Butterfish
WP A-1
SAW 58
January 15, 2014

Stock Assessment of Butterfish (*Peprilus triacanthus*) in the Northwest Atlantic

January 2014

Coastal/Pelagic Working Group
Northeast Fisheries Science Center
National Marine Fisheries Service
Woods Hole Laboratory
Woods Hole, MA 02543

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
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 (*Loligo 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) spring and 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) spring and 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 better for the fall series, and the fall offshore survey is considered the most reliable abundance index because 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 each in the spring and fall series. State data were not used in the assessment.

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 because, 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.

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 ASAP assessment model software (Legault and Restreppo 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 spring and fall surveys and the Northeast Area Monitoring and Assessment Program spring and fall surveys; US landings and discard estimates, and commercial mean weights at age. NEFSC survey and commercial catch data. 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 Albatross IV and 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.

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. 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. 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.

Fishing mortality was estimated to be 0.02 in 2012, which is well below the proposed overfishing reference point F_{MSY} proxy = 0.85. There is a < 1% chance the estimated fishing mortality is above the F_{MSY} proxy.

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.

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.*

If the current fully recruited F (0.02) is 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.

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. TOR1,Table1,Fig1

2). Characterize the survey data that are being used in the assessment. Describe the magnitude of uncertainty in these sources of data.TOR2,Table2,Fig2

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). TOR3,Table3,Fig3

4). Evaluate consumptive removals of butterfish by its predators. If possible, integrate results into the stock assessment (TOR-5). TOR4,Table4,Fig4

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. TOR5,Table5,Fig5

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. TOR6,Fig6

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. TOR7,Fig7

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. TOR8,Table8,Fig8

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. TOR9

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 (*Loligo 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).

References

Edwards RL, Lawday L. 1960. Species Composition of Industrial Trawl-fish Landings in New England, 1958. Spec Sci Rep – Fisher 346. 20 p.

Lyles CH. 1967. Fishery Statistics of the United States, 1965. US Fish Wildl Serv Stat Dig 59. 756 p.

Murawski SA, Frank DG, Chang S. 1978. Biological and Fisheries Data on Butterfish, *Peprilus triacanthus* (Peck). Sandy Hook Laboratory Technical Series Report 6. 39 p.

NEFSC. 1990. Report of the Spring 1990 NEFC Stock Assessment Workshop (Tenth SAW). NEFSC Ref Doc 90-07. 89 p.

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

Waring GT, Anderson ED. 1983. Status of the Northwestern Atlantic Butterfish Stock – 1983. Woods Hole Laboratory Ref Doc 83-41. 39 p.

Wigley SE, Rago PJ, Sosebee KA, Palka DL. 2007. The Analytic Component to the Standardized Bycatch Reporting Methodology Omnibus Amendment: Sampling Design and Estimation of Precision and Accuracy, 2nd edn. NEFSC Ref Doc 07-09. 156 p.

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	Year	USA Catch	CV
1989	4480	0.85	1989	7696	0.49
1990	533	0.37	1990	2831	0.07
1991	4887	0.99	1991	7076	0.68
1992	5025	0.54	1992	7779	0.35
1993	7577	0.32	1993	12185	0.20
1994	6694	0.41	1994	10328	0.26
1995	6353	0.49	1995	8420	0.37
1996	1049	0.71	1996	4604	0.16
1997	1134	0.84	1997	3928	0.24
1998	6412	1.87	1998	8378	1.43
1999	8867	0.36	1999	10977	0.29
2000	7044	0.23	2000	8493	0.19
2001	4969	0.54	2001	9373	0.29
2002	2350	1.25	2002	3222	0.91
2003	2088	1.38	2003	2624	1.10
2004	1323	0.28	2004	1820	0.20
2005	647	0.21	2005	1075	0.13
2006	856	0.71	2006	1411	0.43
2007	239	0.60	2007	918	0.16
2008	1029	0.64	2008	1481	0.44
2009	1079	0.30	2009	1514	0.22
2010	4017	0.33	2010	4593	0.29
2011	1612	0.15	2011	2276	0.10
2012	1040	0.35	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

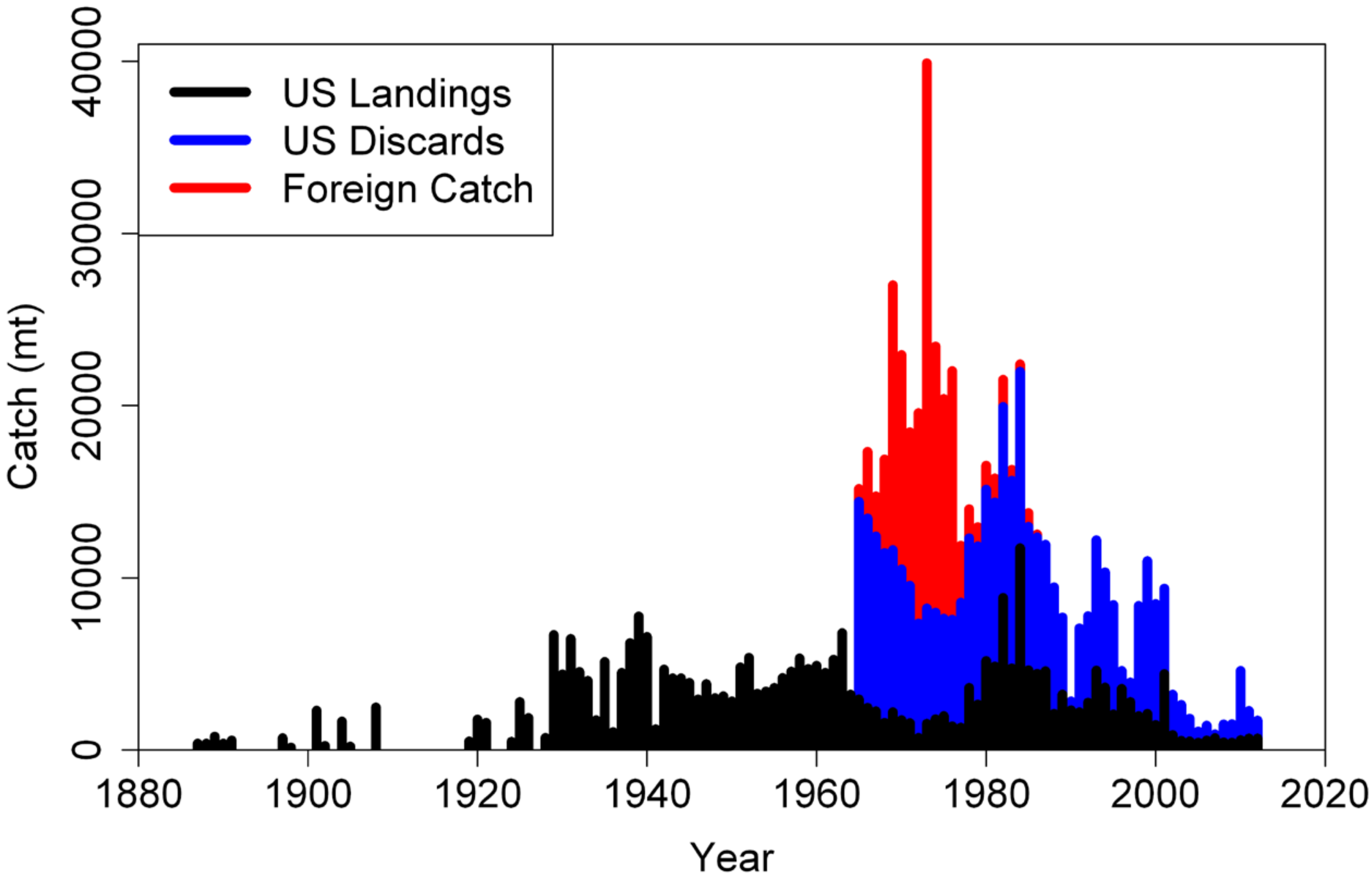


Figure A1.1. Butterfish total catch, 1887-2012. Annual catch data are missing for some years prior to 1930. Discards are unavailable prior to 1965. Total catch between 1965-1988 includes discards estimated by applying an average of discard rates for trawl gear from 1989-1999 to annual landings of all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

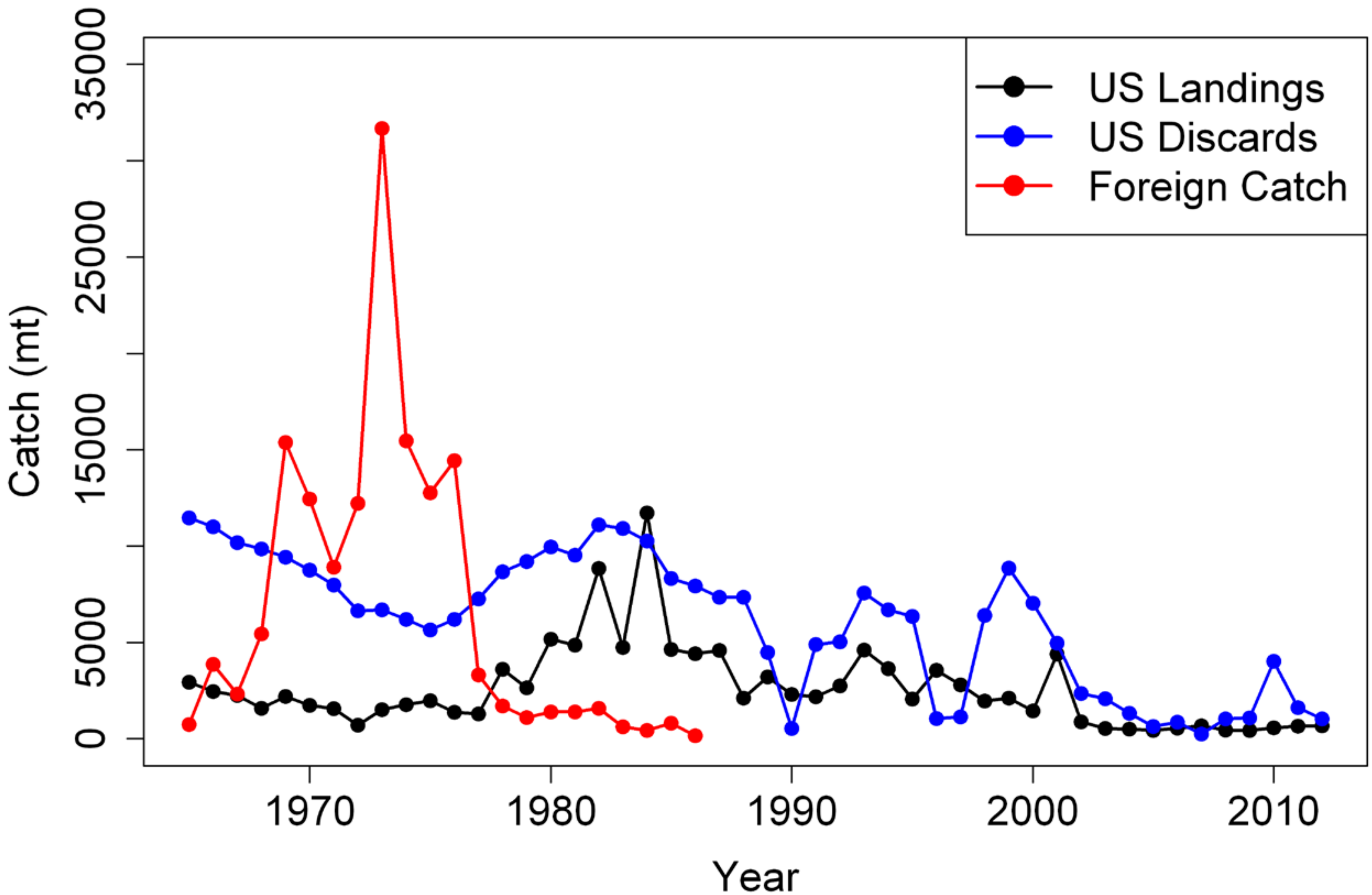


Figure A1.2. US landings, US discards, and foreign catch of butterfish, 1965-2012.

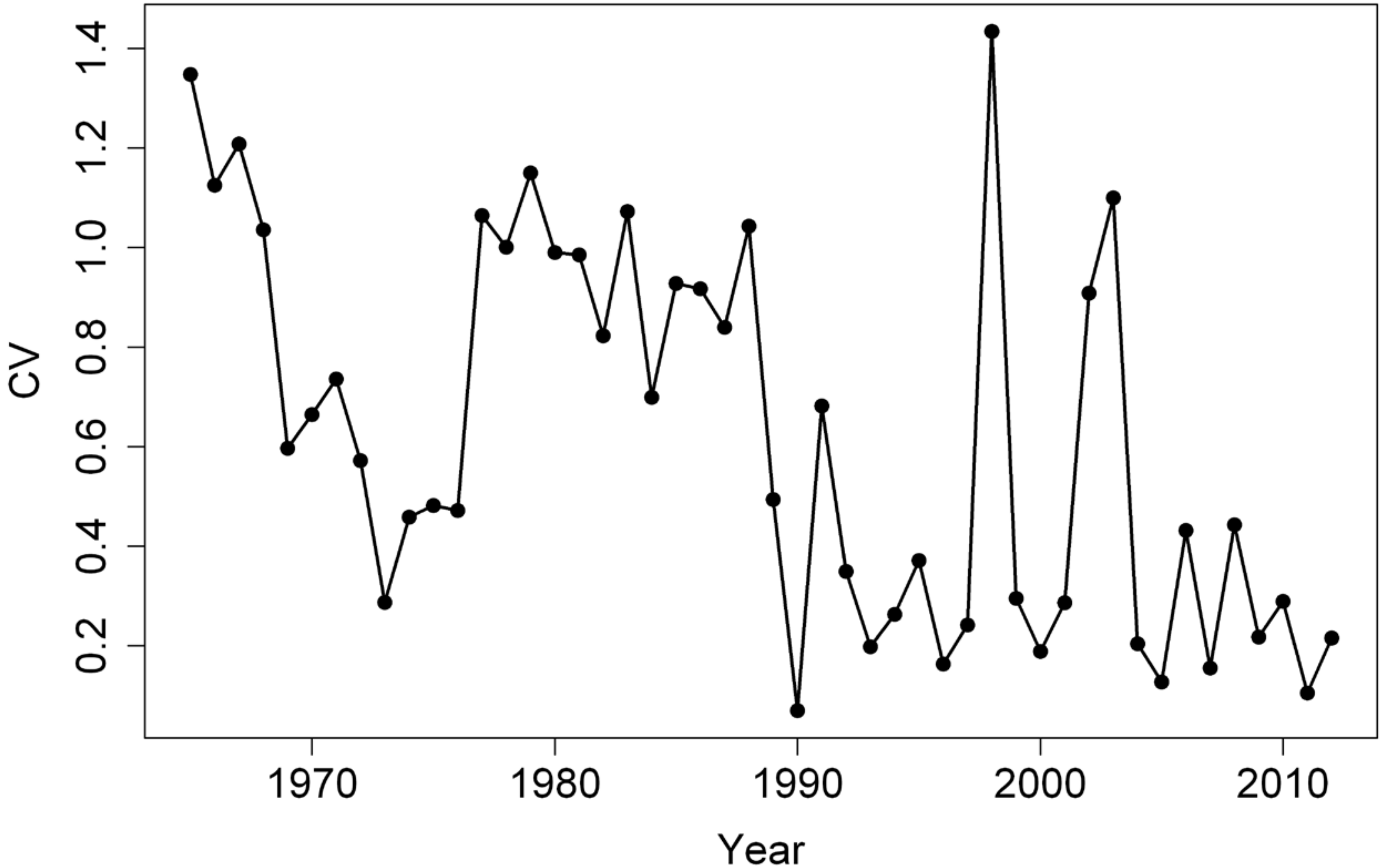


Figure A1.3. Coefficient of variation of butterfish total catch estimates reflecting variance estimates associated with discard estimates.

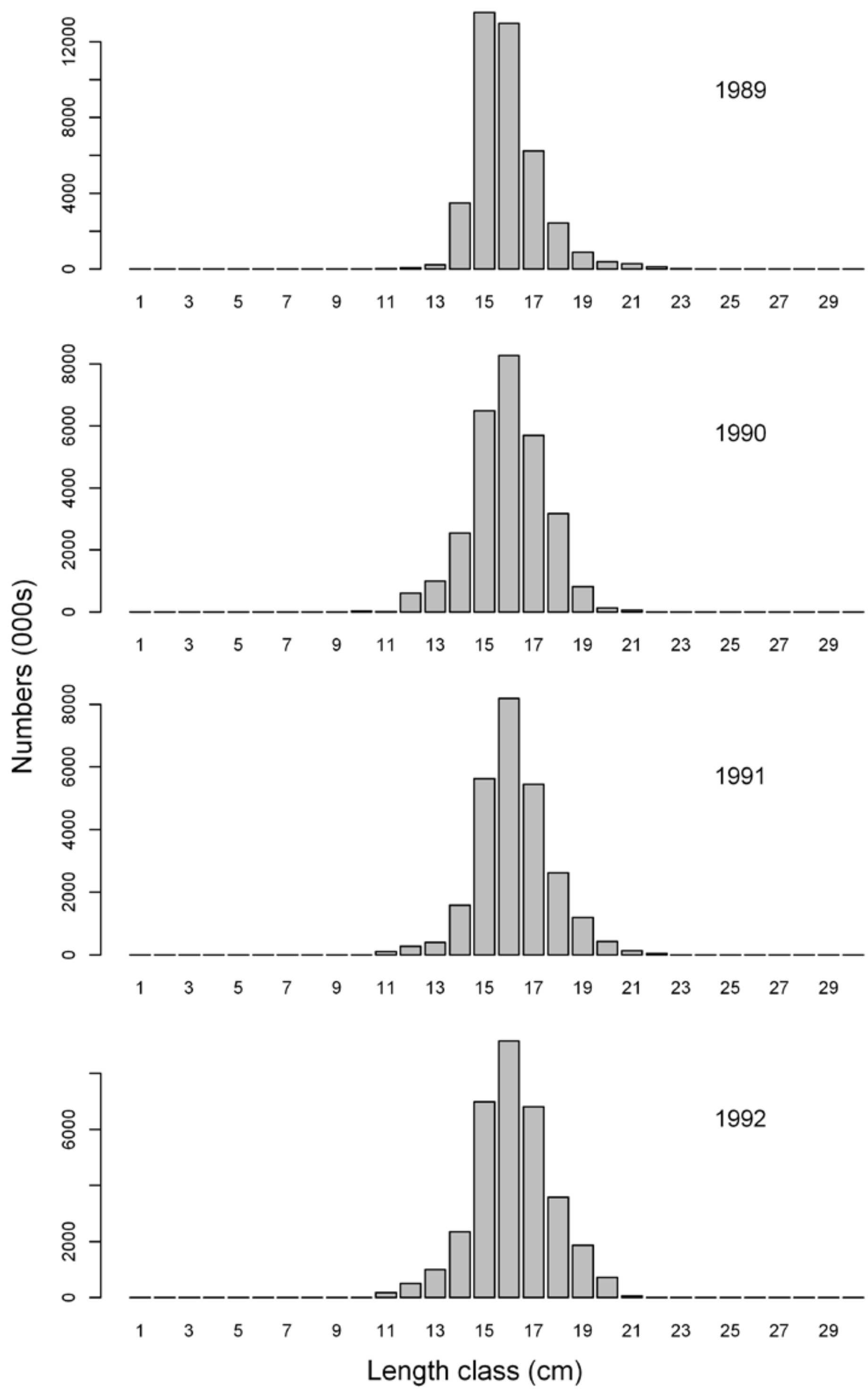


Figure A1.4. Size composition data from New England and Mid-Atlantic commercial landings of butterfish, 1989-1992. Note the Y-axis varies by year.

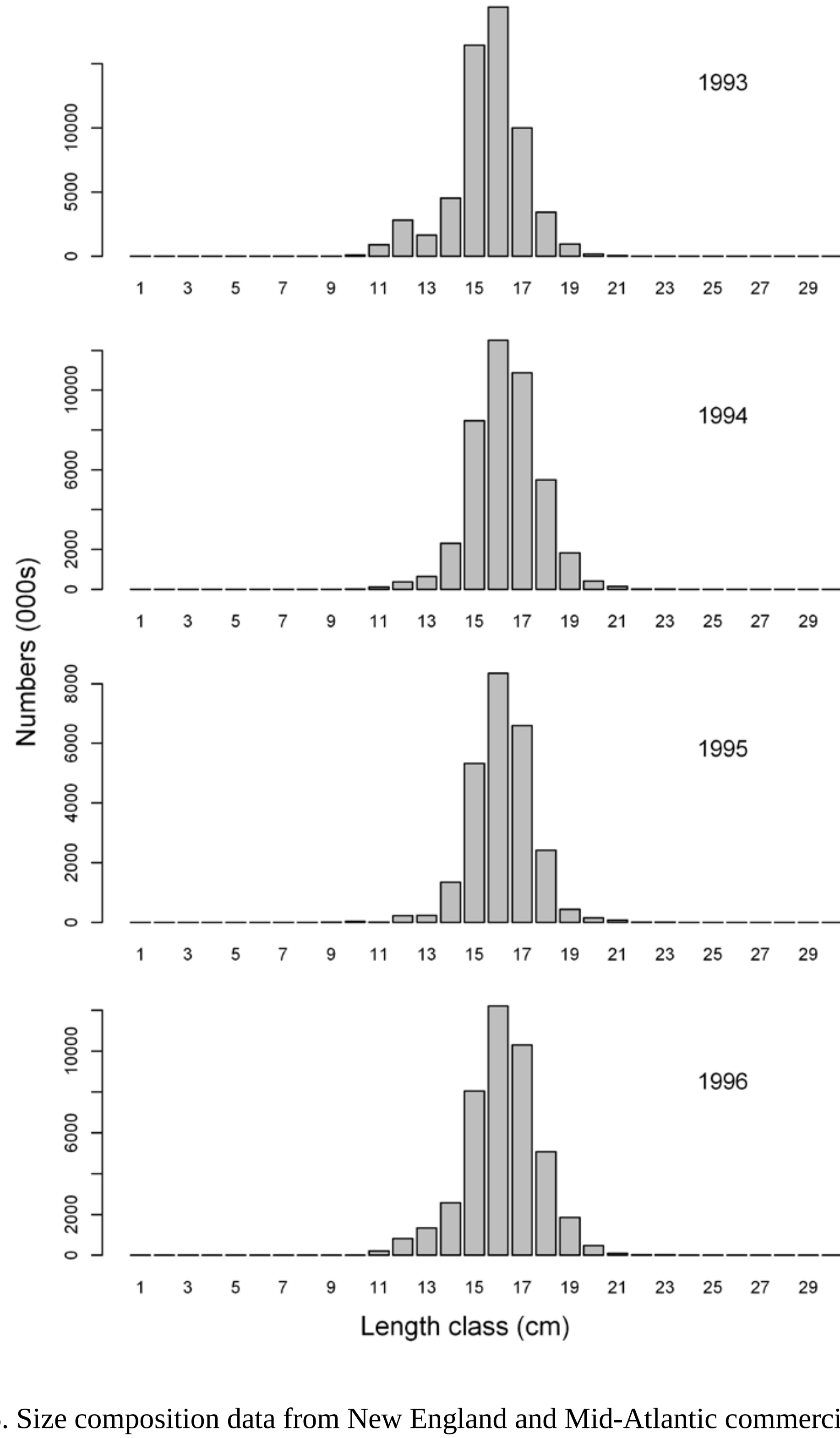


Figure A1.5. Size composition data from New England and Mid-Atlantic commercial landings of butterfish, 1993-1996. Note the Y-axis varies by year.

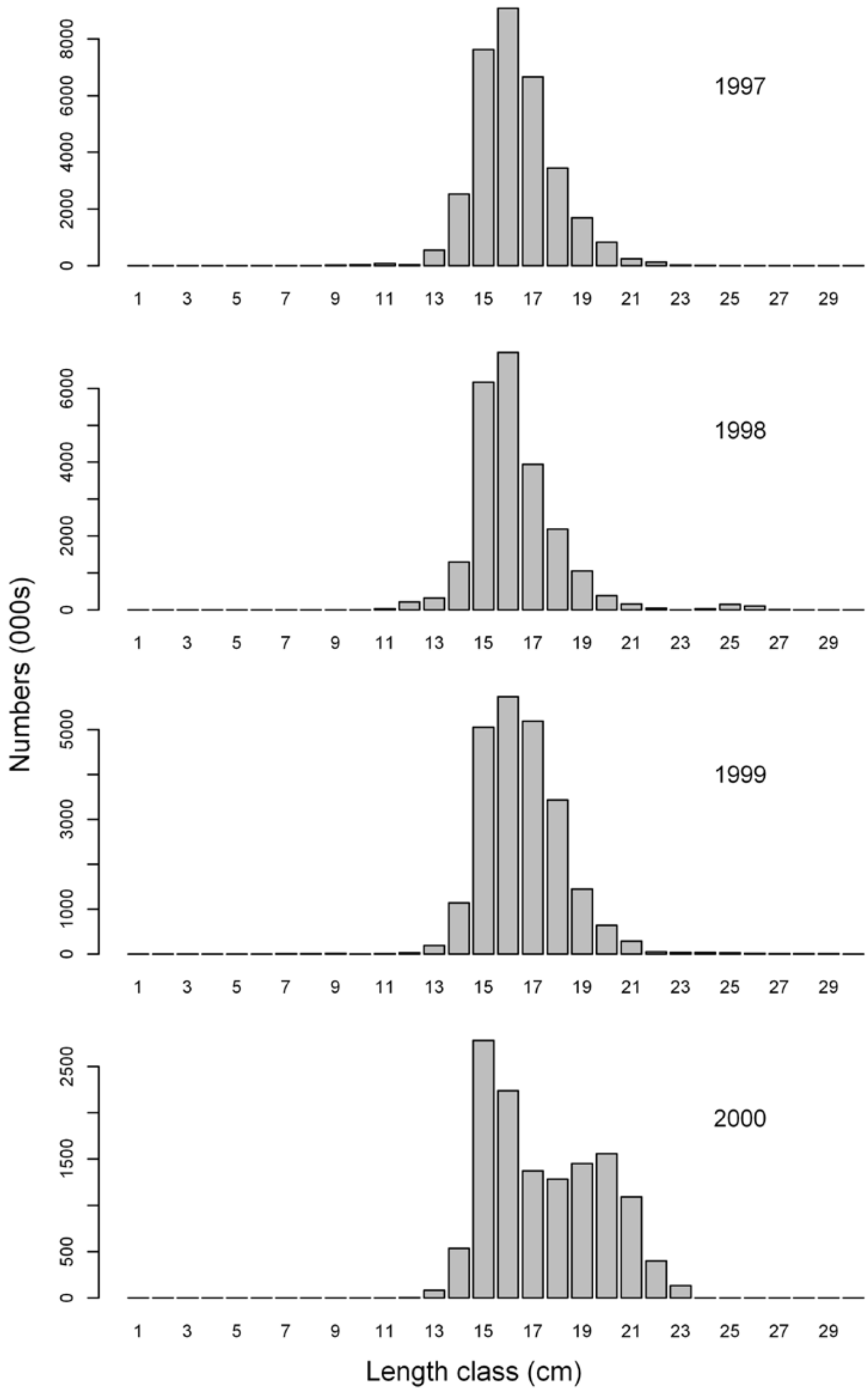


Figure A1.6. Size composition data from New England and Mid-Atlantic commercial landings of butterfish, 1997-2000. Note the Y-axis varies by year.

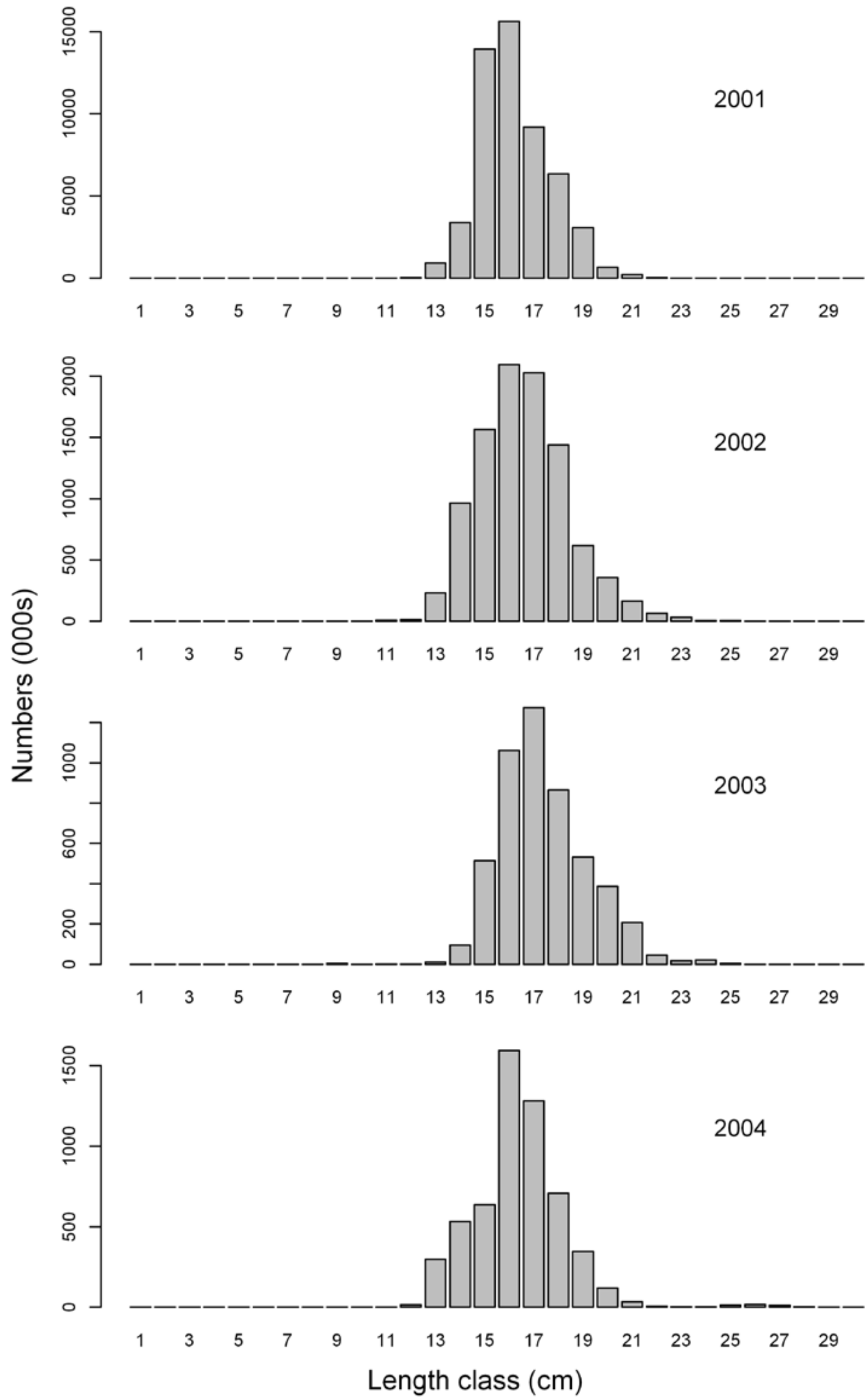


Figure A1.7. Size composition data from New England and Mid-Atlantic commercial landings of butterfish, 2001-2004. Note the Y-axis varies by year.

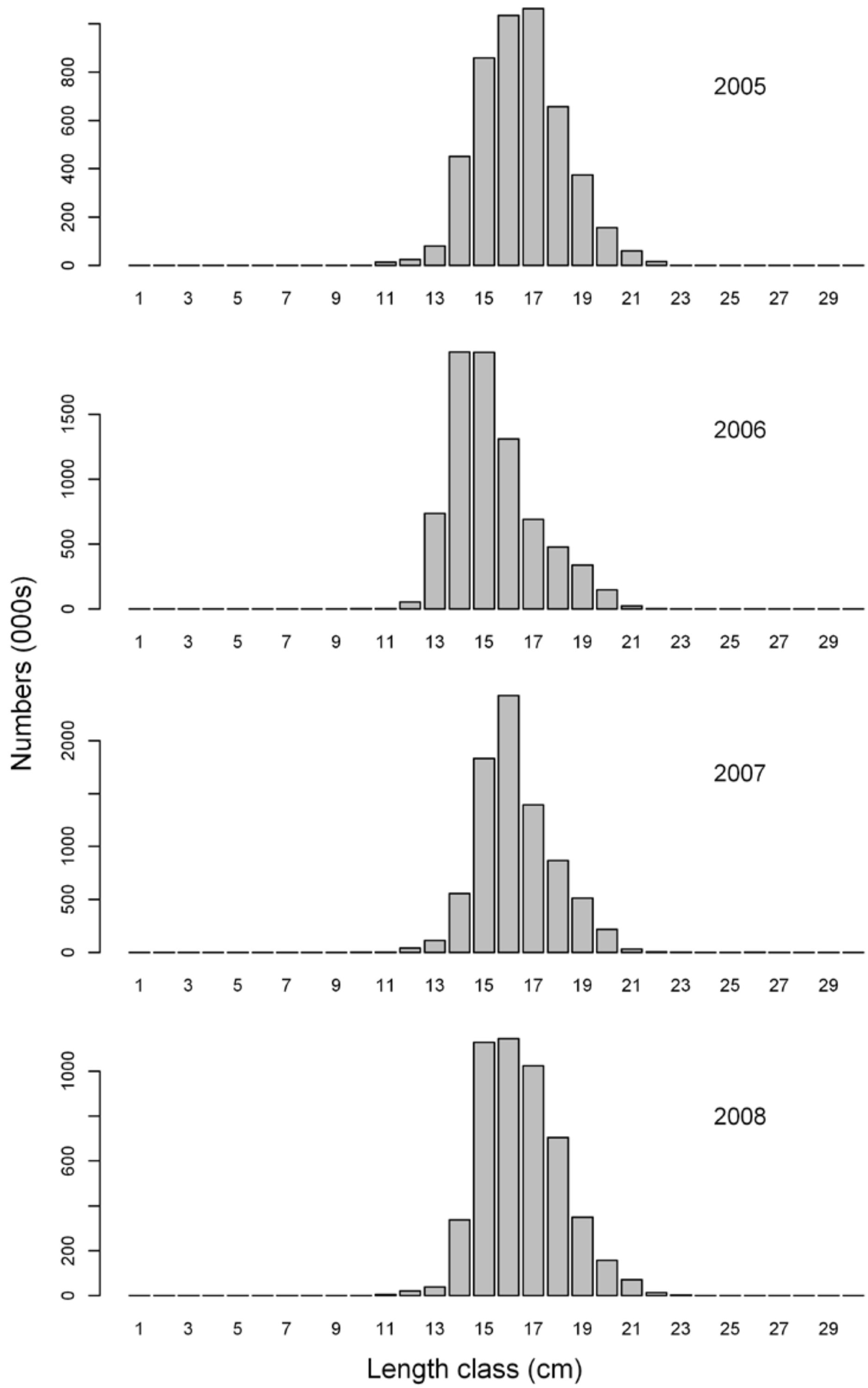


Figure A1.8. Size composition data from New England and Mid-Atlantic commercial landings of butterfish, 2005-2008. Note the Y-axis varies by year.

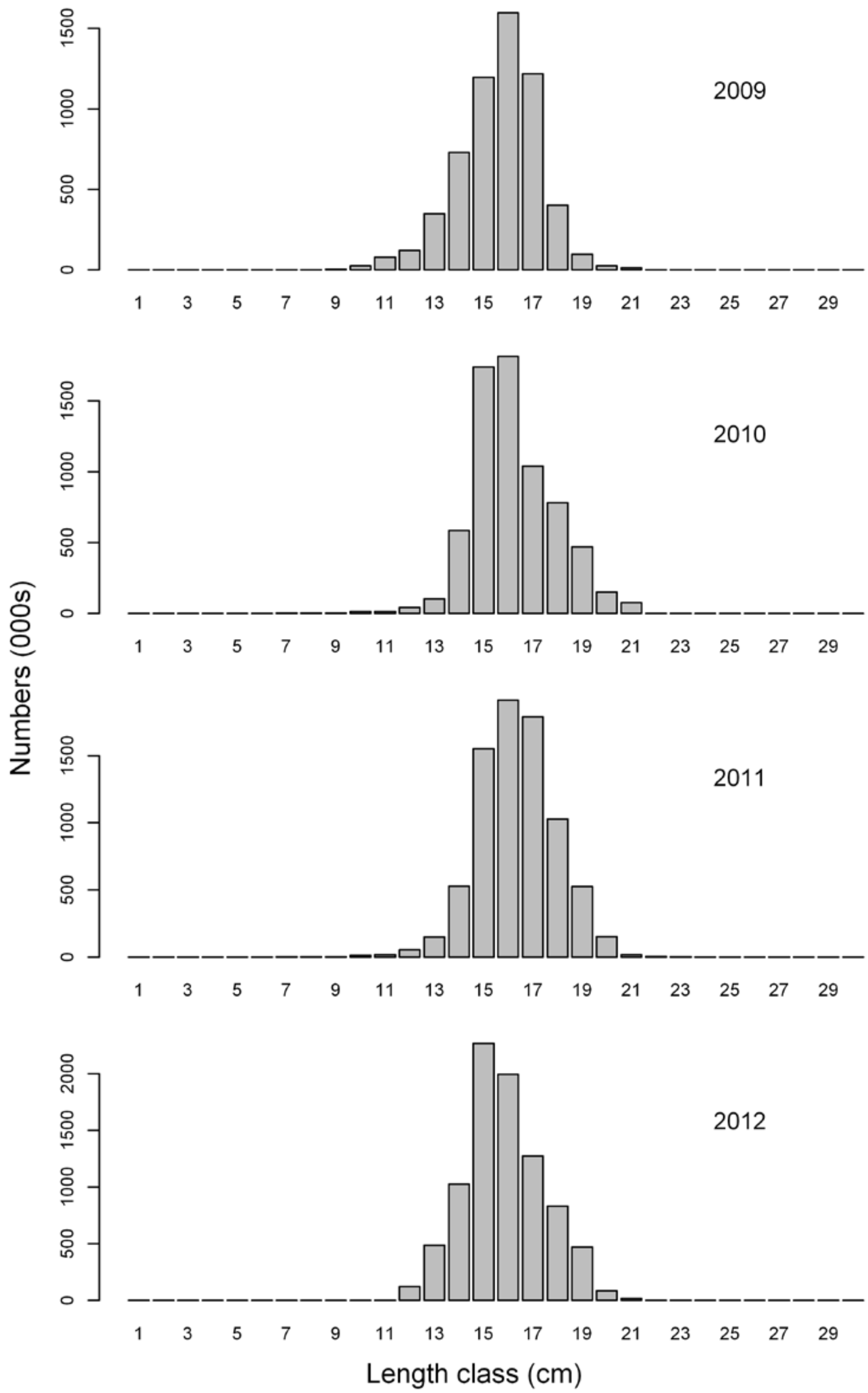


Figure A1.9. Size composition data from New England and Mid-Atlantic commercial landings of butterfish, 2009-2012. Note the Y-axis varies by year.

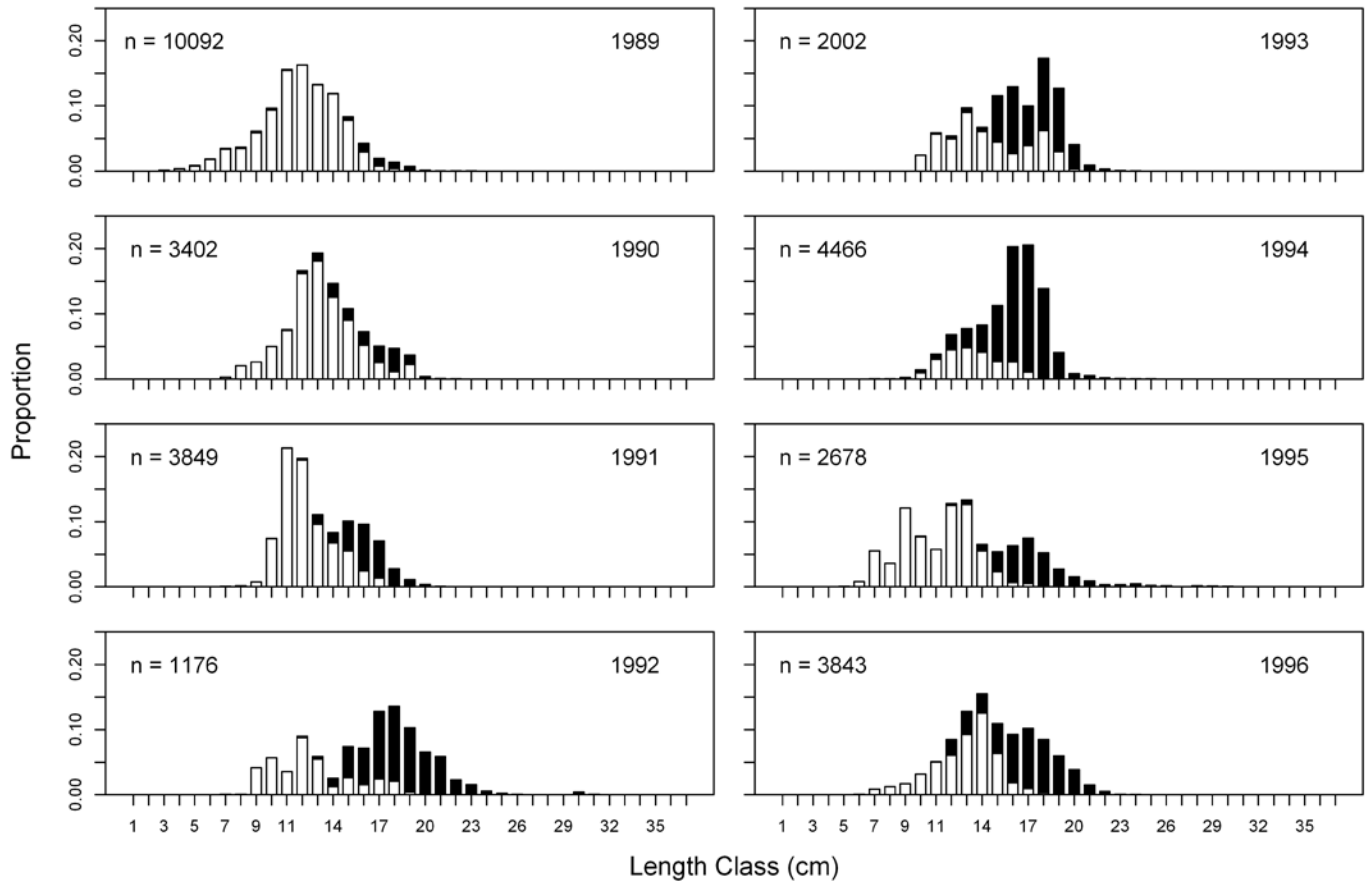


Figure A1.10. Length composition of butterfish from NMFS Observer Program, 1989-1996, with kept fish in black and discards in white. Bars are stacked. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

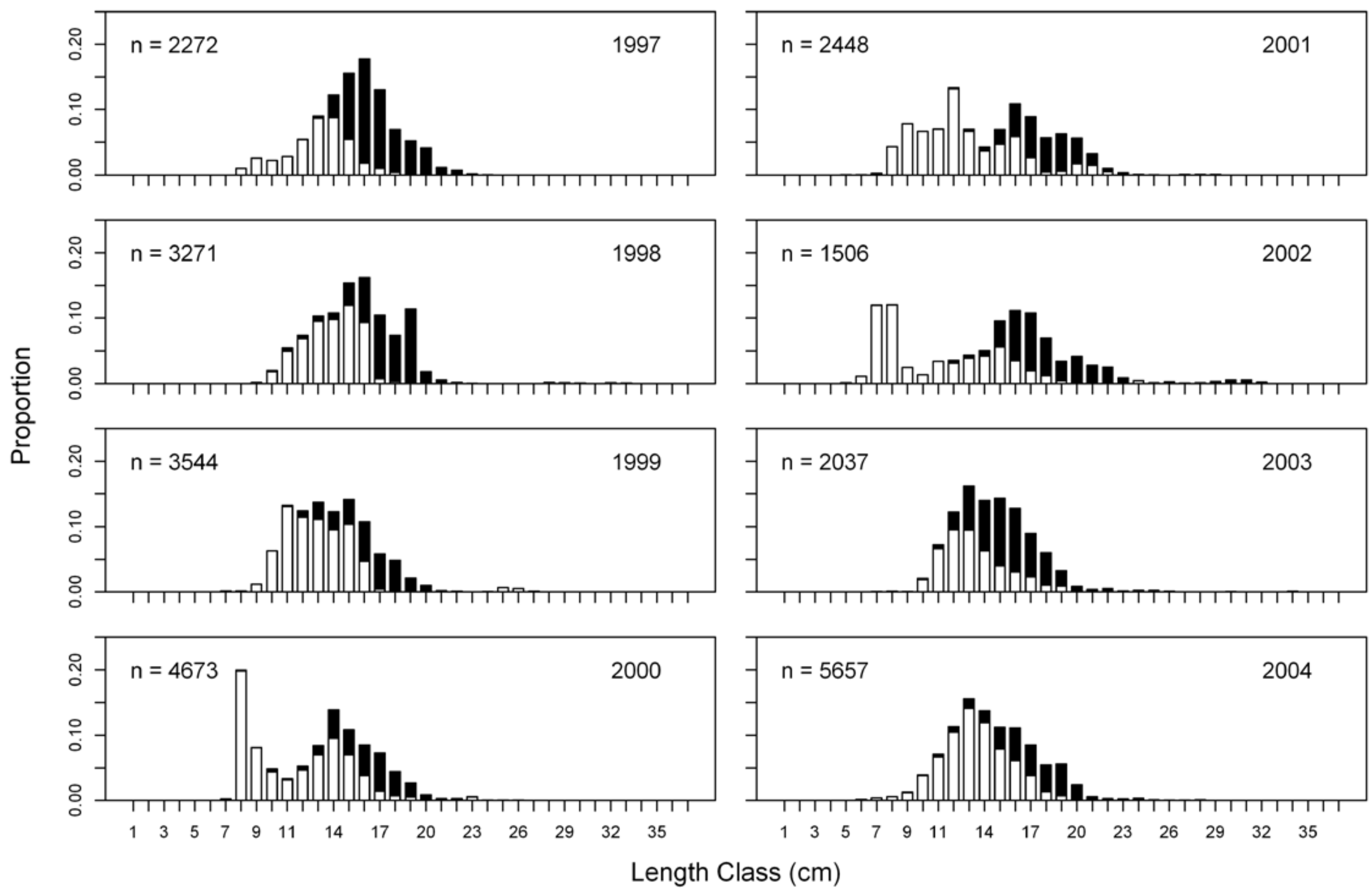


Figure A1.11. Length composition of butterfish from NMFS Observer Program, 1997-2004, with kept fish in black and discards in white. Bars are stacked. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

