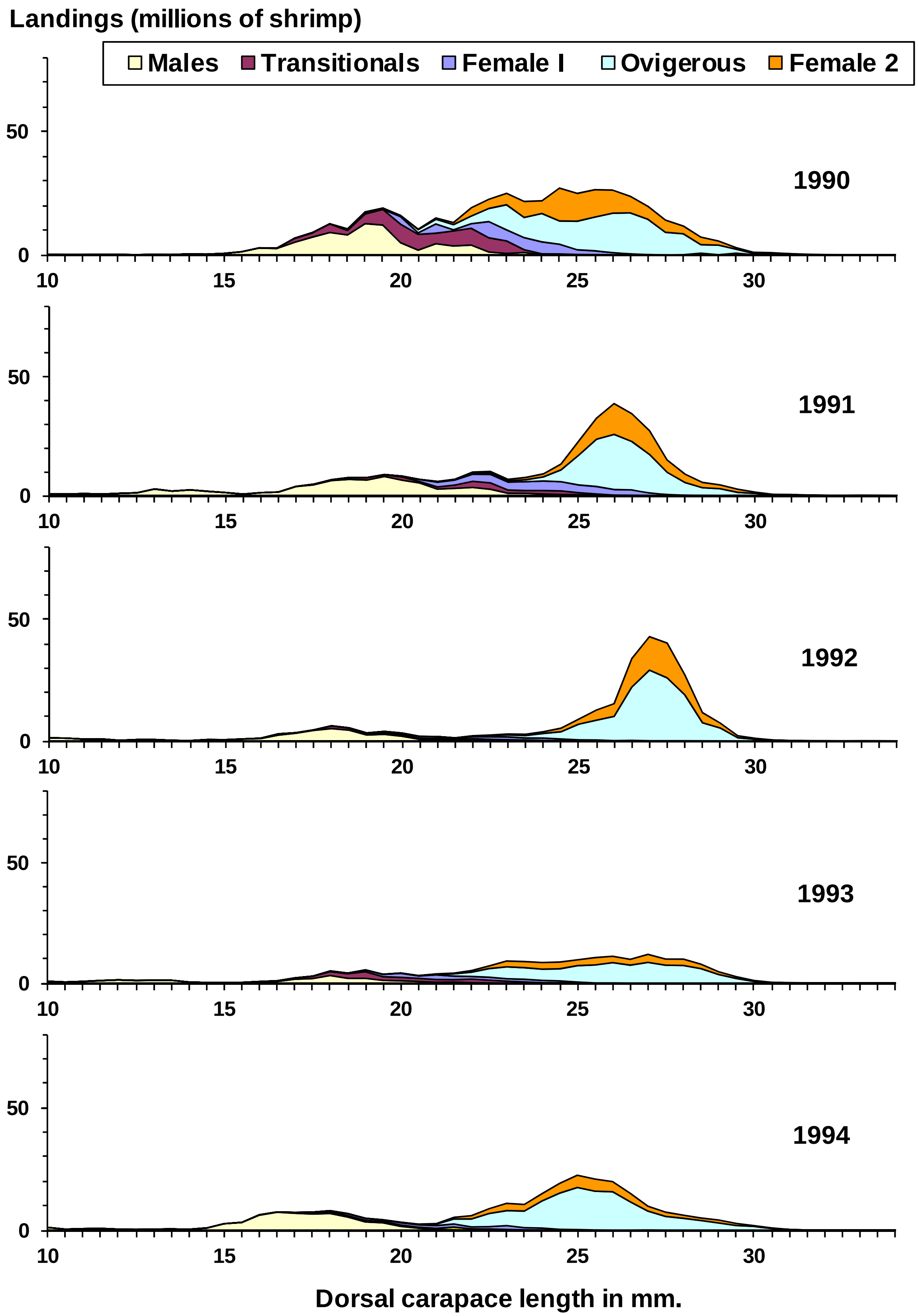


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

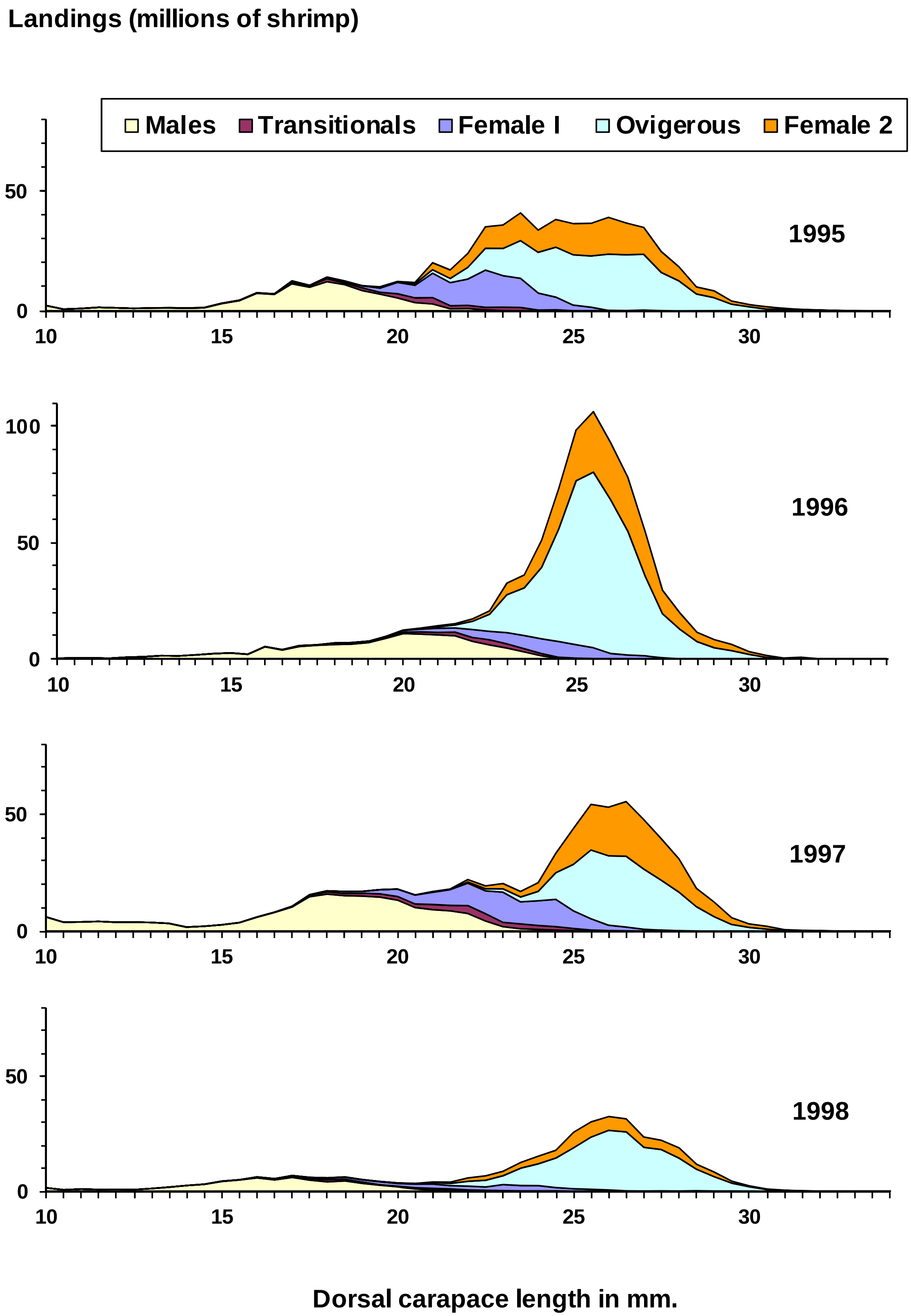


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

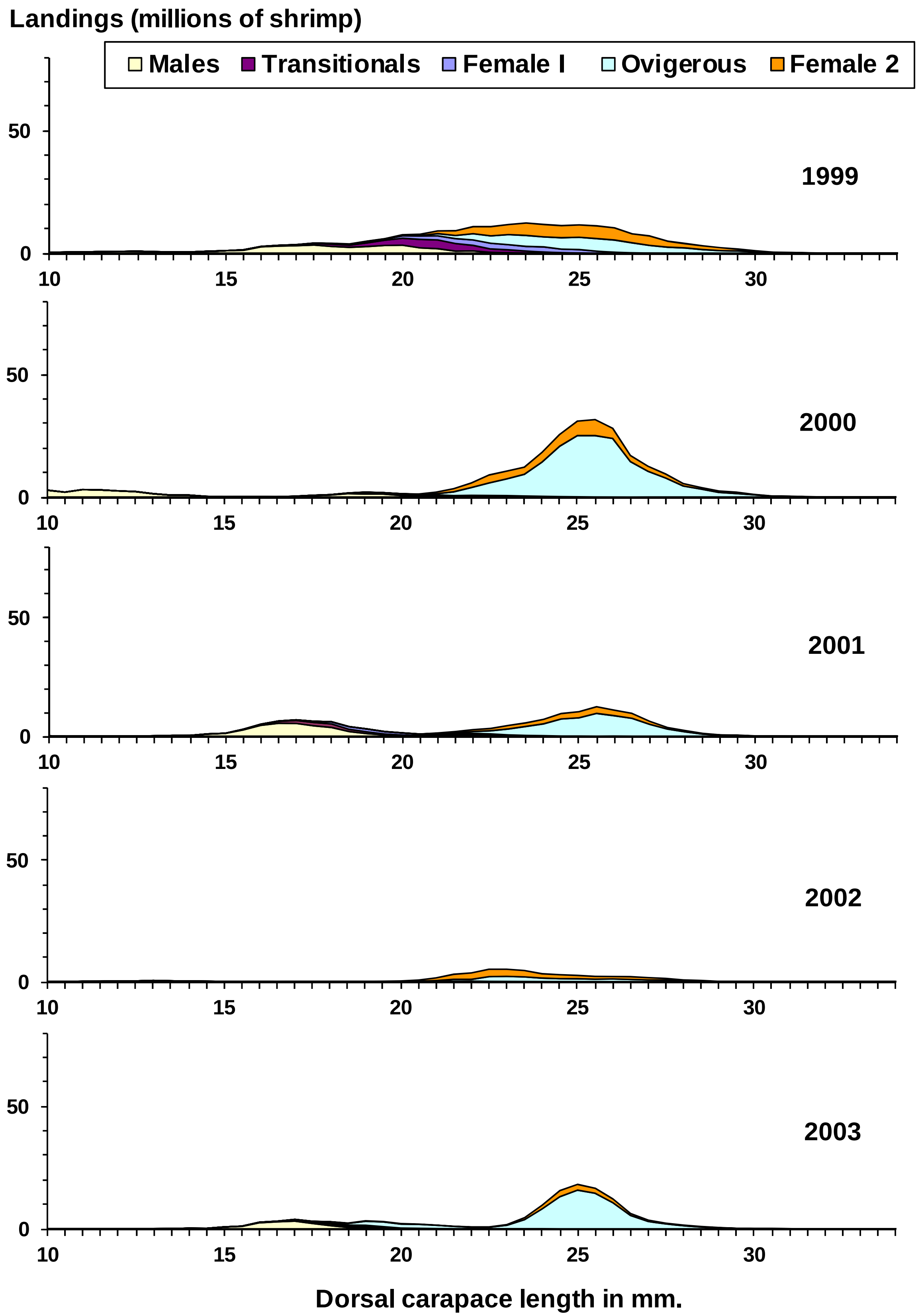


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

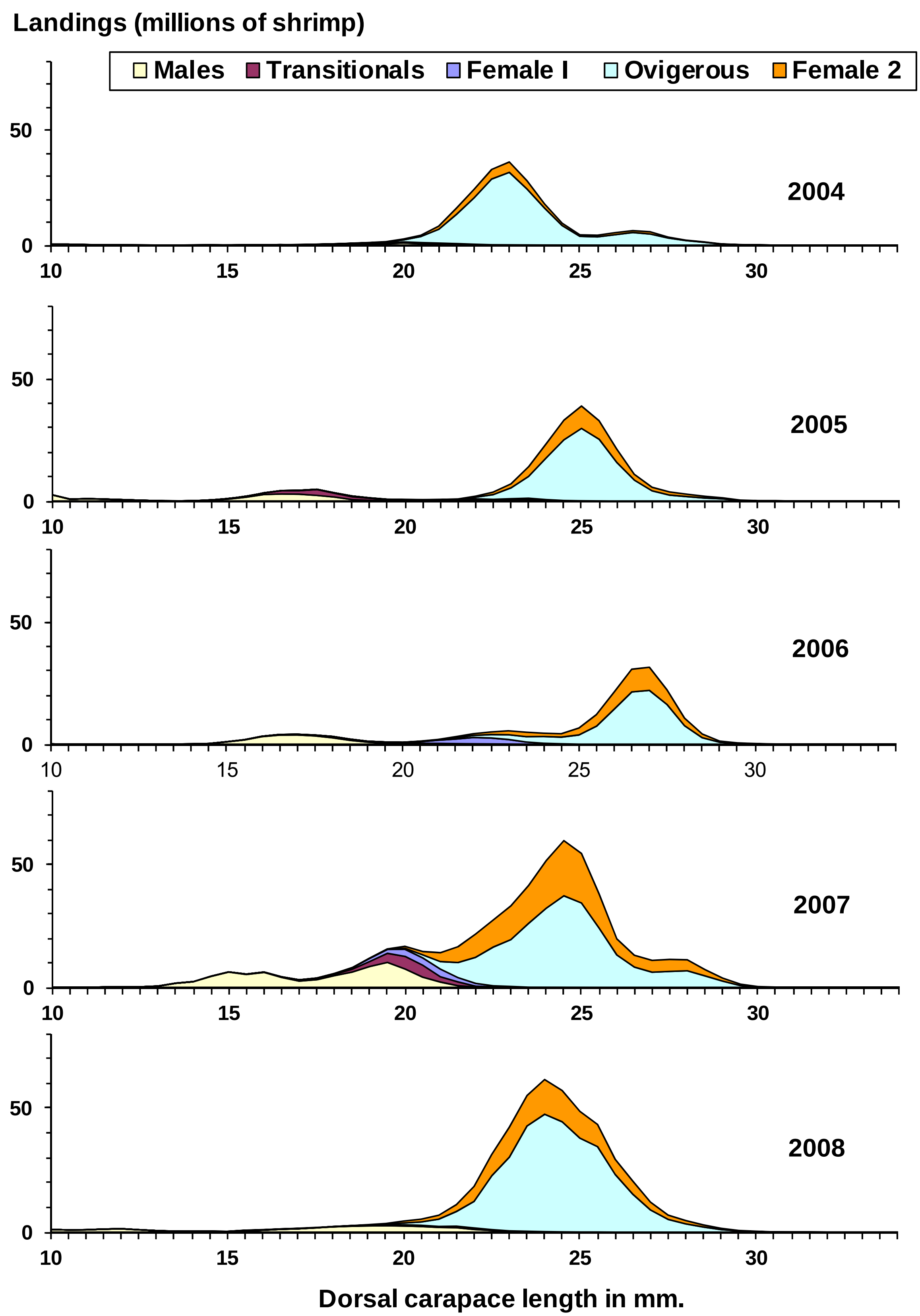


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

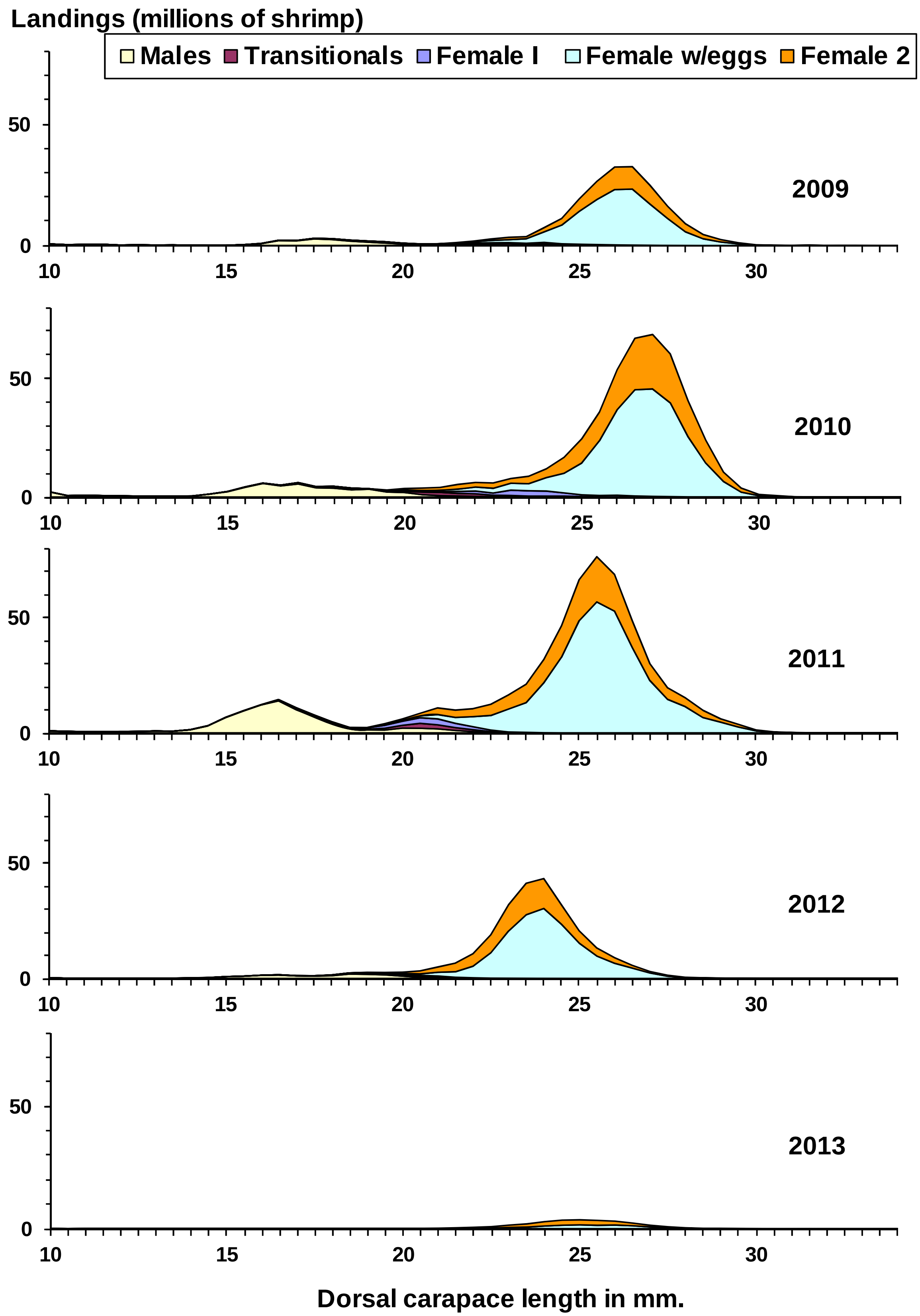


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

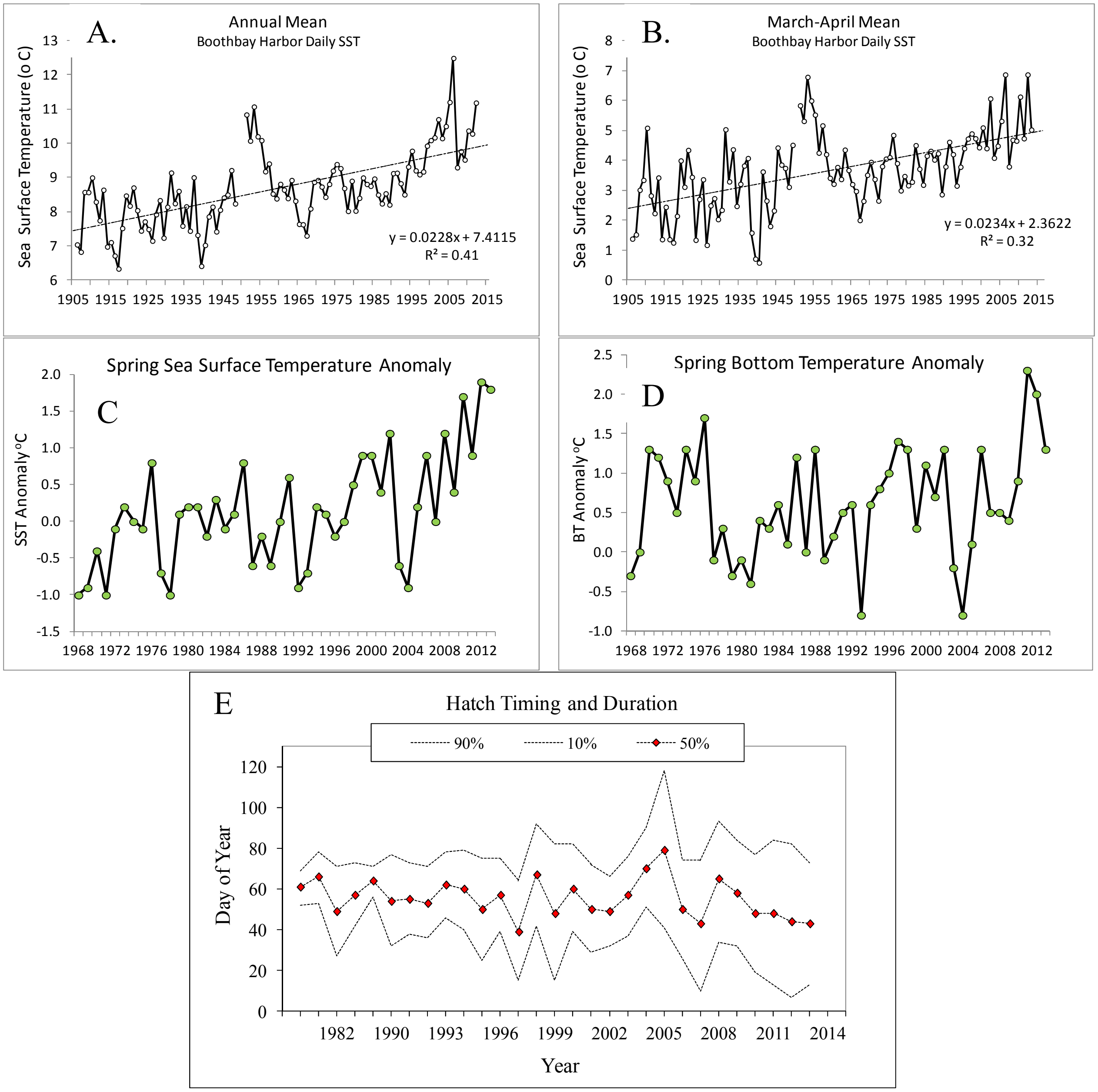


Figure C5.9 (A) Average annual sea surface temperature (SST) at Boothbay Harbor, Maine, during 1906-2013 and (B) average SST during March-April, 1906-2013. (C) Spring sea surface temperature anomaly in shrimp offshore habitat areas from NEFSC trawl surveys, 1968-2013. (D) Spring bottom temperature anomaly in shrimp offshore habitat areas from NEFSC trawl surveys, 1968-2013. (E) Estimated hatch timing (10%=start, 50%=midpoint, 90%=completion) for northern shrimp in the Gulf of Maine, 1980-1983 and 1989-2013 (no data 1984-1988).

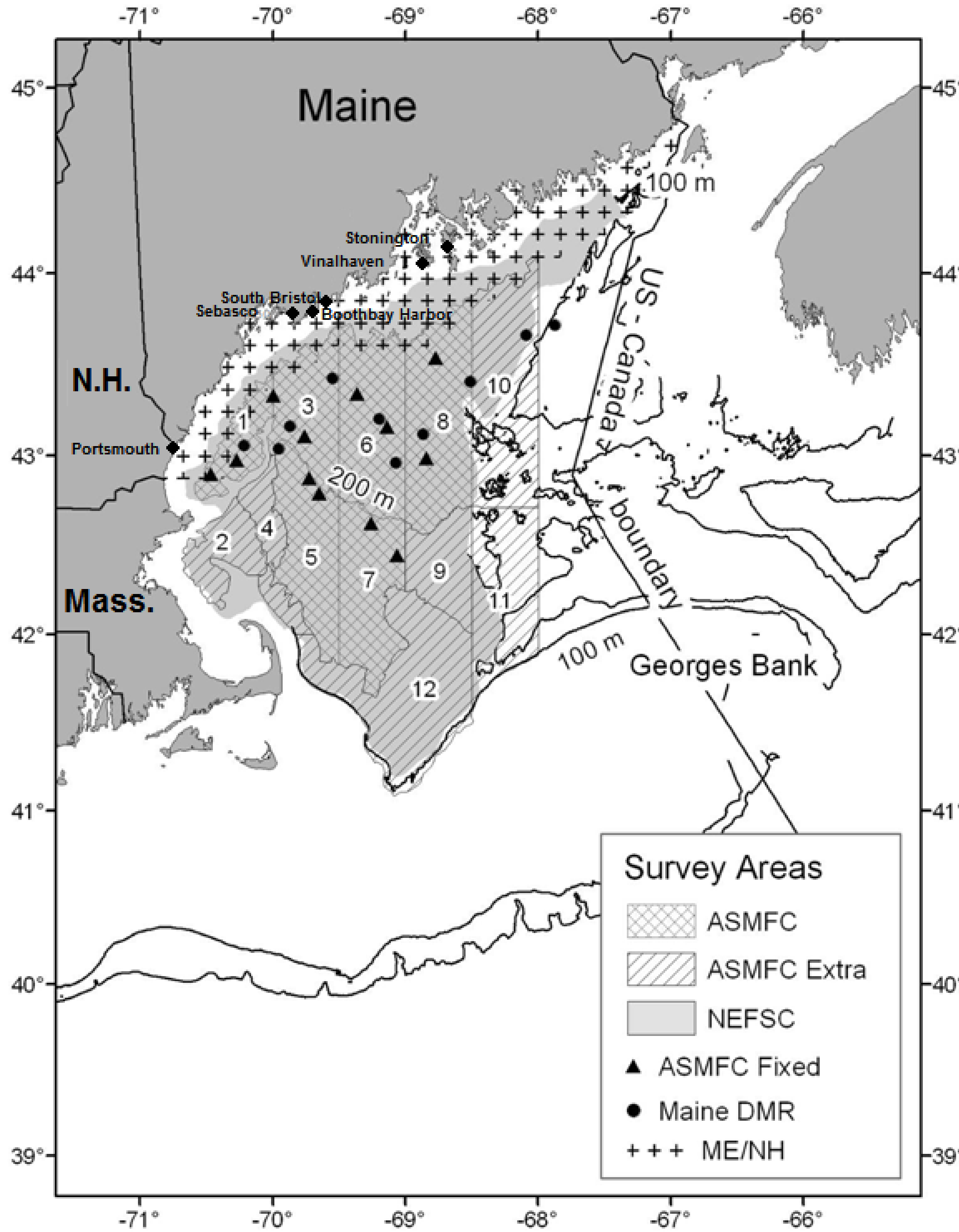


Figure C5.10. Gulf of Maine survey areas and station locations, and harbors mentioned in the text.

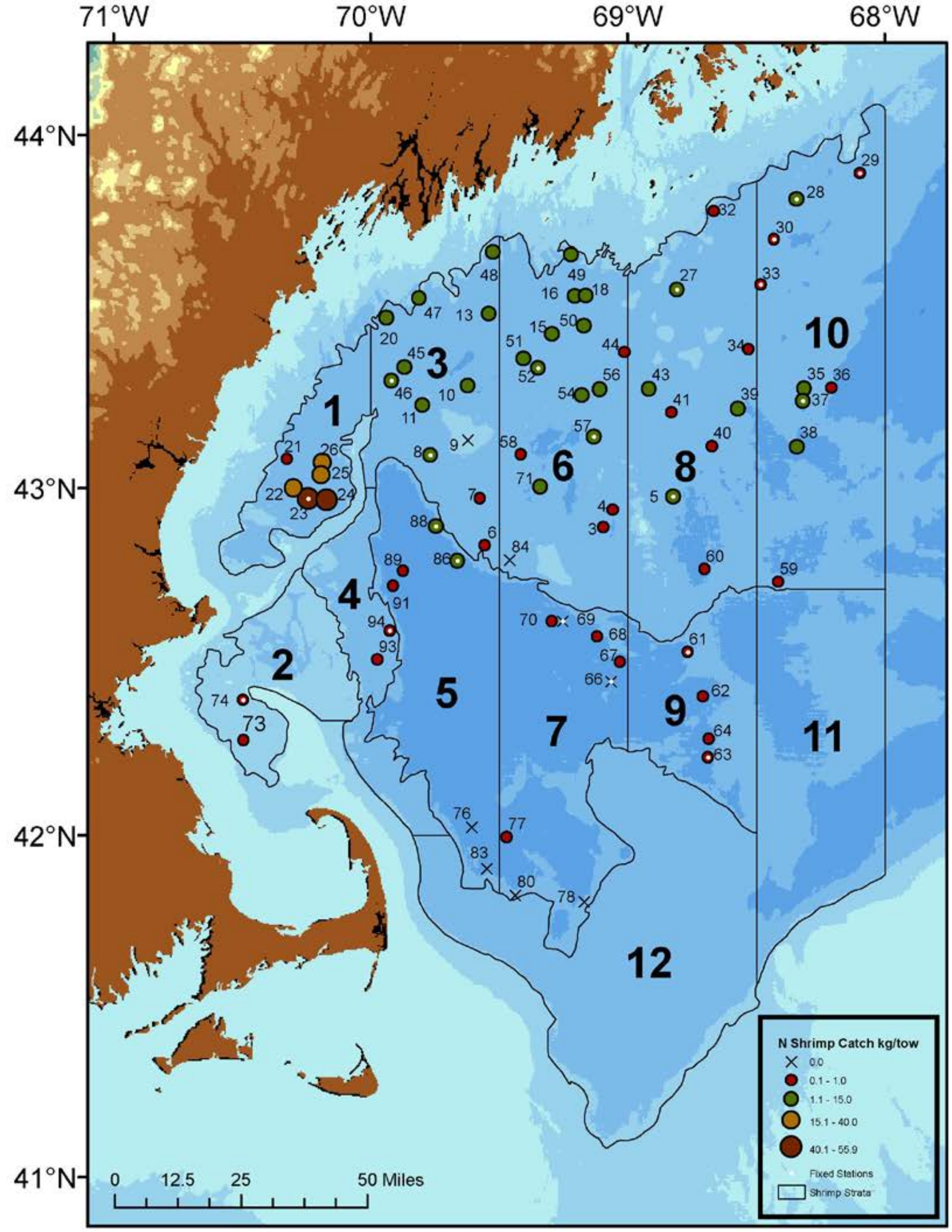


Figure C5.11. State/federal summer northern shrimp survey aboard the *R/V Gloria Michelle*, July 22 – August 14, 2013, fixed and random survey sites and shrimp catches in kg/tow.

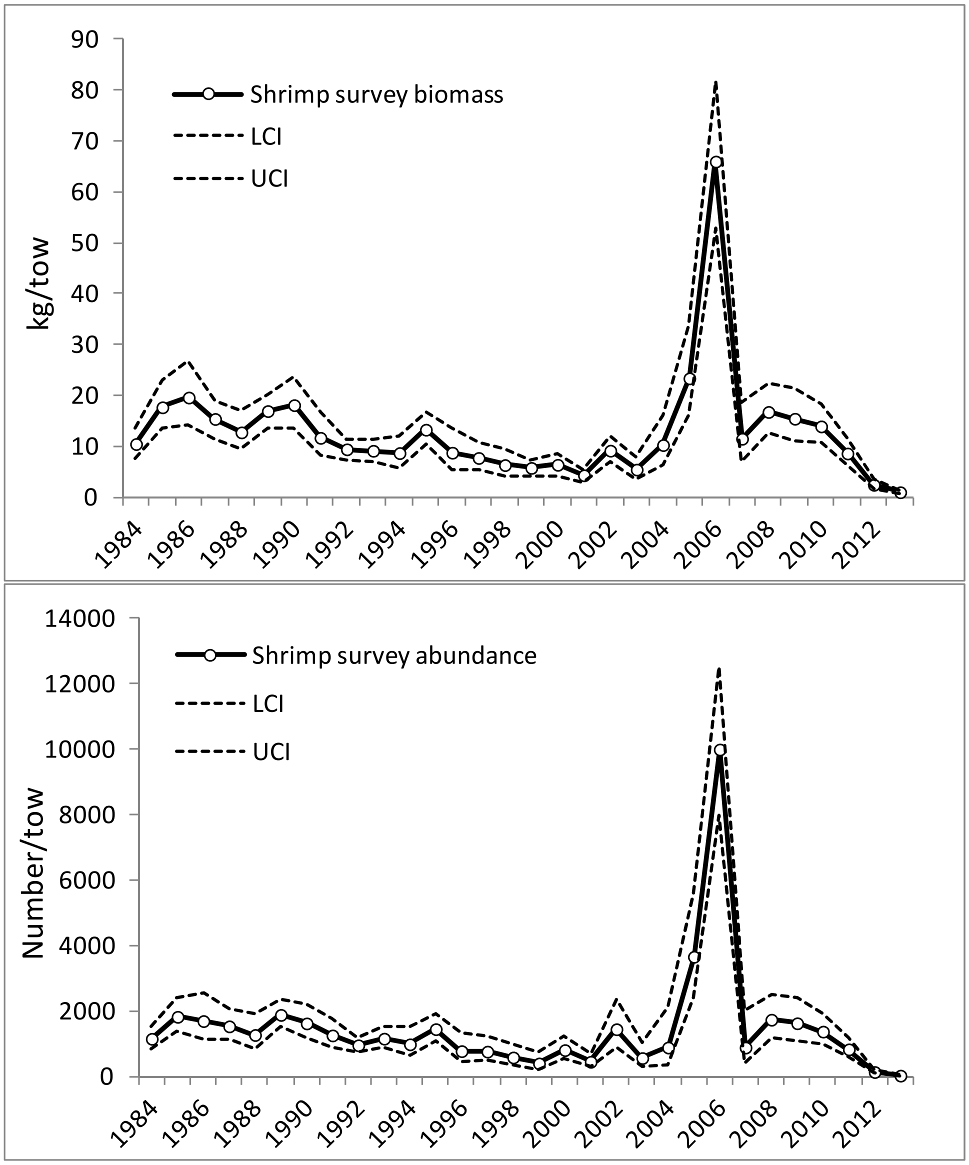


Figure C5.12. Northern shrimp survey indices with 95% confidence intervals from ASMFC summer shrimp survey. LCI lower confidence interval, UCI upper confidence interval.

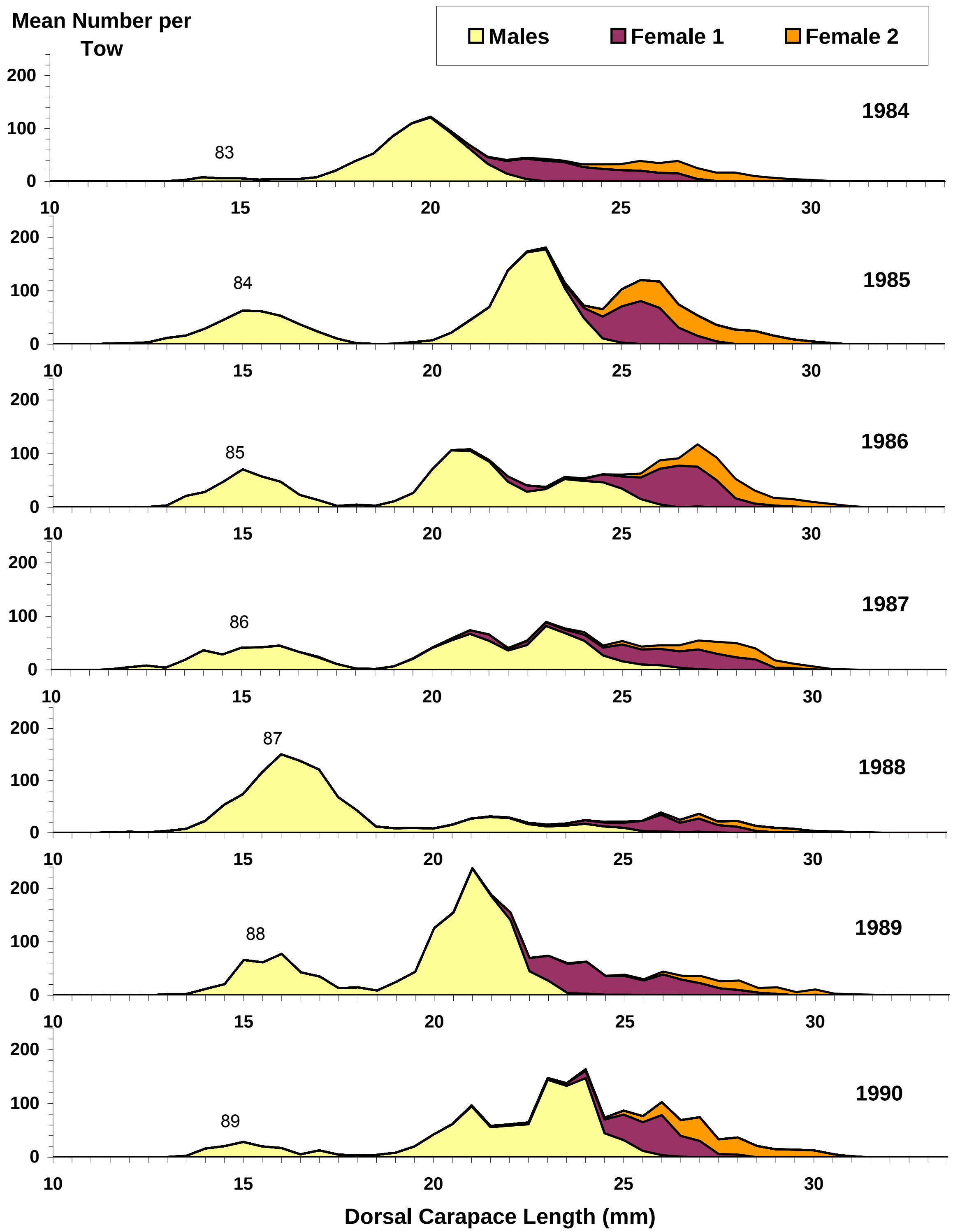


Figure C5.13. Gulf of Maine northern shrimp summer survey mean catch per tow by year, length, and development stage. Two-digit years are year class at assumed age 1.5.

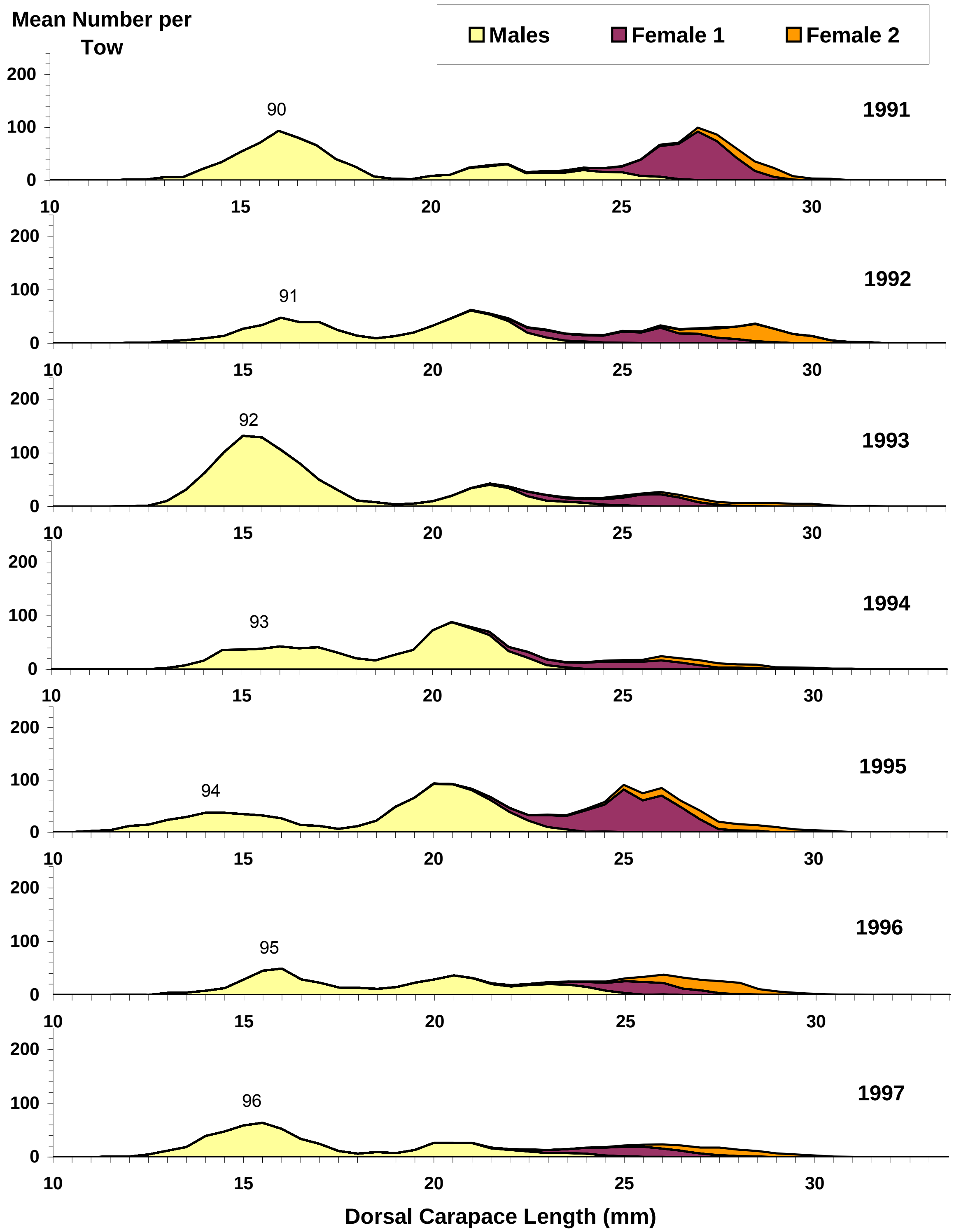


Figure C5.13 continued – summer survey.

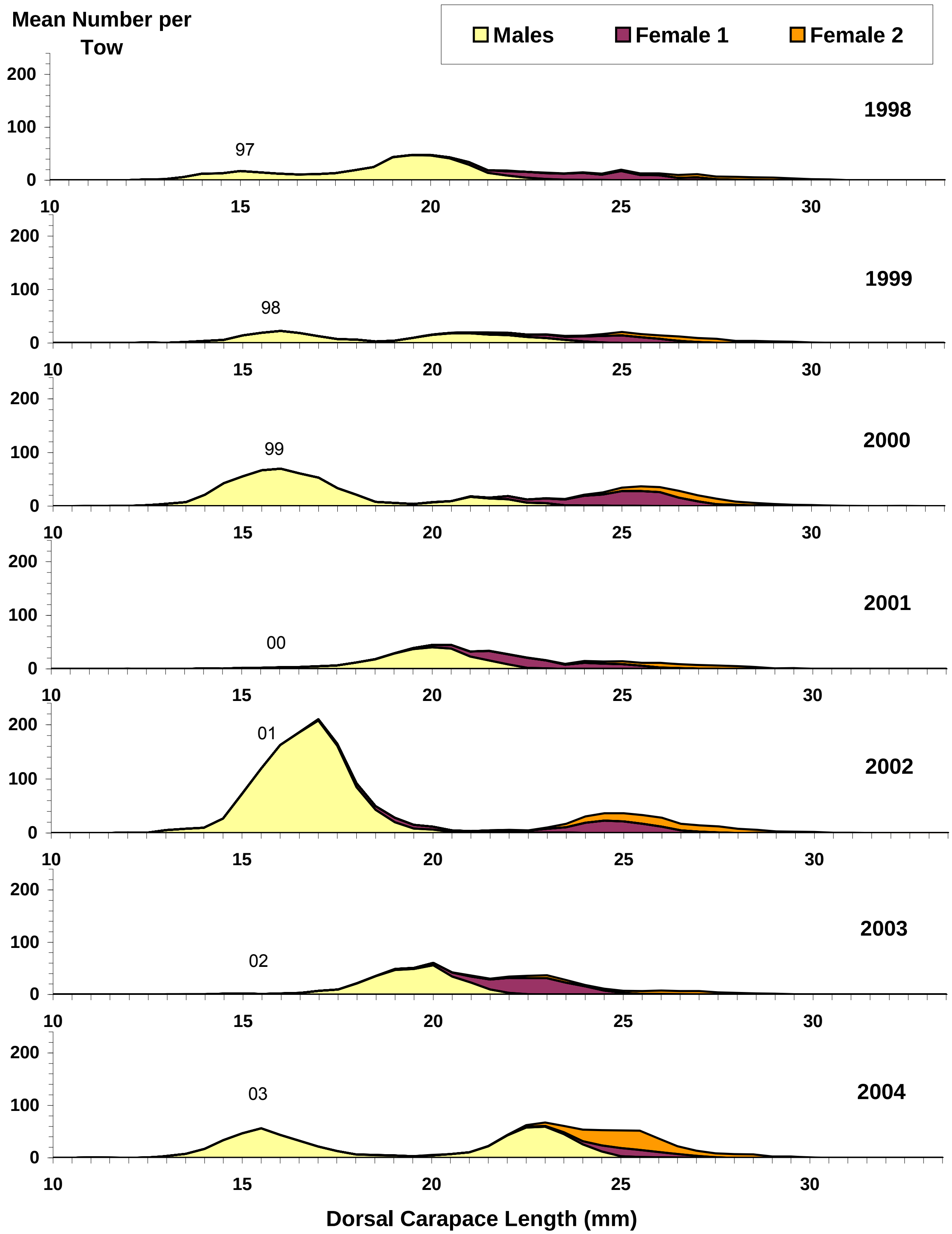


Figure C5.13 continued – summer survey.

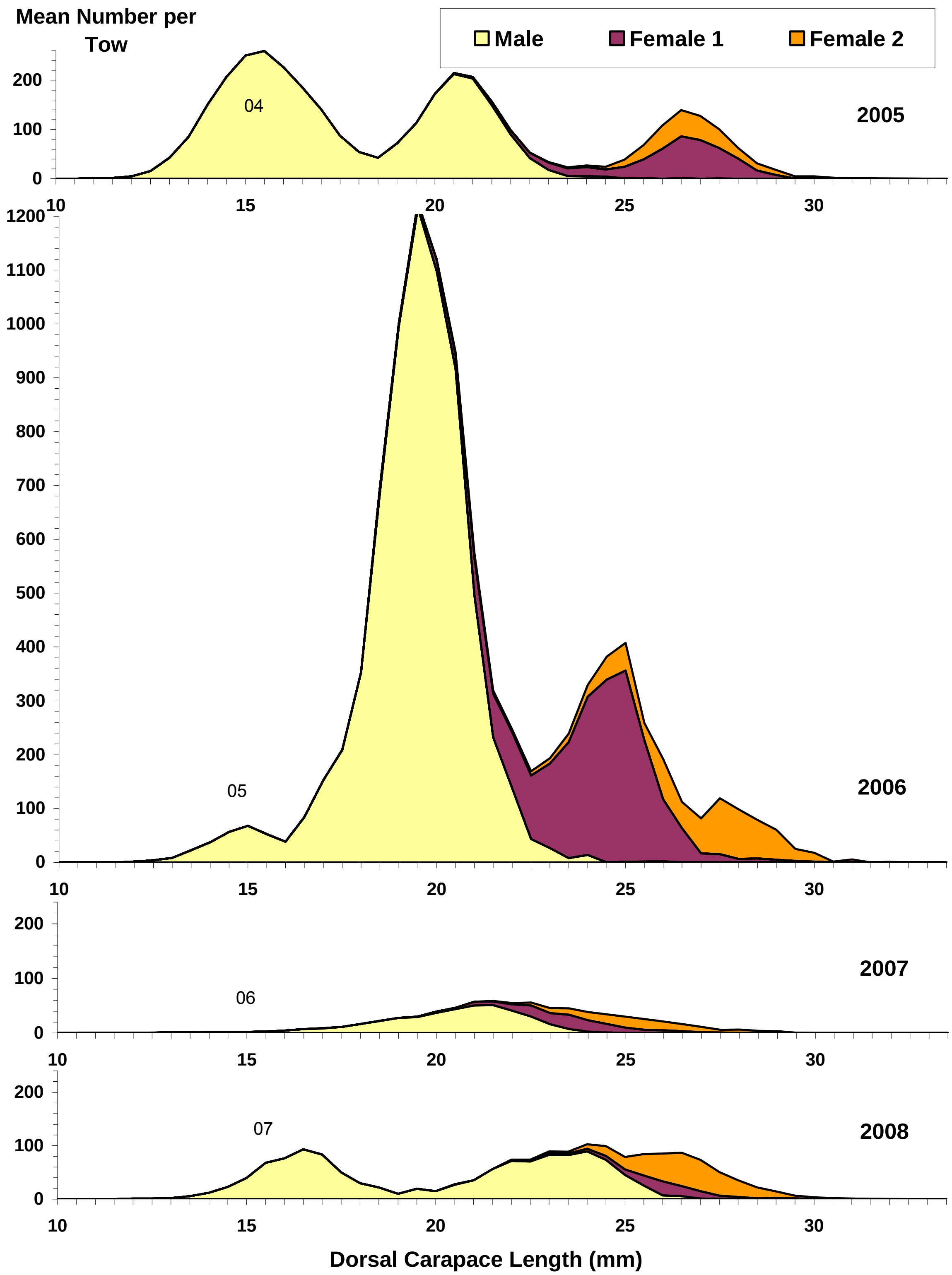


Figure C5.13 continued – summer survey.

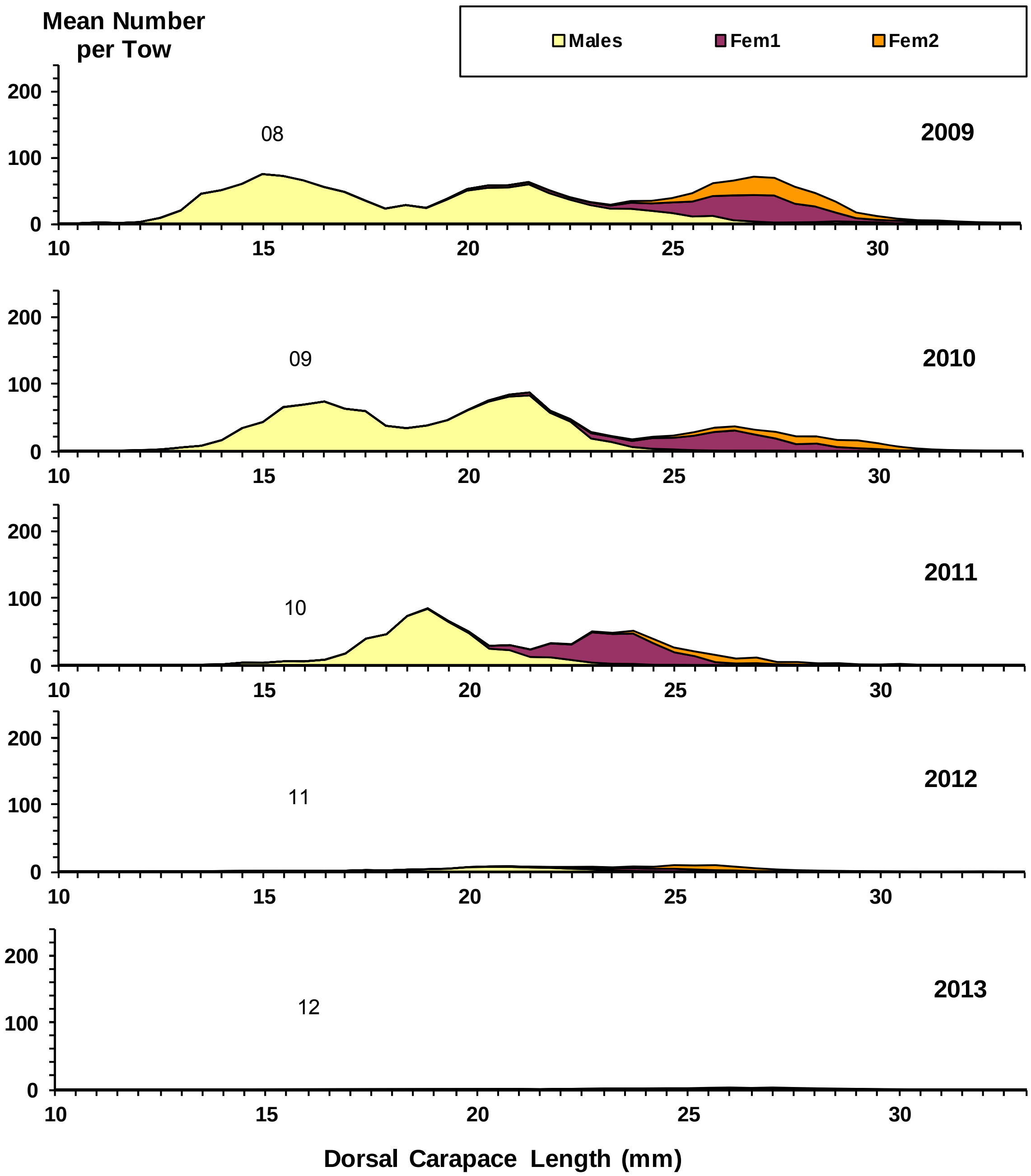


Figure C5.13 continued – summer survey.

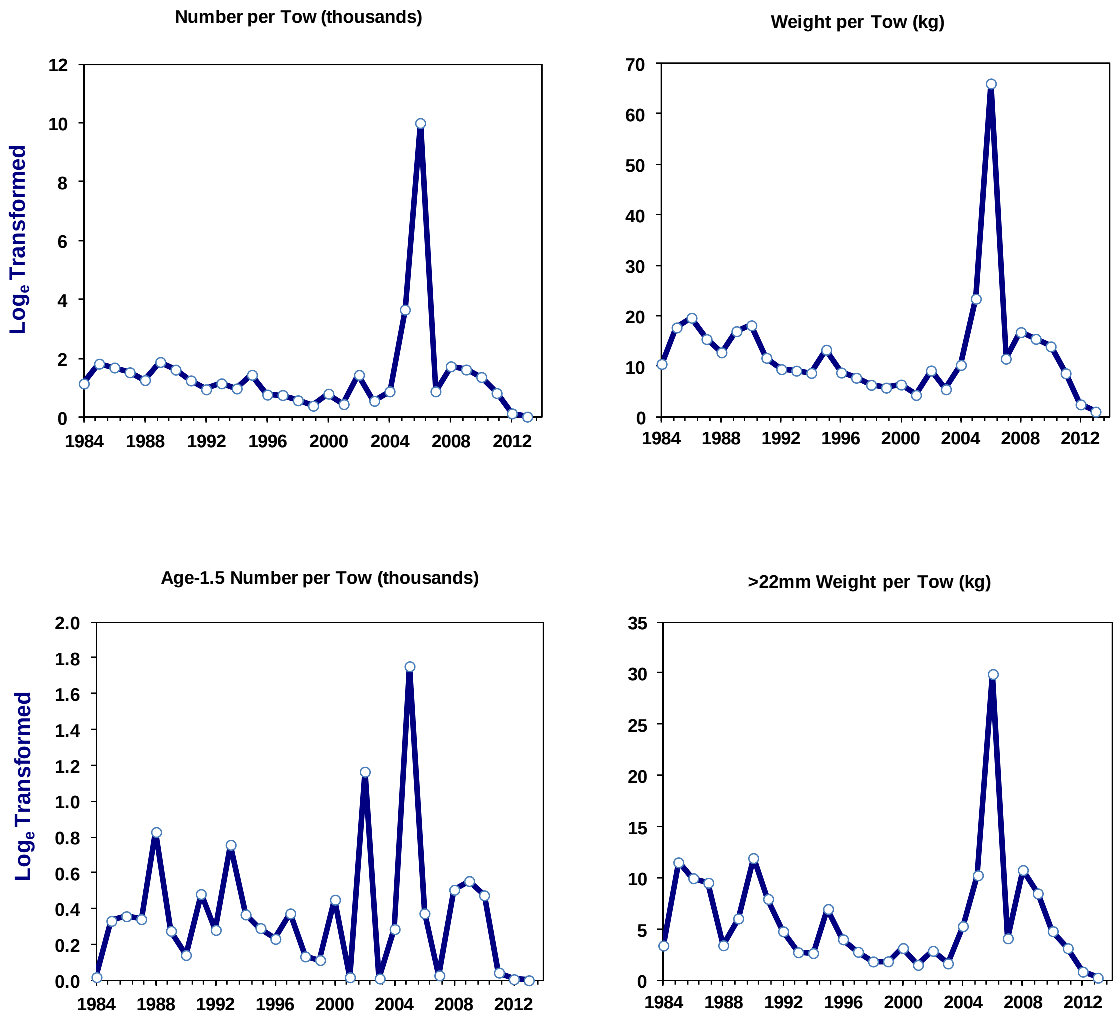


Figure C5.14. Summer survey standardized indices in number and weight for all shrimp (top), age 1.5 (bottom left), and fully-recruited shrimp (bottom right).

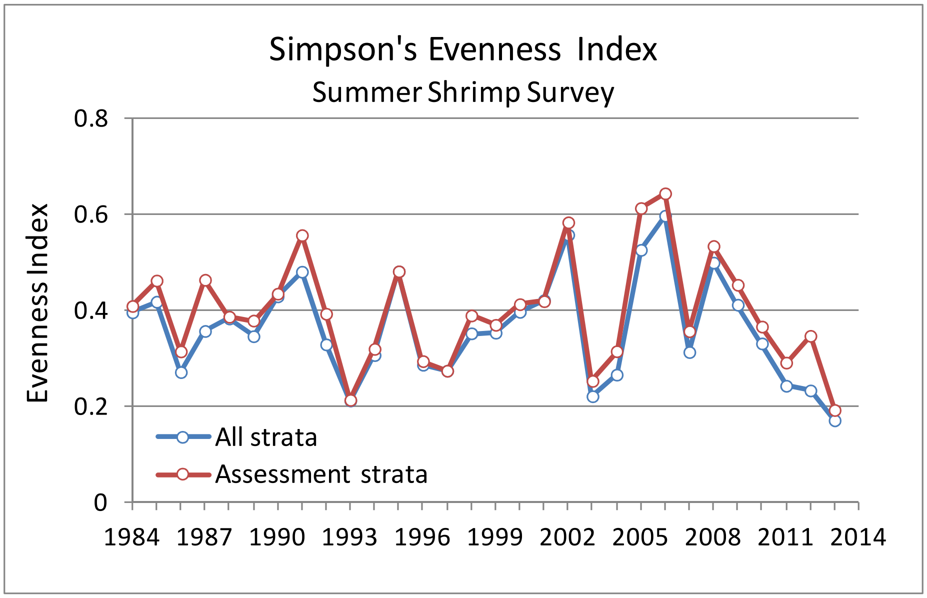


Figure C5.15. Simpson's evenness index (Payne et al. 2005) for northern shrimp in the Gulf of Maine based on summer shrimp survey catches

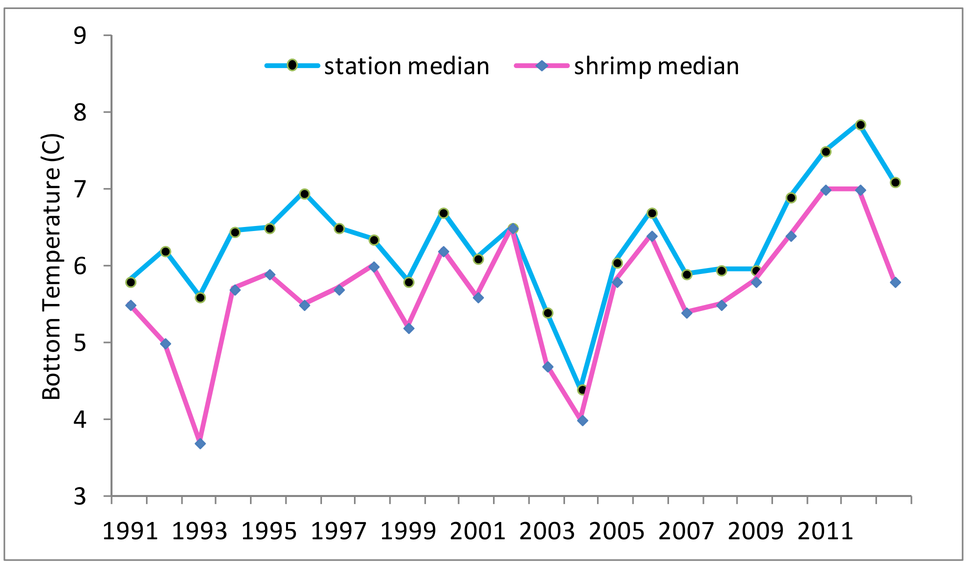


Figure C5.16. Median temperature at sampling stations in summer shrimp survey vs. catch-weighted-median temperature.