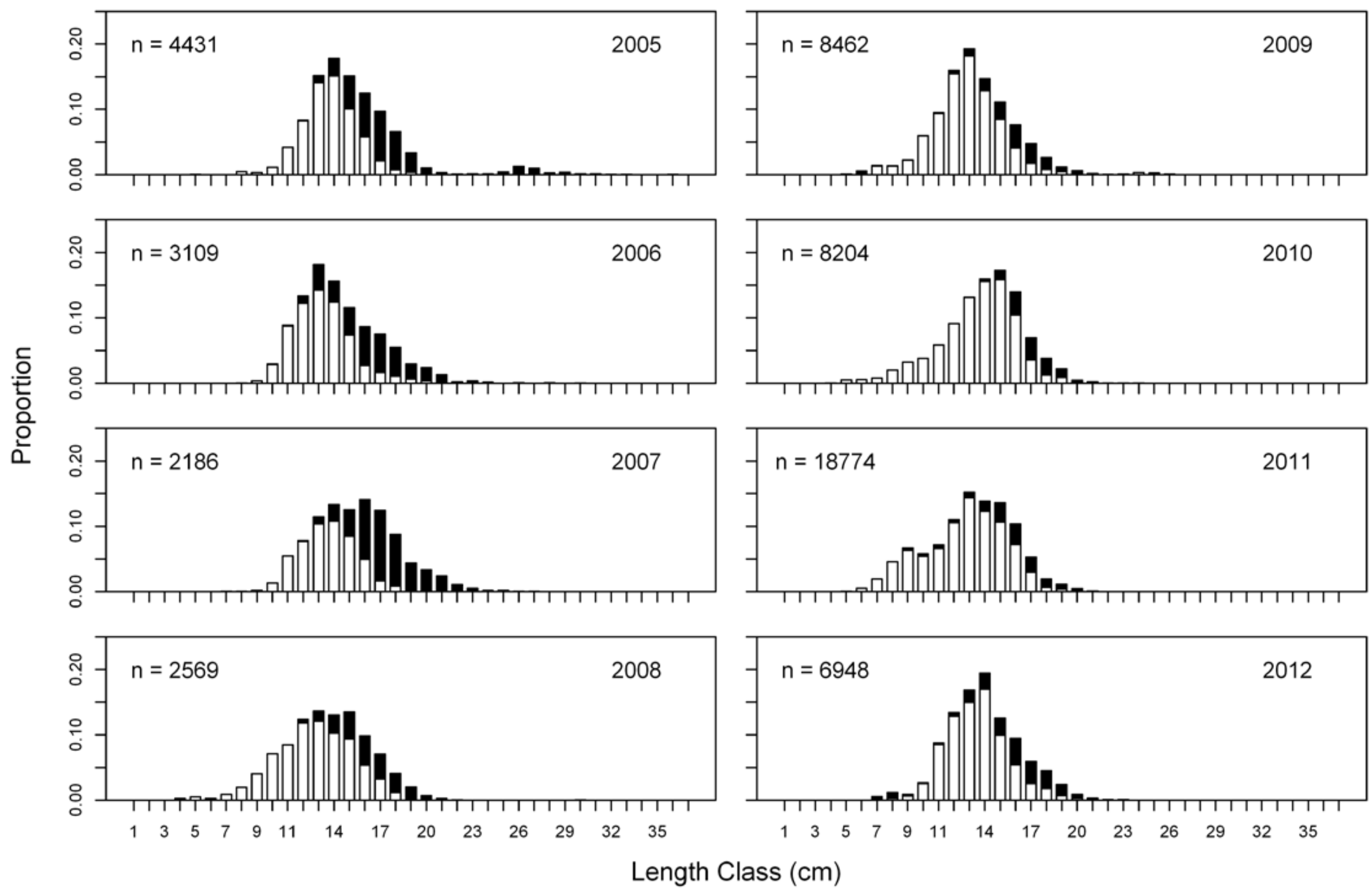


Figure A1.12. Length composition of butterfish from NMFS Observer Program, 2005-2012, with kept fish in black and discards in white. Bars are stacked. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

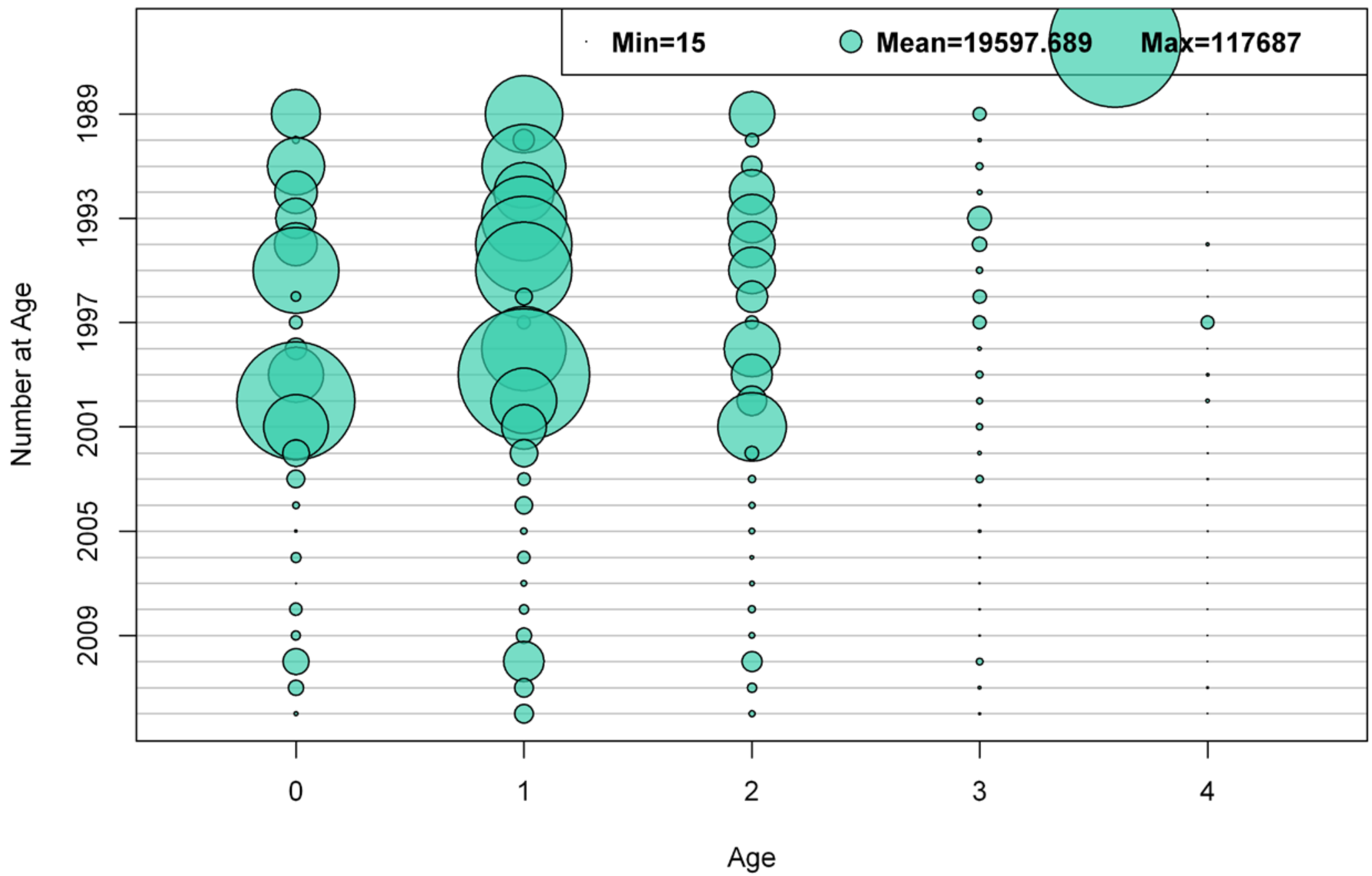


Figure A1.13. Butterfish commercial catch (number) at age, 1989-2012.

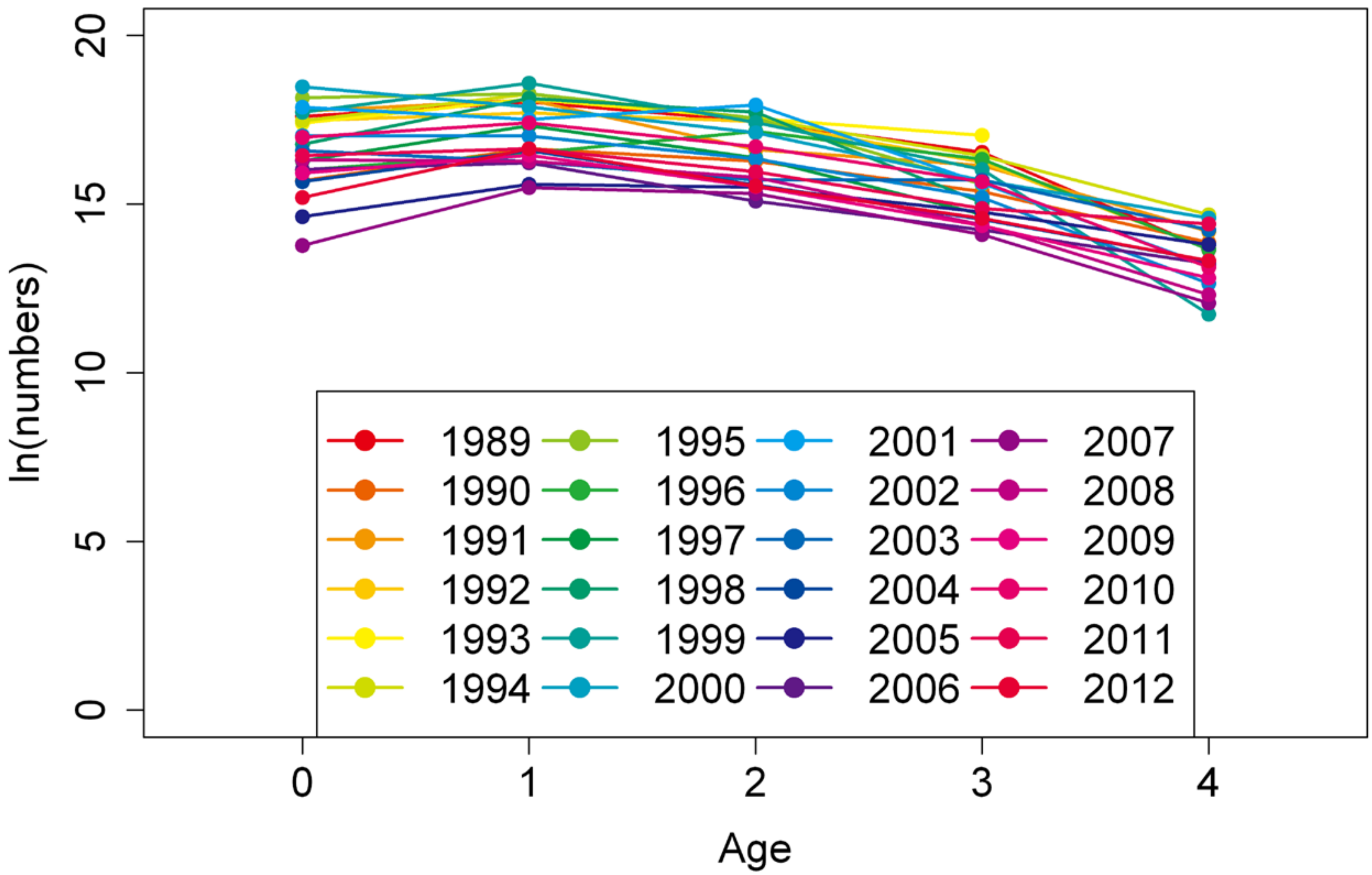


Figure A1.14. Commercial catch curves for butterfish, 1989-2012.

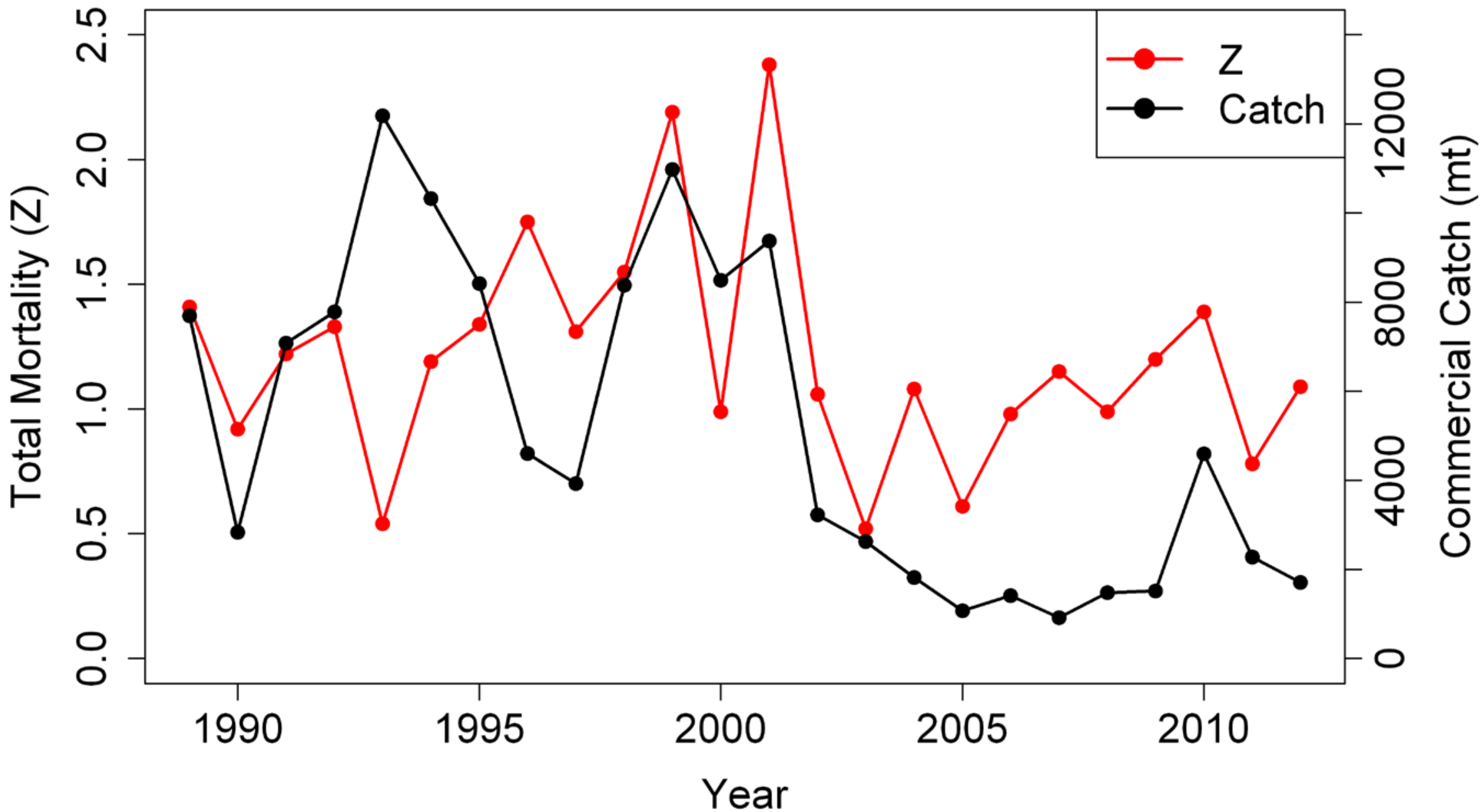


Figure A1.15. Estimates of total mortality (Z), and commercial catch (mt) for butterfish, 1989-2012.

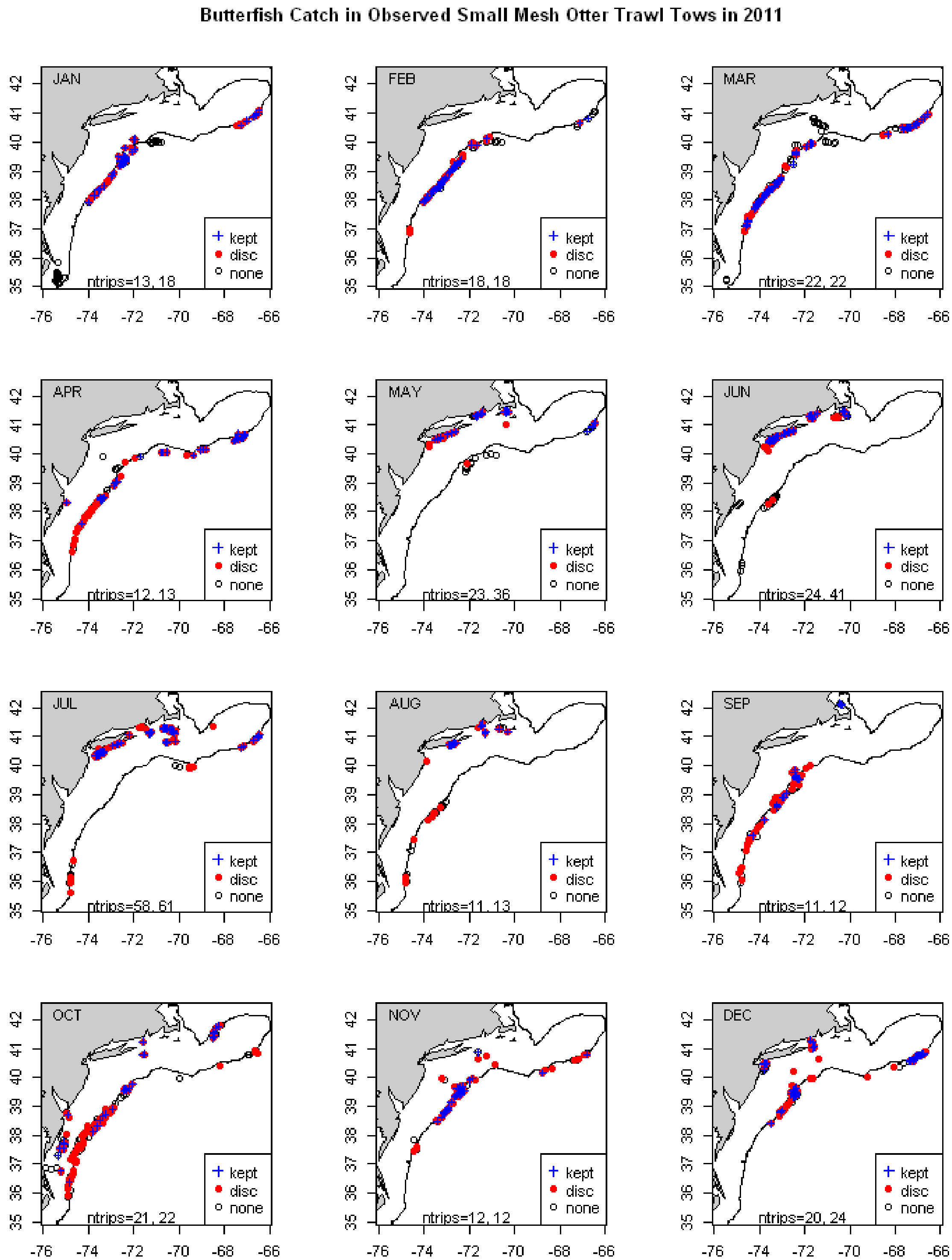


Figure A1.16. Observed commercial small mesh (< 4 inches) bottom trawl tows in 2011 where butterfish were absent (empty circle), present and discarded (red circle), or present and kept (blue +). Bathymetry contour is 100 m. The ntrips denotes the number of observed trips where butterfish were caught,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

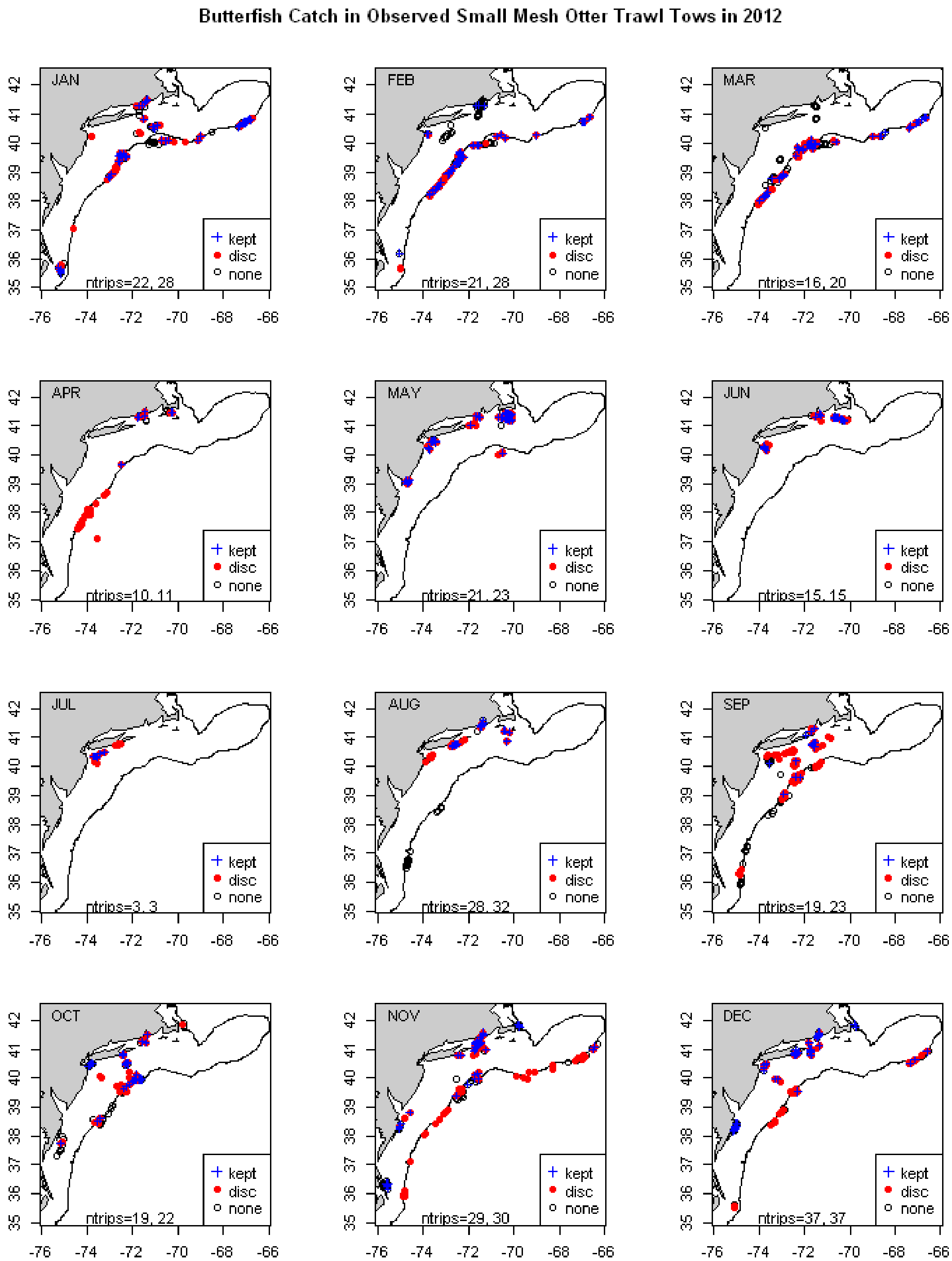


Figure A1.17. Observed commercial small mesh (< 4 inches) bottom trawl tows in 2012 where butterfish were absent (empty circle), present and discarded (red circle), or present and kept (blue +). Bathymetry contour is 100 m. The ntrips denotes the number of observed trips where butterfish were caught,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

TOR2: Survey data

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

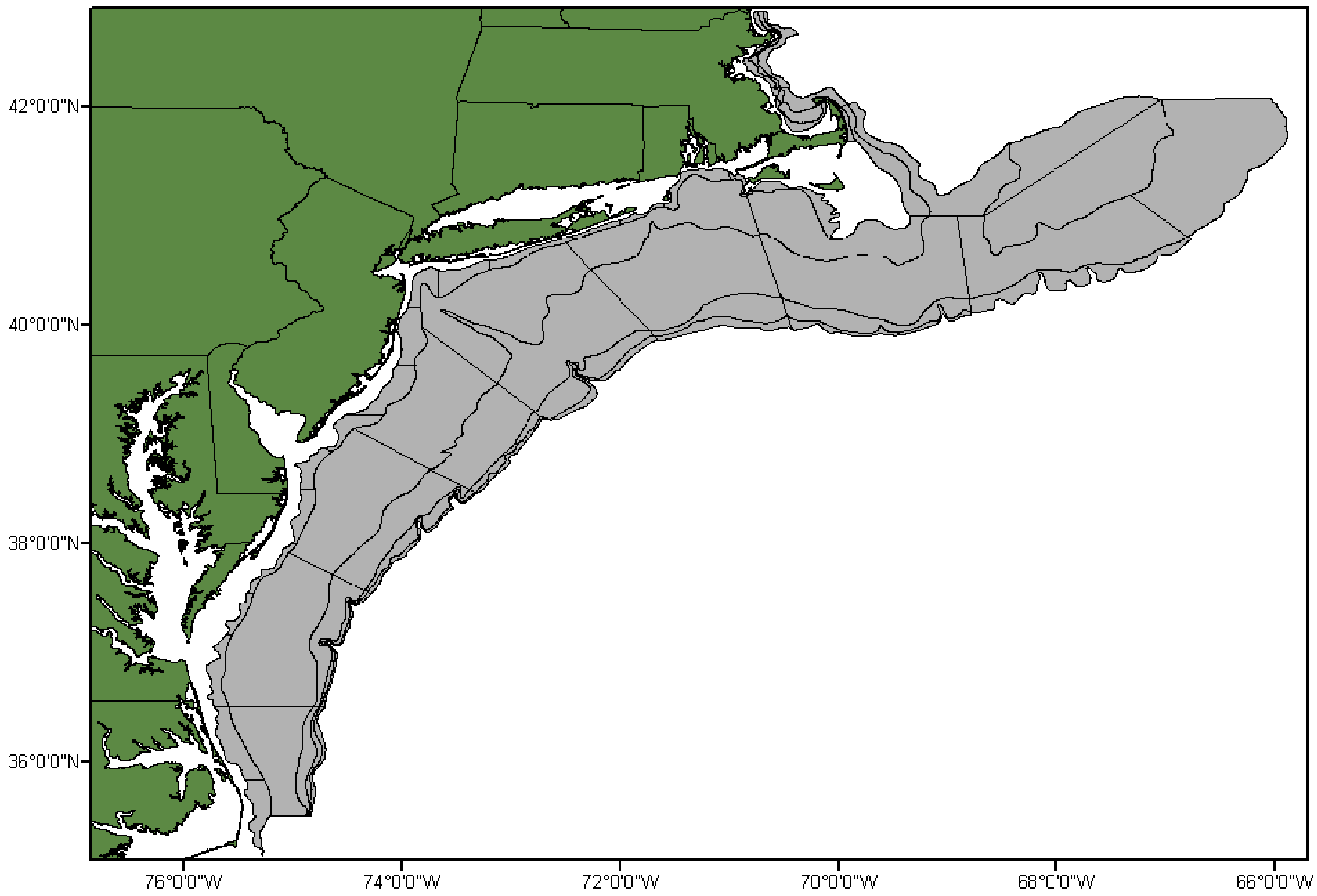


Figure A2.1. Strata used for NEFSC "offshore" indices for butterfish, 1989-2012. Strata include the outermost inshore strata (2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44-46, 56, 59-61 and 64-66) and offshore strata (1-14, 16, 19, 20, 23, 25 and 61-76).

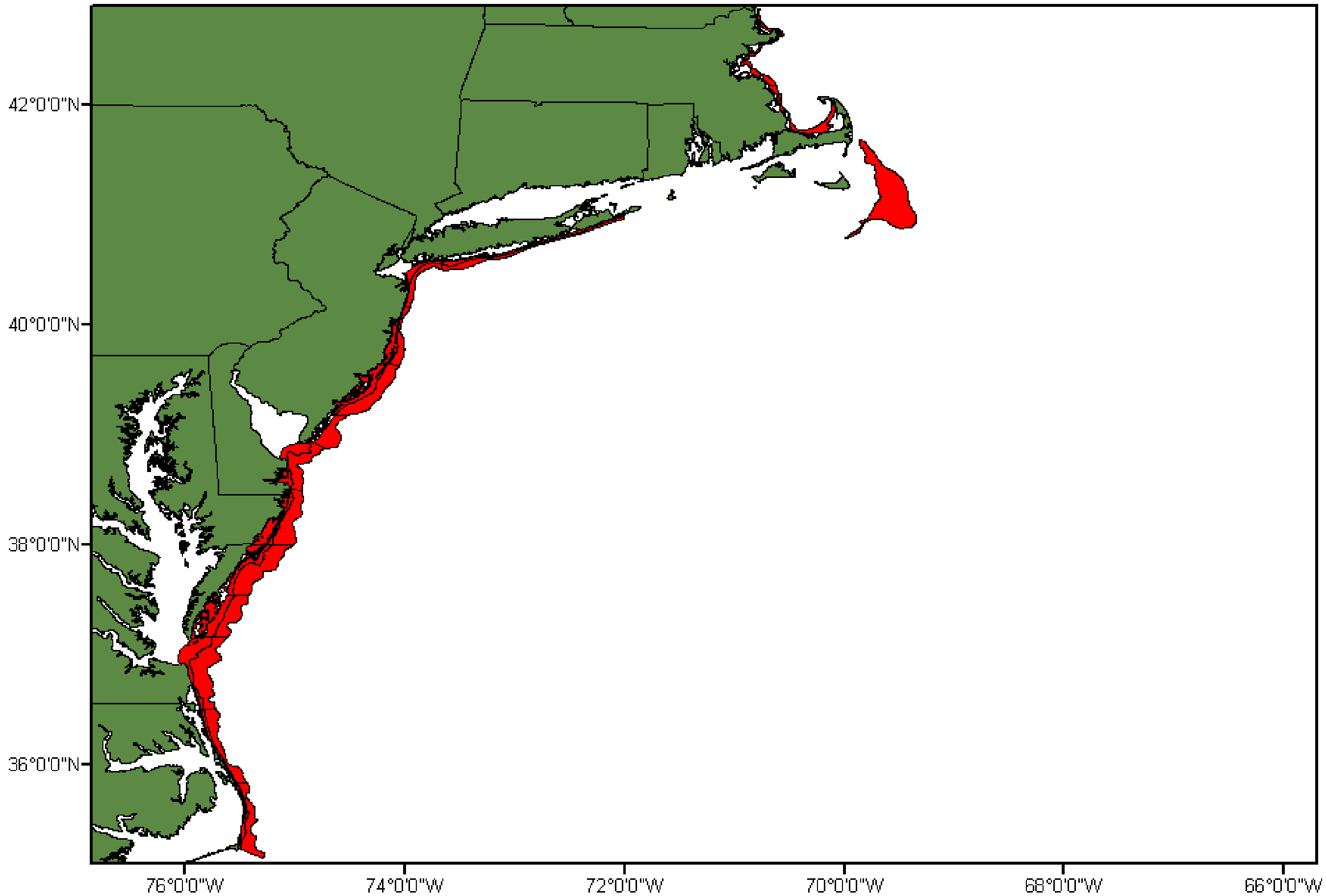


Figure A2.2. Strata used for NEFSC inshore indices for butterfish, 1989-2008. Strata include the two innermost inshore strata (3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18, 19, 21, 22, 24, 25, 27, 28, 30, 31, 33, 34, 36, 37, 39, 40, 42, 43, 55, 58 and 63).

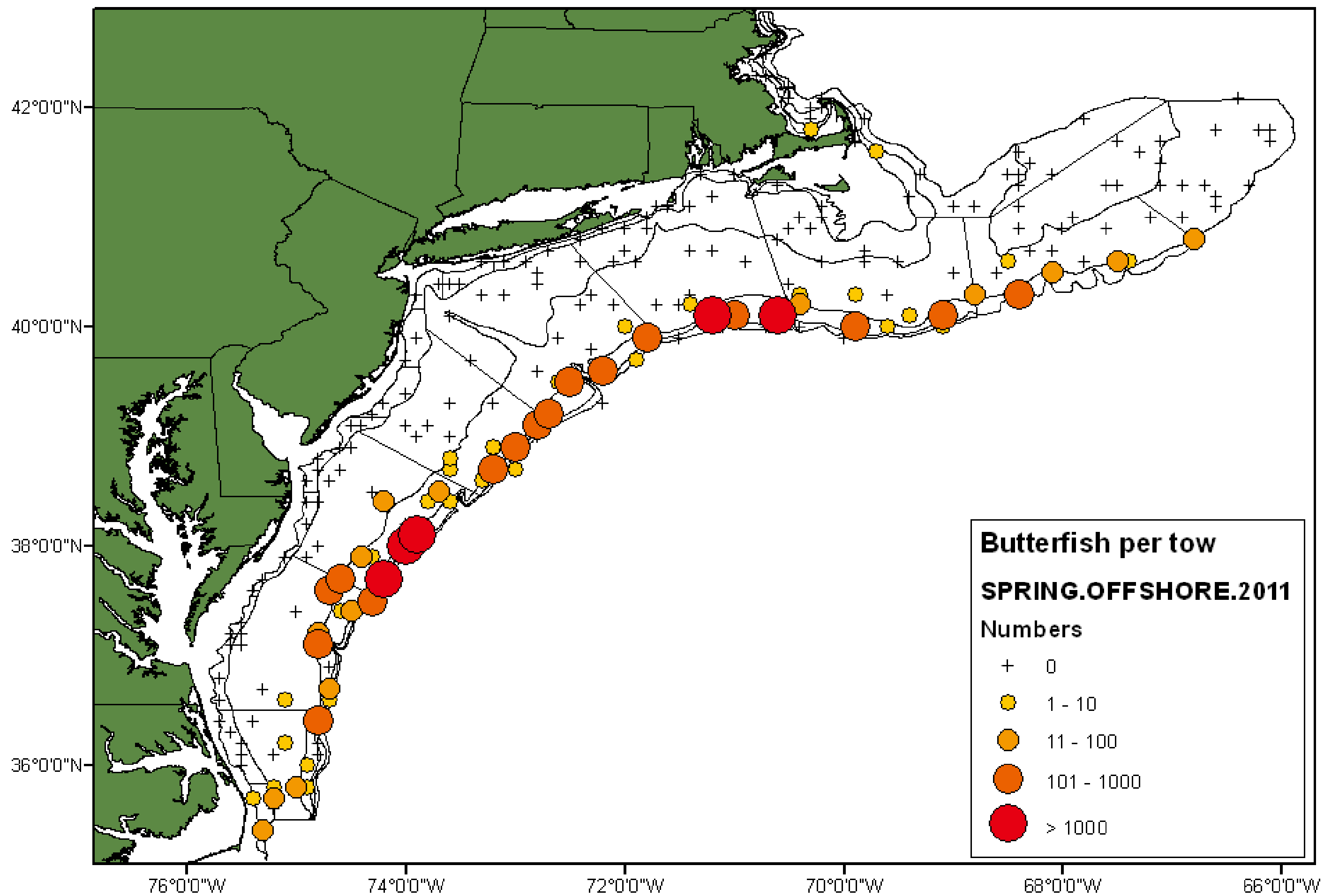


Figure A2.3. NEFSC 2011 spring survey number of butterfish per tow.

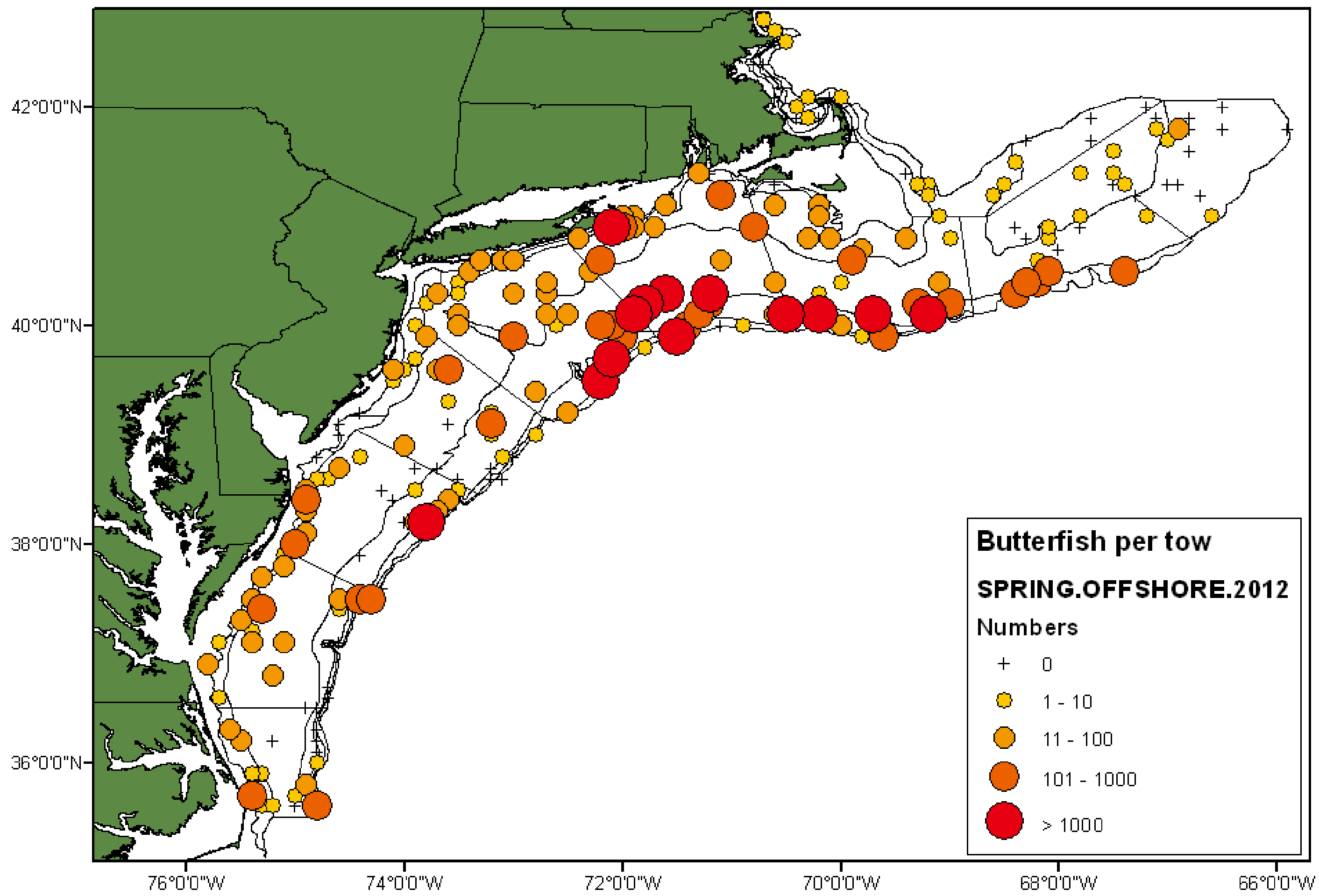


Figure A2.4. NEFSC 2012 spring survey number of butterfish per tow.

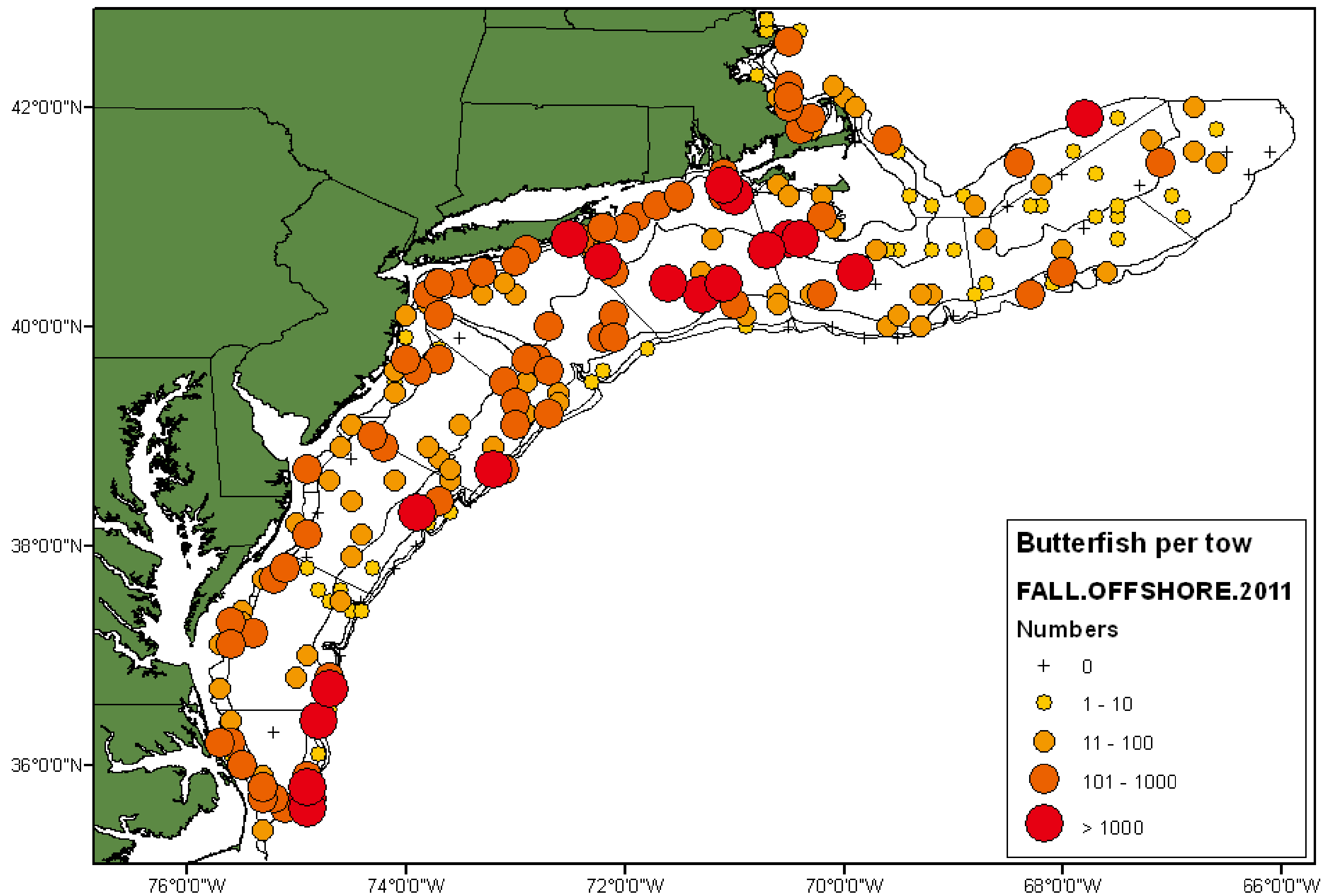


Figure A2.5. NEFSC 2011 fall survey number of butterfish per tow.

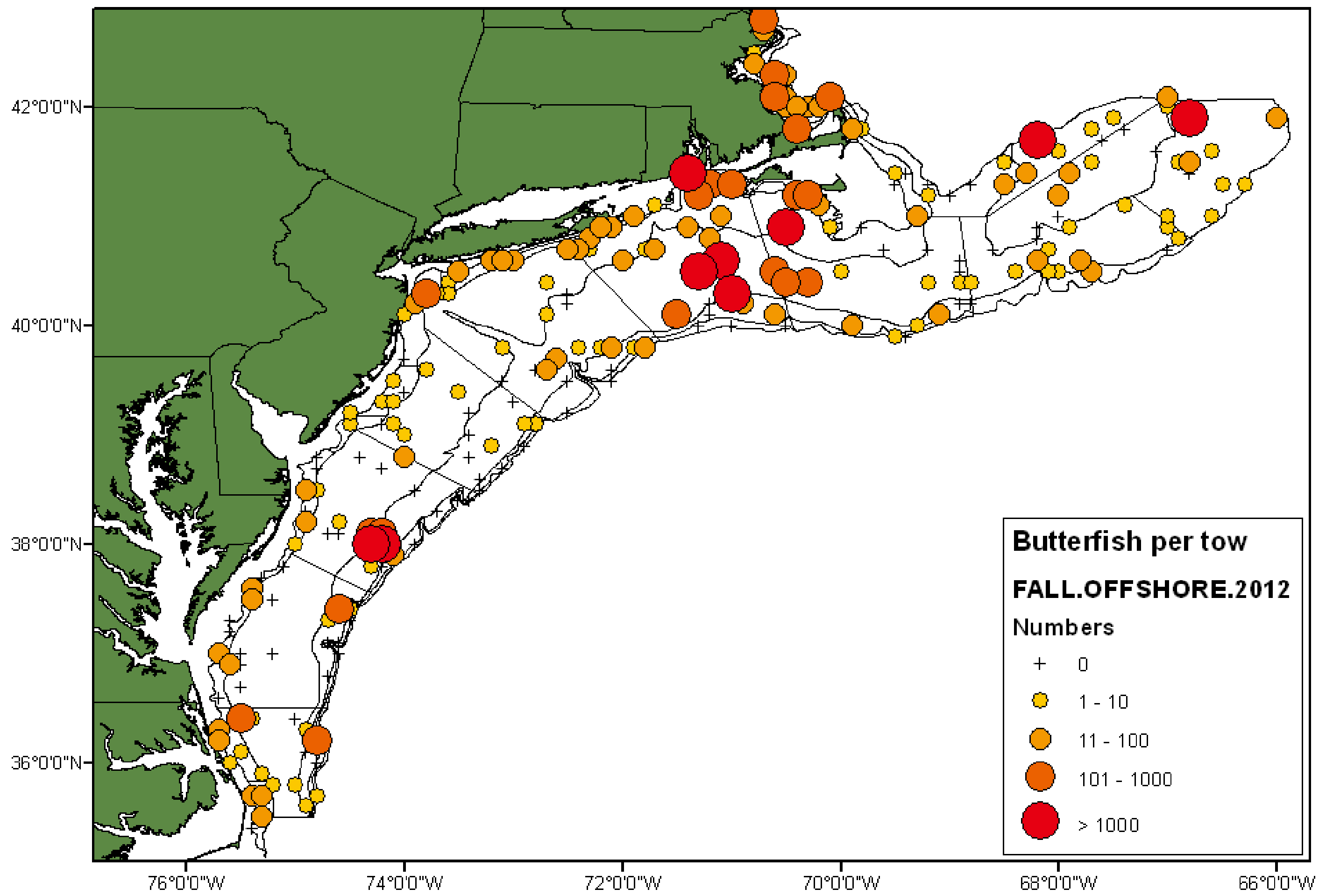


Figure A2.6. NEFSC 2012 fall survey number of butterfish per tow.

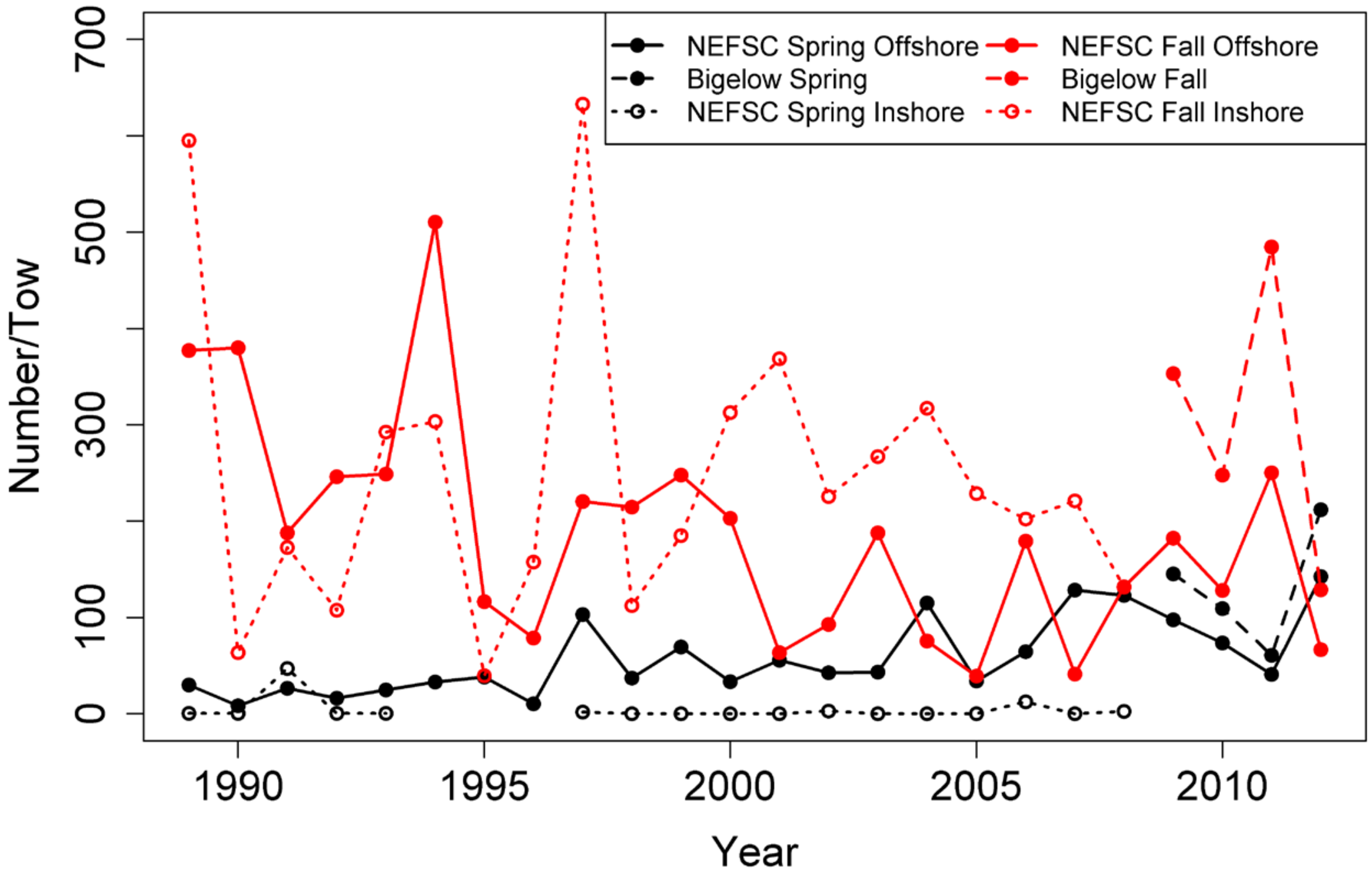


Figure A2.7. NEFSC spring offshore, spring inshore, fall offshore and fall inshore survey stratified mean number per tow for butterfish. Un-calibrated Bigelow data (2009-2012) are also shown.

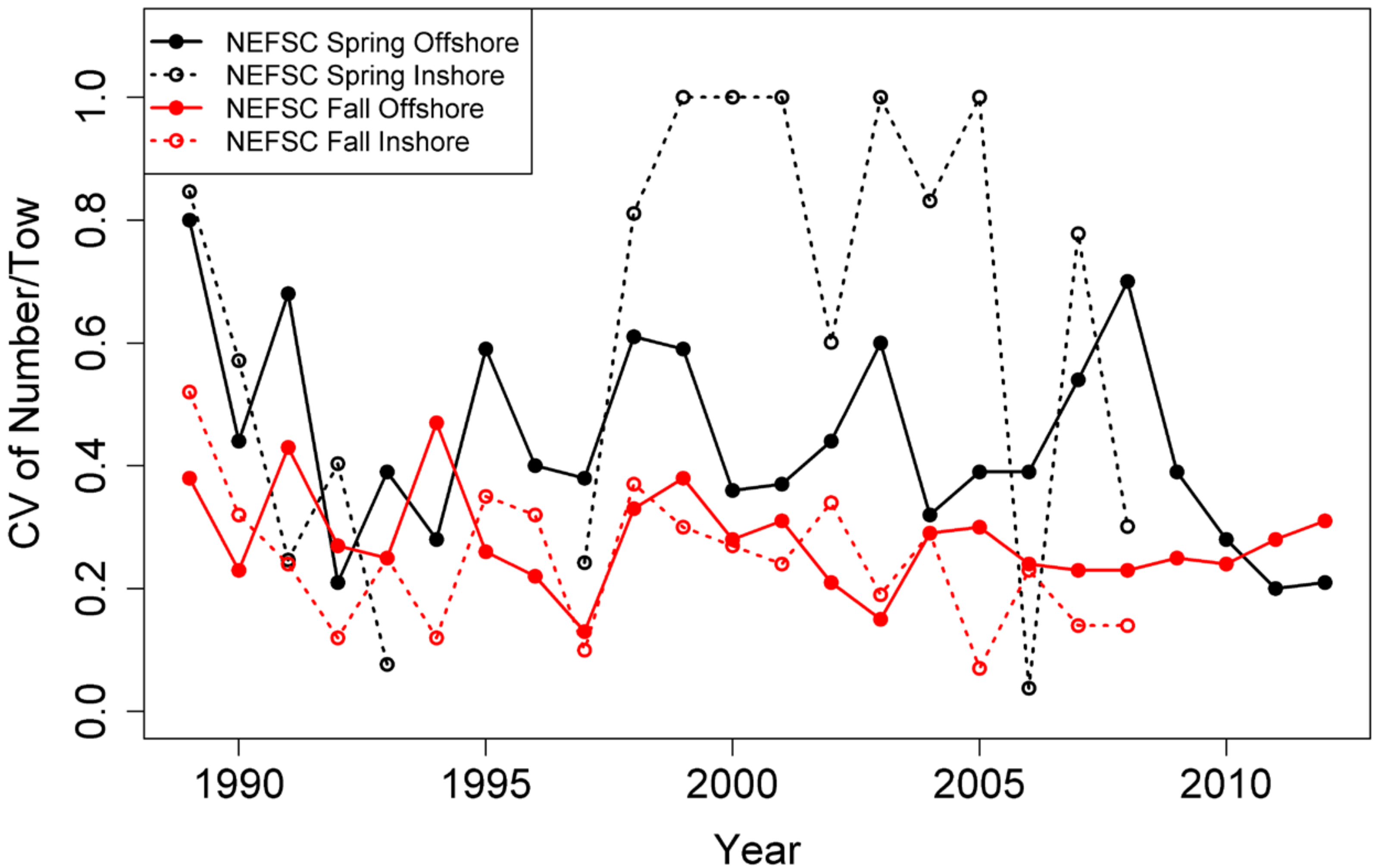


Figure A2.8. Coefficient of variation (CV) for NEFSC spring offshore, spring inshore, fall offshore and fall inshore survey stratified mean number per tow for butterfish.

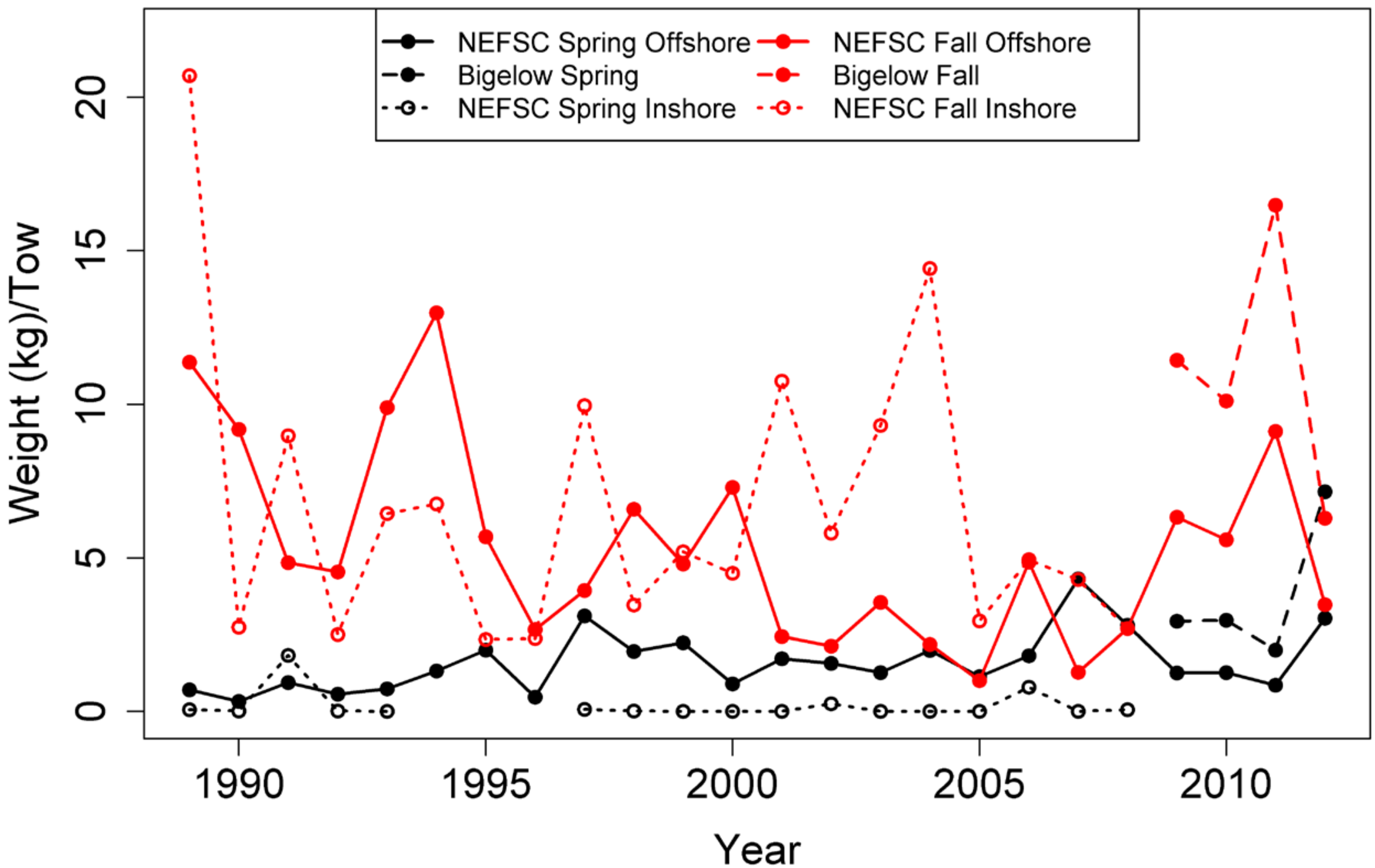


Figure A2.9. NEFSC spring offshore, spring inshore, fall offshore and fall inshore survey stratified mean weight per tow for butterfish. Un-calibrated Bigelow data (2009-2012) are also shown.

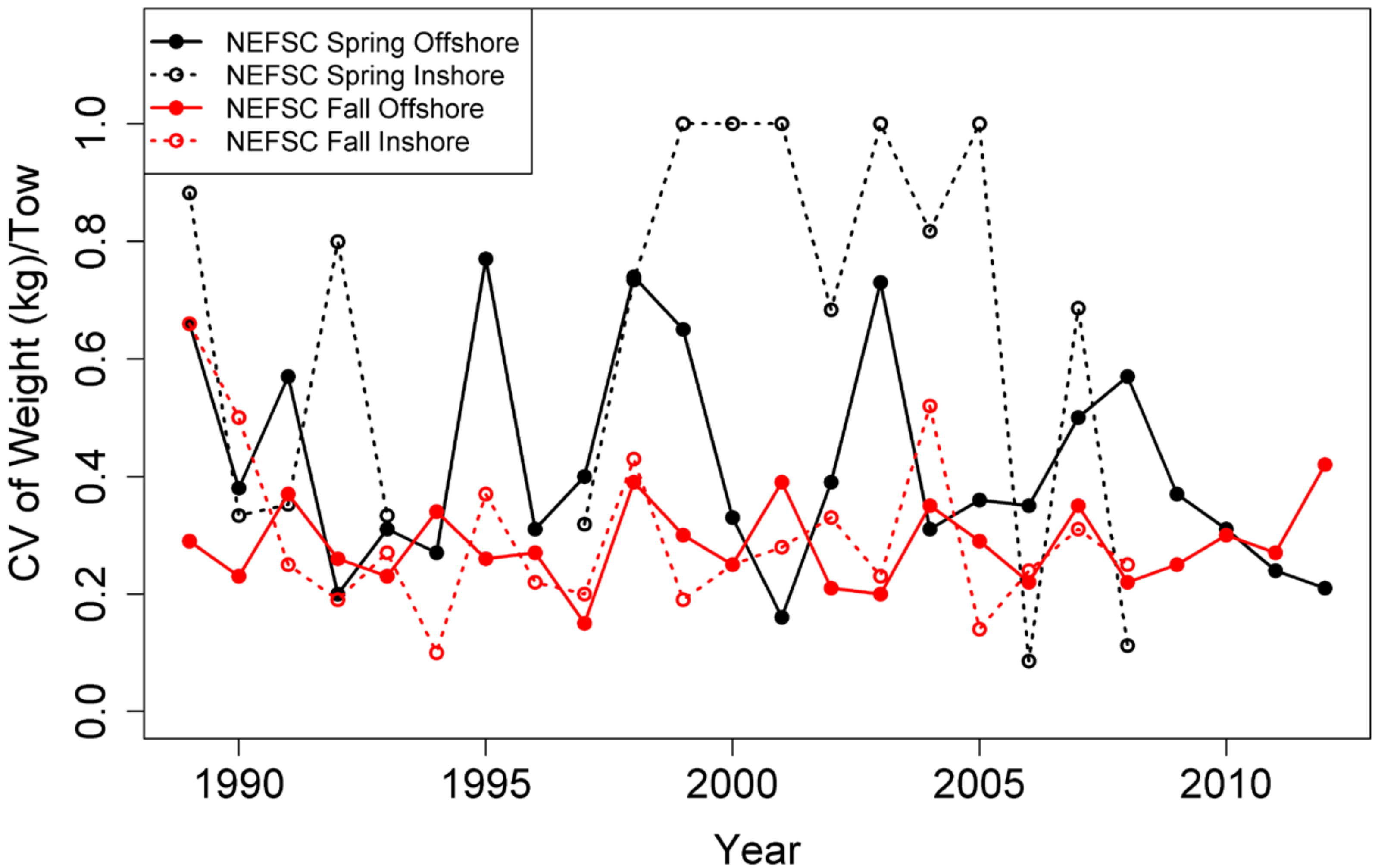


Figure A2.10. Coefficient of variation (CV) for NEFSC spring offshore, spring inshore, fall offshore and fall inshore survey stratified mean weight per tow for butterfish.

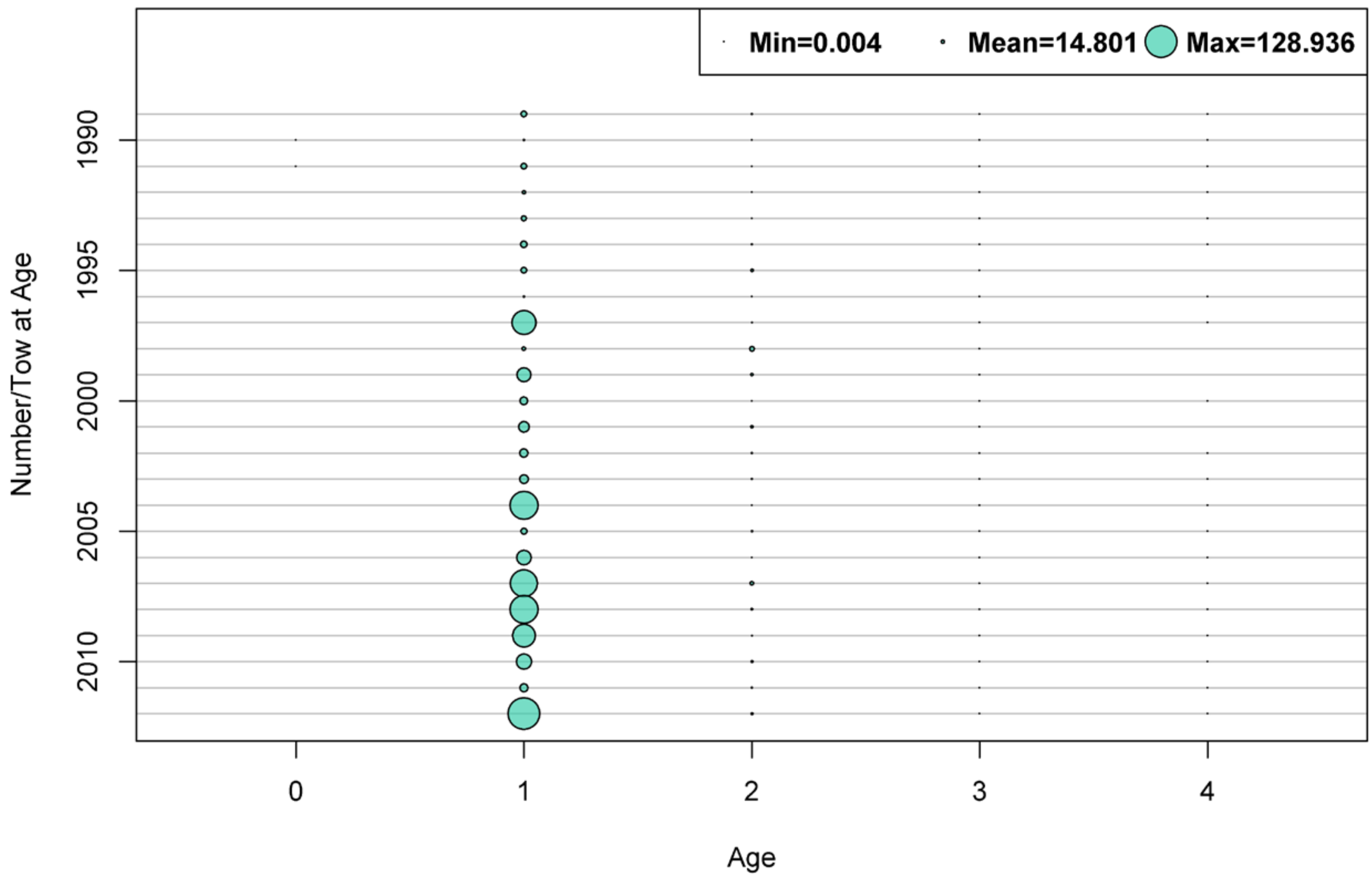


Figure A2.11. Age composition of butterfish in NEFSC spring offshore surveys, 1989-2012.

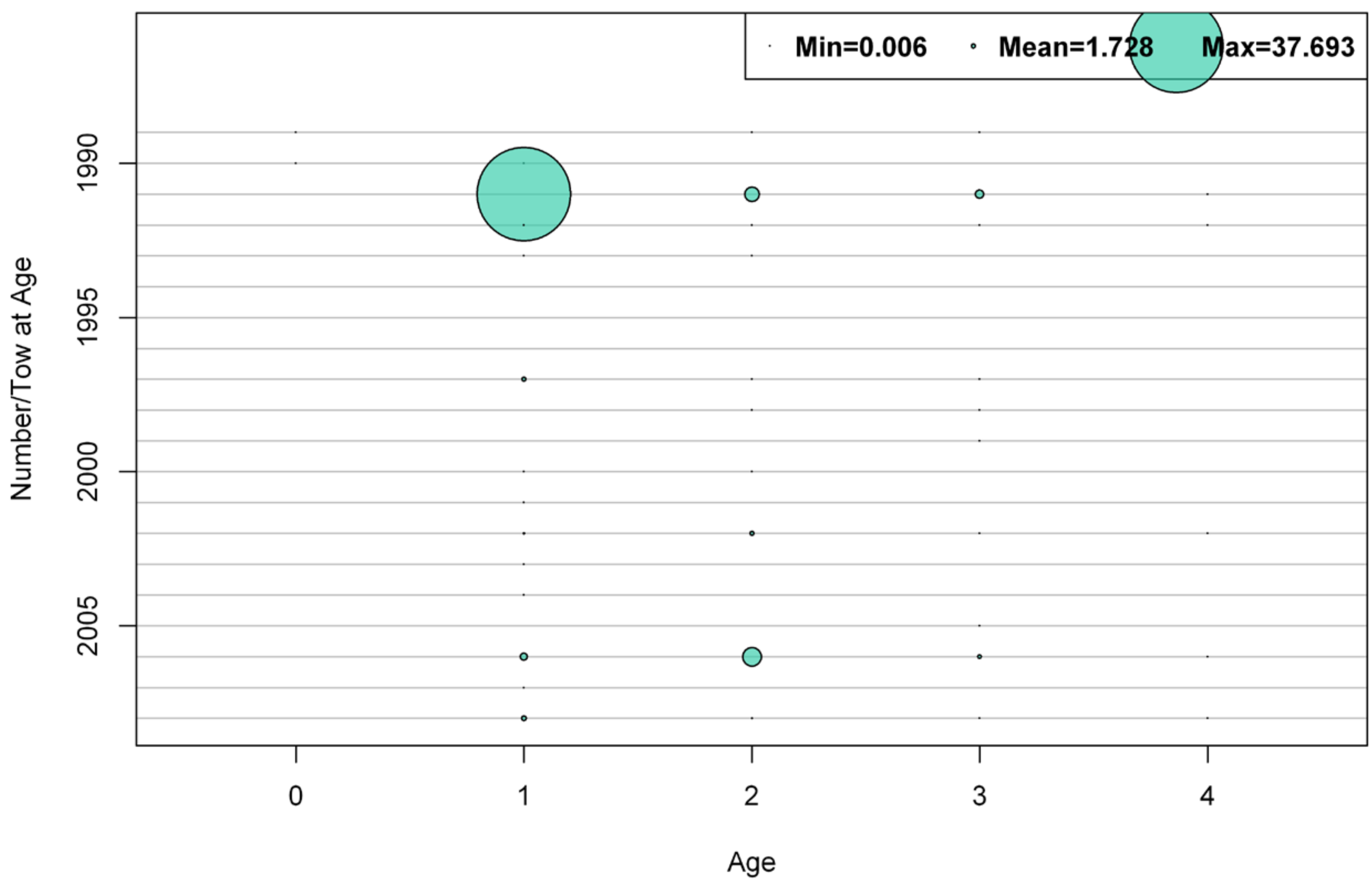


Figure A2.12. Age composition of butterfish in NEFSC spring inshore surveys, 1989-2008. Note: this graph has been re-scaled to the maximum value, which differs from other bubble plots.

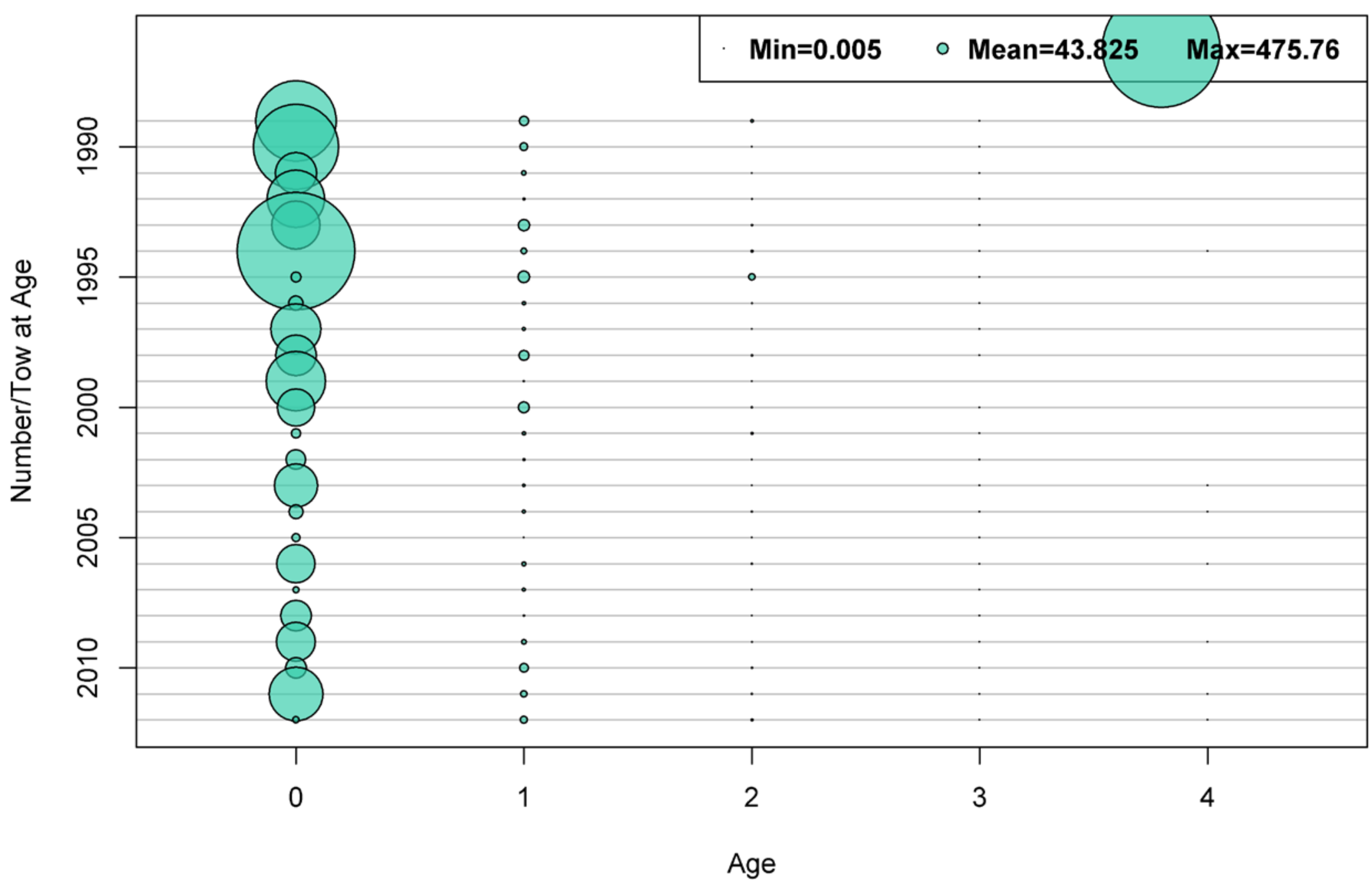


Figure A2.13. Age composition of butterfish in NEFSC fall offshore surveys, 1989-2012.

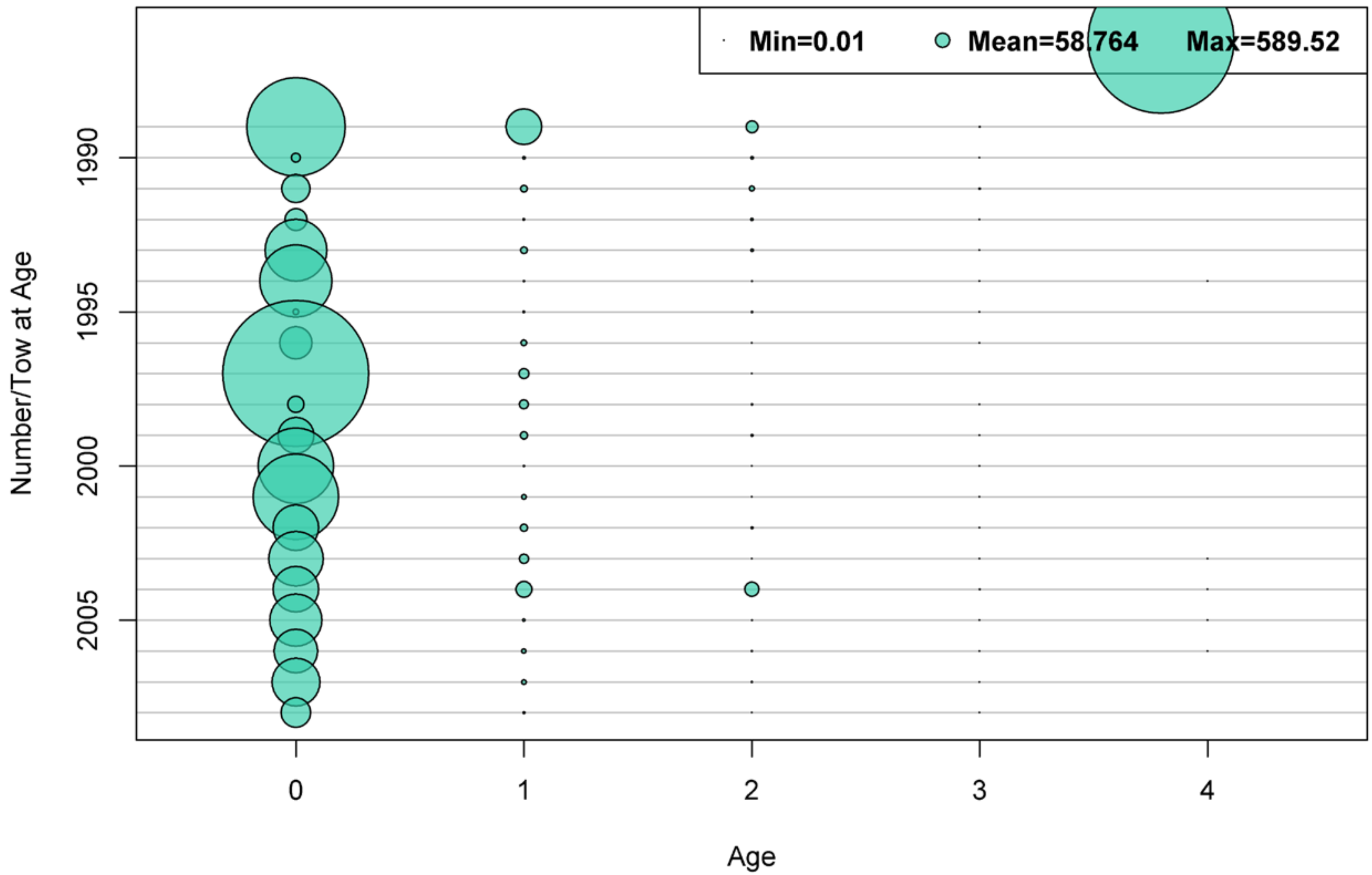


Figure A2.14. Age composition of butterfish in NEFSC fall inshore surveys, 1989-2008.

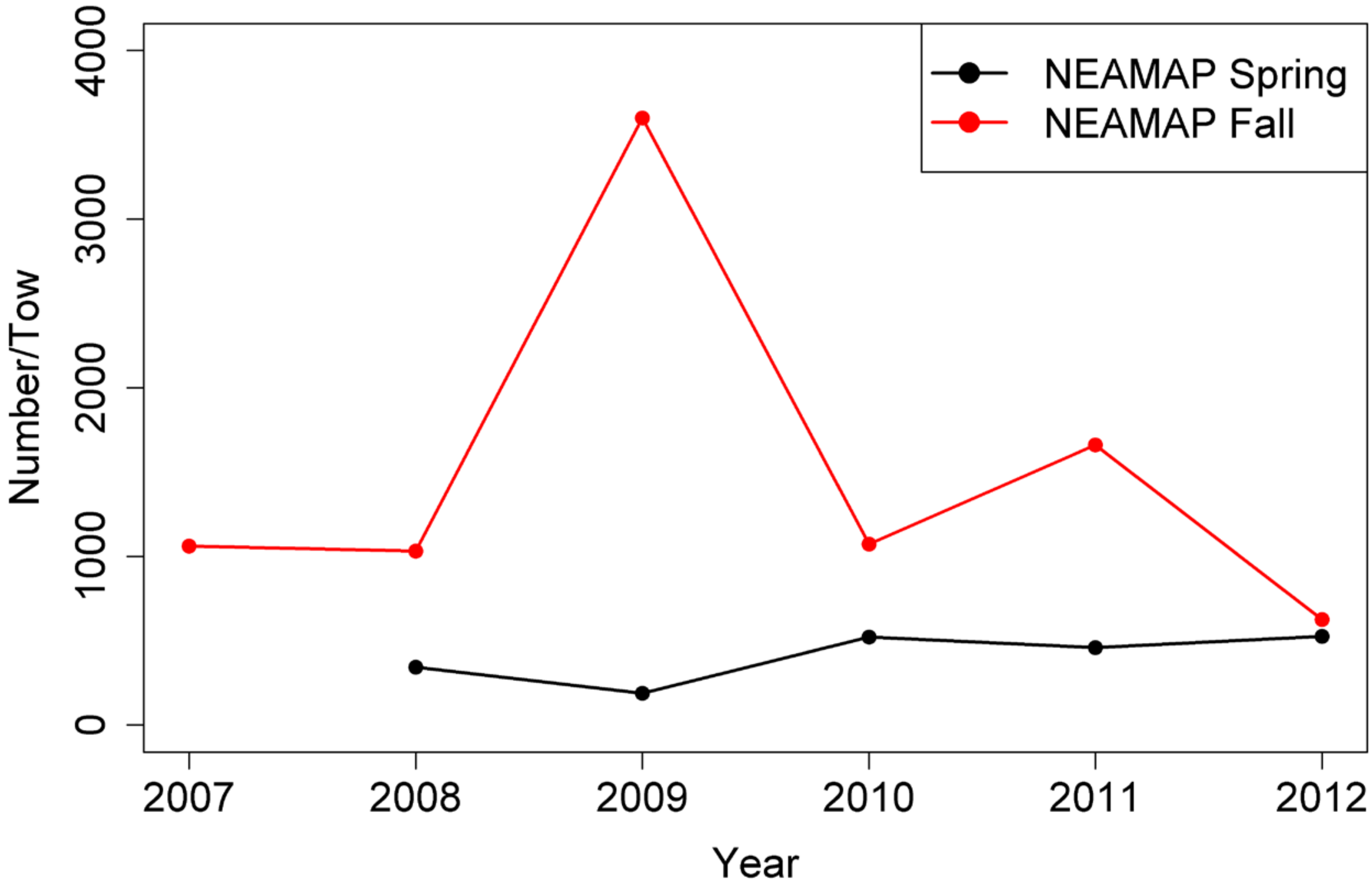


Figure A2.15. NEAMAP spring and fall survey arithmetic mean number per tow for butterfish.

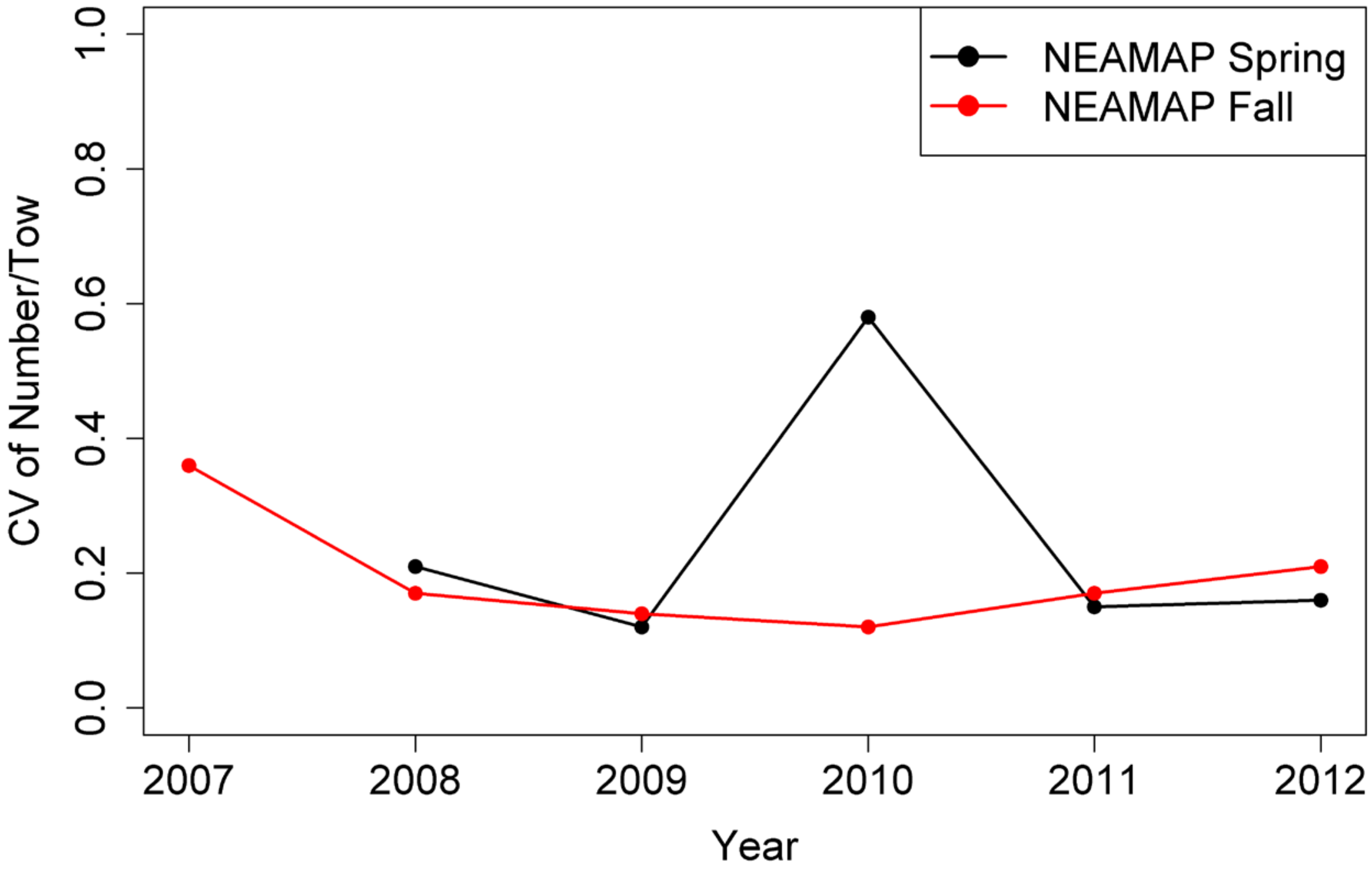


Figure A2.16. Coefficient of variation (CV) for NEAMAP spring and fall survey stratified mean number per tow for butterfish.

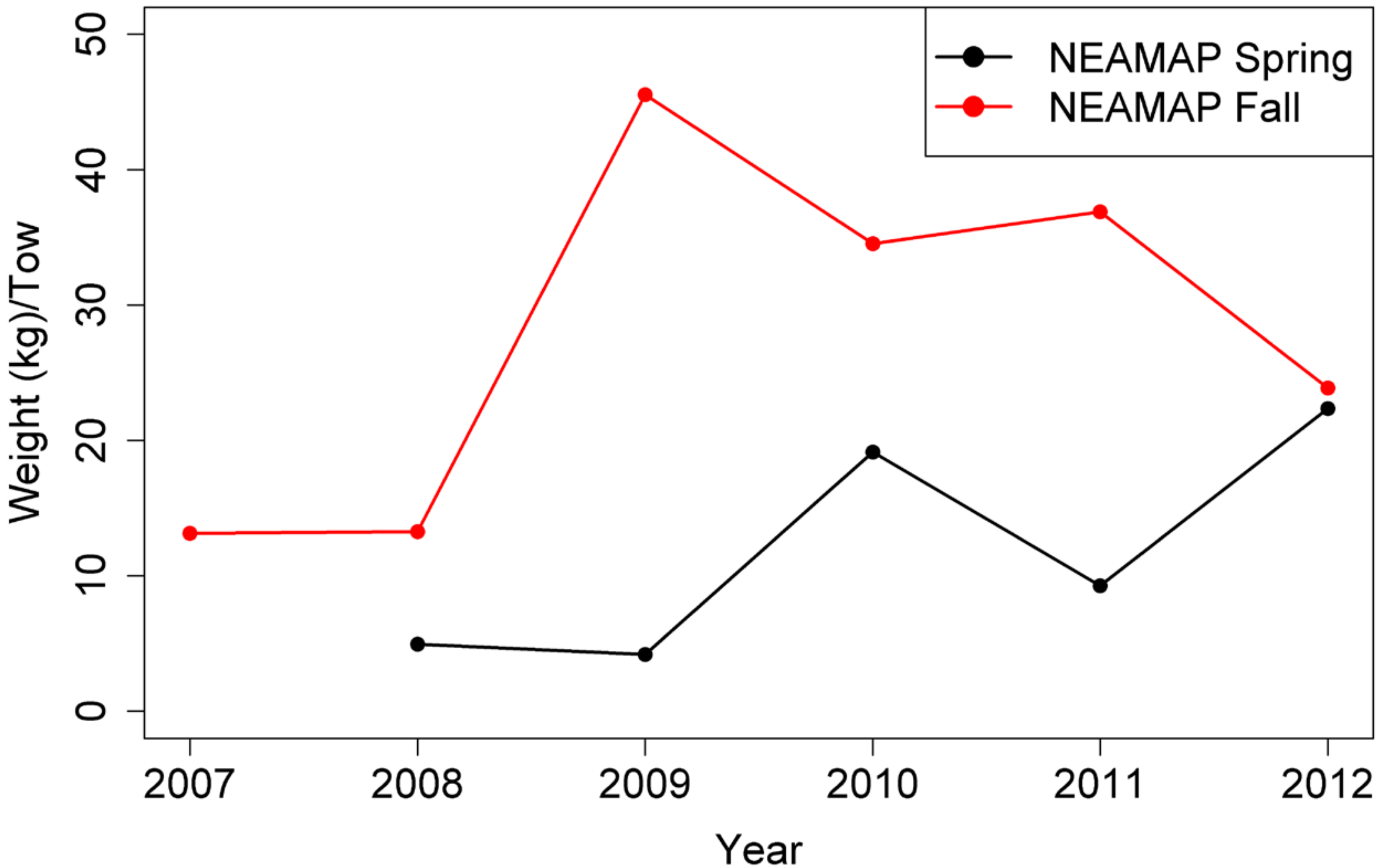


Figure A2.17. NEAMAP spring and fall survey arithmetic mean weight per tow for butterfish.

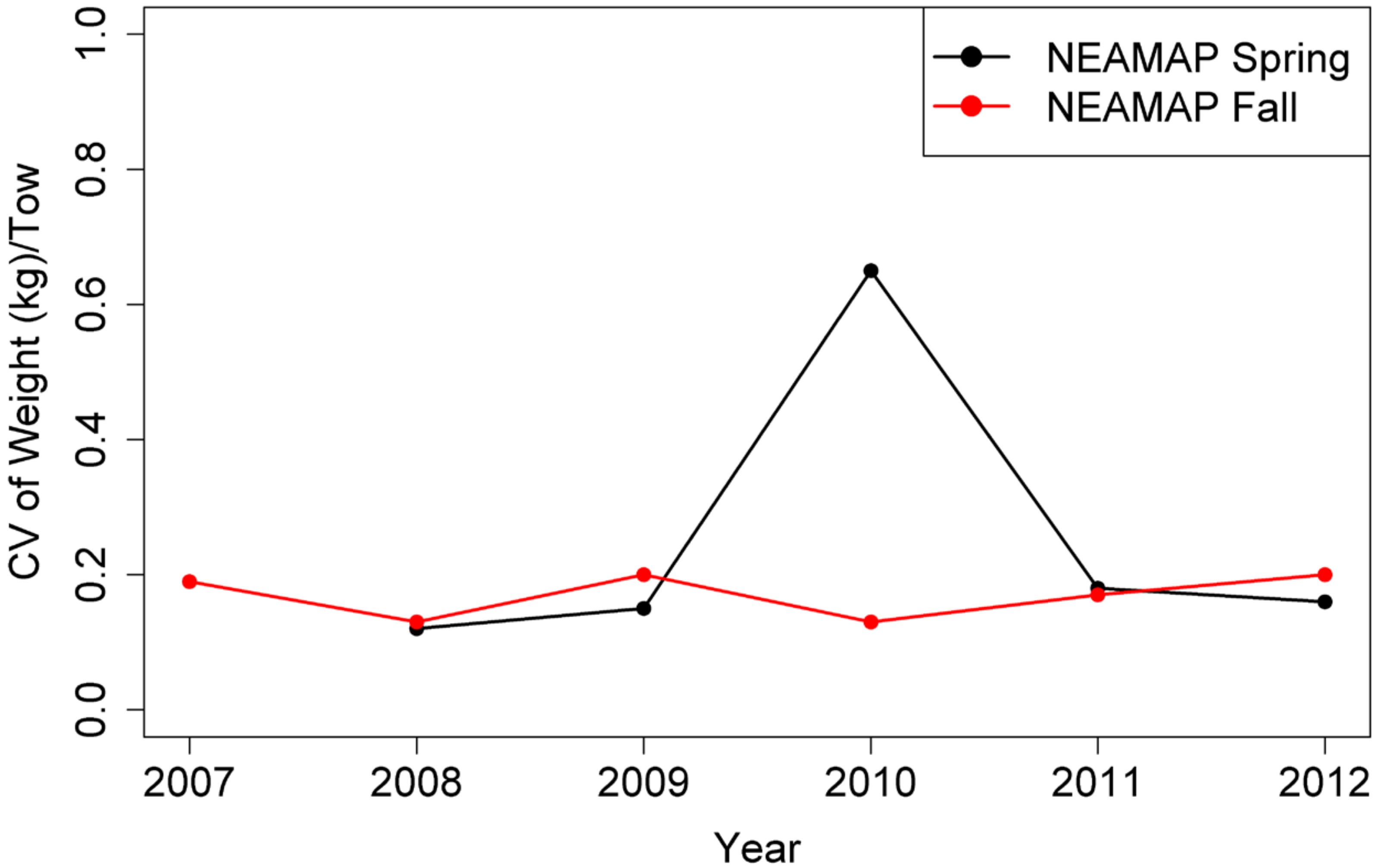


Figure A2.18. Coefficient of variation (CV) for NEAMAP spring and fall survey stratified mean weight per tow for butterfish.