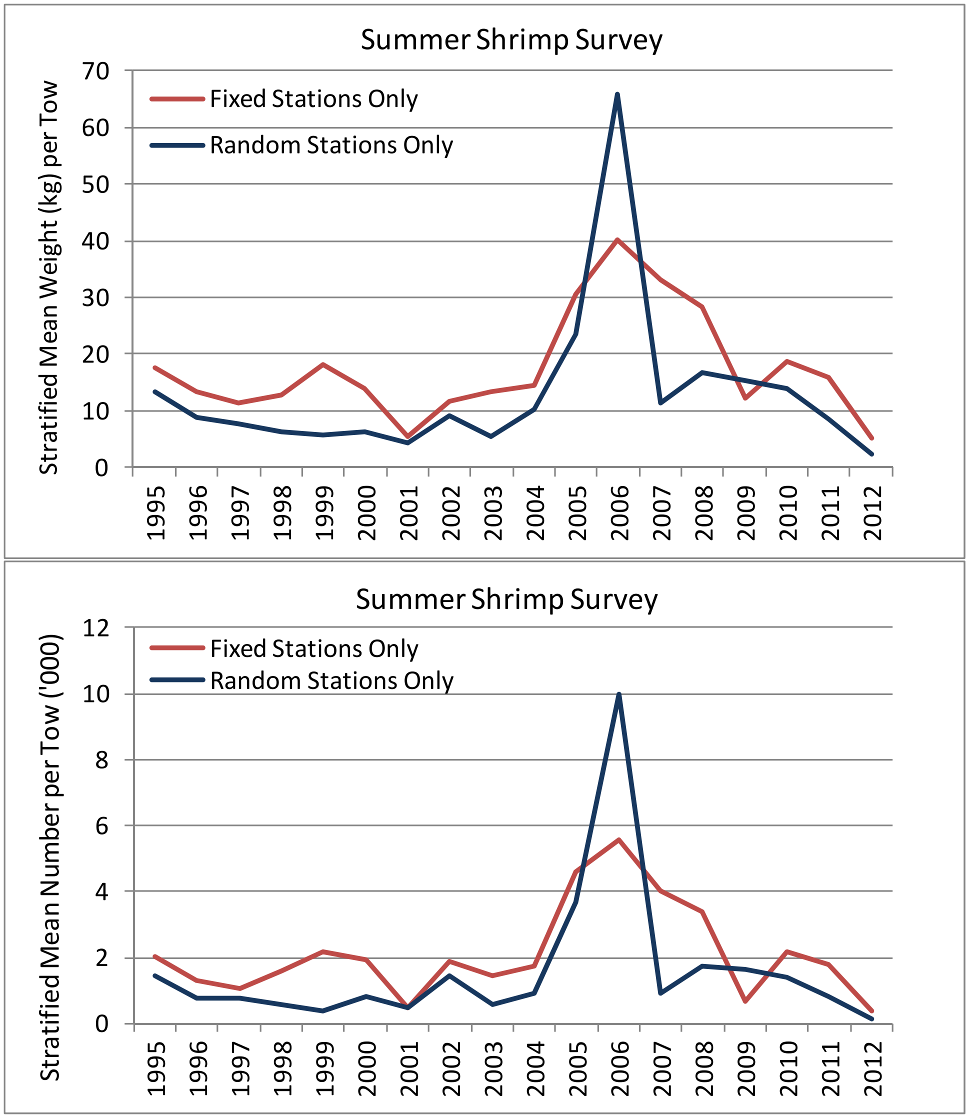


Figure C5.17. Comparison of survey indices from summer shrimp survey based on random stations or fixed stations. All indices $\log_e$ transformed.

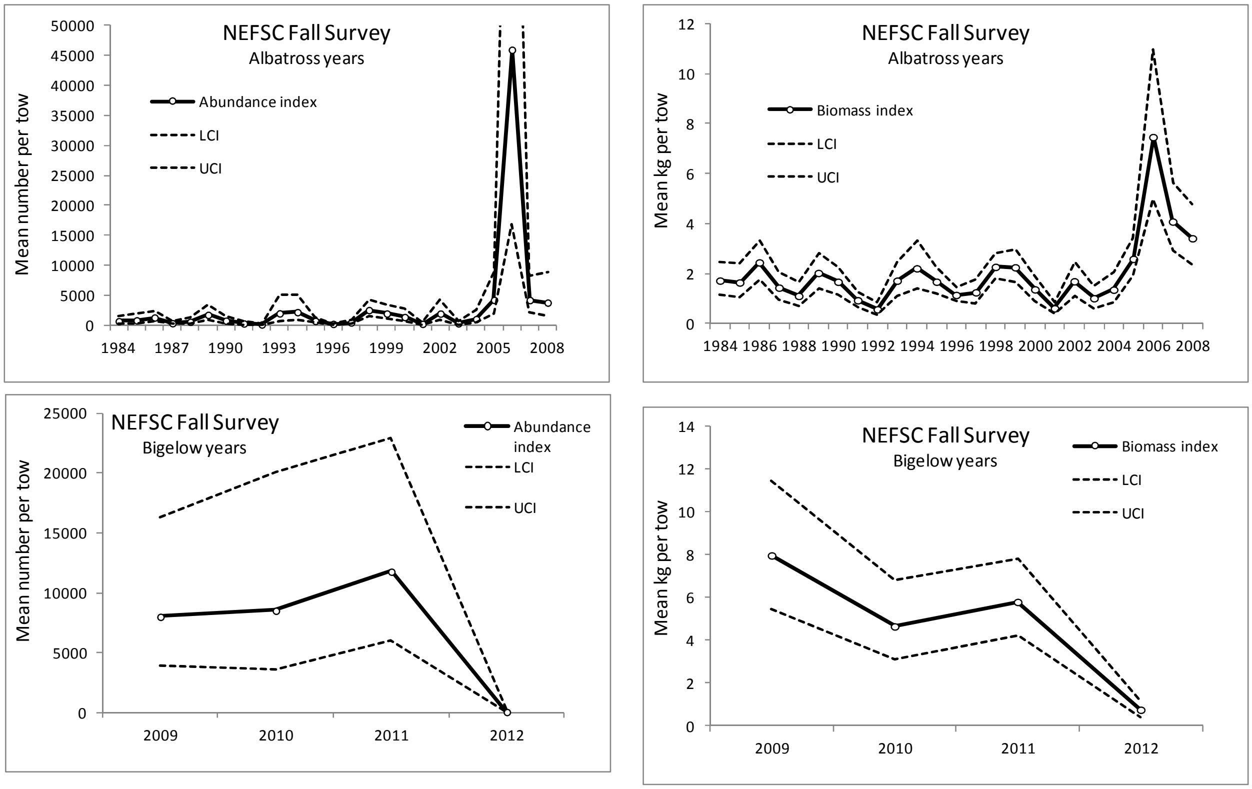


Figure C5.18. Survey indices with 95% confidence intervals for northern shrimp from the NEFSC fall survey, Albatross years (1984-2008) and Bigelow years (2009-2012).

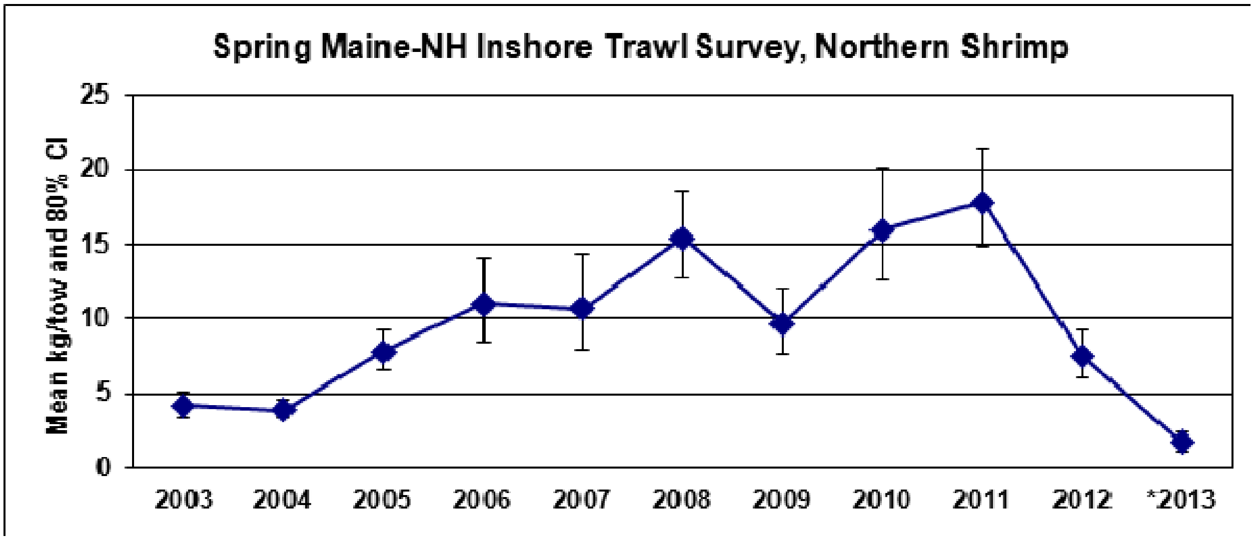


Figure C5.19. Spring Maine-New Hampshire inshore trawl survey northern shrimp biomass indices, with 80% confidence intervals. *2013 data are preliminary.

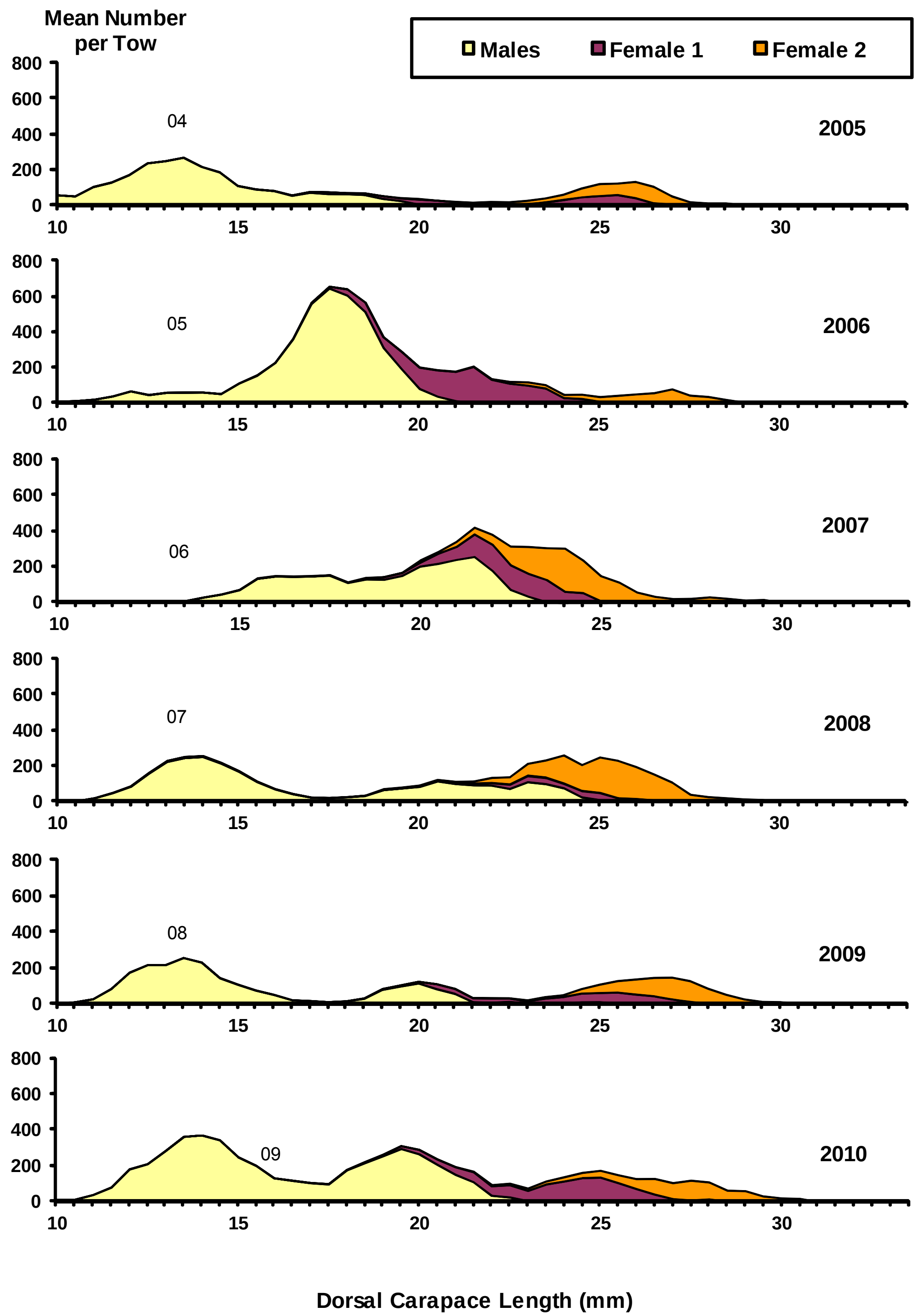


Figure C5.20. Maine-New Hampshire spring inshore survey; northern shrimp untransformed mean catch per tow by year, length, and development stage. Two-digit years are the year class at assumed age 1.

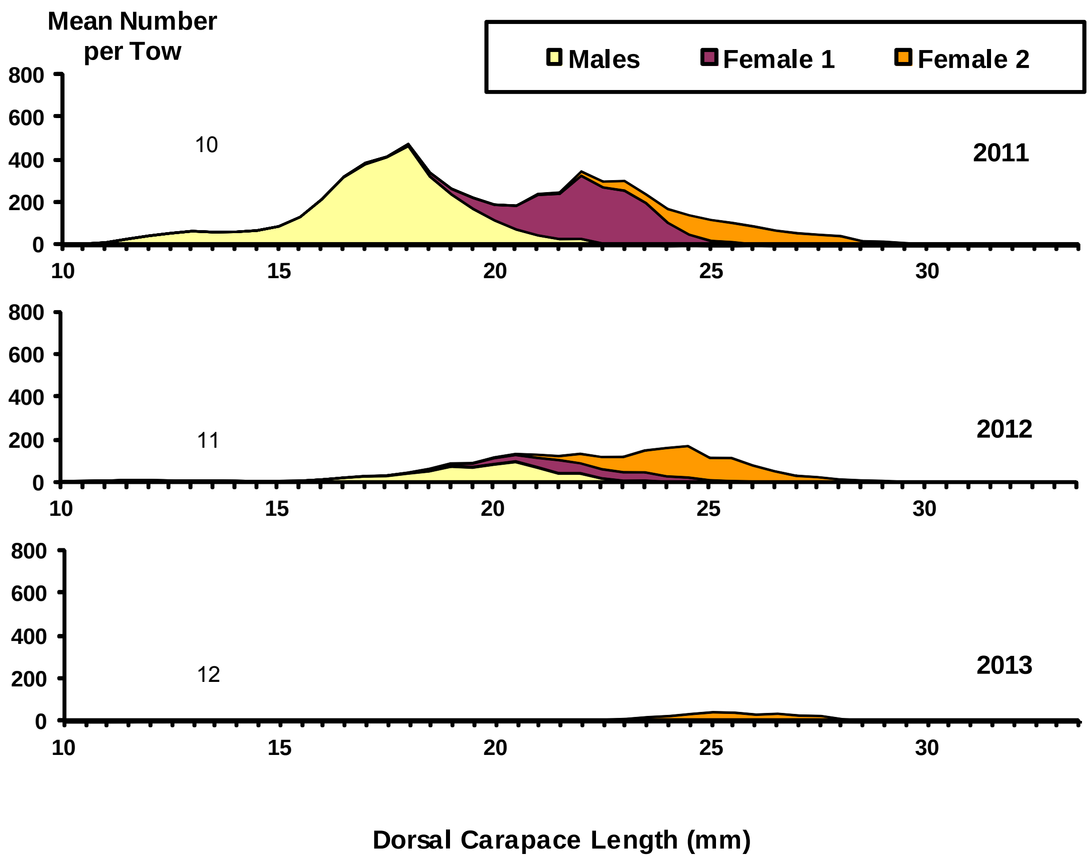


Figure C5.20 continued - ME/NH spring inshore survey.

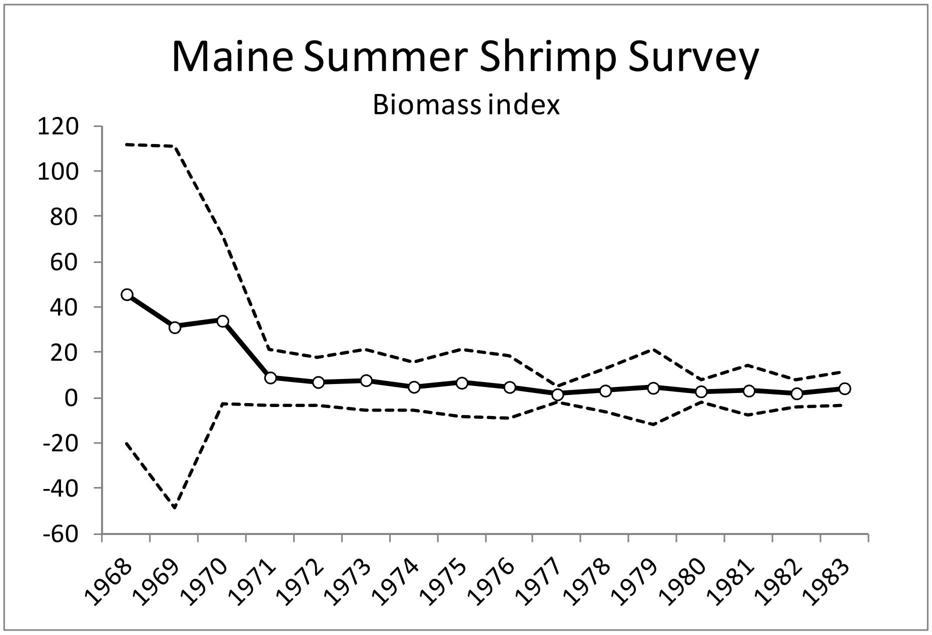


Figure C5.21. Biomass indices and 95% confidence intervals for State of Maine summer shrimp survey conducted during 1968-1983.

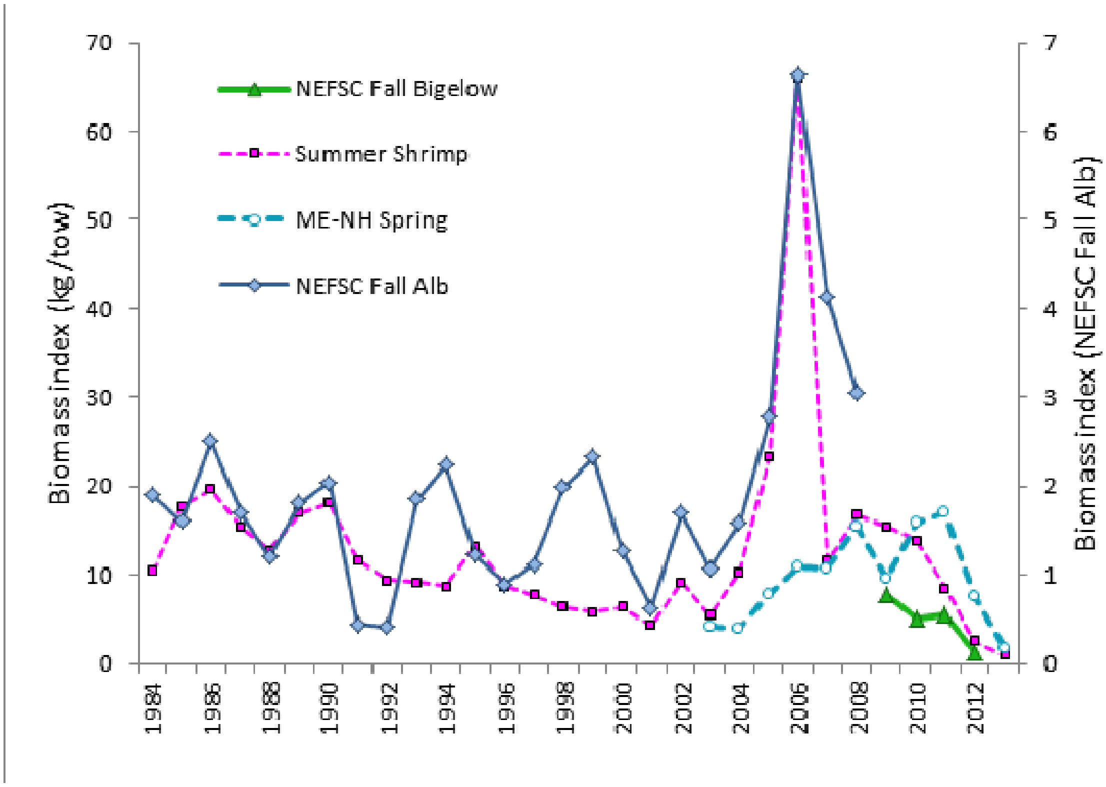


Figure C5.22. Biomass indices (kg/tow) from various northern shrimp surveys in the Gulf of Maine.

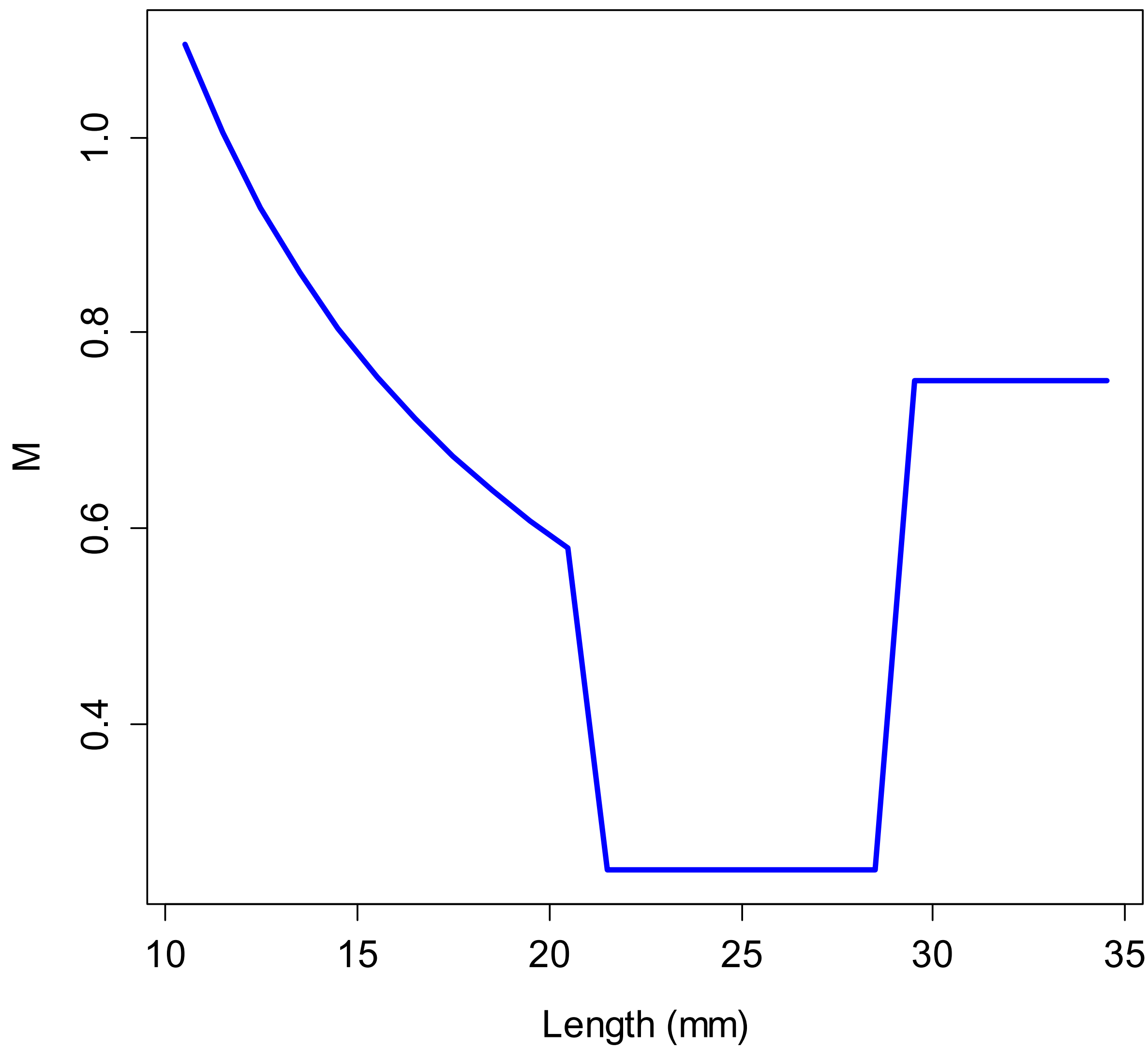


Figure C6.1. Natural mortality (U-shaped) used in the UMaine base run (see table 1).

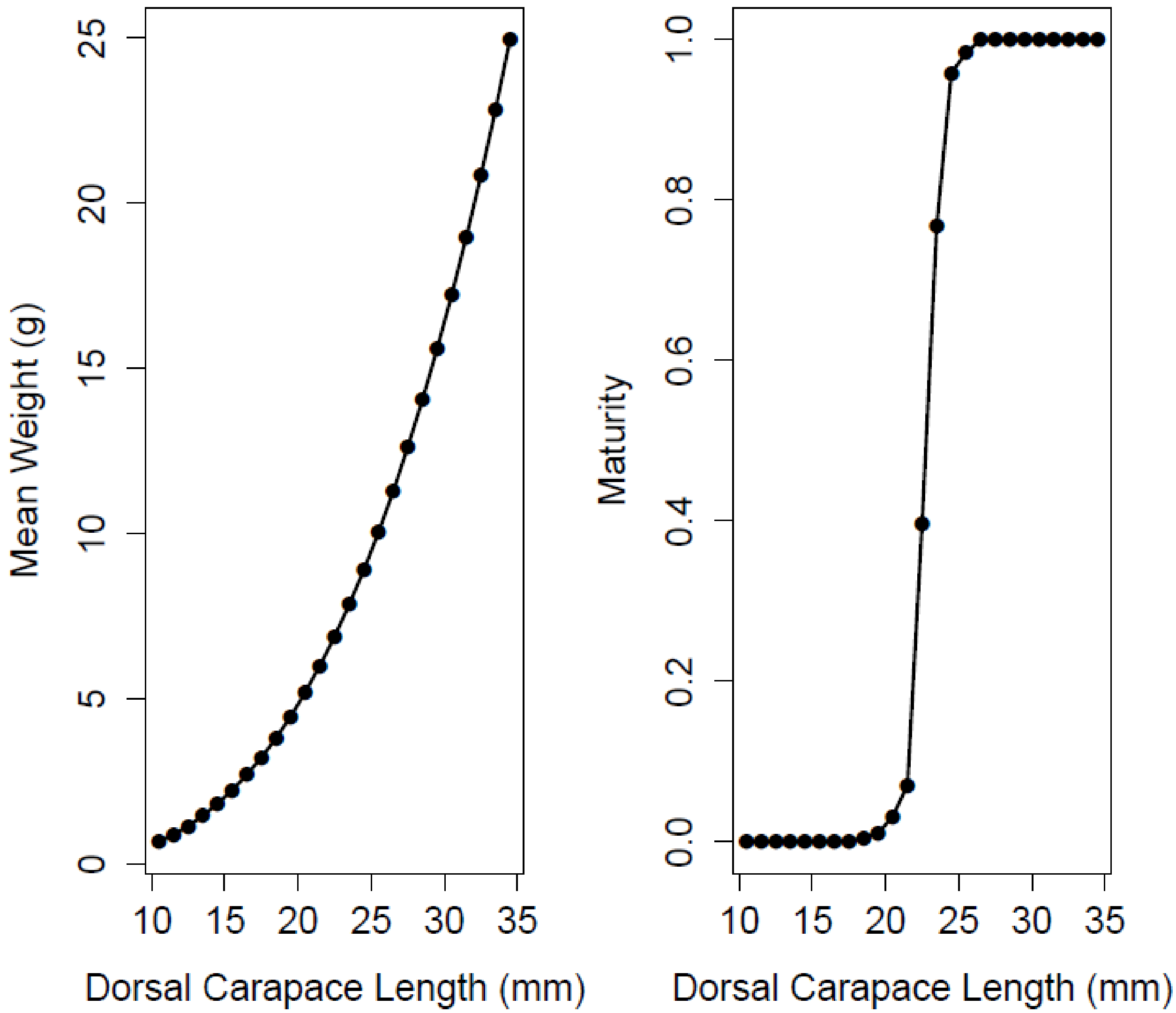


Figure C6.2. Weight-at-length (data were obtained from Haynes and Wigley 1969) and maturity-at-length in 2000 (data were obtained from ASMFC summer survey) of Northern shrimp in the Gulf of Maine.

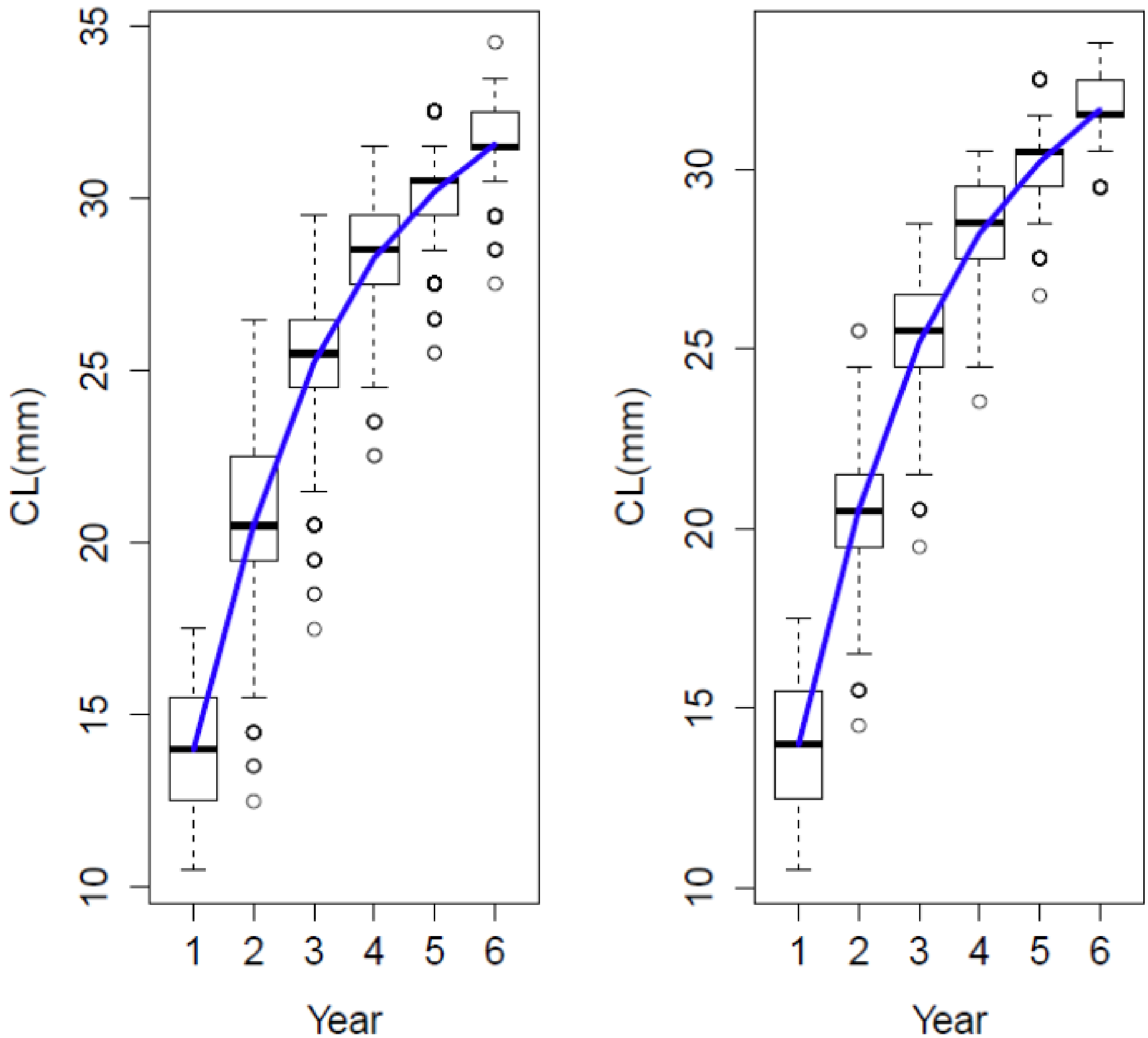


Figure C6.3. Apparent growth of a cohort with no fishing mortality estimated in the UMaine model base run (Left graph is for growth time block 1 and right graph is for growth time block 2 defined in the study to reflect potential impacts of different environment on growth; Table 2). Age values in the X-axis are relative ages. The curves were calculated using the growth transition matrices incorporated in the UMaine model.

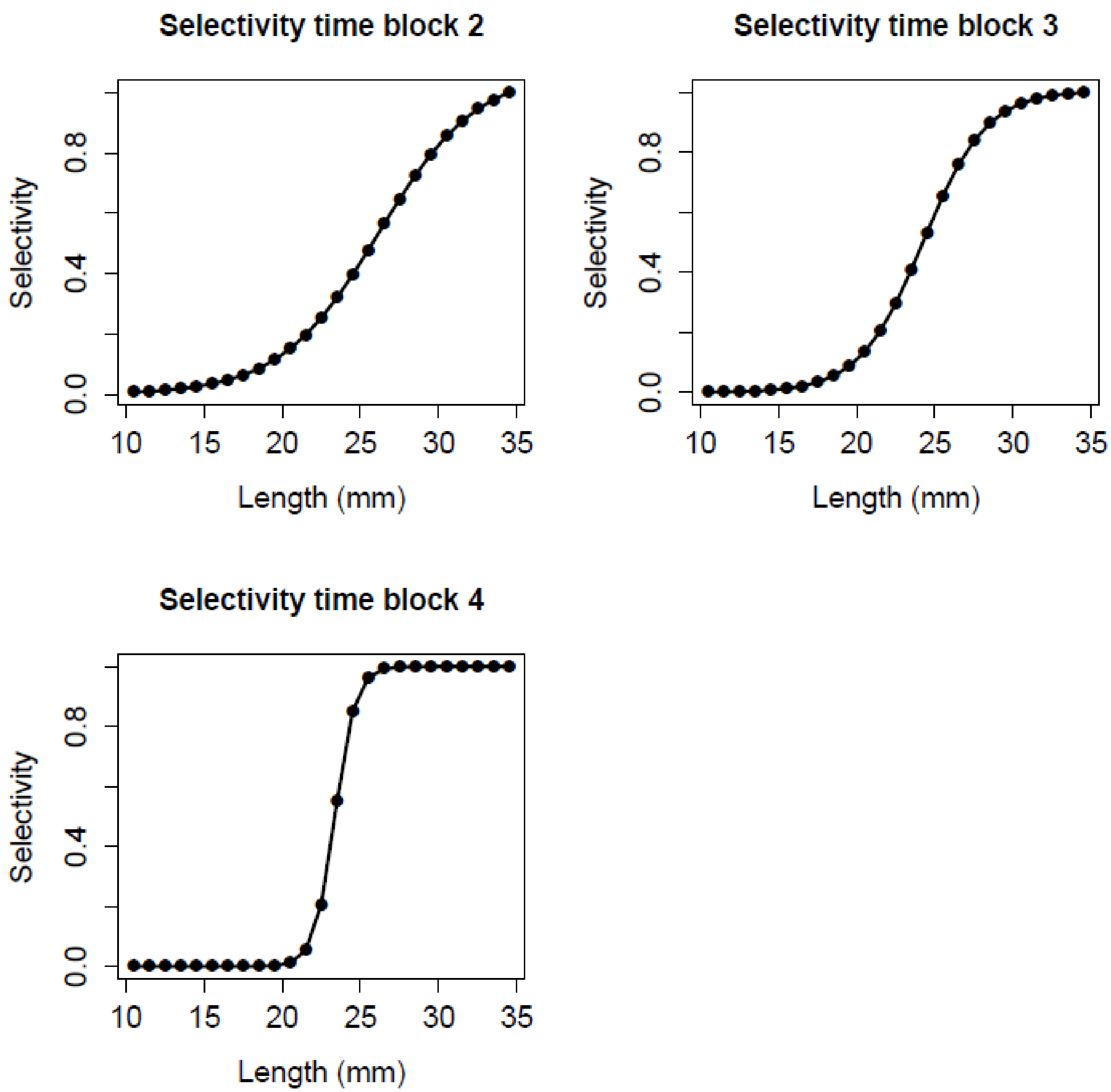


Figure C6.4. Selectivity patterns from the UMaine model base run for each of the fisheries (block 2=mixed fleet; block 3=trawl fleet; block 4=trap fleet).

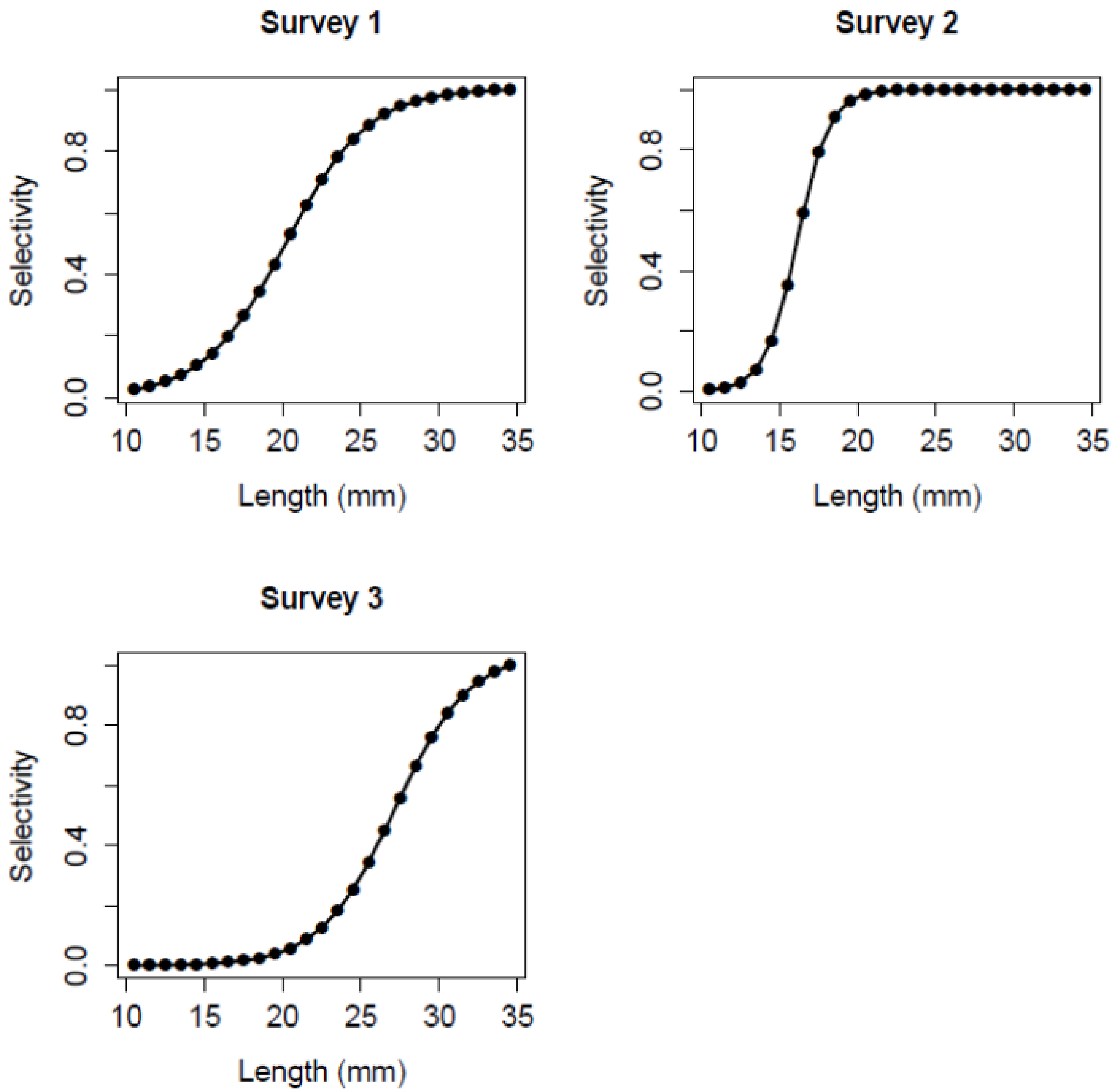


Figure C6.5. Selectivity patterns from the UMaine model base run for each of the surveys (survey 1=NEFSC fall survey; survey 2=ASMFC summer survey; survey 3= NEFSC Bigelow survey)

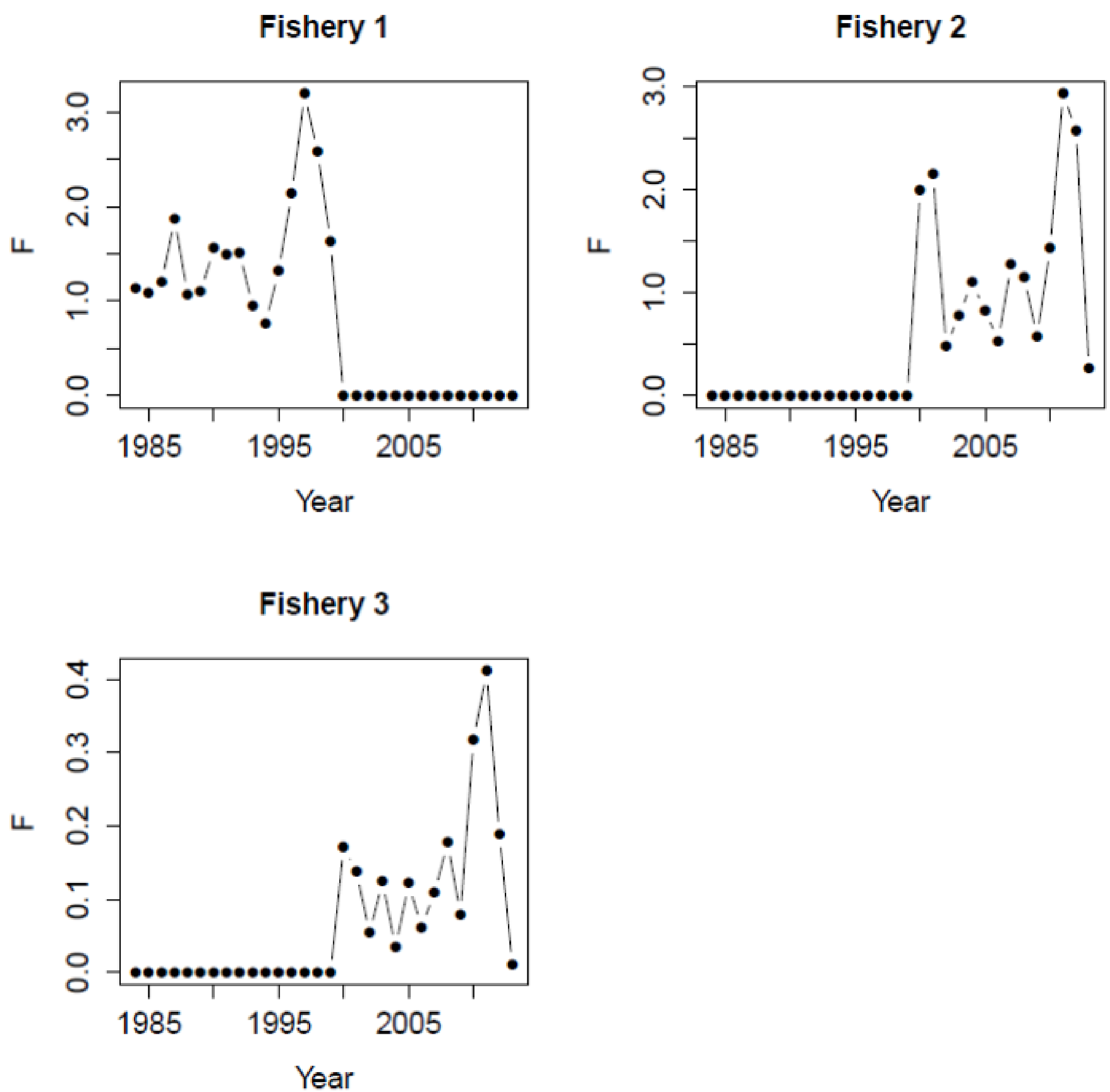


Figure C6.6. Fishing mortality from the UMaine model base run (Fishery 1=mixed fishery; Fishery 2=trawl fishery; Fishery 3=trap fishery).

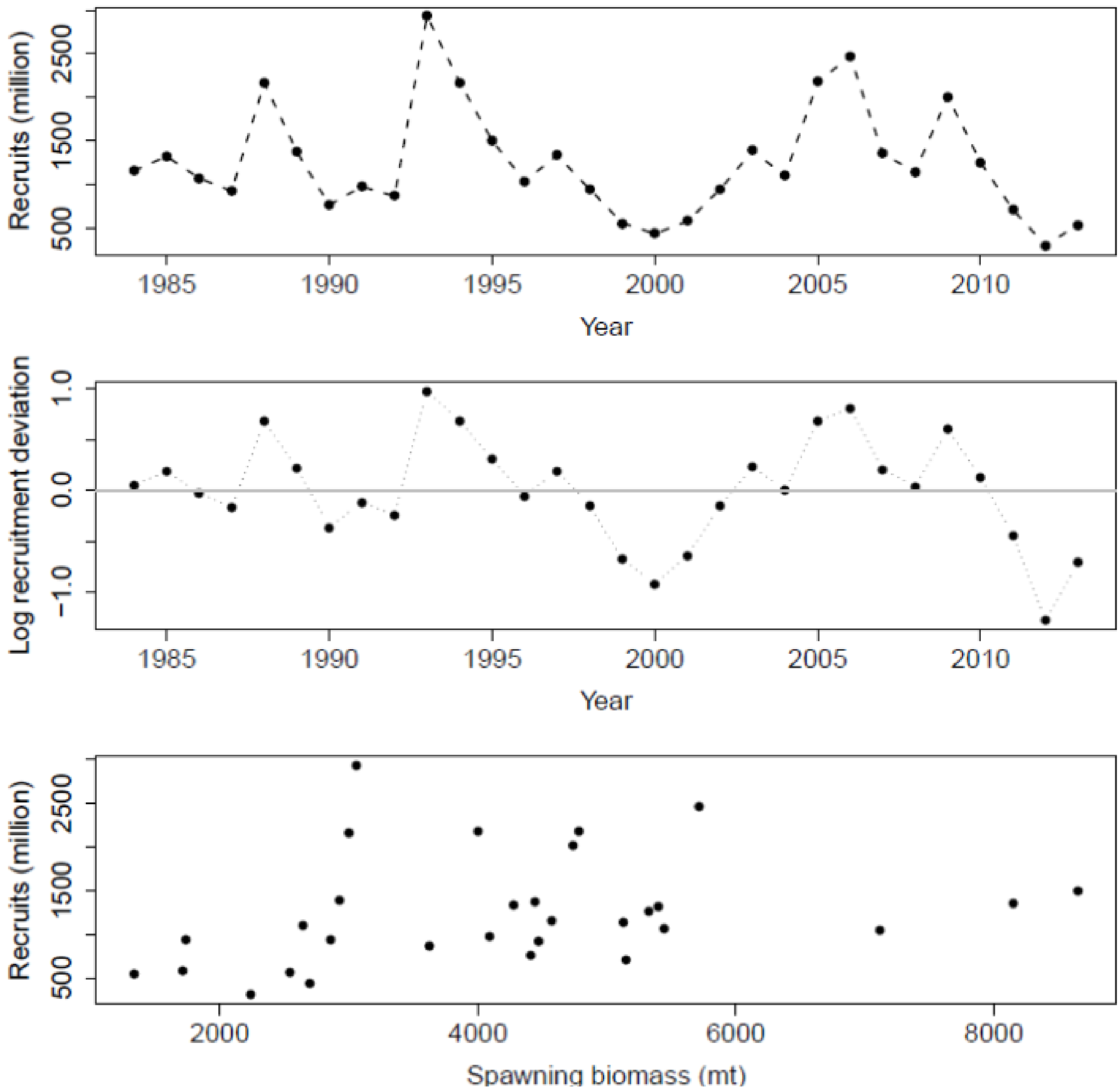


Figure C6.7. Recruitment pattern from UMaine model base run.

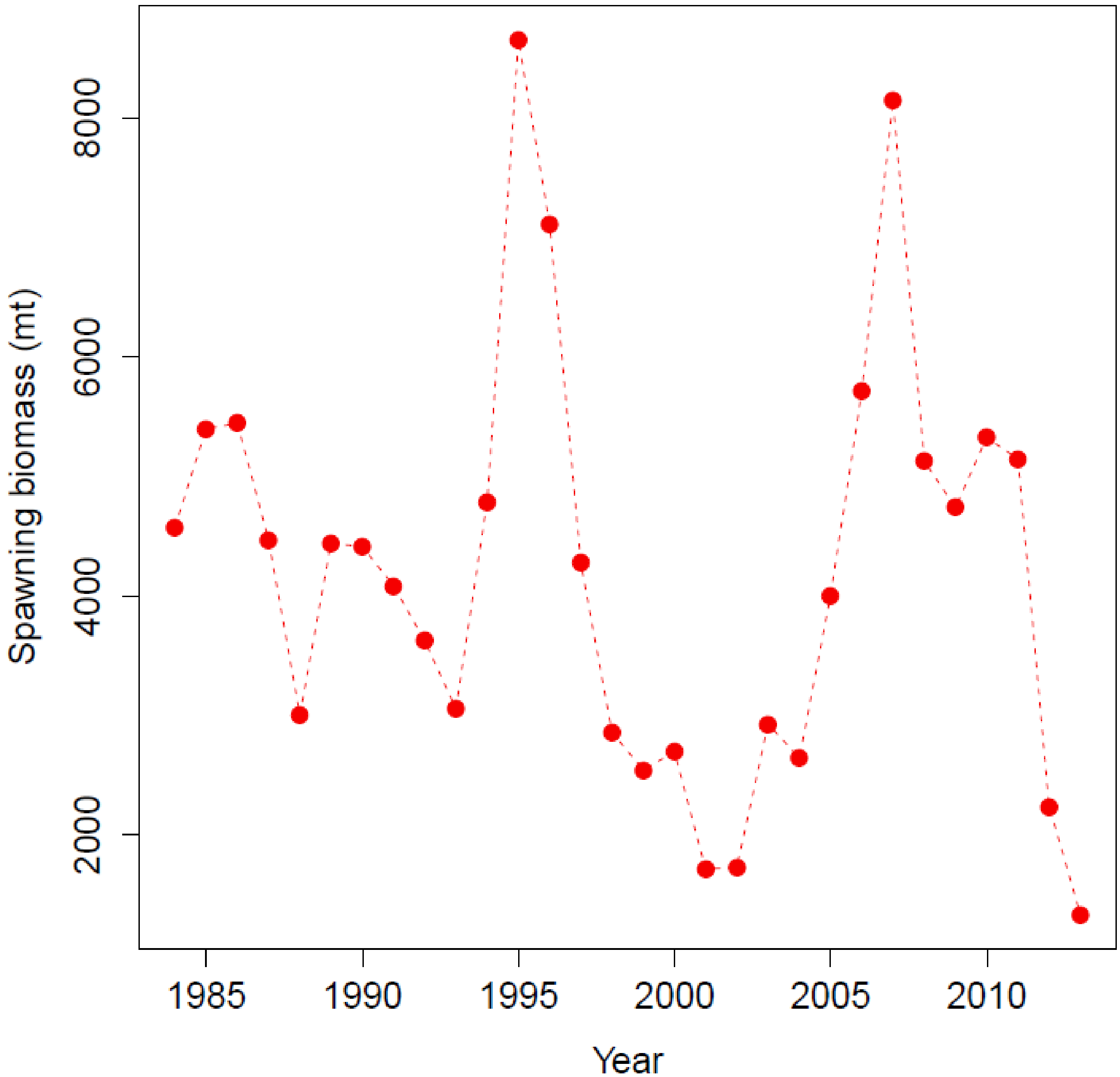


Figure C6.8. Estimates of spawning stock biomass for the UMaine model base run. The spawning stock biomass is measured as the total biomass of females on March 1.

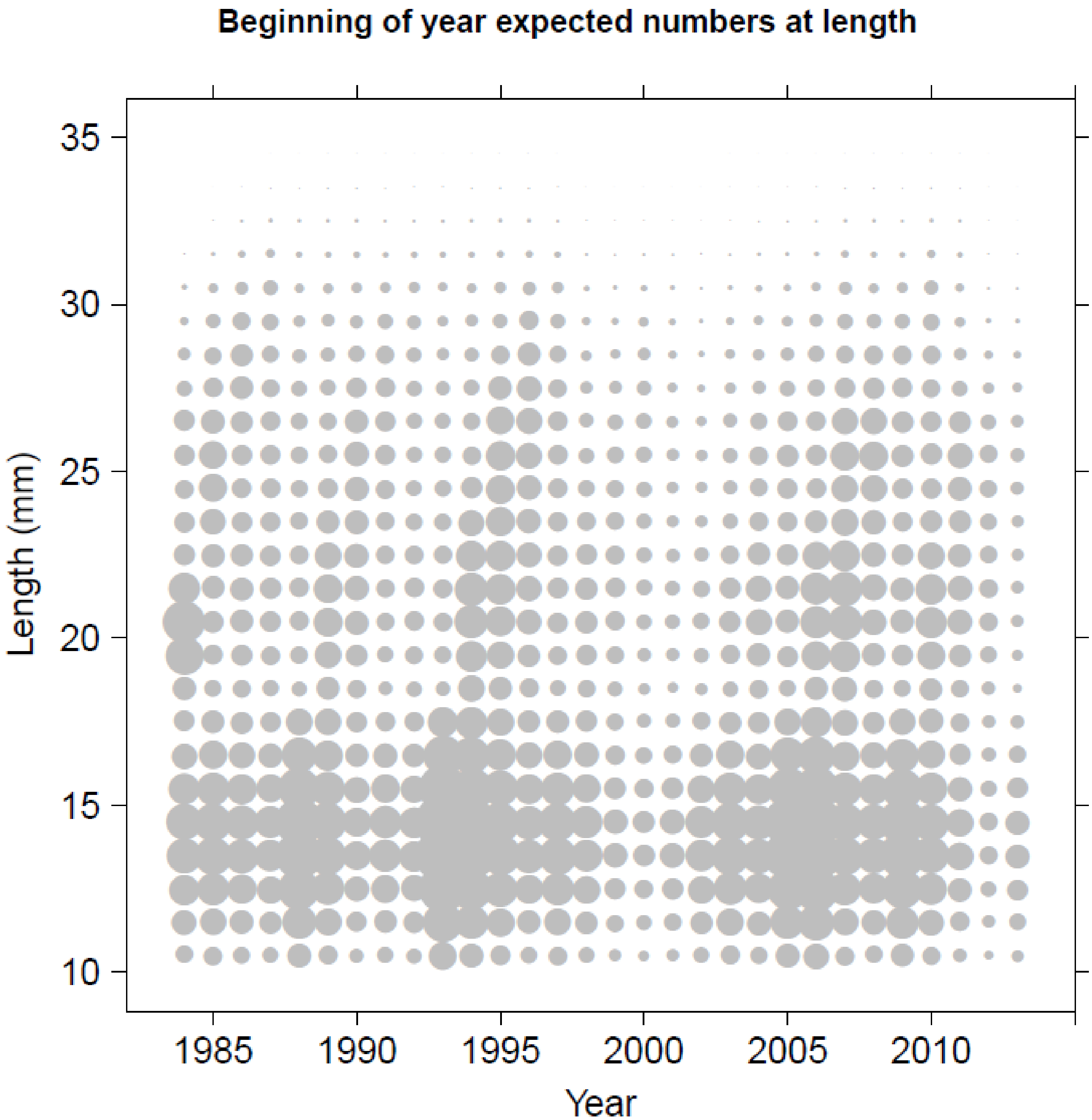


Figure C6.9. "Bubble plot" of the proportion of the estimated abundance at the beginning of each year. Sizes of the bubbles are proportional to the values of abundance.

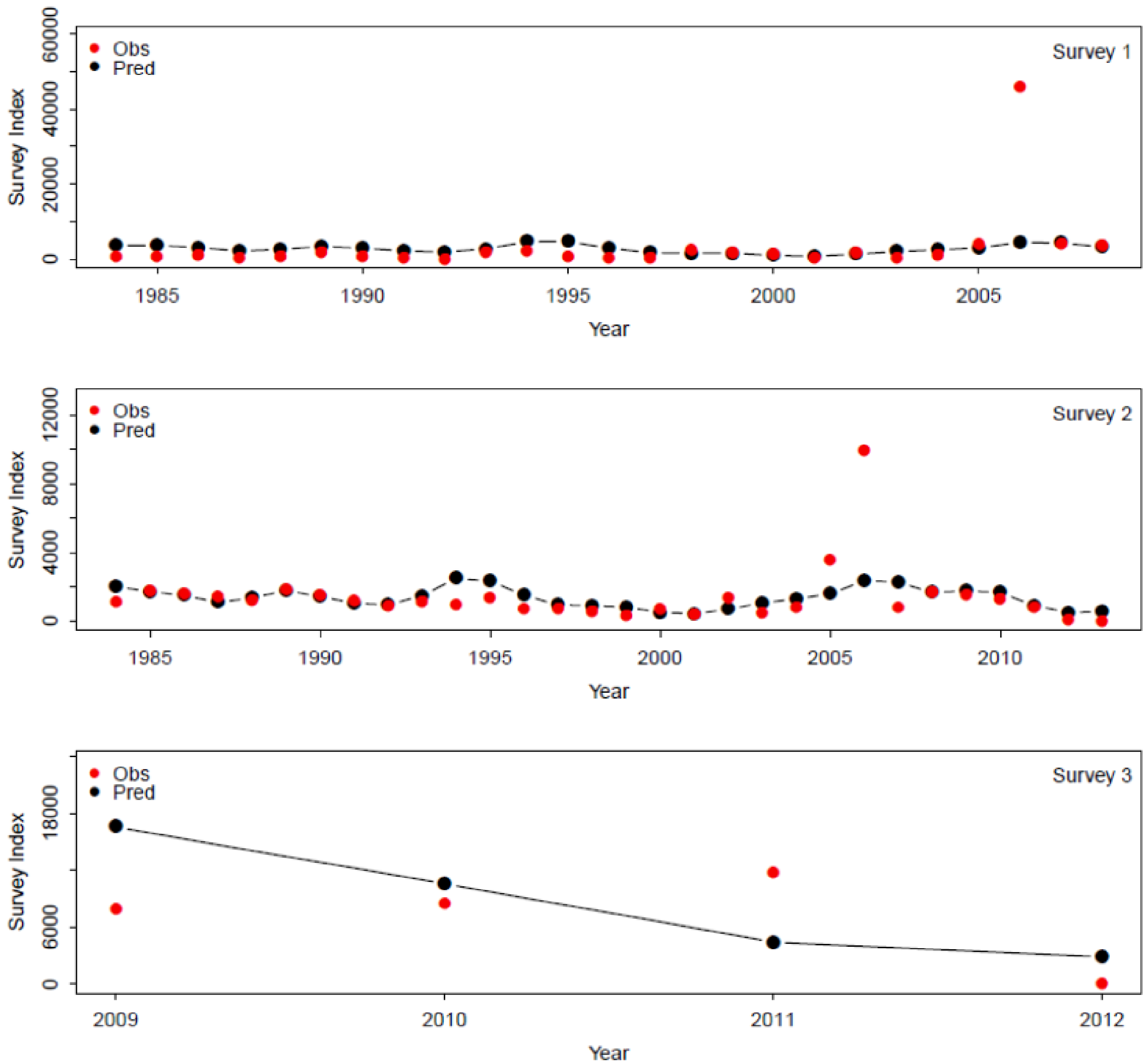


Figure C6.10. Observed (dot) and predicted (line) survey indices for northern shrimp in the UMaine model base run (survey 1=NEFSC fall survey; survey 2=ASMFC summer survey; survey 3= NEFSC Bigelow survey).