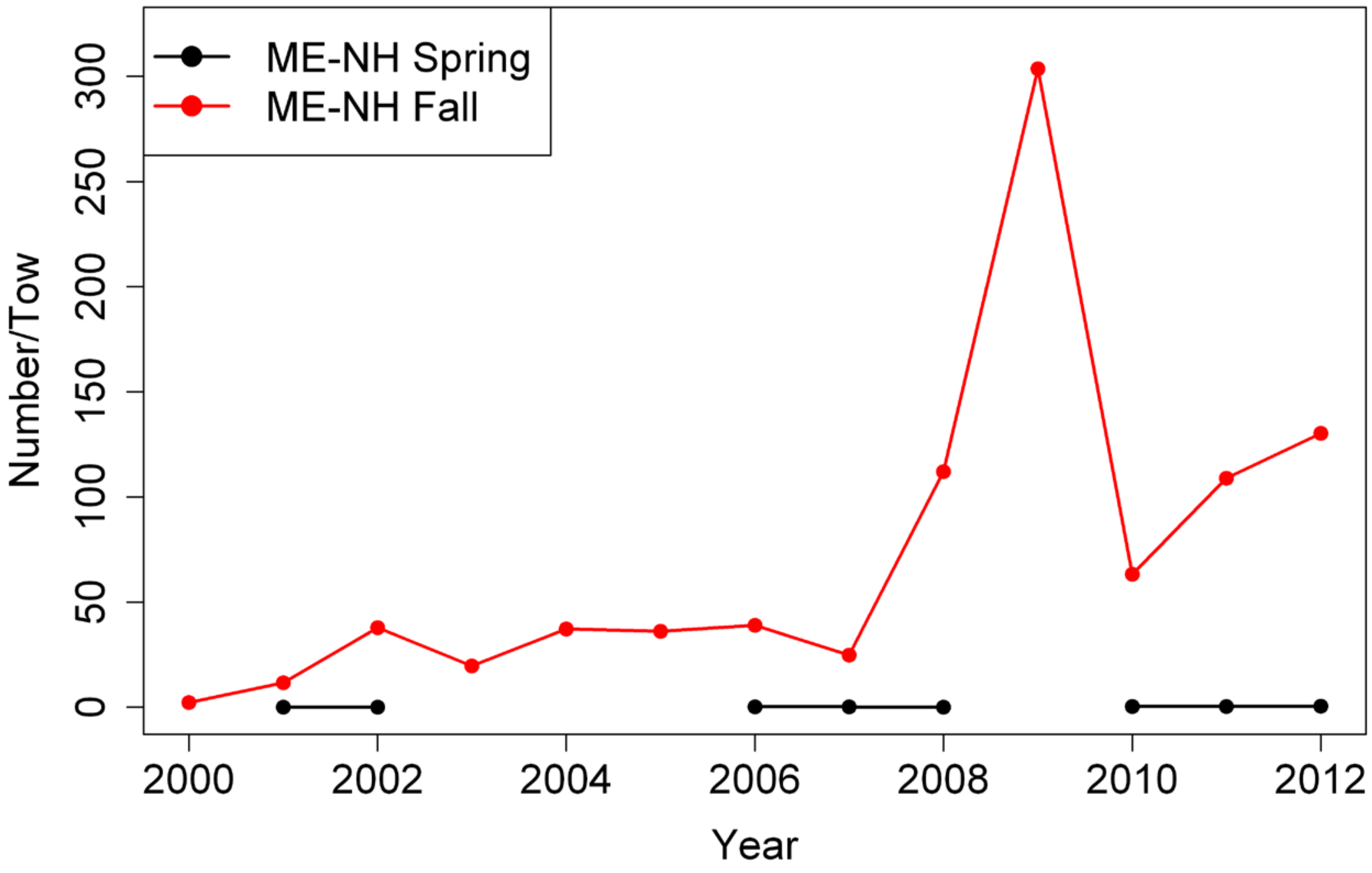


Figure A2.19. Maine-New Hampshire spring and fall survey mean number per tow for butterfish.

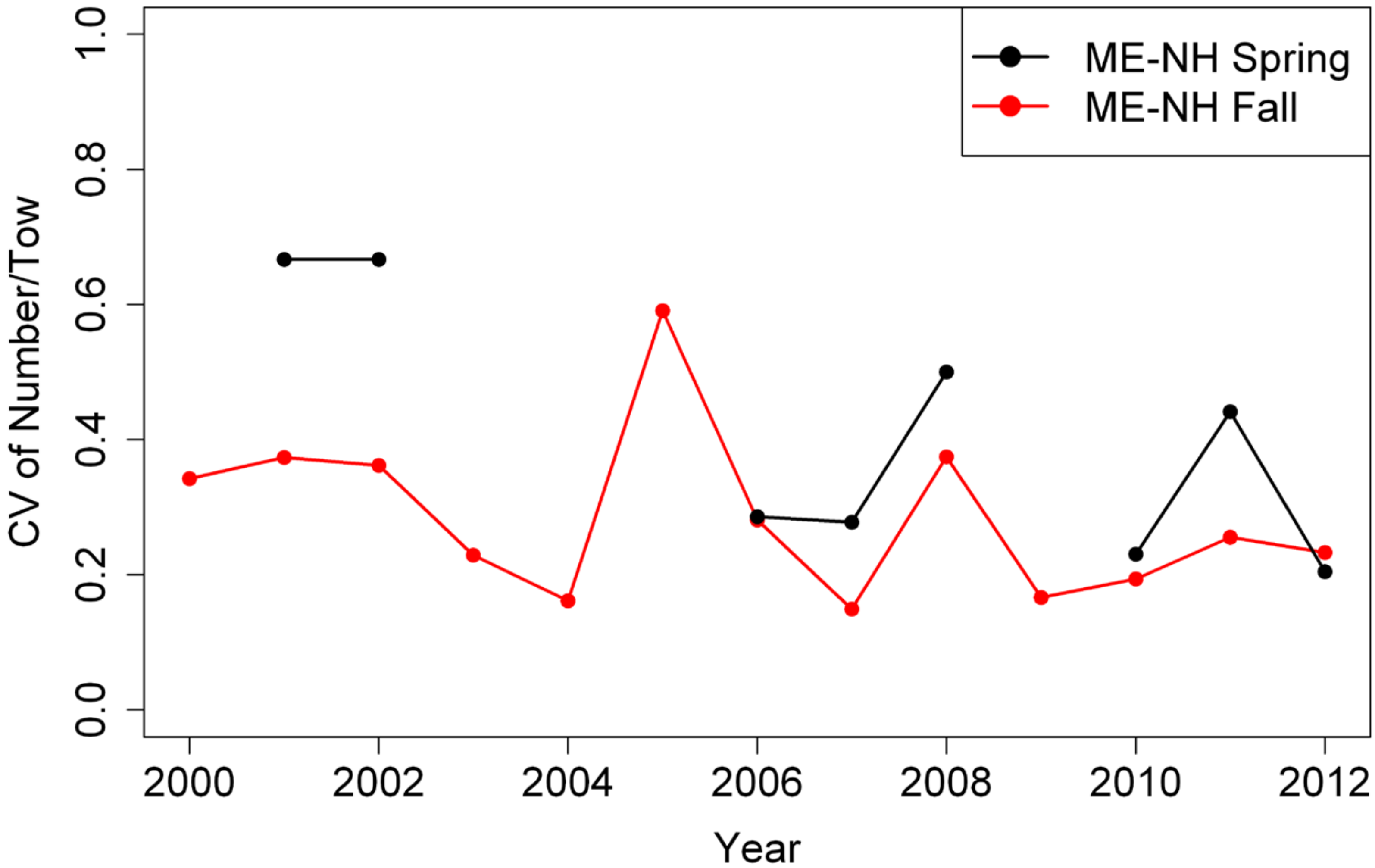


Figure A2.20. Coefficient of variation (CV) for Maine-New Hampshire spring and fall survey mean number per tow for butterfish.

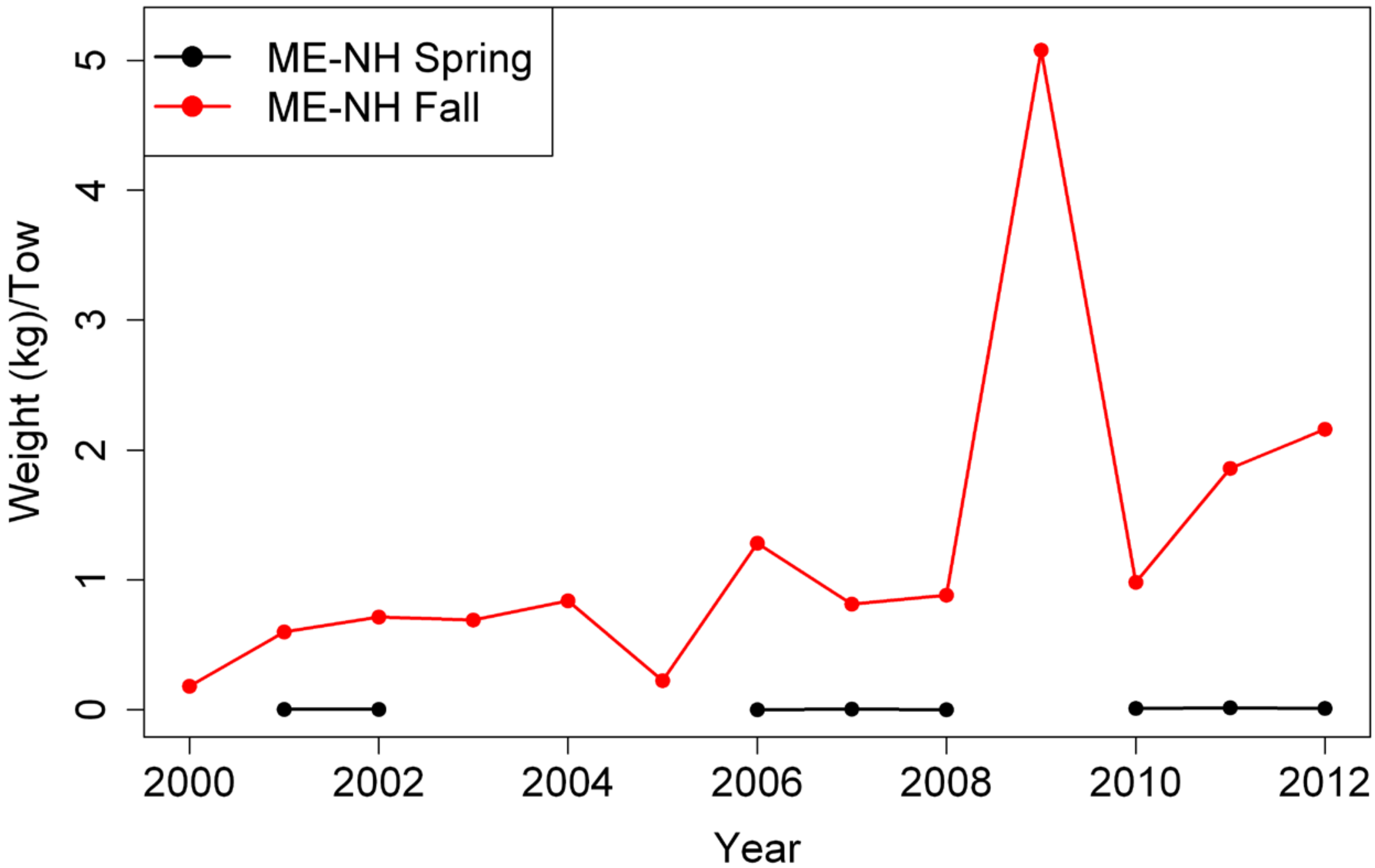


Figure A2.21. Maine-New Hampshire spring and fall survey mean weight per tow for butterfish.

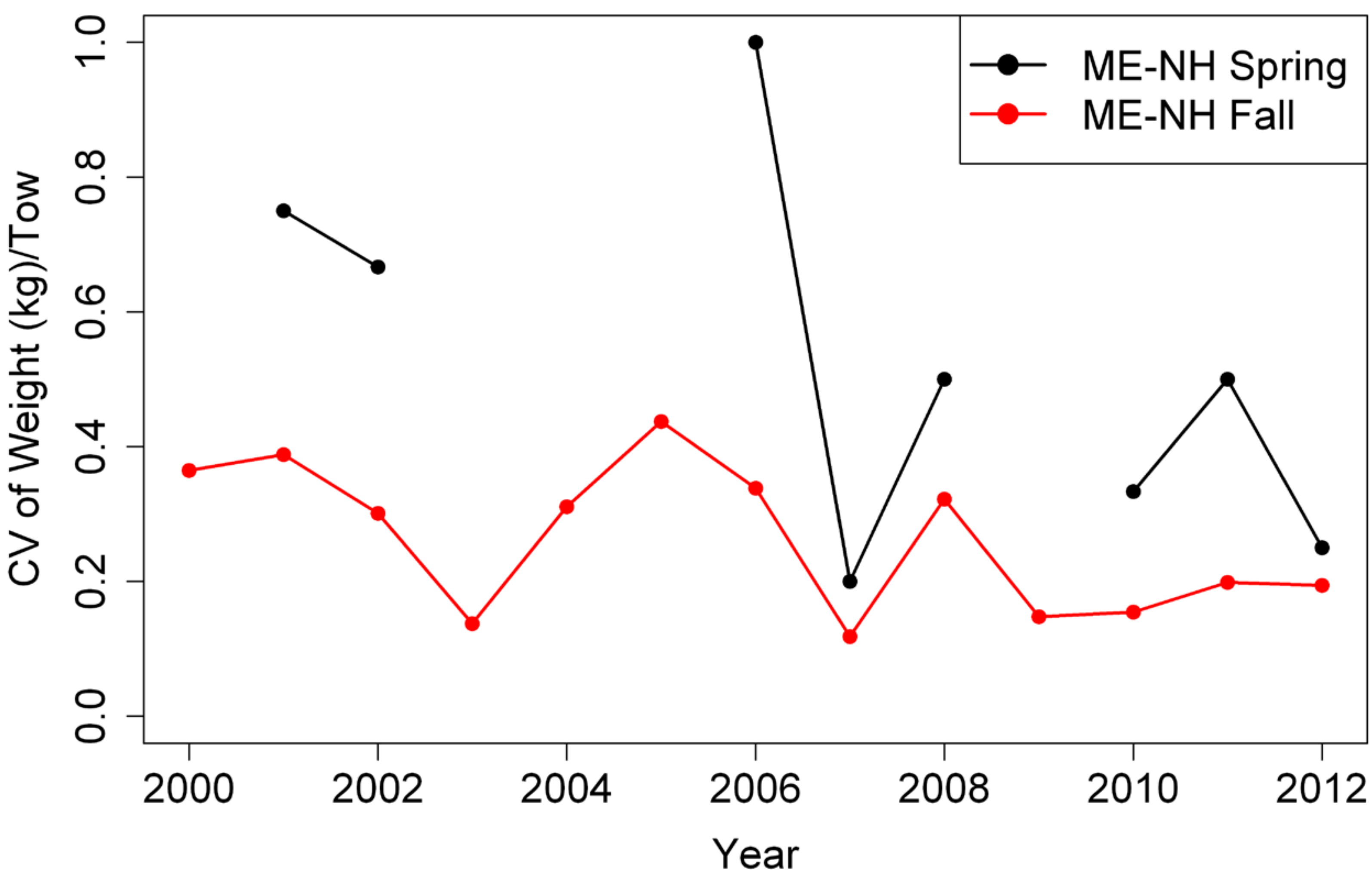


Figure A2.22. Coefficient of variation (CV) for Maine-New Hampshire spring and fall survey mean weight per tow for butterfish.

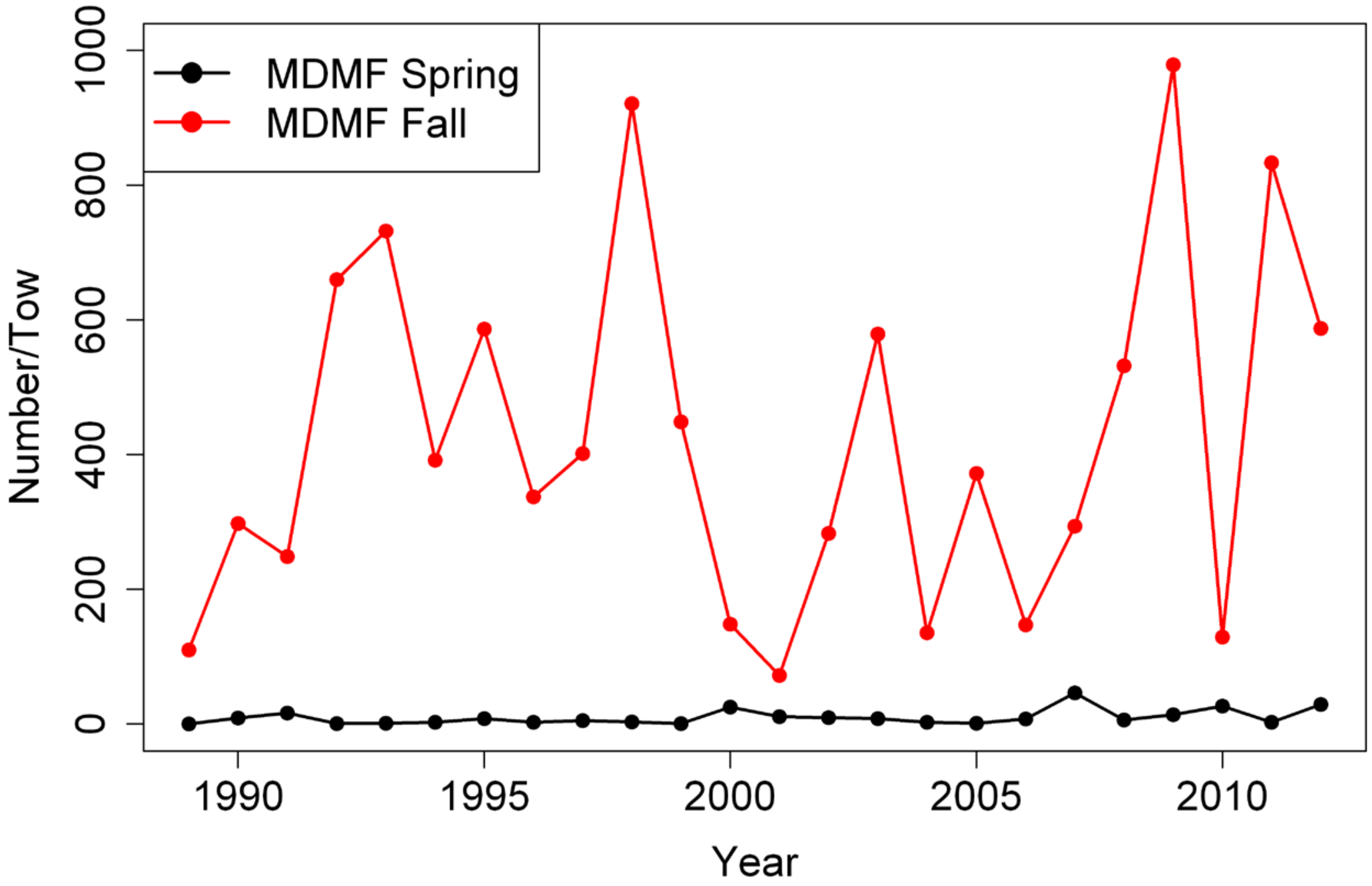


Figure A2.23. MDMF spring and fall survey mean number per tow for butterfish.

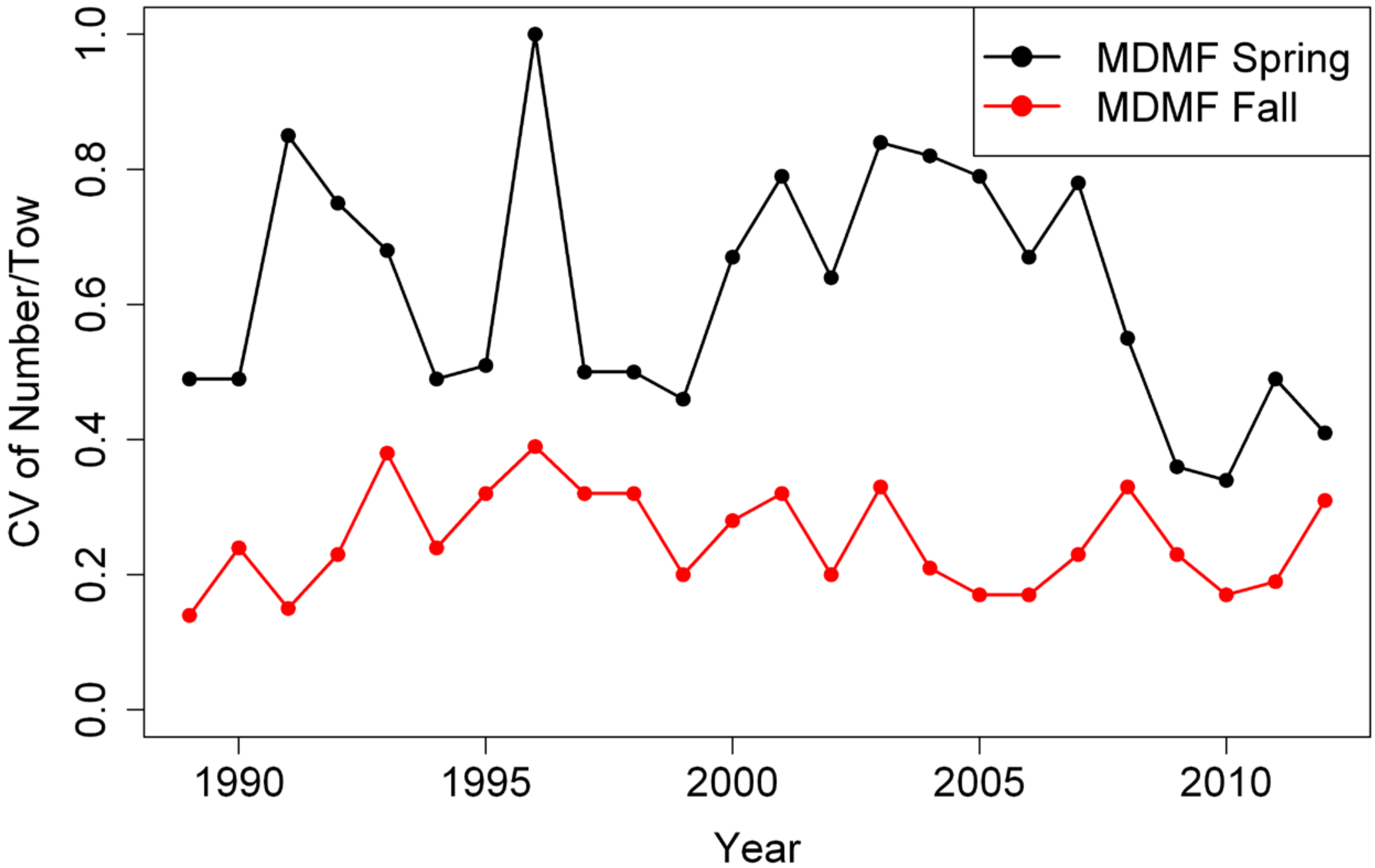


Figure A2.24. Coefficient of variation (CV) for MDMF spring and fall survey mean number per tow for butterfish.

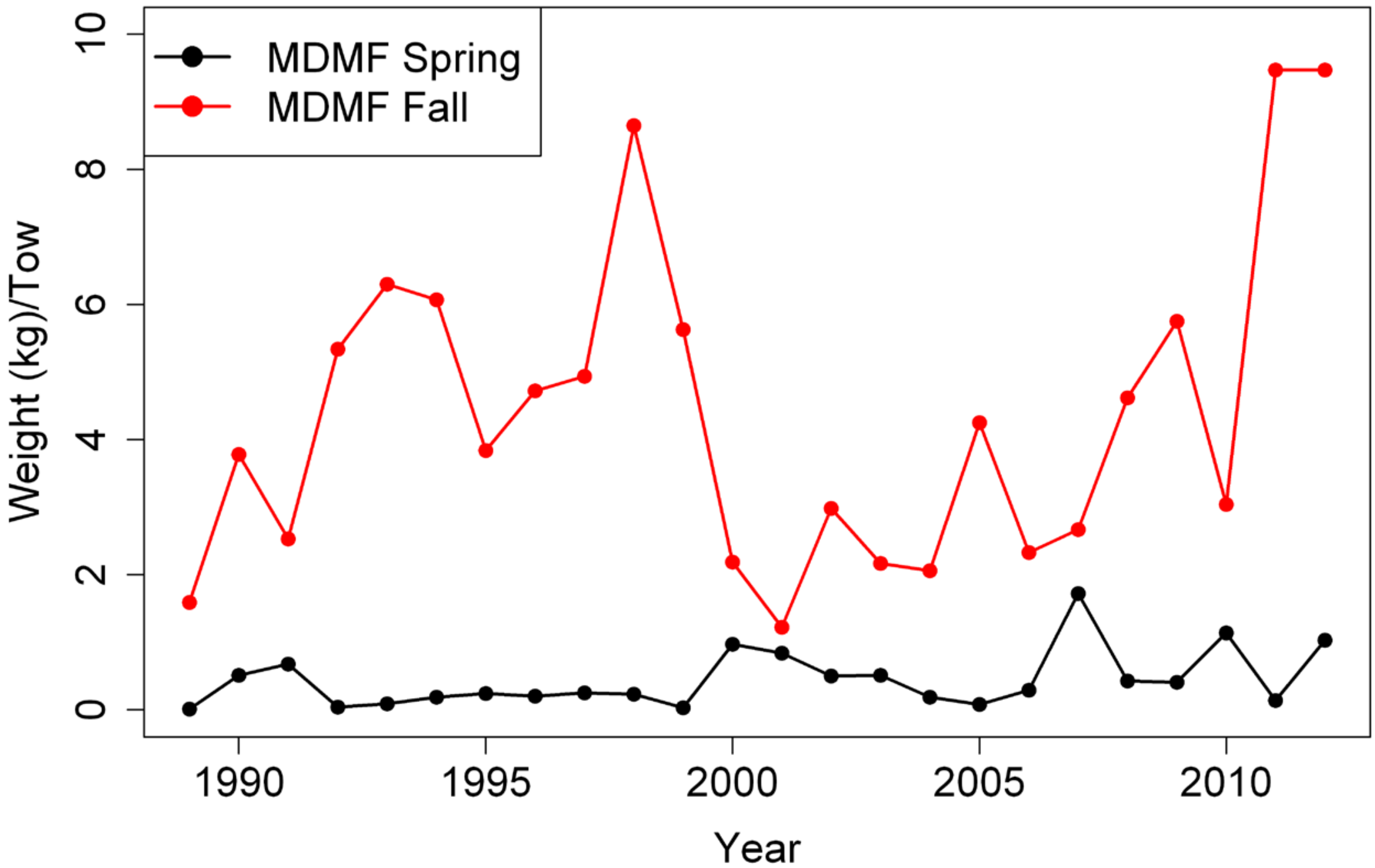


Figure A2.25 MDMF spring and fall survey mean weight per tow for butterfish.

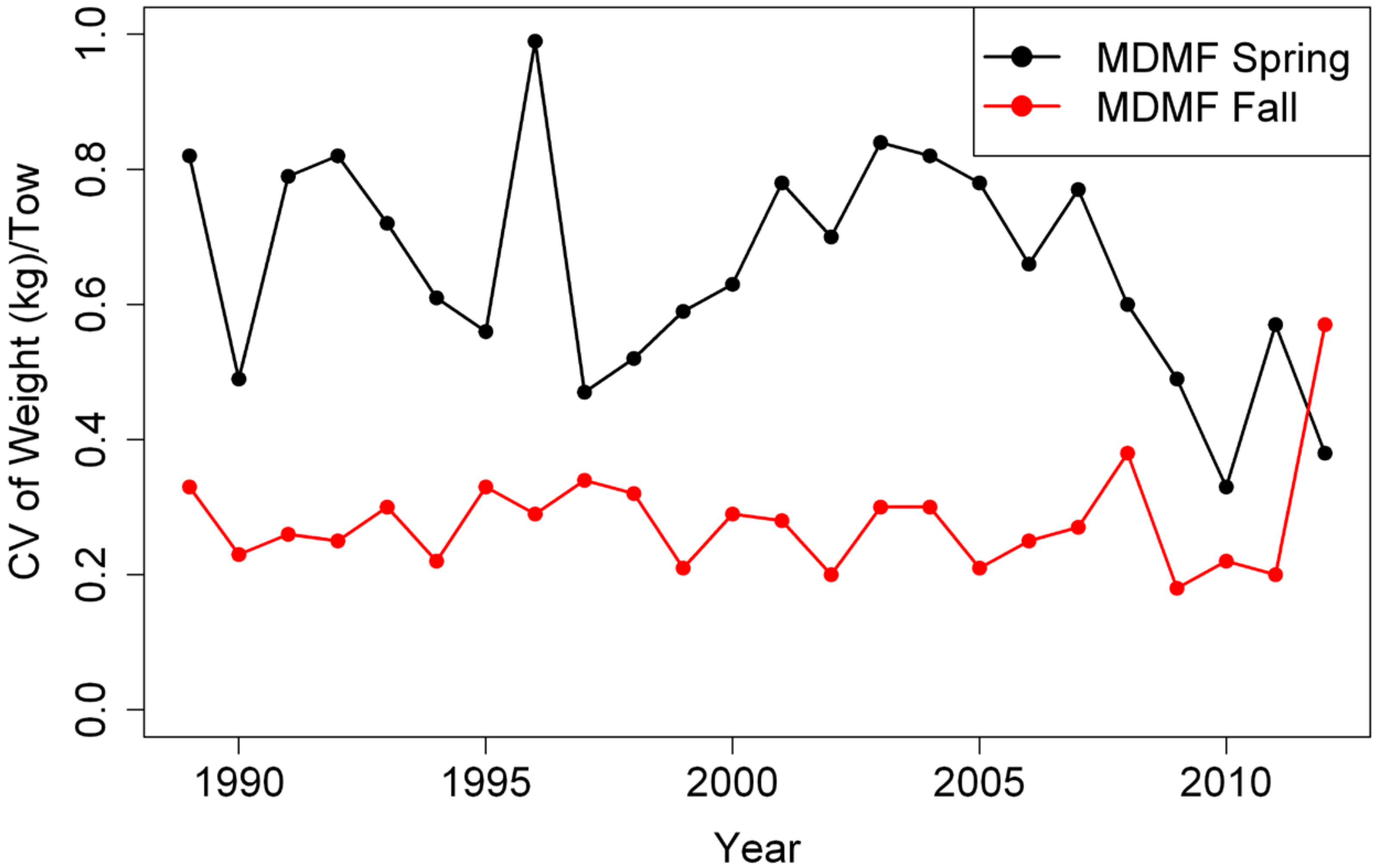


Figure A2.26. Coefficient of variation (CV) for MDMF spring and fall survey mean weight per tow for butterfish.

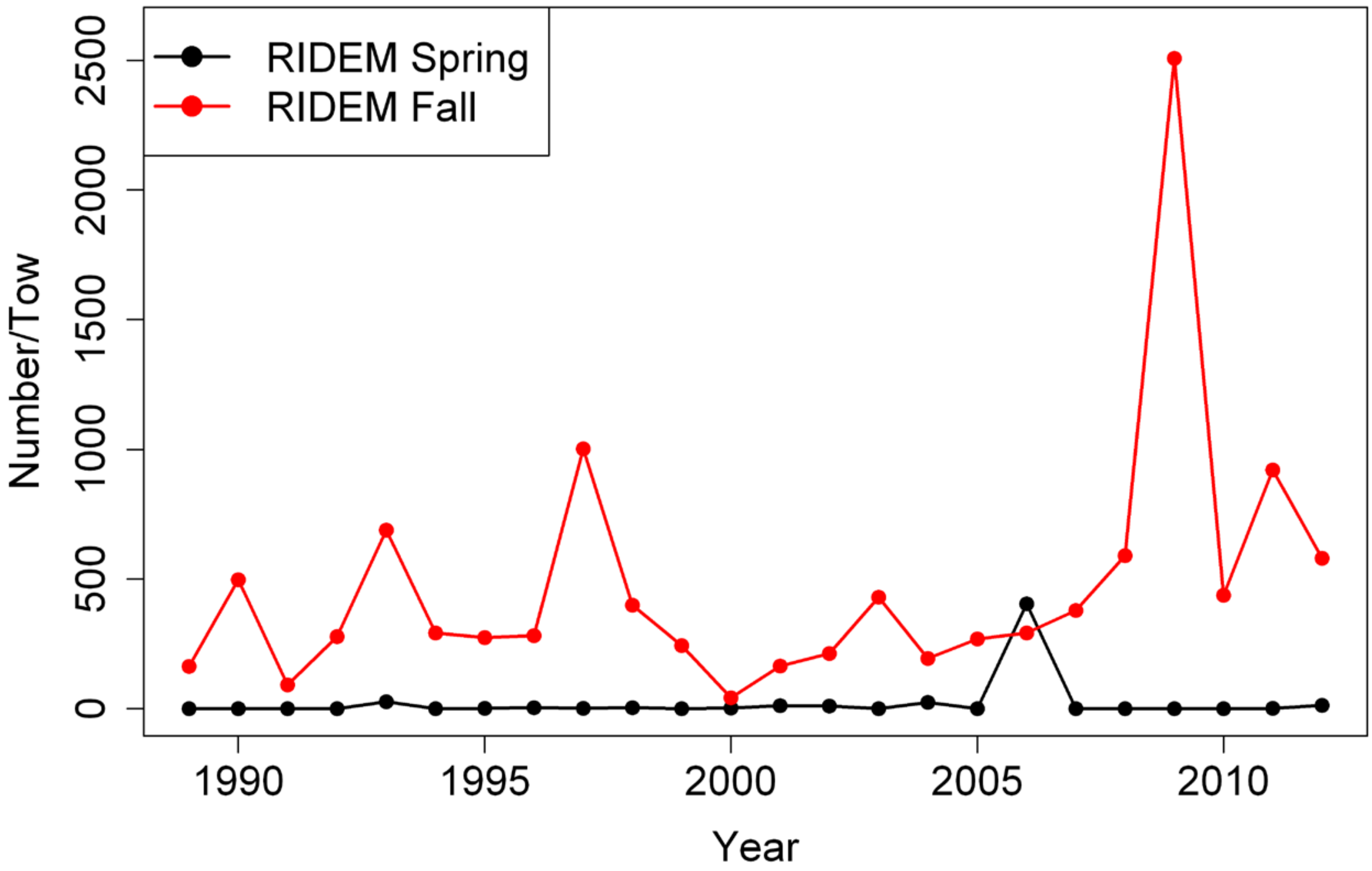


Figure A2.27. RIDEM spring and fall survey mean number per tow for butterfish.

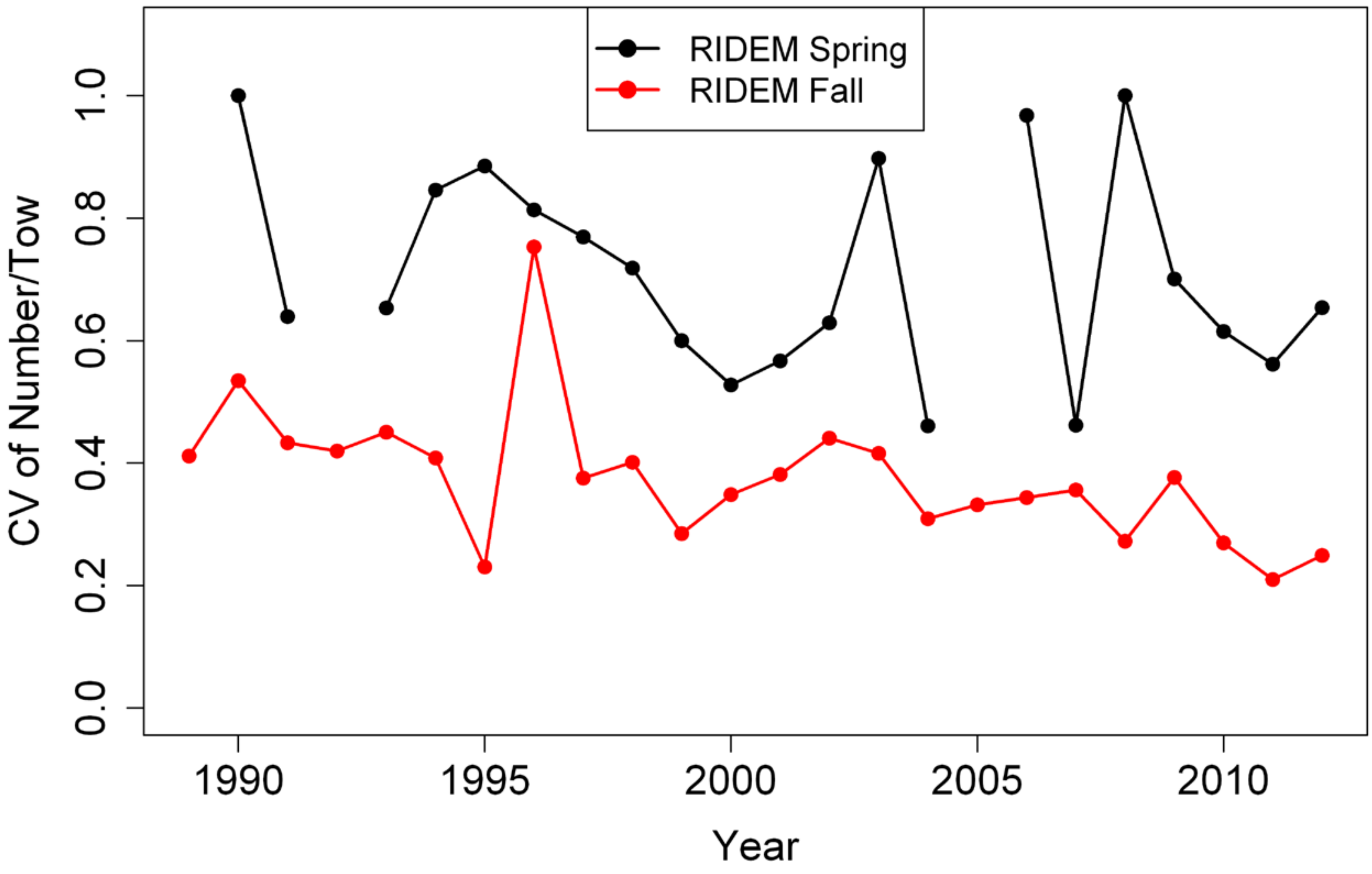


Figure A2.28. Coefficient of variation (CV) for RIDEM spring and fall survey mean number per tow for butterfish.

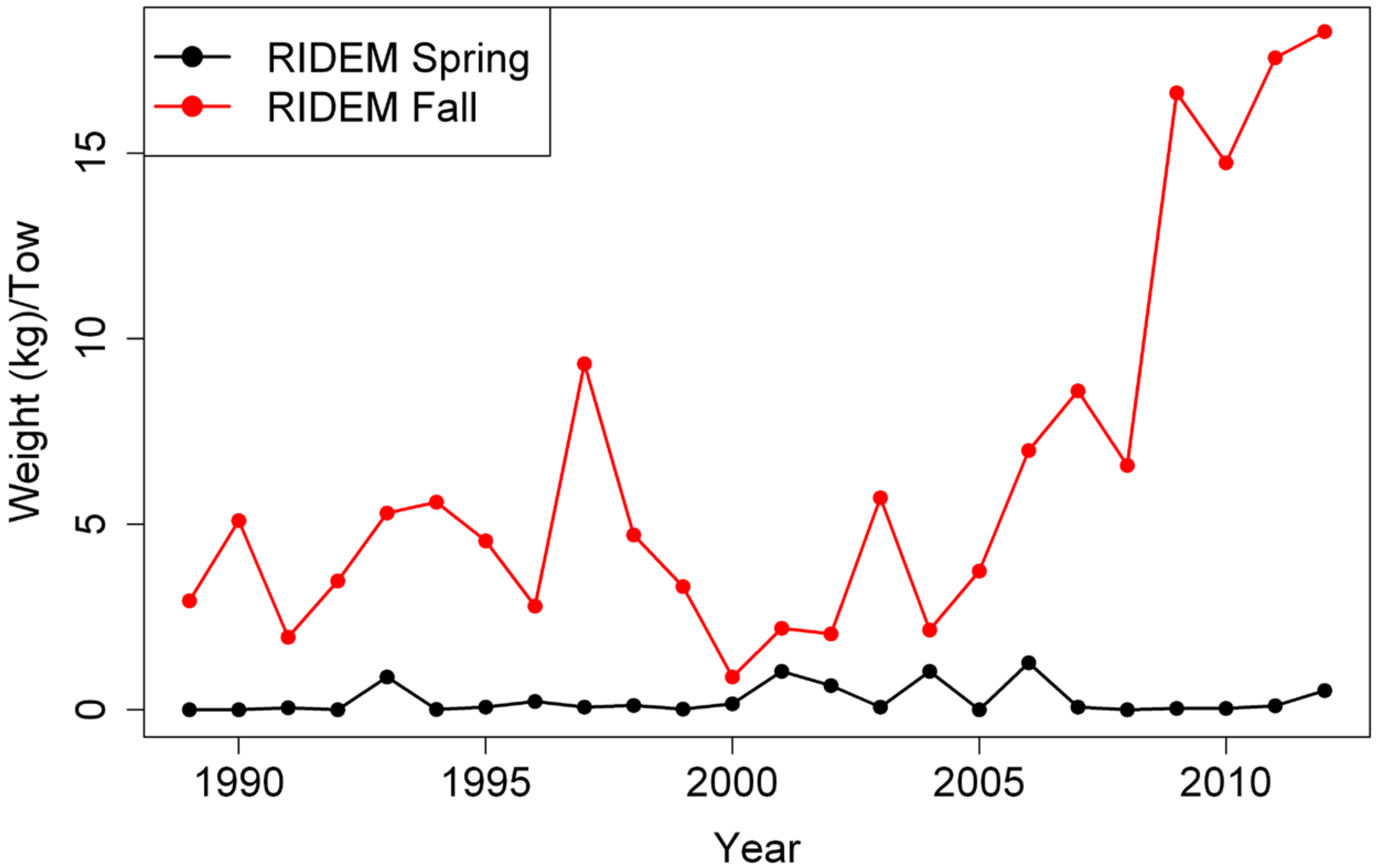


Figure A2.29. RIDEM spring and fall survey mean weight per tow for butterfish.

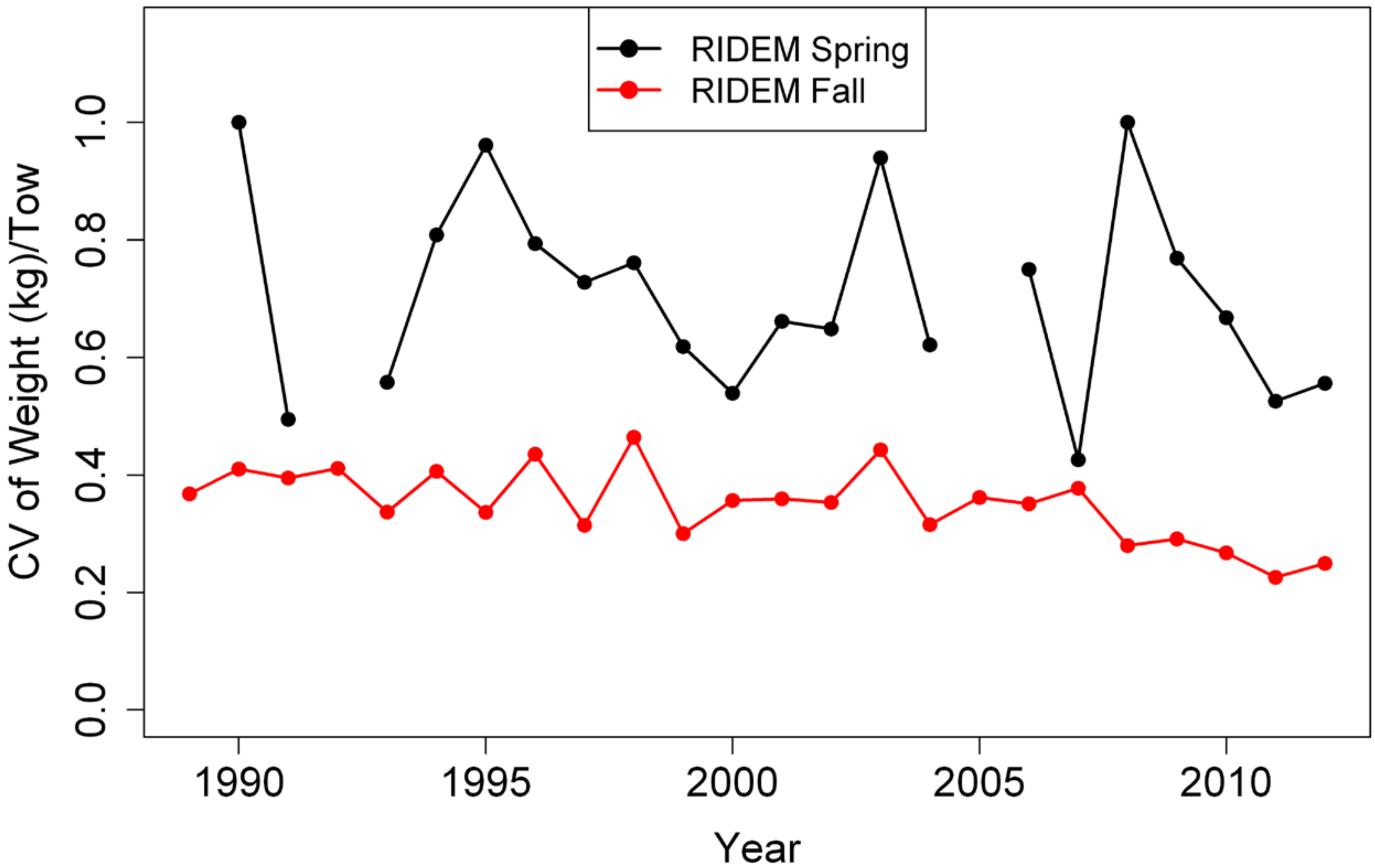


Figure A2.30. Coefficient of variation (CV) for RIDEM spring and fall survey mean weight per tow for butterfish.

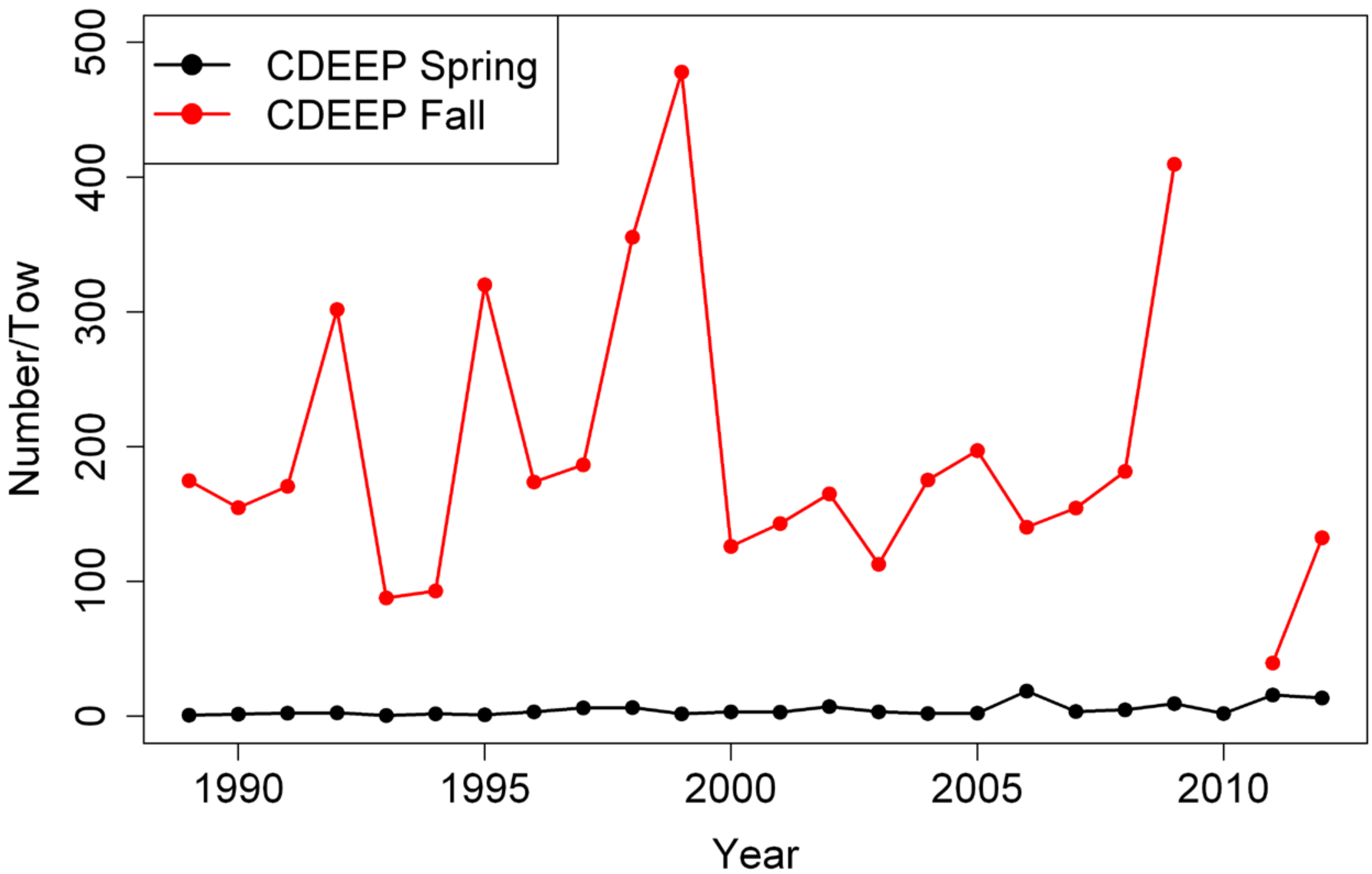


Figure A2.31. CDEEP Long Island Sound spring and fall survey geometric mean number per tow for butterfish.

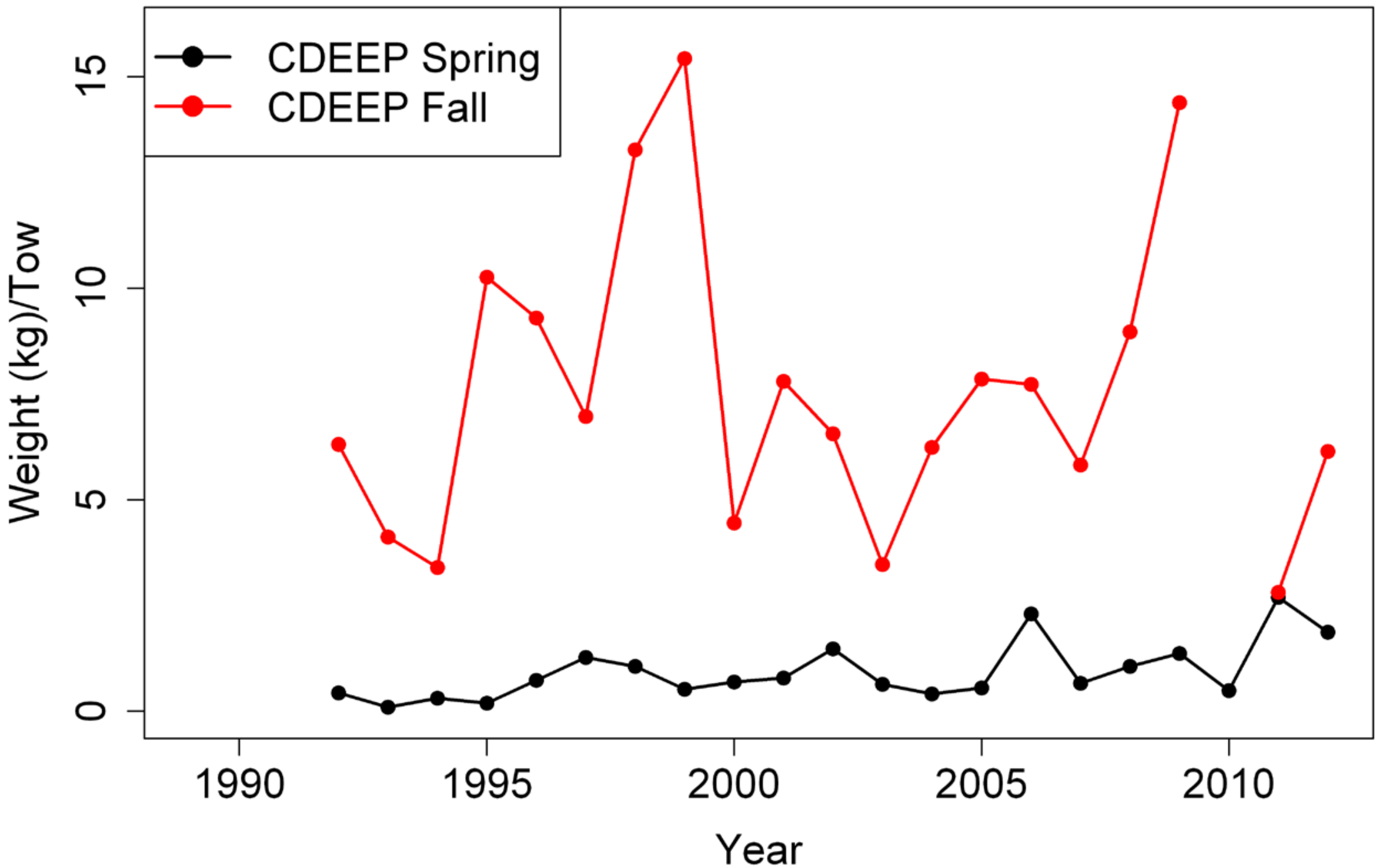


Figure A2.32. CDEEP Long Island Sound spring and fall survey geometric mean weight per tow for butterfish.

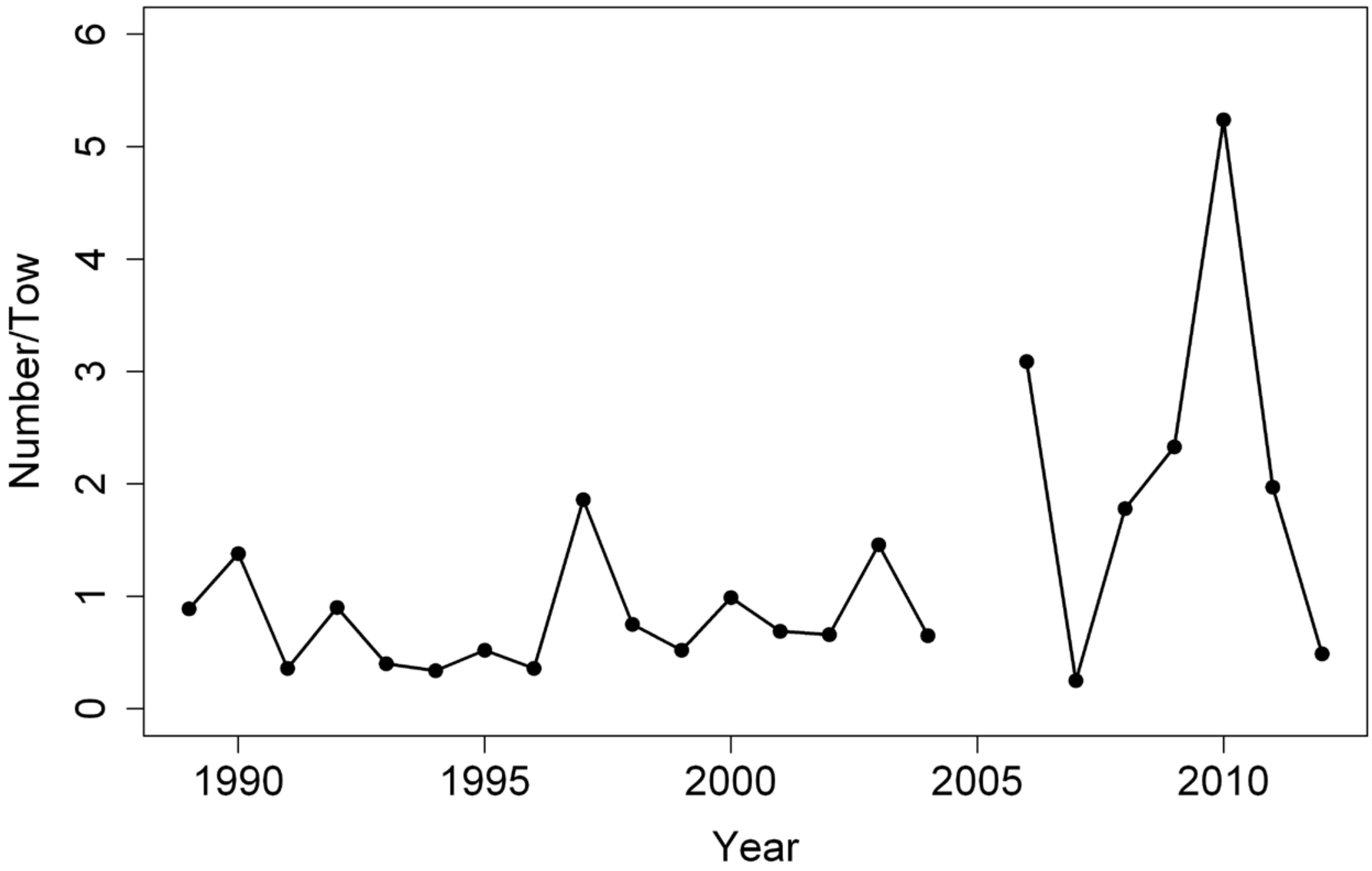


Figure A2.33. NYDEC Peconic Bay survey annual mean number per tow for butterfish.

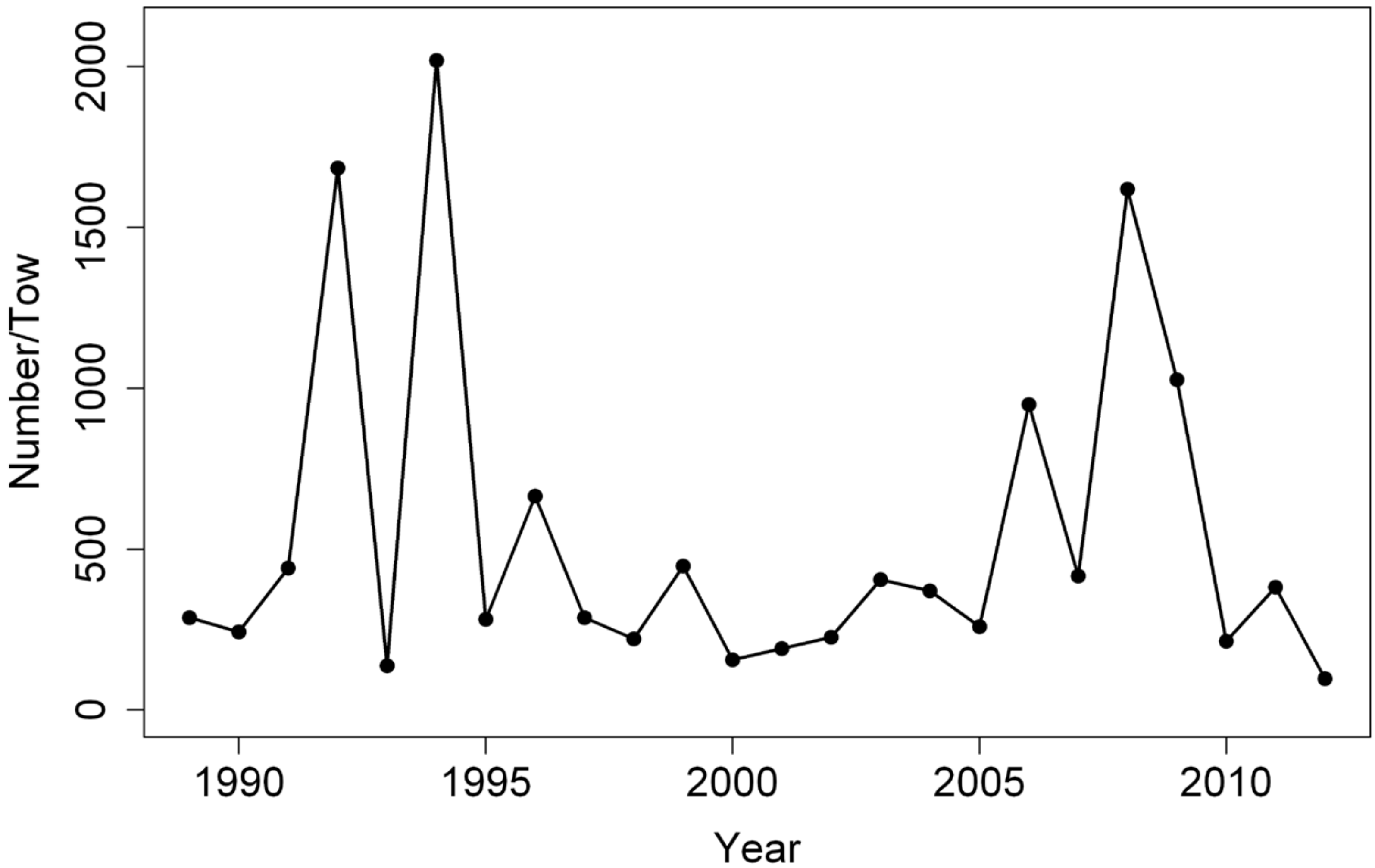


Figure A2.34. NJDEP survey annual stratified mean number per tow for butterfish.

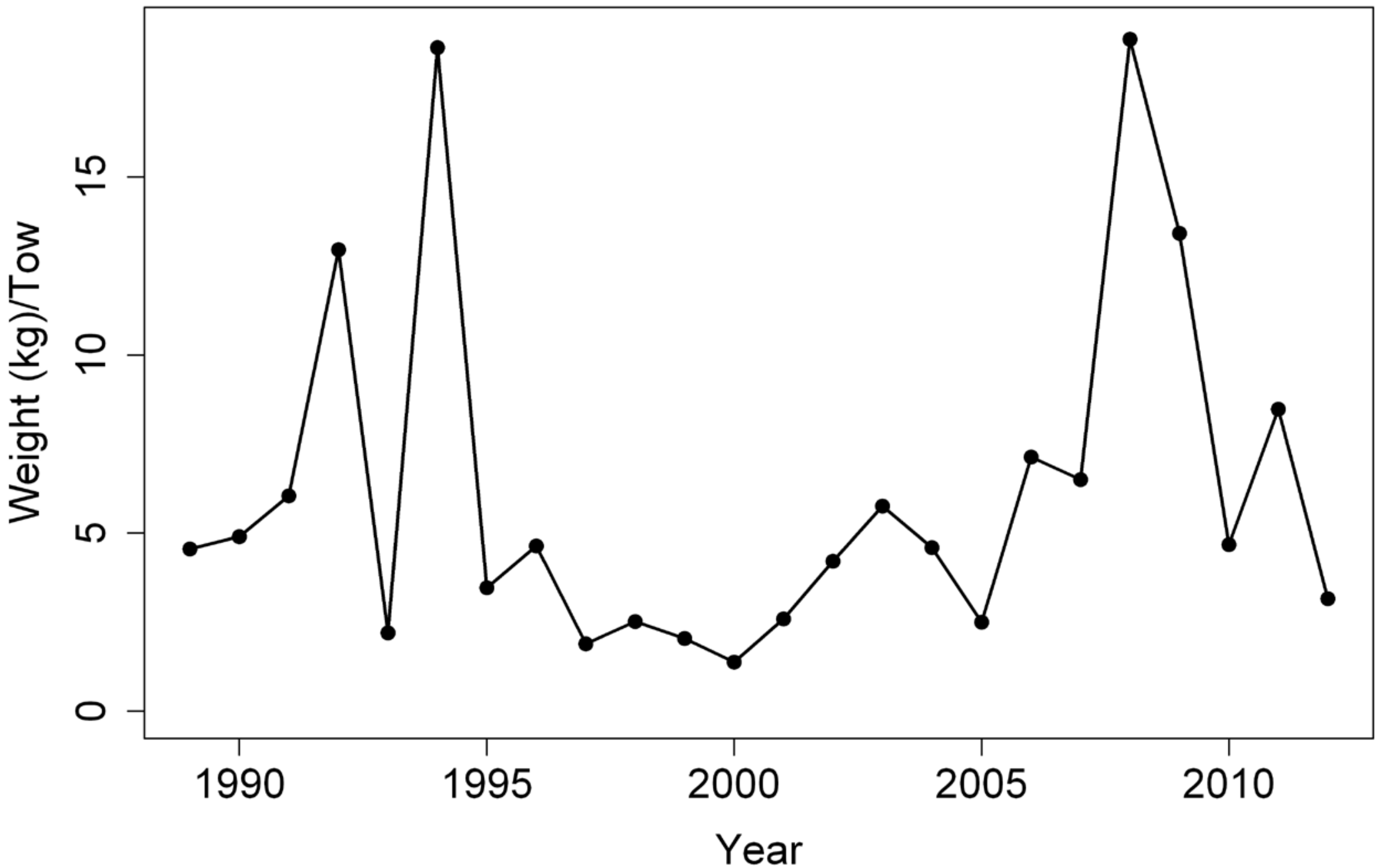


Figure A2.35. NJDEP survey annual stratified mean weight per tow for butterfish.

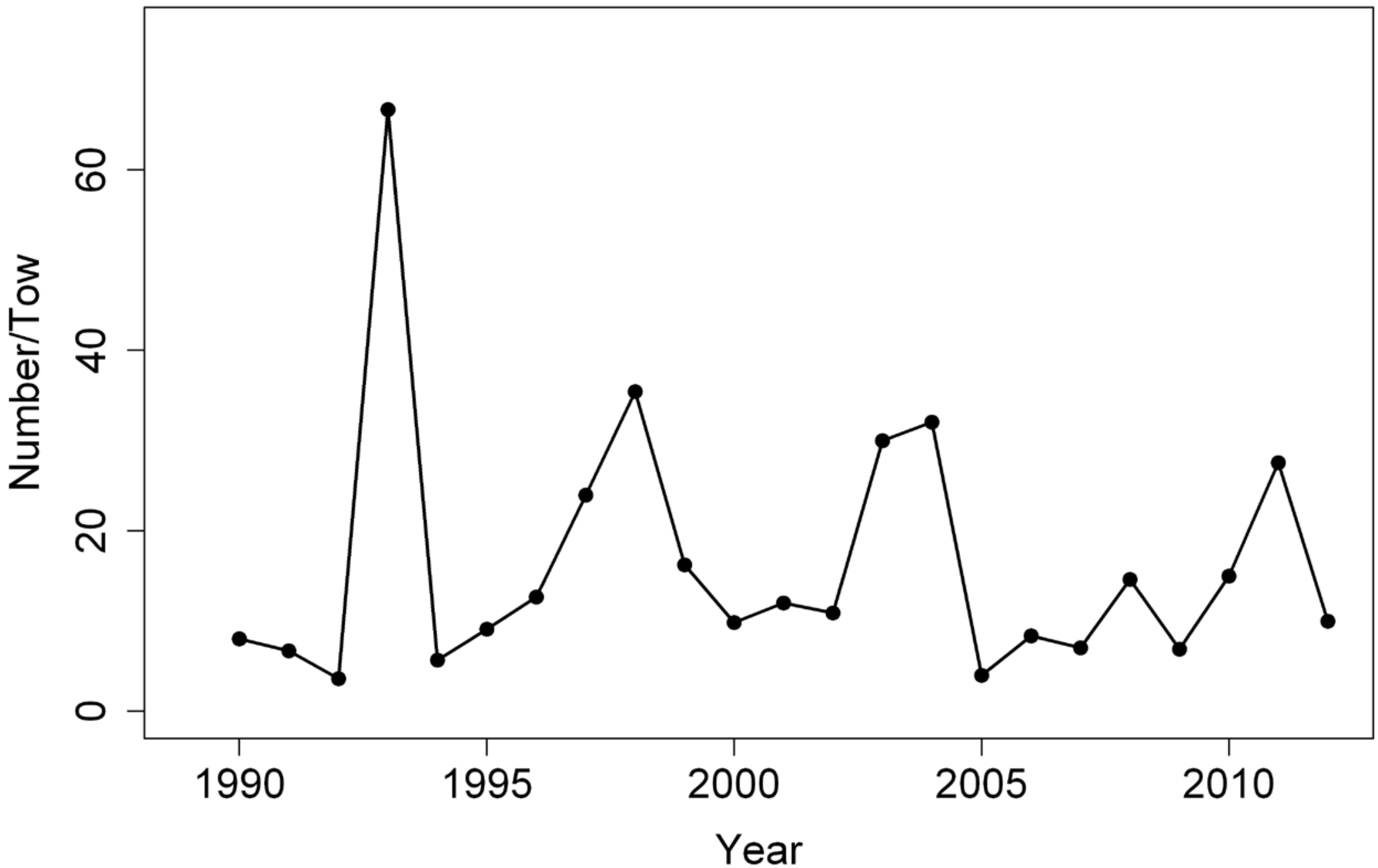


Figure A2.36. DDNREC survey annual mean number per tow for butterfish.

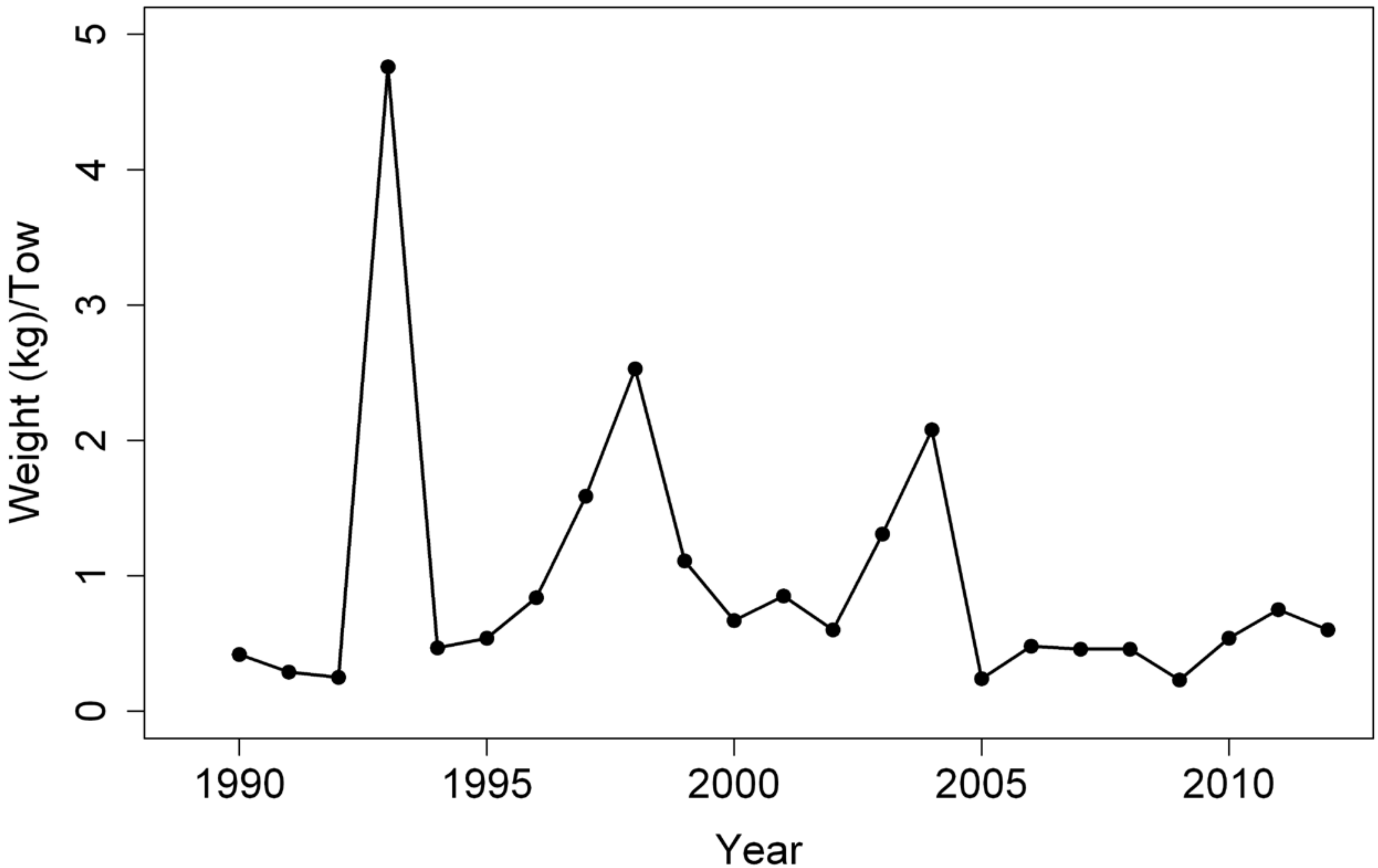


Figure A2.37. DDNREC survey annual mean weight per tow for butterfish.

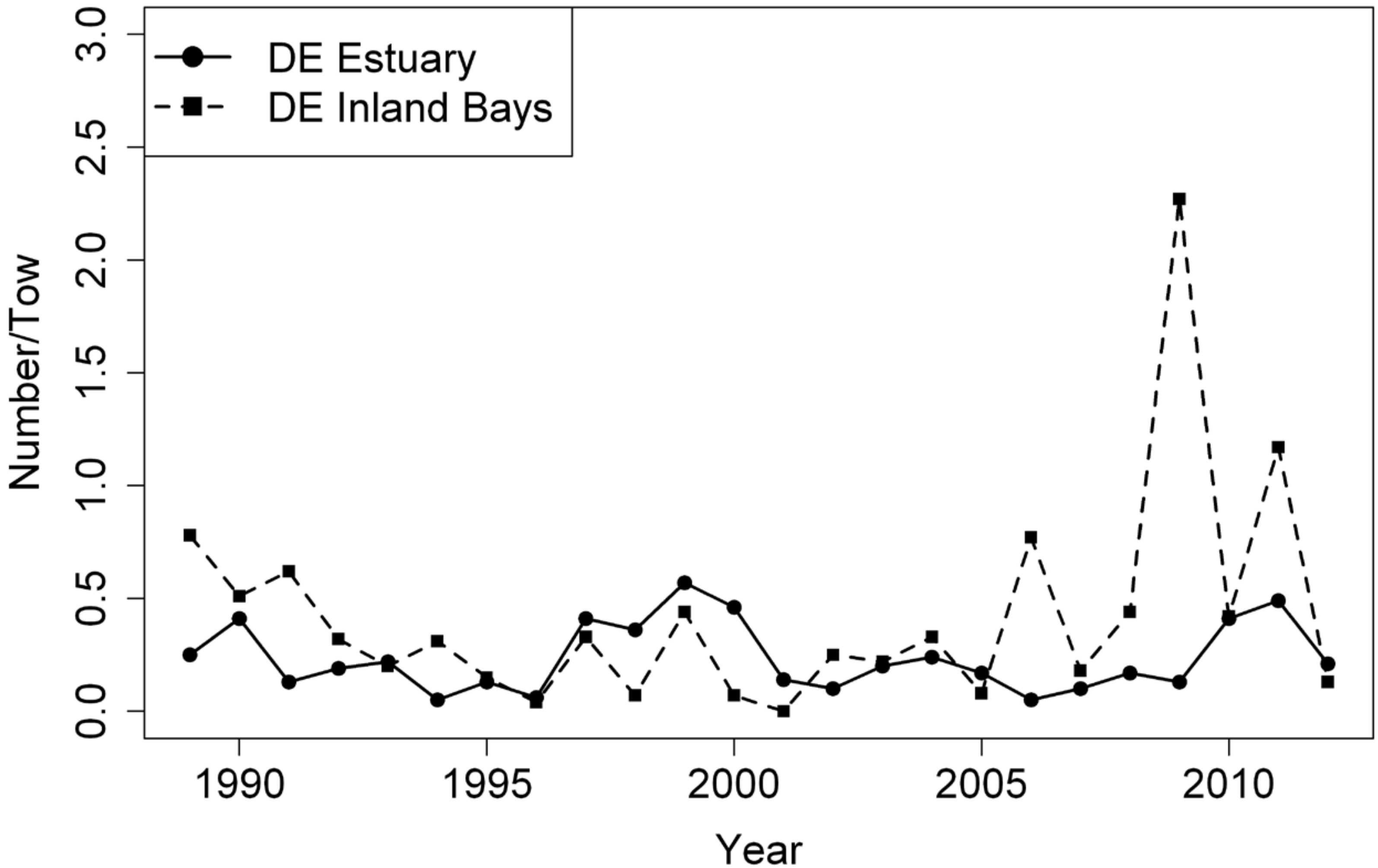


Figure A2.38. DDNREC juvenile survey annual mean number per tow for butterfish.

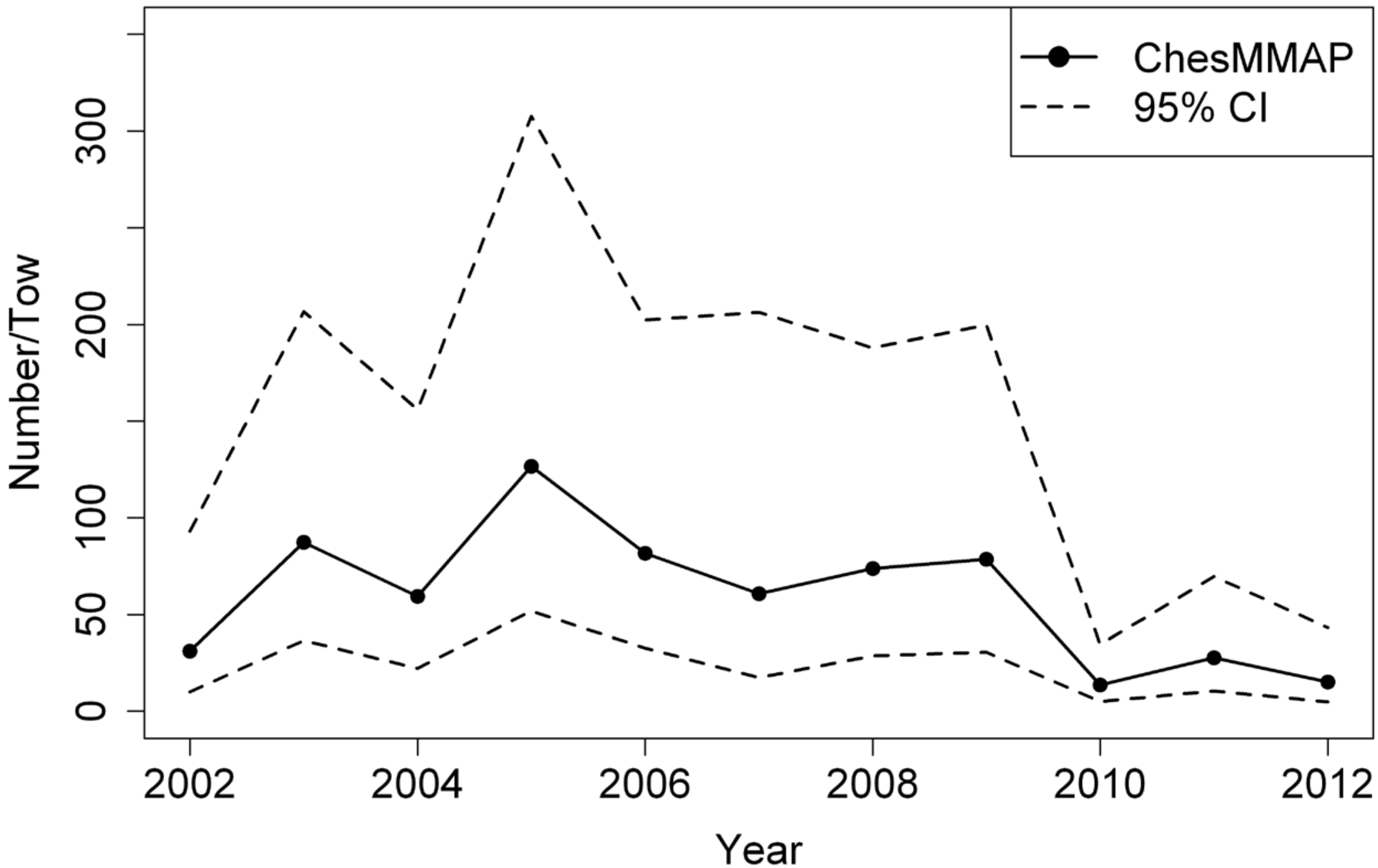


Figure A2.39. ChesMMAP survey geometric mean number per tow and 95% confidence interval for butterfish.

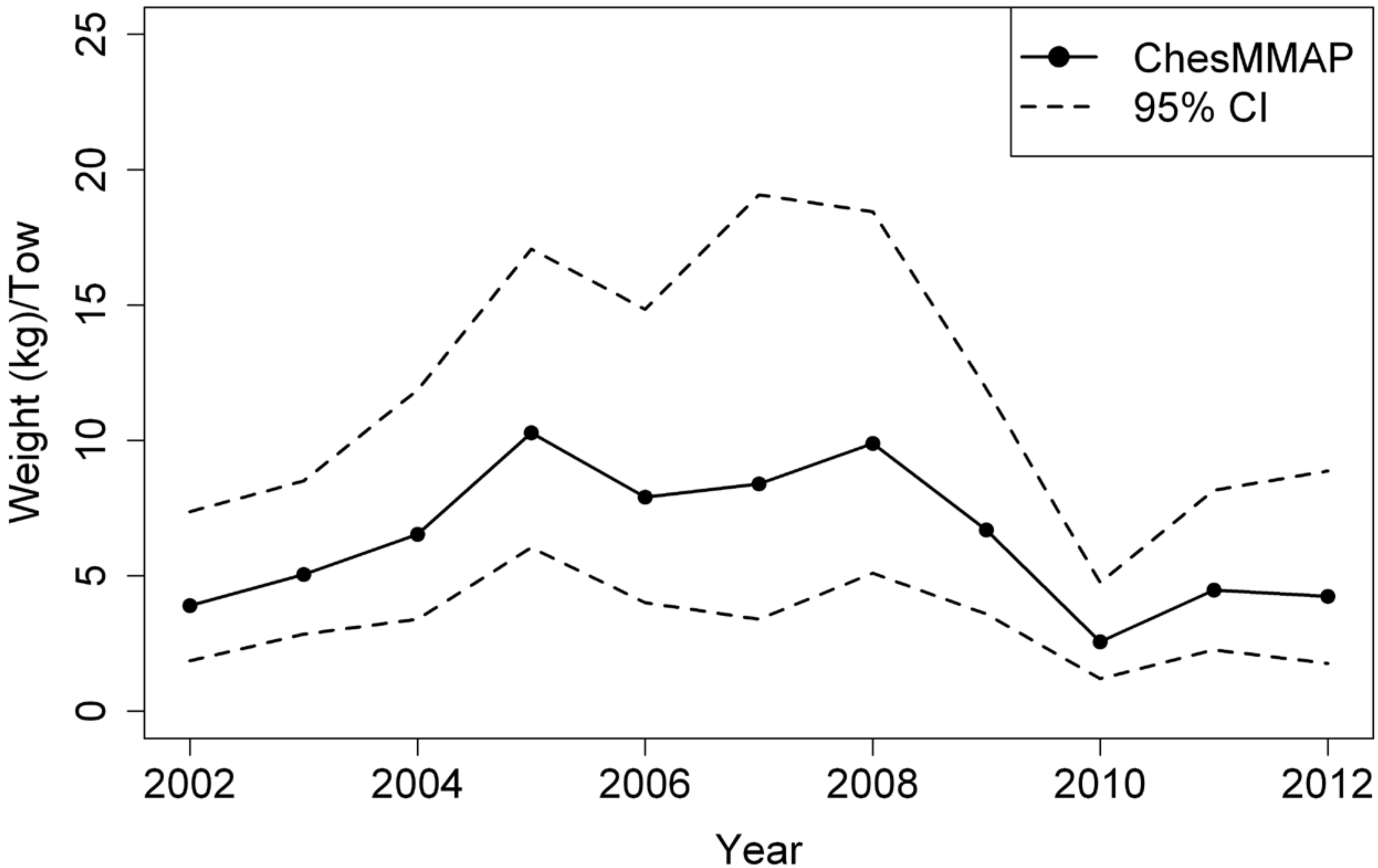


Figure A2.40. ChesMMAP survey geometric mean weight per tow and 95% confidence interval for butterfish.

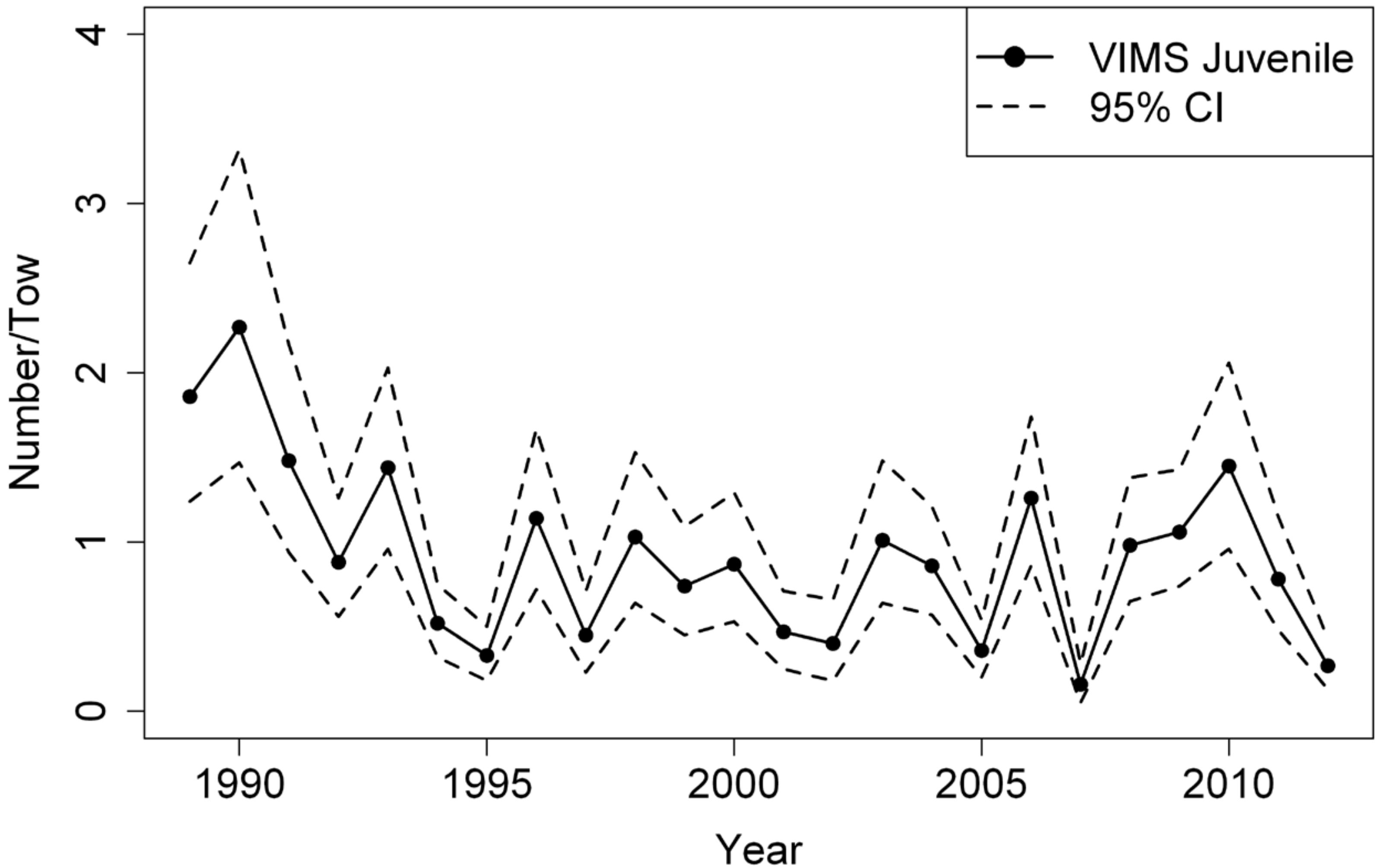


Figure A2.41. VIMS juvenile survey geometric mean number per tow and 95% confidence interval for butterfish.

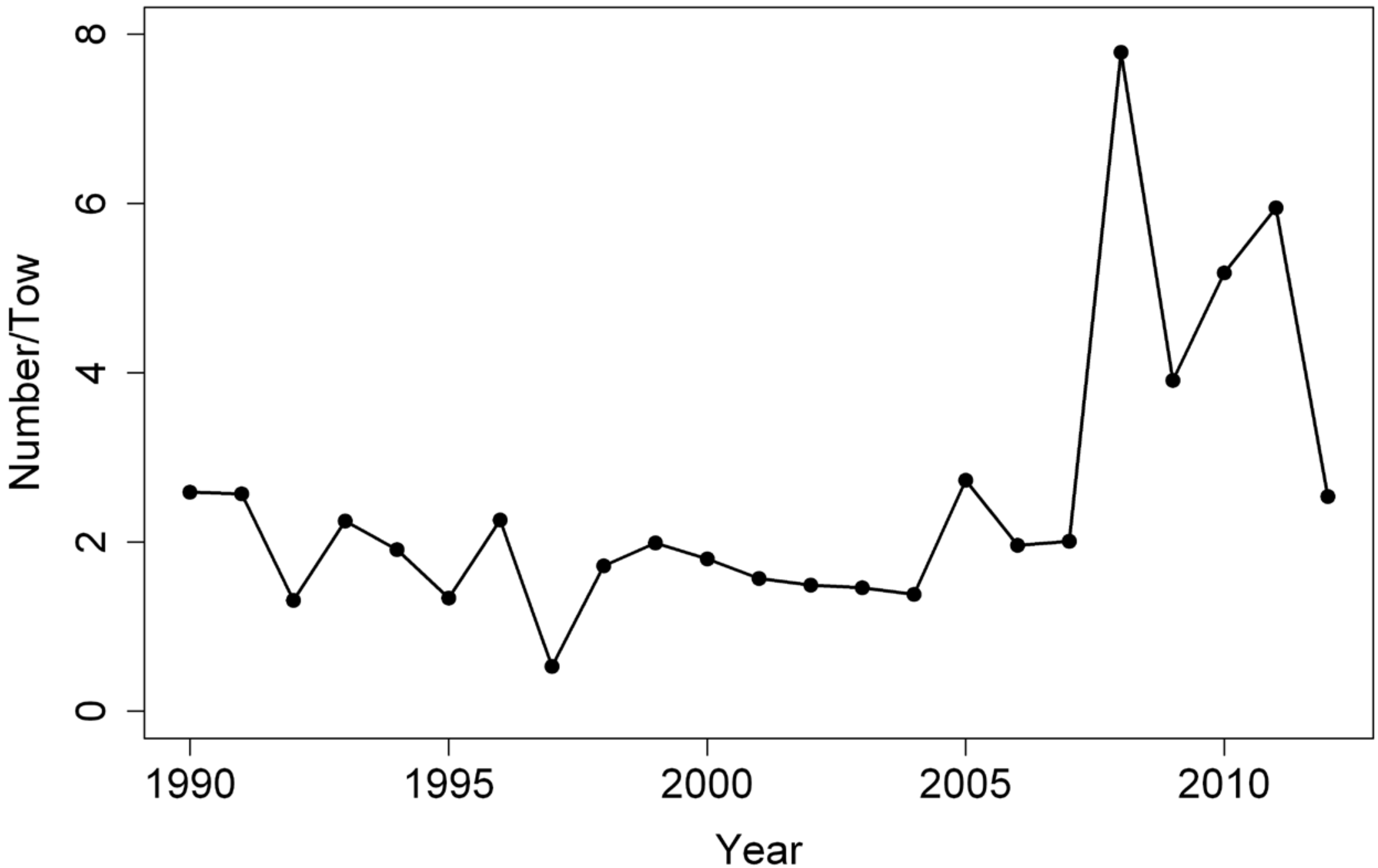


Figure A2.42. NCDENR survey in Pamlico Sound annual weighted mean number per tow for butterfish.

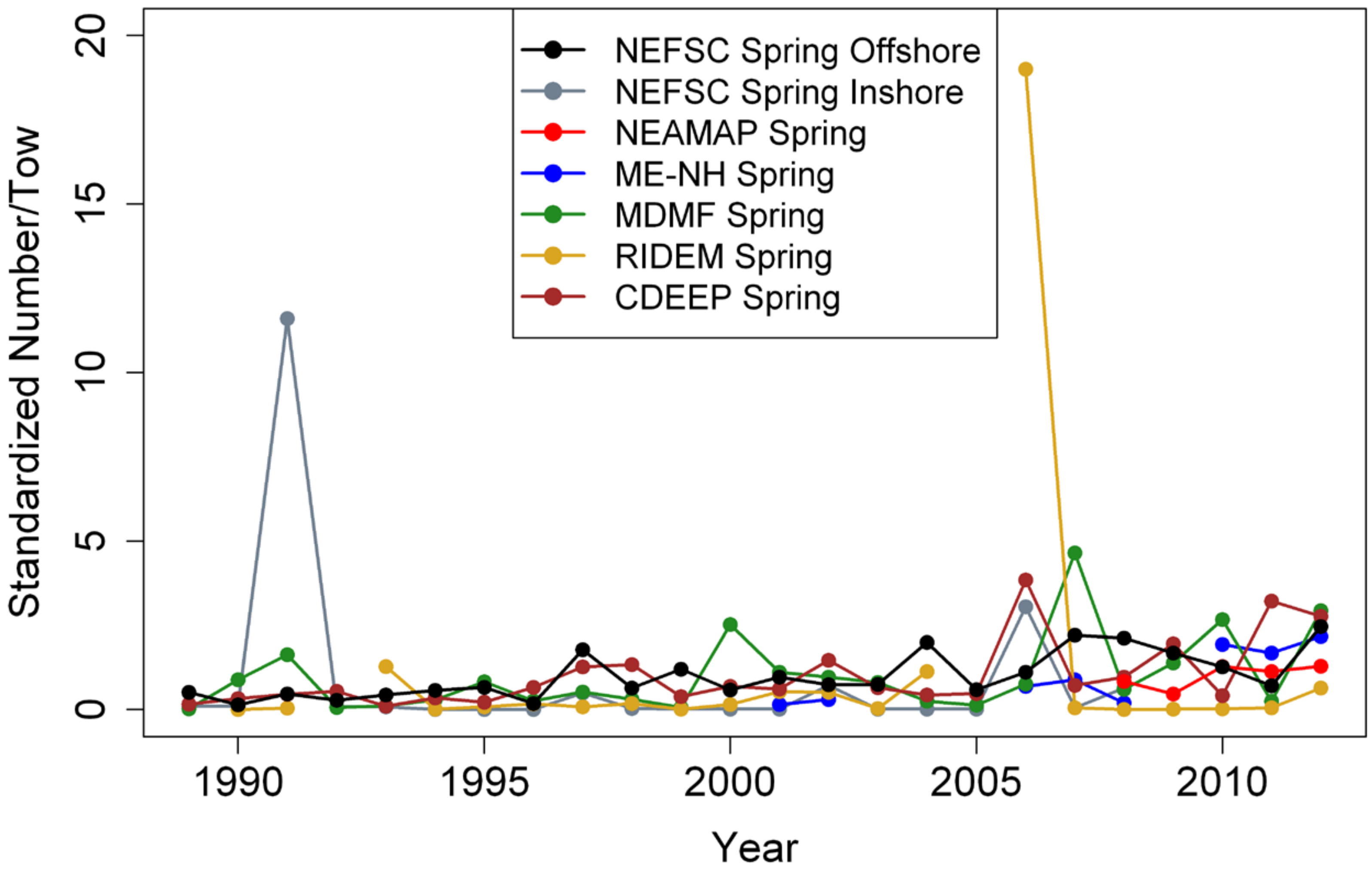


Figure A2.43. Butterfish mean number per tow for NEFSC, NEAMAP, and the various state surveys in spring, standardized to the mean of the respective time series.