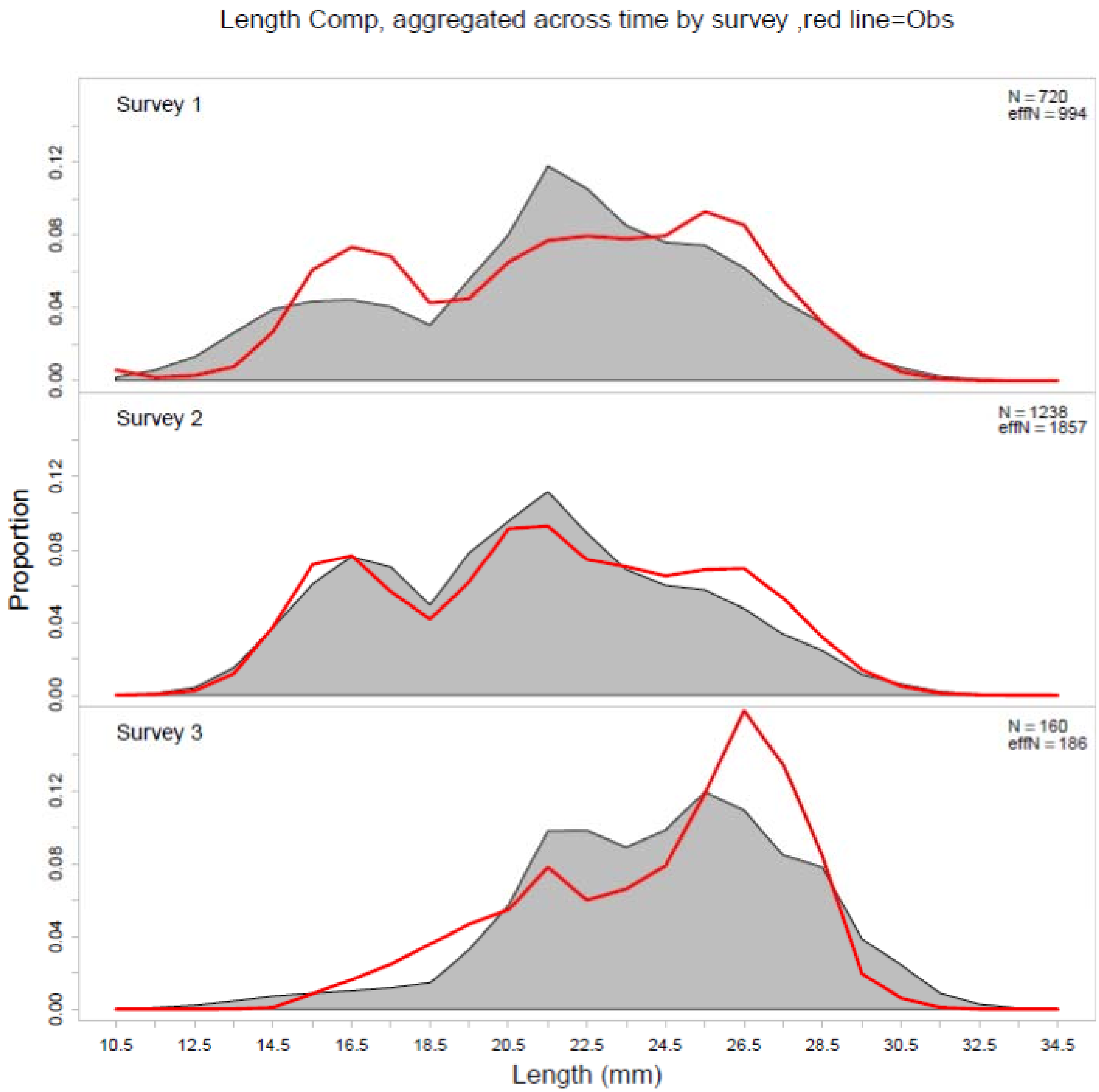


Figure C6.11. Observed (red line) and predicted (in prey) average survey length composition data for northern shrimp in the UMaine model base run (survey 1=NEFSC fall survey; survey 2=ASMFC summer survey; survey 3= NEFSC Bigelow survey).

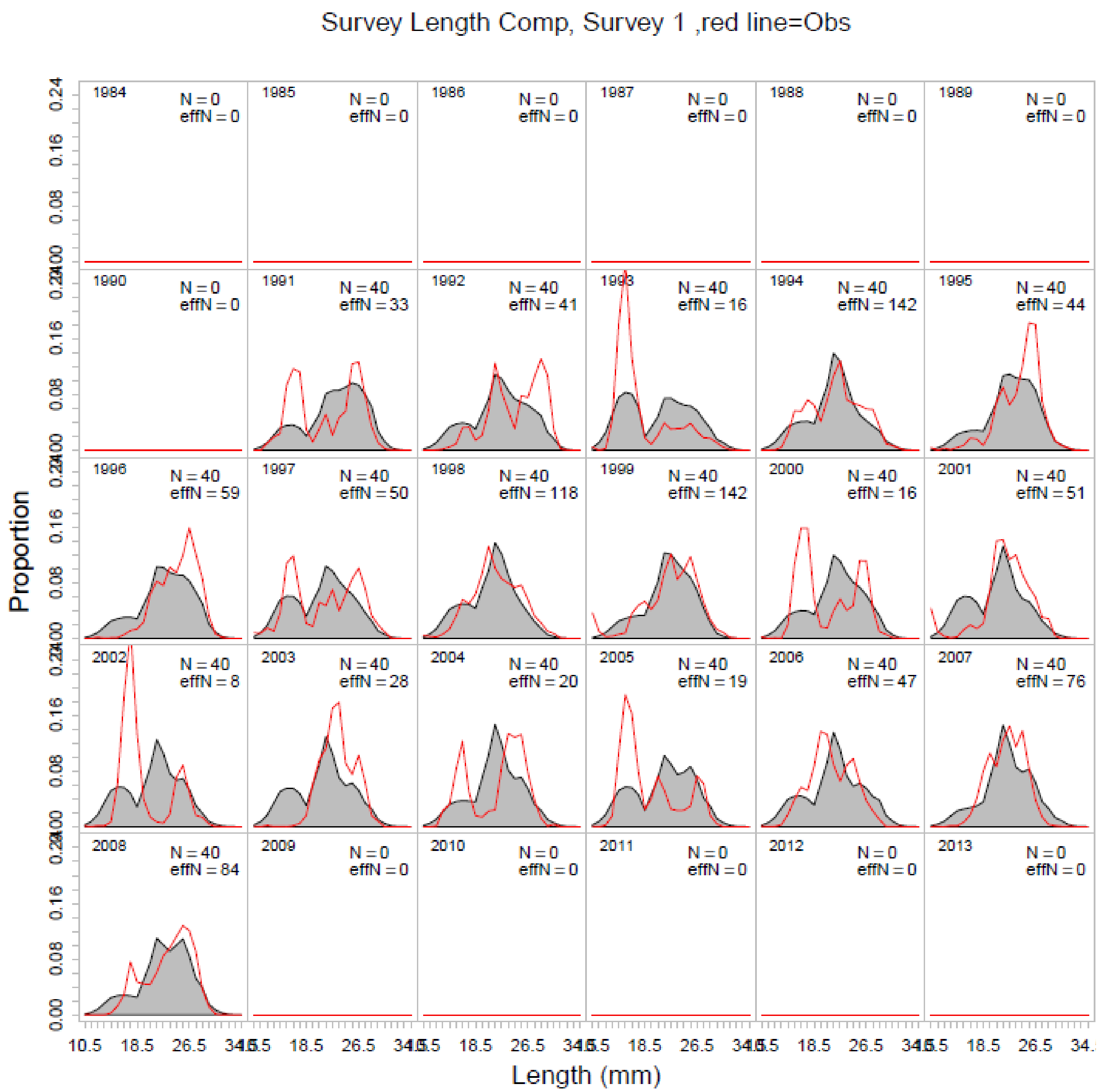


Figure C6.12. Observed (red line) and predicted (in prey) NEFSC fall survey length composition for each year for northern shrimp in the UMaine model base run.

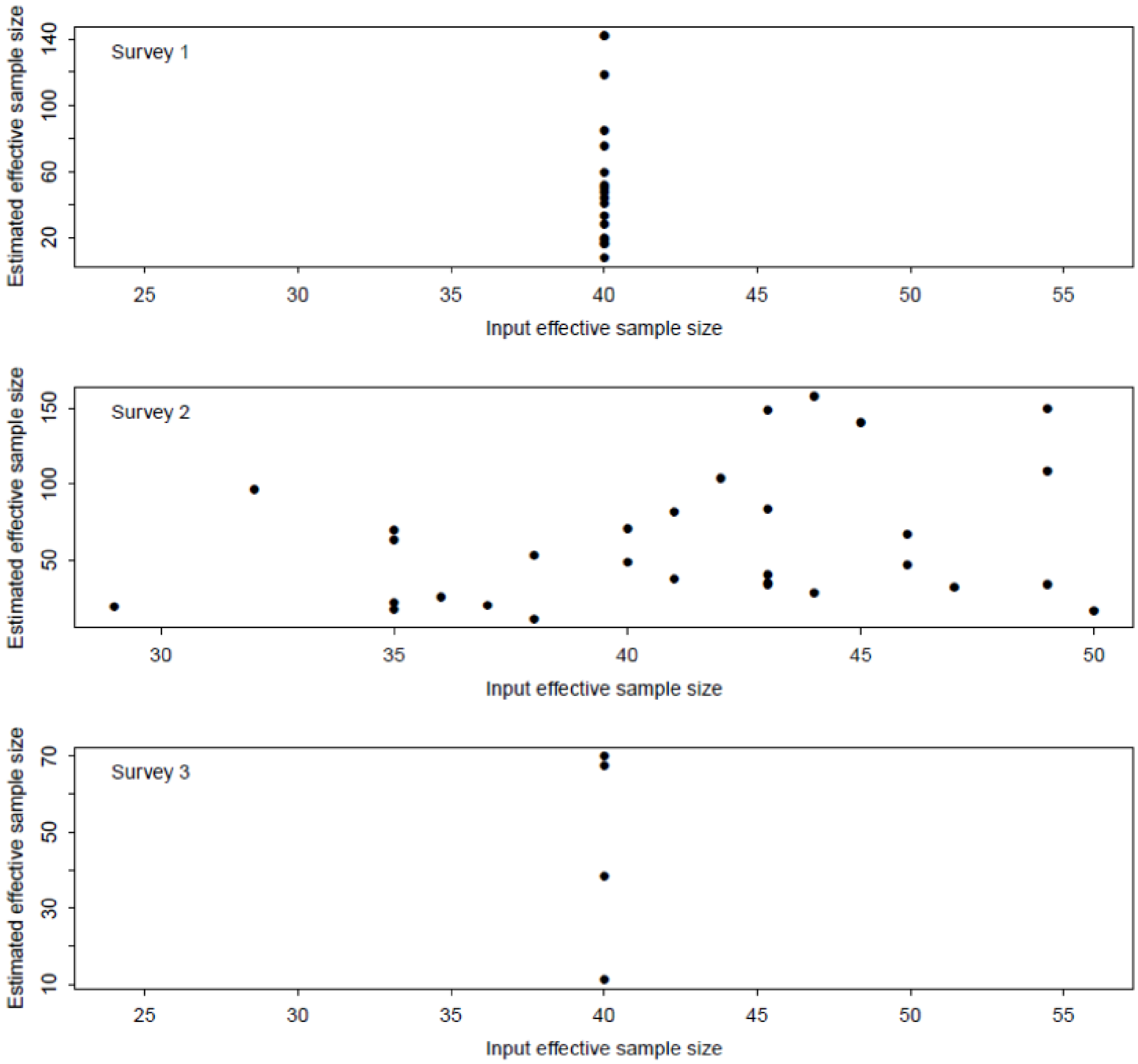


Figure C6.13. Comparison of input effective sample size versus the model estimated effective sample size for the survey indices used in the based run model (survey 1=NEFSC fall survey; survey 2=ASMFC summer survey; survey 3= NEFSC Bigelow survey)

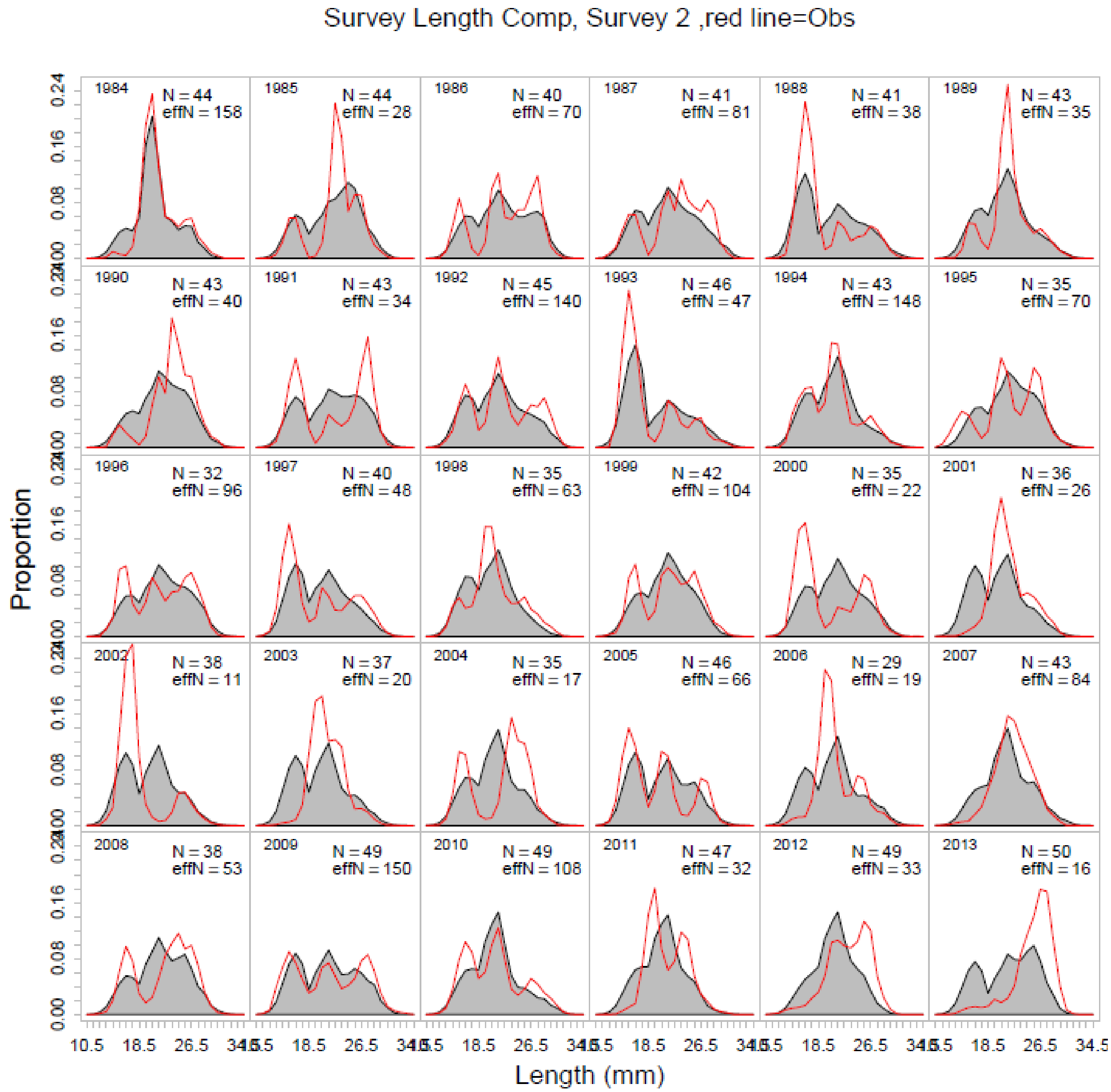


Figure C6.14. Observed (red line) and predicted (in prey) ASMFC summer survey length composition data for each year for northern shrimp in the UMaine model base run.

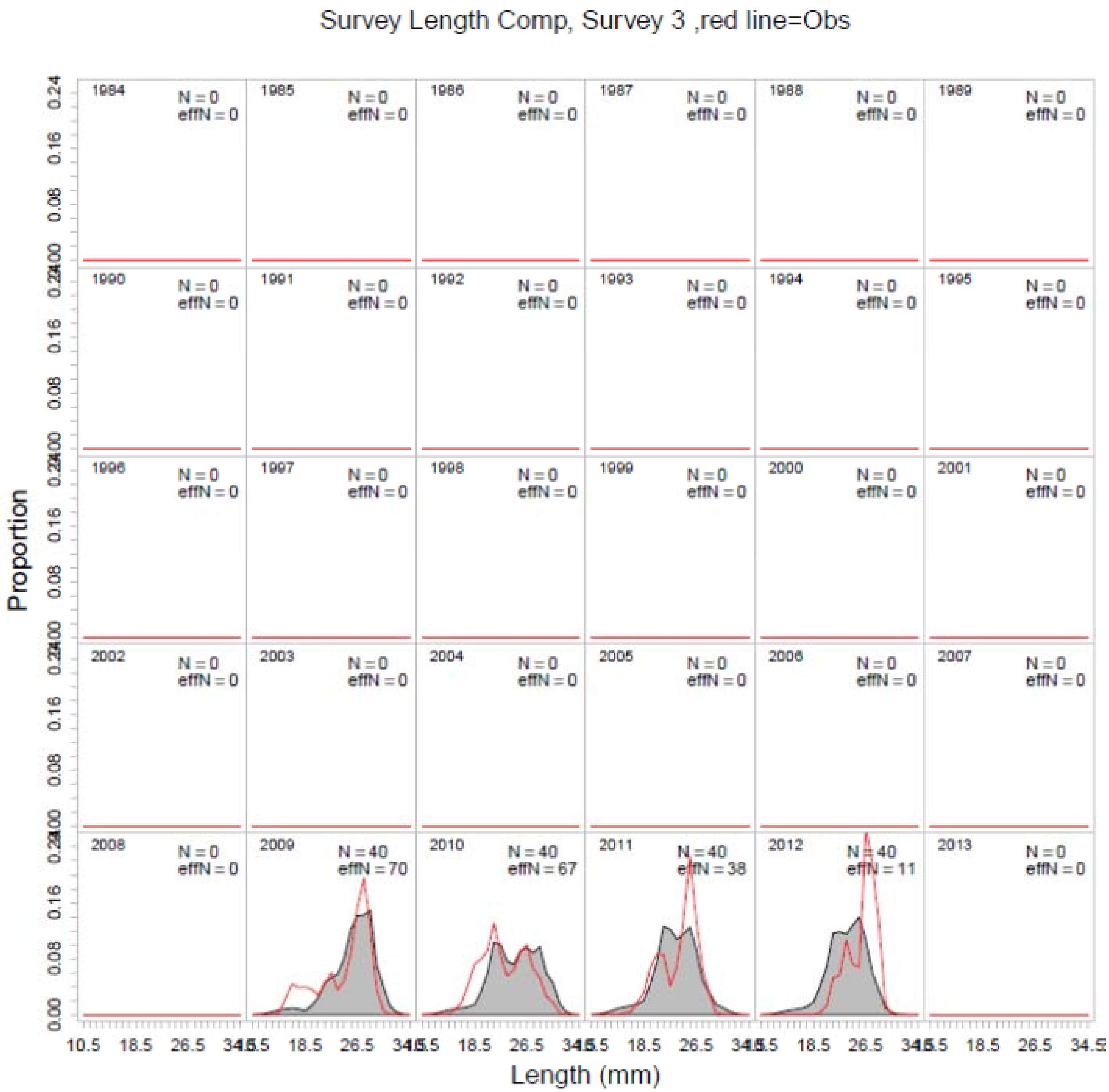


Figure C6.15. Observed (red line) and predicted (in prey) NEFSC Bigelow survey length composition data for each year for northern shrimp in the UMaine model base run.

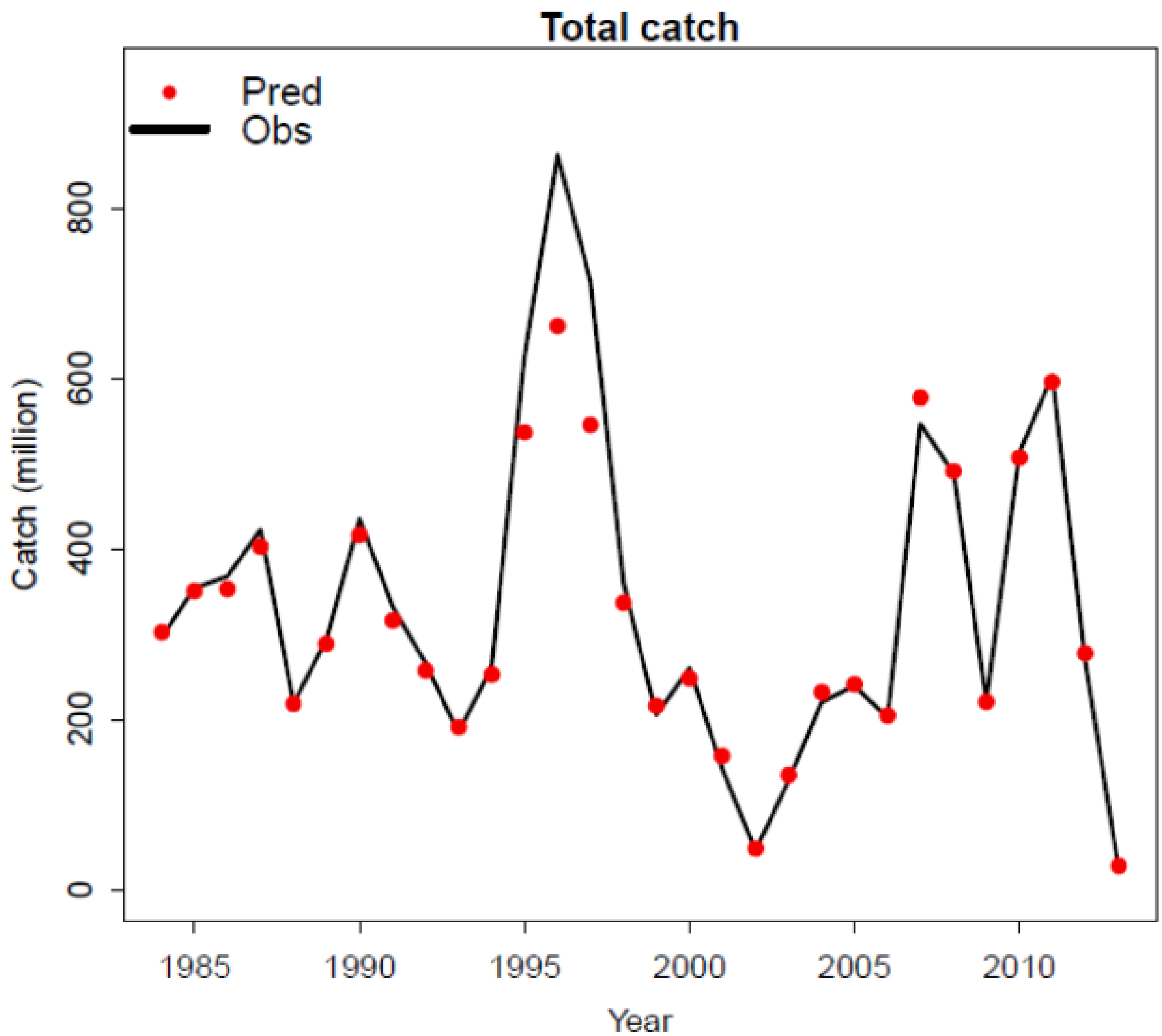


Figure C6.16. Commercial total catch (black line) and predicted values (red dots) for northern shrimp in the UMaine model base run.

Figure C6.17. Commercial total catch by fishery (black line) and predicted values (red dots) for northern shrimp in the UMaine model base run (Fishery 1=mixed fishery; Fishery 2=trawl fishery; Fishery 3=trap fishery).

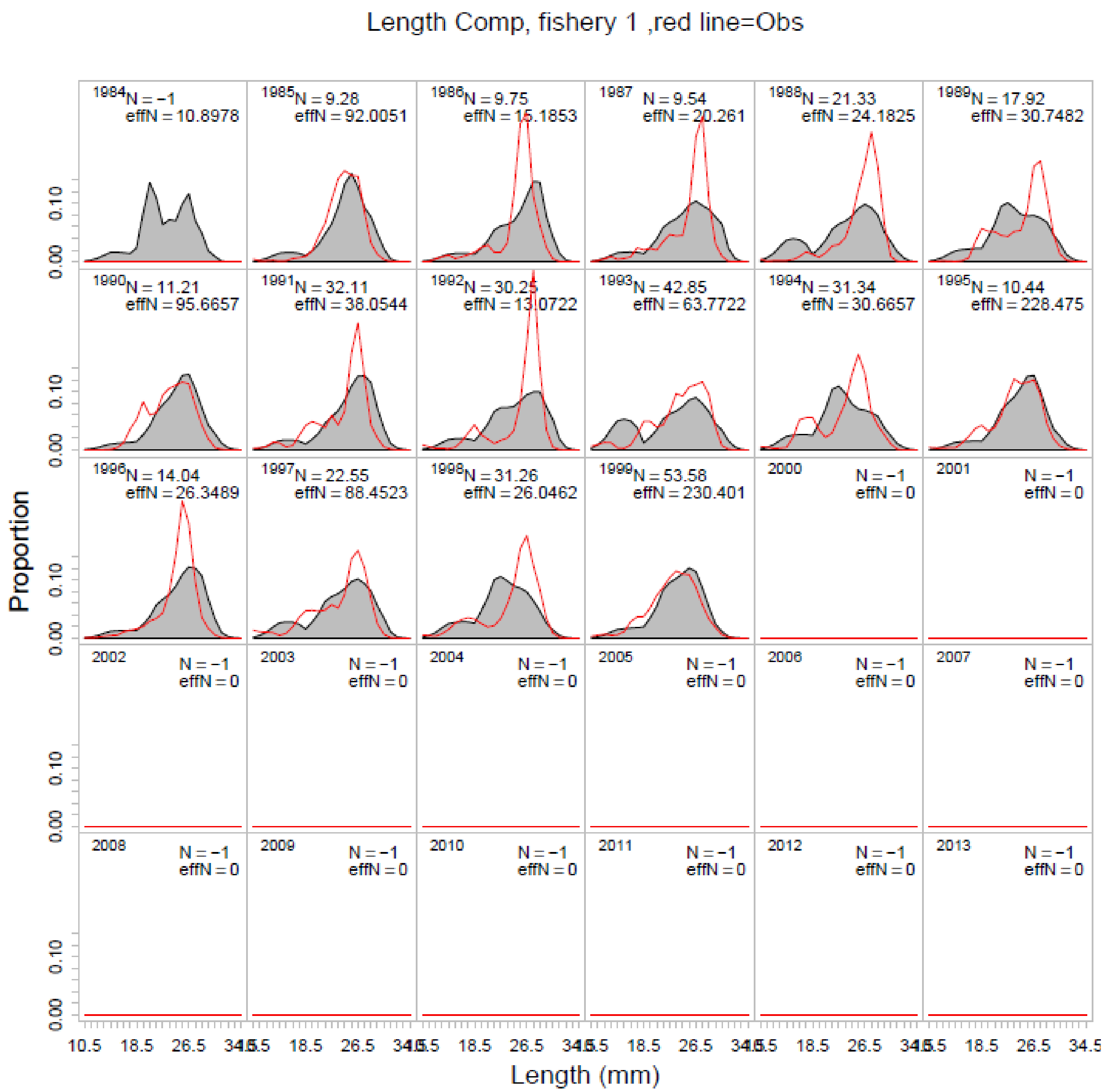


Figure C6.18. Mixed fishery length composition data for each year (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run.

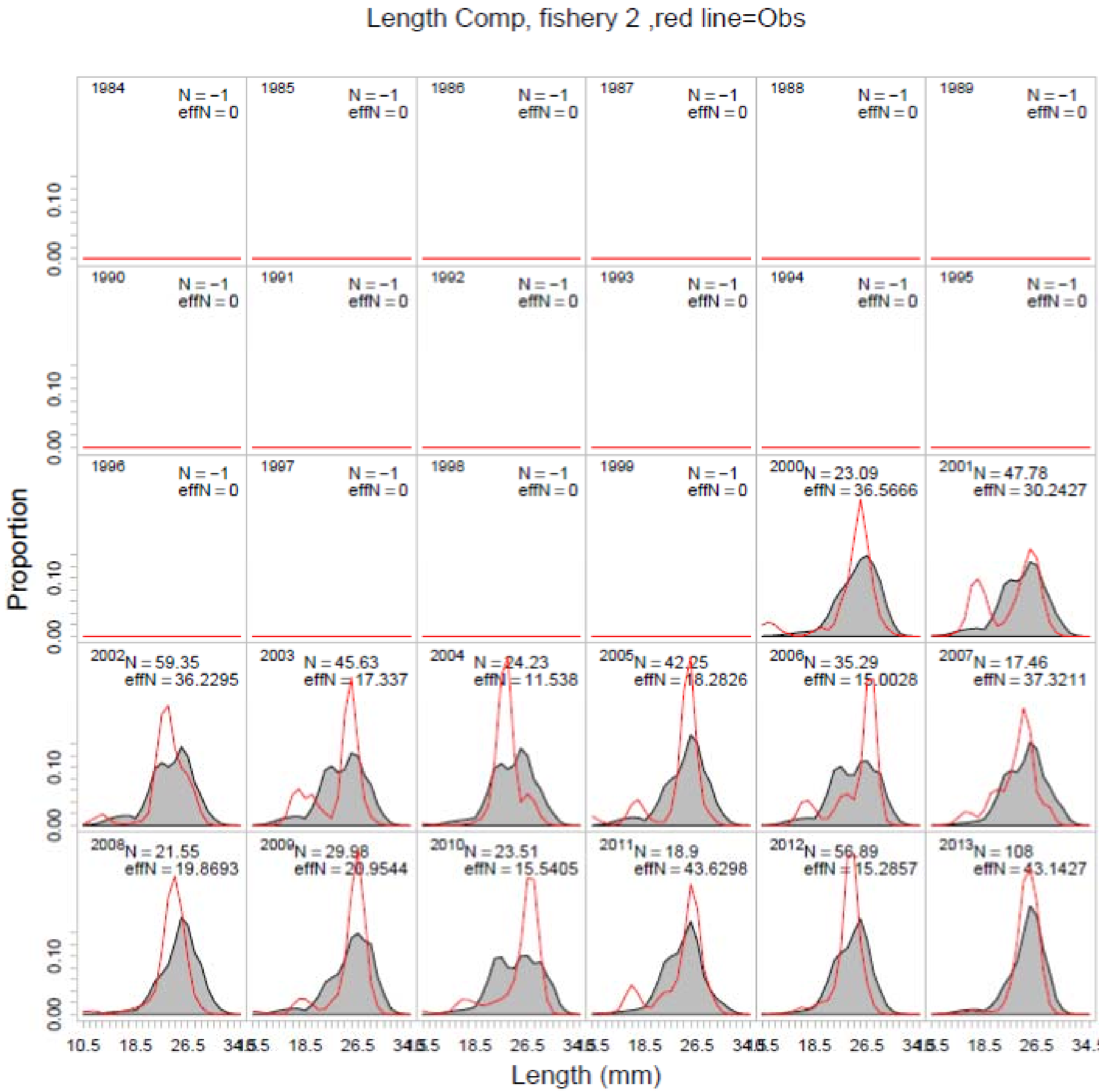


Figure C6.19. Trawl fishery length composition data for each year (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run.

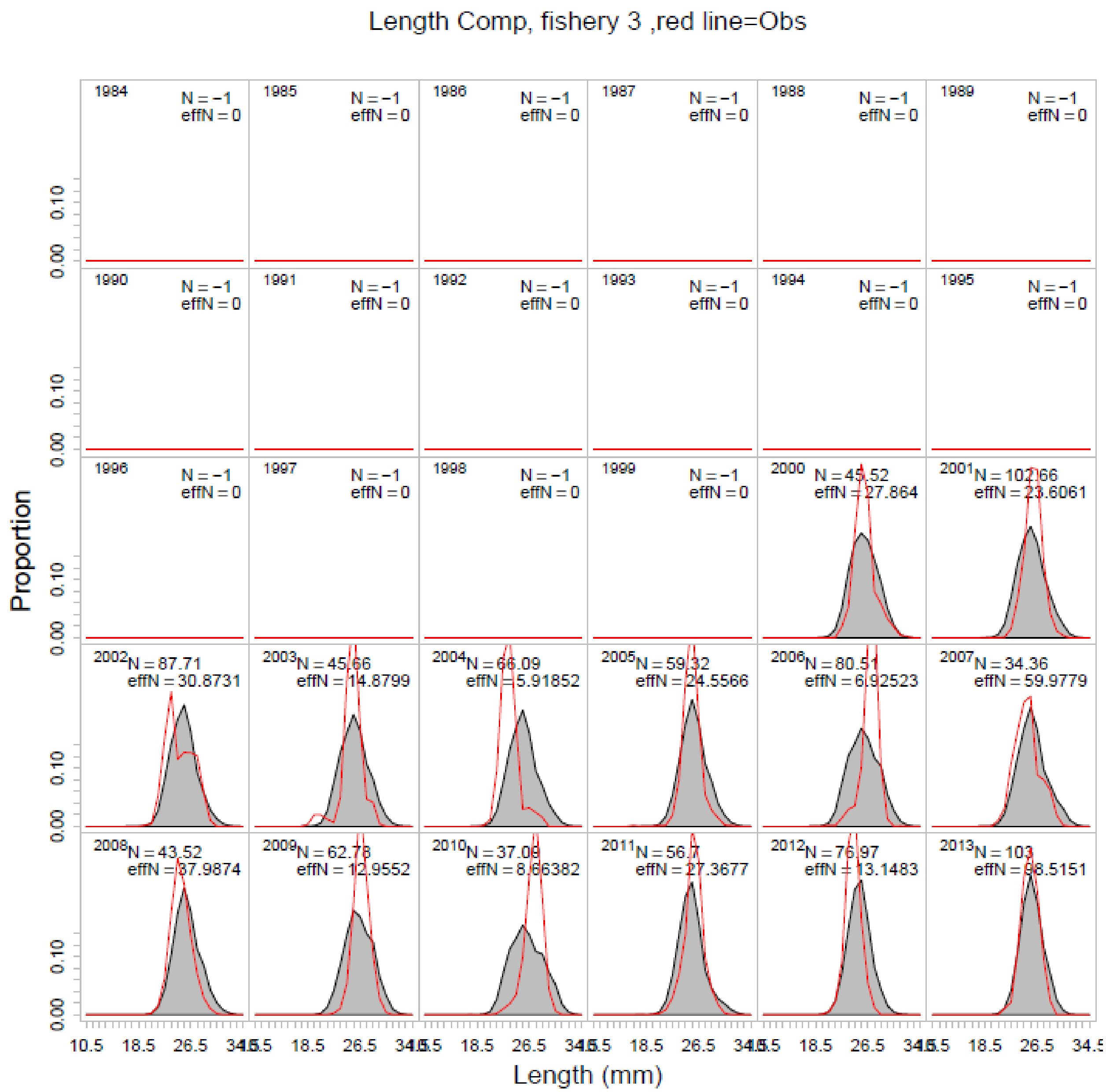


Figure C6.20. Trap fishery length composition data for each year (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run.

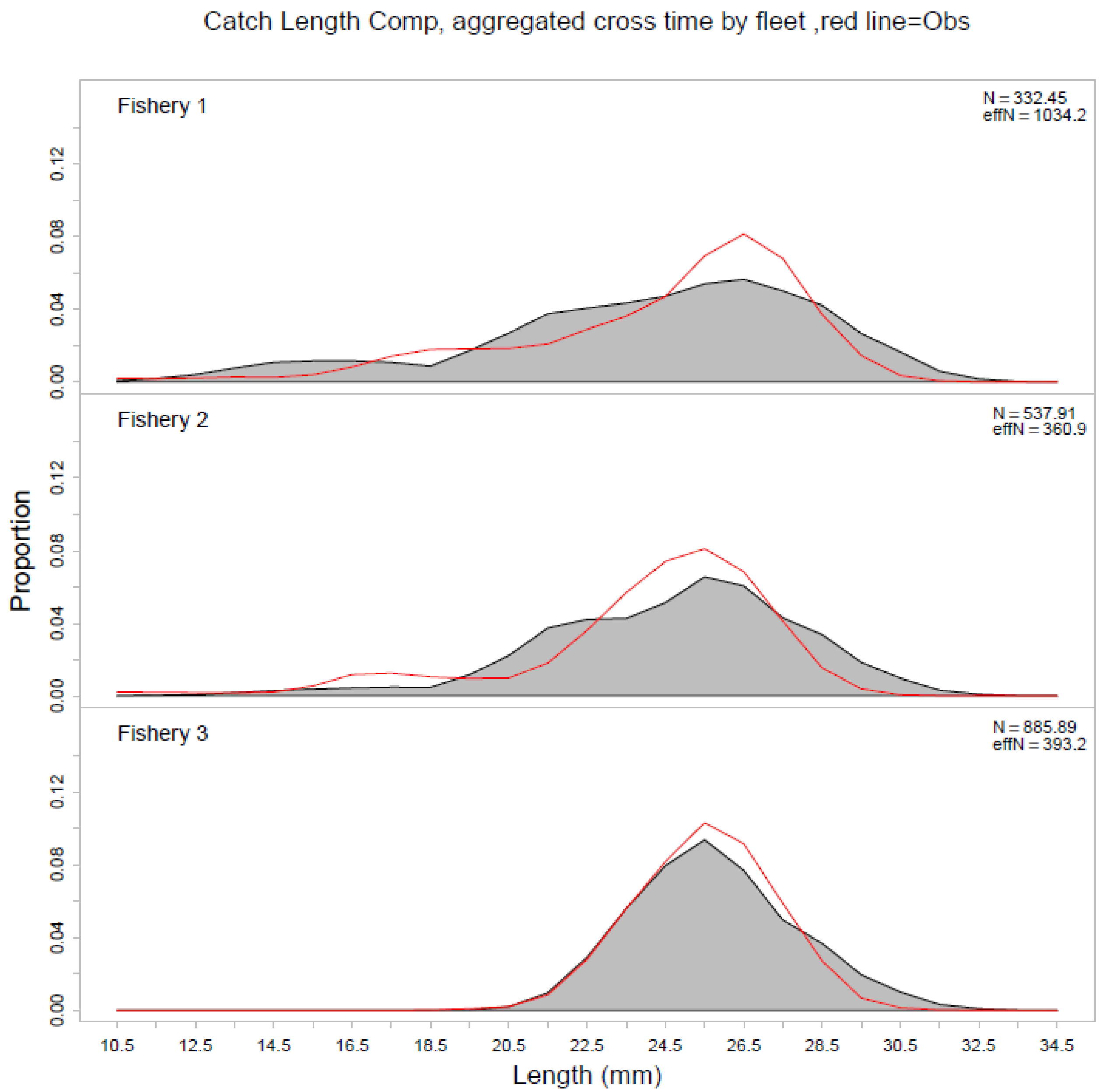


Figure C6.21. Average commercial length composition data (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run (Fishery 1=mixed fishery; Fishery 2=trawl fishery; Fishery 3=trap fishery).

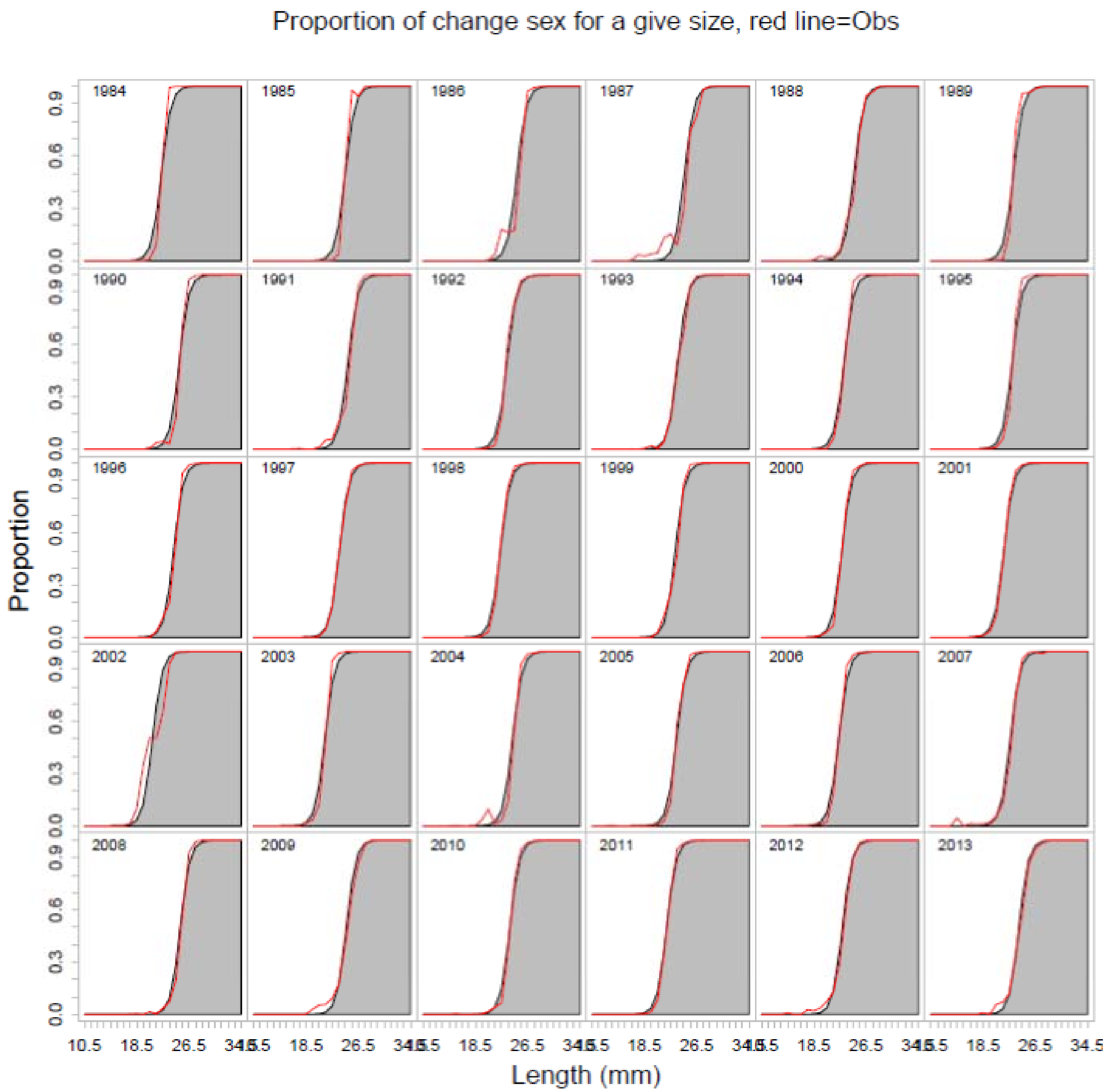


Figure C6.22. Proportion of female data (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run.

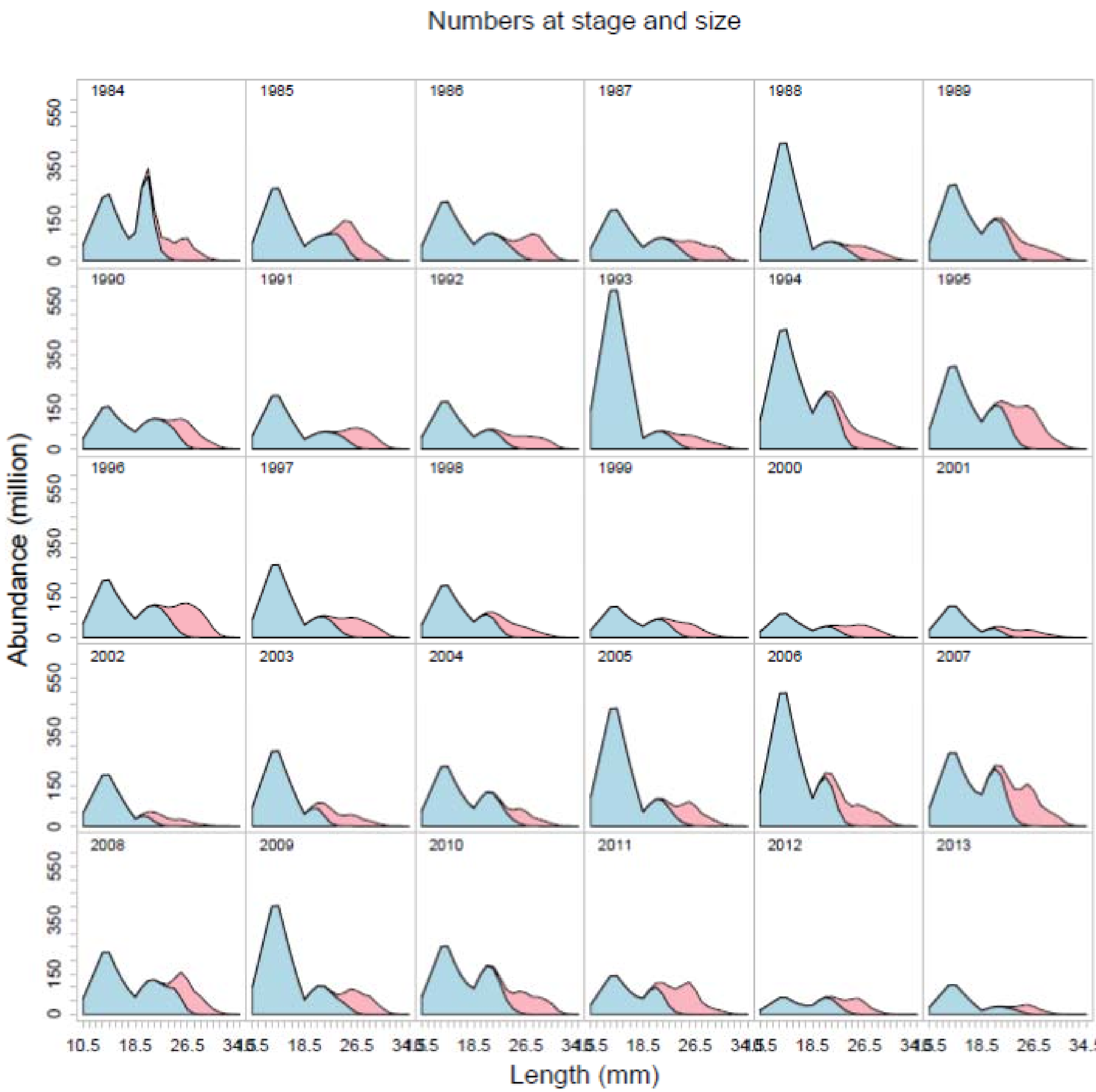


Figure C6.23. Estimated abundance of female (in pink) and non-female (in blue) for each size class at the beginning of each year.

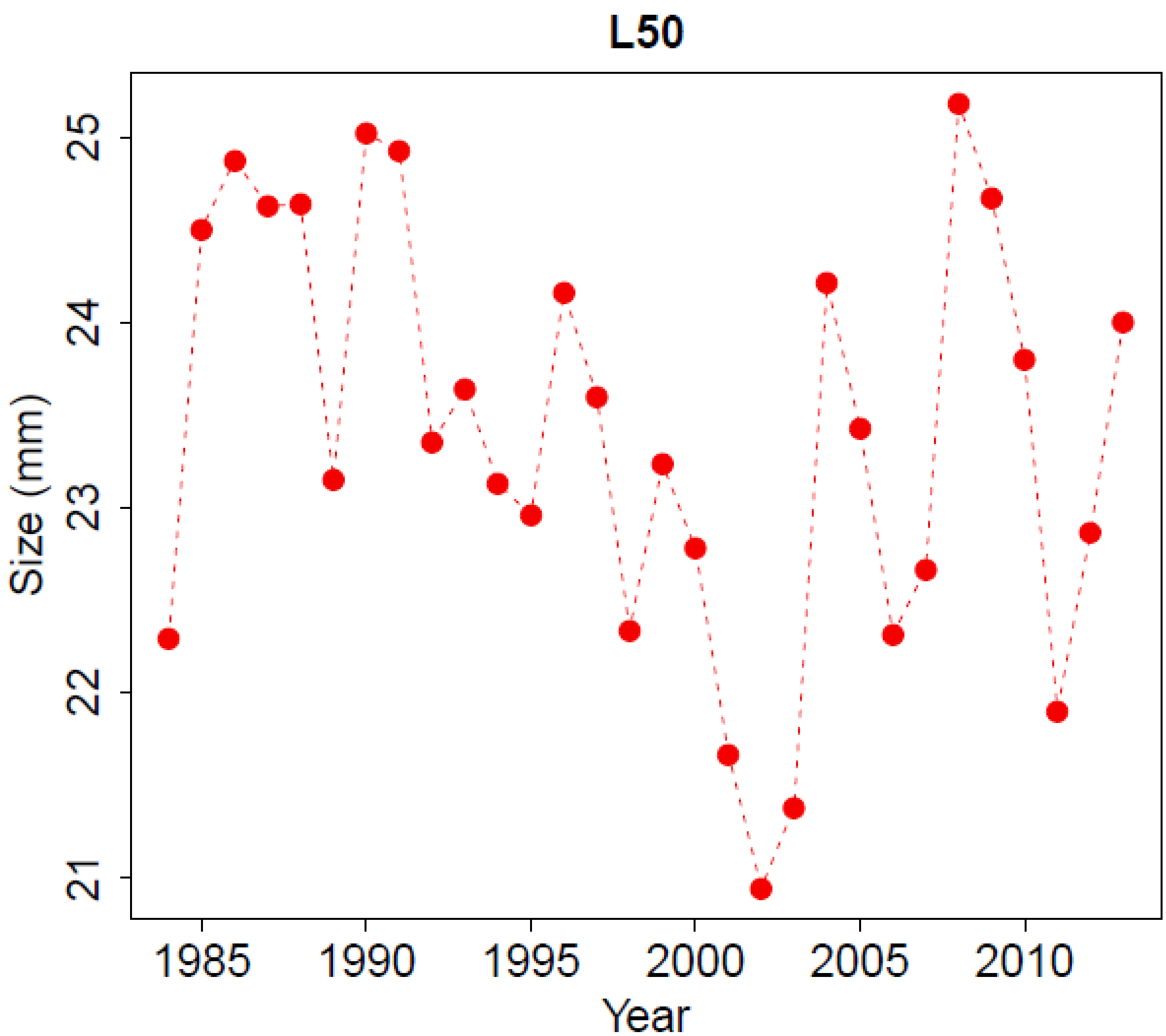


Figure C6.24. Estimated L_{50} (the size at which fifty percents of shrimp change sex to female) for each year from the UMaine model base run.

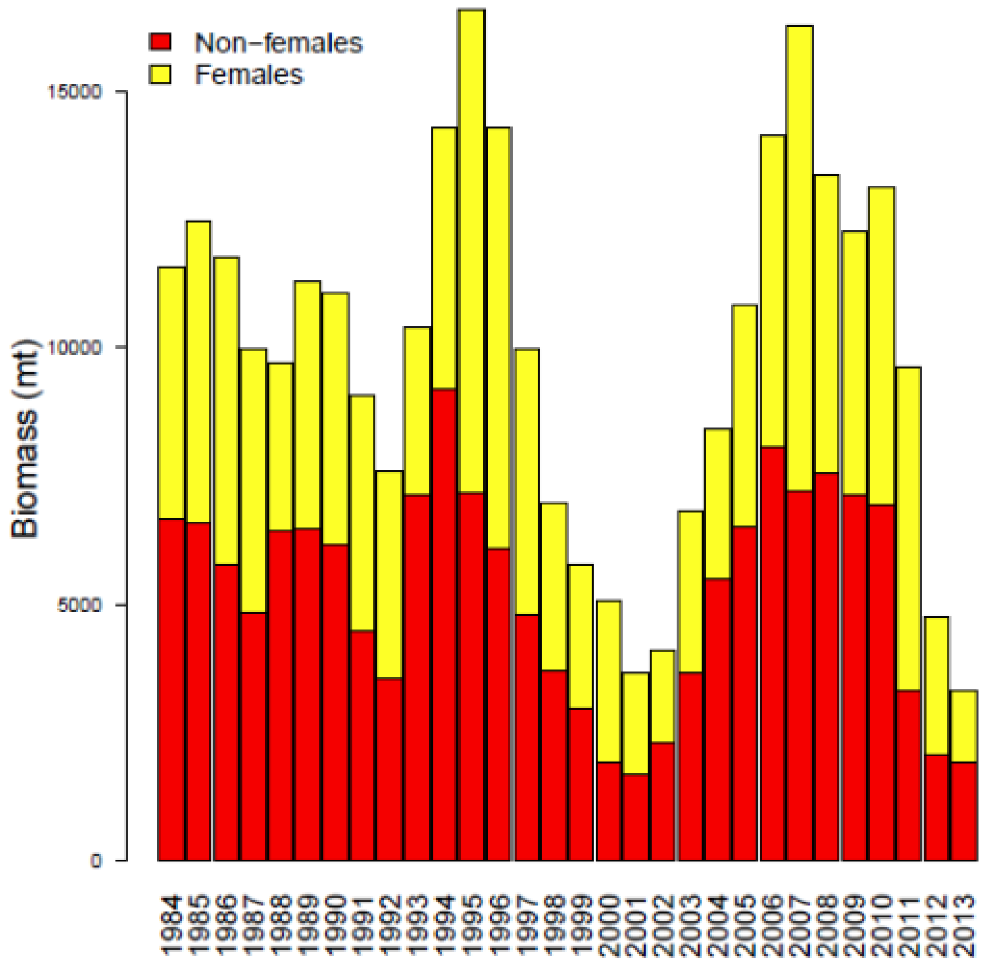


Figure C6.25. Estimates of female biomass (in yellow) and non-female biomass (in red) from the UMaine model base run.

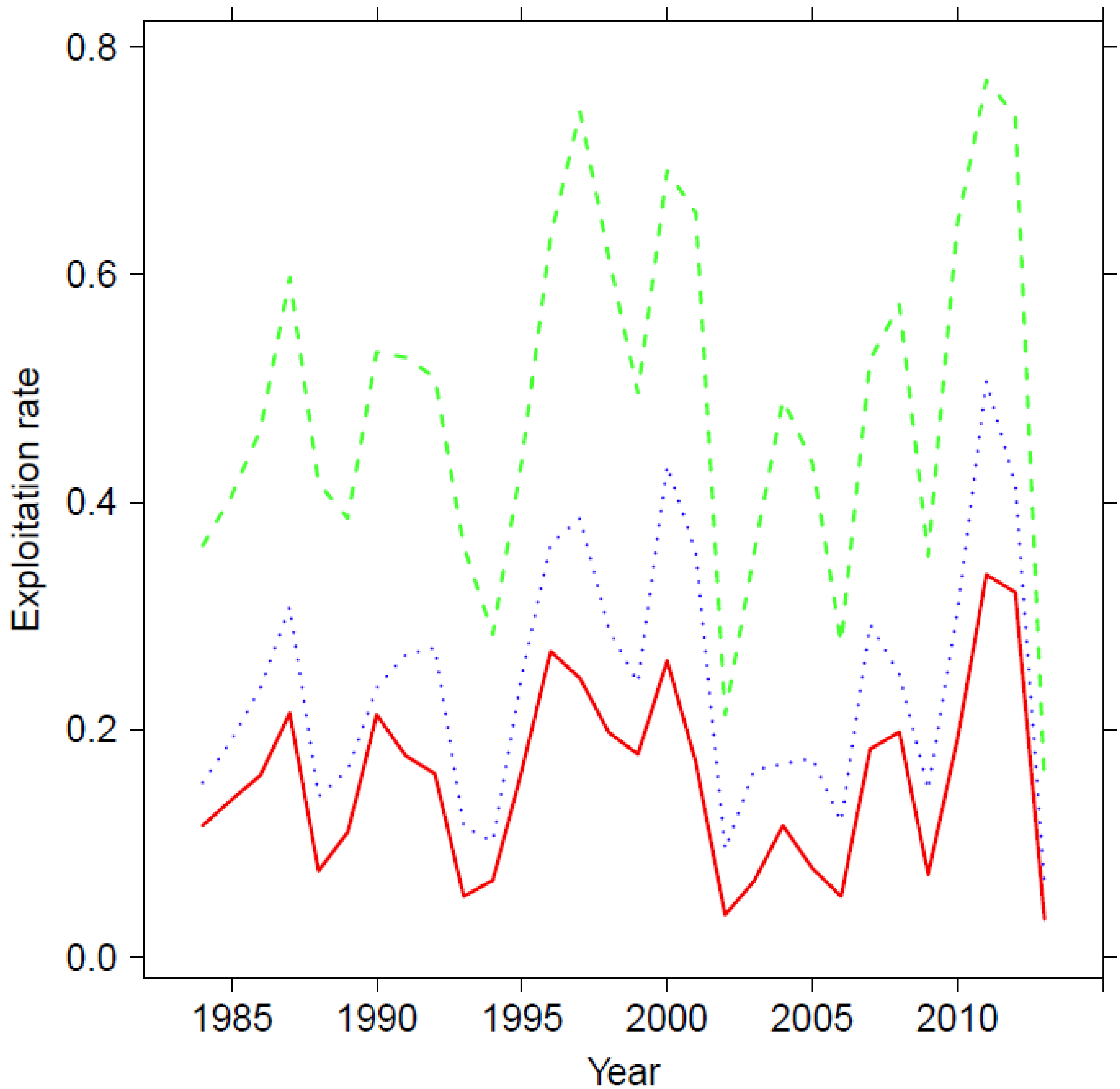


Figure C6.26. Exploitation rates for each year from the UMaine model base run (red line=predicted total catch in numbers/estimates of total numbers; blue line=predicted total catch biomass/estimates of total biomass; green line= predicted total female catch biomass/estimates of female biomass).