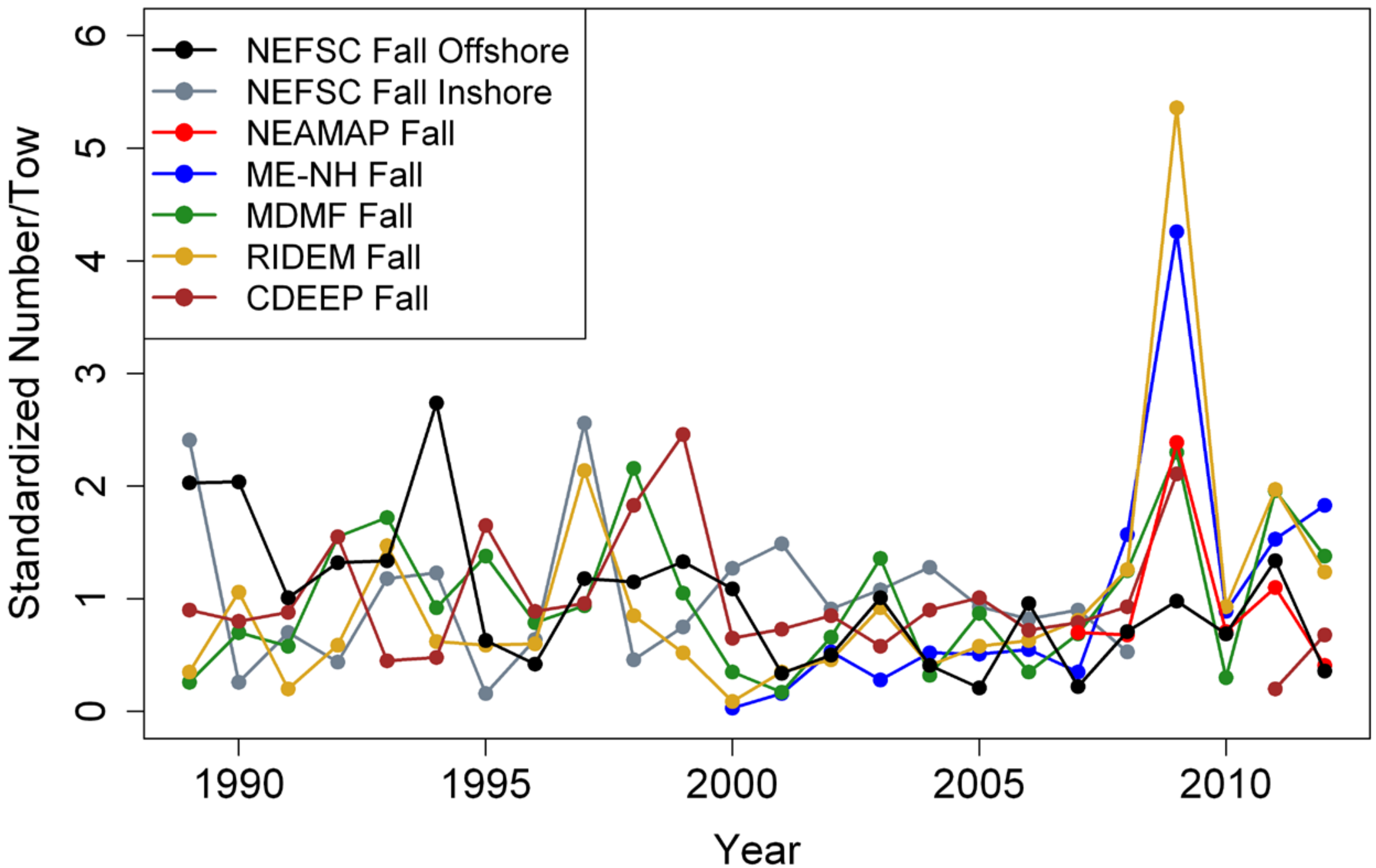


Figure A2.44. Butterfish mean number per tow for NEFSC, NEAMAP, and the various state surveys in fall, standardized to the mean of the respective time series.

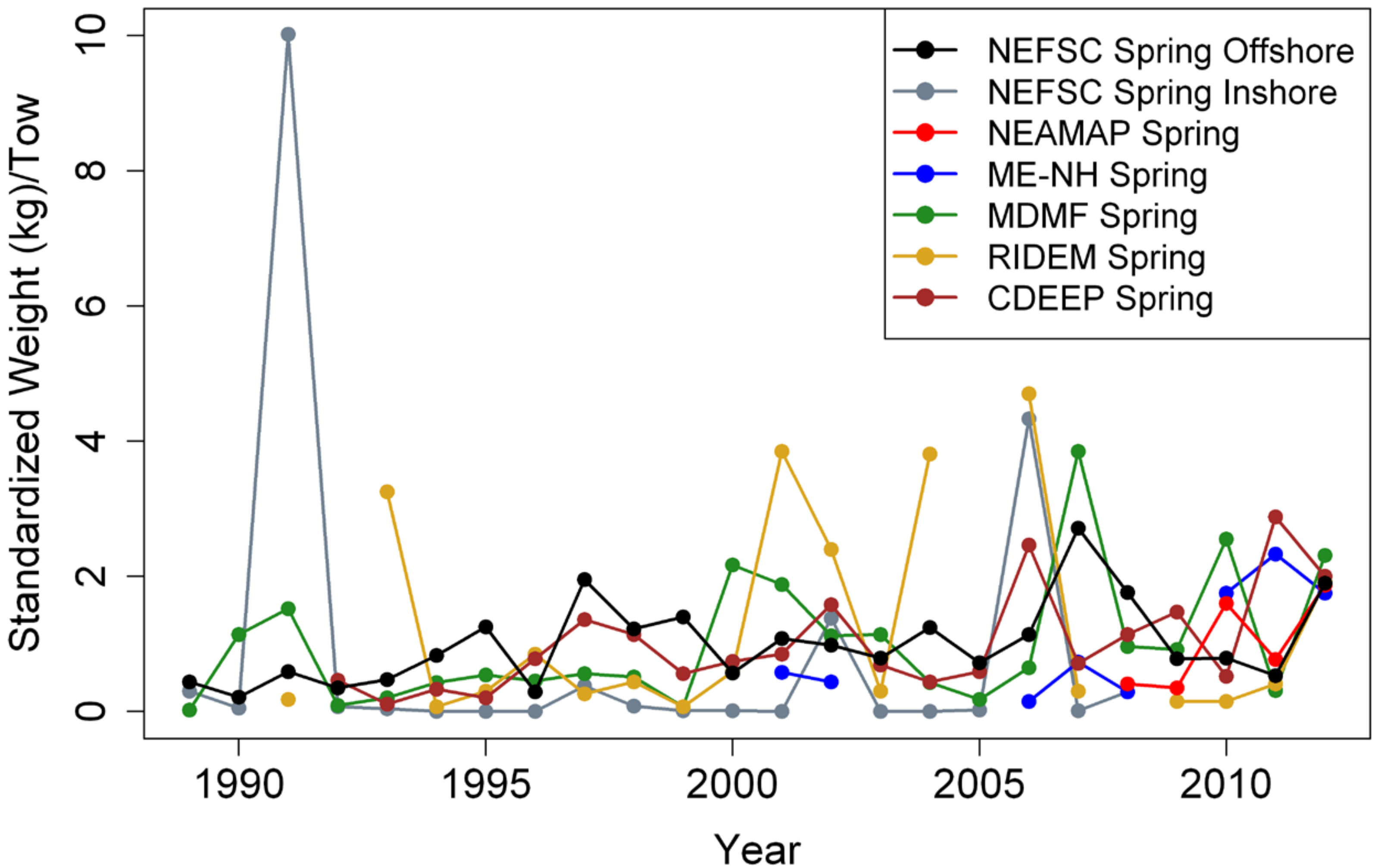


Figure A2.45. Butterfish mean weight per tow for NEFSC, NEAMAP, and the various state surveys in spring, standardized to the mean of the respective time series.

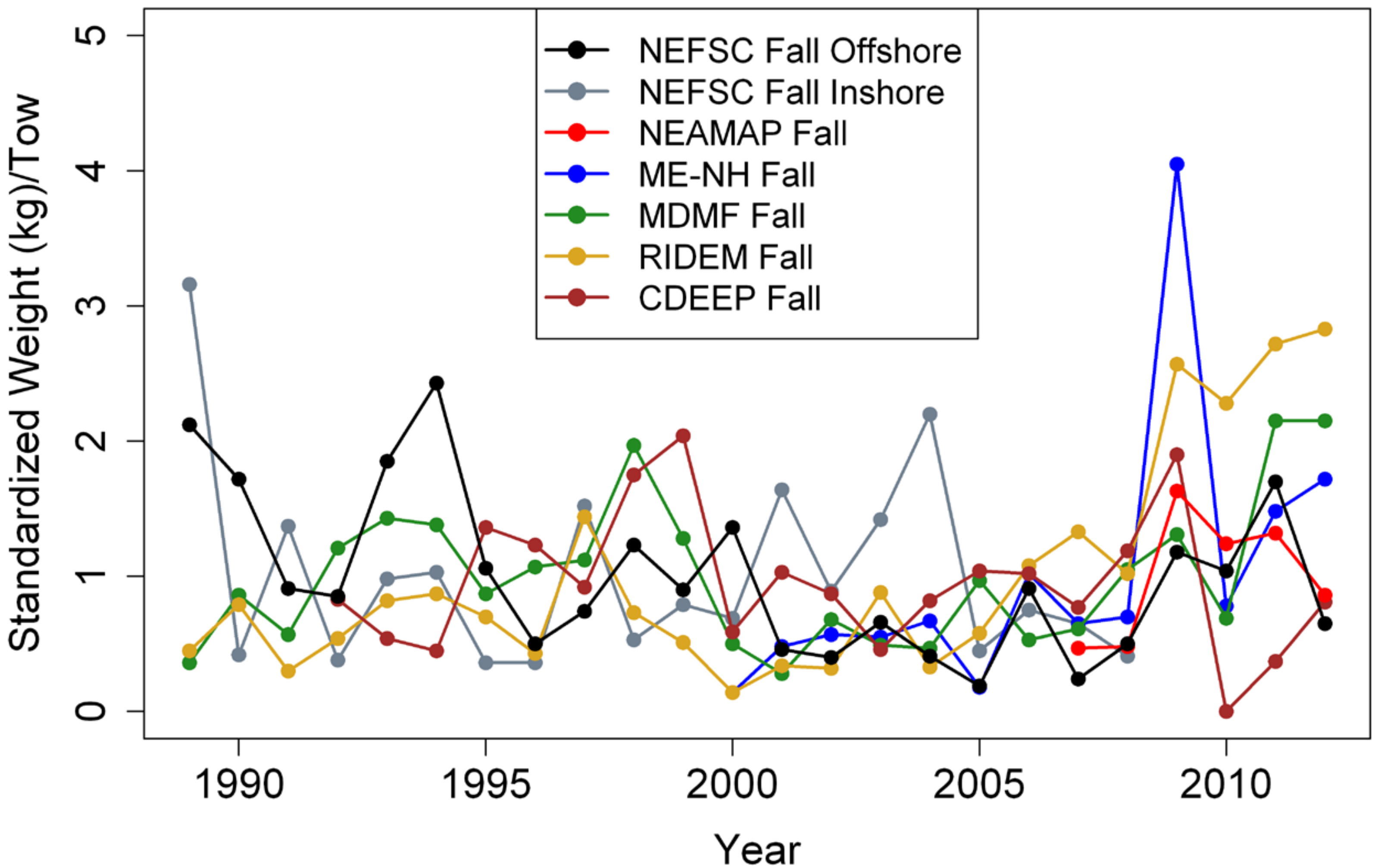


Figure A2.46. Butterfish mean weight per tow for NEFSC, NEAMAP, and the various state surveys in fall, standardized to the mean of the respective time series.

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:

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

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^{o}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).

References

Angilletta MJ (2009) Thermal Adaptation: A Theoretical and Empirical Synthesis. Oxford University Press, Oxford.

Bolker B (2012) bbmle: Tools for general maximum likelihood estimation. R Development Core Team.

Bolker BM (2008) Ecological Models and Data in R. Princeton University Press, Princeton.

Brown JH (2004) Toward a metabolic theory of ecology. Ecology 85:1771–1789.

Cheung WWL, Watson R, Pauly D (2013) Signature of ocean warming in global fisheries catch. Nature 497:365-368.

Dell AI, Pawar S, Savage VM (2011) Systematic variation in the temperature dependence of physiological and ecological traits. Proceedings of the National Academy of Sciences 108:10591-10596.

Denny MW (1993) Air and Water: The Biology and Physics of Life's Media, Vol. Princeton University Press, Princeton New Jersey.

Fleming NE, Wilkin J (2010) Mocha: A 3-d climatology of the temperature and salinity of the mid Atlantic Bight. Eos Trans AGU 91.

Johnson FH, Lewin I (1946) The growth rate of E. coli in relation to temperature, quinine and coenzyme. Journal of Cellular and Comparative Physiology 28:47-75.

Kang D, Curchitser EN (2013) Gulf Stream eddy characteristics in a high-resolution ocean model. Journal of Geophysical Research: Oceans 118:4474-4487.

Kooijman SALM (2010) Dynamic Energy Budget Theory for Metabolic Organization, Vol. Cambridge University Press, Great Britain.

Lande R, Engen S, Sæther B-E (2003) Stochastic Population Dynamics in Ecology and Conservation. Oxford University Press, Oxford, UK.

Magnuson JJ, Crowder LB, Medvick PA (1979) Temperature as an ecological resource. American Zoologist 19:331-343.

Millar RB (2011) Maximum Likelihood Estimation and Inference: With Examples in R, SAS and ADMB, Vol. Wiley.

Petitgas P, Alheit J, Peck MA, Raab K, Irigoien X, Huret M, van der Kooij J, Pohlmann T, Wagner C, Zarraonaindia I, Dickey-Collas M (2012) Anchovy population expansion in the North Sea. Marine Ecology Progress Series 444:1-13.

Pinsky ML, Worm B, Fogarty MJ, Sarmiento JL, Levin SA (2013) Marine Taxa Track Local Climate Velocities. Science 341:1239.

Shchepetkin AF, McWilliams JC (2003) A method for computing horizontal pressure-gradient force in an oceanic model with a nonaligned vertical coordinate. J Geophys Res 108:3090.

Shchepetkin AF, McWilliams JC (2005) The regional oceanic modeling system (ROMS): a split-explicit, free-surface, topography-following-coordinate oceanic model. Ocean Modeling. 9:347-404.

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

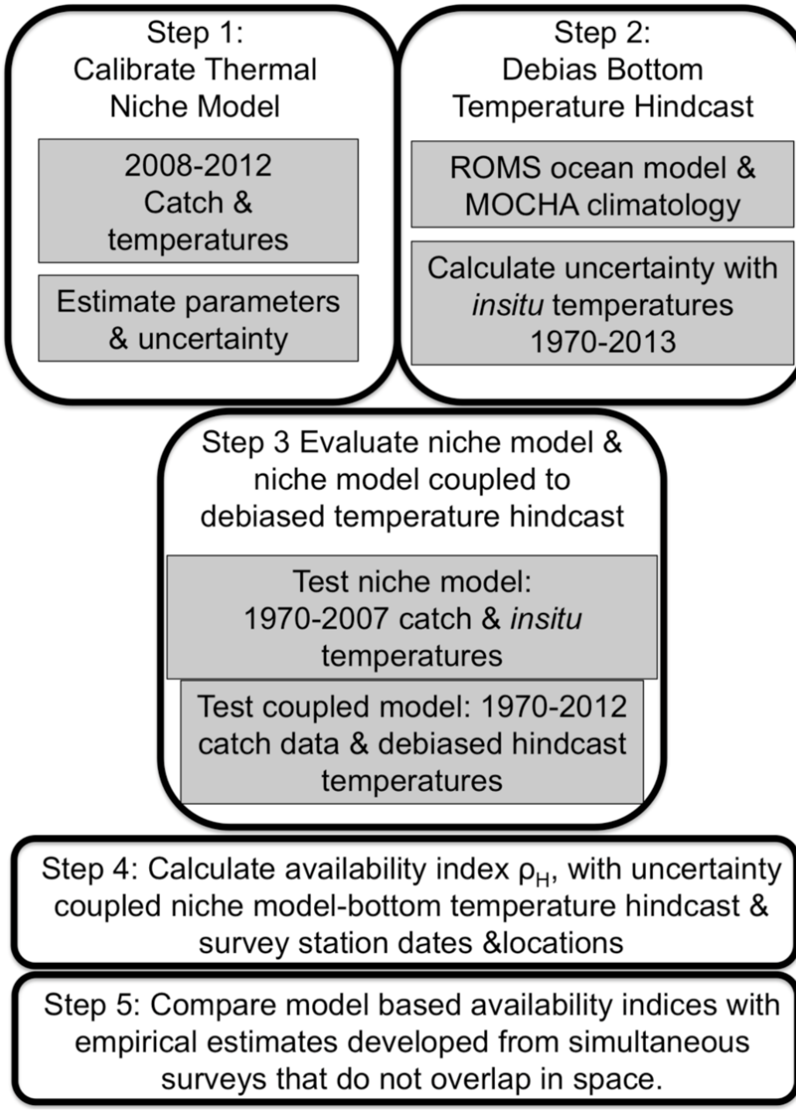


Figure A3.1. Steps in the development of a stock availability estimate to fishery independent surveys based upon thermal habitat. In step 1, Catch and temperatures from 7 fishery independent surveys throughout the Northwest Atlantic were used to calibrate a thermal niche model. Step 2, bottom temperatures 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.

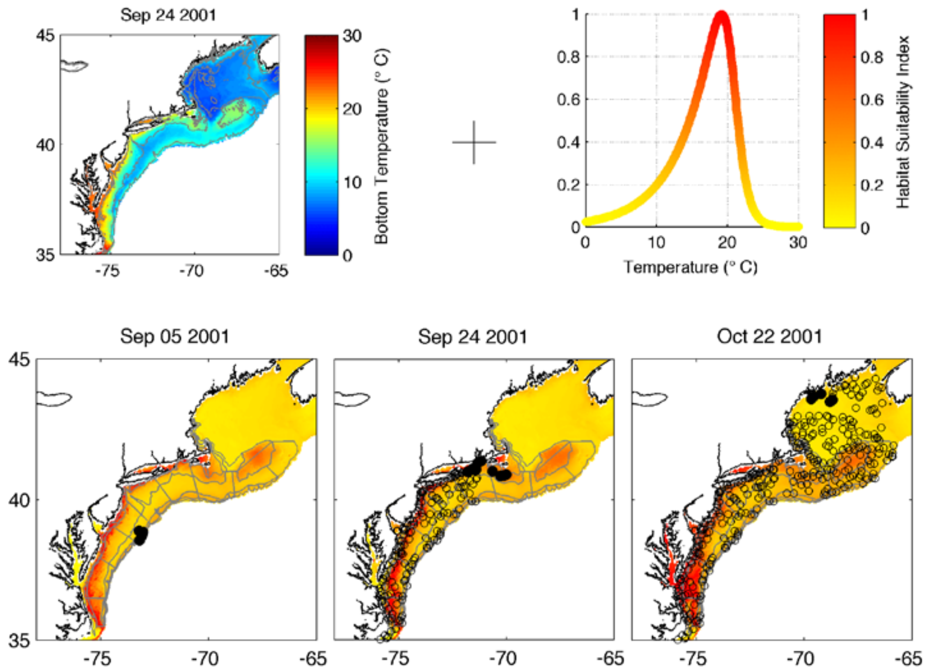


Figure A3.2. Thermal habitat suitability was projected in space and time by coupling the niche model rescaled from 0 (unsuitable habitat) to 1 (highly suitable habitat) to daily hindcasts of bottom temperature. De-biased ROMS bottom water temperature hindcast for the median date of the 2001 fall NEFSC 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.

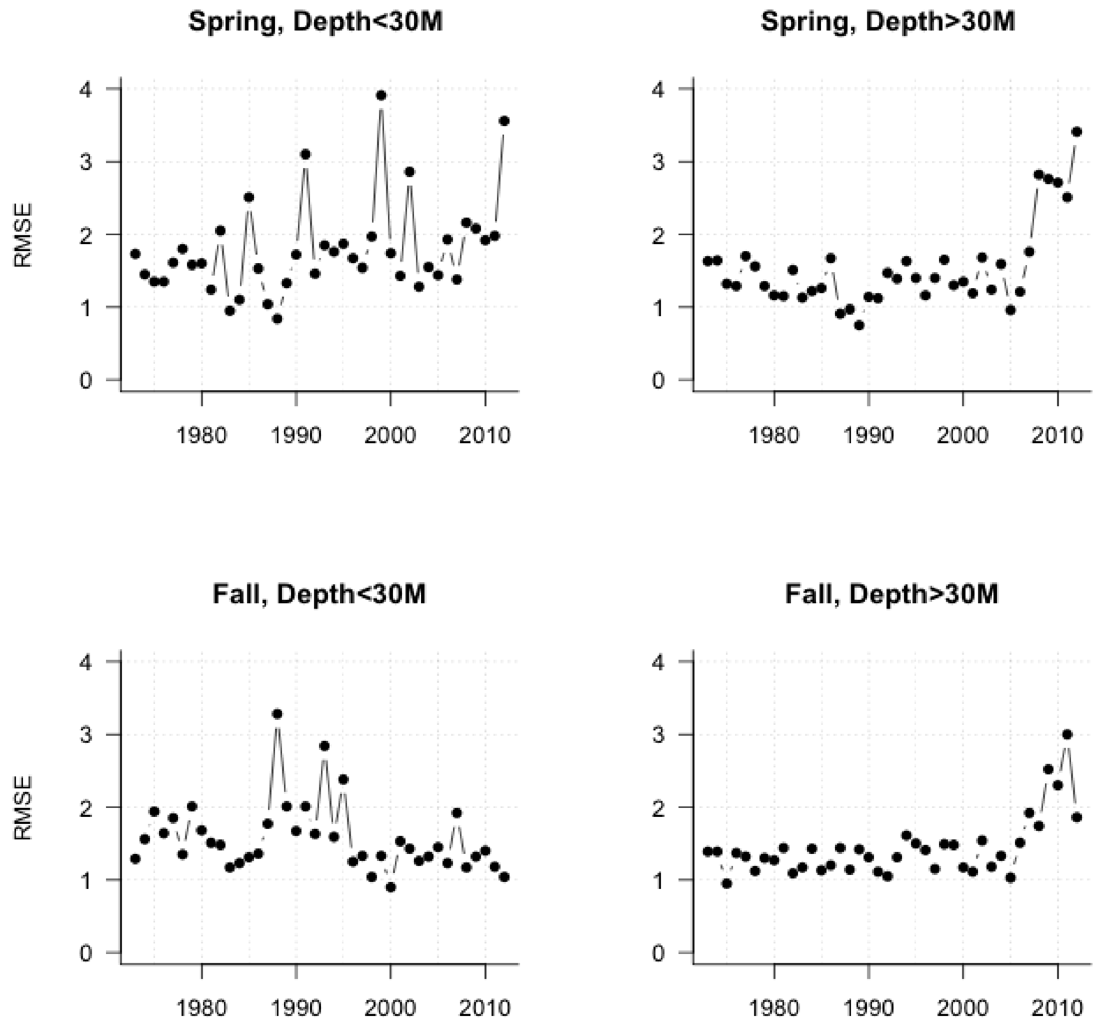


Figure A3.3. Root Mean Square Standard Errors RMSE de-biased bottom temperatures hindcast by ROMS calculated using bottom water temperatures measured *in situ* for shallow (<30 m) and deeper waters (>30 m), during spring and fall, from 1973-2012 (see *Appendix 1*). RMSEs were applied to mean de-biased 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.

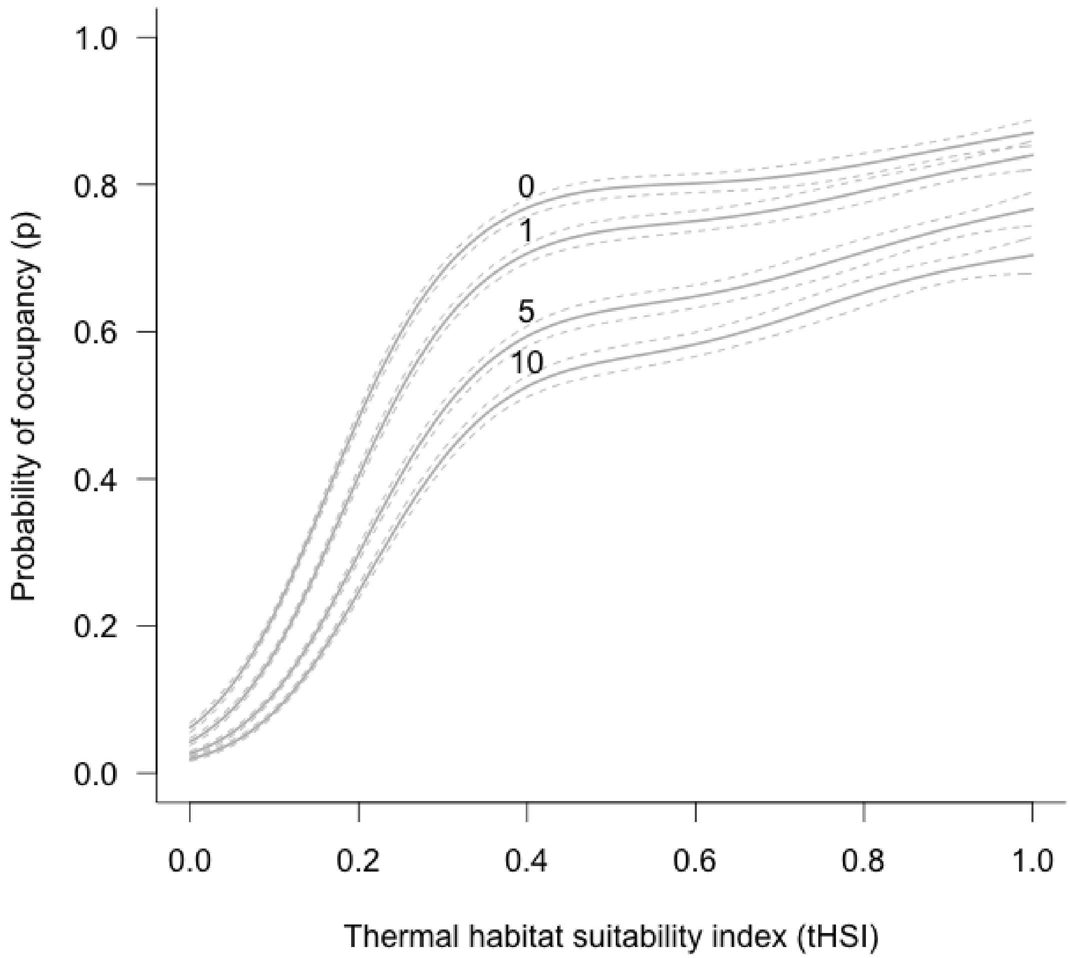


Figure A3.4. Probability of butterfish occupancy (+/- 2 SE) in samples collected in 7 fishery independent surveys from 1970-2007 in relation to thermal habitat suitability (tHSI) predicted by coupling the niche model to bottom water temperatures measured *in situ* with the samples. Data used in model 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).

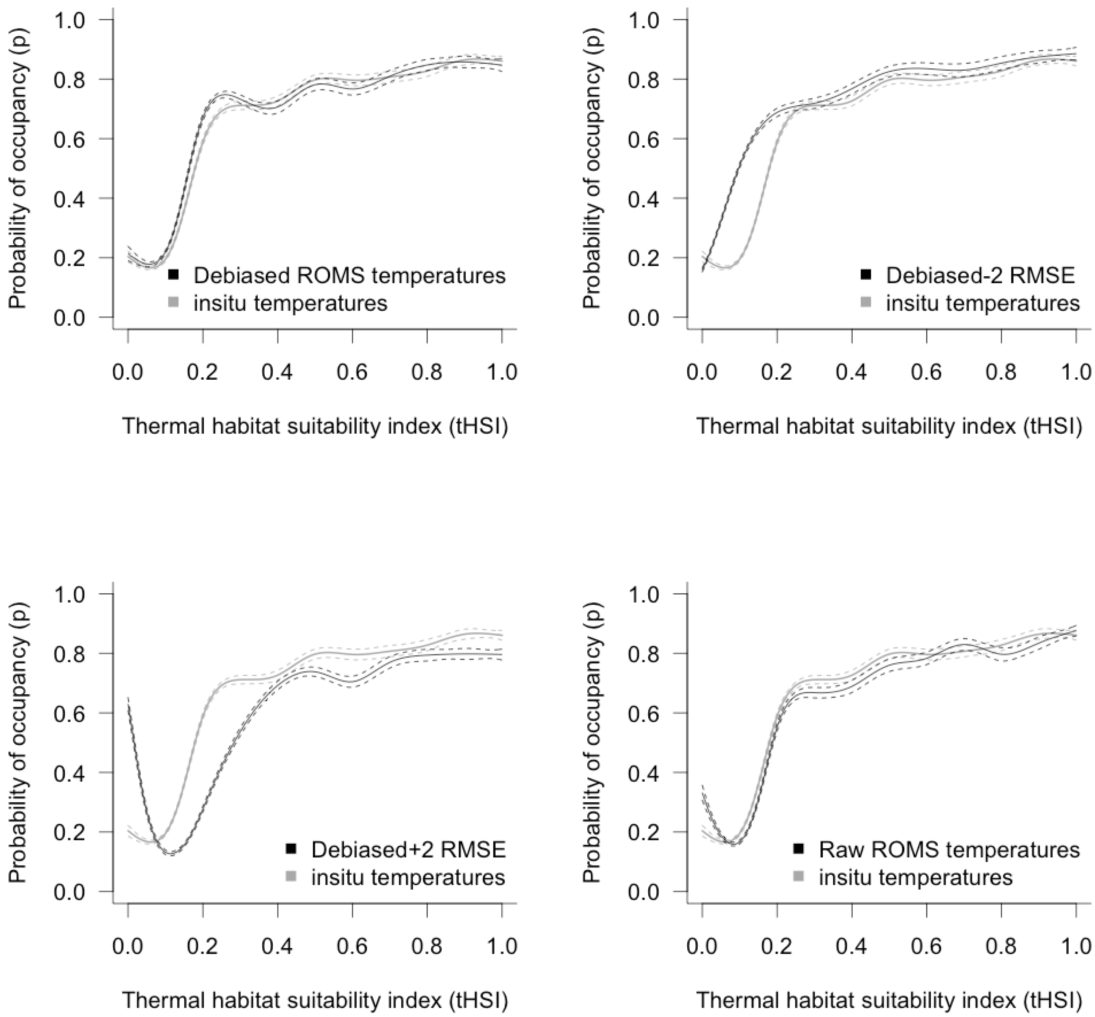


Figure A3.5. Trends in butterfish sample occupancy (+/- 2 SE) with thermal habitat suitability in 1973-2012 evaluation samples predicted using the niche model coupled to the ROMS temperature hindcast (black lines) and temperature measured *in situ* (gray lines). Trends in sample occupancy with tHSI values 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.

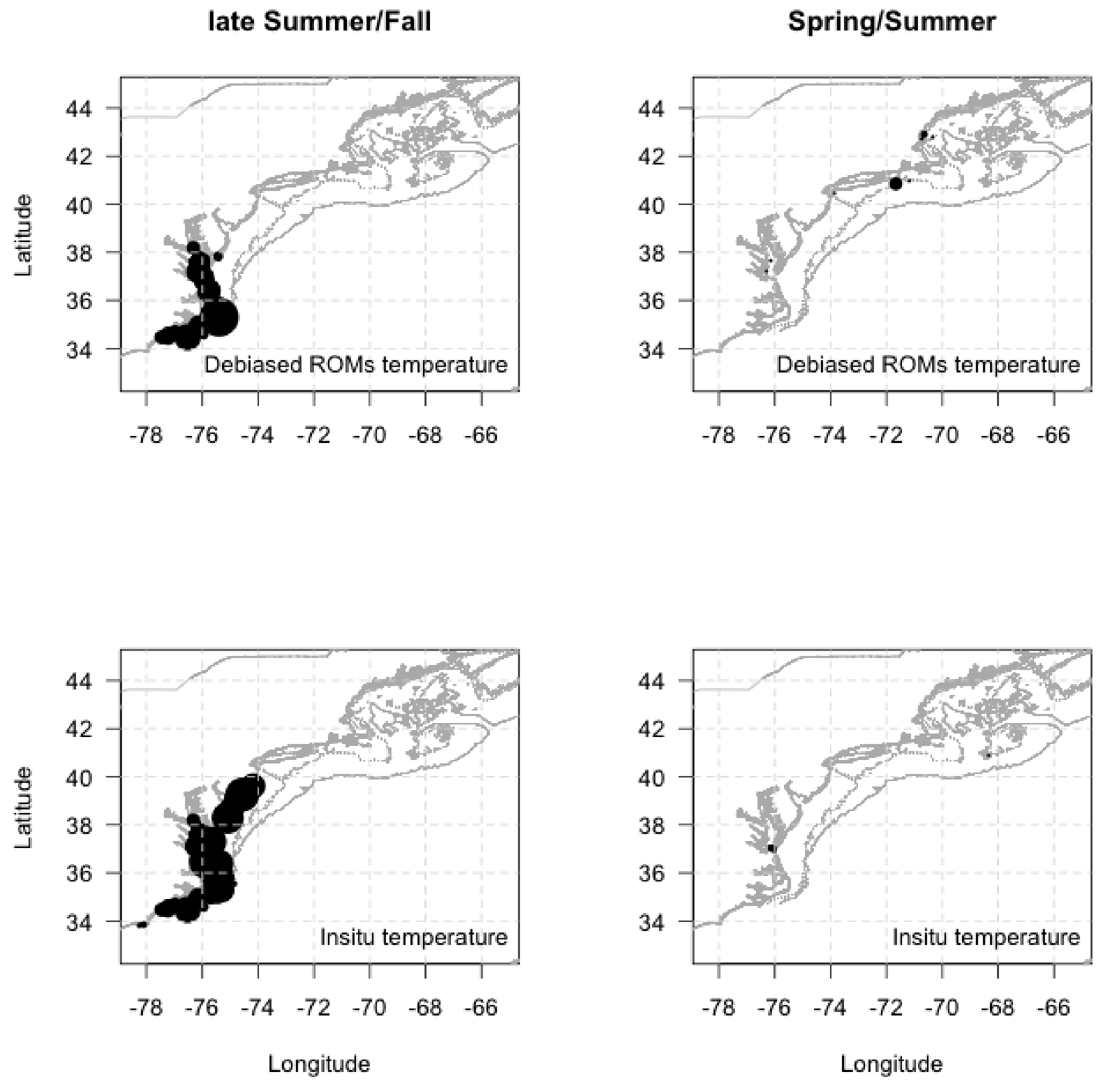


Figure A3.6. Evaluation of spatial pattern in evaluation samples collected during late summer and fall (left panels) and spring and early summer (right panels) that produced butterfish but which had low thermal habitat suitability (<0.1; i.e. "false negatives") predicted using bottom temperatures de-biased 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.

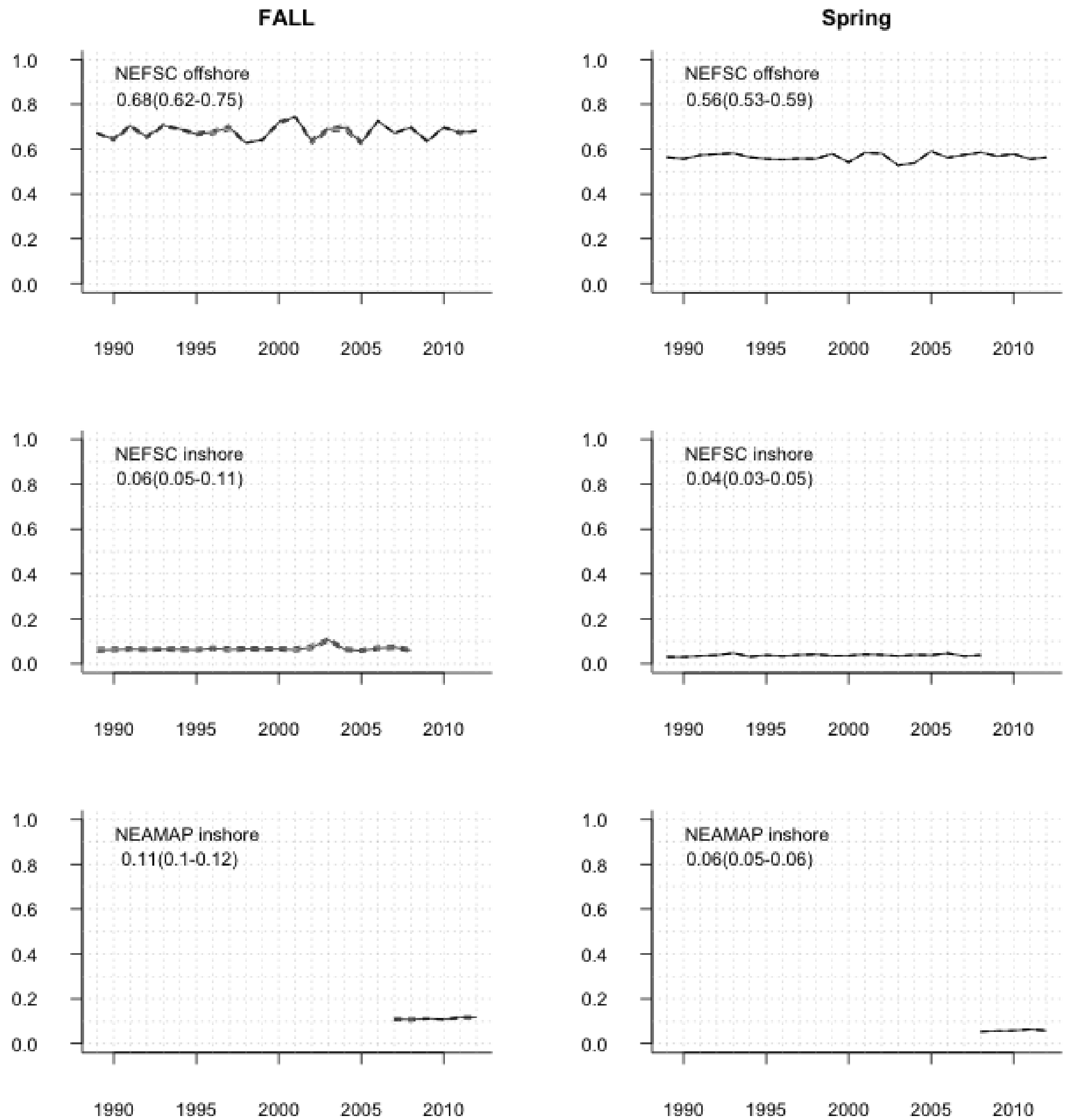


Figure A3.7. Availability ρ_H of butterfish to spring and fall NEFSC and NEAMAP surveys from 1989 through 2012 calculated as the proportion of available thermal habitat suitability sampled within the model domain estimated using the thermal niche model coupled to the de-biased ROMS bottom temperature 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:

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

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

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

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:

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

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}:

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

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:

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

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:

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

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.

References

Azarovitz, T.R. 1981. A brief historical review of the Woods Hole Laboratory trawl survey time series. In: Doubleday WG; Rivard D., eds. Bottom trawl surveys. Can Spec. Publ. Fish. Aquat. Sci. 58; p 62-67.

Bajkov, A.D. 1935. How to estimate the daily food consumption of fish under natural conditions. Trans. Amer. Fish. Soc. 65:288-289.

Belleggia, M., Mabragaña, E., Figueroa, D.E., Scenna, L.B., Barbini, S.A., Díaz de Astarloa, J.M. 2008. Food habits of the broad nose skate, *Bathyraja brachyurops* (Chondrichthyes, Rajidae), in the south-west Atlantic. Sci. Mar. 72:701-710.

Braccini, J.M. 2008. Feeding ecology of two high-order predators from south-eastern Australia: the coastal broadnose and the deepwater sharpnose sevengill sharks. Mar. Ecol. Prog. Ser. 371:273-284.

Durbin, E.G., Durbin, A.G., Langton, R.W., Bowman, R.E. 1983. Stomach contents of silver hake, *Merluccius bilinearis*, and Atlantic cod, *Gadus morhua*, and estimation of their daily rations. Fish. Bull. 81:437-454.

Eggers, D.M. 1977. Factors in interpreting data obtain by diel sampling of fish stomachs. J. Fish. Res. Board Can. 34:290-294.

Elliot, J.M., Persson, L. 1978. The estimation of daily rates of food consumption for fish. J. Anim. Ecol. 47:977-991.

Gerking, S.D. 1994. Feeding ecology of fish. San Diego [CA]: Academic Press.

Kitchell, J.F., Stewart, D.J., Weininger, D. 1977. Applications of a bioenergetics model to yellow perch (*Perca flavescens*) and walleye (*Stitzostedion vitreum vitreum*). J. Fish. Res. Board Can. 34:1922-1935.

Koen Alonso, M., Crespo, E.A., García, N.A., Pedraza, S.N. 2002. Fishery and ontogenetic driven changes in the diet of the spiny dogfish, *Squalus acanthias*, in Patagonian waters, Argentina. Environ. Biol. Fish. 63:193-202.

Link, J.S., Almeida, F.P. 2000. An overview and history of the food web dynamics program of the Northeast Fisheries Science Center, Woods Hole, MA. NOAA Tech. Memo. NMFS-NE-159, 60 p.

Link, J.S., Garrison, L.P. 2002. Changes in piscivory associated with fishing induced changes to the finfish community on Georges Bank. Fish. Res. 55:71-86.

Link, J.S., Garrison, L.P., Almeida, F.P. 2002. Interactions between elasmobranchs and groundfish species (Gadidae and Pleuronectidae) on the Northeast U.S. Shelf. I: Evaluating predation. N. Am. J. Fish. Mange. 22:550-562.

Miller, T.J., Das, C., Politis, P.J., Miller, A.S., Lucey, S.M., Legault, C.M., Brown, R.W., Rago, P.J. 2010. Estimation of Albatross IV to Henry B. Bigelow calibration factors. NEFSC Ref. Doc. 10-05; 230 p.

Northeast Fisheries Center (NEFC). 1988. An evaluation of the bottom trawl survey program of the Northeast Fisheries Center. NOAA Tech. Memo. NMFS-F/NEC-52, 83 p.

Northeast Fisheries Science Center (NEFSC). 2007. 44th Northeast Regional Stock Assessment Workshop (44th SAW): 44th SAW assessment report. NEFSC Ref. Doc. 07-10; 661 p.

Overholtz, W.J., Murawski, S.A., Foster, K.L. 1991. Impact of predatory fish, marine mammals, and seabirds on the pelagic fish ecosystem of the northeastern USA. ICES Mar. Sci. Symp. 193:198-208.

Overholtz, W.J., Link, J.S., Suslowicz, L.E. 1999. Consumption and harvest of pelagic fishes in the Gulf of Maine-Georges Bank ecosystem: Implications for fishery management. Proceedings of the 16th Lowell Wakefield Fisheries Symposium – Ecosystem Considerations in Fisheries Management. AK-SG-99-01:163-186.

Overholtz, W.J., Link, J.S., Suslowicz, L.E. 2000. The impact and implications of fish production on pelagic fish and squid on the eastern USA shelf. ICES J. Mar. Sci. 57:1147-1159.

Overholtz, W.J., Link, J.S. 2007. Consumption impacts by marine mammals, fish, and seabirds on the Gulf of Maine-Georges Bank Atlantic Herring (*Clupea harengus*) complex during 1977-2002. ICES J. Mar. Sci. 64:83-96.

Pennington, M. 1985. Estimating the average food consumption by fish in the field from stomach contents data. Dana 5:81-86.

Reid, R.N., Almeida, F.P., Zetlen, C.A. 1999. Essential fish habit source document: fishery-independent surveys, data sources, and methods. NOAA Tech. Memo. NMFS-NE-122, 39 p.

Smith, B.E., Link, J.S. 2010. The trophic dynamics of 50 finfish and 2 squid species on the northeast US continental shelf. NOAA Tech Memo. NMFS-NE-216, 640 p.

Taylor, M.H., Bascuñán, C. 2000. CTD data collection on Northeast Fisheries Science Center Cruises: Standard Operating Procedures. NEFSC Ref. Doc. 00-11; 28 p.

Taylor, M.H., Bascuñán, C., Manning, J.P. 2005. Description of the 2004 oceanographic conditions on the northeast continental shelf. NEFSC Ref. Doc. 05-03; 90 p.

Tsou, T.S., Collie, J.S. 2001a. Estimating predation mortality in the Georges Bank fish community. Can. J. Fish. Aquat. Sci. 58:908-922.

Tsou, T.S., Collie, J.S. 2001b. Predation-mediated recruitment in the Georges Bank fish community. ICES J. Mar. Sci. 58:994-1001.

Ursin, E., Pennington, M., Cohen, E.B., Grosslein, M.D. 1985. Stomach evacuation rates of Atlantic cod (*Gadus morhua*) estimated from stomach contents and growth rates. Dana 5:63-80.

Zuur, A.F., Tuck, I.D., Bailey, N. 2003. Dynamic factor analysis to estimate common trends in fisheries time series. Can. J. Fish. Aquat. Sci. 60: 542-552.

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

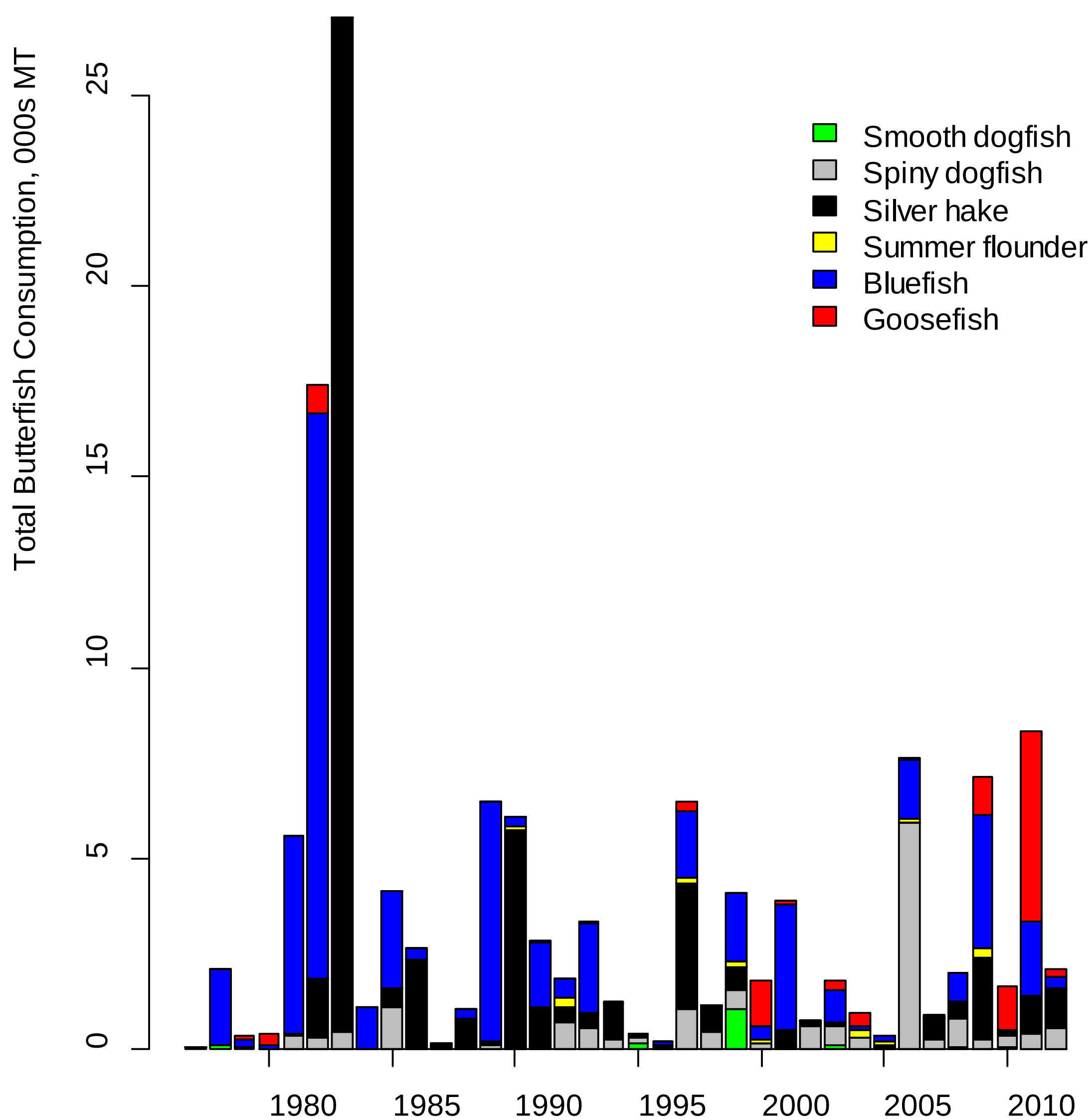


Figure A4.1. Total butterfish (*Peprilus triacanthus*) consumption by each fish predator (1977-2012).

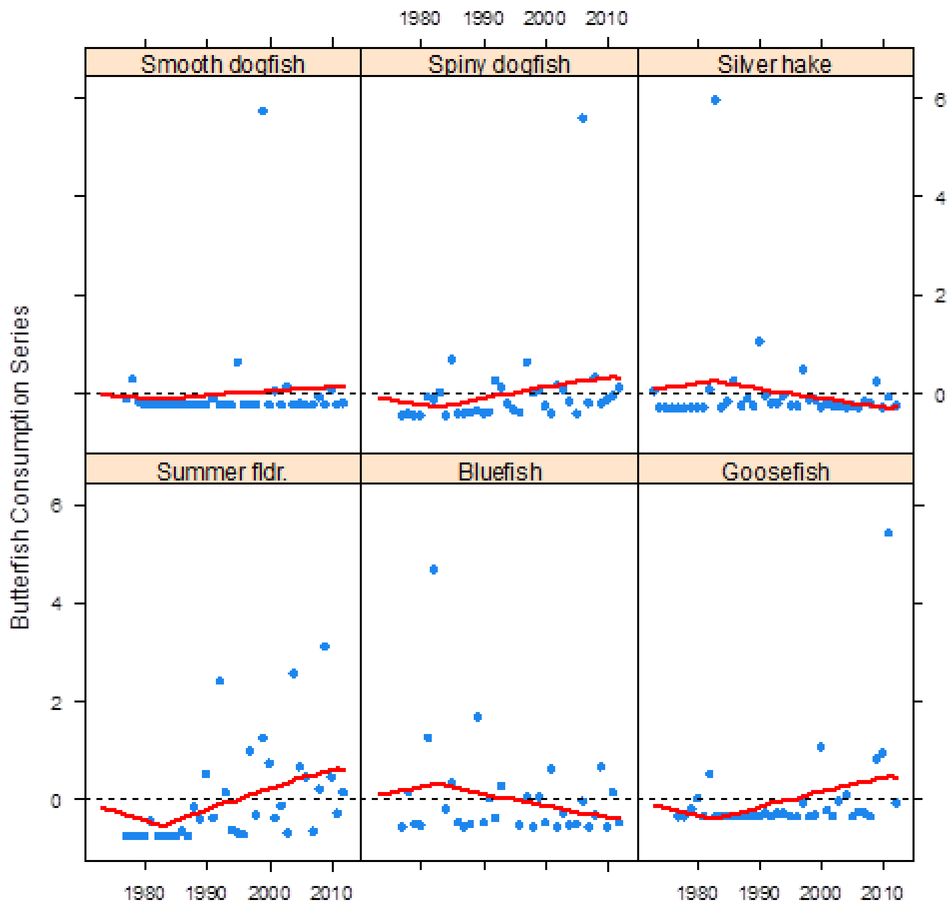


Figure A4.2. Fitted values (red lines) for annual butterfish consumption data by predator (blue dots). Chosen model contains 1 trend and a diagonal and equal covariance matrix (Table A4.12). Data were transformed with mean = 0 and SD = 1.

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

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,

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

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,

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

where $p(a\,|\,l)$ 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.

References

Deriso RB. 1980. Harvesting strategies and parameter estimation for an age-structured model. Can J Fish Aquat Sci 37(2):268-282.

Legault CM, Restrepo VR. 1999. A flexible forward age-structured assessment program. Col Vol Sci Pap ICCAT 49:246-253.

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. 233 p.

Miller, T.J. 2013. A comparison of hierarchical models for relative catch efficiency based on paired-gear data for U.S. Northwest Atlantic fish stocks. Can J Fish Aquat Sci 70(9): 1306-1316.

Mohn, R. 1999. The retrospective problem in sequential population analysis: an investigation using cod fishery and simulated data. ICES J Mar Sci 56(4): 473-488.

NEFSC. 2004. 38th Northeast Regional Stock Assessment Workshop (38th SAW) *Stock Assessment Review Committee (SARC) Consensus Summary of Assessments*. NEFSC Ref Doc 04-03. 246 p.

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

NOAA Fisheries Toolbox. (NFT). 2013. Age structured assessment program (ASAP) version 3.0.13 (Internet address: http://nft.nefsc.noaa.gov).

Schnute J. 1985. A general theory for analysis of catch and effort data. Can J Fish Aquat Sci 42(3):414-429.

Smith. S.J. 1997. Boostrap confidence limits for groundfish trawl survey estimates of mean abundance. Can J Fish Aquat Sci 54(3): 616-630.

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

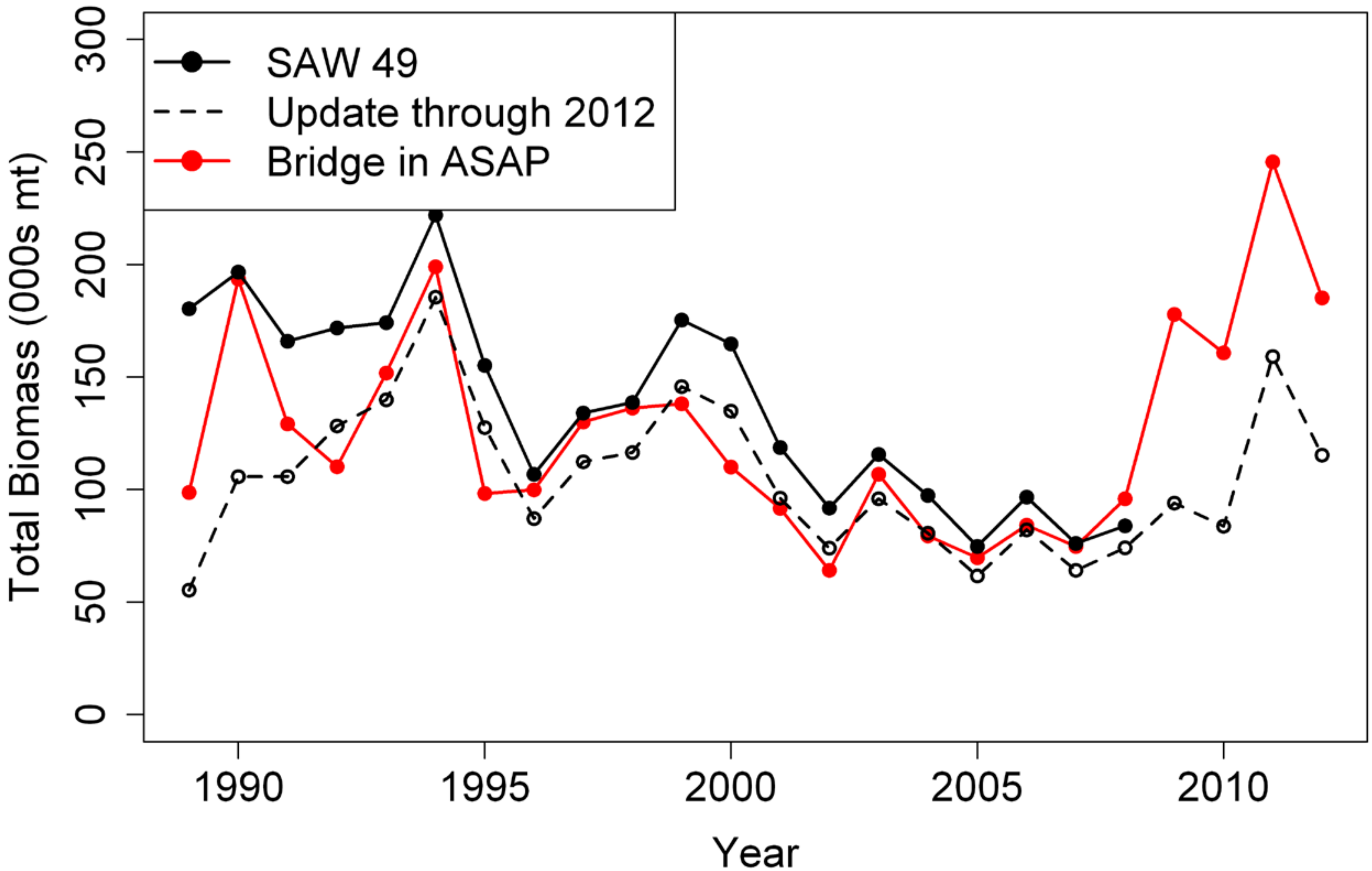


Figure A5.1. KLAMZ estimated total biomass from the last assessment (NEFSC, 2010), KLAMZ update using data through 2012, and total biomass in ASAP using the same parameters as the KLAMZ model.

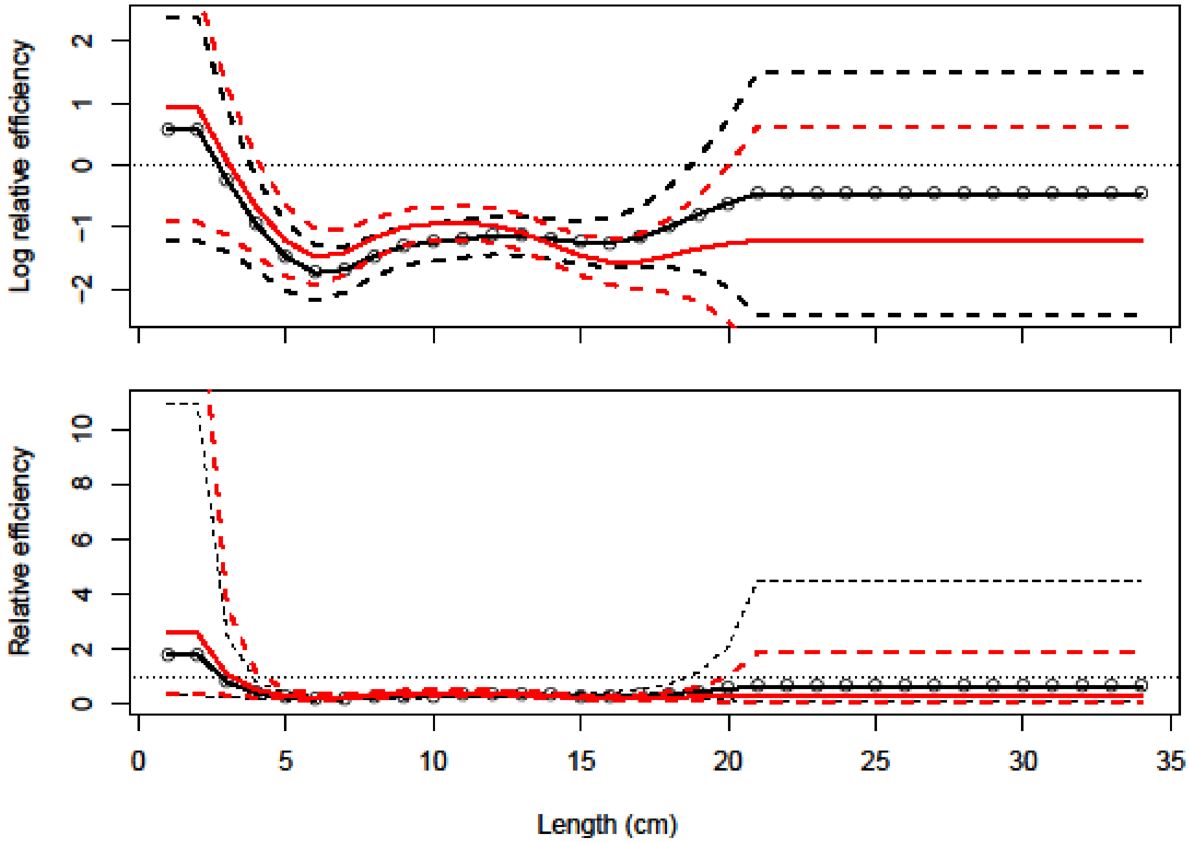


Figure A5.2. Estimates of relative catch efficiency (black) from Miller (2013) and modified from the base model (red).

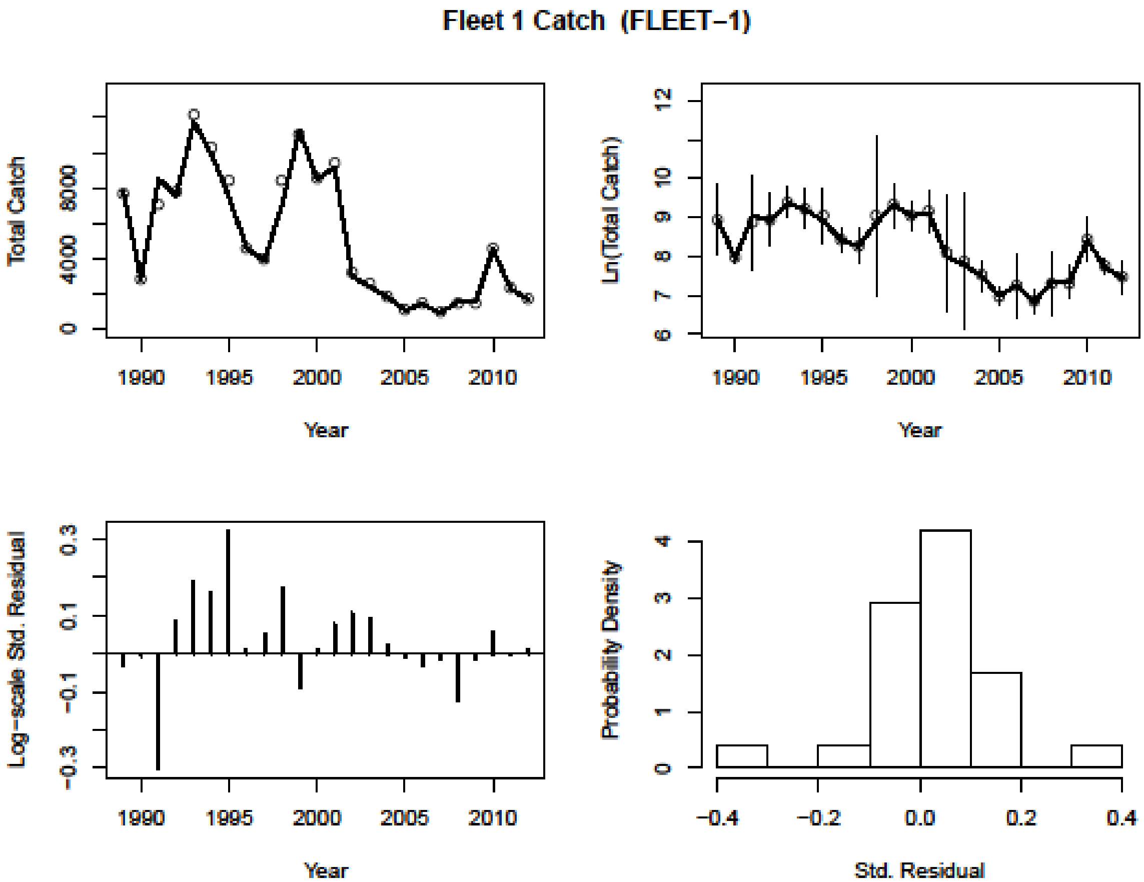


Figure A5.3. Diagnostics for aggregate catch from the base model.

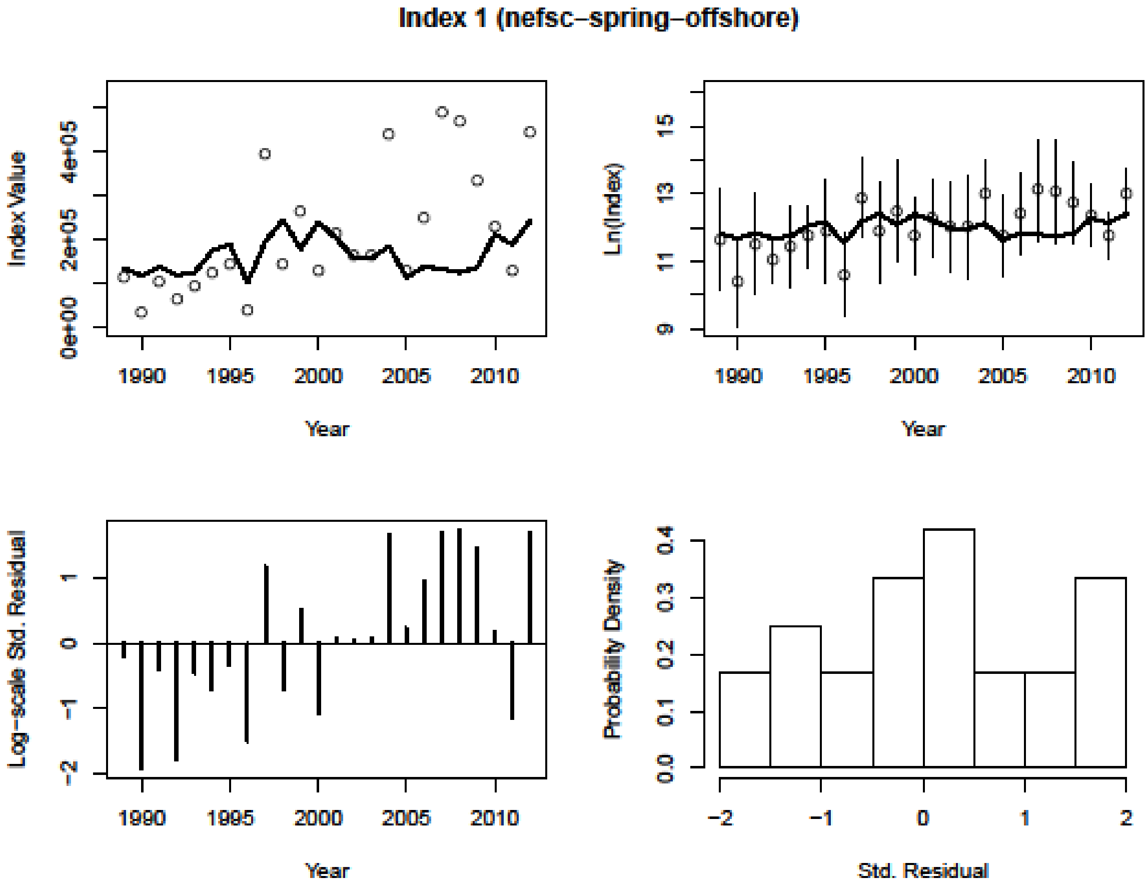


Figure A5.4. Diagnostics for NEFSC spring offshore survey from the base model.

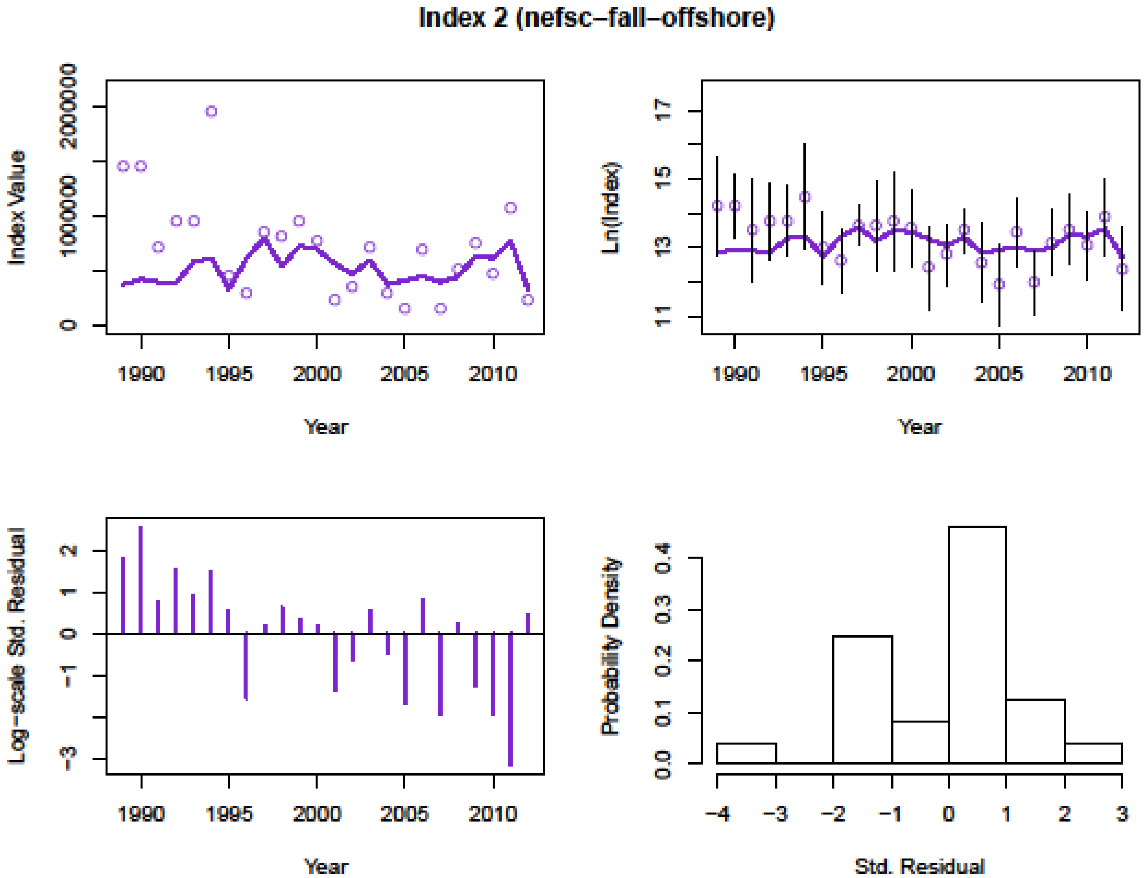


Figure A5.5. Diagnostics for NEFSC fall offshore survey from the base model.

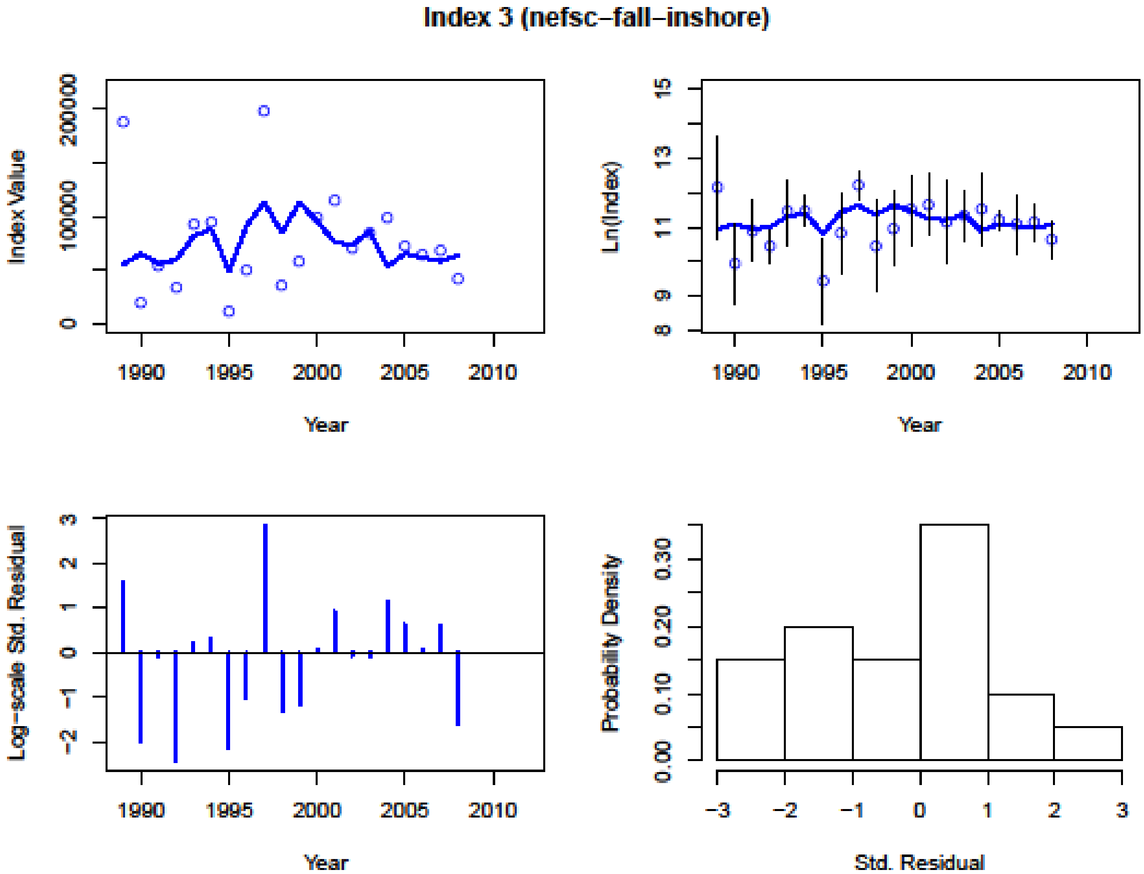


Figure A5.6. Diagnostics for NEFSC fall inshore survey from the base model.

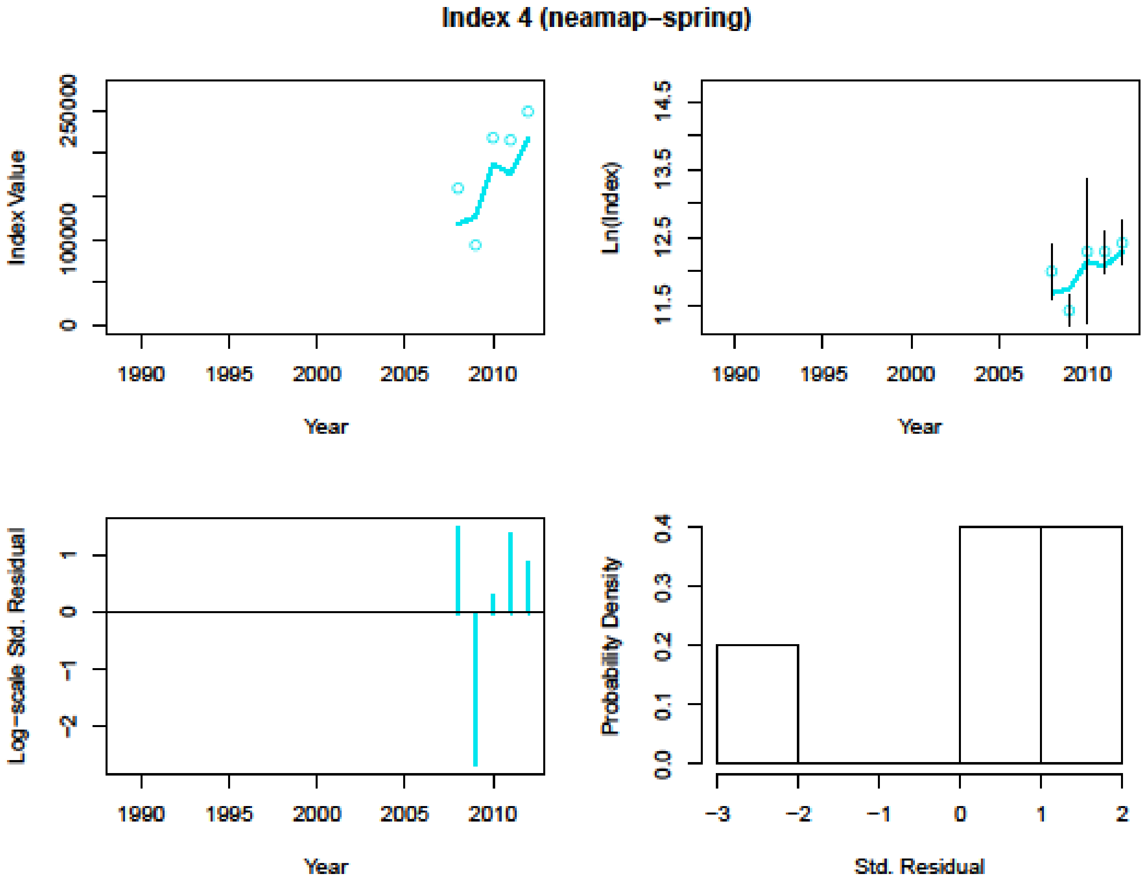


Figure A5.7. Diagnostics for NEAMAP spring survey from the base model.

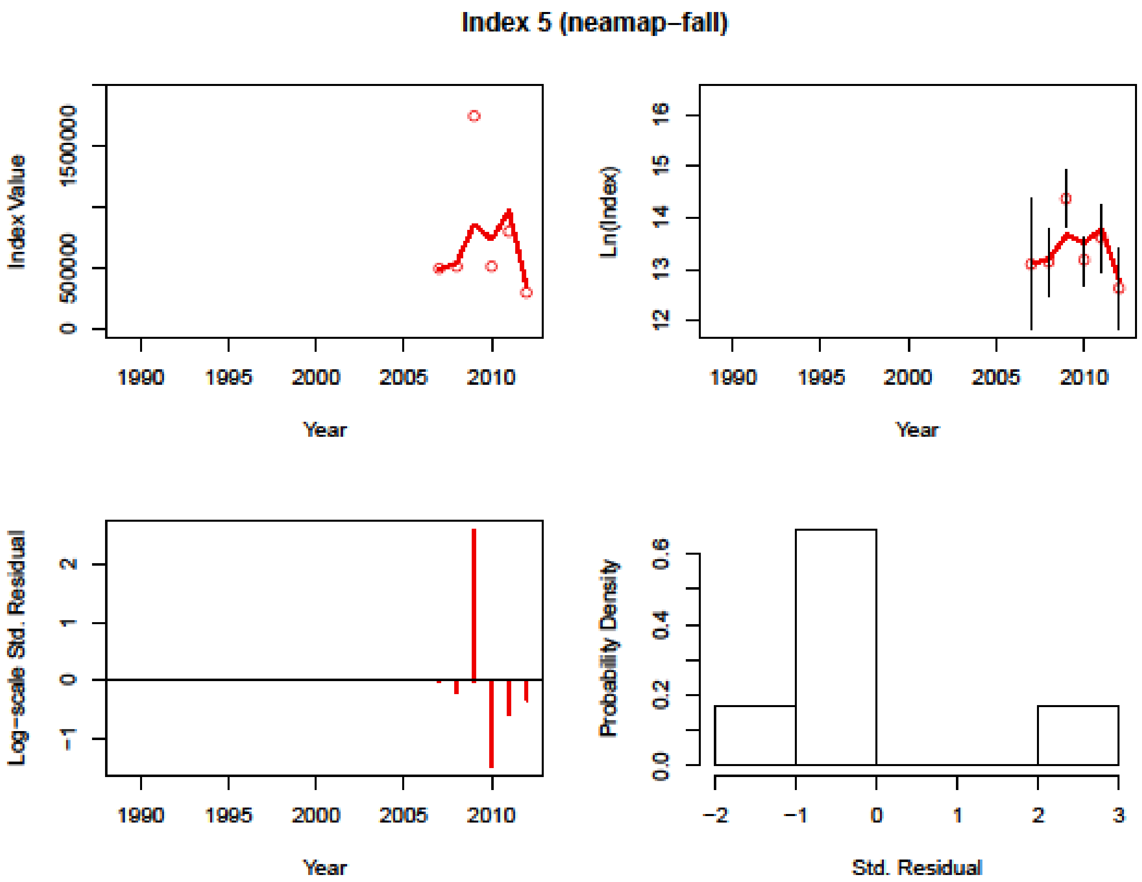


Figure A5.8. Diagnostics for NEAMAP fall survey from the base model.

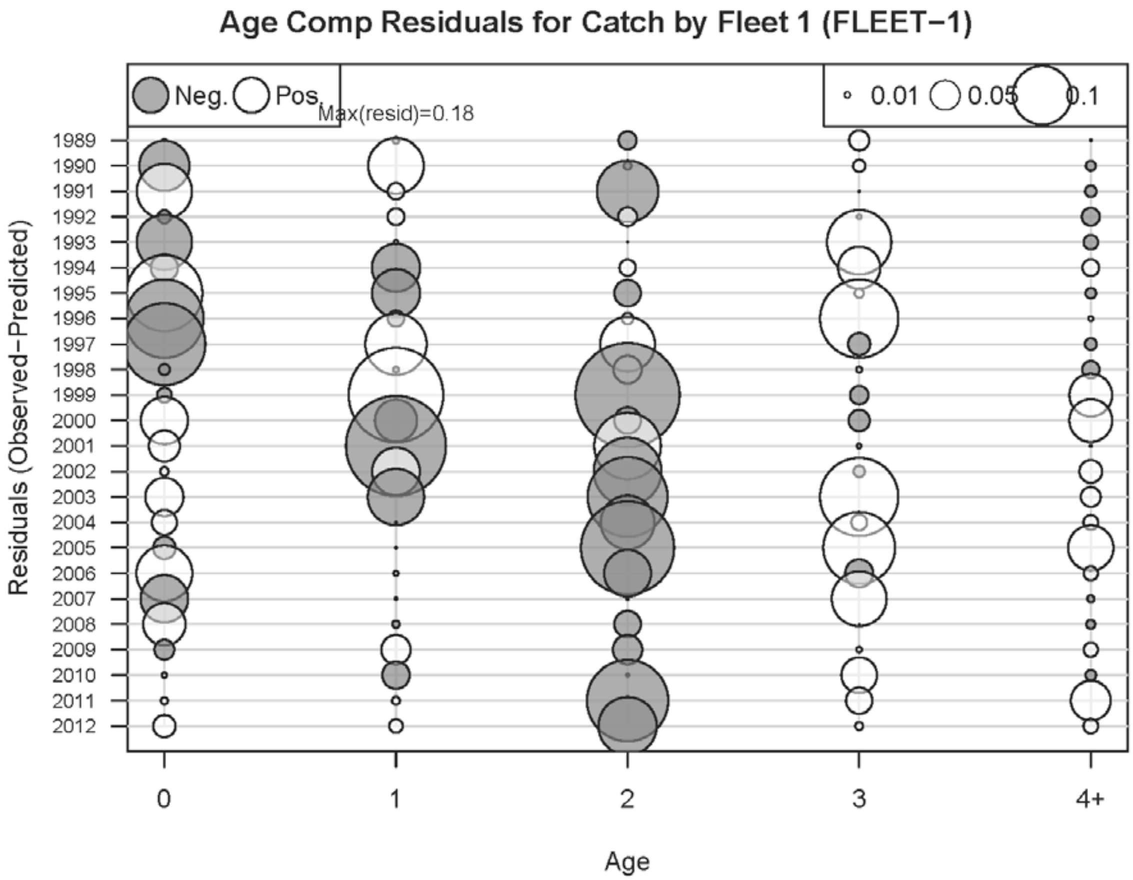


Figure A5.9. Residuals for catch age composition from the base model.

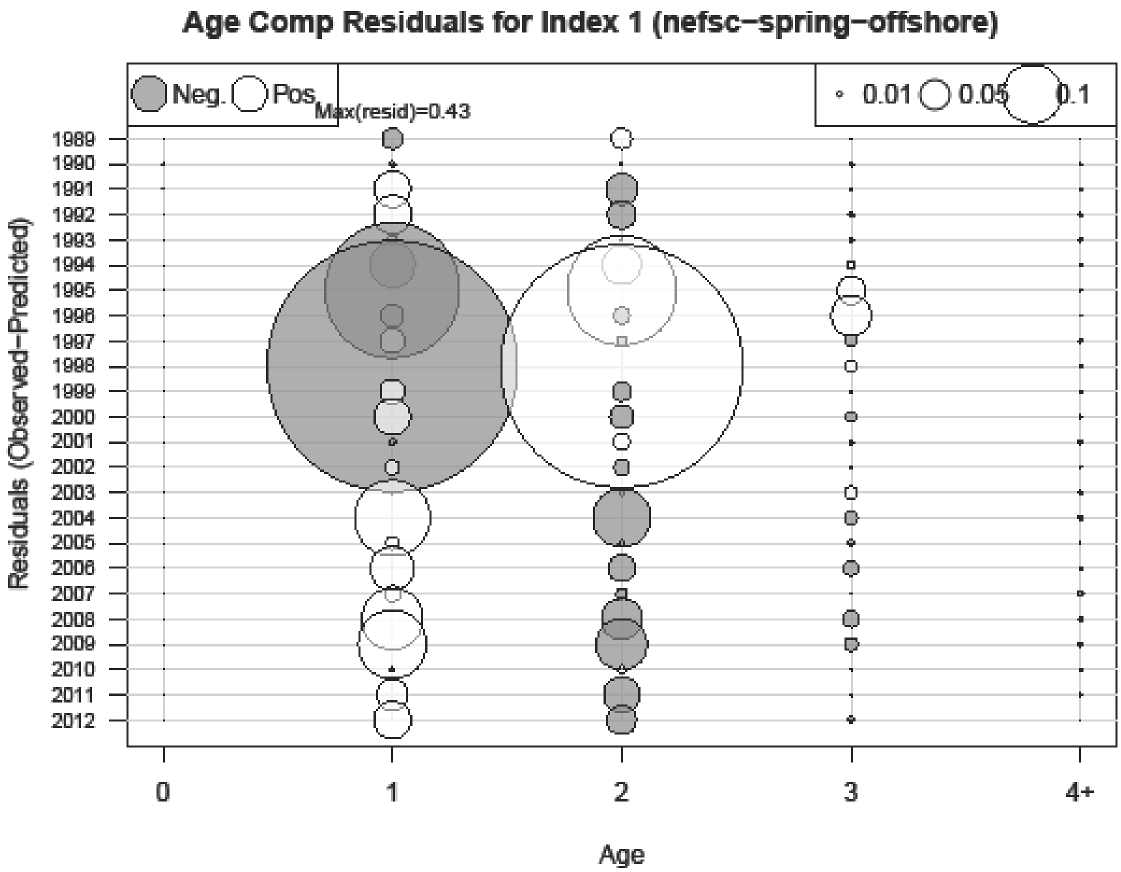


Figure A5.10. Residuals for NEFSC spring offshore age composition from the base model.

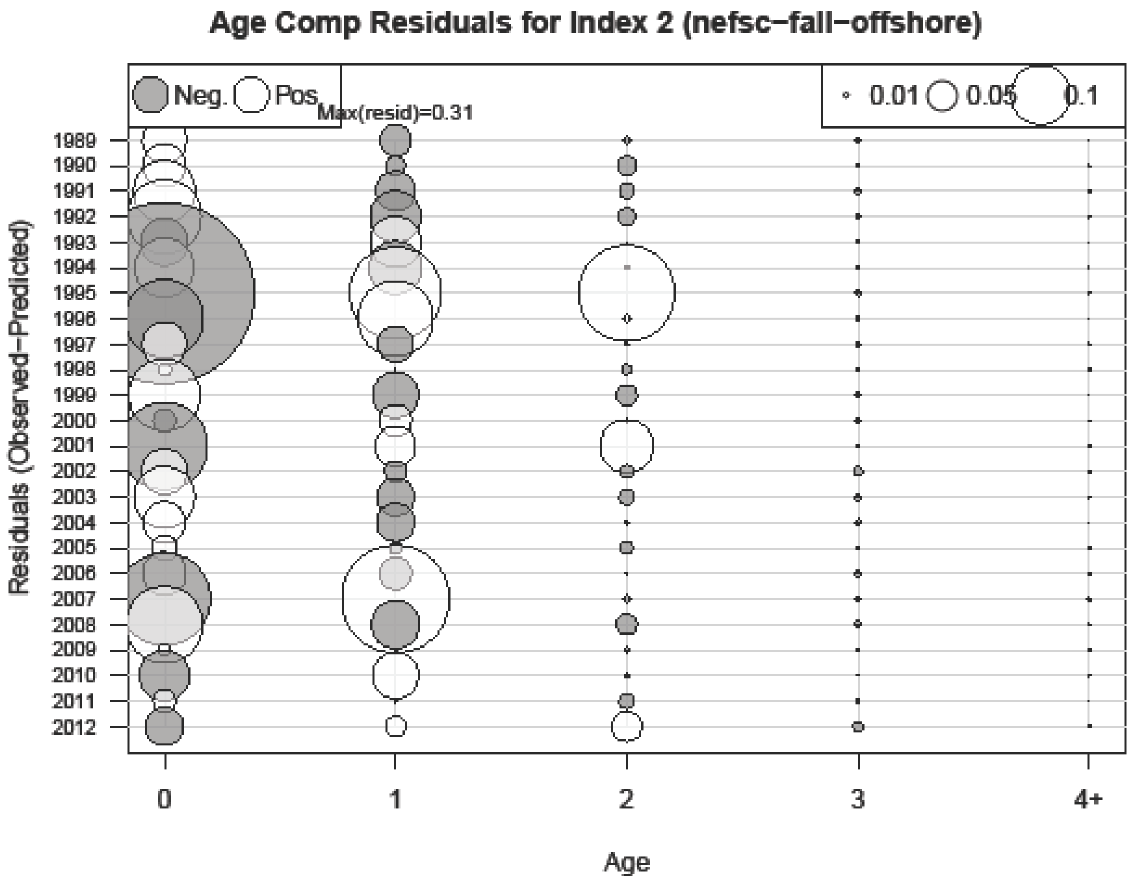


Figure A5.11. Residuals for NEFSC fall offshore age composition from the base model.

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

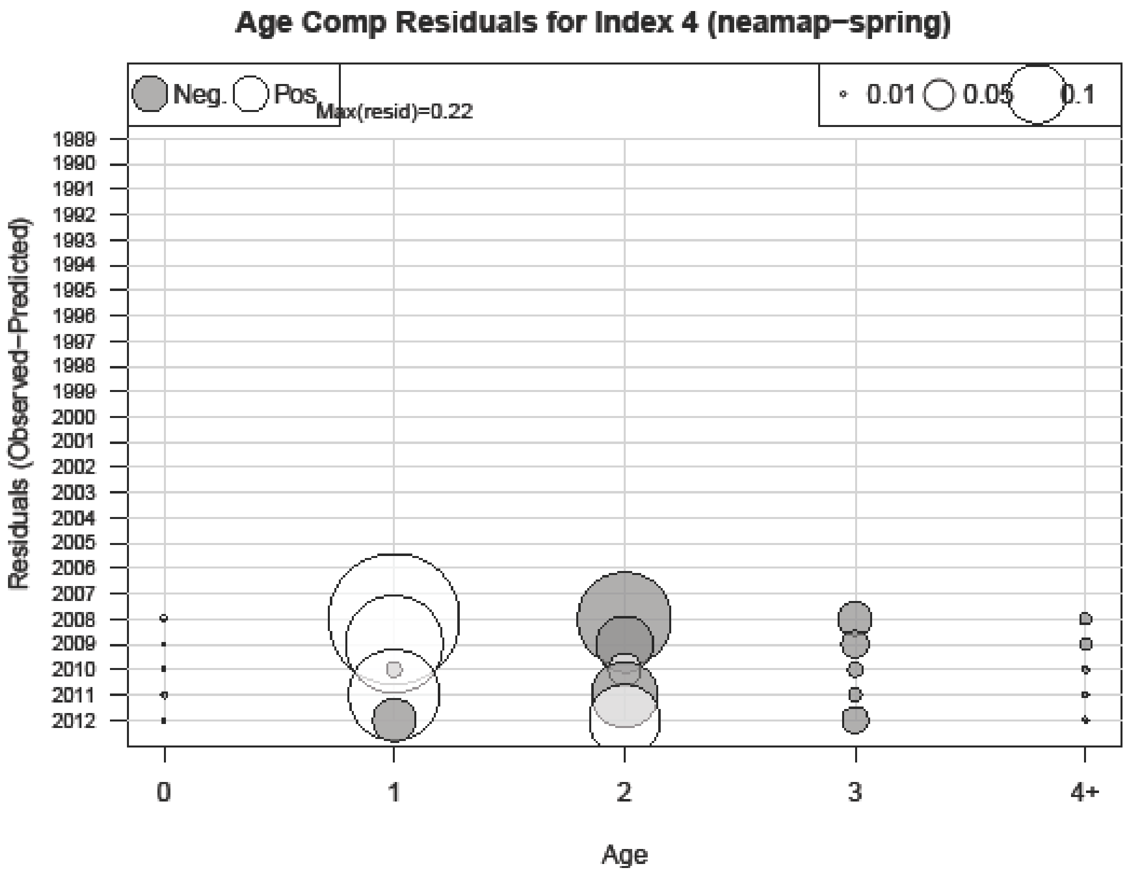


Figure A5.13. Residuals for NEAMAP spring age composition from the base model.