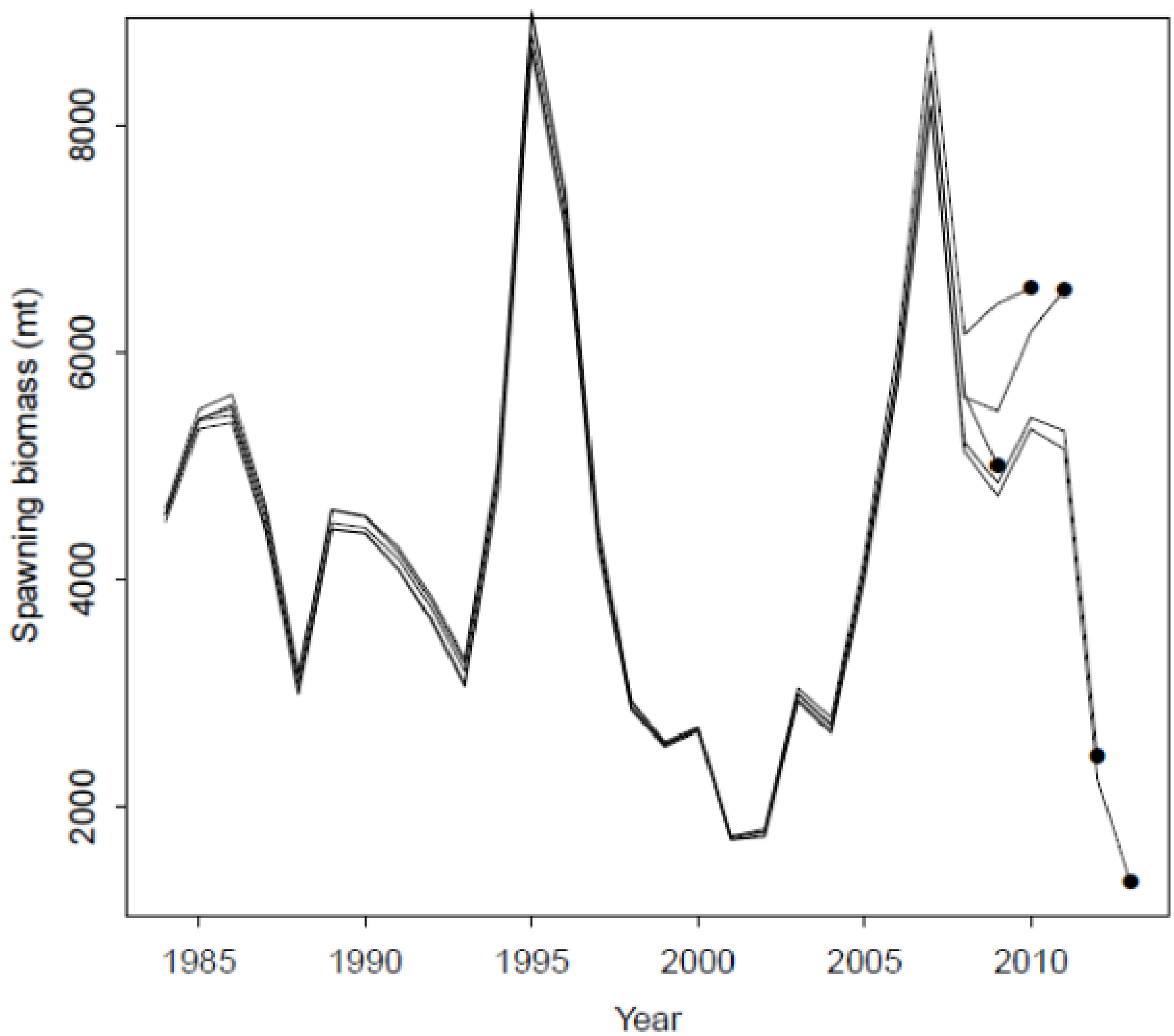


Figure C6.27. Retrospective pattern for spawning stock biomass for the UMaine model base run (Mohn rho=0.22 for 2009 as reference year)

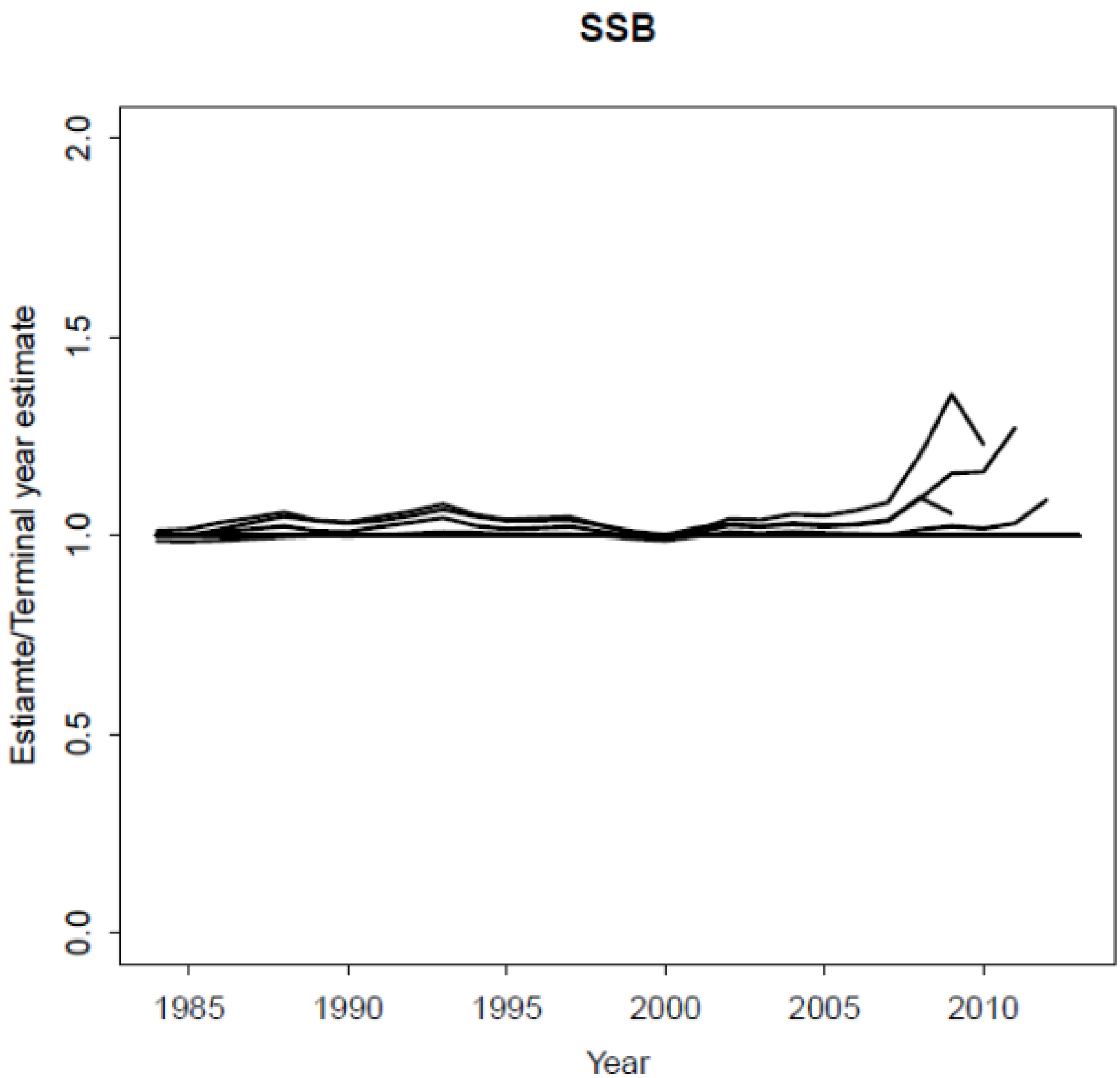


Figure C6.28. Retrospective pattern for spawning stock biomass for the UMaine model base run (Mohn rho=0.22 for 2009 as reference year).

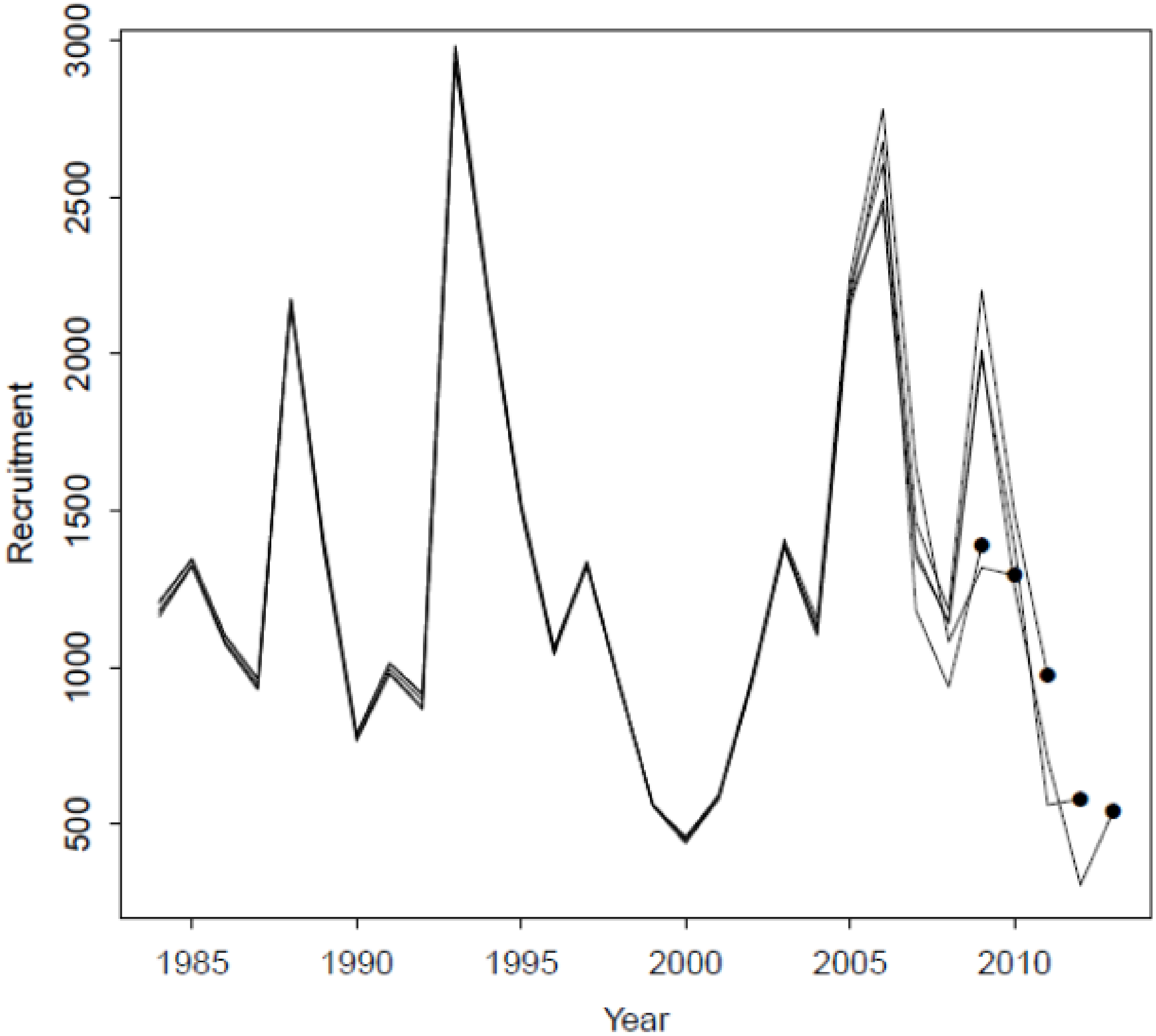


Figure C6.29. Retrospective pattern for recruitment for the UMaine model base run (Mohn rho=0.93 for 2009 as reference year)

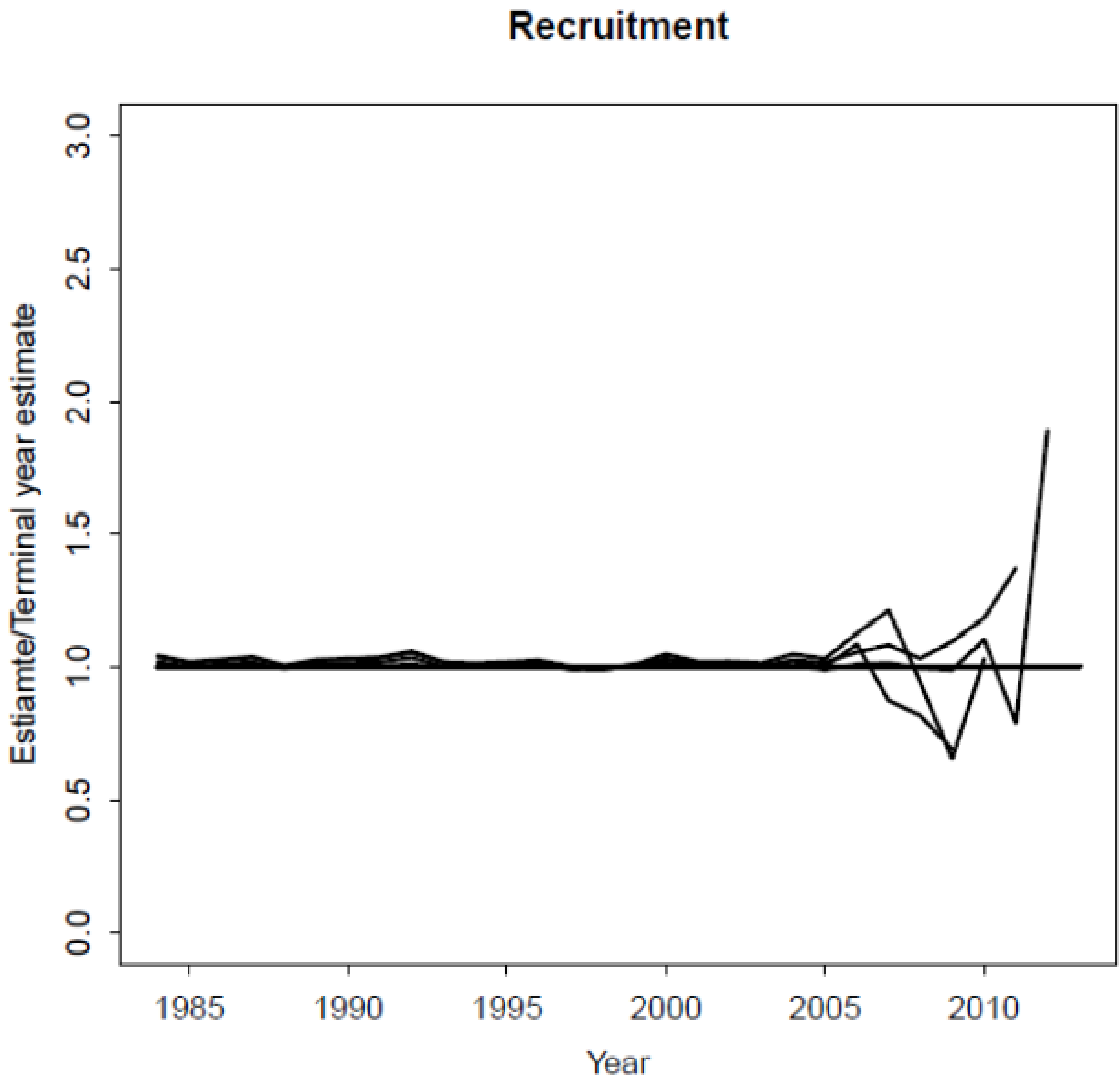


Figure C6.30. Retrospective pattern for recruitment for the UMaine model base run (Mohn rho=0.93 for 2009 as reference year).

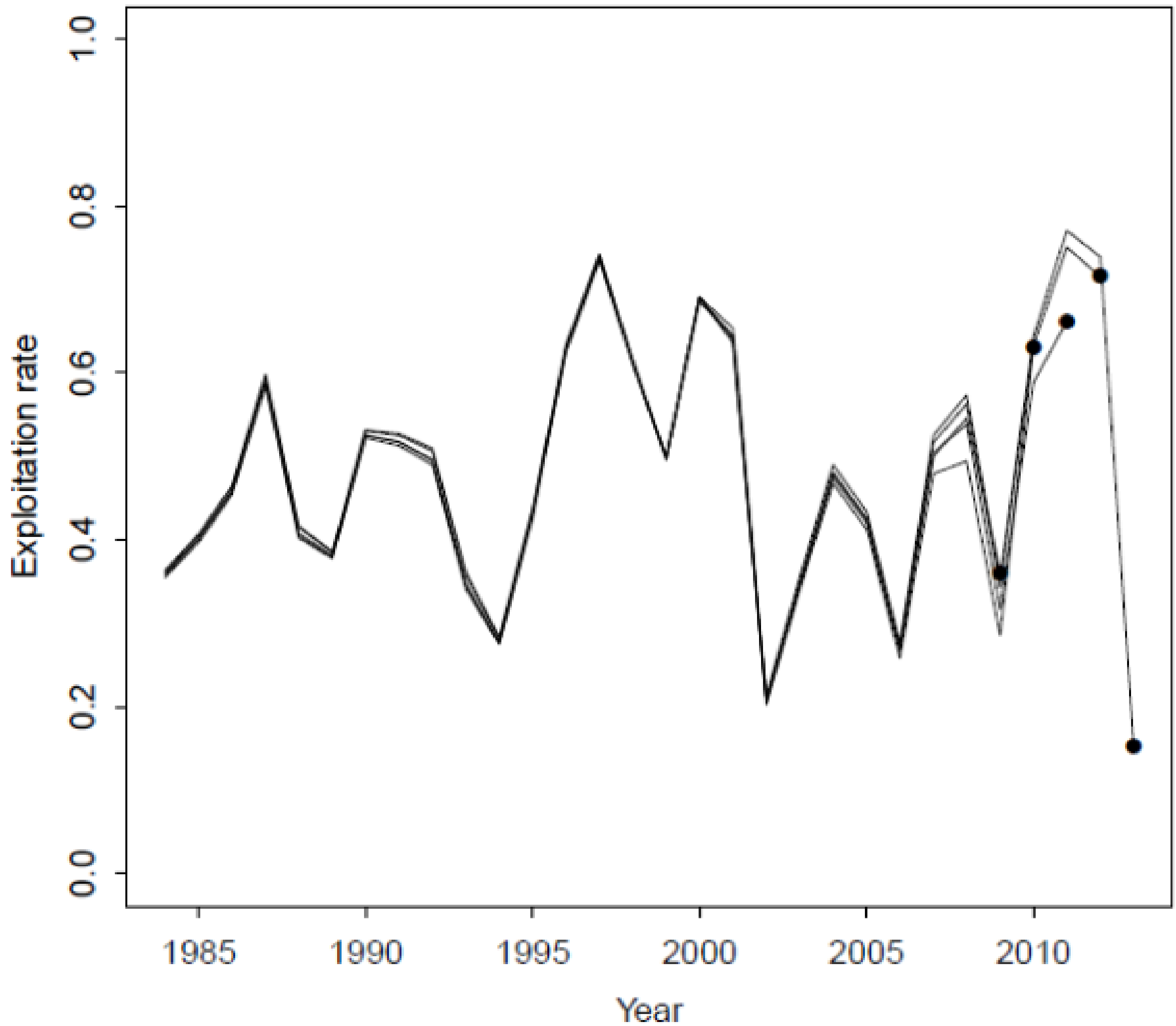


Figure C6.31. Retrospective pattern for exploitation rate (predicted total female catch biomass/estimates of female biomass) for the UMaine model base run (Mohn rho=-0.47 for 2009 as reference year)

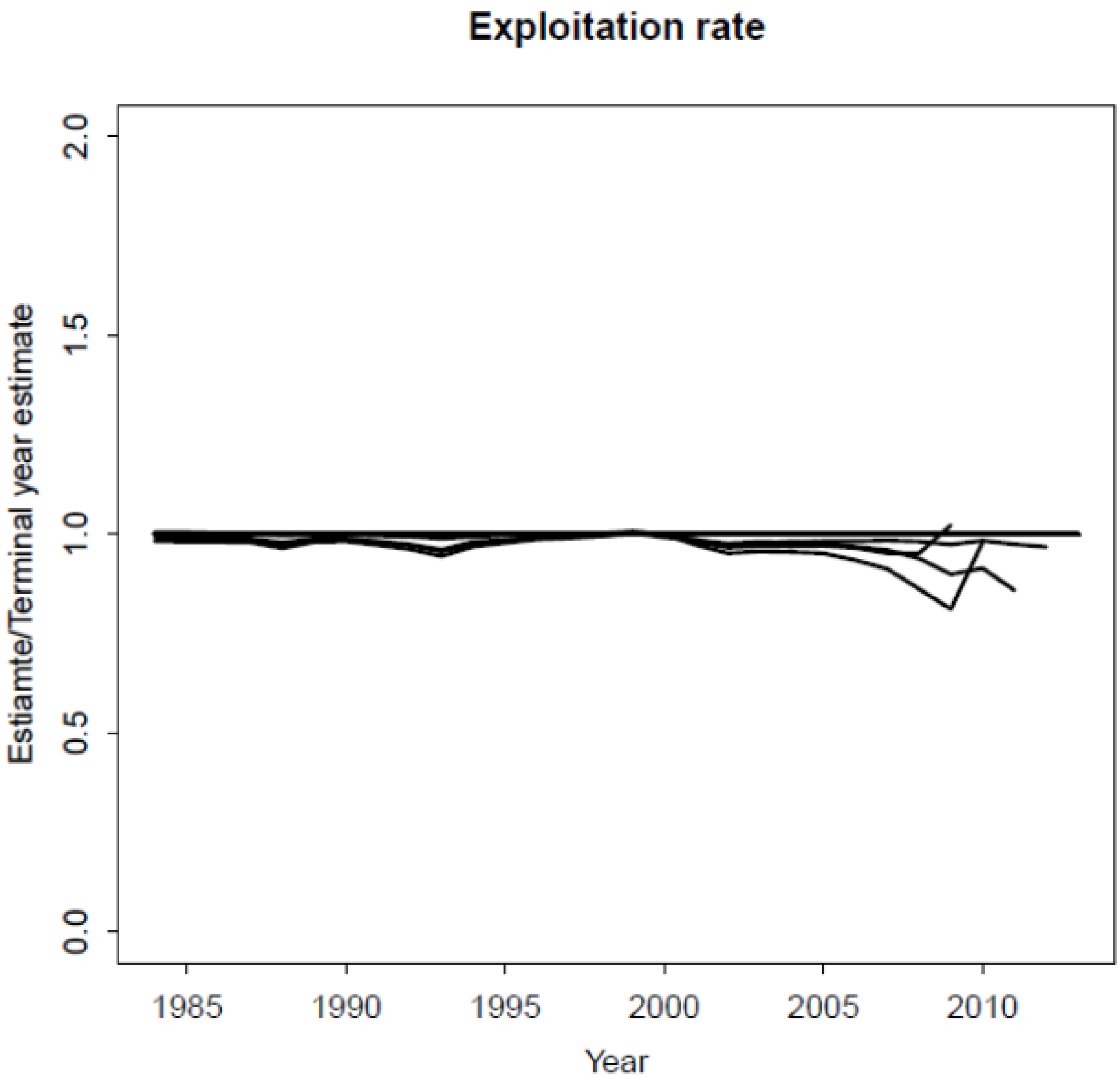


Figure C6.32. Retrospective pattern for exploitation rate (total catch in number/total abundance) for the UMaine model base run (Mohn rho=-0.47 for 2009 as reference year).

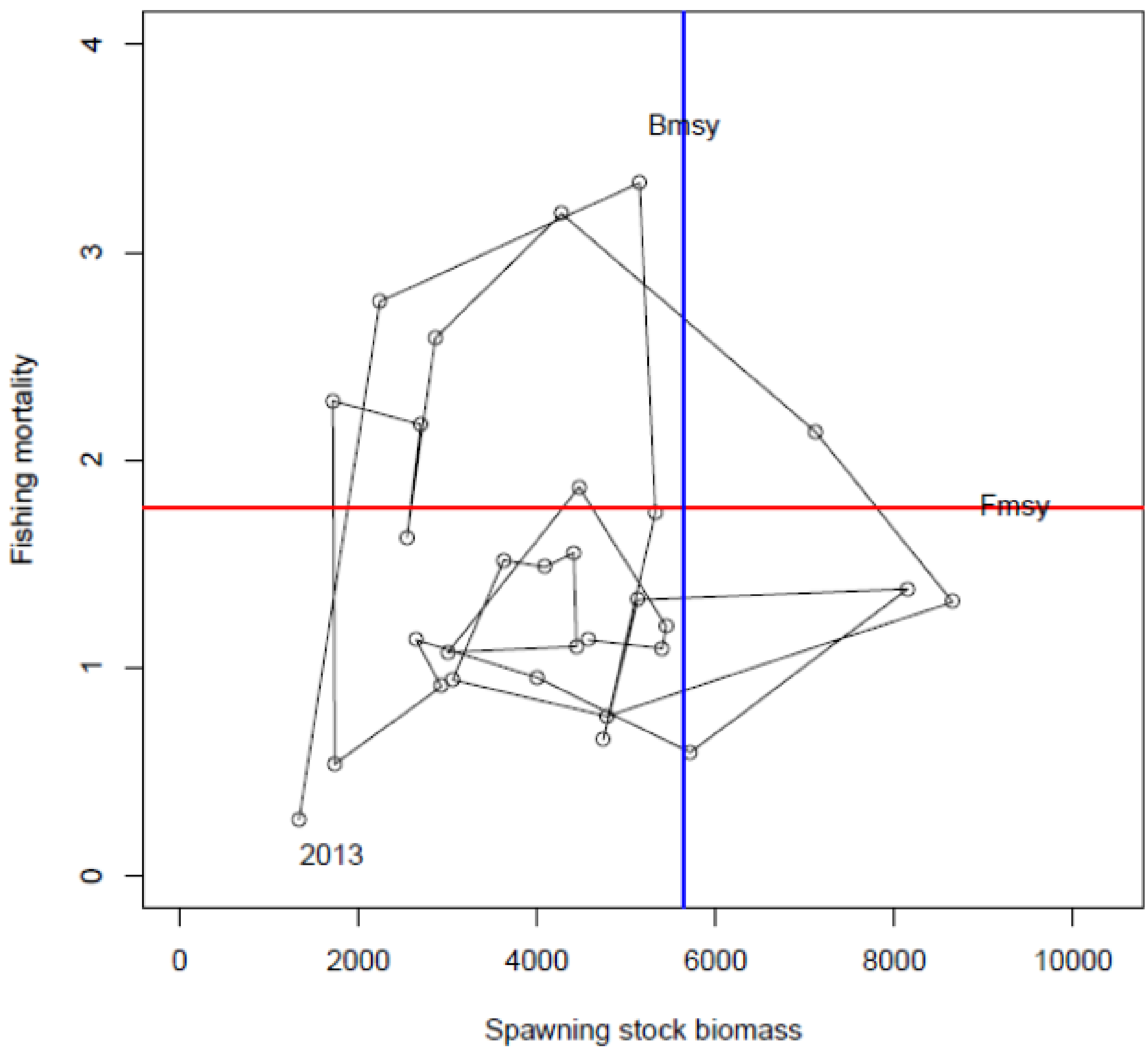


Figure C6.33. Phase plot for the base case. Fishing mortality is the total fishing mortality for fully recruited shrimp. Spawning stock biomass is measured in metric tons. F_{msy} and B_{MSY} for the base case are listed in Table 5.

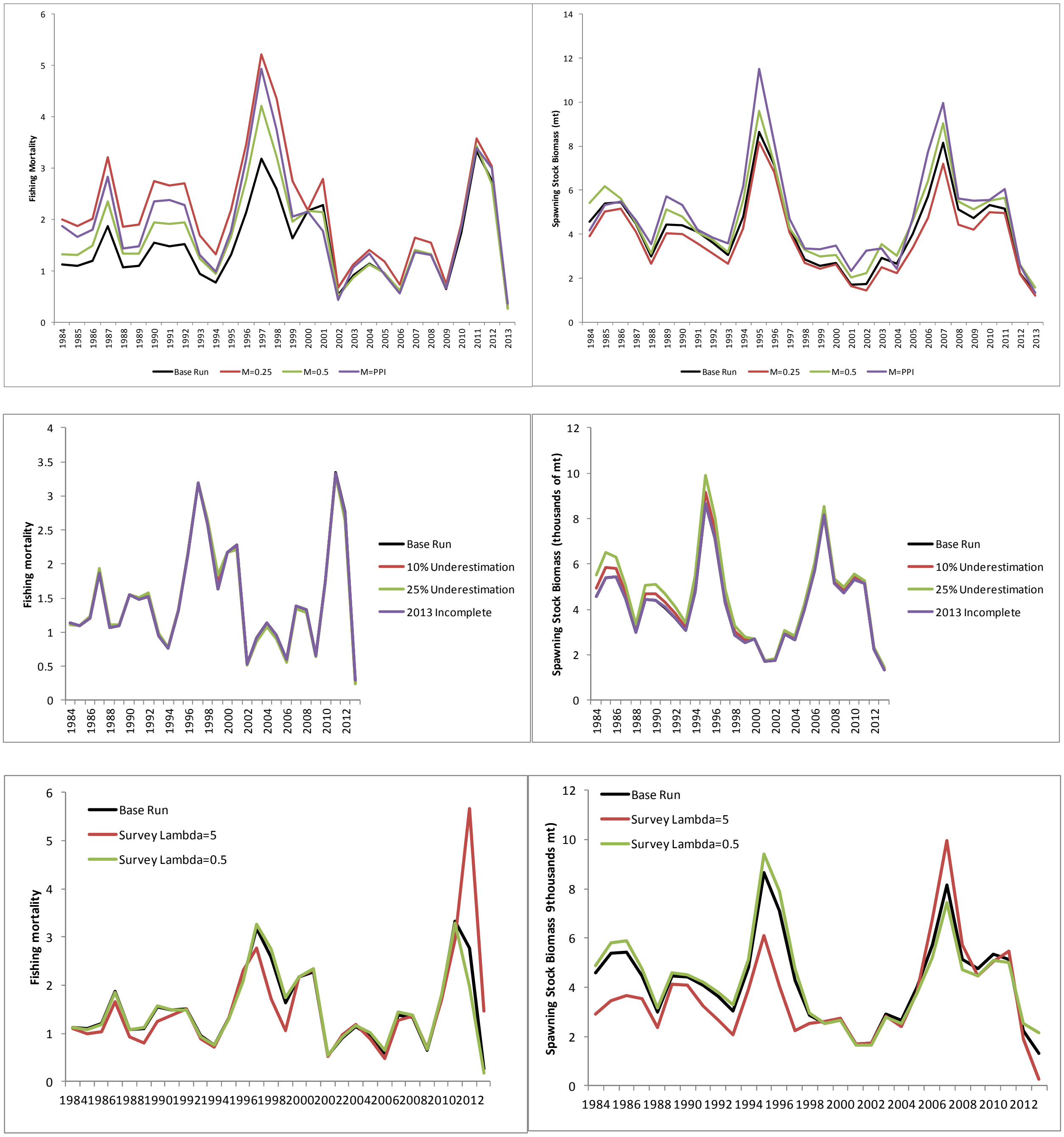


Figure C6.34. Sensitivity runs for UME model examining the effects of assumptions about natural mortality (top), underreporting of catch in the early time period or terminal year (middle), upweighting or downweighting of survey likelihood components relative to total catch (bottom), and choice of growth matrix (next page).

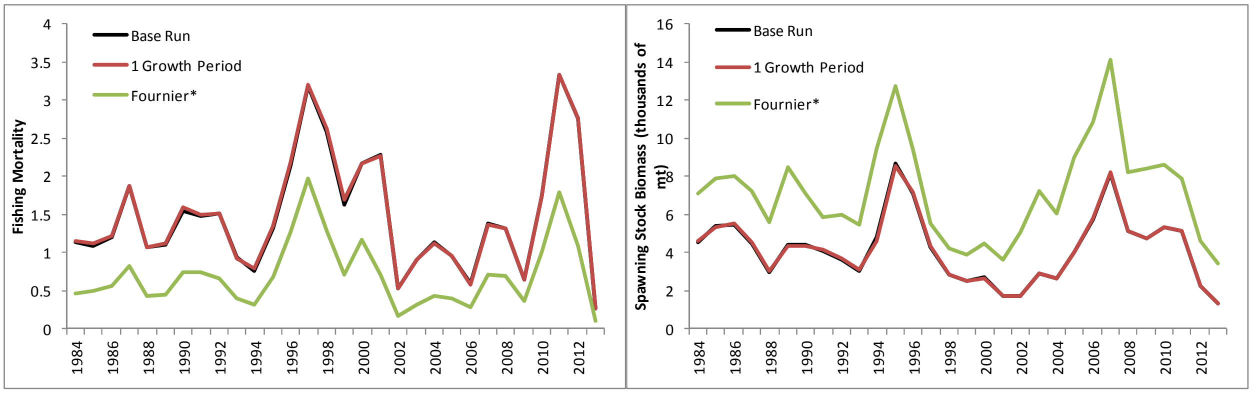


Figure C6.34 cont.

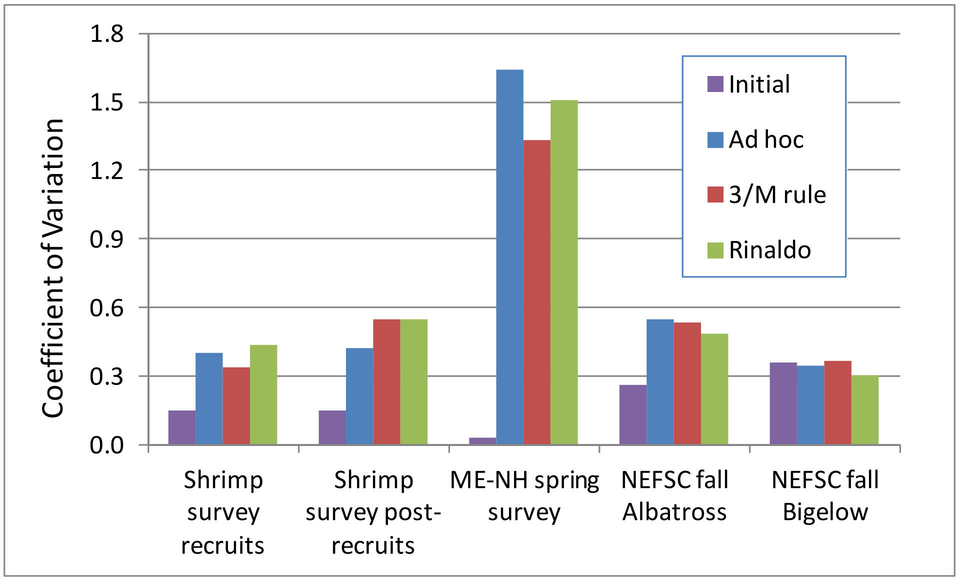


Figure C6.35. Adjustments to observed CV for each survey under different model scenarios for M. 'Initial' is CV estimated from survey data, '3/M rule' and 'Rinaldo' are PPI-scaled values.

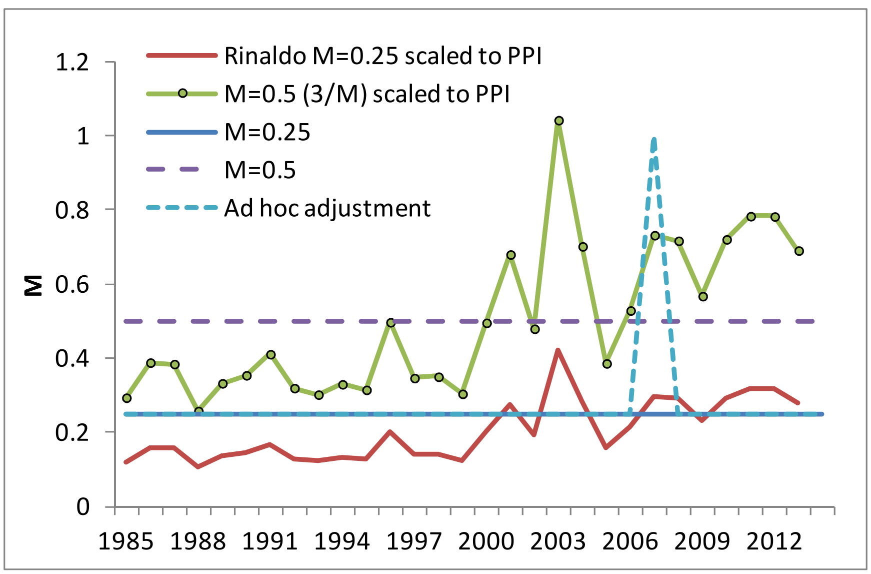


Figure C6.36. Values of natural mortality (M) explored in the CSA modeling framework.

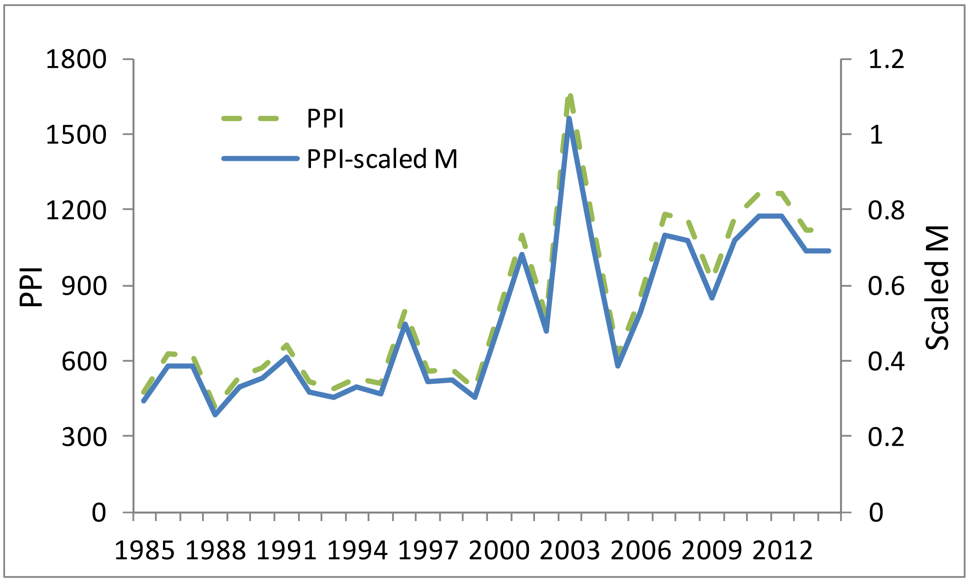


Figure C6.37. Predation pressure index (PPI) and scaled M using baseline M=0.5. For further detail, see Appendix C2.

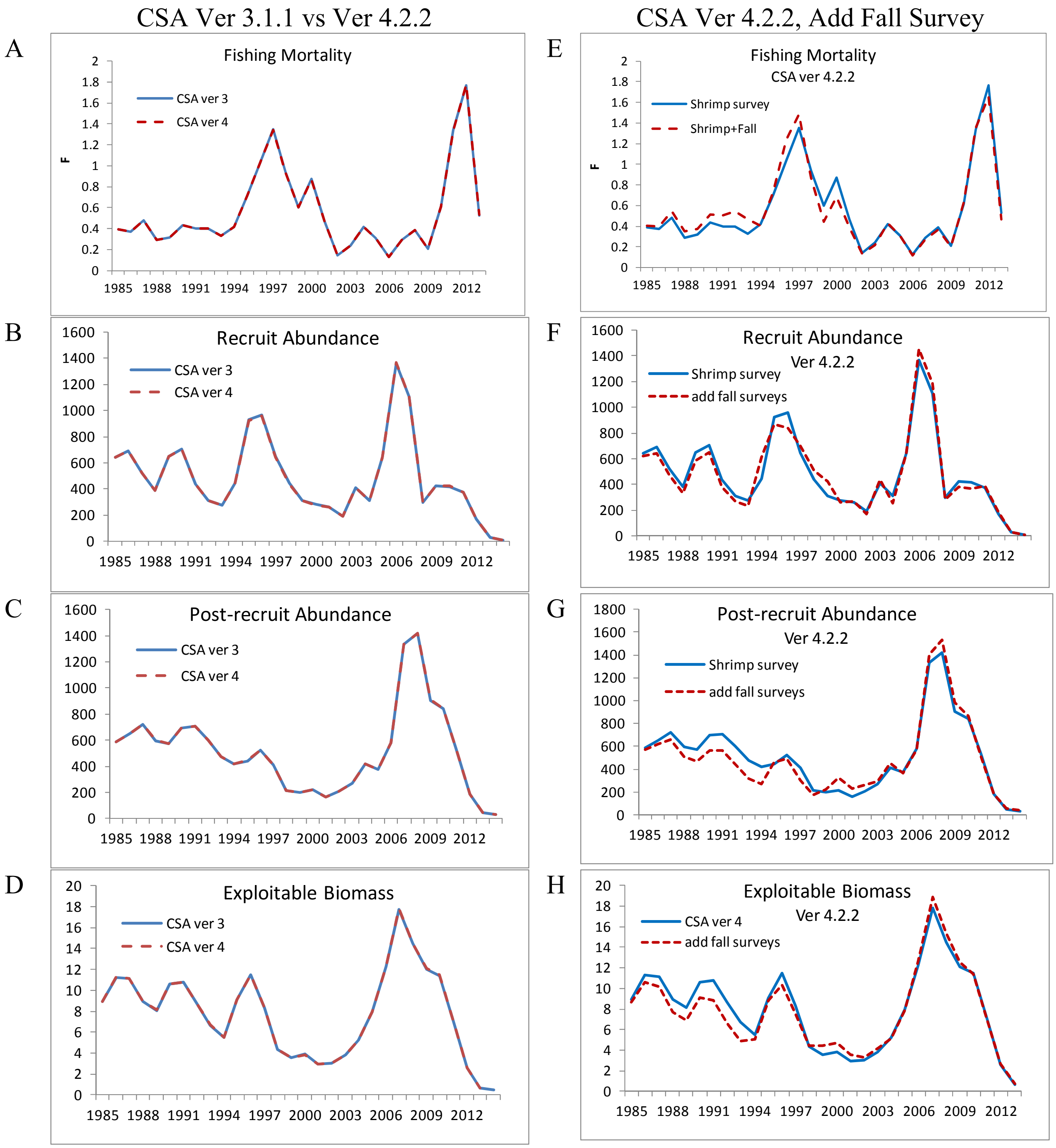


Figure C6.38. A-D: comparison of estimates from CSA version 3.1.1 (run 1) and CSA version 4.2.2 (run 2) using 2013 annual assessment update final CSA run (M=0.25) as basis; E-H: run 2 vs run 3 (additional surveys). Catch CV=0.01 in version 4.2.2. runs (version 3 assumed catch CV=0).

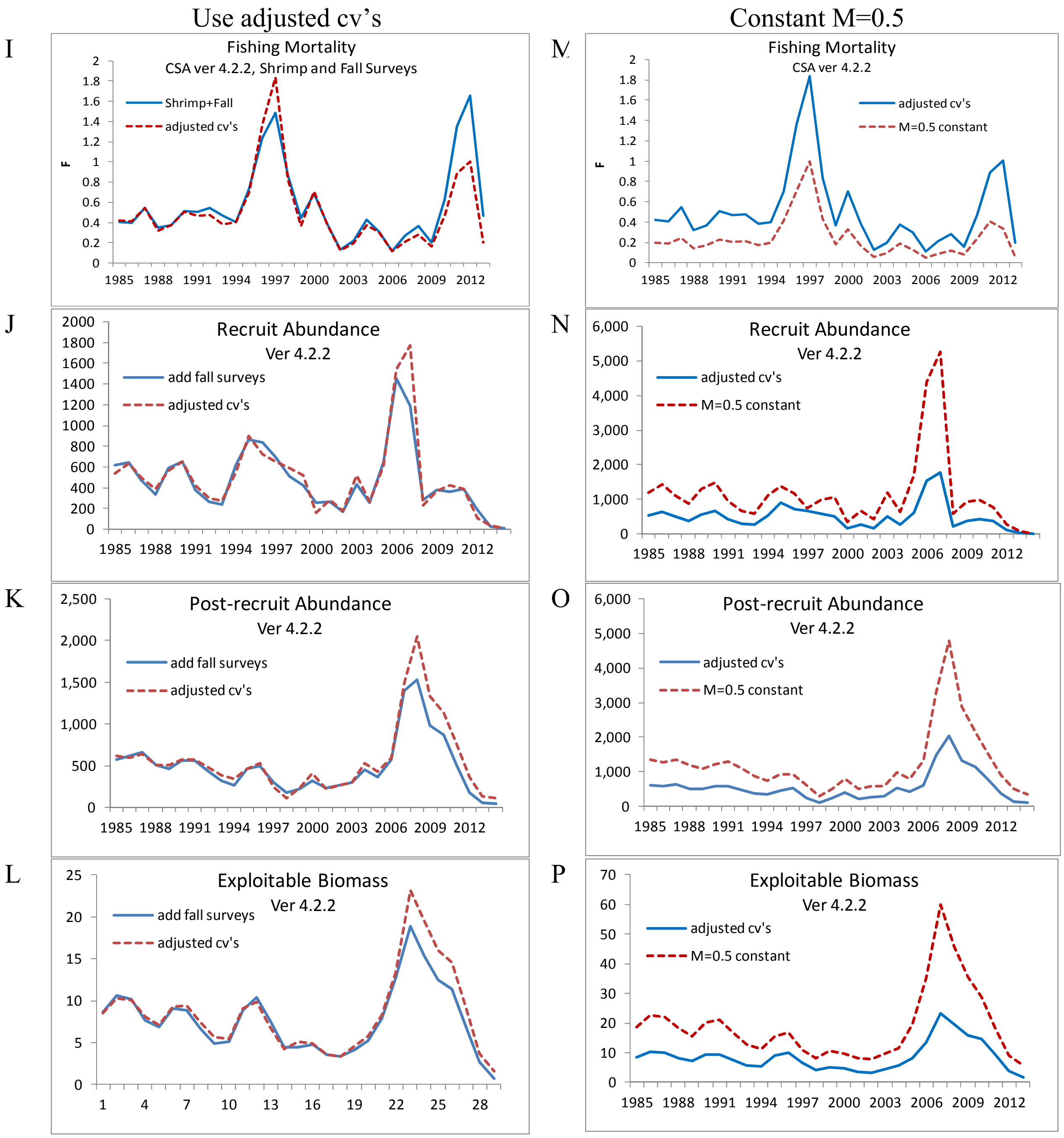


Figure C6.38, continued. I-L: run 3 (includes fall surveys) vs. run 4 (uses adjusted cv's for surveys and catch cv=0.05); M-P: run 4 vs run 5 (constant M=0.5). Catch CV=0.05 in I-P.

PPI-adjusted M

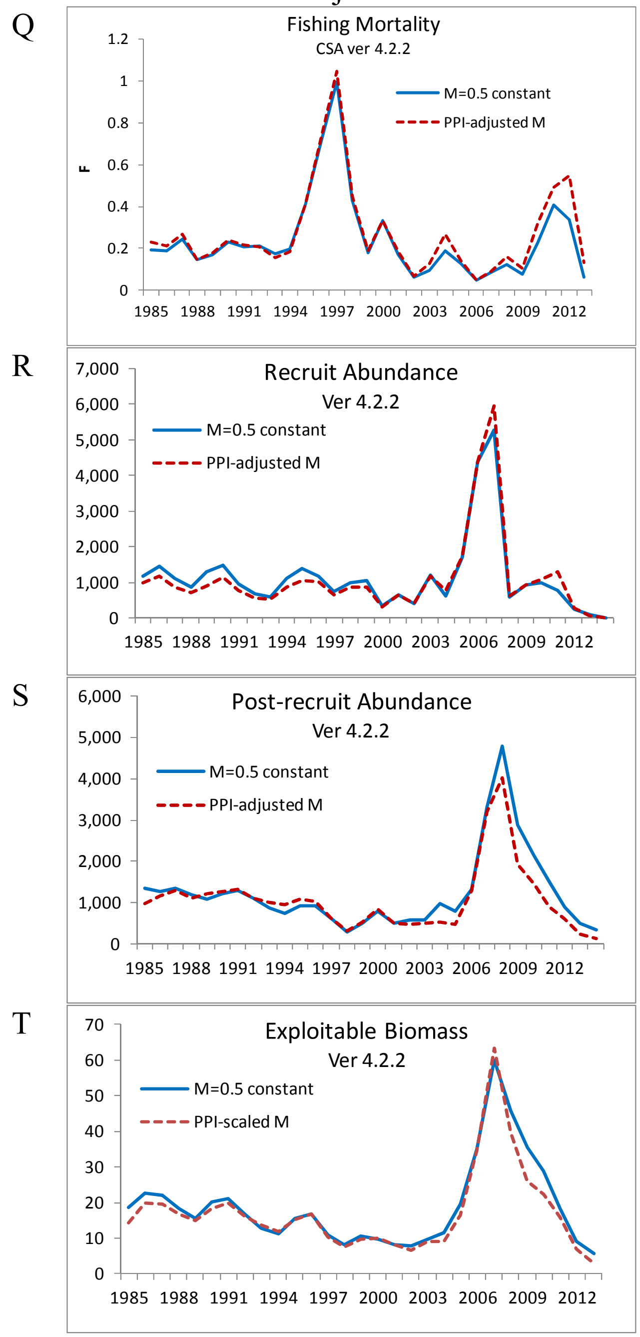


Figure C6.38, continued. Q-T: run 5 (M=0.5, constant) vs. run 6 (PPI-adjusted M using M=0.5 as baseline for adjustments). Catch CV=0.05.

Original run vs final run | Original run vs final run, re-scaled

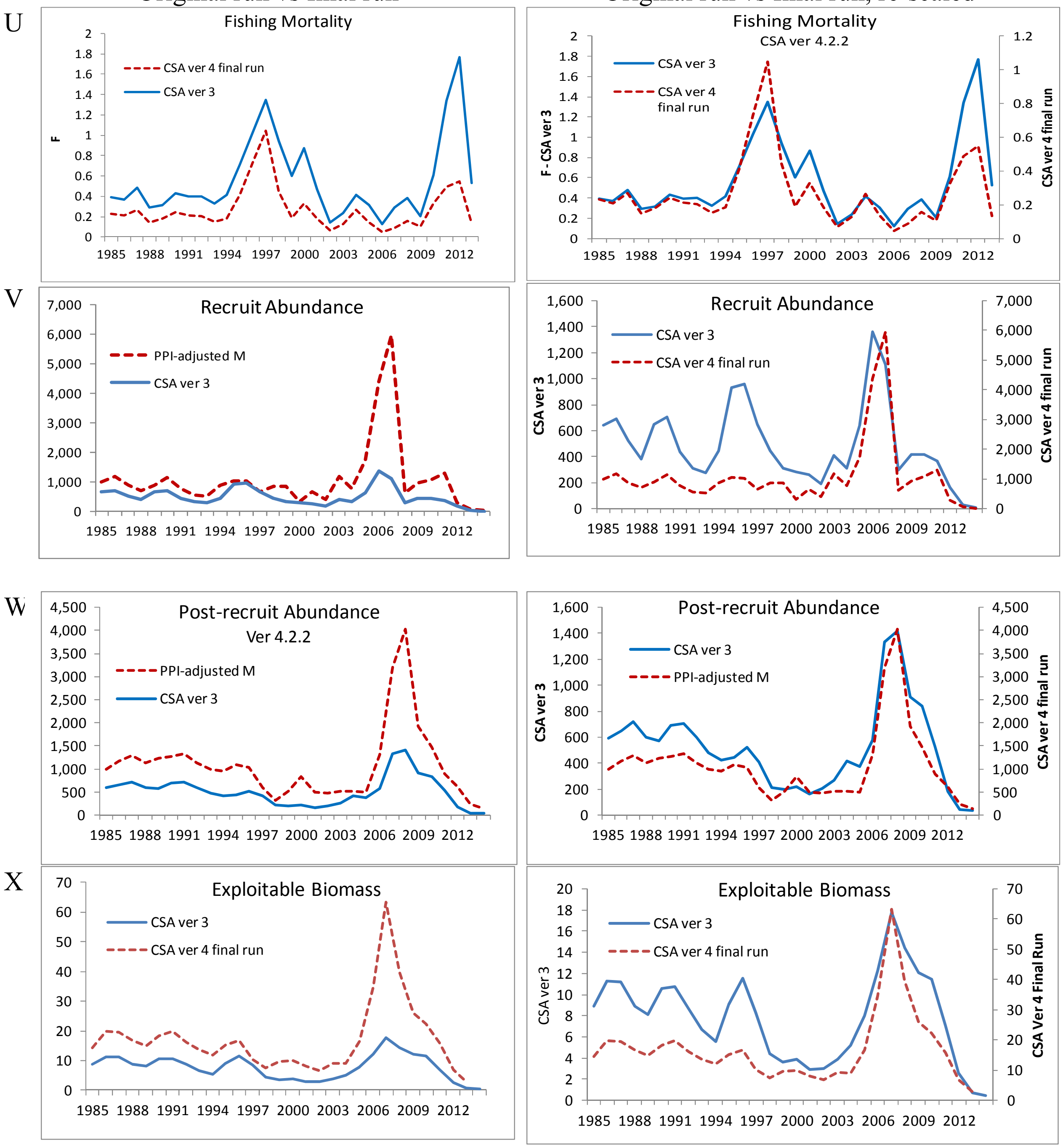


Figure C6.38, continued. Original run (run 1, CSA ver 3.1.1) vs final run (run 6, PPI-adjusted M). Left column: 1 y-axis; right column: 2 y-axes.

2013 Annual Assessment Final Run (M=0.25) | 2013 Benchmark Final Run

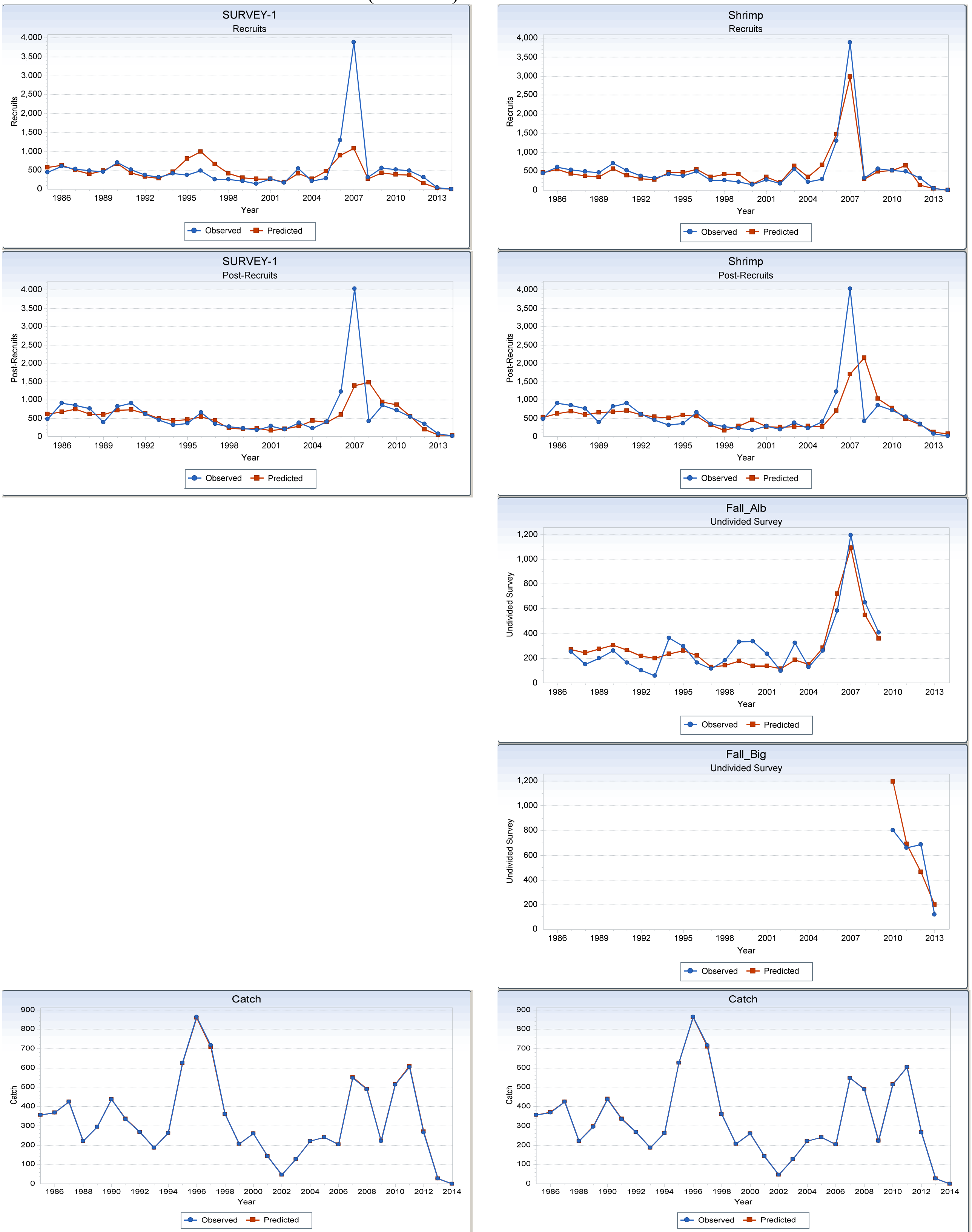


Figure C6.39. Comparison of model fits to data from 2013 annual assessment final model and 2014 benchmark final model.

2013 Annual Assessment Final Run (M=0.25) 2013 Benchmark Final Run

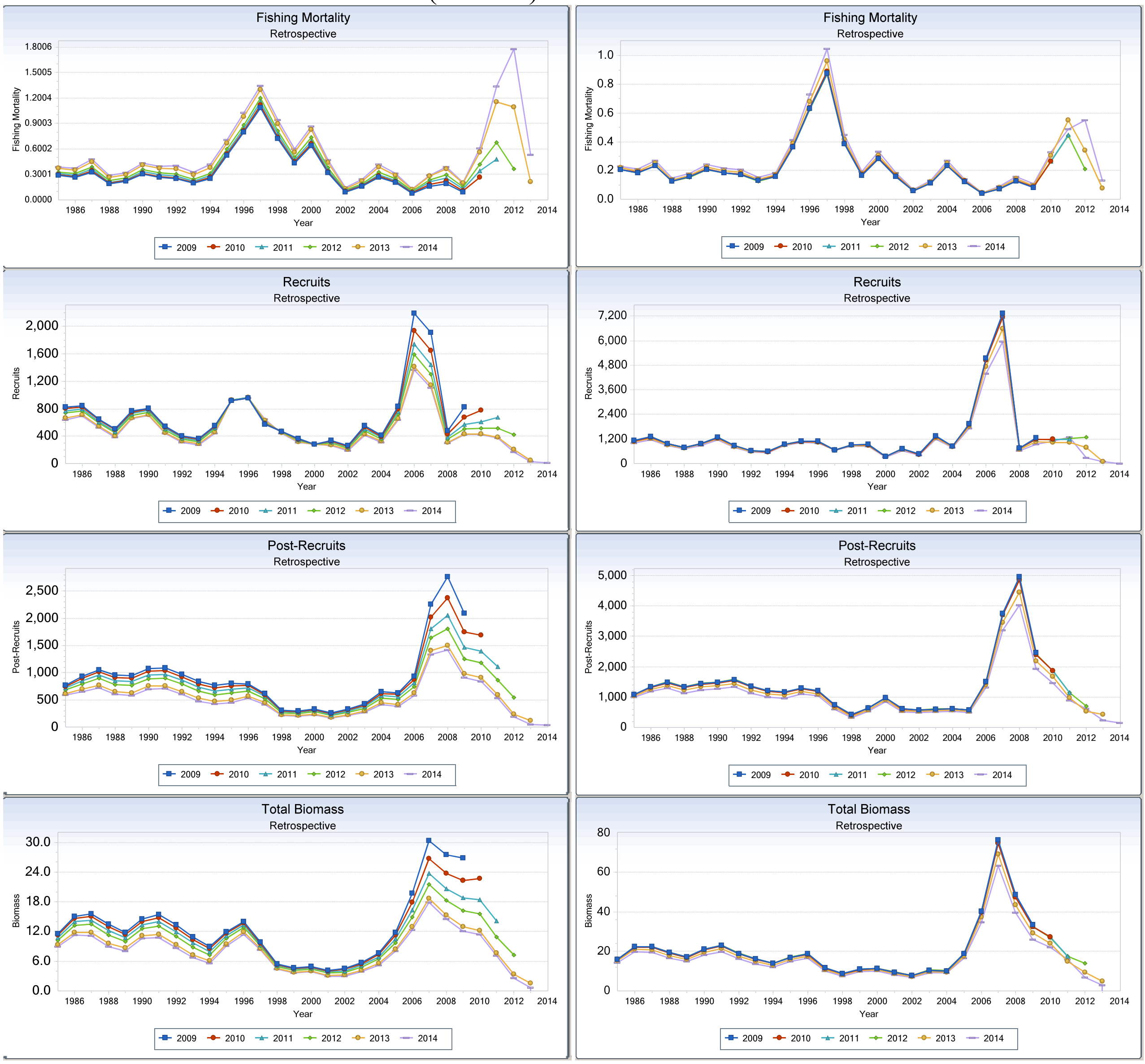


Figure C6.40. Retrospective patterns for 2013 annual assessment update final run implemented in CSA ver. 4.2.2 and benchmark final run.

2013 Annual Assessment Final Run (M=0.25) 2013 Benchmark Final Run

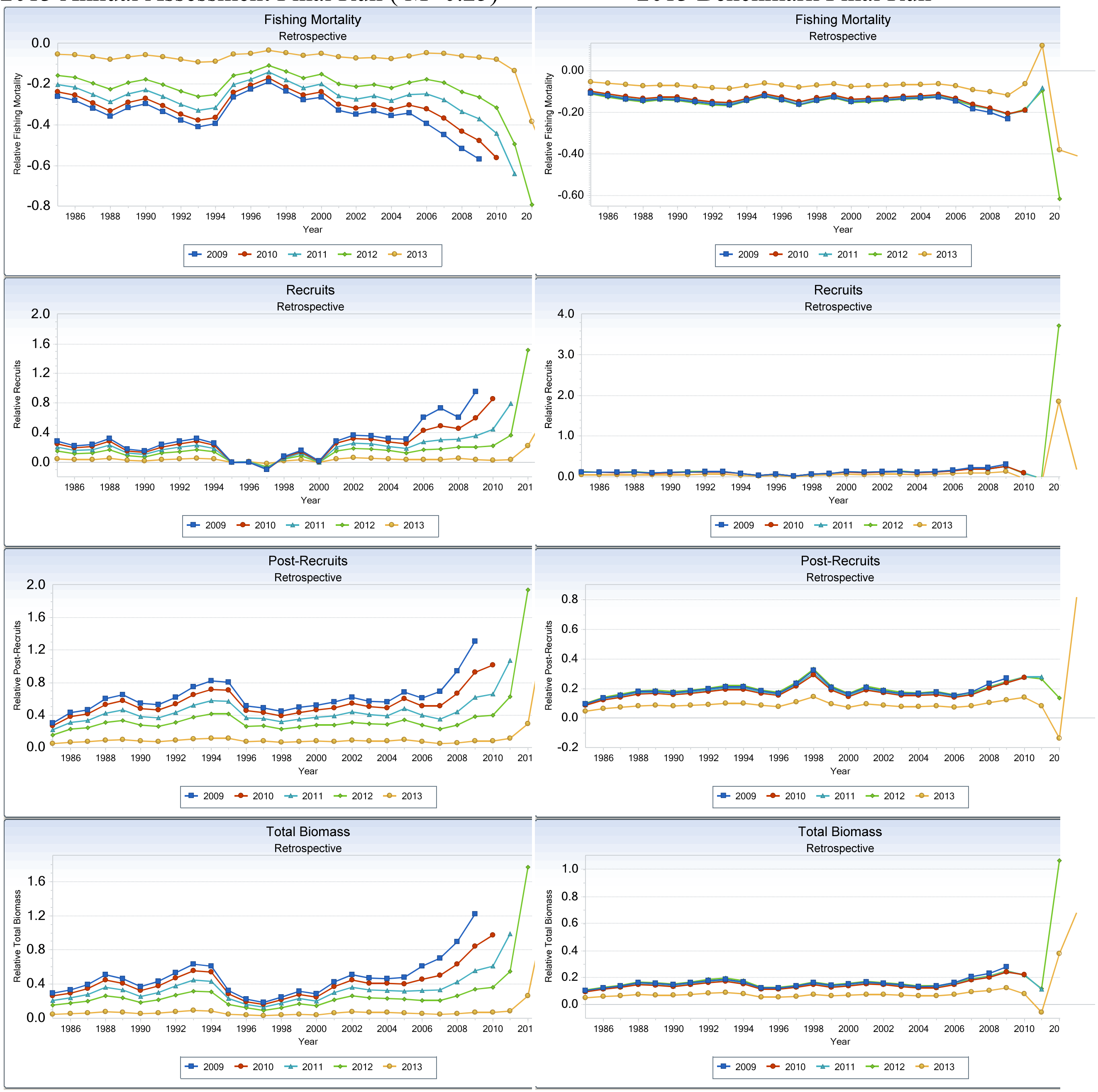


Figure C6.40, continued. Relative retrospective patterns for 2013 annual assessment update final run implemented in CSA ver. 4.2.2 and benchmark final run.

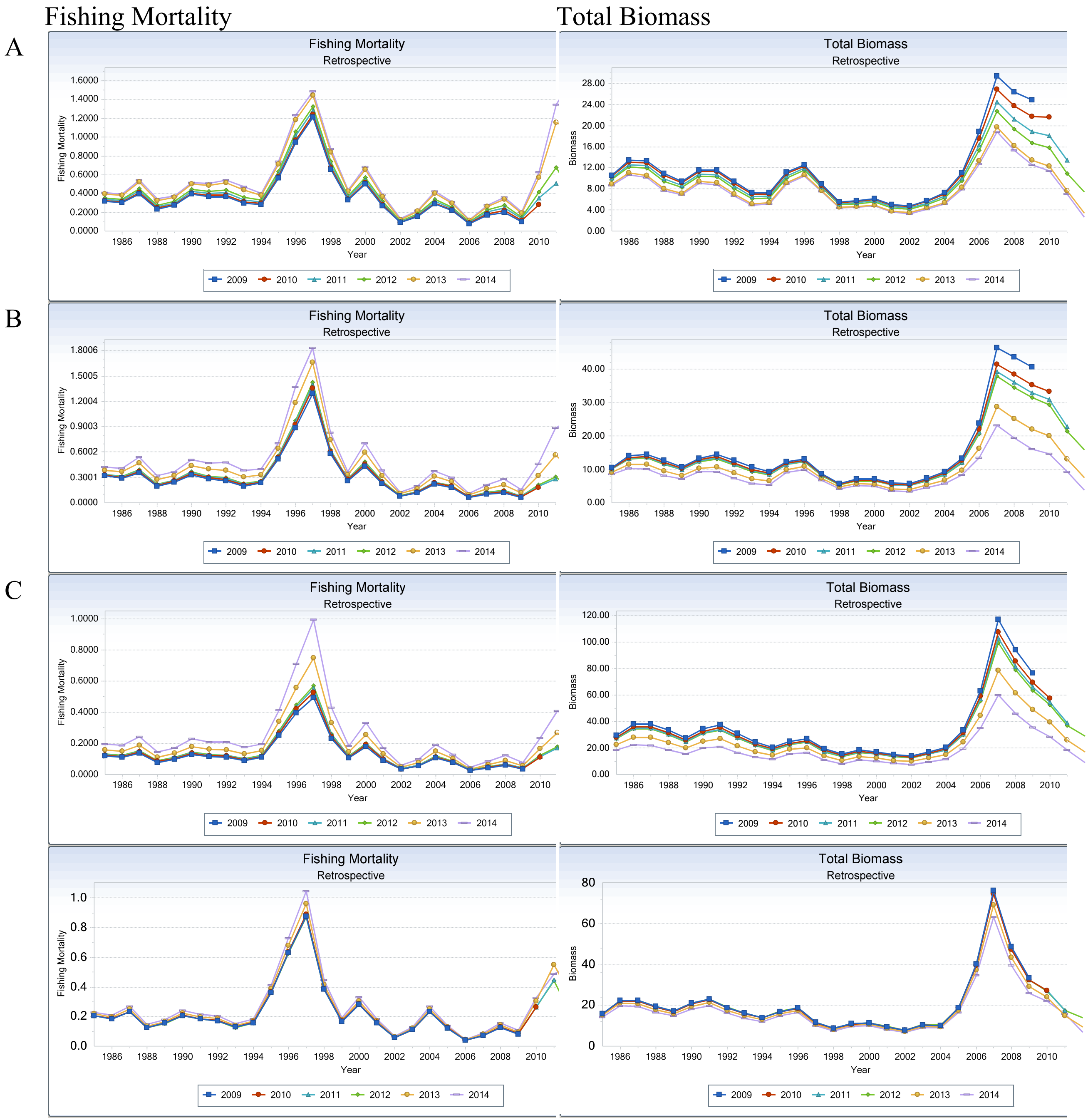


Figure C6.41. Retrospective patterns for fishing mortality and total biomass from incremental changes to 2013 annual assessment model. A. Add fall surveys; B. use adjusted CVs; C. Change to constant M=0.5; D. apply PPI-scaled M.

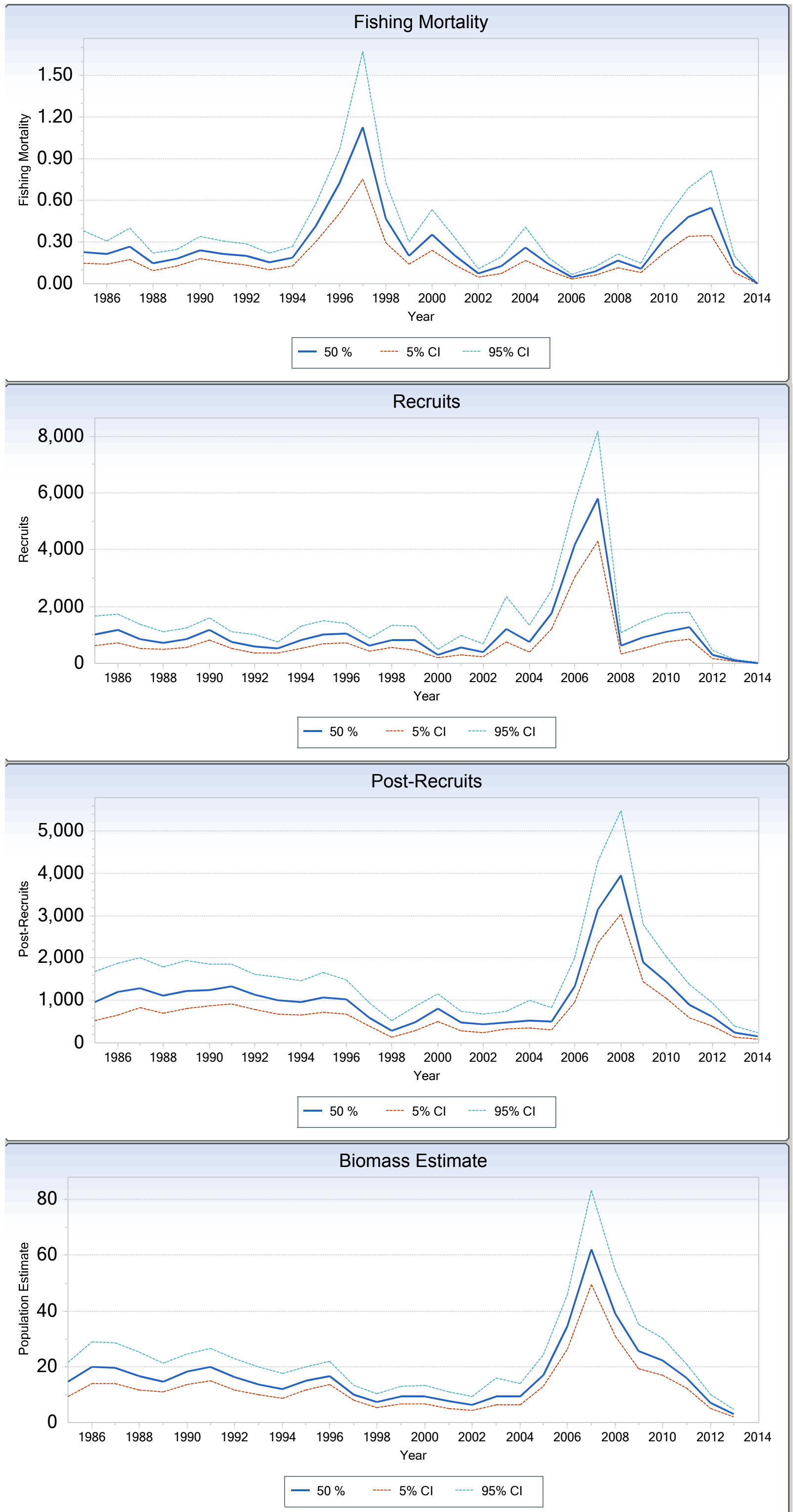


Figure C6.42. MCMC-generated 90% confidence intervals on estimates from final CSA model run.

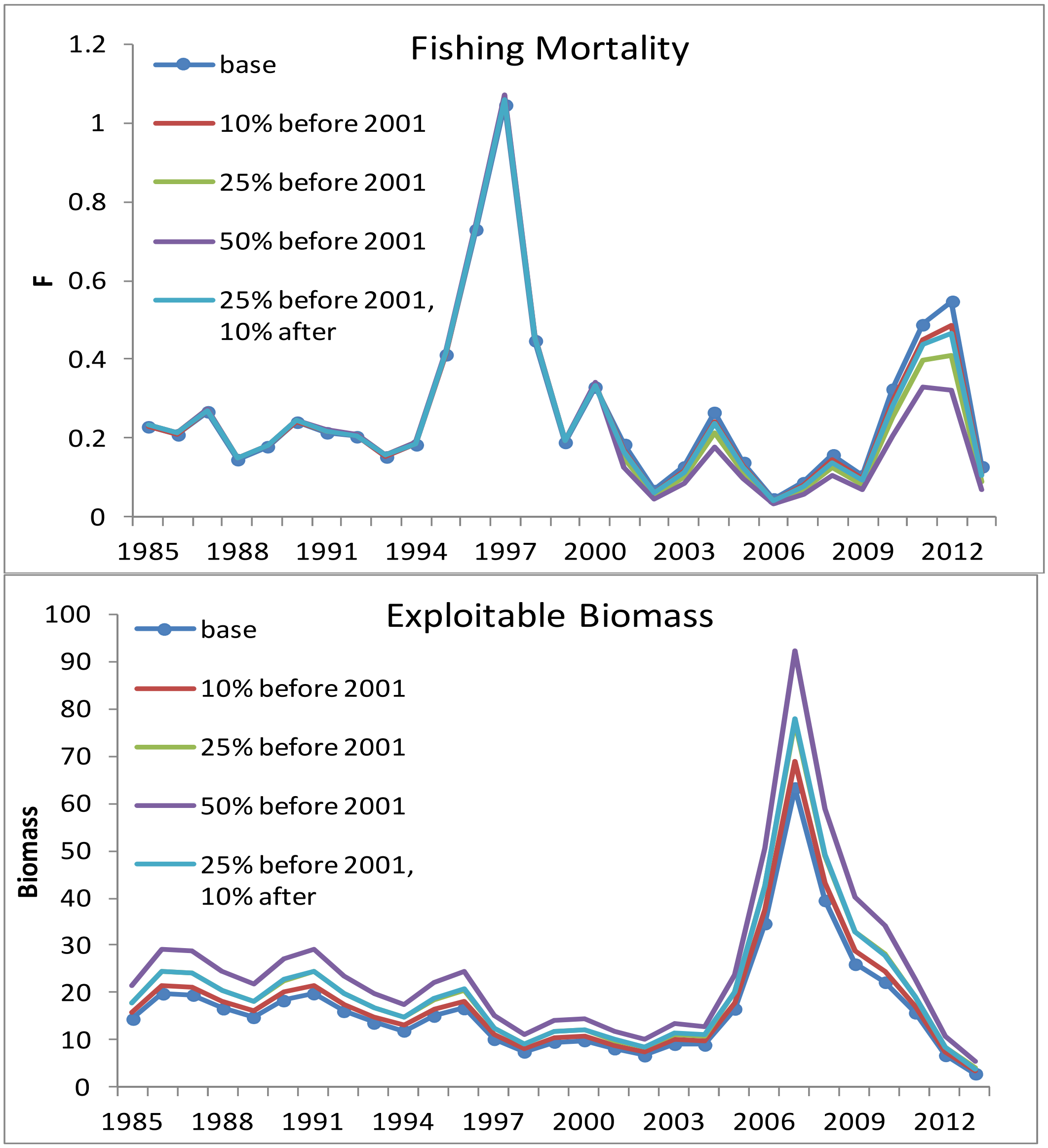


Figure C6.43. Effects on final CSA model estimates of different assumptions on under-reporting of catch. Base assumes no under-reporting.

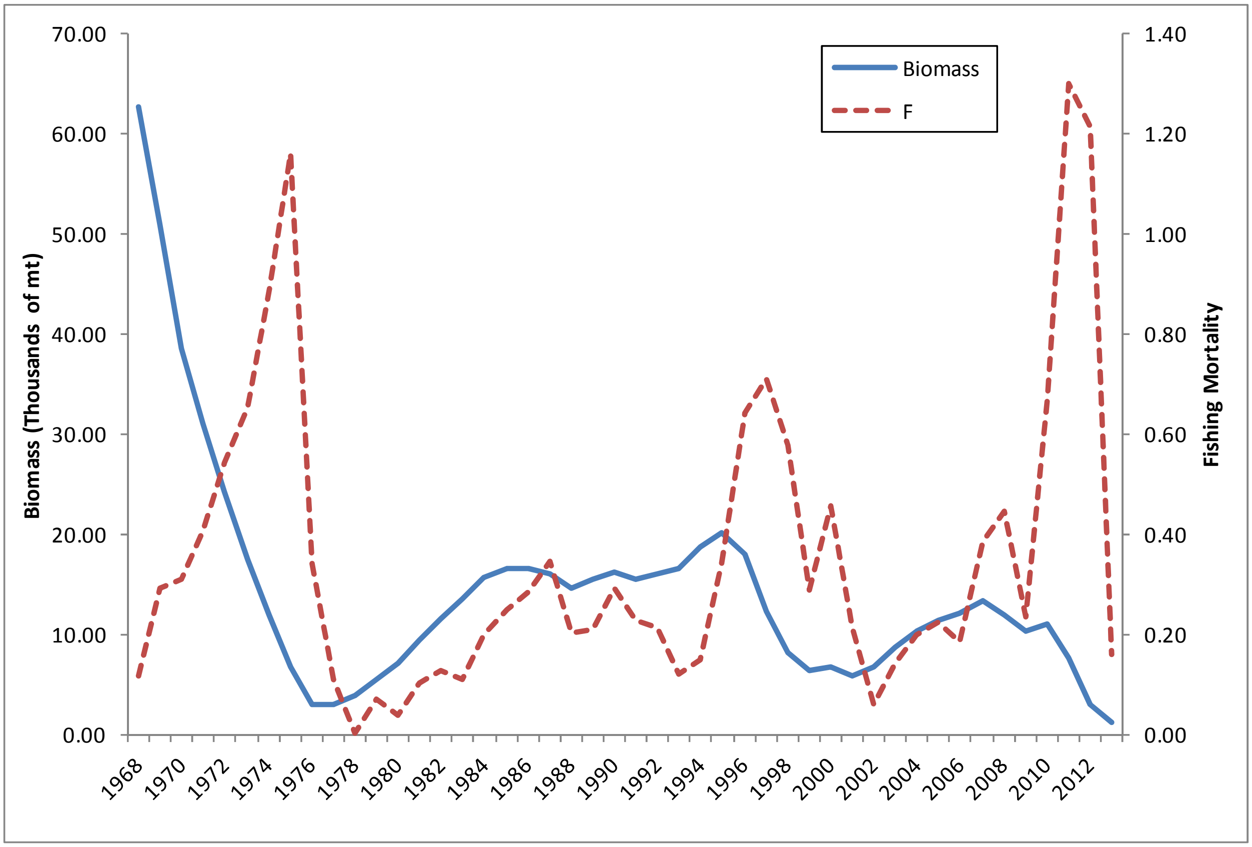


Figure C6.44. Biomass and fishing mortality estimates from the ASPIC surplus production model.

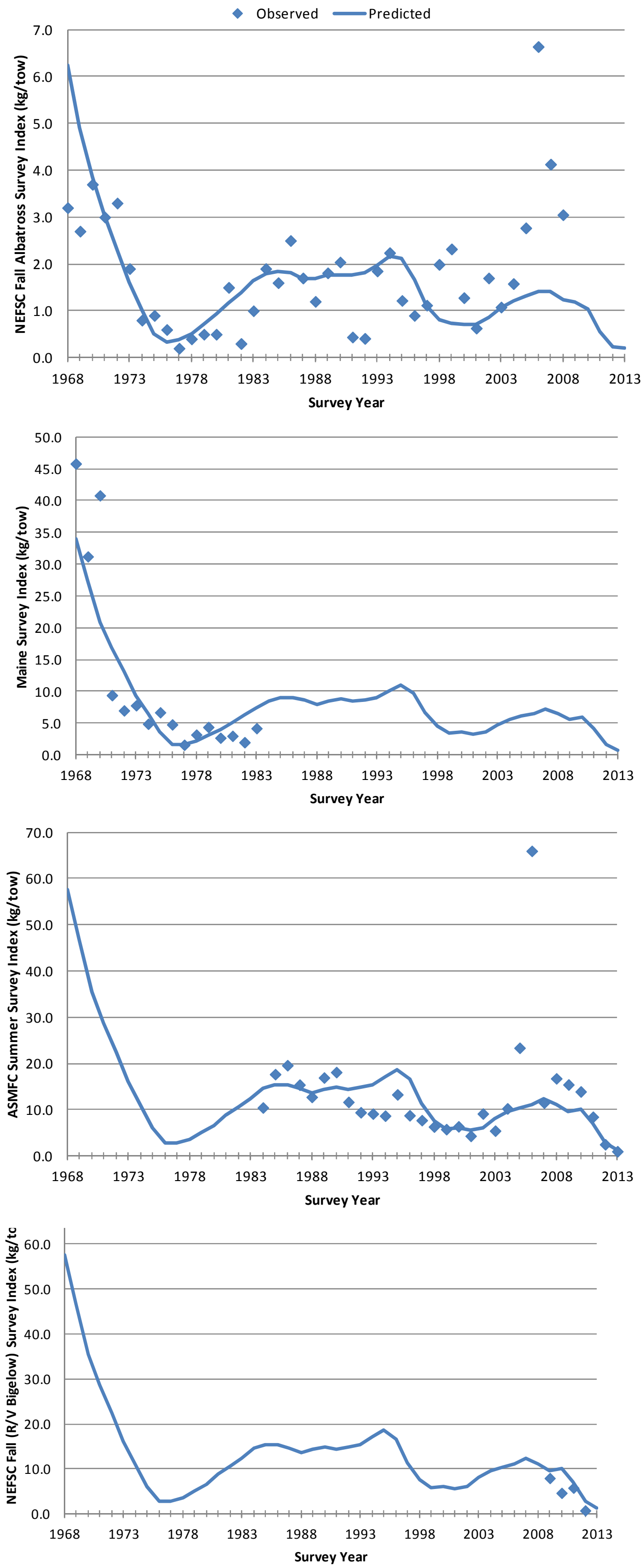


Figure C6.45. Observed and predicted survey values from the ASPIC model.

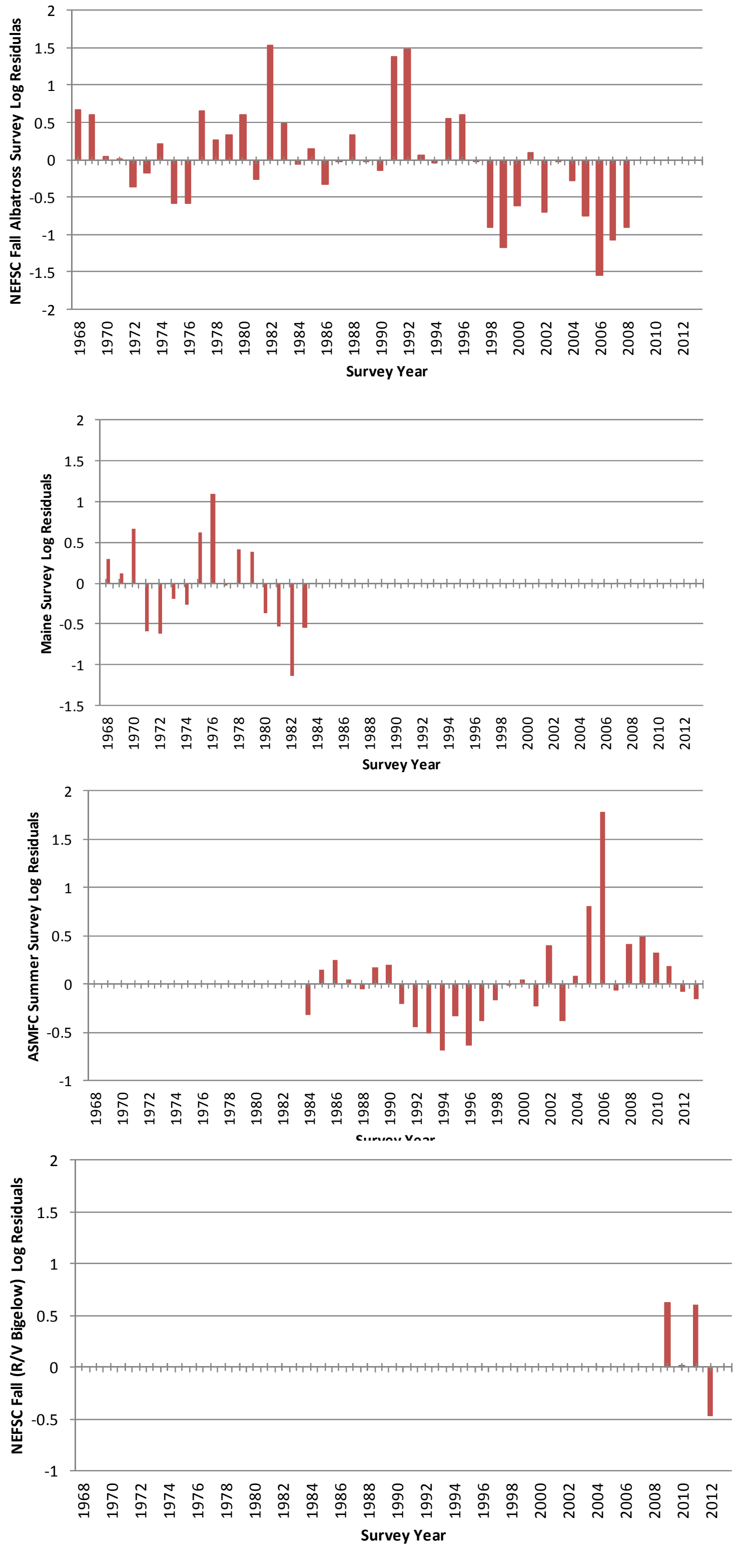


Figure C6.46. Survey residuals from the ASPIC model.

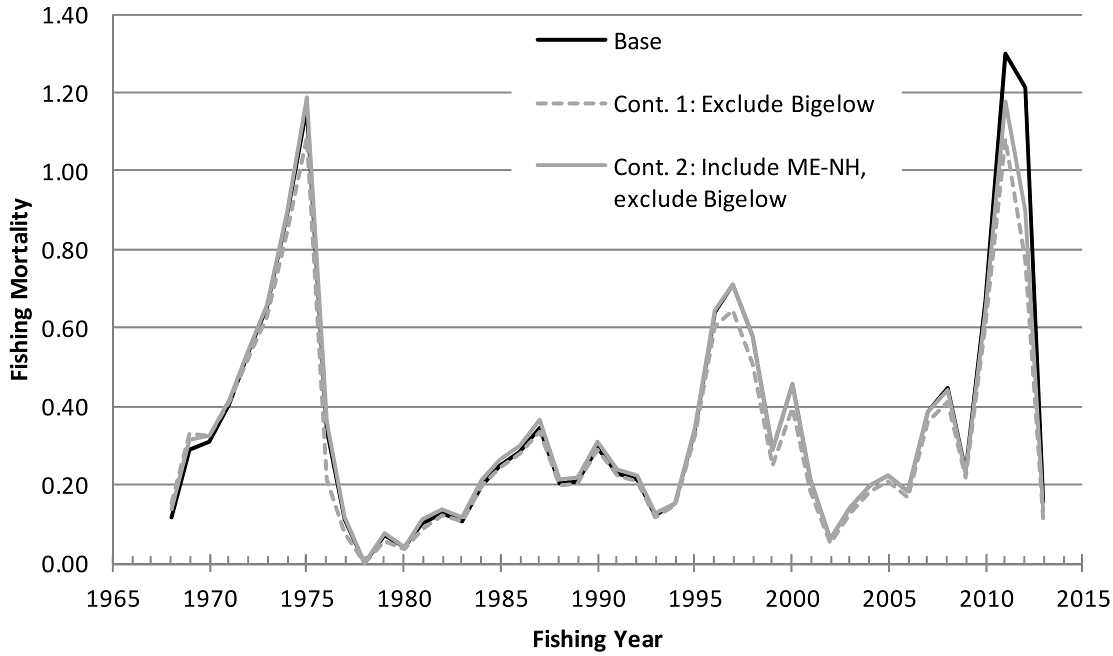


Figure C6.47. ASPIC fishing mortality estimates derived from continuity runs: 1.) excluding NEFSC fall survey conducted on R/V Bigelow (2009-2012), and 2.) including Maine-New Hampshire spring inshore survey (2003-2013) and excluding NEFSC R/V Bigelow fall survey (2009-2012).

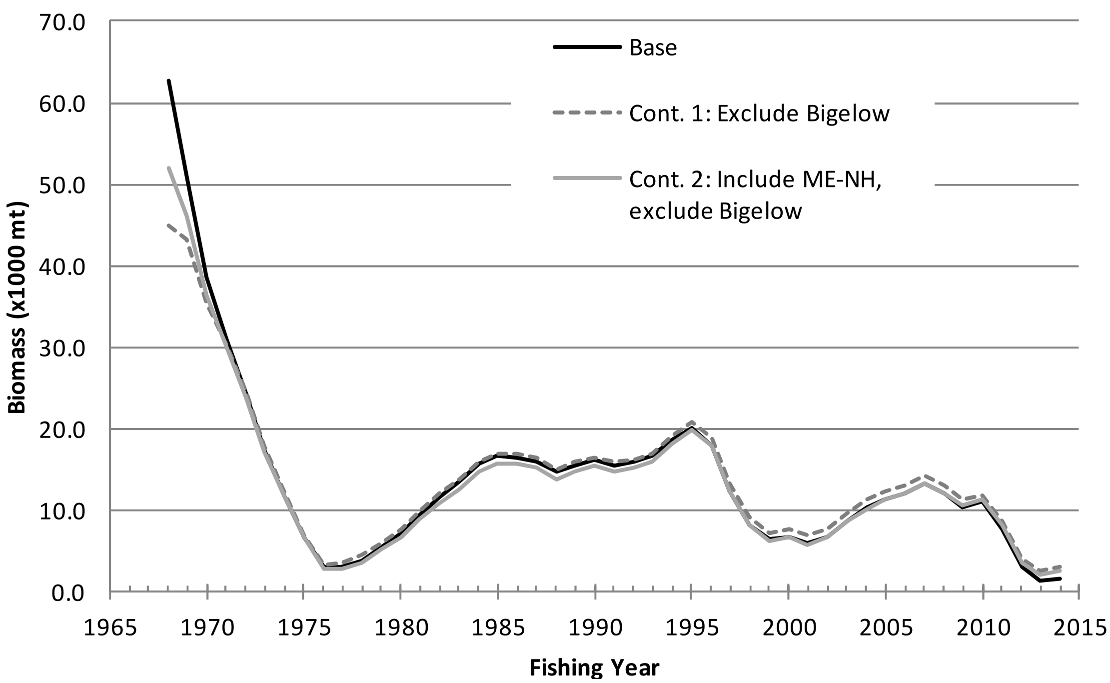
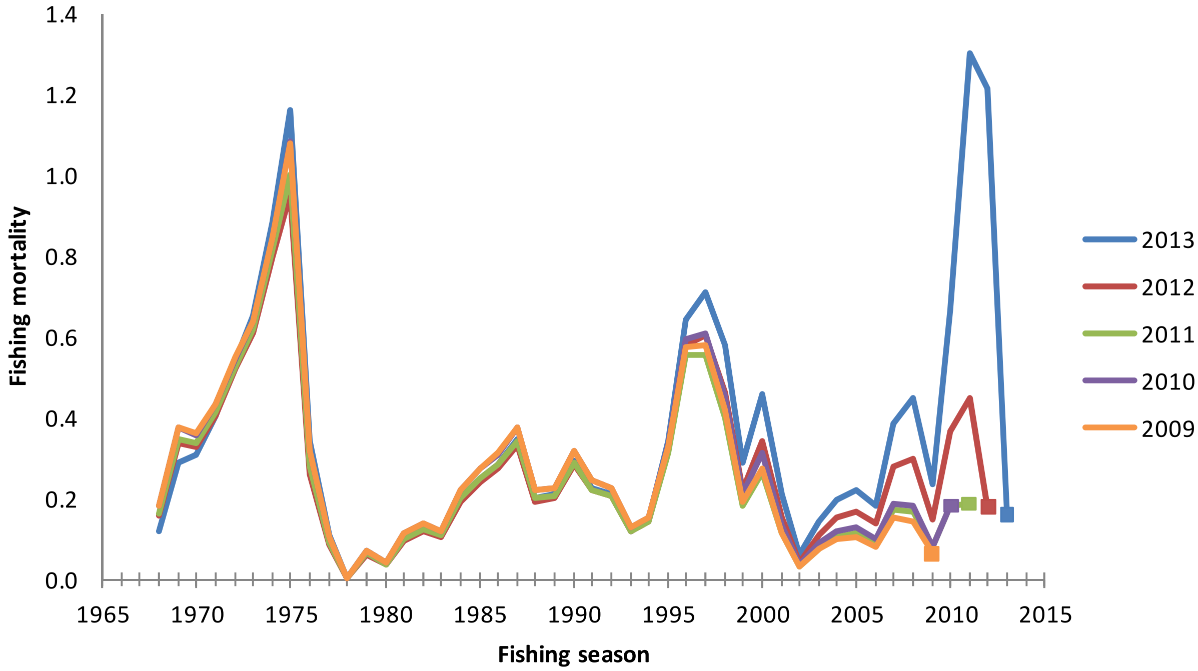


Figure C6.48. ASPIC biomass estimates derived from continuity runs: 1.) excluding NEFSC fall survey conducted on R/V Bigelow (2009-2012), and 2.) including Maine-New Hampshire spring inshore survey (2003-2013) and excluding NEFSC R/V Bigelow fall survey (2009-2012).



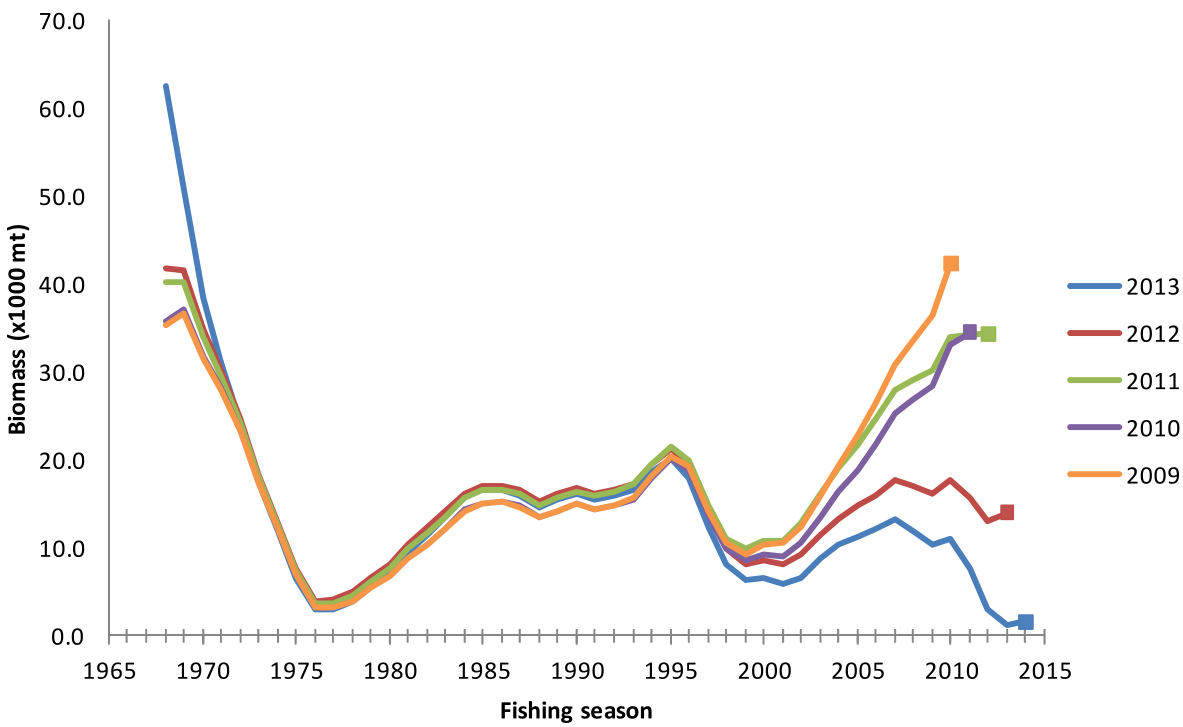


Figure C6.49. Retrospective pattern in fishing mortality (top) and biomass (bottom) from the ASPIC model.

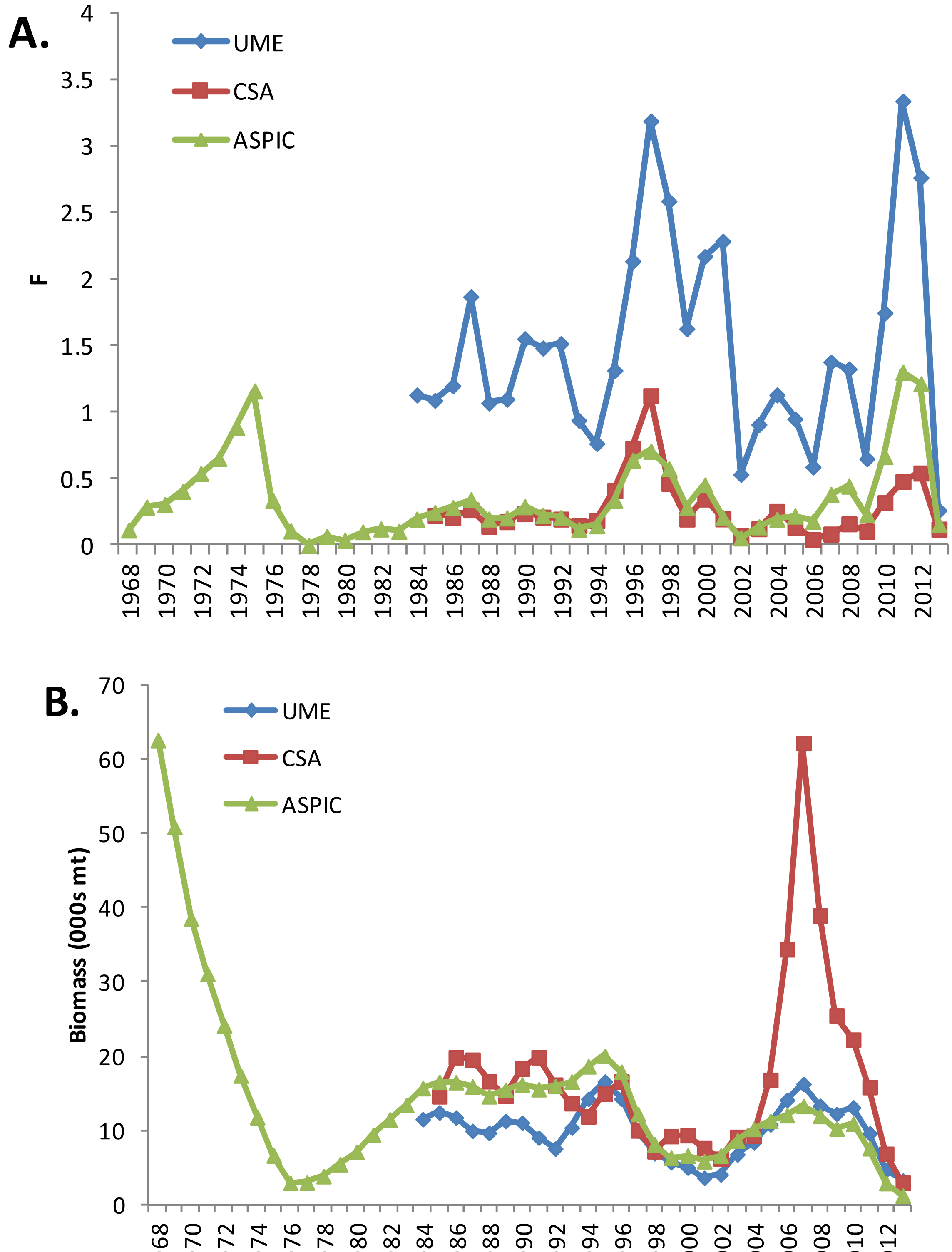


Figure C6.50. Comparison of model estimates of fishing mortality (A) and biomass (B).

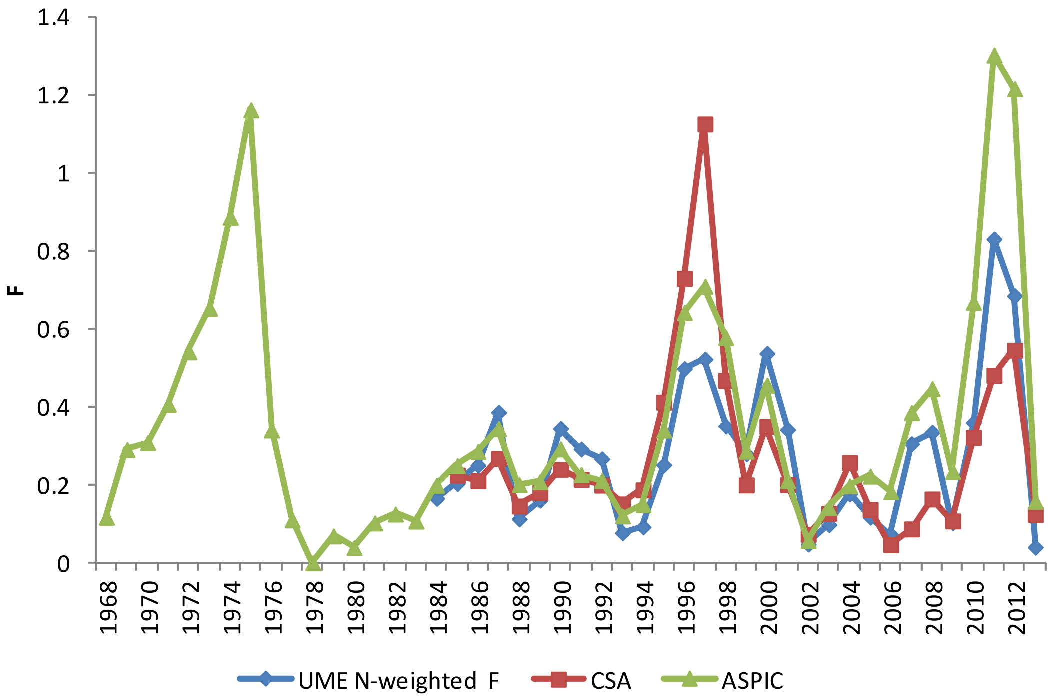


Figure C6.51. Comparison of N-weighted F from UME model with F estimates from CSA and ASPIC model.

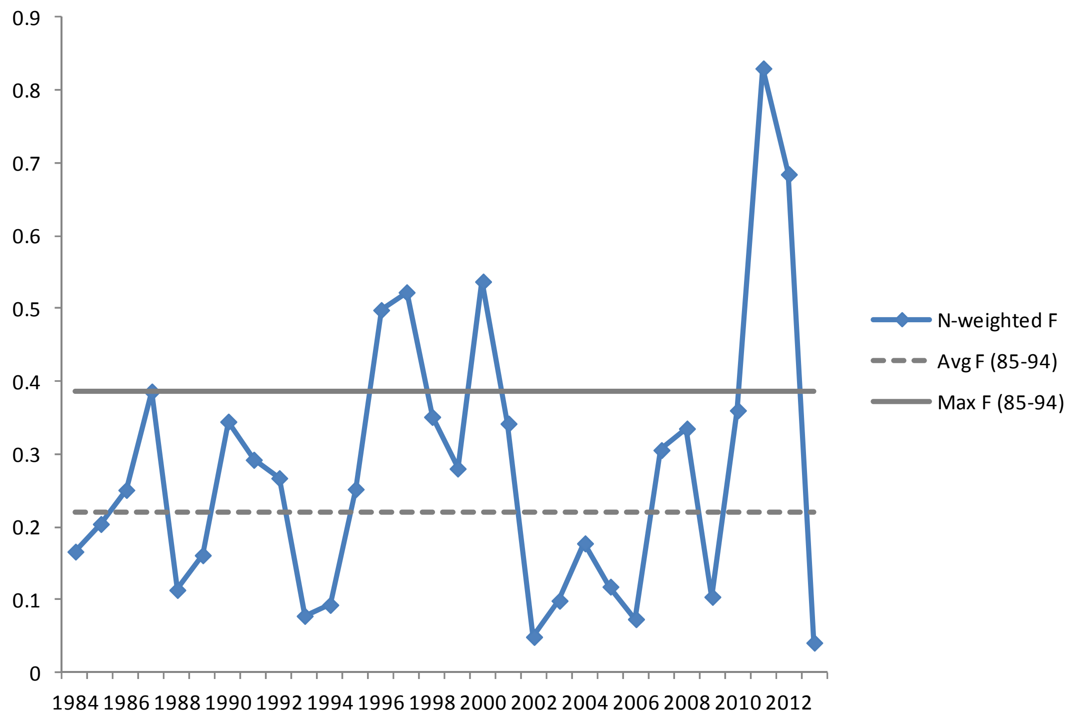


Figure C7.1A. N-weighted F from the UME model plotted with the historical proxy F_{target} (average F from 1985-1994, dashed line) and the $F_{threshold}$ (maximum F from 1985-1994, solid line).

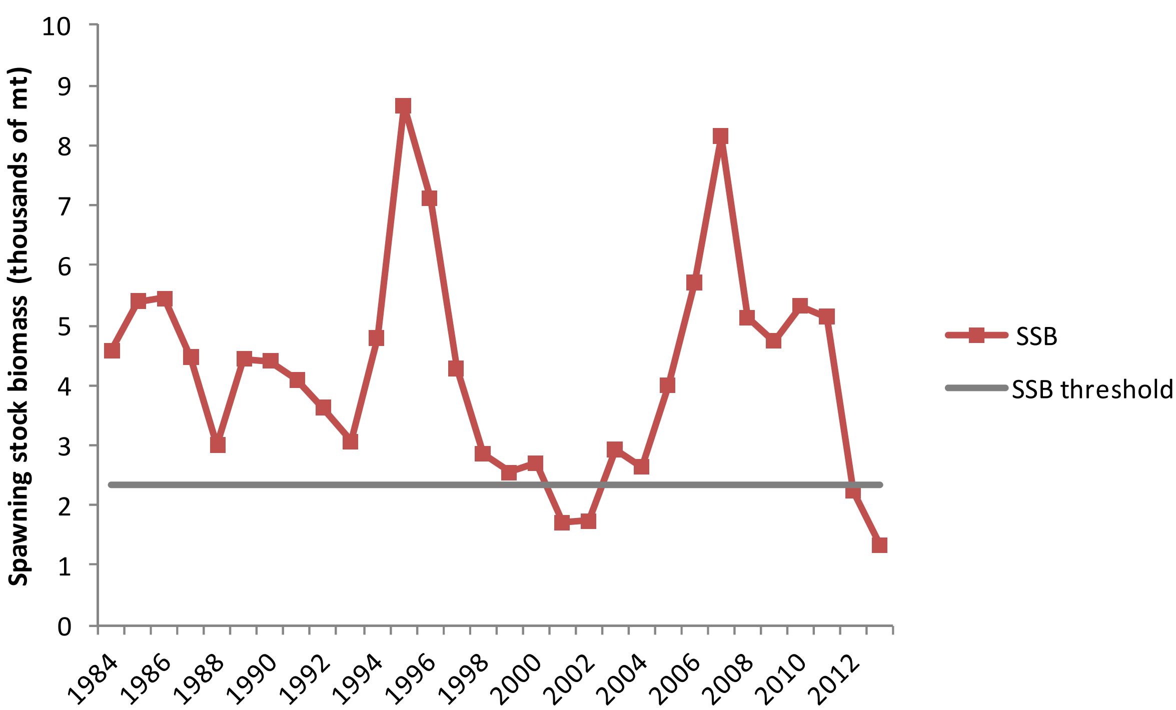


Figure C7.1.B. Spawning stock biomass from the UME model plotted with the historical SSB threshold (solid line).

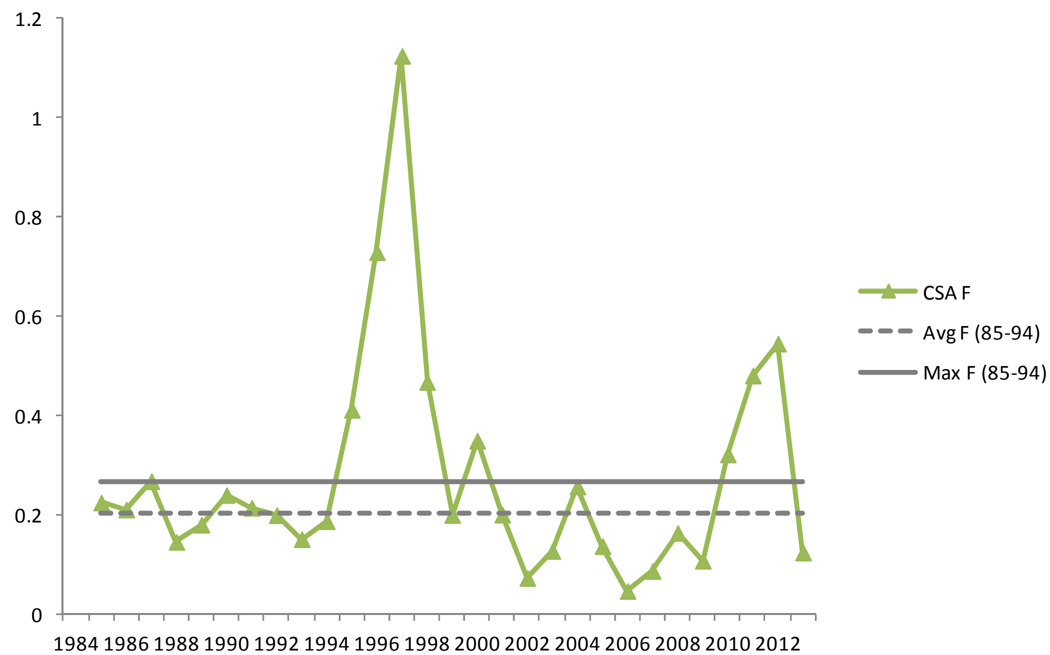


Figure C7.2.A. Fishing mortality estimates from the CSA model plotted with the historical proxy F_{target} (average F from 1985-1994, dashed line) and the $F_{threshold}$ (maximum F from 1985-1994, solid line).

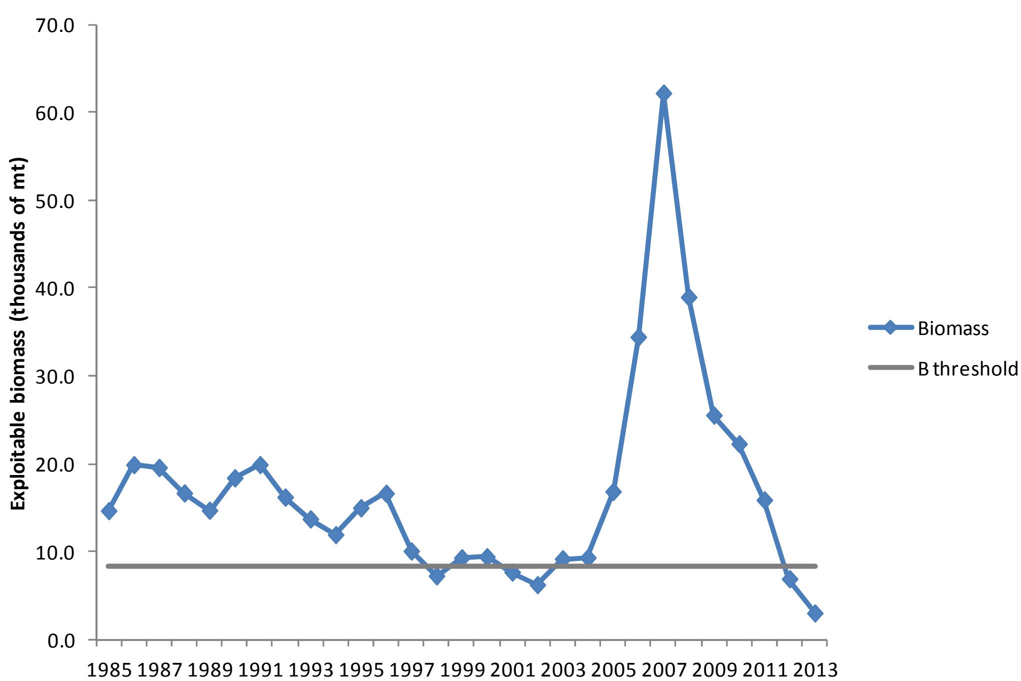


Figure C7.3.B. Exploitable biomass estimates from the CSA model plotted with the historical B threshold (solid line).

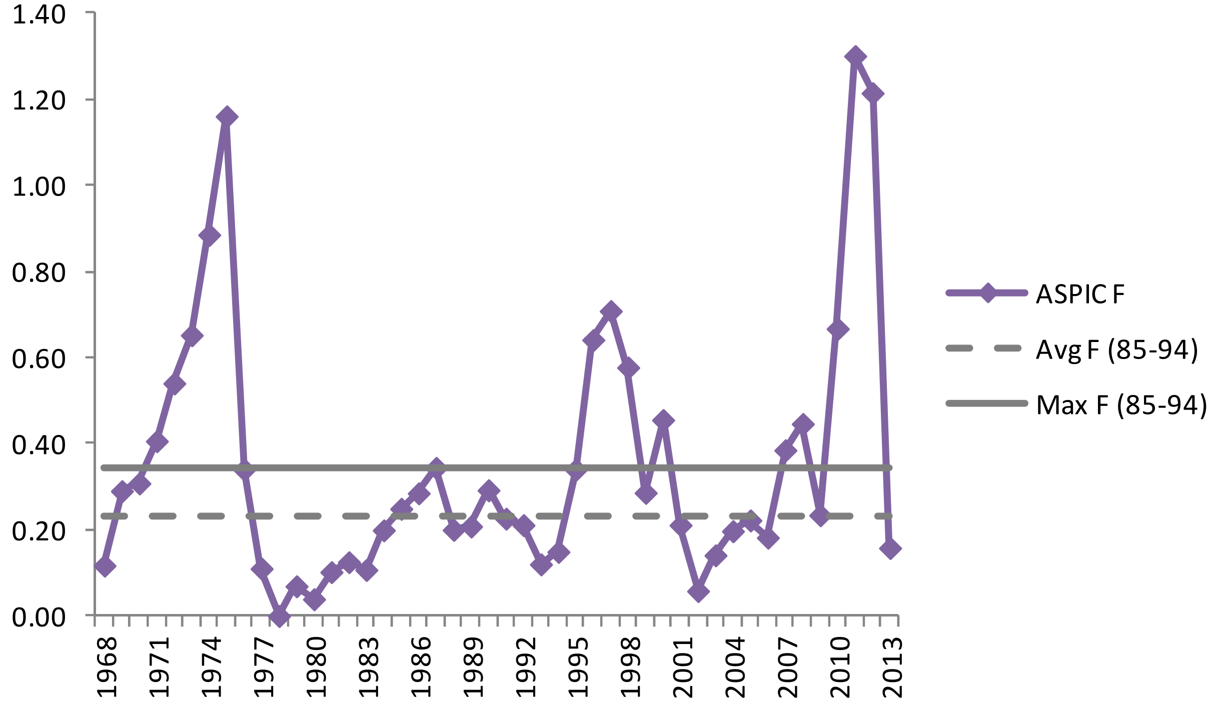


Figure C7.3. Fishing mortality estimates from the ASPIC model plotted with the historical proxy F_{target} (average F from 1985-1994, dashed line) and the $F_{threshold}$ (maximum F from 1985-1994, solid line).

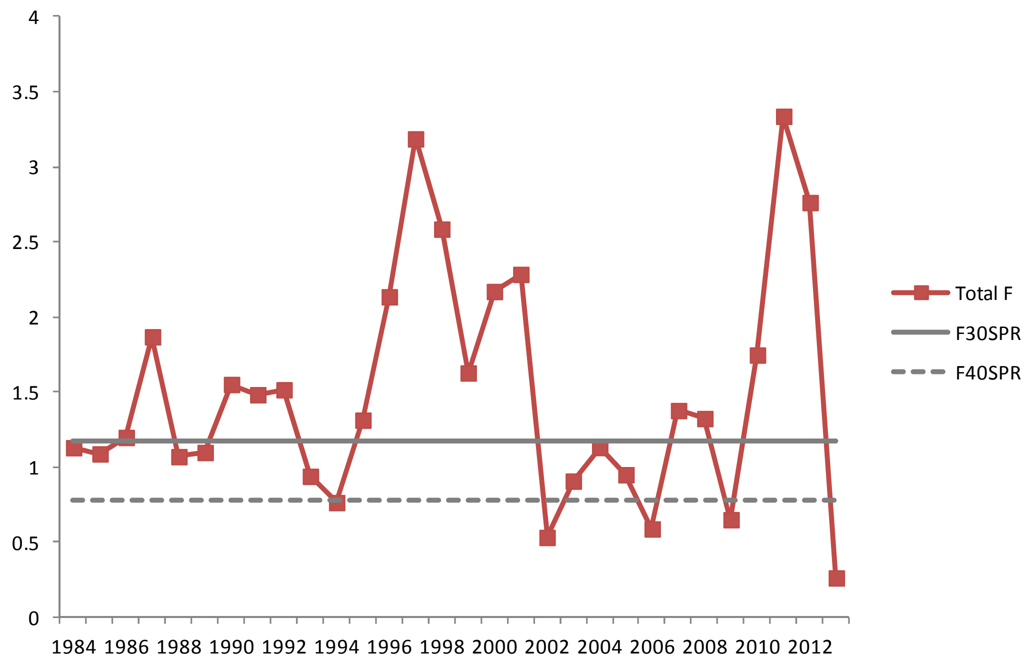


Figure C7.4. Total full F estimated from the UME model plotted with model-based reference points ($F_{30\%SPR}$, solid line, and $F_{40\%SPR}$, dashed line).

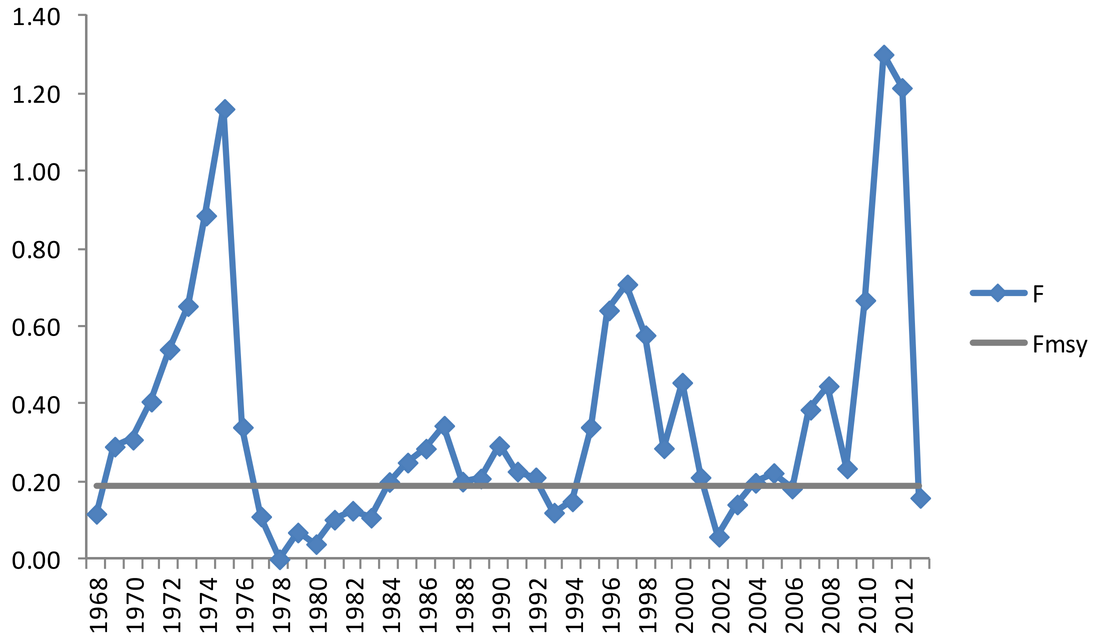


Figure C7.5.A. Fishing mortality estimates from the ASPIC model plotted with model-based reference points (F_{MSY}).

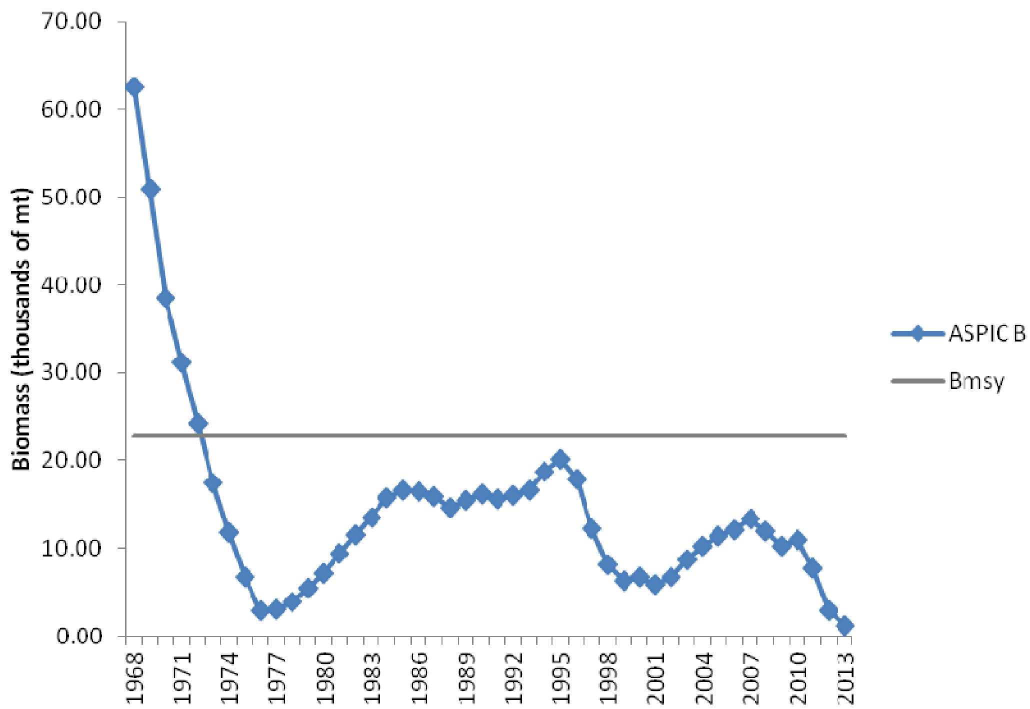


Figure C5.7.B. Biomass estimates from the ASPIC model plotted with model-based reference point (B_{MSY}).

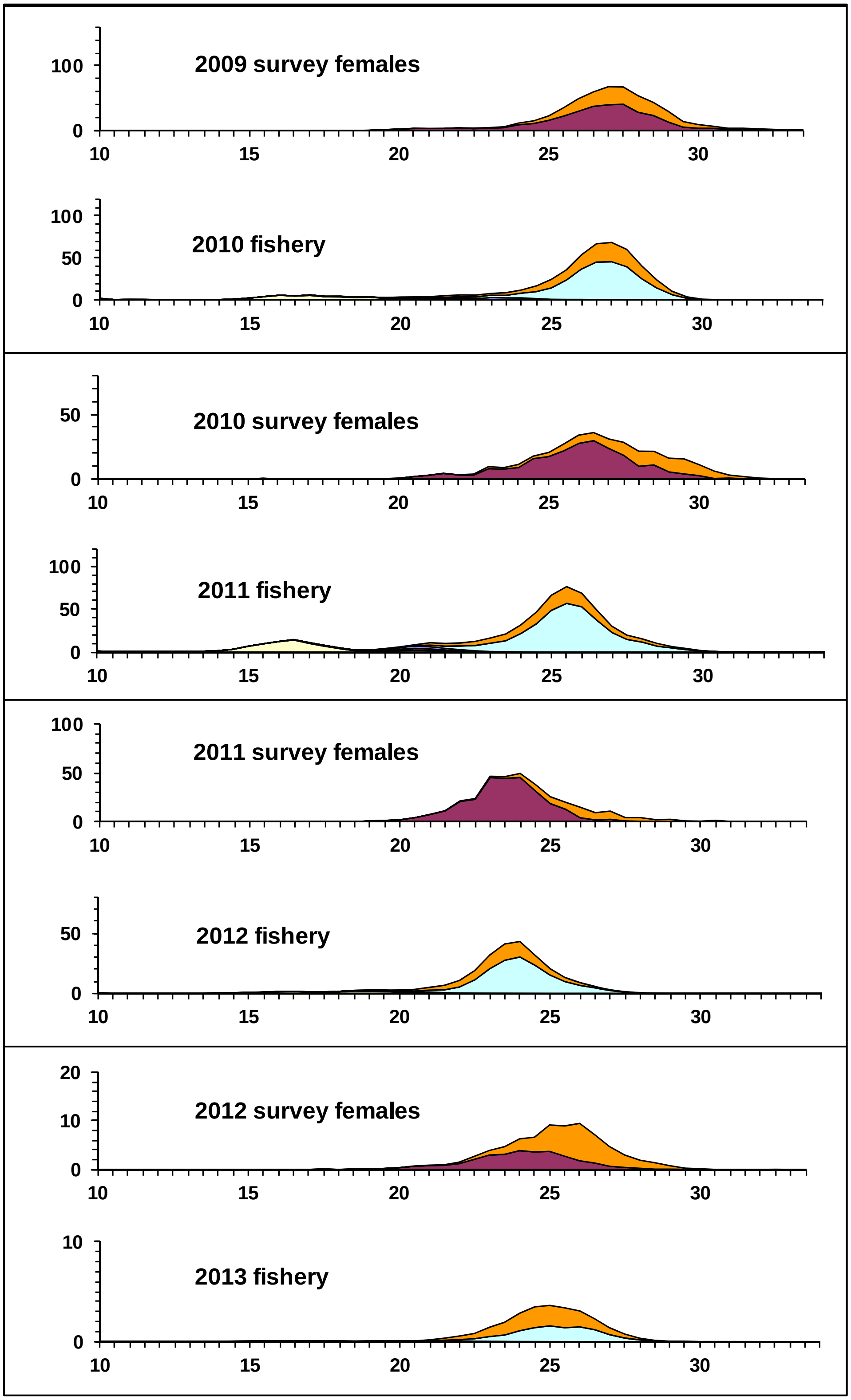


Figure C9.1. Length-frequency distributions of the female northern shrimp from the summer survey and of all sexes and stages in the fishery the following year.

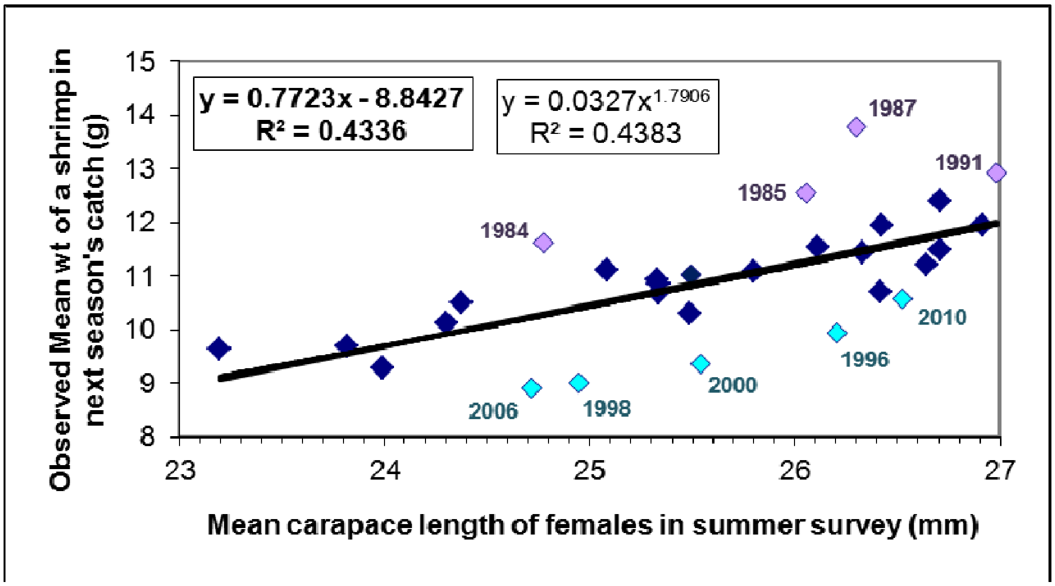


Figure C9.2. Linear relationship between the mean weight of a shrimp in the fishery landings (y) and the mean carapace length of female shrimp in the previous summer survey (x), for survey years 1984 to 2012. An exponential relationship is also calculated. Survey years in which the observed mean weight differs from predicted by more than 1 g (outliers) are indicated.

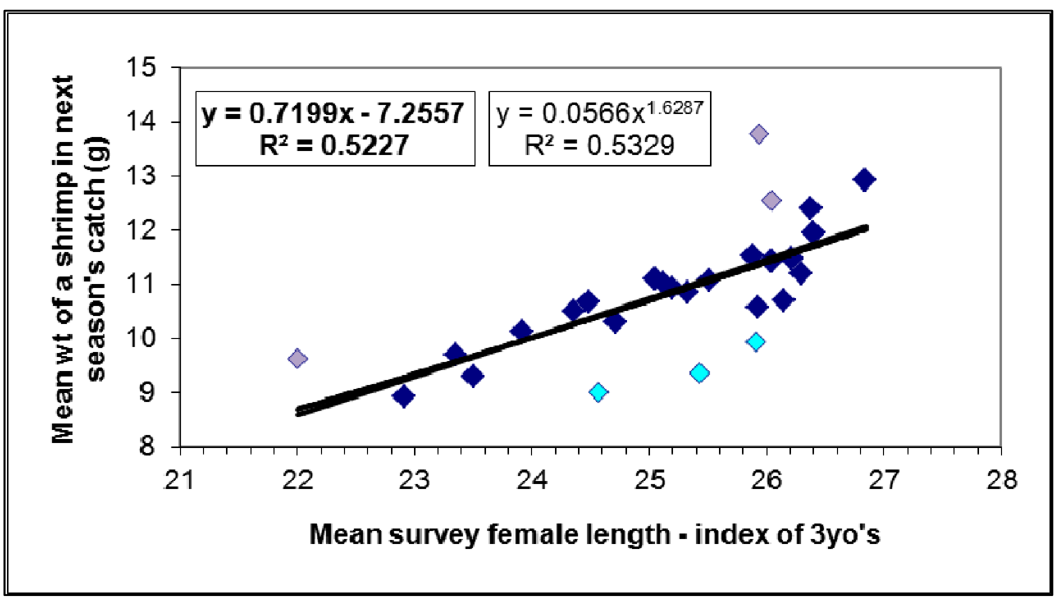


Figure C9.3. Linear relationship between the mean weight of a shrimp in the fishery landings (y) and the mean carapace length of female shrimp in the previous summer survey (x), corrected for the number of 3-y-o's, for survey years 1985 to 2012. An exponential relationship is also calculated. Observed mean weights differing from predicted by more than 1 g (outliers) are indicated.

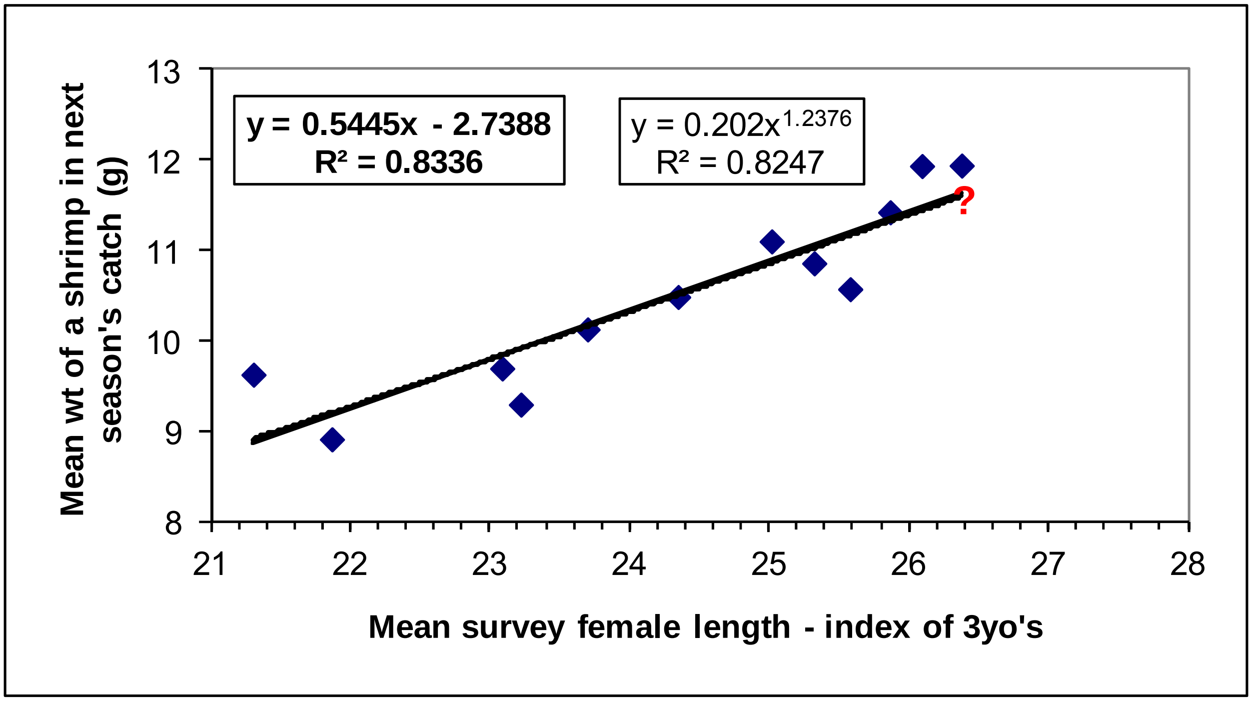


Figure C9.4. Linear relationship between the mean weight of a shrimp in the fishery landings (y) and the mean carapace length of female shrimp in the previous summer survey (x), corrected for the number of 3-y-o's, for survey years 2001 to 2012. An exponential relationship is also calculated. The predicted mean weight (g) of a shrimp in a 2014 fishery is indicated by "?".

Appendix C1. Technical Documentation and User's Guide for UMaine Northern Shrimp Size-Structured Assessment Model (UME SSAM) version 01

Introduction

Northern Shrimp Size-Structured Assessment Model (NS SSAM) is a size/stage-structured assessment model developed for the northern shrimp stock assessment. It contains a number of options that are described in this User's Guide. The technical documentation provides the basic equations used in the program along with the statistical methods used to develop fit different objective function to fit the model to data. The assessment program has two independent options for the modeling time step, annual and seasonal (season 1= January -March; season 2 = April-June; season 3 = July –September; and season 4 = October – December).

Basic Equations

The description of the model is for the seasonal time step. Models for the annual time step are similar (but simpler for many models). The calculation of the objective functions is described in the next section.

Natural mortality M

Weighted M

The weighted and seasonal M for shrimp of size bin *k*, in year *t*, season *m* is calculated as:

$$M_{k,t,m} = w_t \, w_k M_m \qquad (1)$$

where w_t is pre-specified annual weighting factor, w_k is pre-specified size weighting factor; and M_m is seasonal natural mortality which could be either pre-specified or estimated.

Lorenzen M

The natural mortality for shrimp of size bin *k*, in year *t*, season *m* is calculated:

$$M_{k,t,m} = M_{u,m} W_{k,t}^{b_m} \qquad (2)$$

where $M_{u,m}$ is the natural mortality at unit weight in season *m*; $W_{k,t}$ is the weight at size bin *k*, in year *t*; and b_m is allometric scaling factor. $M_{u,m}$ and b_m are treated as parameters.

Fishing mortality

Fishing mortality is assumed to be separable, meaning it is the product of a year effect (*Fmult*) and selectivity at size (*S*). The fishing mortality for a fleet *f*, year *t*, season *m*, and size bin *k* is calculated as:

$$F_{f,m,t,k} = Fmult_{f,m,t} S_{f,b,k} \qquad (3)$$

The *Fmult* for a fleet *f*, year *t* and season *m* is determined by two sets of parameters, $Fmult_{f,m,1}$, the parameter for first year and each season for that fleet, and $FDev_{f,m,t}$, the deviation of the parameter from the value in the first year for that fleet. Both sets of parameters are estimated in log space:

$$\log(Fmult_{f,m,t}) = \log(Fmult_{f,m-1,t}) + \log(FDev_{f,m,t}) \qquad (4)$$

For a given fleet, multiple time blocks could be specified to allow for time dependence. Within each selectivity block, there are four options/functions for estimating selectivity ($S_{f,b,k}$):

1. estimate parameters for each size bin (one parameter for each size bin)
2. logistic function (2 parameters: a, b)

$$S_{f,b,k} = \frac{1}{1+\exp(b_{f,b}(a_{f,b} - L_k))} \qquad (5)$$

3. double logistic (4 parameters: a, b, c, d)

$$S_{f,b,k} = \frac{1}{1+\exp(b_{f,b}(a_{f,b}-L_k))}(1-\frac{1}{1+\exp(d_{f,b}(c_{f,b}-L_k))}) \quad (6)$$

4. double normal (4 or 6 parameters, details could be found in Methot Jr, Richard D., and Chantell R. Wetzel. "Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management."*Fisheries Research* (2012).)

Note for option 2, 3 and 4, the selectivity at size is divided by the maximum value over all size bins for scaling, making the re-scaled selectivity vector having a maximum value of 1.0 for the defined time block.

Recruitment

Recruitment is modeled as the product of annual recruitment and the proportion of the annual recruitment (R_t) that recruits to each season (λ_m) and each size-class (λ_k):

$$R_{m,t,k} = R_t \lambda_k \lambda_m \quad (7)$$

The proportion of the recruitment in each pre-defined size-class can either be pre-specified or estimated along with the other parameters of the model. The proportion of the recruitment in each season is pre-specified.

Annual recruitment

There are three options to estimate annual recruitment:

1. estimated as free parameters and modeled as:

   $$R_t = \overline{R}\, e^{RDev_t} \quad (8)$$

   where $RDev_t$ is the recruitment deviation of year t from the expected R (*R_bar*) and treated as bounded parameters, meaning their sum is zero, so that they are centered on the expected R.

2. assumed to be temporally auto-correlated

   $$RDev_t = \sqrt{R_h}\, RDev_{t-1} + \sqrt{1-R_h}\, eps_t \quad (9)$$

   where R_h is the degree of autocorrelation between recruitments of the neighboring years, and eps_t is $RDev_t$ assuming there is no autocorrelation. R_h and eps_t are parameters.

3. related to spawning stock biomass according to a stock-recruitment relationship (B-H or Ricker)

   $$\overline{R}_t = \frac{\alpha SSB_t}{\beta + SSB_t} \quad (10)$$

   or

   $$\overline{R}_t = \alpha SSB_t e^{-\beta SSB_t} \quad (11)$$

   where α and β are parameters and SSB_t is the spawning stock biomass of year t.

Initial conditions

The numbers-at-size at the start of the first year which specifies the state of population when model starts could be specified by eight options:

0. estimate parameters for each size-class
1. pre-specified proportions-at-size (Pia_k) and estimate the total numbers (N) for the first year, the numbers-at-size is calculated as:

   $$N_k = Pia_k N \quad (12)$$

2. pre-specified proportions-at-size (Pia_k) and estimate the total numbers (N) for the first year, the numbers-at-size is calculated as:

$$N_k = \frac{e^{Pia_k}}{1+e^{Pia_k}} N \quad (13)$$

3. assume proportions-at-size (Pia_k) follows a log-normal distribution with mean μ and standard deviation σ and calculated as:

$$Pia_k = \frac{1}{\sqrt{2\pi}\sigma L_k} \exp(-\frac{(\ln(L_k)-u)^2}{2(\sigma)^2}) \quad (14)$$

The numbers-at-size is calculated as option 1. N, μ, and σ are the parameters to be estimated.

4. assume proportions-at-size (Pia_k) follows a log-normal distribution as option 3 and the numbers-at-size is calculated as option 2 (3 parameters: N, μ, and σ).
5. assume proportions-at-size (Pia_k) follows a normal distribution with mean μ and standard deviation σ and calculated as:

$$Pia_k = \frac{1}{\sqrt{2\pi}\sigma} \exp(-\frac{(L_k-u)^2}{2(\sigma)^2}) \quad (15)$$

The numbers-at-size is calculated as option 1. N, μ, and σ are the parameters to be estimated.

6. assume proportions-at-size (Pia_k) follows a normal distribution as option 5 and the numbers-at-size is calculated as option 2 (3 parameters: N, μ, and σ).
7. assume proportions-at-size (Pia_k) follows a mixture normal distribution consists of three normal distributions to account for multiple peaks:

$$Pia_k = \pi_1 f_1(L_k) + \pi_2 f_2(L_k) + \pi_3 f_3(L_k) \quad (16)$$

where $\pi_1+\pi_2+\pi_3=1$, $f_1(L)$, $f_2(L)$ and $f_3(L)$ have a normal form but have different means and variances. The numbers-at-size is calculated as option 1. There are nine parameters in this case, N, μ_1, σ_1, μ_2, σ_2, μ_3, σ_3, π_1, and π_2.

Note for options 3-7, the proportion at size is divided by the summation value over all size bins, resulting in the final proportion vector having the summation of 1.

Growth

Growth transition matrix, determining the probability of an average shrimp growing from a size class into other size-classes, is required in size-based models. NSLSAP allows time dependence in growth transition matrix by setting time blocks (maximum number of time blocks could be the number of time-steps, meaning that time-step specific growth transition matrix could be specified). There are two options for growth transition matrix:

1. estimated externally and pre-specified as inputs
2. derived from VBGF model, estimate VBGF parameters (5 parameters) along with other model parameters

The expected growth increment during a time-step (season) is assumed to follow a normal distribution with mean and variance calculated as:

$$E(\Delta L_m) = (L_{\infty,b} - L_k)(1.0 - e^{-\alpha_m K_b}) \quad (17)$$

$$Var(\Delta L_m) = Var(L_{\infty,b})(1-e^{-\alpha_m K_b})^2 + \alpha_m^{\ 2}(L_{\infty,b}-L_k)^2 Var(K_b) e^{-2\alpha_m K_b} + 2\rho_b \alpha_m SD(L_{\infty,b}) SD(K_b)(1-e^{-\alpha_m K_b})(L_{\infty,b}-L_k)e^{-\alpha_m K_b} \quad (18)$$

where $L_{inf,\,b}$, K_b, standard deviation of $L_{inf,\,b}$, K_b, and correlation between $L_{inf,\,b}$, K_b (ρ) are the five parameters could be estimated for a given time block (b). α_m is a input proportion used for partitioning the growth within a year. If α_m=1, the five parameters are seasonal specific, otherwise, they are annual specific and the annual growth is partitioned according to the pre-specified proportion vector (α_m).

If d_{low} and d_{up} are the lower and upper ends of size class d, the probabilities of a shrimp growing from size class k to size class d can be computed as:

$$P_{k->d} = \int_{dlow}^{dup} f(x \mid E(\Delta L), Var(\Delta L))dx \tag{19}$$

More detailed description could be found in Chen et al.2003.

Population dynamics

The number of shrimp in size bin k at the beginning of year t and season m is calculated as:

$$N_{k,t,m} = N_{k,t,m-1} SV_{k,t,m-1} G_{k,m-1} + R_{k,t,m} \tag{20}$$

$G_{k,m-1}$ is the growth transition matrix in the previous season; $R_{k,t,m}$ is the recruitment of year t that recruits to season m and size-class k; and $SV_{k,t,m-1}$ is the survival rate for shrimp in size bin k in previous season year t, and calculated as:

$$SV_{k,t,m} = \exp\left(-\left(\sum_f \left(F_{f,m,t,k}\right) + M_{m,t,k}\right)\right) \tag{21}$$

where $F_{f,m,t,k}$ and $M_{m,t,k}$ could be found in the sections of ***Fishing mortality*** and ***Natural mortality***, respectively.

Stock biomass

Weight-at-size

The weight of a shrimp in size-class k, year t is calculated as:

$$\log\left(W_{t,k}\right) = a_t + b_t \log\left(L_k\right) \tag{22}$$

where a_t and b_t are inputs.

Maturity-at-size

The proportion of matured shrimp for a size-class k, year t is calculated by a logistic function as:

$$Pm_{t,k} = \frac{G}{1+\exp\left(-K_t\left(L_k - L_{50\%,t}\right)\right)} \tag{23}$$

where G_t, K_t and $L_{50\%,t}$ are inputs.

Sex change

Sex change is assumed to be length-dependent and the proportion of shrimps that change sex to female in a given year is modeled by a logistic function:

$$Ps_{t,k} = \frac{1}{1+\exp\left(-\frac{2\log(3)}{R_{sex}}\left(L_k - L_{50\%,t}\right)\right)} \tag{24}$$

where $L_{50\%,t}$ and R_{sex} are two sets of parameters to be estimated.

The female biomass for year t could be calculated as:

$$B_t^f = \sum_k N_{t,k} W_{t,k} Ps_{t,k} \tag{25}$$

The non-female biomass for year t could be calculated as:

$$B_t^{nf} = \sum_k N_{t,k} W_{t,k} \left(1 - Ps_{t,k}\right) \tag{26}$$

Spawning stock biomass

The spawning stock biomass is calculated based on the population abundance at size (*N*), the weight at size (*W*), proportion of maturity at size (*Pm*), proportion of female at size (*Ps*), and the proportion of the total mortality during the year prior to spawning (p_{SSB}) as:

$$SSB_t = \sum_k N_{t,k} e^{-p_{SSB} Z_{t,k}} W_{t,k} Pm_{t,k} Ps_{t,k} \quad (27)$$

Predicted catch

Predicted landings in units of numbers of shrimp for each fleet, year, season and size-class are derived from the Baranov catch equation:

$$C^{pred,n}_{f,m,t,k} = \frac{F_{f,m,t,k}}{F_{f,m,t,k} + M_{m,t,k}} (1 - \exp(-(F_{f,m,t,k} + M_{m,t,k}))) N_{t,k,m} \quad (28)$$

Predicted landings in weight for each fleet, year, season and size-class are calculated:

$$C^{pred,n}_{f,m,t,k} = \frac{F_{f,m,t,k}}{F_{f,m,t,k} + M_{m,t,k}} (1 - \exp(-(F_{f,m,t,k} + M_{m,t,k}))) N_{t,k,m} W_{t,k} \quad (29)$$

Catchability

Fishery catchability

Time blocks could be set up for fishery catchability, within a block (*b*), the fishery catchability for fleet *f* and season *m* is calculated internally as:

$$\ln(q_{f,m,b}) = \frac{1}{n_b} \sum_b \ln\left(\frac{CPUE^{Obs}_{f,m,t}}{(B^{exploit}_{f,m,t})^{E_{f,m,b}}}\right) \quad (30)$$

or

$$\ln(q_{f,m,b}) = \ln\left(\frac{1}{n_b} \sum_b \left(\frac{CPUE^{Obs}_{f,m,t}}{(B^{exploit}_{f,m,t})^{E_{f,m,b}}}\right)\right) \quad (31)$$

where $CPUE^{obs}_{f,m,t}$ is the observed CPUE for fleet *f*, year *t*, and season *m*; n_b is the number of time block for a given fleet; $E_{f,m,b}$ is the power parameter accounting for the nonlinearity; $B^{exploit}_{f,m,t}$ is calculated as:

$$B^{exploit}_{f,m,t} = \sum_k \overline{N}_{m,t,k} S_{b,k} W_{t,k} \quad (32)$$

$$\overline{N}_{m,t,k} = N_{m,t,k} \frac{1 - e^{-(\sum_f F_{f,m,t,k} + M_{m,t,k})}}{\sum_f F_{f,m,t,k} + M_{m,t,k}} \quad (33)$$

Survey catchability

Survey catchability which is modeled similar as fleet catchability and calculated internally as:

$$\ln(q_{ind,b}) = \frac{1}{n_b} \sum_b \ln\left(\frac{I^{Obs}_{ind,t}}{B^{Survey}_{ind,t}}\right) \quad (34)$$

or

$$\ln(q_{ind,b}) = \ln\left(\frac{1}{n_b} \sum_b \frac{I^{Obs}_{ind,t}}{B^{Survey}_{ind,t}}\right) \quad (35)$$

where $I^{obs}_{ind,t}$ is the observed index for survey *ind*, and year *t*; n_b is the number of time block for a given survey. $B^{survey}_{ind,t}$ is calculated as:

$$B^{Survey}_{ind,t} = \sum_k N^{Survey}_{ind,t,k} W_{t,k} \quad (36)$$

$$N^{Survey}_{ind,t,k} = N_{ind,t,k} S_{ind,t,k} \quad (37)$$

where $S_{ind,t,k}$ is the selectivity of survey *ind*, year *t* and size-class *k*; N_{ind} could be found in the the section of ***Predicted indices*** below.

Predicted indices

The observed indices have two characteristics that are matched when predicted values are computed, the time of year of the index and the units (numbers or biomass). The estimated population numbers at size are modified to the time of the index according to:

$$N_{ind,t,k} = N_{t,k}\left(1-\exp\left(-(indmonth/12)Z_{t,k}\right)\right) \quad (38)$$

where *indmonth* refers to the end of the month, so *indmonth*=0 is January 1 and *indmonth*=12 is December 31. If the units for an index are biomass, then the N_{ind} values are multiplied by user defined weights at size matrix. The selectivity associated with each index is either matched to a fleet or modeled independently using the same way as the fleet selectivity (4 options: size based, logistic, double logistic or double normal). The final predicted index (I_{pred}) is formed by summing the product of N_{ind} and selectivity values (S) over the size classes and multiplying by the catchability (q) for the index:

$$Ipred_{ind,t} = q_{ind,t} \sum_k N_{ind,t,k} S_{ind,t,k} \quad (39)$$

Predicted CPUE

The predicted CPUE for fleet *f*, year *t*, and season *m* is calculated as:

$$CPUE^{pred}_{f,m,t} = q_{f,m,b}\left(B^{exploit}_{f,m,t}\right)^{E_{f,m,b}} \quad (40)$$

where $q_{f,m,b}$ is the catchability for fleet *f*, time block *b*, and season *m*; $E_{f,m,b}$ is the power parameter; $B^{exploit}_{f,m,t}$ is calculated as section ***Fishery catchability***.

Predicted length composition

The predicted catch length composition is calculated as:

$$Pc^{pred}_{f,m,t,k} = \frac{C^{pred}_{f,m,t,k}}{\sum_k C^{pred}_{f,m,t,k}} \quad (41)$$

where $Pc^{pred}_{f,m,t,k}$ is the proportion of predicted catch for fleet *f*, year *t*, season *m* and size-class *k*; $C^{pred}_{f,m,t,k}$ is the predicted catch for fleet *f*, year *t*, season *m* and size-class *k*.

The predicted survey length composition is calculated as:

$$Pi^{pred}_{ind,t,k} = \frac{N^{Survey}_{ind,t,k}}{\sum_k N^{Survey}_{ind,t,k}} \quad (42)$$

where $Pi^{pred}_{ind,t,k}$ is the proportion of abundance at the survey time of survey *ind*, year *t*, and size-class *k*.

Reference Points

The program computes a number of common reference points based on estimated or pre-specified selectivity and biological characteristics. The reference points are computed through a bisection algorithm which produces an accuracy of approximately 1E-05. The reference points computed are $F_{0.1}$, F_{MAX}, $F_{30\%SPR}$, $F_{40\%SPR}$, and F_{MSY}. The associated maximum sustainable yield (MSY) and spawning stock biomass at F_{MSY} are also provided.

Objection Function Calculation (Fitting the model)

The overall objective function in NSLSAP is the sum of log likelihood functions linking observed and predicted values of various life history and fishery processes. A penalty function is also included in the overall objective function to exclude biologically unrealistic estimates. There are multiple assumptions for error distributions provided in the calculation of the objective function. All are converted to negative log likelihoods for use in the minimization conducted by ADMB. All log likelihood functions contain constant terms that do not change for any value of the parameters. These constants can be either included or excluded from the objective function. All model fits contain a lambda value that allows emphasis of that particular part of the objective function along with an input coefficient of variation (CV) that is used to measure how strong a particular deviation is. The CV is converted to a variance (σ^2) and associated standard deviation (σ) using the equation

$$\sigma^2 = \ln\left(CV^2 + 1\right) \tag{43}$$

Likelihood functions for length composition

For catch and survey proportion at size, two likelihood functions are available:

1. Multinomial distribution

$$\ln(P) = \ln(ESS\,!) - \sum_k \ln\left(x_k!\right) + ESS \sum_k p_k^{Obs} \ln p_k^{pred} \tag{44}$$

where *ESS* is the input effective sample size and is used to create the number of shrimp in each bin (x_k); $p^{obs}{}_k$ denotes an observed proportion and $p^{pred}{}_k$ denotes the associated predicted proportion. Model estimated *ESS* is calculated as:

$$ESS^{pred} = \frac{\sum_k p_k^{pred}(1 - p_k^{pred})}{\sum_k (p_k^{pred} - p_k^{Obs})^2} \tag{45}$$

2. Robust normal for proportion (Fourier *et al*. 1990)

$$\ln(P) = \sum_k (-\ln(\frac{1}{ESS}\sqrt{2\pi(p_k^{pred}(1-p_k^{pred}) + \frac{0.1}{SN}}))) + \ln(\exp(-\frac{(p_k^{obs} - p_k^{pred})^2}{2(p_k^{pred}(1-p_k^{pred}) + \frac{0.1}{SN})\left(\frac{1}{ESS}\right)^2}) + 0.01)) \tag{46}$$

Likelihood functions for others

For catch, CPUE, indices, recruitment deviation and priors, seven log likelihood functions are provided:

1. Robust

$$\ln\left(P\right) = -\ln\left(\sqrt{2\pi}\sigma_I^{obs}\right) + \ln\left(\exp\left(-\frac{\left(\ln\left(I^{obs}\right) - \ln\left(I^{pred}\right)\right)^2}{2\left(\sigma_I^{obs}\right)^2}\right) + 0.01\right) \tag{47}$$

2. Student t

$$\ln\left(P\right) = -\ln\left(\frac{1.32934}{\sqrt{4\pi}}\right) - 2.5\ln\left(\left(\frac{\ln\left(I^{obs}\right) - \ln\left(I^{pred}\right)}{2\sigma_I^{obs}}\right)^2 + 1\right) \tag{48}$$

3. Normal distribution for the recruitment deviation

$$\ln(P) = -\frac{\sum (Dev)^2}{2(\sigma_{eps})^2} - \ln\left(\sqrt{2\pi}\sigma_{eps}\right) \quad (49)$$

4. Log normal

$$\ln(P) = -\ln\left(\sqrt{2\pi}\sigma_I^{obs}\right) - \ln\left(I^{obs}\right) - \frac{\left(\ln\left(I^{obs}\right) - \ln\left(I^{pred}\right)\right)^2}{2\left(\sigma_I^{obs}\right)^2} \quad (50)$$

5. Log normal without the term for observations

$$\ln(P) = -\ln\left(\sqrt{2\pi}\sigma_I^{obs}\right) - \frac{\left(\ln\left(I^{obs}\right) - \ln\left(I^{pred}\right)\right)^2}{2\left(\sigma_I^{obs}\right)^2} \quad (51)$$

6. Normal

$$\ln(P) = -\ln(\sqrt{2\pi}\sigma_I^{obs}) - \frac{(I^{obs} - I^{pred})^2}{2(\sigma_I^{obs})^2} \quad (52)$$

7. Cauchy distribution

$$\ln(P) = -\ln\left(0.675\sigma\pi\left(1 + \left(\frac{I^{obs} - I^{pred}}{0.675\sigma}\right)^2\right)\right) \quad (53)$$

Penalty

One penalty function is included for the estimated fishing mortality. It's a penalty associated with any F greater than an input maximum value, calculated as 1000*(F-max F)^2 for F> max F, where max F should be a maximum fishing mortality level that the user believe possible for the fishery and will be defined by the user.

Users' Guide

Input

The assessment model could operate on either annual time-step or seasonal time-step depending on the user's choice. For each time-step, **9 input files are required** to run the model. Of the 9 input files 3 are common files and 6 are time-step specific files. The names of the files should not be changed.

Appendix C1. Table 1. File names for each time-step.

	COMMON FILES	ANNUAL TIME-STEP FILES	SEASONAL TIME-STEP FIELS
	Control.DAT	BPR_Data_Year.DAT	BPR_Data_Season.DAT
	Biology_Data.DAT	CatchDataYear.DAT	CatchDataSeason.DAT
	Survey_Data.DAT	GrowthMatrix.DAT	GrowthMatrix.DAT
		Parameters_Ini_Year.DAT	Parameters_Ini_Season.DAT
		Prior_Year.DAT	Prior_Season.DAT
		Porjection_Year.DAT	Projection_Season.DAT
Sub Folder		**Year**	**Season**
Folder	**InputFiles**	**InputFiles**	**InputFiles**

In all these input files, "#" precedes a comment line which will not affect the run.

Summary of data required

- Weight-at-size matrix
- Maturity-at-size matrix
- Survey indices, CV, ESS, length composition
- Proportion of female at size for each year
- Annual catch, CV, ESS, length composition
- Growth matrix or VBGF parameters

Summary of other information for specifying the model

- Time-step
- Number of size bins and lower and upper boundary for each size bin
- Natural mortality weighting factors by size and year
- Number of size bins to which recruitment recruits
- Spawning month
- Initial condition
- Survey selectivity
- Fleet selectivity

Control file (Control.dat)

- Model time-step set-up (1-year; 4-season)
- Number of years
- Number of seasons in each year
- Number of months in each season
- First year of the input data (e.g., 1985)
- First year of the data used for a particular run (any subset of the input data)

- Last year of the data used for a particular run (facilitate retrospective analysis)
- Likelihood constants set-up (1-included in the objective function; 0-excluded)
- Tracking a particular cohort (e.g., 1990; the program will output the dynamic of year class 1990)

Biology data file (Biology_Data.dat)

- Number of size bins
- Lower and upper boundary for each size bin (units of millimeter)
- Parameters of Length-weight relation for calculating weight-at-size matrix

(number of years by 3, the first column is year, the second and third columns are the parameters a_t and b_t in **Equation 22***)*

- Parameters of maturity-length model for calculating maturity-at-size matrix

(*4 by the number of years, the first column is year, the second, third and fourth columns are the parameters G_t, K_t and $L_{50\%,t}$ in* **Equation 23**)

- Size weighting factor for natural mortality (w_k in **Equation 1**)
- Annual weighting factor for natural mortality (w_t in **Equation 1**)
- Number of size bins to which recruitment recruits (the length of vector λ_k in **Equation 7**)
- Proportions of the annual recruitment recruits to each season (λ_m *in* **Equation 7***, only be used when time-step is season*)
- Spawning month (defined as the beginning of the month)
- Stock-recruitment relation set-up (1-no functional relation; 2-BH model; 3- Ricker model)
- Initial condition set-up (0-7; see section ***Initial Conditions***)
- Proportions-at-size (Pia_k in **Equations 12 and 13;** *this vector will only be used when the initial condition is set to 1 or 2*)

Survey data file (Survey_Data.dat)

- Number of available survey indices
- Unit of each survey index (1-biomass; 0-numbers)
- Start size bin of selectivity for each survey
- End size bin of selectivity for each survey
- Tuning set-up for each index for a particular run (1-include; 0-not include)
- Likelihood function set-up for length composition data for each survey (1-multinomial [**Equation 44**]; 2-robust normal for proportion [**Equation 46**])
- Likelihood function set-up for index for each survey (1-7; see section ***Likelihood functions for others***)
- Lambda value of composition component in objective function for each survey
- Lambda value of index component in objective function for each survey
- Number of data points for survey indices (e.g., 44: 2 indices * 22 years)
- Survey data matrix (number of rows=number of data points, number of columns=6 + number of size bins)

Year	Index number	Index month	Index value	CV	ESS	Size bin 1	Size bin 2	……	End size bin
		Indmonth in Equation 38			Effective sample size	Survey length composition			

- Lambda value of sex change component in objective function
- Proportions of female at size matrix (number of size bins by number of years)
- Number of survey catchability
- Catchability calculation method set-up (1-**Equation 34**; 2-**Equation 35**)
- Survey catchability time blocks set-up (a matrix of number of years by number of survey catchability plus one)

An example showing two time blocks for each of the two indices (4 blocks total):

year	Index 1	Index 2
1985	1	3
1986	1	3
1987	2	3
1988	2	4

Each cell in the shaded area indicates the time block in which a particular index falls for a particular year. For index 1, there are two time blocks, q1 for 1985-1986 and q2 for 1987-1988. For index 2, there are two time blocks as well, q3 for 1985-1987 and q4 for 1988.

- Fleet selectivity reference (**negative value**-not use fleet selectivity as survey selectivity; **fleet number**-use that particular fleet selectivity as survey selectivity)
- Number of survey selectivity time blocks
- Survey selectivity option for each survey (1-4, same options as fleet selectivity, see section ***Fishing Mortality***)
- Survey selectivity time blocks set-up

Catch data file (CatchDataYear.dat)

- Number of fleets
- Unit of catch for each fleet (0-number[million]; 1-biomass[1000mt])
- Start size bin of selectivity for each fleet
- End size bin of selectivity for each fleet
- Likelihood function set-up for length composition data for each survey (1-multinomial [**Equation 44**]; 2-robust normal for proportion [**Equation 46**])
- Likelihood function set-up for total catch for each fleet (1-7; see section ***Likelihood functions for others***)
- Likelihood function set-up for CPUE for each fleet (1-7; see section ***Likelihood functions for others***)
- Lambda value of composition component in objective function for each fleet
- Lambda value of total catch in objective function for each fleet
- Lambda value of CPUE in objective function for each fleet
- Number of data points for catch data
- Catch data matrix (number of rows=number of data points, number of columns=9 +

number of size bins)

-

Year	Time-step	Fleet number	Total catch	CV of catch	CPUE or effort value	CPUE or effort	CV of CPUE or effort	ESS	…
						1-CPUE 0-effort			Length comp

- Tuning set-up for each CPUE for a particular run (1-include; 0-not include)
- Number of CPUE catchability (time blocks)
- Catchability calculation method set-up (1-**Equation 34**; 2-**Equation 35**)
- CPUE catchability time blocks set-up (same as survey catchability)
- Number of fleet selectivity time blocks
- Fleet selectivity option for each fleet (1-4, see section ***Fishing Mortality***)
- Fleet selectivity time blocks set-up

Growth matrix data file (GrowthMatrix_Year.dat)

- Growth transition matrix set-up (1-use VBGF parameters to derive the growth transition matrix internally, see section of ***Growth***, in this case the VBGF parameters could be estimated along with other model parameters; 0-input growth transition matrix directly)
- Number of growth transition matrices
- Growth proportion for each Season (α_m in **Equation 17**, will not be used when time-step is year)

Biology reference point data file (BPR_Data_Year.dat)

- Maximum value of F in penalty term
- Selectivity set-up for calculating reference point (**-1**-input; **0**-averaged fleet selectivity; **fleet number**-use that particular fleet selectivity)
- Selectivity input (only be used when above option is set to -1)
- Equilibrium period used for calculating reference point
- Reference year for natural mortality (e.g., 20: use the natural mortality of 20th year for calculating reference point)
- Proportions of F for each season (1 for annual time-step)
- Growth matrix set-up (specify which time block of growth matrix will be used for calculating reference point)

Initial value of parameters input file (Parameters_Ini_Year.dat)

- Fleet Selectivity Parameters
- Fishing mortality of the first year for each fleet
- Fishing mortality deviations for each year and fleet (fleet outer loop, year inner loop)
- CPUE catchability power parameter for each time block
- Survey index selectivity parameter for each time block
- Initial condition parameters
- R-S relationship parameters (α and β)
- Recruitment deviations (log scale)
- Recruitment autocorrelation coefficient
- Standard deviation of recruitment deviation in log scale

- Natural mortality
- Lorenzen natural mortality (b_m in **Equation 2**)
- *Linf* for each time block ($L_{inf,\,b}$ in **Equation 17**)
- *K* for each time block (K_b in **Equation 17**)
- Standard deviation of $L_{inf,\,b}$ (**Equation 18**)
- Standard deviation of K_b (**Equation 18**)
- Correlation between $L_{inf,\,b}$ and K_b (**Equation 18**)
- Proportion of recruitment-at-size (λ_k in **Equation 7**)
- L_{50} for each year ($L_{50\%,t}$ in **Equation 24**)
- R_{sex} (R_{sex} in **Equation 24**)

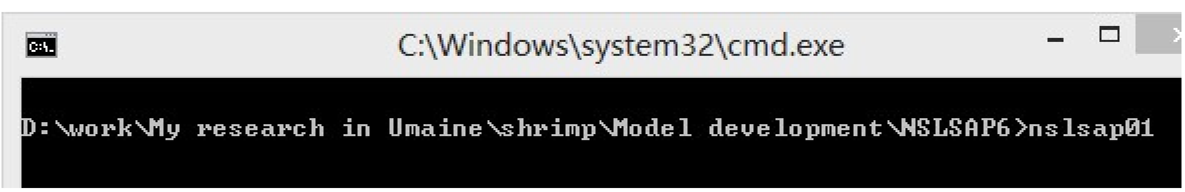
Prior input file (Prior_Year.dat)

Prior file inputs the priors for each parameter for MCMC run. For each parameter, input the mean, lower bound, upper bound, phase (negative value turns off the parameter), standard deviation, lambda, and likelihood function.

Running the model

The NSLSAP01 model is written in ADMB (Automatic Differentiation Model Builder) and the source code could be found in NSLASAP01.tpl file. The process of creating the model with ADMB involves writing, compiling, and testing. An integrated development environment (IDE) allows the user to perform these tasks more efficiently than with a basic editor and a shell. ADMB-IDE is a great tool for modifying the code, compiling the code, and running the model. The manual for ADMB-IDE is available at:
http://www.admb-project.org/tools/admb-ide/manual

Once the code is compiled into an executable file (NSLSAP01.exe) the model could be run in a command window. Shift-Right-clicked on folder which contains the model files in windows explorer to open a command window and then type “nslsap01” into command window to run the model (see the example below). The results will be sent to a series of output files which are described in Output section.



Output

For each run the model produces a series of output files, most of them are standard ADMB output files. The independent variables of the optimization are in a file named NSLSAP01.par (NSLSAP01.bar is an equivalent binary file). A more user-friendly report is in the file NSLSAP01.rep. The estimated standard deviations and correlations are in files named NSLSAP01.std and NSLSAP01.cor. In addition, a report file named “NSLSAP01_1985_2001_1.rep” which indicates the data range and time-step used for that particular run is also produced.

1 **NSLSAP01.rep:** Results for the run, including spawning biomass, numbers-at-length, recruitment, fits to the data, fishing mortality, MSY and related quantities, etc.

2 **NSLSAP01.par:** a standard ADMB output file, giving the objective function value, its gradient (this should be very small if the model has converged) and the parameters estimated/fixed for that run.
3 **NSLSAP01.std:** a standard ADMB output file, with the parameters estimated for that run and their estimated Hessian-based standard deviation.

R program is used to read and plot the ADMB output. Three r code files stored in the model folder were used. The file named "reptoRlist.r" reads the contents of the report file (NSLSAP01.rep) and stores the contents in R in the form of a list object. The file named "PlotFuncs.r" contains all the functions for producing different plots. The file named "OutputPlots.r" is used to call the functions and get the plots. The explanations of that file are as follows:

setwd("D:/work/My research in UMaine/shrimp/Model development/NSLSAP6")
 # set working directory to the folder containing the model files (change to yours by typing the directory in the "")

source("reptoRlist.r")
 # run the r code in reptoRlist.r

filename="NSLSAP01"
 # specify the name of files outputted from ADMB

report<-read.admb(filename)
 # read the contents of the report file (NSLSAP01.rep) and stores the contents in the list object (report)

source("PlotFuncs.r")
 # run the r code in PlotFuncs.r

PlotWL(2000,1)
 # plot weigth-at-length

PlotML(2000)
 # plot maturity-at-length

PlotGM(2000,20)
 # plot growth transition matrix

PlotSelF(2000,1,1)
 # plot fleet selectivity

PlotSelS(2000,1)
 # plot survey selectivity

PlotF(1,1)

 # plot fishing mortality

PlotM(2000)
 # plot natural mortality

PlotR()
 # plot recruitment

PlotSSB()
 # plot spawning stock biomass

PlotAbun()
 # plot numbers-at-length

PlotSLC(1)
 # plot survey length composition

PlotSLCA()
 # plot aggregated survey length composition

PlotSI(1)
 # plot survey index

PlotTC()
 # plot total catch

PlotC(2)
 # plot total catch by fleet

PlotCC(2,1)
 # plot catch length composition

PlotCCA(2)
 # plot aggregated catch length composition

PlotRoSSB(1985,2002,2006,4)
 # plot retrospective error for SSB

PlotSexComp()
 # plot sex composition

PlotFfit()
 # plot the fit of sex change

PlotLfifty()
 # plot the fit of L50

PlotSpB()
 # plot the sex-specific biomass over time

R version 3.0.0 for windows is available at: http://cran.r-project.org/bin/windows/base/

Once you have R installed, open "OutputPlots.r" and run the code you will get the plots.

Appendix C2. Predation Pressure Index

Predation Pressure Index

A simple index of predation pressure on northern shrimp *Pandalus borealis* was developed using survey biomass indices of predators and frequency of occurrence of Pandalids in predator stomachs from food habits sampling conducted during NEFSC spring and autumn bottom trawl surveys. The motivation was to include information on predation on shrimp in the assessment models without having to develop absolute estimates of consumption, which require more detailed calculations and depend on several assumptions in order to scale to absolute estimates.

Methods

Predators of Pandalids were identified based on food habits sampling in the northern shrimp assessment strata in the western Gulf of Maine (NEFSC bottom trawl strata 01240, 0126-1028, 0137-0140) during 1973-2011 spring and fall surveys. Predators were retained in the analysis if at least 100 stomachs containing Pandalids were sampled during all years and spring and fall seasons combined. I used 'collection category' prey taxonomic resolution and prey category 'PANFAM', which included *P. montagui, P. propinquus, Dichelopandalus leptocerus*, and unidentified Pandalids. *P. borealis* was identified to species in only about 3% of stomachs containing Pandalids. In survey catches in the shrimp assessment area, *P. borealis* accounted for 89-93% of the aggregate biomass of *P. montagui, D. leptocerus and P. borealis* on average (fall and summer surveys, respectively, Appendix C2. Figure 1). The Pandalid category excluded Euphausiids and Crangon shrimp.

For each identified predator, I estimated relative frequency of occurrence of Pandalids in predator stomachs (% of stomachs containing Pandalids in fall and spring surveys during 1973-2011). Annual fall biomass indices (NEFSC surveys, stratified mean weight (kg) per tow) were estimated for each predator using only the northern shrimp assessment strata (listed above). The indices from 2009-2012 were converted to 'Albatross units' by applying conversion coefficients for biomass developed for each species (Miller 2010). For Atlantic halibut and pollock, data were insufficient for estimating conversion coefficients (Miller 2010). For halibut, I applied the value used in the most recent assessment, which was the average coefficient for all flatfish species (J. Blaylock, pers. comm.). For pollock, the coefficient was assumed equal to one (Miller 2013 CJFAS).

To calculate the predation pressure index, annual biomass indices for each predator were weighted by the % frequency of occurrence of shrimp (averaged over time for each predator) and then summed across predators to derive an annual index of predation pressure that took into account both the biomass of the predators and how heavily each appeared to prey on shrimp.

$$PPI_{is} = \sum^{j} B_{ijs} * P_j$$

Where

PPI = predation pressure index
i = year
s = season (fall)

j= predator species
B = biomass index
P = proportion of stomachs containing Pandalids

An alternative PPI was explored using annual estimates of percent frequency in each predator's diet (vs. the average over time for each predator) in order to reflect inter-annual variation in predator response to shrimp densities.

$$PPI(2)_{is} = \sum^{ij} B_{ijs} * P_{ij}$$

To reduce the number of predators for this more detailed analyses, we included only predators that contributed more than 1% to the PPI score for all years combined.

The PPI(2) approach required extrapolating to fill in years with missing data for some of the predators (Appendix C2. Table 1). This was done using relationships estimated for years when complete data were available for all 10 species (1999-2010). The relationships were between % frequency for each predator and (1) % freq for all predators with complete time series, (2) shrimp recruitment index or (3) mean shrimp carapace length (Appendix C2. Figure 2).

Complete data for 2011-2012 food habits became available after most of the work on the PPI had been completed, so only the annual PPI (PPI2) was updated for these years.

Results

PPI
Sixty species were recorded with Pandalidae in stomach contents during 1973-2011 NEFSC spring and fall surveys (Appendix C2. Table 1). Of these, 21 had at least 100 sampled stomachs over the time series and were retained for the PPI (Appendix C2. Table 2). Frequency of occurrence of Pandalids in stomachs of these 21 predators ranged 1.2% (American plaice) to 35.7% (barndoor skate) and averaged 8.9% (Appendix C2. Table 2, Appendix C2. Figure 3).

Trends in predator biomass are shown in Figure 4, and aggregate predator biomass for the 21 predator species and trends in the PPI are shown in Figure 5. The PPI index based on the top 10 predators accounted for 96% of the PPI overall (Appendix C2. Table 3) and closely followed trends in the PPI based on all 21 species (Appendix C2. Figure 6). In general, the PPI was lowest during the mid-1980s to mid-1990s, increased after 1999 and has remained relatively high since.

PPI(2)
Filling in the gaps for missing data in the annual diet estimates did not have a strong effect on the annual averages over all predators (Appendix C2. Figure 7). Using annual % diet frequency (PPI(2)) resulted in the same broad trend of generally higher predation pressure after the mid-1990s, but there was a sharp divergence since 2010 (Appendix C2. Figure 8). PPI(2) was related to the annual shrimp recruitment index (Appendix C2. Figure 9). The relationship between %

frequency in the diet and % of diet (Appendix C2. Figure 10) suggests predators may take a higher proportion of the shrimp population when shrimp densities are higher.

Discussion

The approach taken here is very different from the fine-grained approach of Link and Idoine (2009) ("L&I") in which estimates of absolute consumption were developed. The L&I estimates were initially developed for SARC 45 (NEFSC 2007) for comparison with abundance estimates from the assessment models. The intent of the PPI is not to provide consumption estimates, but to give a broad indication of trends in predation pressure that may be factored into assessment models.

Appendix C2. Figure 11A shows a comparison of trends in the PPI and trends in the L&I consumption estimates (thousand mt) . The trends do not match, even when the PPI is based on the same 10 species included in Link and Idoine (2009). If only the 10 species identified by L&I are used to construct the PPI, the trends still do not match (Appendix C2. Figure 11B).

The L&I estimates were based on sampling in the entire Gulf of Maine including portions of the Scotian Shelf (NEFSC strata 01240-01400) to derive swept area estimates of predator abundance and to estimate per capita consumption of Pandalids. L&I noted that abundance changes would likely dominate the scaling of estimates of consumption. Divergent trends in biomass and abundance of the 10 predator species of L&I explains some of the divergence in trends in the PPI and L&I because trends in abundance and biomass do not track closely (Appendix C2. Figure 11). In addition, several influential species were not included in L&I (redfish, spiny dogfish, Atlantic herring, haddock) because of a large gap in sampling of these species early in the time series. Omitting these species from the PPI had a substantial effect on trends in the PPI (Appendix C2. Figure 12).

References

Link, J.S. & J. S. Idoine (2009). Estimates of predator consumption of the northern shrimp *Pandalus borealis* with implications for estimates of population biomass in the Gulf of Maine. North American Journal of Fisheries Management 29: 1567-1583.

Miller T, Das C, Politis P, Long A, Lucey S, Legault C, Brown R, Rago P. 2010. Estimation of */Henry B. Bigelow/* calibration factors. NEFSC Bottom Trawl Survey/ /Calibration Peer Review Working Paper. NEFSC, Woods Hole, MA. 376 p.

Miller, T.J. 2013. A comparison of hierarchical models for relative catch efficiency based on paired-gear data for US Northwest Atlantic fish stocks. Can. J. Fish. Aquat. Sci. 70: 1306–1316.

Appendix C2. Table 1. Complete list of species recorded as having Pandalids in stomach contents during NEFSC spring and fall surveys, 1973-2011.

≥ 100 stomachs (included in PPI)	< 100 stomachs (excluded from PPI)
SILVER HAKE	SUMMER FLOUNDER
ATLANTIC COD	BLACKBELLY ROSEFISH
WHITE HAKE	SMOOTH DOGFISH
RED HAKE	ATLANTIC MACKEREL
LONGHORN SCULPIN	YELLOWTAIL FLOUNDER
LITTLE SKATE	WEAKFISH
FOURSPOT FLOUNDER	ROSETTE SKATE
SPINY DOGFISH	BLACK SEA BASS
WINDOWPANE	OFFSHORE HAKE
SPOTTED HAKE	CLEARNOSE SKATE
WINTER SKATE	AMERICAN SHAD
SMOOTH SKATE	WITCH FLOUNDER
POLLOCK	WINTER FLOUNDER
SEA RAVEN	BLUEBACK HERRING
THORNY SKATE	NORTHERN SEAROBIN
HADDOCK	CUSK
ACADIAN REDFISH	BLUEFISH
ATLANTIC HERRING	OCEAN POUT
BARNDOOR SKATE	STRIPED SEAROBIN
GOOSEFISH	ATLANTIC WOLFFISH
AMERICAN PLAICE	SCUP
ATLANTIC HALIBUT	CUNNER
	FAWN CUSK-EEL
	CHAIN DOGFISH
	MOUSTACHE SCULPIN
	FOURBEARD ROCKLING
	ATLANTIC CROAKER
	GULF STREAM FLOUNDER
	NORTHERN SHORTFIN SQUID
	LONGFIN HAKE
	WRYMOUTH
	STRIPED BASS
	BULLNOSE RAY
	SPANISH MACKEREL
	ATLANTIC SHARPNOSE SHARK
	SPOT
	ALEWIFE
	BUTTERFISH

Appendix C2. Table 2. Overall frequency of occurrence of Pandalids in predator stomachs and percent by volume of Pandalids in stomachs containing Pandalids (unweighted estimate), 1973-2011 spring and fall NEFSC surveys combined.

Predator	Frequency of Occurrence	Avg % of prey that was Pandalids (by wt)	Number stomachs sampled
BARNDOOR SKATE	35.7	22.8	28
SMOOTH SKATE	20.8	15.8	751
WHITE HAKE*	15.5	12.4	6,924
RED HAKE*	13.1	10.5	5,111
ATLANTIC COD*	12.9	8.8	5,311
ATLANTIC HALIBUT	12.5	10.8	192
LITTLE SKATE	11.0	6.4	493
LONGHORN SCULPIN*	9.6	8.2	1,782
THORNY SKATE*	8.6	3.0	1,888
SILVER HAKE*	7.5	6.8	14,157
ACADIAN REDFISH	6.6	6.0	2,375
POLLOCK*	6.4	4.3	1,905
FOURSPOT FLDR*	5.0	4.6	337
WINTER SKATE	4.4	2.3	344
SEA RAVEN*	4.3	3.0	1,487
SPINY DOGFISH	3.5	2.2	6,825
GOOSEFISH	2.9	1.8	2,414
HADDOCK	2.8	1.7	1,985
ATLANTIC HERRING	1.9	1.7	4,527
WINDOWPANE*	1.4	1.2	213
AMERICAN PLAICE	1.2	1.1	5,284

* species included in Link and Idoine (2009)

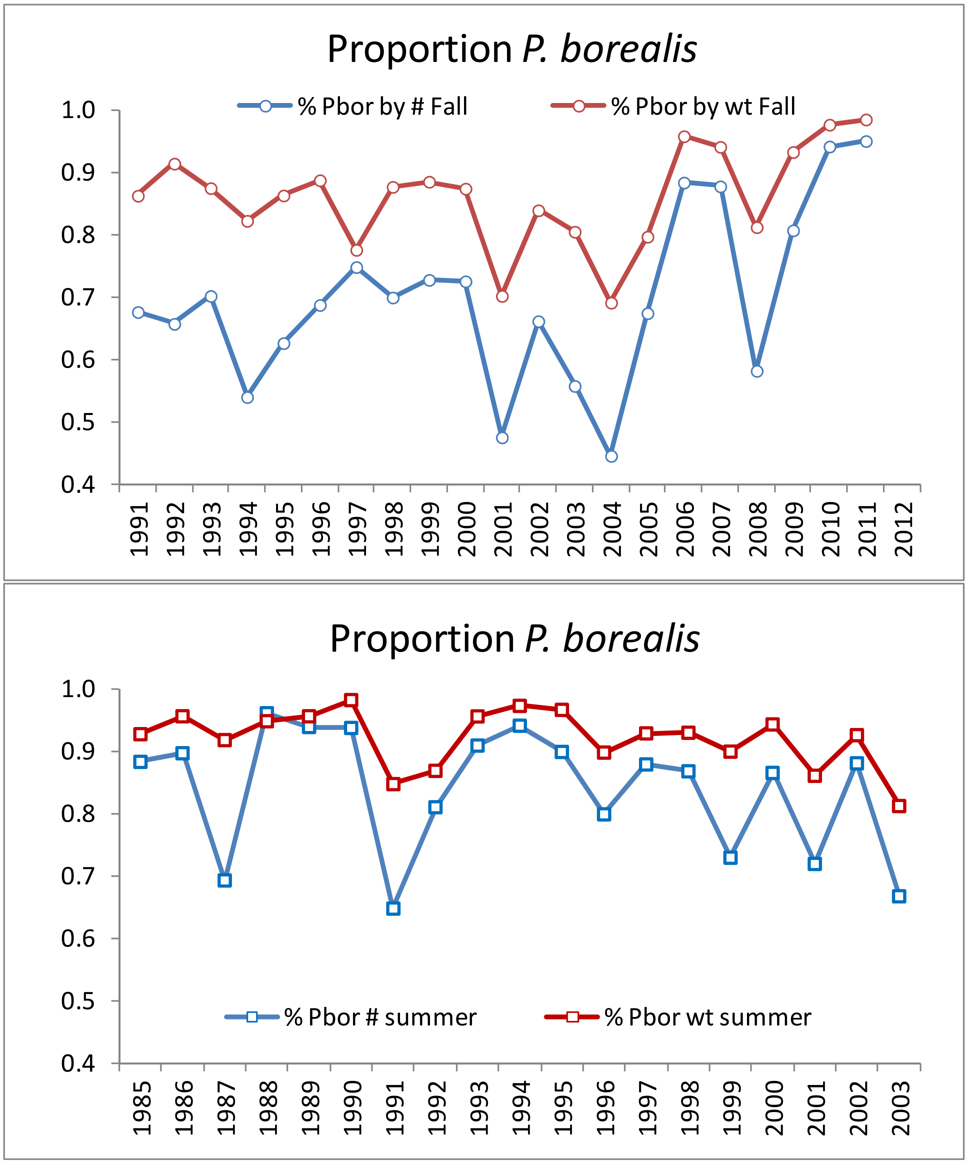
Appendix C2. Table 3. Relative importance of each predator ranked by % contribution to the PPI (A.) averaged over all years, (B.) during 1977-1993 and (C.) during 1994-2010.

A. Predator	% of PPI all years	B. Predator	% of PPI <=1993	C. Predator	% of PPI >1993
ACADIAN REDFISH	20.6%	WHITE HAKE*	23.8%	ACADIAN REDFISH	28.8%
WHITE HAKE*	17.3%	ATLANTIC COD*	19.8%	SPINY DOGFISH	26.3%
SPINY DOGFISH	15.2%	ACADIAN REDFISH	14.0%	WHITE HAKE*	9.2%
ATLANTIC COD*	15.1%	THORNY SKATE*	10.5%	ATLANTIC COD*	9.2%
SILVER HAKE*	7.5%	SILVER HAKE	7.0%	SILVER HAKE	8.2%
THORNY SKATE*	6.4%	SPINY DOGFISH	6.3%	RED HAKE*	5.7%
RED HAKE*	5.1%	POLLOCK*	5.2%	HADDOCK	2.7%
POLLOCK*	3.8%	RED HAKE*	4.7%	ATLANTIC HERRING	2.4%
HADDOCK	3.0%	HADDOCK	3.2%	POLLOCK*	2.1%
ATLANTIC HERRING	1.5%	GOOSEFISH	1.1%	THORNY SKATE*	1.3%
AMERICAN PLAICE	0.8%	AMERICAN PLAICE	1.1%	BARNDOOR SKATE	0.9%
GOOSEFISH	0.8%	ATLANTIC HERRING	0.9%	LONGHORN SCULPIN*	0.8%
SMOOTH SKATE	0.7%	SMOOTH SKATE	0.7%	SMOOTH SKATE	0.6%
LONGHORN SCULPIN*	0.6%	LONGHORN SCULPIN*	0.4%	AMERICAN PLAICE	0.5%
BARNDOOR SKATE	0.6%	WINTER SKATE	0.4%	GOOSEFISH	0.5%
WINTER SKATE	0.3%	BARNDOOR SKATE	0.3%	WINTER SKATE	0.3%
ATLANTIC HALIBUT	0.3%	ATLANTIC HALIBUT	0.3%	ATLANTIC HALIBUT	0.2%
SEA RAVEN*	0.2%	SEA RAVEN*	0.2%	SEA RAVEN*	0.2%
LITTLE SKATE	0.1%	LITTLE SKATE	0.1%	LITTLE SKATE	0.2%
FOURSPOT FLOUNDER*	0.0%	FOURSPOT FLOUNDER*	0.0%	FOURSPOT FLOUNDER*	0.0%
WINDOWPANE*	0.0%	WINDOWPANE*	0.0%	WINDOWPANE*	0.0%

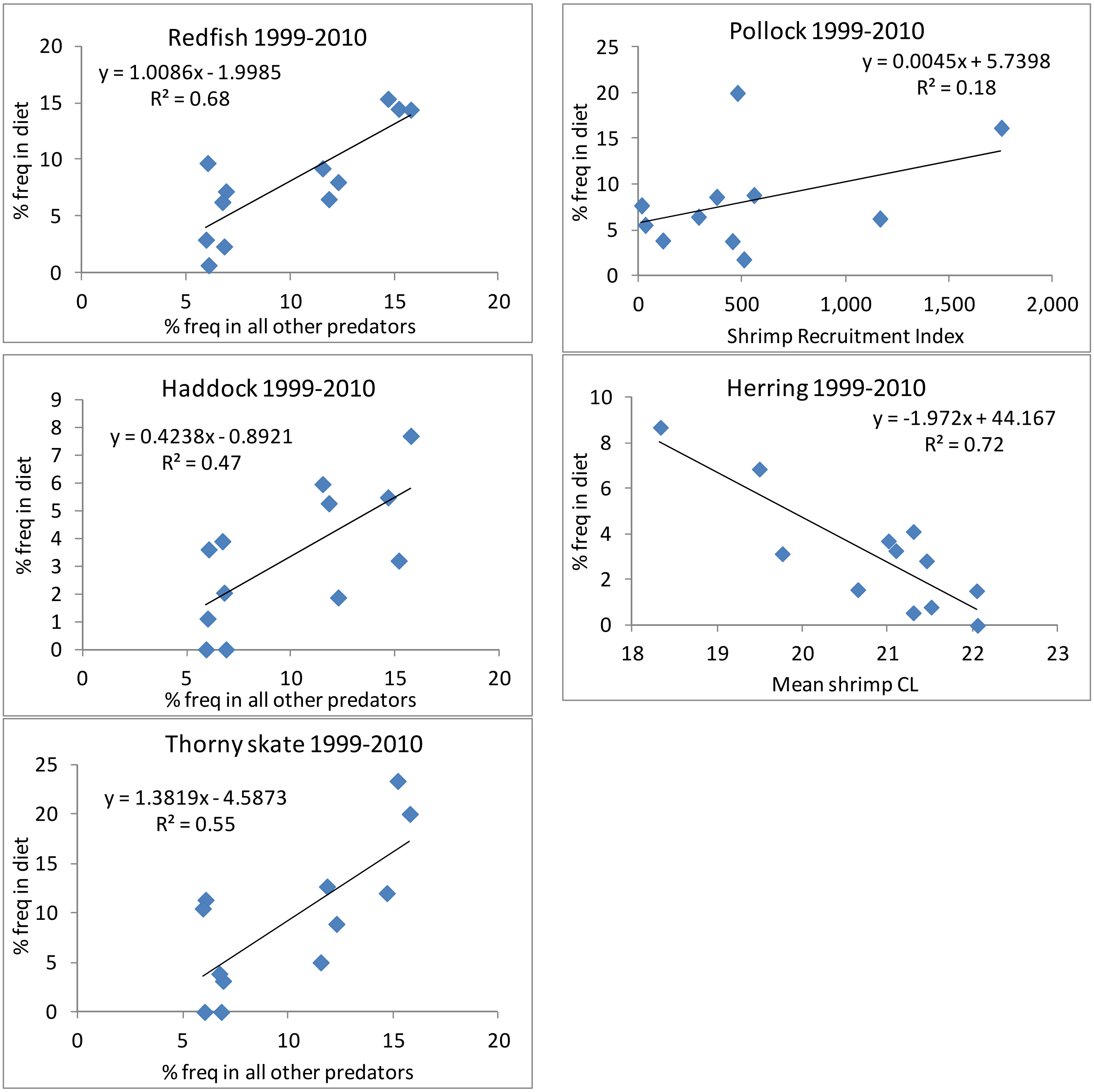
* included in Link and Idoine (2009)

Appendix C2. Table 4. Percent frequency of occurrence of Pandalids in stomachs of predators with highest % contribution to the PPI. Shaded cells were estimated from relationships shown in Figure 2.

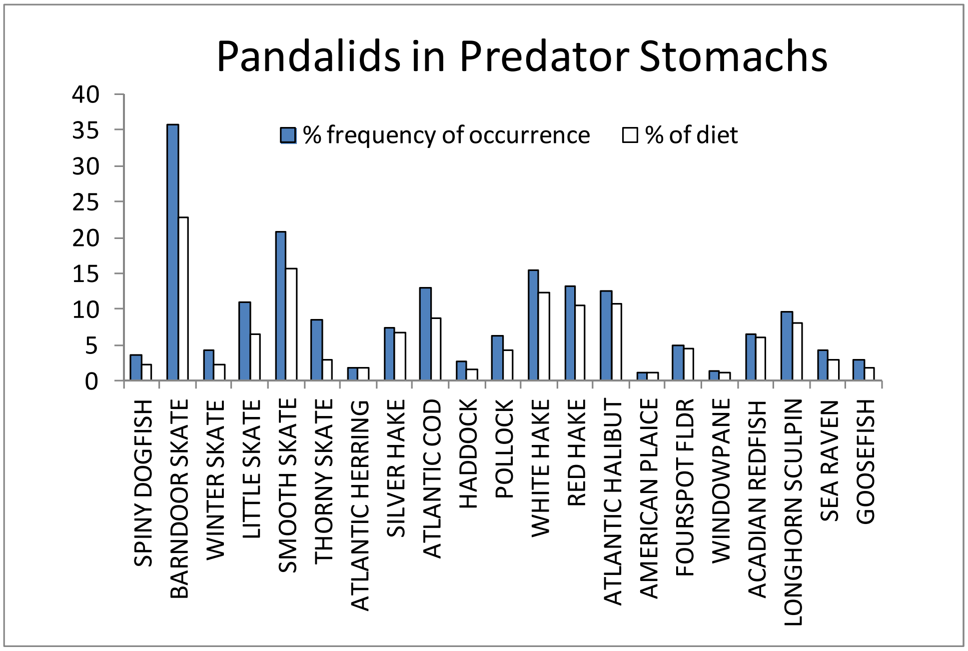
	WHITE HAKE*	RED HAKE*	SILVER HAKE*	ATLANTIC COD*	HADDOCK	POLLOCK*	ACADIAN REDFISH	ATLANTIC HERRING	THORNY SKATE*	SPINY DOGFISH
1984	8.8	4.2	0.0	9.7	0.0	5.8	0.0	1.3	0.9	0.9
1985	3.6	1.9	0.6	5.4	0.0	2.2	3.3	1.3	2.8	1.3
1986	9.0	4.4	2.2	5.6	1.7	7.4	0.0	0.0	1.1	1.6
1987	6.2	8.2	1.8	4.5	0.0	2.4	0.0	0.0	0.0	0.0
1988	13.6	12.7	5.2	2.5	2.1	2.0	0.0	1.3	4.1	1.1
1989	6.4	9.2	3.2	7.8	0.0	1.5	0.0	1.3	3.4	0.5
1990	9.6	17.2	4.3	11.3	2.9	2.6	0.0	0.0	4.5	2.5
1991	23.2	21.7	9.7	15.4	5.3	6.9	12.7	1.3	6.0	2.6
1992	14.4	19.3	5.9	14.4	3.8	2.5	9.1	1.6	8.0	1.2
1993	15.8	16.4	10.6	21.7	4.8	4.4	11.6	0.9	16.5	2.8
1994	22.4	25.0	10.7	24.4	6.6	8.3	15.9	1.0	24.1	6.1
1995	28.9	22.0	15.5	22.5	0.0	7.1	16.6	2.3	8.3	3.3
1996	19.9	12.3	6.1	19.1	4.5	6.8	10.9	3.1	2.7	6.4
1997	8.0	8.5	9.7	21.3	3.3	14.7	8.0	1.2	11.1	2.0
1998	23.0	14.4	11.6	13.3	4.1	13.8	11.6	0.7	15.4	5.1
1999	23.0	18.6	11.5	16.0	3.2	3.8	14.5	0.5	23.3	7.0
2000	18.1	12.3	9.9	16.2	1.9	3.8	8.0	3.1	8.9	5.0
2001	4.5	6.2	11.0	12.4	0.0	5.8	7.2	0.8	3.1	0.5
2002	7.1	5.8	6.6	7.7	1.1	6.3	9.7	8.7	0.0	3.0
2003	8.7	1.1	7.2	7.3	3.6	7.7	0.7	3.3	11.3	6.1
2004	21.3	10.9	9.9	10.6	6.0	6.5	9.2	2.8	5.0	5.1
2005	20.7	16.7	11.1	11.7	7.7	16.2	14.4	6.9	20.0	18.8
2006	27.2	12.6	7.0	17.2	5.5	8.6	15.3	3.7	12.0	9.5
2007	13.2	2.9	2.5	12.9	3.9	5.6	6.3	1.5	3.8	2.3
2008	11.8	7.3	5.1	5.8	2.0	1.8	2.3	0.0	0.0	4.1
2009	15.5	14.7	8.5	13.0	5.3	8.8	6.5	4.1	12.7	7.5
2010	5.5	6.1	5.7	5.5	0.0	20.0	2.9	1.6	10.4	7.0
2011	9.8	7.0	3.4	12.5	0.0	6.7	1.0	0.6	6.7	4.4
2012	5.6	5.3	4.2	3.6	0.7	4.3	1.3	0.5	3.6	3.2



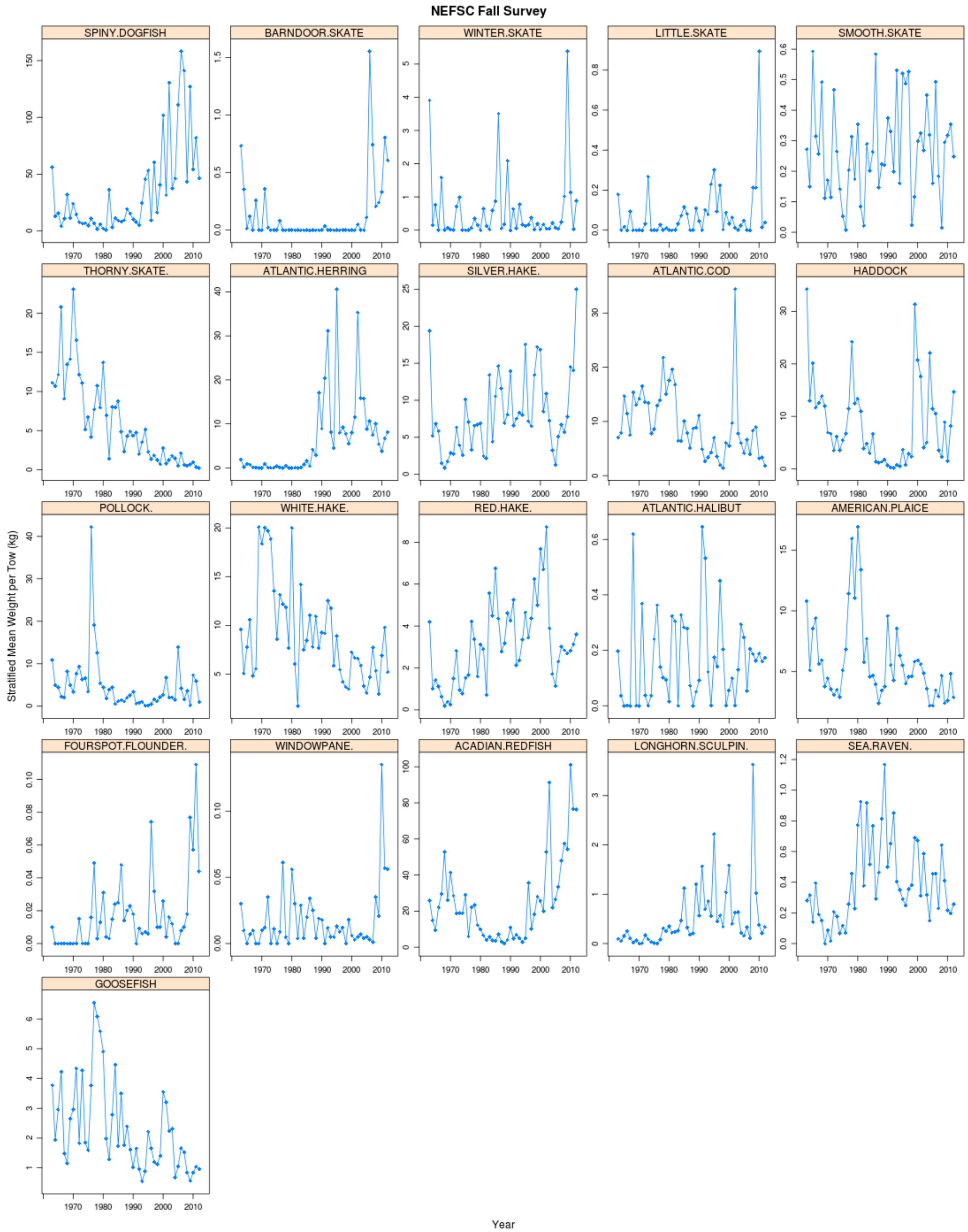
Appendix C2. Figure 1. Proportion of *P. borealis* in surveys (of total Pandalids not including *P. propinquus*), top panel fall survey; bottom panel summer shrimp survey.



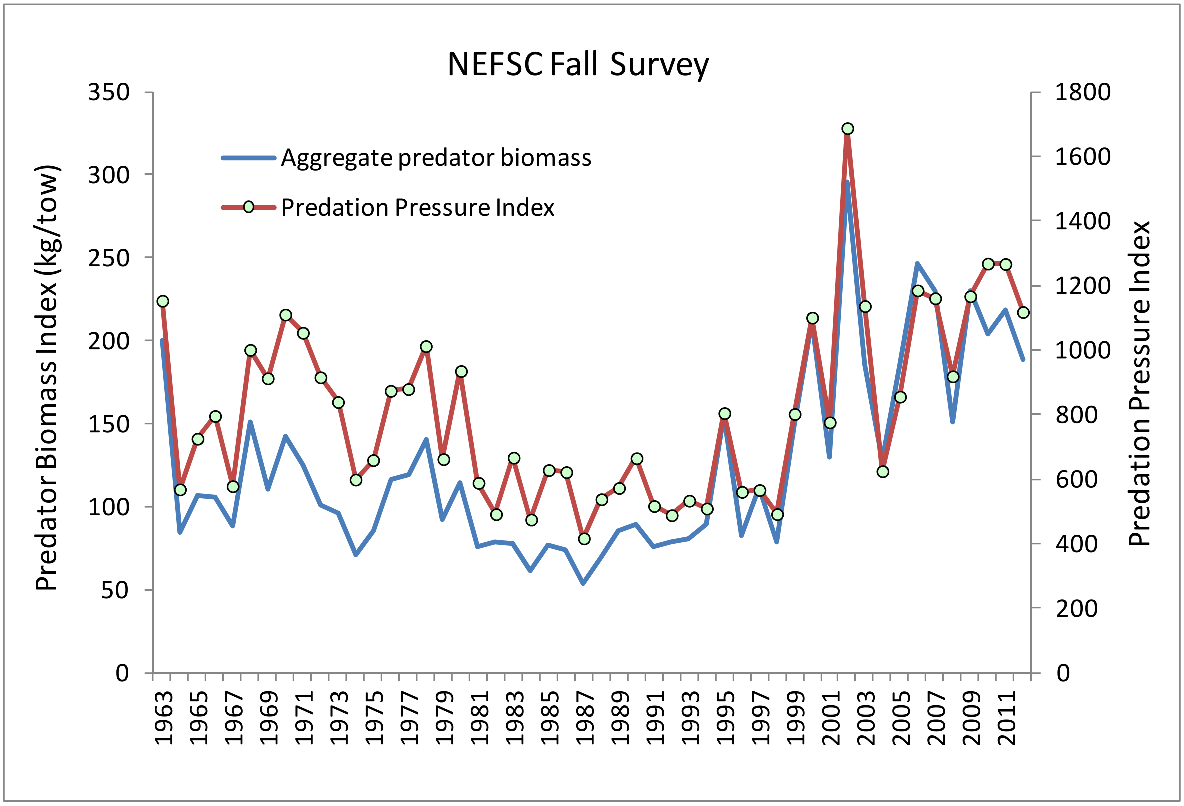
Appendix C2. Figure 2. Relationships used to fill gaps in annual % frequency in diet for predators with missing data during 1984-1998. X-axis labeled "% freq in all other predators" indicates predators with complete time series starting in 1984. CL carapace length.



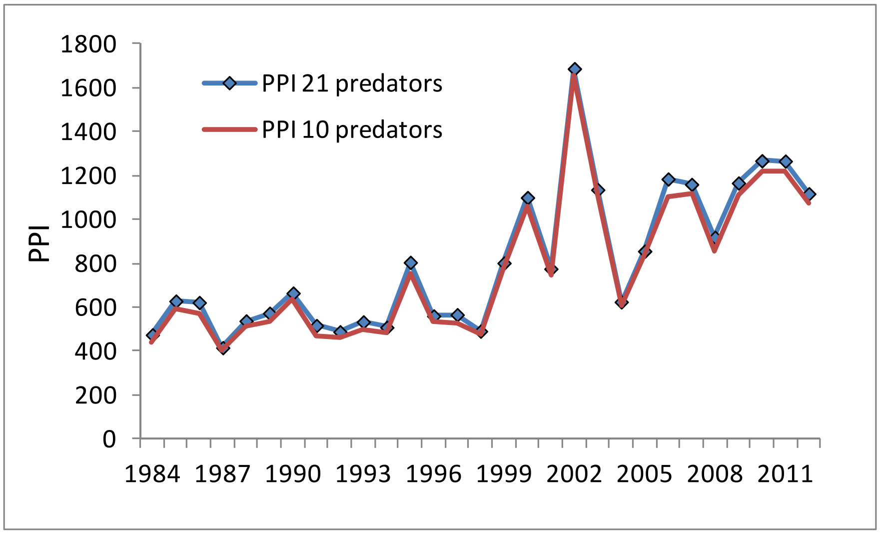
Appendix C2. Figure 3. Overall frequency of occurrence of Pandalids in predator stomachs and percent by volume of Pandalids in stomachs containing Pandalids (unweighted estimate), 1973-2011 spring and fall NEFSC surveys. 2011 data incomplete for some species.



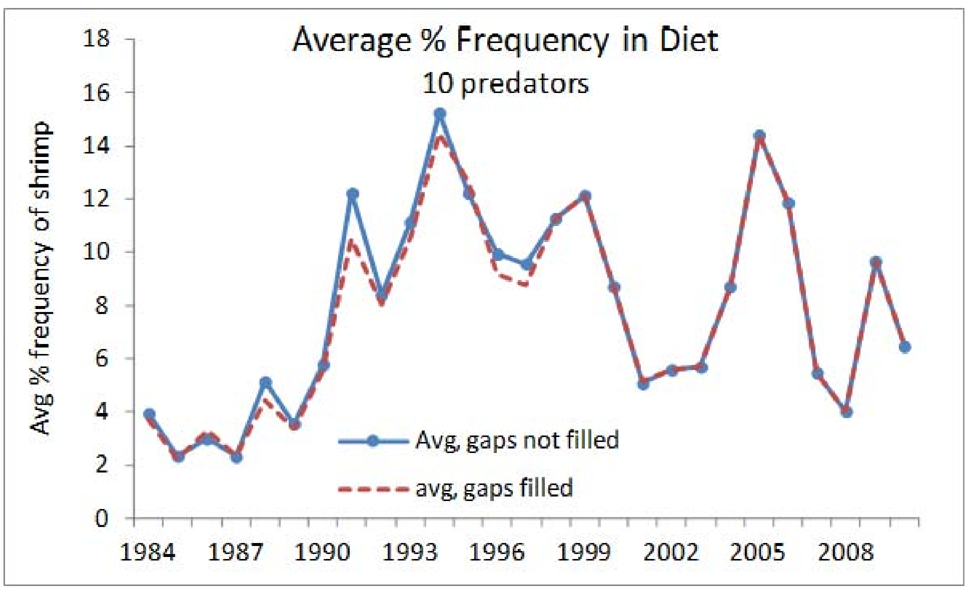
Appendix C2. Figure 4. Biomass indices (stratified mean kg per tow) for 21 predators of Pandalids in the western Gulf of Maine from NEFSC fall bottom trawl surveys. Indices for years after 2008 were adjusted for change in survey methods in 2009.



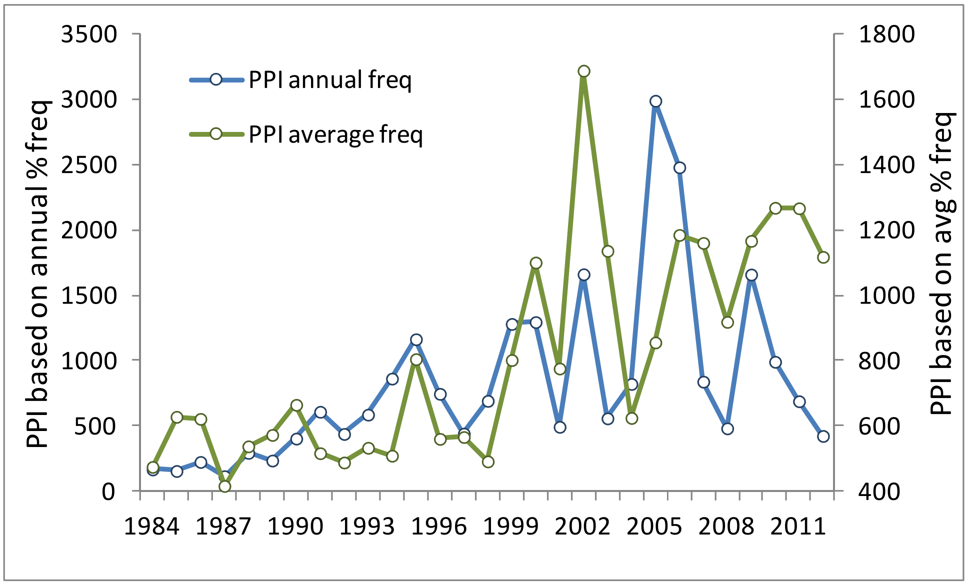
Appendix C2. Figure 5. Aggregate predator biomass indices from NEFSC fall survey (stratified mean kg per tow in shrimp assessment strata) and PPI, 1963-2012.



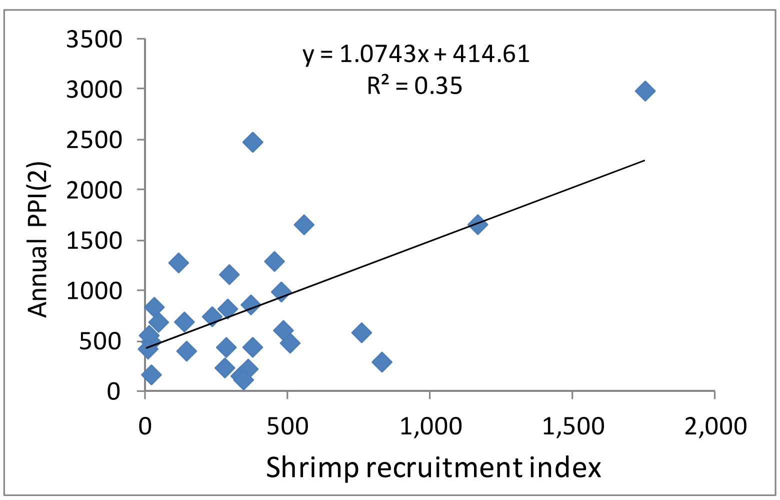
Appendix C2. Figure 6. PPI estimated from 21 species of predators vs. 10 predators that were most influential.



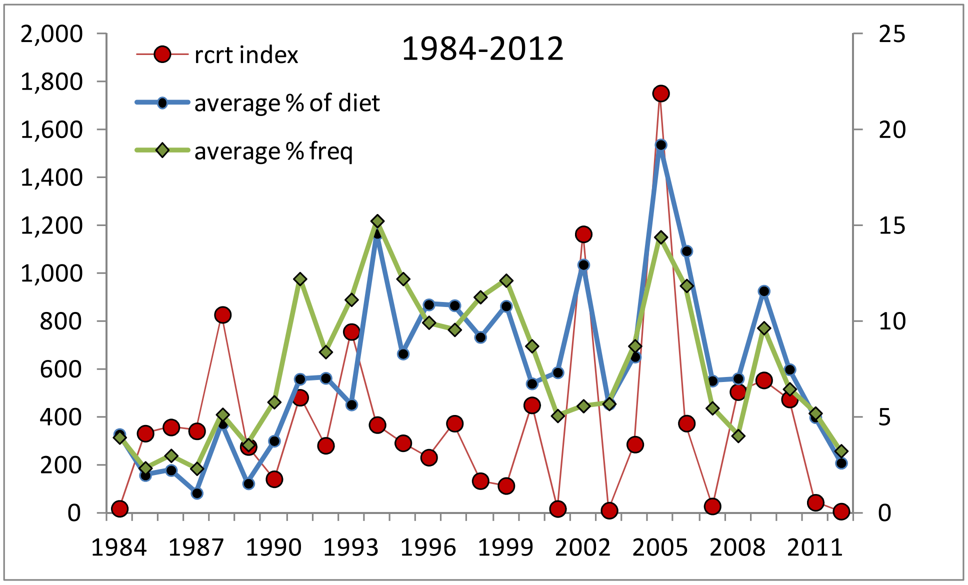
Appendix C2. Figure 7. Average annual % frequency of shrimp in diets of 10 predators with and without missing data filled in for some predators in some years.

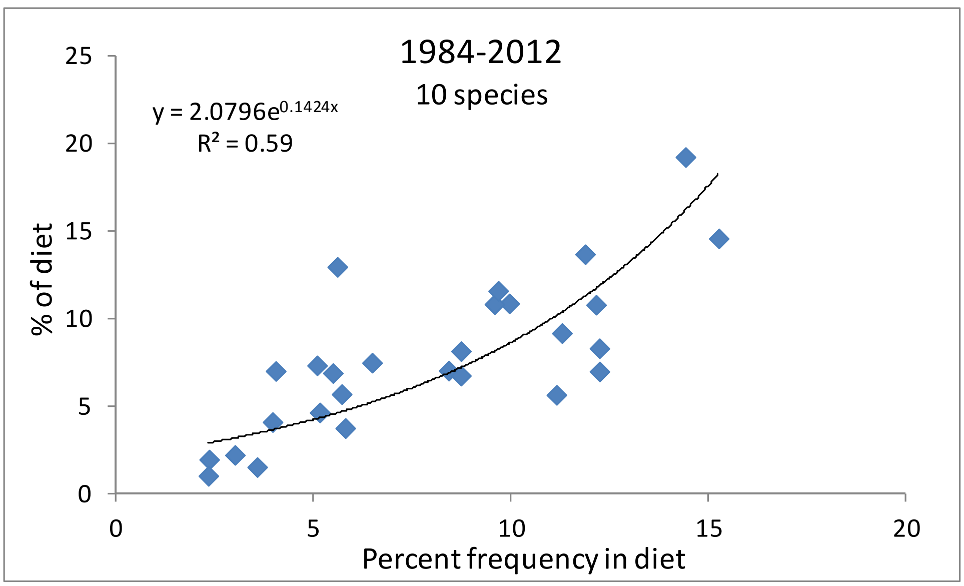


Appendix C2. Figure 8. Comparison of PPI calculated using average % frequency of Pandalids in diet for each predator (averaged over time) vs. using annual % frequency of Pandalids in diet for each predator.



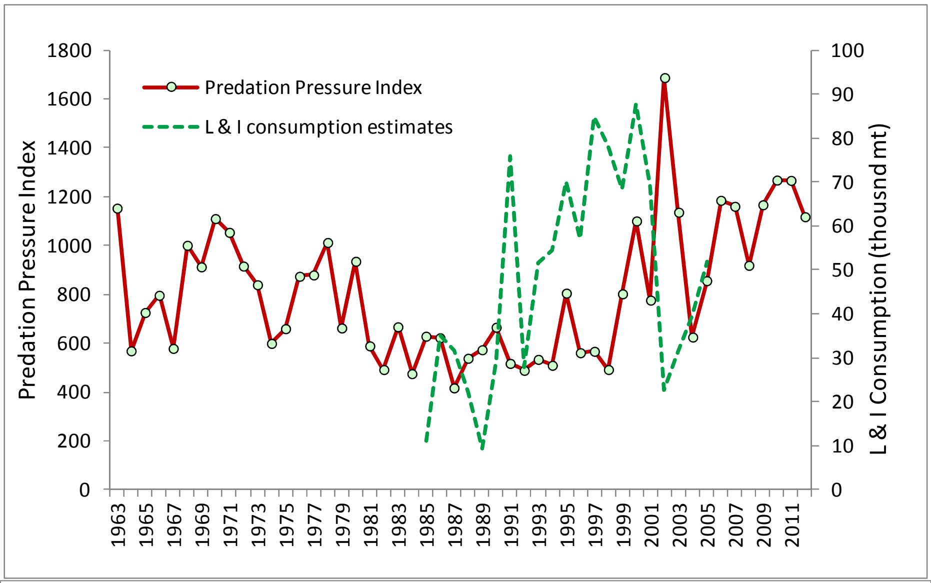
Appendix C2. Figure 9. Relationship between PPI(2) (annual % frequency) and shrimp recruitment index from summer shrimp surveys.



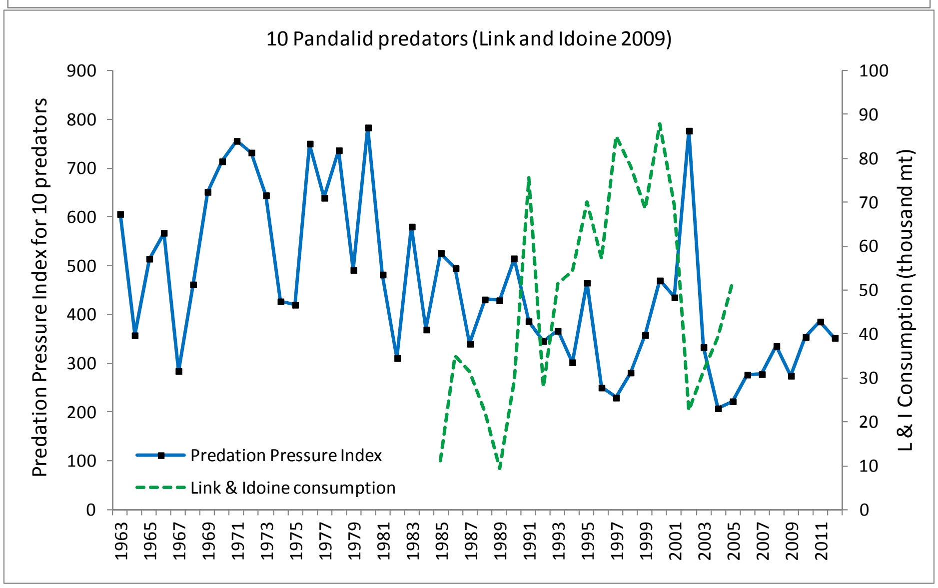


Appendix C2. Figure 10. Top: time series of recruitment indices from summer shrimp survey, % frequency of Pandalids in diet of top 10 predators, and % by volume of Pandalids in diet (unweighted). Bottom: relation between % frequency of Pandalids in diet and % by volume of Pandalids in diet.

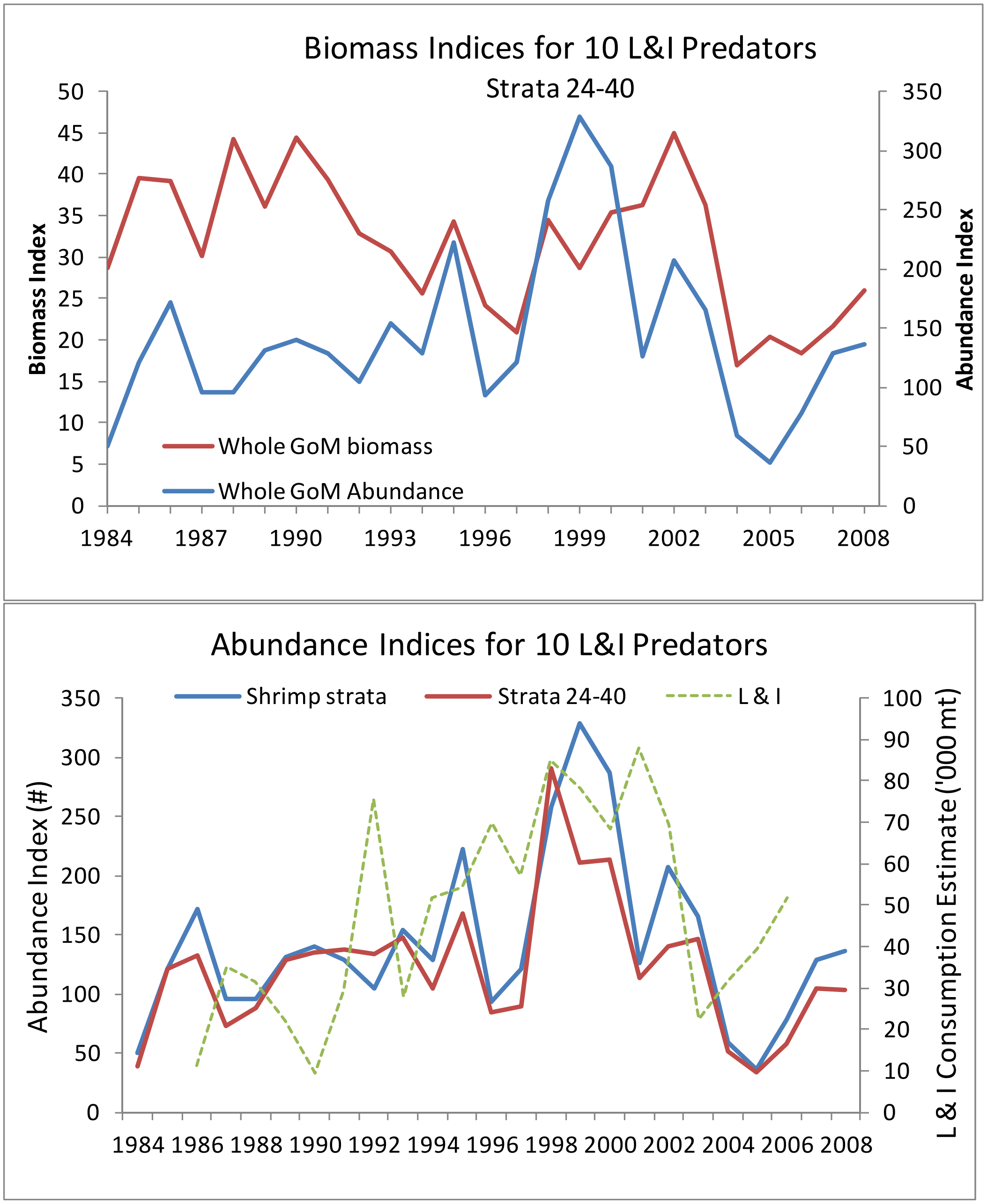
A.



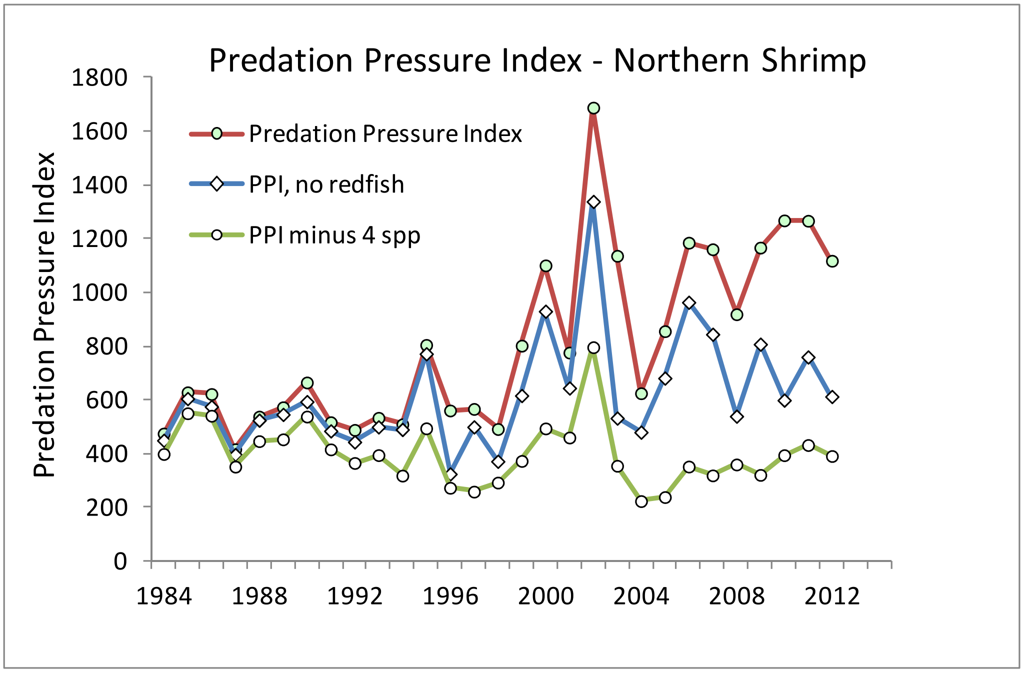
B.



Appendix C2. Figure 11. Comparison of predation pressure index (PPI) based on fall survey biomass indices with estimates of *P. borealis* consumption from Link and Idoine (2009) (L&I). (A.) PPI using 21 identified predators vs. consumption based on 10 predators estimated by L&I; (B.) PPI using only the 10 species identified by L&I vs. consumptions estimates.



Appendix C2. Figure 12. (A) Biomass and abundance for 10 L&I predators for entire Gulf of Maine; (B) abundance indices of the 10 L&I predators for the western Gulf of Maine shrimp assessment strata and the entire Gulf of Maine (strata 01240-01400), with L&I consumption estimates overlaid.



Appendix C2. Figure 13. PPI vs. PPI with redfish not included, and PPI without redfish, dogfish, herring and haddock.

Appendix C3. Technical documentation for Collie-Sissenwine Analysis (CSM, Version 4) stock assessment model

CSA is a relatively simple two-bin stock assessment model that estimates abundance, fishing mortality and recruitment using total catch numbers and survey data (Collie and Sissenwine 1983; Conser 1995). The "recruit" group in the model consists of animals that will recruit at or during the current time step. The "post-recruit" group contains all older individuals. Typically, both groups are assumed fully available to the fishery but this assumption can be relaxed in practice if fishing mortality rates are viewed as rates for fully recruited animals.

CSA (Version 4) used in this assessment was completely reprogrammed in AD-Model Builder during 2013 and is available with a graphical user interface in the NOAA Fisheries Toolbox at http://nft.nefsc.noaa.gov/. The update uses maximum likelihood rather than weighted sums of squares to estimate parameters. Multiple survey indices of two types can be used and the user must supply survey and year specific CVs that measure the precision of survey and catch observations. Pope's approximation is no longer used to simulate the population because accuracy of the approximation degrades at high mortality rates and because Baranov's catch equation (which assumes continuous fishing) works well for pulse fisheries in most cases. As in previous versions, natural morality in each year is specified by the user and not estimable in the model. The updated model does not allow for process errors because their original formulation was problematic and did not improve model performance, they can be difficult to estimate objectively, and because they are no longer required with high fishing mortality rates to avoid negative abundance estimates and numerical problems (Mesnil 2003 and p. 39 in ASMFC 2006).

Population dynamics

Abundance in each year N_y is:

$$N_y = P_y + R_y$$

where R_y is the number of new recruits to the model in year y and P_y is the abundance of all older individuals. Post-recruits are related to total abundance in the previous year:

$$P_y = N_{y-1} e^{-Z_{y-1}}$$

where $Z_y = F_y + M_y$ is the instantaneous annual rate for total mortality, and F_y and M_y are instantaneous annual rates for fishing and natural mortality. Stock biomass is calculated:

$$B_y = N_y b_y$$

where b_y is a mean weight per individual.

Post-recruits in the first year, recruitments and fishing mortality rates are parameters that can be estimated in the model. Natural mortality rates and mean weights are specified by the user and may change over time.

Observations

Predicted catch in number is calculated:

$$\hat{C}_y = \frac{F_y}{Z_y} N_y (1 - e^{-Z_y})$$

Catch weight is:

$$W_y = \hat{C}_y w_y$$

where w_y is the mean weight of individuals in the catch as specified by the user.

There are two types of surveys in the model. A "recruit/post-recruit" survey involves paired indices (one for recruits and the other for post-recruits) derived from the same survey. "Aggregate" surveys involve a single index (for recruits plus post-recruits, recruits only or post-recruits only, but see below in the latter case) from each survey. Recruit/post-recruit surveys involve an assumption about catchability of recruits relative to post-recruits. The aggregate approach is the same as used in most other stock assessment models but using a single selectivity parameter for recruits that can be estimated in the model (the selectivity of post-recruits is assumed equal to one and recruit selectivity can be larger or smaller).[1] Multiple surveys of either type can be used in the same model run. It is probably better, however, to use only one recruit/post-recruit pair at a time because relative catchability assumptions have a very strong effect on model estimates. Relative catchability assumptions for multiple surveys may conflict and cause serious problems with model fit.

Recruit/post-recruit survey data are pairs of survey indices and are derived from a single survey. Post-recruit indices are predicted:

$$\hat{p}_y = q_p P_y$$

where q_p is a catchability coefficient. Recruit indices are predicted:

$$\hat{r}_y = s_p q_p R_y$$

where s_p is a relative catchability parameter for recruits relative to post-recruits. Relative catchability is specified by the user while the catchability for post-recruits q_p is a parameter that can be estimated in the model.

Aggregate surveys are predicted:

$$\hat{u}_y = Q\left(gR_y + P_f\right)$$

where g and Q are selectivity and catchability parameters that can be estimated in the model.

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[1] To implement an aggregate survey for post-recruits only, set the recruit selectivity parameter to zero. To implement an aggregate survey for recruits only, fix or estimate the recruit selectivity parameter to be a value much larger than one.

Goodness of fit

Parameters are estimated to minimize the negative log likelihood of the data. The negative log likelihood used to measure goodness of fit to the catch data assumes that measurement errors are log normal :

$$\mathcal{L} = \sum_{y} \left\{ \ln(s) + 0.5 \left[\frac{\ln(C_y) - \ln(\hat{C}_y)}{s} \right]^2 \right\}$$

where s is a log scale standard deviation based on an assumed CV measurement errors in the catch data that are supplied by the user:

$$s = \sqrt{\ln(CV^2 + 1)}$$

The negative log likelihood for goodness of fit to a survey index also assumes log normal errors but the standard deviation may vary from year to year and among surveys. Using an aggregate survey as an example:

$$\mathcal{L} = \sum_{y} \left\{ \ln s_y + 0.5 \left[\frac{\ln(u_y) - \ln(\hat{u}_y)}{s_y} \right]^2 \right\}$$

The annual variances are calculated from CVs for measurement errors in each survey observation that are supplied by the user.

The total negative log likelihood used to estimate parameters is:

$$\mathcal{L}_{total} = \sum_{j} \omega_j \mathcal{L}_j$$

where the ω_j are user specified weights for each type of data in the model. The user specified weights are normally one except during sensitivity or other types of diagnostic analyses.

The user can "tune" variances used in goodness of fit calculations by adjusting the assumed CVs. In particular, the assumed CVs may be adjusted over the course of several runs until the implied CV based on residuals approximately matches the assumed value:

$$CV_{implied} = \sqrt{e^{s^2} - 1}$$

and s^2 is the variance of the log scale residuals.

Variances for model parameters and other model estimates can be calculated in CSA by asymptotic approximation or MCMC analysis. The software produces a comma delimited database file containing data, estimates and diagnostics as well as a separate output file for likelihood profile analysis. The NOAA Fisheries Tool Box GUI produces a number of useful graphics and diagnostics. An R program that creates graphics and additional diagnostics is also available on the Tool Box website.

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Appendix C4. Parameter estimates from CSA final model.

index	name	value	std.dev	index	name	value	std.dev	index	name	value	std.dev	index	name	value	std.dev
1	logrhat	6.91	0.33	61	logqhat	-0.6304	0.1614	121	f_calc	0.11	0.02	181	totnum	2213.8	537.5
2	logrhat	7.06	0.28	62	logqhat	-1.9209	0.2062	122	f_calc	0.33	0.08	182	totnum	5695.7	1174.0
3	logrhat	6.77	0.30	63	logqhat	0.0540	0.3174	123	f_calc	0.49	0.11	183	totnum	9145.7	1772.6
4	logrhat	6.56	0.29	64	logphat1	6.8974	0.4082	124	f_calc	0.55	0.18	184	totnum	4647.5	946.6
5	logrhat	6.79	0.31	65	logsrx[2]	0.0000	0.0002	125	f_calc	0.13	0.05	185	totnum	2880.1	623.1
6	logrhat	7.05	0.24	66	logsrx[3]	-6.9077	0.1925	126	f_calc	0.00	0.00	186	totnum	2552.4	546.4
7	logrhat	6.66	0.25	67	rhat	998.0	328.8	127	qhat	0.53	0.09	187	totnum	2183.4	387.0
8	logrhat	6.33	0.26	68	rhat	1166.9	332.0	128	qhat	0.15	0.03	188	totnum	885.9	219.3
9	logrhat	6.25	0.26	69	rhat	873.8	266.3	129	qhat	1.06	0.33	189	totnum	315.9	112.9
10	logrhat	6.76	0.30	70	rhat	705.9	206.1	130	phat	989.68	403.97	190	totnum	153.4	58.5
11	logrhat	6.95	0.29	71	rhat	887.2	272.8	131	phat	1177.70	342.27	191	totbio	14.47	3.49
12	logrhat	6.92	0.25	72	rhat	1148.7	270.0	132	phat	1289.30	334.76	192	totbio	19.82	4.21
13	logrhat	6.49	0.29	73	rhat	778.0	196.9	133	phat	1126.60	305.96	193	totbio	19.56	4.12
14	logrhat	6.75	0.36	74	rhat	560.3	147.7	134	phat	1223.30	320.03	194	totbio	16.66	3.83
15	logrhat	6.75	0.34	75	rhat	518.2	136.9	135	phat	1264.90	319.52	195	totbio	14.84	3.20
16	logrhat	5.76	0.32	76	rhat	864.5	261.3	136	phat	1330.60	332.97	196	totbio	18.37	3.67
17	logrhat	6.46	0.34	77	rhat	1042.0	299.5	137	phat	1127.90	293.97	197	totbio	19.86	4.23
18	logrhat	6.01	0.37	78	rhat	1016.9	254.8	138	phat	999.42	275.46	198	totbio	16.10	3.74
19	logrhat	7.08	0.28	79	rhat	657.9	190.0	139	phat	962.49	266.14	199	totbio	13.65	3.34
20	logrhat	6.65	0.42	80	rhat	855.3	304.5	140	phat	1092.60	295.76	200	totbio	11.98	2.74
21	logrhat	7.45	0.29	81	rhat	853.5	289.7	141	phat	1031.50	288.23	201	totbio	15.12	2.85
22	logrhat	8.39	0.23	82	rhat	317.0	101.7	142	phat	600.48	220.71	202	totbio	16.69	3.15
23	logrhat	8.69	0.22	83	rhat	640.8	220.4	143	phat	312.69	151.93	203	totbio	10.22	2.01
24	logrhat	6.43	0.39	84	rhat	407.6	149.0	144	phat	525.85	235.60	204	totbio	7.54	2.14
25	logrhat	6.85	0.29	85	rhat	1183.2	330.7	145	phat	841.41	221.47	205	totbio	9.62	2.13
26	logrhat	6.99	0.28	86	rhat	769.1	324.5	146	phat	507.00	155.61	206	totbio	9.93	2.26
27	logrhat	7.16	0.21	87	rhat	1721.9	505.7	147	phat	483.17	146.02	207	totbio	8.22	2.02
28	logrhat	5.61	0.41	88	rhat	4386.8	1007.8	148	phat	515.08	135.05	208	totbio	6.73	1.64
29	logrhat	4.40	0.39	89	rhat	5943.9	1335.3	149	phat	526.59	140.54	209	totbio	9.17	2.07
30	logrhat	2.65	0.46	90	rhat	620.7	243.2	150	phat	491.95	179.47	210	totbio	9.01	2.43
31	logf_calc	-1.47	0.26	91	rhat	944.3	274.6	151	phat	1308.90	364.90	211	totbio	16.62	3.91
32	logf_calc	-1.56	0.24	92	rhat	1084.6	300.9	152	phat	3201.80	691.58	212	totbio	34.65	7.01
33	logf_calc	-1.32	0.24	93	rhat	1286.9	274.1	153	phat	4026.70	851.99	213	totbio	63.30	12.11
34	logf_calc	-1.92	0.25	94	rhat	274.2	113.3	154	phat	1935.80	461.58	214	totbio	39.53	8.07
35	logf_calc	-1.72	0.24	95	rhat	81.7	32.0	155	phat	1467.80	353.04	215	totbio	26.06	5.67
36	logf_calc	-1.42	0.23	96	rhat	14.2	6.5	156	phat	896.52	264.28	216	totbio	22.26	4.78
37	logf_calc	-1.54	0.24	97	f_calc	0.23	0.06	157	phat	611.77	173.23	217	totbio	15.80	2.95
38	logf_calc	-1.59	0.25	98	f_calc	0.21	0.05	158	phat	234.16	98.54	218	totbio	6.81	1.69
39	logf_calc	-1.88	0.26	99	f_calc	0.27	0.06	159	phat	139.24	56.51	219	totbio	2.92	1.07
40	logf_calc	-1.69	0.25	100	f_calc	0.15	0.04	160	phat	76.89	29.34	220	totbio		
41	logf_calc	-0.89	0.23	101	f_calc	0.18	0.04	161	totnum	1987.7	459.9				
42	logf_calc	-0.32	0.26	102	f_calc	0.24	0.05	162	totnum	2344.7	494.3				
43	logf_calc	0.04	0.30	103	f_calc	0.21	0.05	163	totnum	2163.1	450.3				
44	logf_calc	-0.80	0.36	104	f_calc	0.20	0.05	164	totnum	1832.5	414.2				
45	logf_calc	-1.66	0.24	105	f_calc	0.15	0.04	165	totnum	2110.5	446.0				
46	logf_calc	-1.11	0.26	106	f_calc	0.18	0.05	166	totnum	2413.6	475.2				
47	logf_calc	-1.69	0.28	107	f_calc	0.41	0.10	167	totnum	2108.6	443.9				
48	logf_calc	-2.69	0.26	108	f_calc	0.73	0.19	168	totnum	1688.1	379.4				
49	logf_calc	-2.06	0.25	109	f_calc	1.05	0.31	169	totnum	1517.6	360.1				
50	logf_calc	-1.32	0.32	110	f_calc	0.45	0.16	170	totnum	1827.0	411.7				
51	logf_calc	-1.97	0.26	111	f_calc	0.19	0.05	171	totnum	2134.6	397.6				
52	logf_calc	-3.06	0.22	112	f_calc	0.33	0.09	172	totnum	2048.4	373.1				
53	logf_calc	-2.43	0.21	113	f_calc	0.18	0.05	173	totnum	1258.3	224.7				
54	logf_calc	-1.84	0.22	114	f_calc	0.07	0.02	174	totnum	1168.0	336.6				
55	logf_calc	-2.24	0.23	115	f_calc	0.13	0.03	175	totnum	1379.4	300.5				
56	logf_calc	-1.12	0.25	116	f_calc	0.27	0.09	176	totnum	1158.4	256.6				
57	logf_calc	-0.72	0.22	117	f_calc	0.14	0.04	177	totnum	1147.8	288.8				
58	logf_calc	-0.60	0.32	118	f_calc	0.05	0.01	178	totnum	890.8	218.2				
59	logf_calc	-2.05	0.38	119	f_calc	0.09	0.02	179	totnum	1698.3	399.3				
60	logf_calc	-16.22	0.38	120	f_calc	0.16	0.04	180	totnum	1295.7	363.8				

Appendix C5. Changes to Gulf of Maine Northern Shrimp Data Since the 2007 SAW

Landings data from the NMFS landings database (derived from dealer reports) were queried in 2009 (and again in 2012 without change), and the northern shrimp landings for 1958 through 1999 were updated for the 2013 assessment. See Appendix C5 Table 1 for a comparison. Most changes were small, with a mix of additions and reductions. The greatest change was the addition of 373 mt to the 1996 landings.

Landings data for 2000 through 2006 were queried from the federal and Maine state harvester report data in 2011, and are compared with data from the 2007 SAW in Appendix C5 Table 1. All data differences were additions, with the greatest being the addition of 465 mt in 2000 (which had previously been based on the dealer database) and an additional 446 mt in 2006 (the terminal year at the time of the 2007 SAW), probably due to the receipt of additional, late 2006 harvester reports.

The numbers of vessels in the fishery for recent years (since 1997) was also reported in the 2007 SAW report. In 2011, corrections were made to these data. 1997 through 1999 were compared with the data reported in the 1997 through 1999 NSTC stock assessment reports and one minor modification was made. For 2000 through 2006, the vessel counts were re-calculated from the harvester report database. The most notable differences were for 2003, in which the number of vessels had been over-reported by about 12% in the earlier report, possibly because of double counting of vessels that were in both the federal and Maine state databases, and for 2006, the terminal year for the 2007 report, in which vessels were under-reported by about 17%, probably because of late harvester reporting (Appendix C5 Table 2).

The numbers of trips in the fishery were also re-calculated for 2000 through 2006. In the 2007 report, trap trips for 2000-2006 had not been included, so the total number of trips increased about 15% to 30%. The total trips for 1987 were also adjusted to include a few out-of-season experimental trips, to be consistent with other years (Appendix C5 Table 3).

During 2013, the NSTC reviewed all the port sample data from 1985 through 2012, in an effort to standardize and computerize all data, particularly for Maine, by reviewing raw data sheets and older databases. Data for samples that had not been computerized were found and added, and others were corrected. A few samples that were found to be incomplete in the databases (some lengths missing or the catch or sample weights missing) and for which no raw data sheets could be found were eliminated. The biggest change was the addition of several samples for 1993, which resulted in a 10% increase in the number of shrimp measured for that year (Appendix C5 Table 4).

The NSTC also reviewed and changed the way the port sample data were expanded to landings to estimate the total number of shrimp in catches. In the past, all the samples for each state-month-gear were pooled, and the average weight of a shrimp was calculated by dividing the total weight of the samples by the total number of northern shrimp in those samples, for each state, month, and gear. Then the landings for that state-month-gear were divided by the average weight of one shrimp, to estimate the total number of shrimp in the landings, for each season. In 2013, the NSTC recalculated these estimates for 1985-2013, by first expanding each sample to that sample's catch weight before pooling by state, month and gear. This resulted in larger catches being more heavily weighted in the calculation. This had a relatively small effect, without trend, on the calculation of the mean weight of a shrimp, however. The greatest change was a 6% increase in the mean weight in 1999. (Appendix C5 Table 5).

The changes noted above to the landings data, corrections to the port sample data, and the re-weighting of the sample data, all resulted in changes to the estimated number of shrimp in the landings, used in the CSA model input. Most notable were increases in the 2000-2006 estimates, closely aligned with the increases in reported landings described above, with the largest increase of 19% in 2006 (the terminal year) (Appendix C5 Table 6).

Maine pounds per hour towing data from port interviews were unchanged, except that the 1999 value was corrected from 152 lbs/hr to 147 lbs/hr because of the addition of data for 27 more interviews.

Pounds per trip changed somewhat because of the changes to the total landings and the number of trips described above. Pounds per trip generally declined for 2000-2006 in the 2013 assessment because of the inclusion of trap trips, which usually have a lower mean catch rate per trip than trawl trips (Appendix C5 Table 7).

Minor corrections were made to the ASMFC summer survey data. For the 1985 survey, the retransformed age 1.5 number per tow was corrected from 337 to 332, the >22mm number per tow from 1,184 to 1,169, and the total number per tow from 1,849 to 1,825. For the 2006 survey, the retransformed age 1.5 number per tow was corrected from 423 to 374, the >22mm number per tow from 2,703 to 2,773, and the total number per tow from 9,996 to 9,998.

Appendix C5. Table 1. Northern shrimp landings data (mt) as reported in the 2007 SAW report compared with the 2013 assessment.

	2013		2007 SAW		Difference (mt)	% of 2013
	annual	seasonal	annual	seasonal		
1958	2.2		2.3		-0.1	-4.5%
1959	7.8		7.7		0.1	1.3%
1960	40.9		40.9		0.0	0.0%
1961	30.8		30.9		-0.1	-0.3%
1962	175.7		176.0		-0.3	-0.2%
1963	254.7		254.4		0.3	0.1%
1964	422.5		422.5		0.0	0.0%
1965	949.3		955.0		-5.7	-0.6%
1966	1,766.4		1,766.4		0.0	0.0%
1967	3,171.2		3,171.1		0.1	0.0%
1968	6,610.2		6,610.0		0.2	0.0%
1969	12,824.3		12,823.9		0.4	0.0%
1970	10,669.5		10,669.3		0.2	0.0%
1971	11,129.6		11,129.3		0.3	0.0%
1972	11,095.0		11,094.9		0.1	0.0%
1973	9,404.7		9,404.8		-0.1	0.0%
1974	7,944.7		7,944.7		0.0	0.0%
1975	5,286.6		5,286.7		-0.1	0.0%
1976	1,022.4		1,022.3		0.1	0.0%
1977	381.2		387.2		-6.0	-1.6%
1978	3.3		0.0		3.3	100.0%
1979	438.7		486.5		-47.8	-10.9%
1980	332.8		339.1		-6.3	-1.9%
1981	1,073.9		1,071.2		2.7	0.3%
1982	1,574.3		1,574.5		-0.2	0.0%
1983	1,573.9		1,566.5		7.4	0.5%
1984	3,226.9		3,226.8		0.1	0.0%
1985		4,131.9		4,130.9	1.0	0.0%
1986		4,635.0		4,635.0	0.0	0.0%
1987		5,266.0		5,253.2	12.8	0.2%
1988		3,035.6		3,031.3	4.3	0.1%
1989		3,315.4		3,315.4	0.0	0.0%
1990		4,662.5		4,661.6	0.9	0.0%
1991		3,585.3		3,571.4	13.9	0.4%
1992		3,460.0		3,443.6	16.4	0.5%
1993		2,142.9		2,142.9	0.0	0.0%
1994		2,915.2		2,914.8	0.4	0.0%
1995		6,456.6		6,466.4	-9.8	-0.2%
1996		9,539.4		9,166.1	373.3	3.9%
1997		7,119.5		7,079.1	40.4	0.6%
1998		4,166.8		4,174.4	-7.6	-0.2%
1999		1,865.9		1,816.1	49.8	2.7%
2000		2,855.0		2,389.5	465.5	16.3%
2001		1,331.0		1,329.1	1.9	0.1%
2002		452.7		423.7	29.0	6.4%
2003		1,344.4		1,211.00	133.4	9.9%
2004		2,131.4		1,948.70	182.7	8.6%
2005		2,610.1		2,553.20	56.9	2.2%
2006		2,322.7		1,876.60	446.1	19.2%

Appendix C5. Table 2. Northern shrimp fishery numbers of vessels in the 2007 SAW report compared with the 2013 assessment.

	2013	2007 SAW	Difference	% of 2013
1997	311	310	1	0.3%
1998	260	260	0	0.0%
1999	238	238	0	0.0%
2000	304	285	19	6.3%
2001	275	288	-13	-4.7%
2002	198	200	-2	-1.0%
2003	222	248	-26	-11.7%
2004	192	190	2	1.0%
2005	197	197	0	0.0%
2006	144	119	25	17.4%

Appendix C5. Table 3. Northern shrimp fishery numbers of trips in the 2007 SAW report compared with the 2013 assessment.

	2013	2007 SAW	Difference	% of 2013
1987	12,497	12,285	212	1.7%
1988	9,240	9,240	0	0.0%
1989	9,561	9,561	0	0.0%
1990	9,758	9,758	0	0.0%
1991	7,968	7,968	0	0.0%
1992	7,798	7,798	0	0.0%
1993	6,158	6,158	0	0.0%
1994	5,990	5,990	0	0.0%
1995	10,465	10,465	0	0.0%
1996	11,791	11,791	0	0.0%
1997	10,734	10,734	0	0.0%
1998	6,606	6,606	0	0.0%
1999	3,811	3,811	0	0.0%
2000	4,554	3,335	1,219	26.8%
2001	4,133	3,599	534	12.9%
2002	1,304	1,010	294	22.5%
2003	3,022	2,157	865	28.6%
2004	2,681	2,277	404	15.1%
2005	3,866	3,091	775	20.0%
2006	2,478	1,646	832	33.6%

Appendix C5. Table 4. Numbers of shrimp measured from port samples, as reported in the 2007 SAW report compared with the 2013 assessment.

	2013	2007 SAW	Difference	% of 2013
1985	6,032	5,998	34	1%
1986	6,415	6,259	156	2%
1987	5,699	5,603	96	2%
1988	6,393	6,079	314	5%
1989	8,885	9,351	-466	-5%
1990	8,132	8,248	-116	-1%
1991	15,058	14,611	447	3%
1992	10,225	10,111	114	1%
1993	12,852	11,556	1,296	10%
1994	12,221	11,076	1,145	9%
1995	14,270	13,977	293	2%
1996	28,320	27,903	417	1%
1997	35,033			
1998	23,916			
1999	22,529			
2000	11,458			
2001	14,714	15,091	-377	-3%
2002	5,243	5,243	0	0%
2003	11,805	11,596	209	2%
2004	10,972	10,432	540	5%
2005	19,539	19,539	0	0%
2006	16,218	16,314	-96	-1%

Appendix C5. Table 5. Mean weight of a shrimp (g) in the landings, as used by CSA in the 2007 SAW report compared with the 2013 assessment.

	2013	2007 SAW	Difference	% of 2013
1985	11.6	11.7	-0.1	-0.9%
1986	12.6	12.8	-0.3	-2.2%
1987	12.4	12.4	0.1	0.5%
1988	13.8	13.3	0.5	3.8%
1989	11.2	11.7	-0.5	-4.4%
1990	10.7	10.5	0.1	1.2%
1991	10.7	11.2	-0.4	-4.2%
1992	12.9	13.1	-0.2	-1.6%
1993	11.5	11.0	0.5	4.0%
1994	11.1	10.8	0.3	2.8%
1995	10.3	10.5	-0.2	-2.1%
1996	11.0	11.5	-0.4	-4.0%
1997	9.9	10.0	0.0	-0.1%
1998	11.5	11.2	0.4	3.2%
1999	9.0	8.4	0.6	6.3%
2000	10.9	11.4	-0.5	-4.4%
2001	9.4	9.4	-0.1	-0.6%
2002	9.6	9.5	0.1	0.9%
2003	10.5	10.7	-0.2	-1.4%
2004	9.6	9.8	-0.2	-1.7%
2005	10.9	10.9	0.0	-0.3%
2006	11.4	11.5	0.0	-0.2%

Appendix C5. Table 6. Estimated numbers of shrimp (millions) in landings, as used by CSA in the 2007 SAW report compared with the 2013 assessment.

	2013	2007 SAW	Difference	% of 2013
1985	356	353	3	1%
1986	369	361	8	2%
1987	424	425	-1	0%
1988	220	228	-8	-4%
1989	296	284	12	4%
1990	437	442	-5	-1%
1991	335	320	15	4%
1992	268	262	6	2%
1993	187	195	-8	-4%
1994	263	270	-7	-3%
1995	627	615	12	2%
1996	865	799	66	8%
1997	716	711		
1998	361	374		
1999	207	215		
2000	261	209		
2001	142	141	1	1%
2002	47	44	3	6%
2003	128	114	14	11%
2004	221	199	22	10%
2005	240	234	6	3%
2006	203	164	39	19%

Appendix C5. Table 7. Mean pounds per trip from the 2007 SAW report compared with the 2013 assessment.

	2013	2007 SAW	Difference	% of 2013
1991	992	988	4	0.4%
1992	978	974	4	0.4%
1993	767	767	0	0.0%
1994	1,073	1,073	0	0.0%
1995	1,360	1,362	-2	-0.1%
1996	1,784	1,714	70	3.9%
1997	1,462	1,454	8	0.6%
1998	1,391	1,317	74	5.3%
1999	1,079	1,067	12	1.1%
2000	1,382	1,444	-62	-4.5%
2001	710	740	-30	-4.2%
2002	765	831	-66	-8.6%
2003	981	1,029	-48	-4.9%
2004	1,753	1,821	-68	-3.9%
2005	1,488	1,541	-53	-3.5%
2006	2,066	2,252	-186	-9.0%

Appendix C6. Additional Model Runs Conducted during SARC58 Review

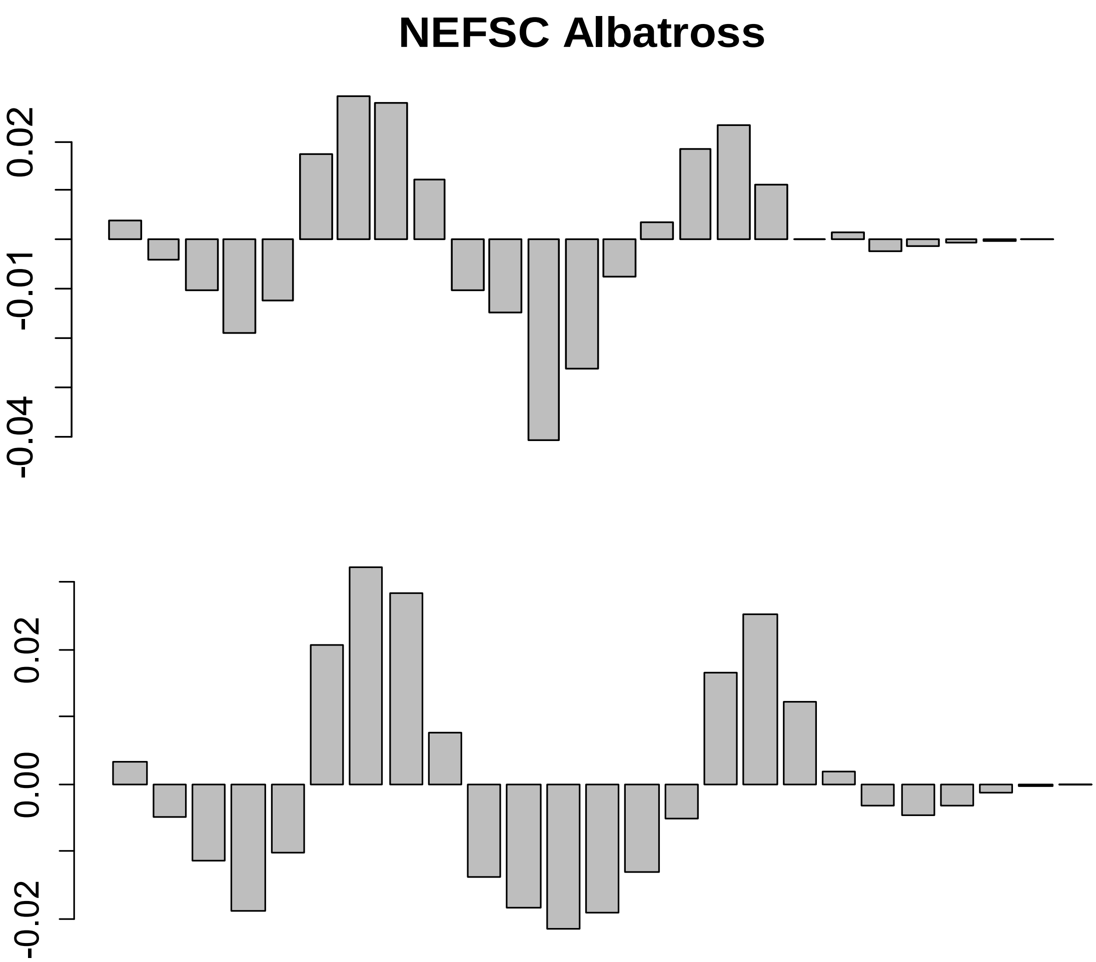
The Panel requested additional runs of the UME and CSA model at the workshop to explore the effects of data weighting on the fit to the indices and model estimates of F.

Table C6.1 Requested and additional weighting schemes for the UME model. All runs were done with M=0.5 for all size classes.

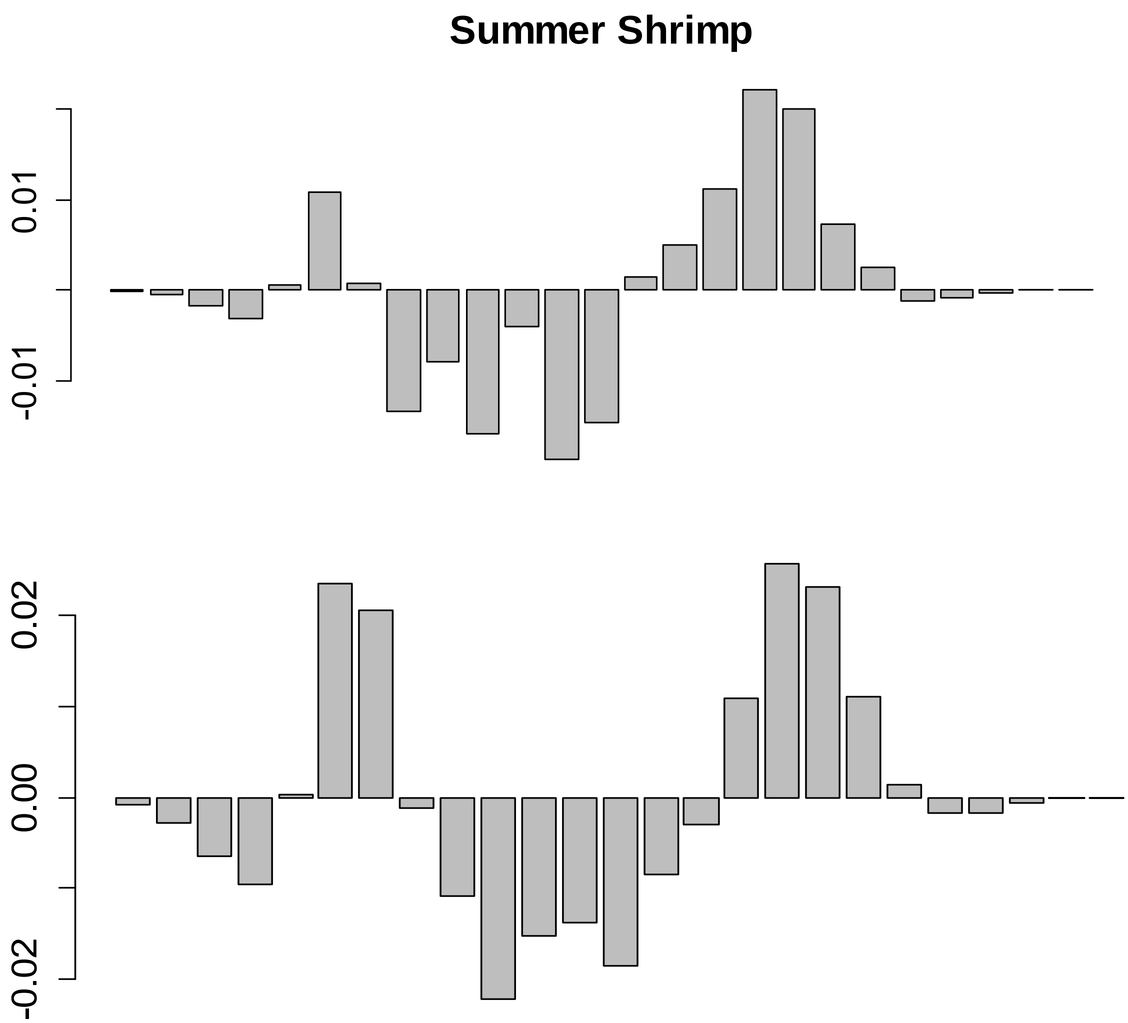
Base Model	Panel Request
Survey λ = 1 **Total catch λ = 1** **Size comp. λ = 1** **Survey CVs = CSA adjusted** **Catch CV = 0.05**	Survey λ = 2 Total catch λ = 0.5 Size comp. λ = 1 Survey CVs = CSA adjusted Catch CV = 0.05

Table C6.2. Base model and additional weighting schemes considered for the CSA model.

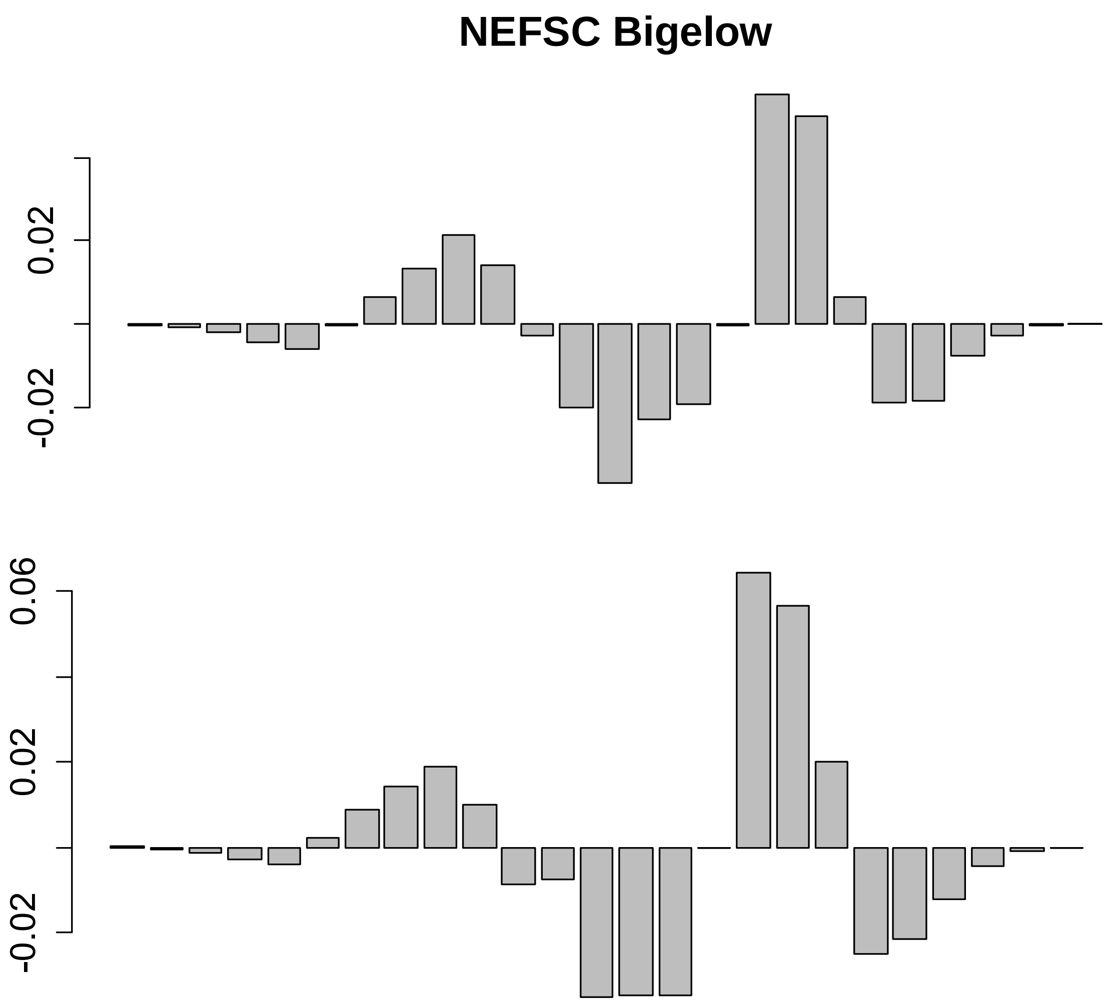
Base Model	Additional Runs	
All survey λ = 1 **Total catch λ = 1** **Survey CVs = CSA adjusted** **M=PPI** **Catch CV = 0.05**	Shrimp survey λ = 2 Total catch λ = 0.5 NEFSC survey λ = 1 Survey CVs = CSA adjusted M=PPI Catch CV=0.2	Shrimp survey λ = 2 Total catch λ = 0.01 NEFSC survey λ = 1 Survey CVs = CSA adjusted M=PPI Catch CV=0.2



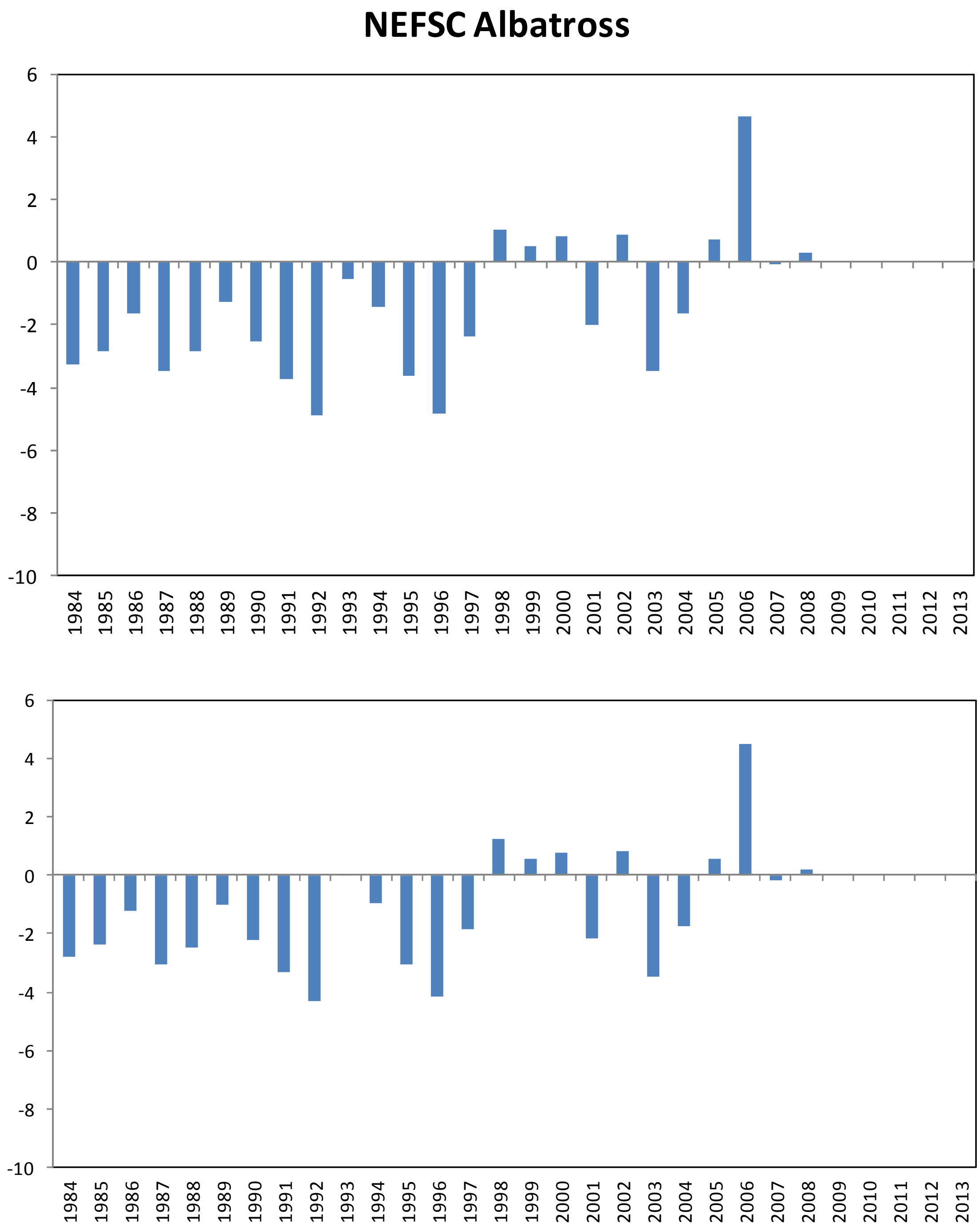
Appendix C6. Figure 1. Average proportion-at-size residuals for the NEFSC Albatross survey (observed - predicted) for the UME base model configuration (top) and the Panel's requested configuration (bottom).



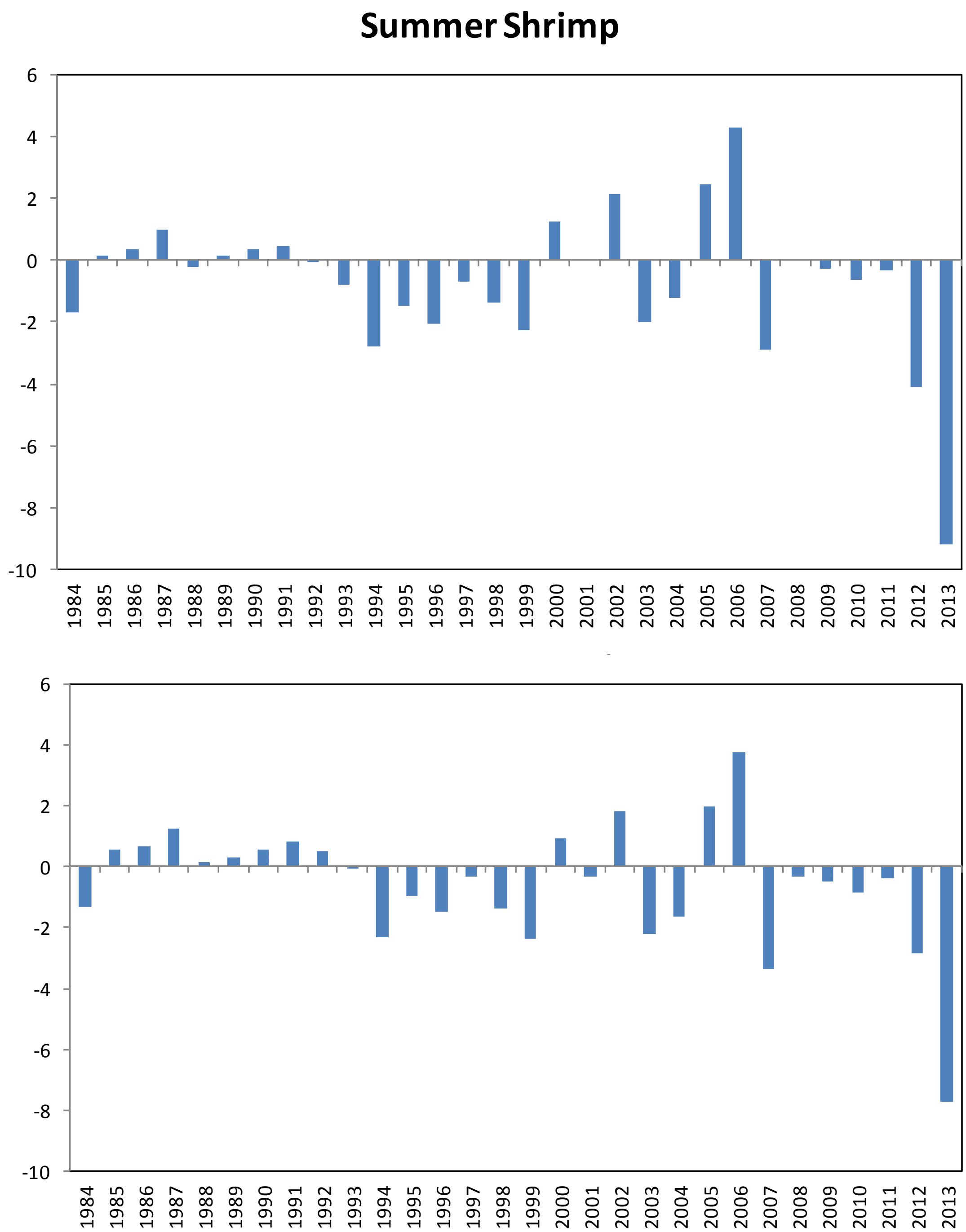
Appendix C6. Figure 2. Average proportion-at-size residuals for the ASMFC summer shrimp survey (observed - predicted) for the UME base model configuration (top) and the Panel's requested configuration (bottom).



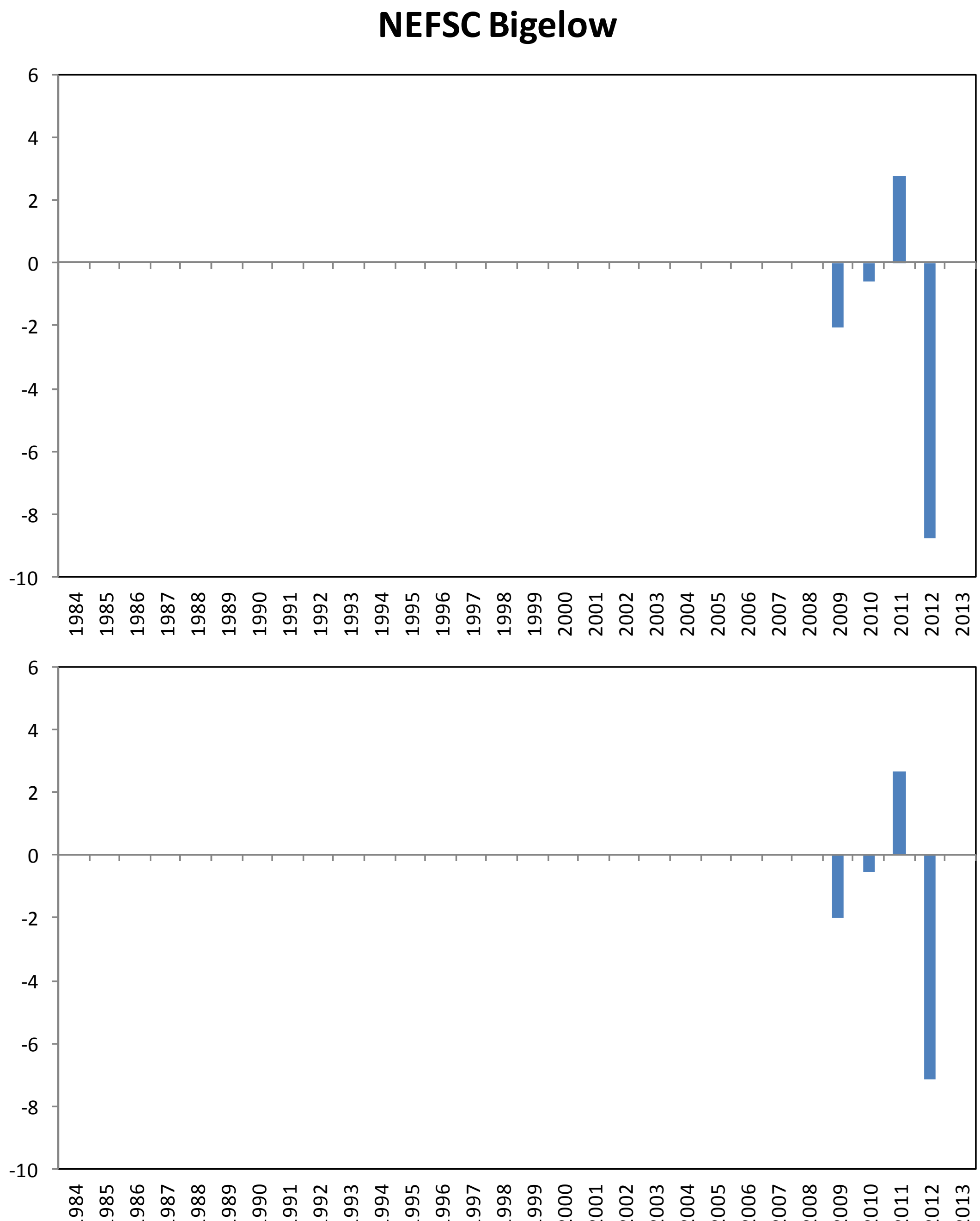
Appendix C6. Figure 3. Average proportion-at-size residuals for the NEFSC Bigelow survey (observed - predicted) for the UME base model configuration (top) and the Panel's requested configuration (bottom).



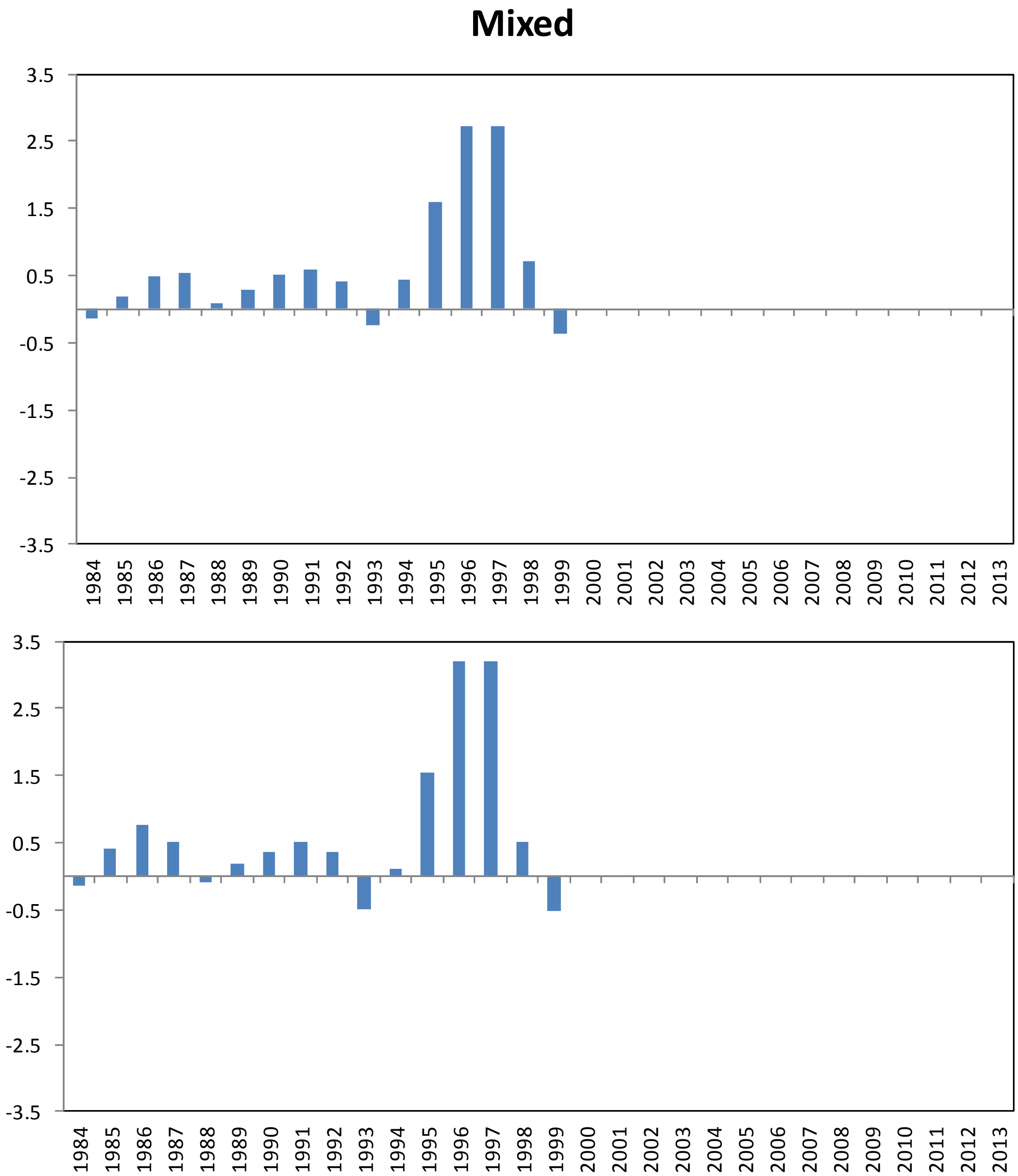
Appendix C6. Figure 4. Standardized residuals for the NEFSC Albatross index for the UME base model configuration (top) and the Panel's requested configuration (bottom).



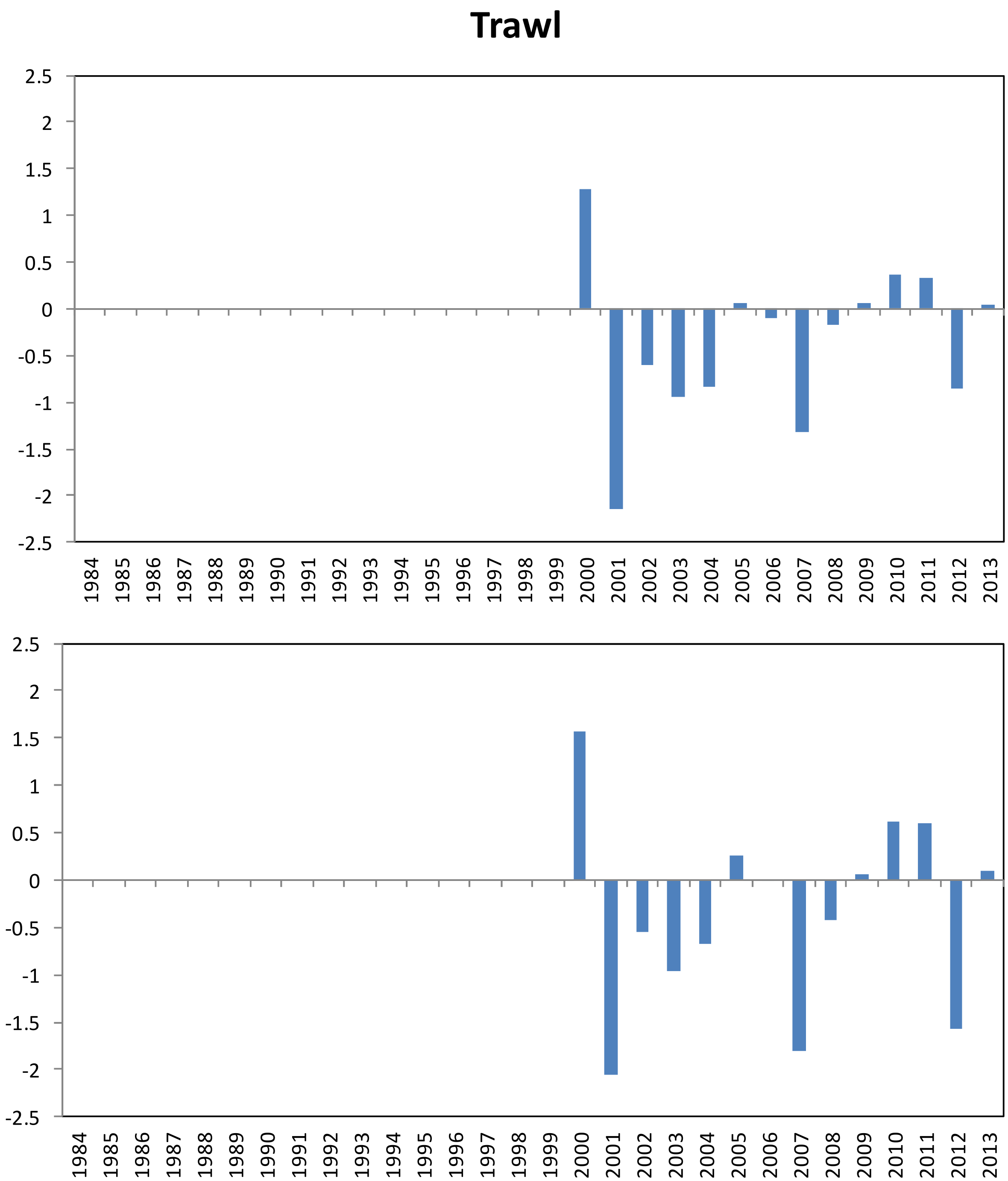
Appendix C6. Figure 5. Standardized residuals for the ASMFC summer shrimp survey index for the UME base model configuration (top) and the Panel's requested configuration (bottom).



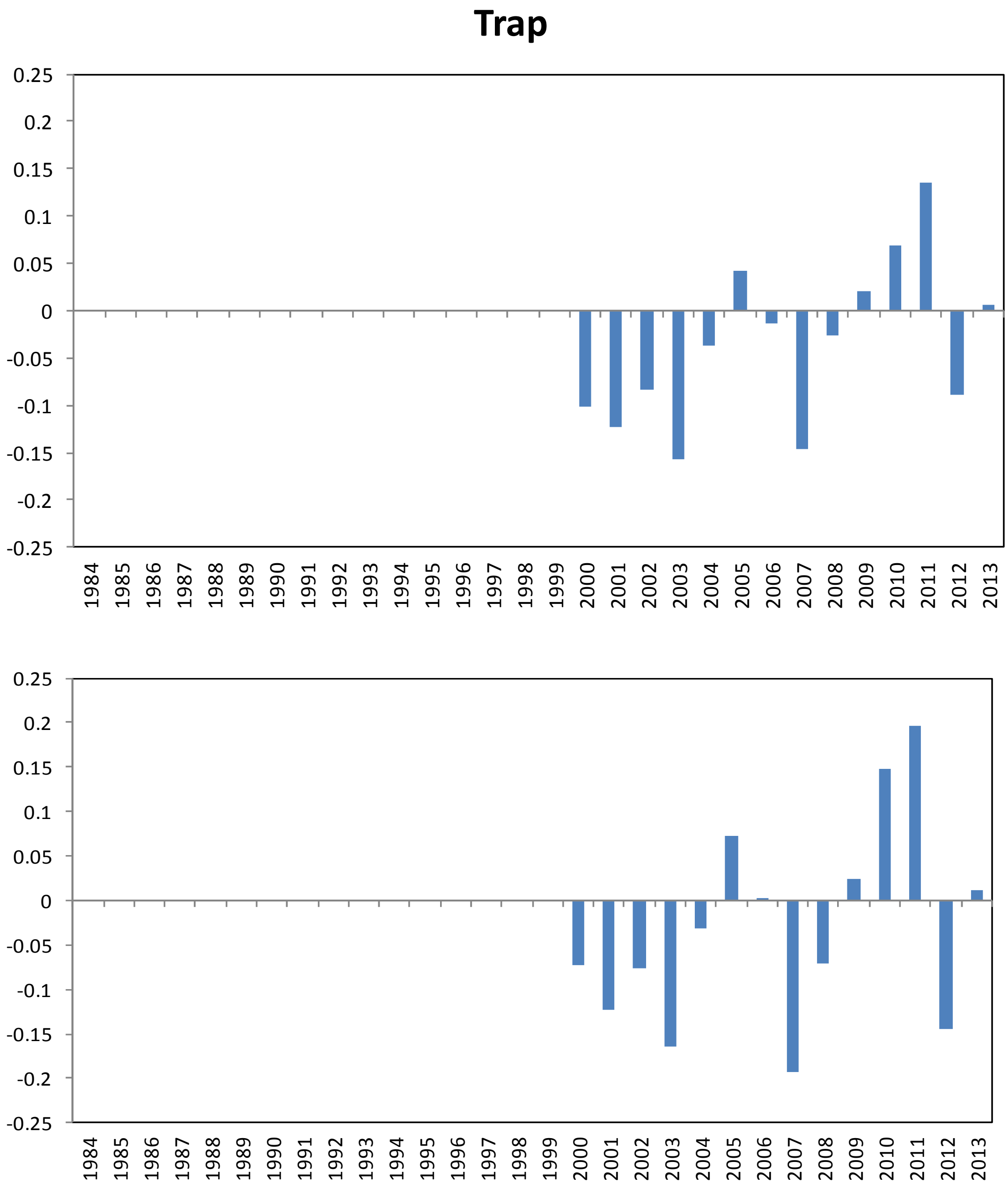
Appendix C6. Figure 6. Standardized residuals for the NEFSC Bigelow survey index for the UME base model configuration (top) and the Panel's requested configuration (bottom).



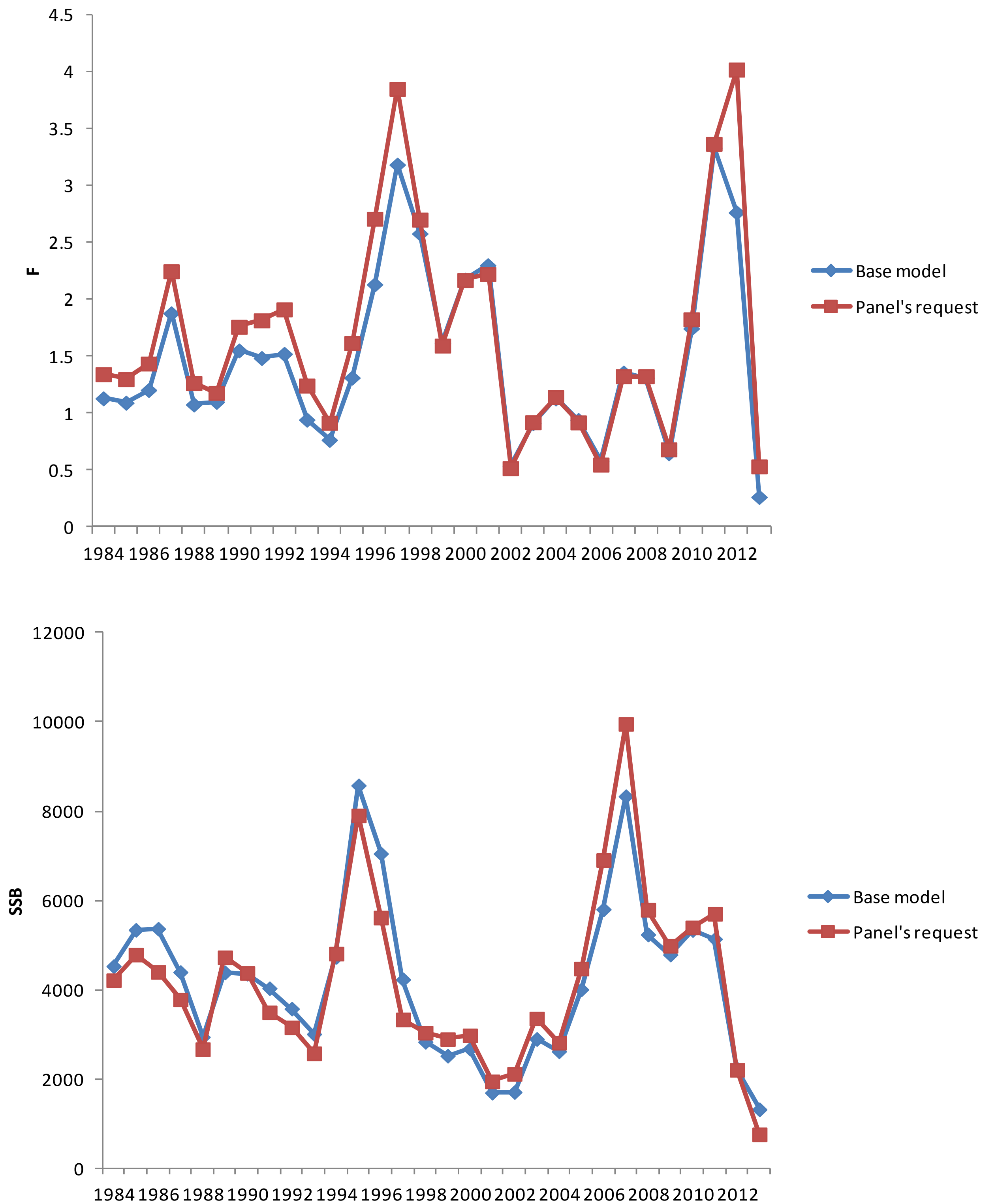
Appendix C6. Figure 7. Standardized residuals for total catch from the mixed fleet for the UME base model configuration (top) and the Panel's requested configuration (bottom).



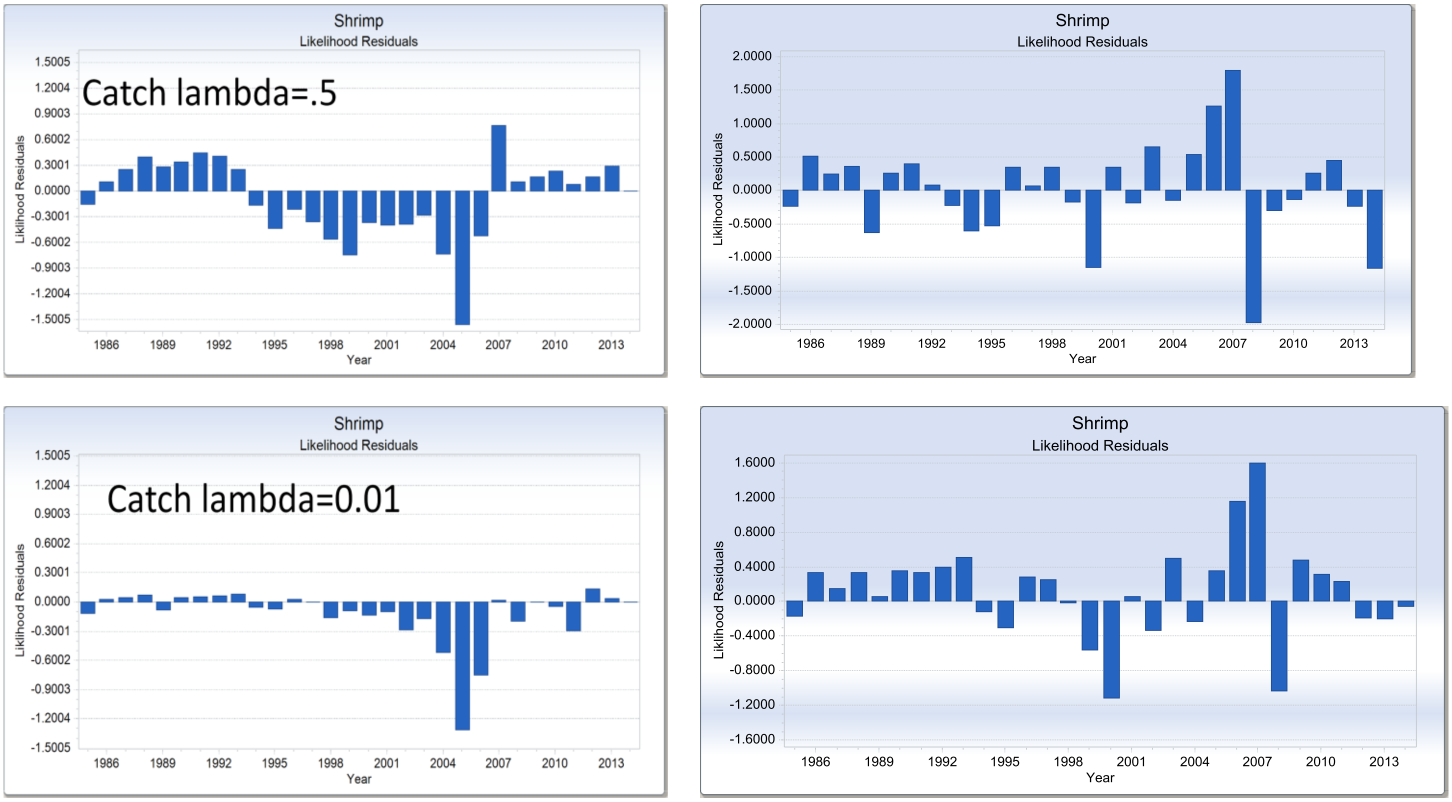
Appendix C6. Figure 8. Standardized residuals for total catch from the trawl fleet for the UME base model configuration (top) and the Panel's requested configuration (bottom).



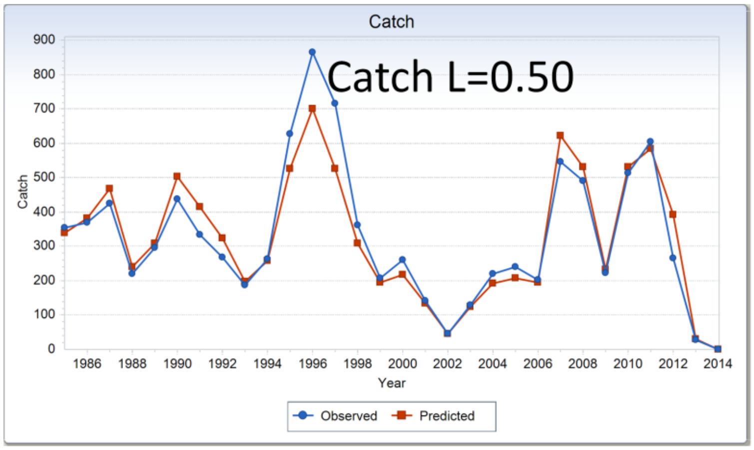
Appendix C6. Figure 9. Standardized residuals for total catch from the trap fleet for the UME base model configuration (top) and the Panel's requested configuration (bottom).

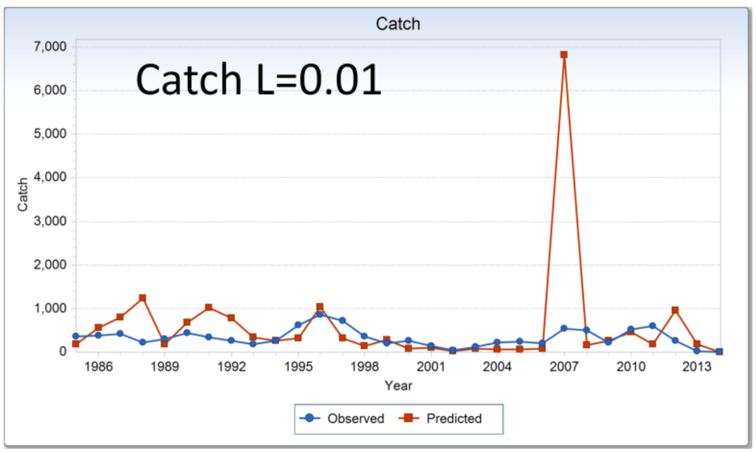


Appendix C6. Figure 10. Model estimates of F (top) and SSB (bottom) for the UME base model configuration and the Panel's requested configuration.

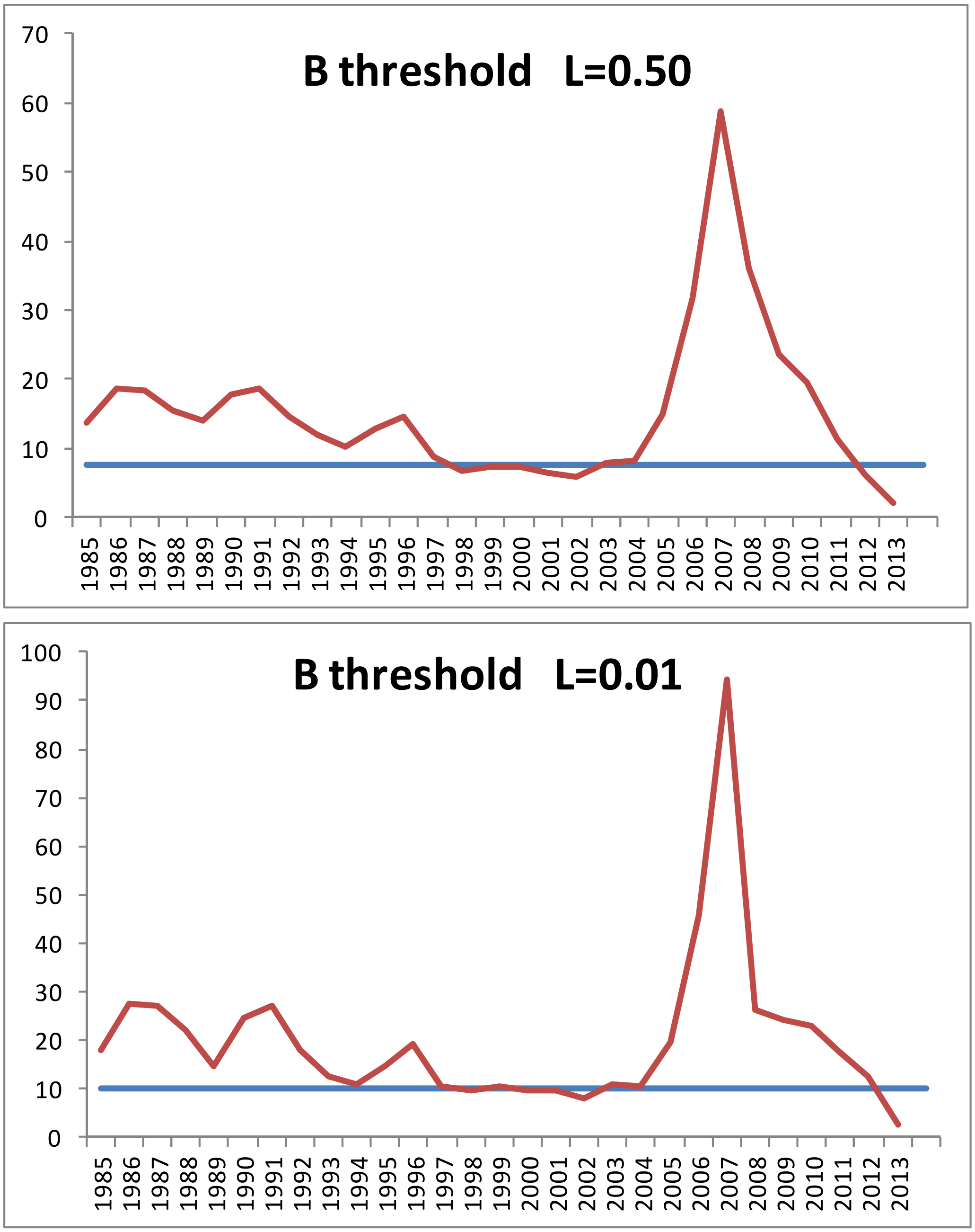


Appendix C6. Figure 11.Standardized residuals from the CSA model for the ASMFC summer shrimp survey index for recruits (left) and post-recruits (right), for different likelihood weights for total catch (λ=0.5, top, and λ=0.01, bottom).

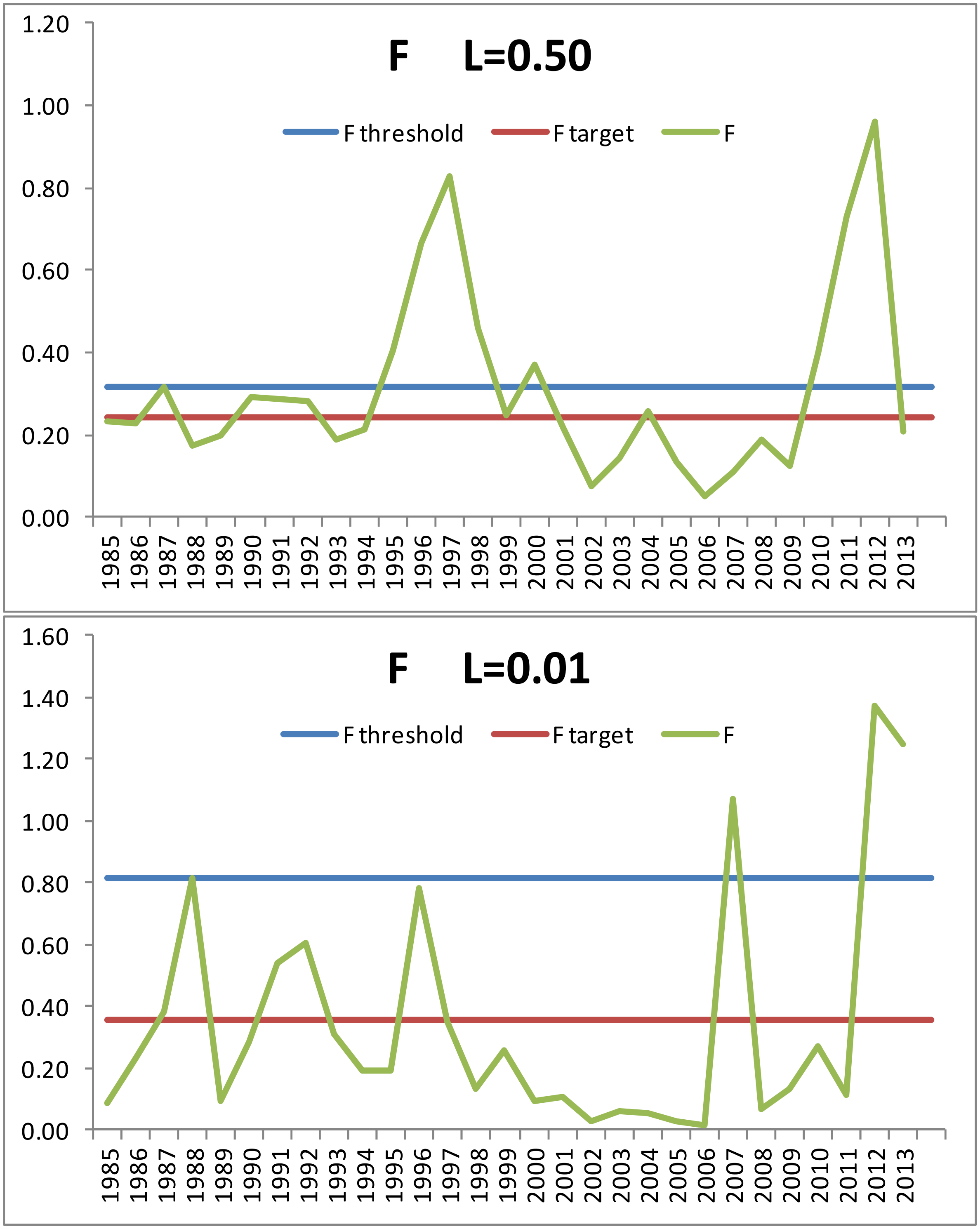




Appendix C6. Figure 12. Observed and predicted total catch from the CSA model for different likelihood weights (λ) on total catch.



Appendix C6. Figure 13. Biomass estimates from the CSA model compared to the biomass threshold estimates for total catch λ=0.5 (top) and total catch λ=0.01 (bottom).



Appendix C6. Figure 14. Fishing mortality estimates from the CSA model compared to the F target and threshold estimates for total catch λ=0.5 (top) and total catch λ=0.01 (bottom).

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