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

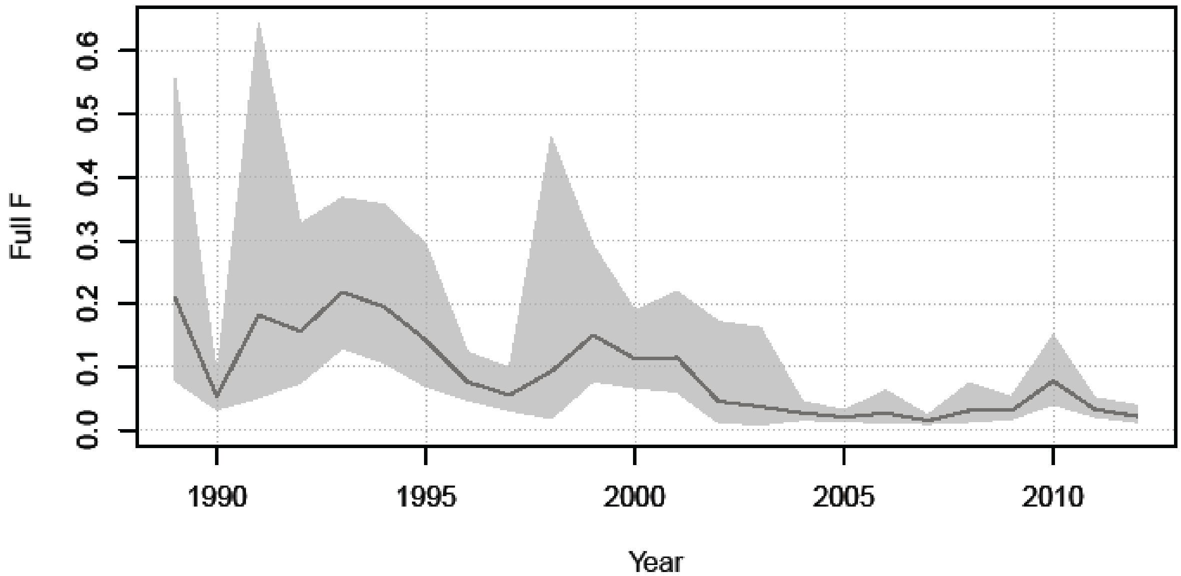


Figure A5.15. Estimated fully selected fishing mortality rate and 95% confidence intervals from the base model.

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

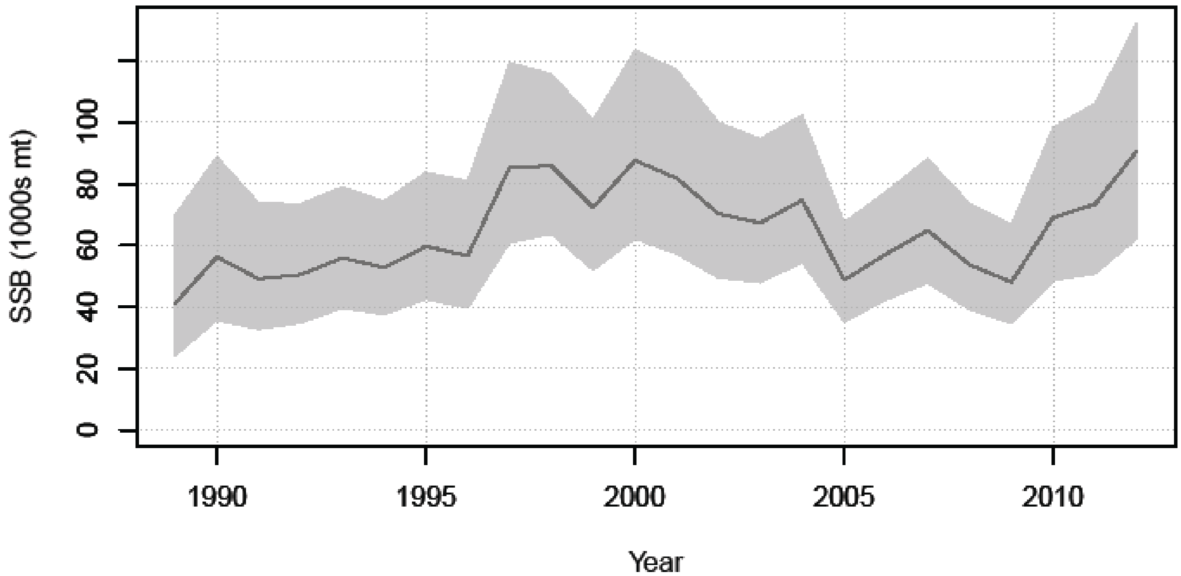


Figure A5.17. Estimated spawning biomass and 95% confidence intervals from the base model.

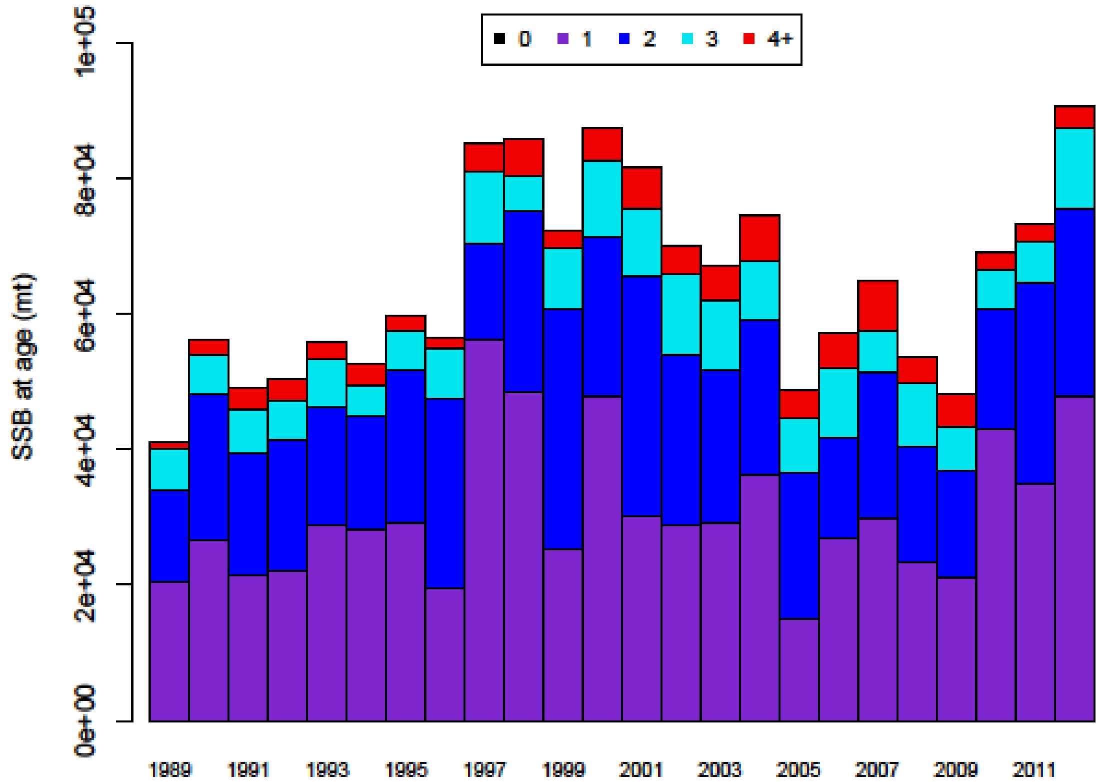


Figure A5.18. Estimated annual spawning biomass at age from the base model.

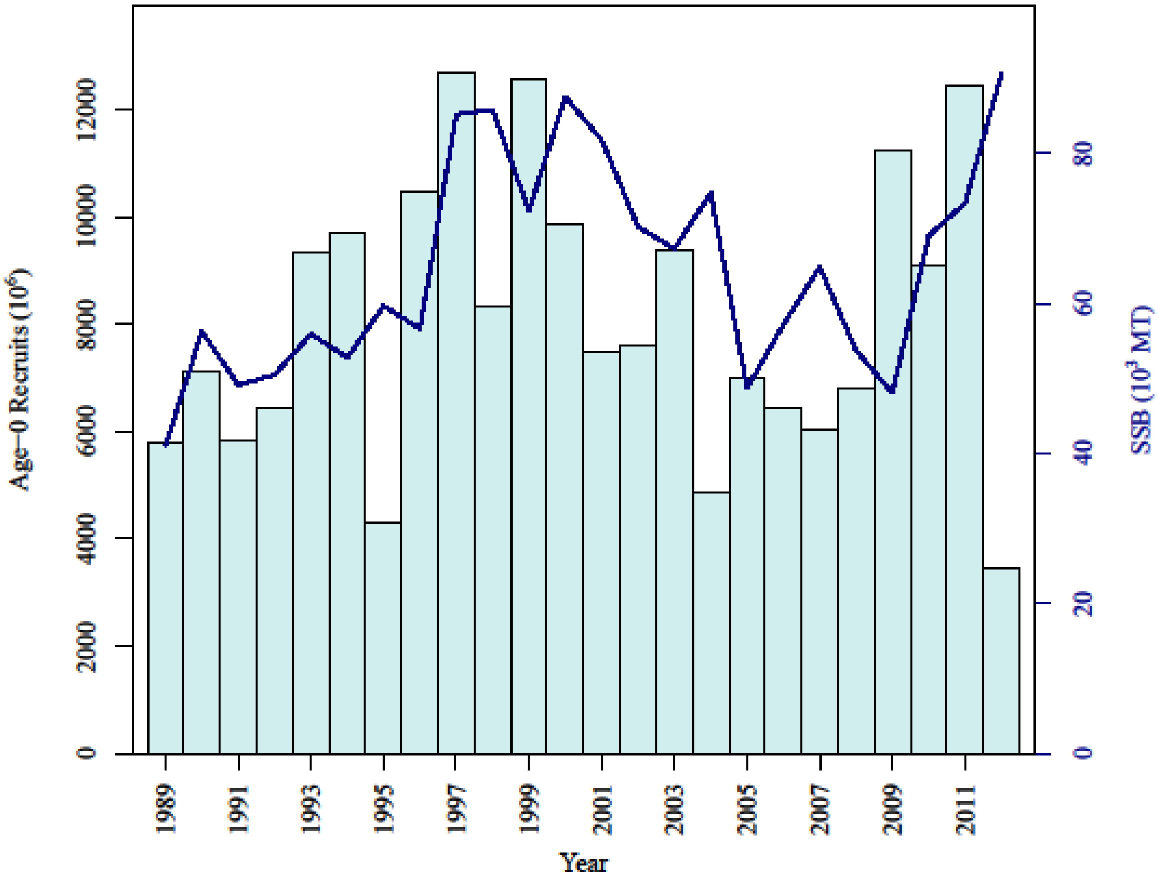


Figure A5.19. Butterfish recruitment (vertical bars), and the spawning stock biomass (blue line) that produced the corresponding recruitment. Year refers to spawning year.

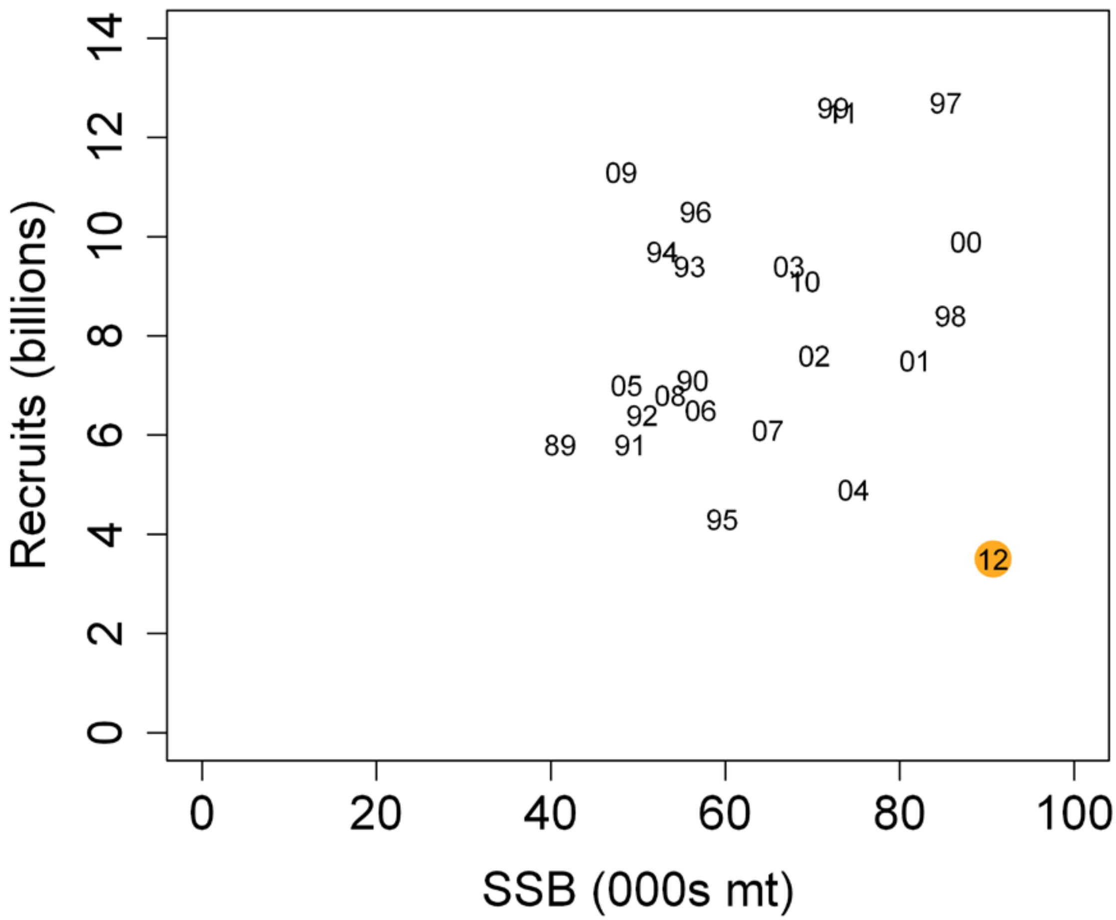


Figure A5.20. Butterfish stock-recruitment scatter plot, with two digit indicator of model SSB year.

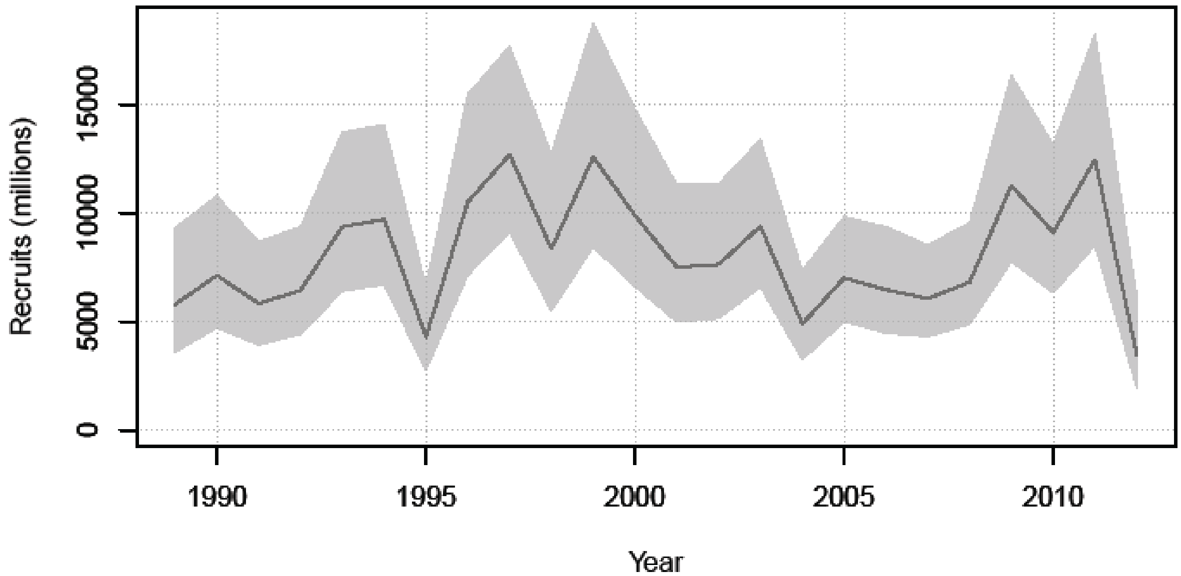


Figure A5.21. Estimated recruitment and 95% confidence intervals from the base model.

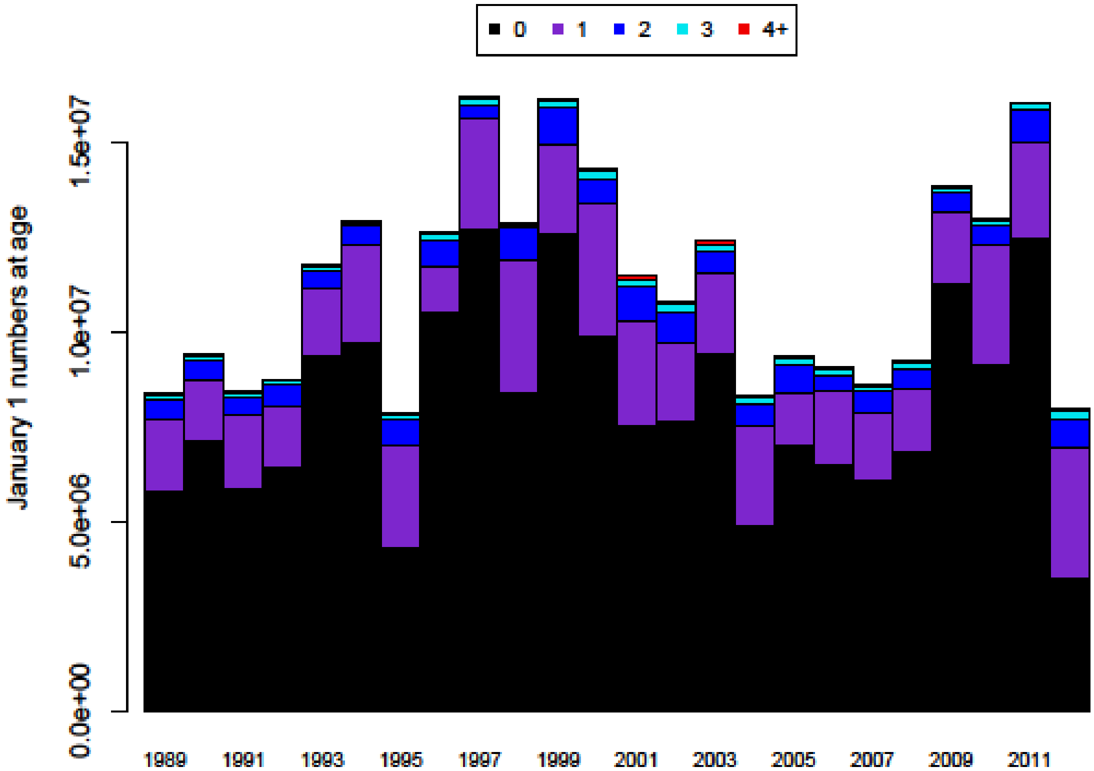


Figure A5.22. Estimated numbers at age at beginning of year from the base model.

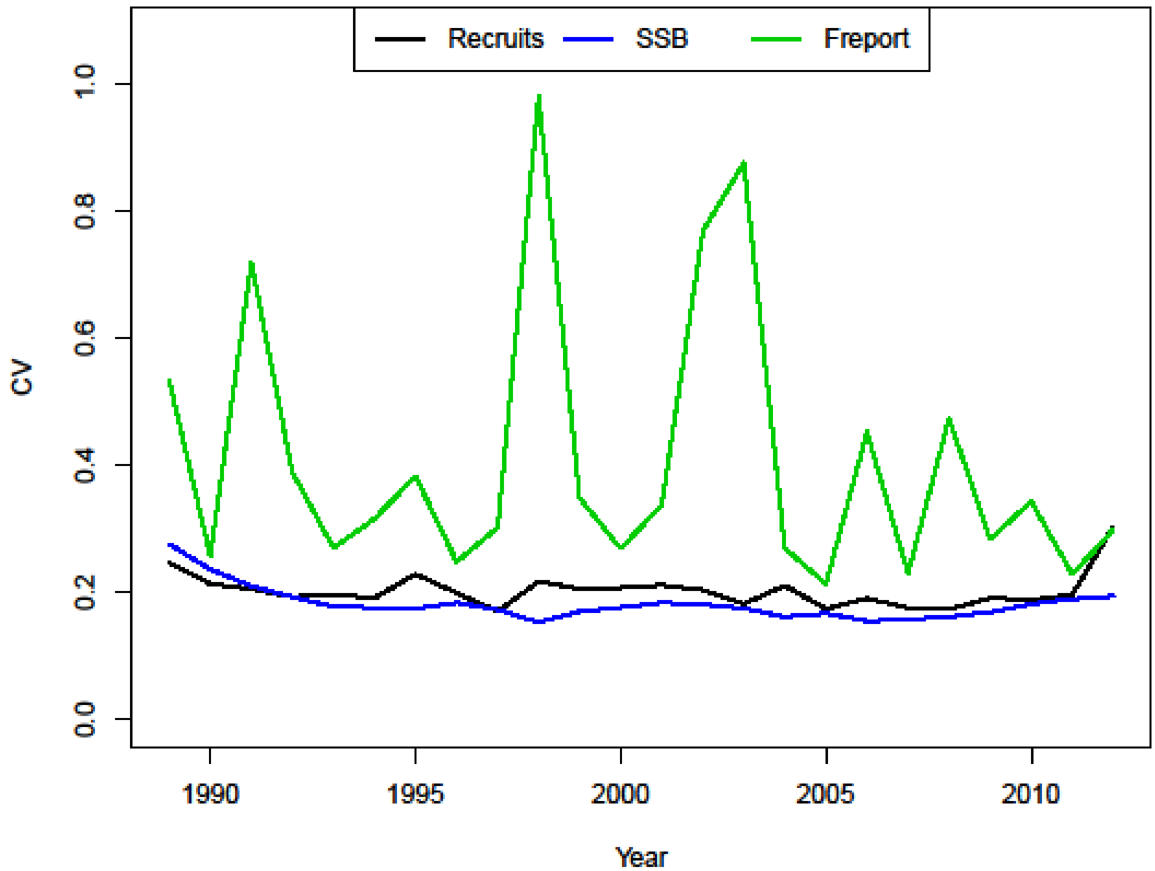


Figure A5.23. Coefficients of variation for estimates of SSB, recruits and fully selected fishing mortality rate from the base model.

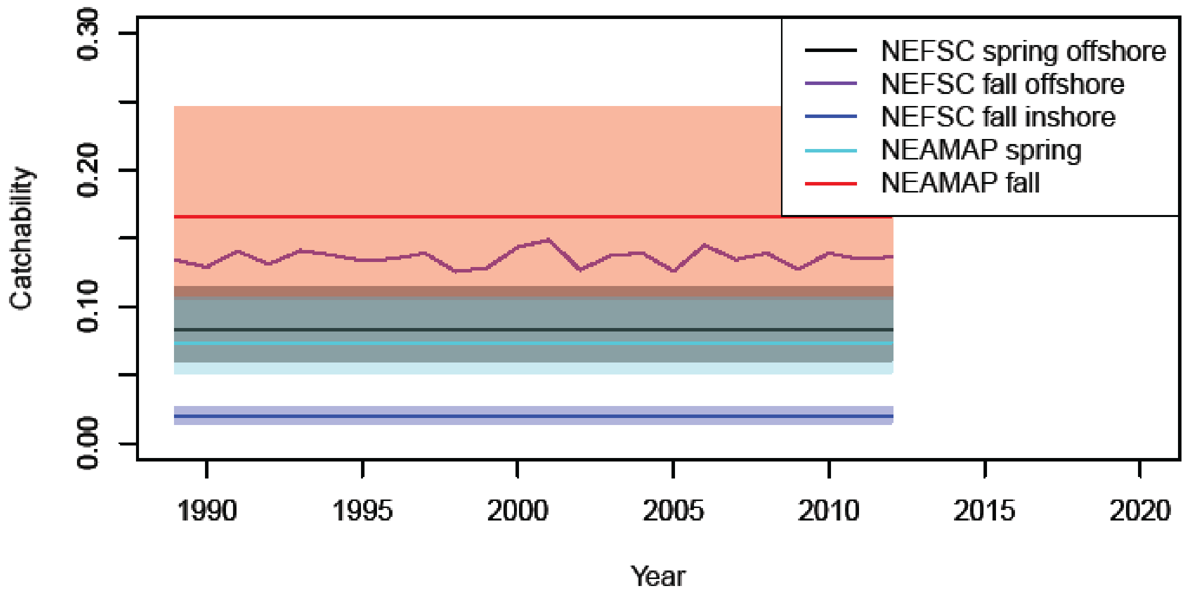


Figure A5.24. Index catchability and 95% confidence intervals from the base model.

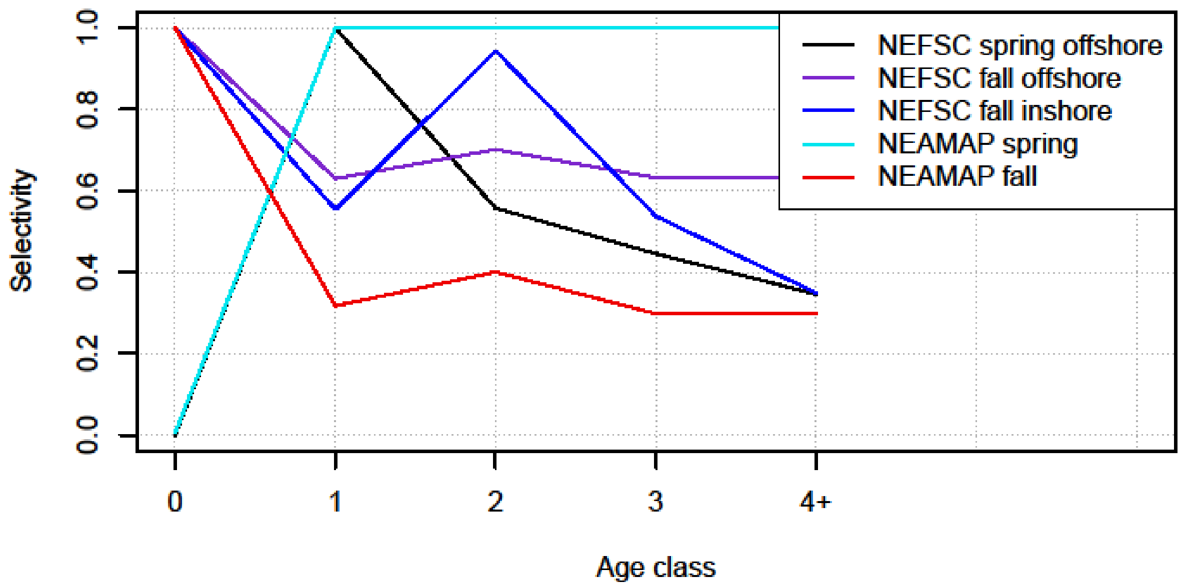


Figure A5.25. Index selectivities from the base model.

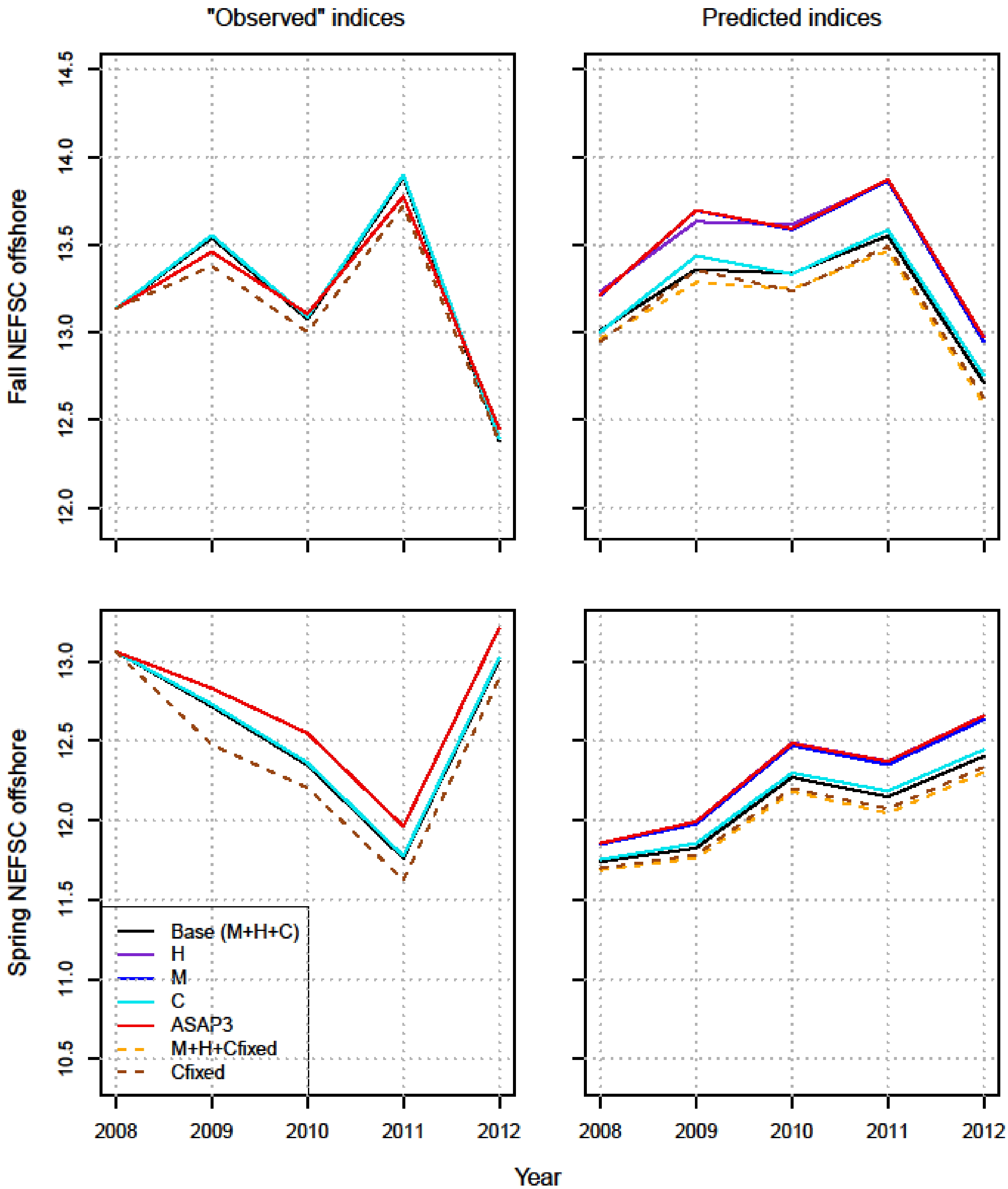


Figure A5.26. Log-scale observed and predicted abundance indices in years 2008-2012 for models described in Table 1.

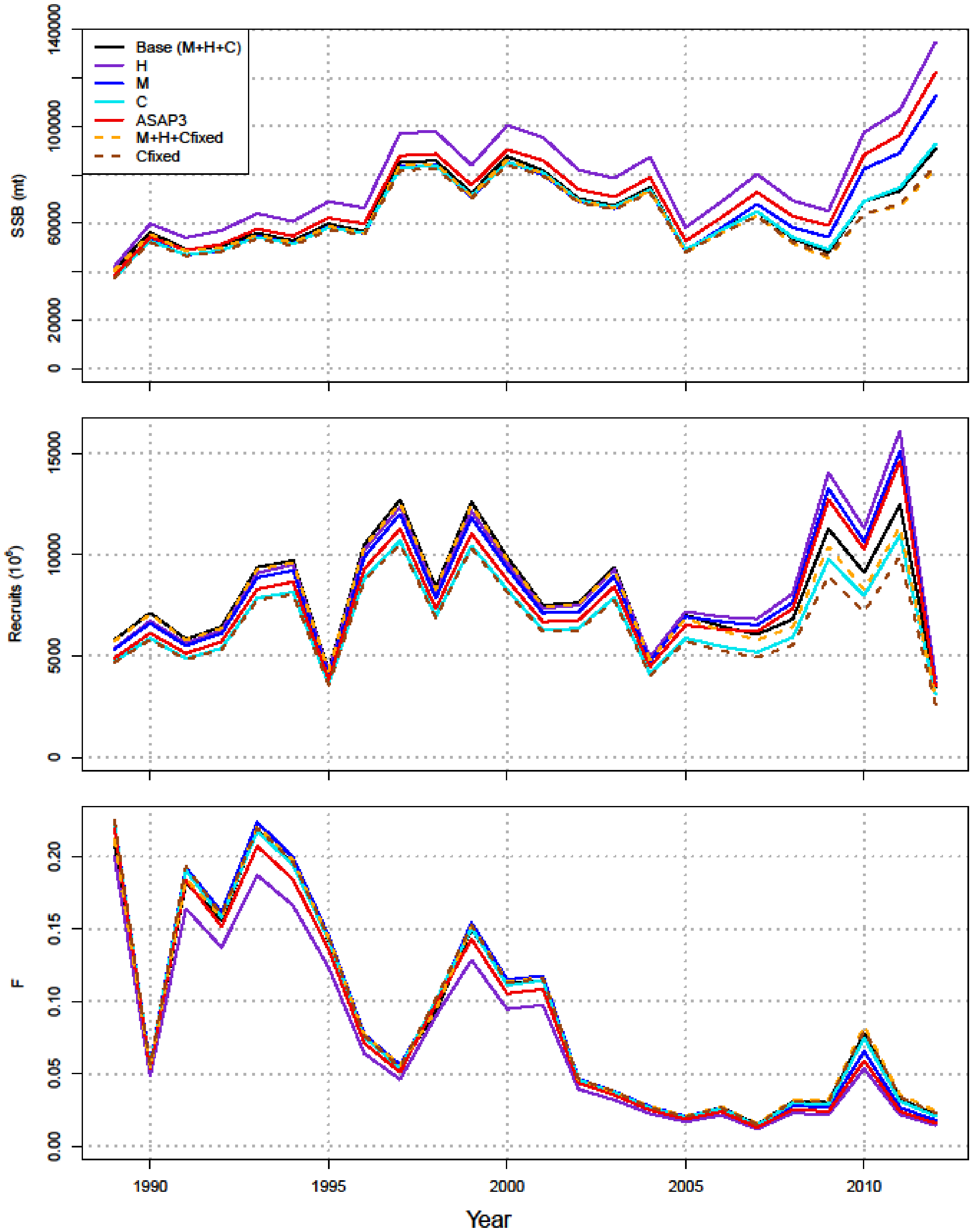


Figure A5.27. Annual estimates of spawning biomass, recruitment and fishing mortality rate for models described in Table 1.

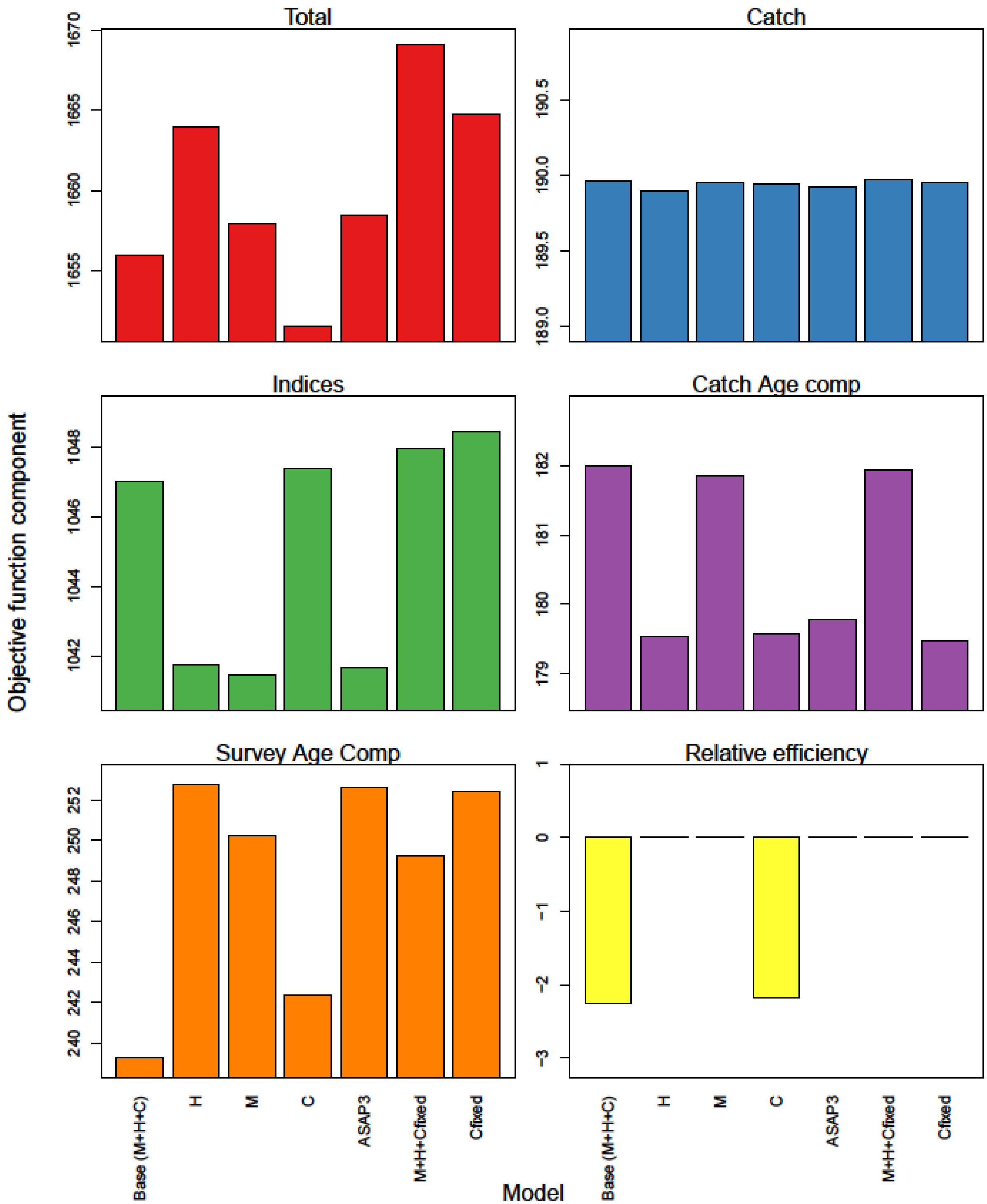


Figure A5.28. Minimized objective function and components for each of the models described in Table 1.

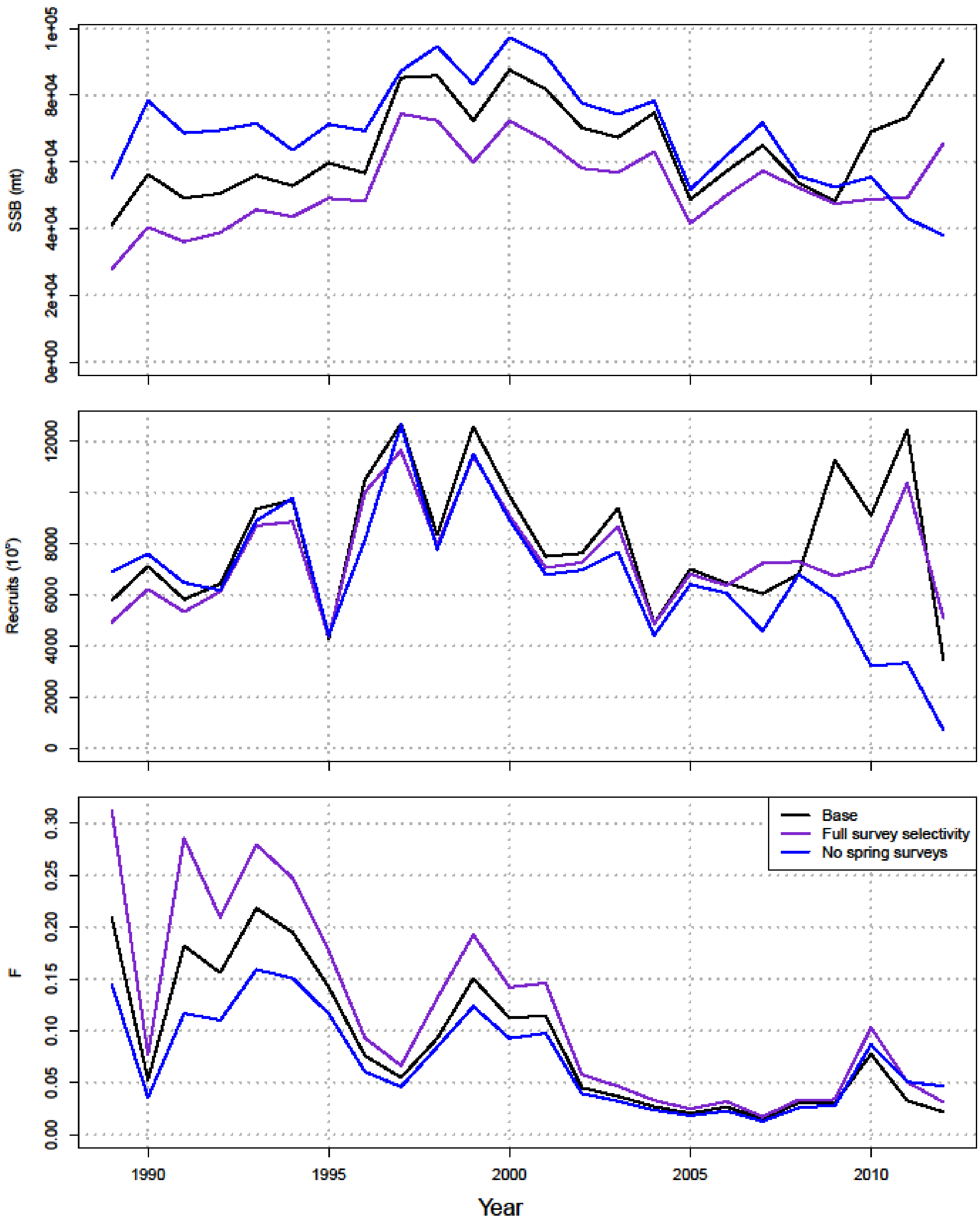


Figure A5.29. Annual estimates of spawning biomass, recruitment, and fishing mortality rate for the base model and alternatives with full survey selectivity assumed and without any spring survey data.

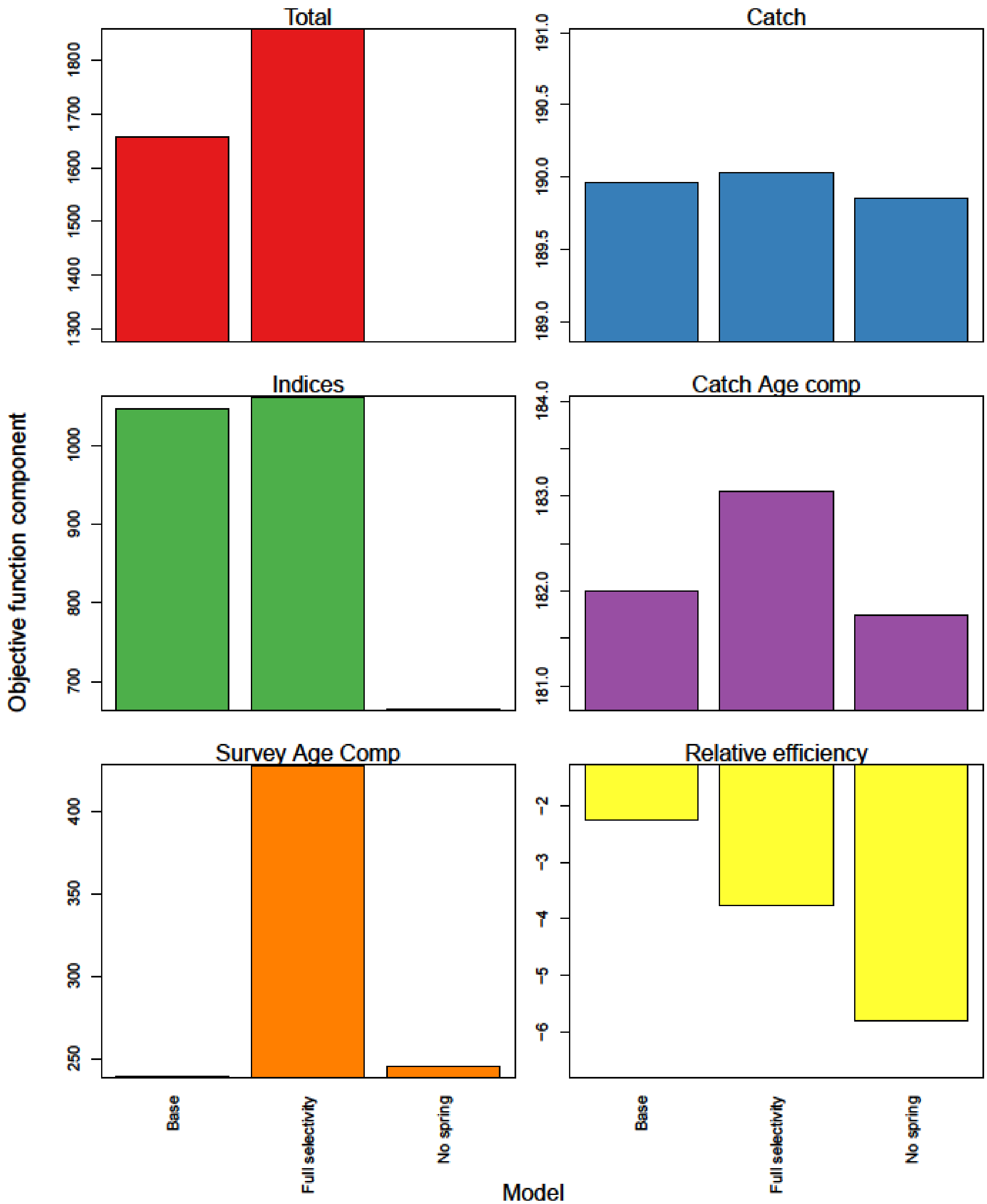


Figure A5.30. Minimized objective function and components for the base model and alternatives with full survey selectivity assumed and without any spring survey data.

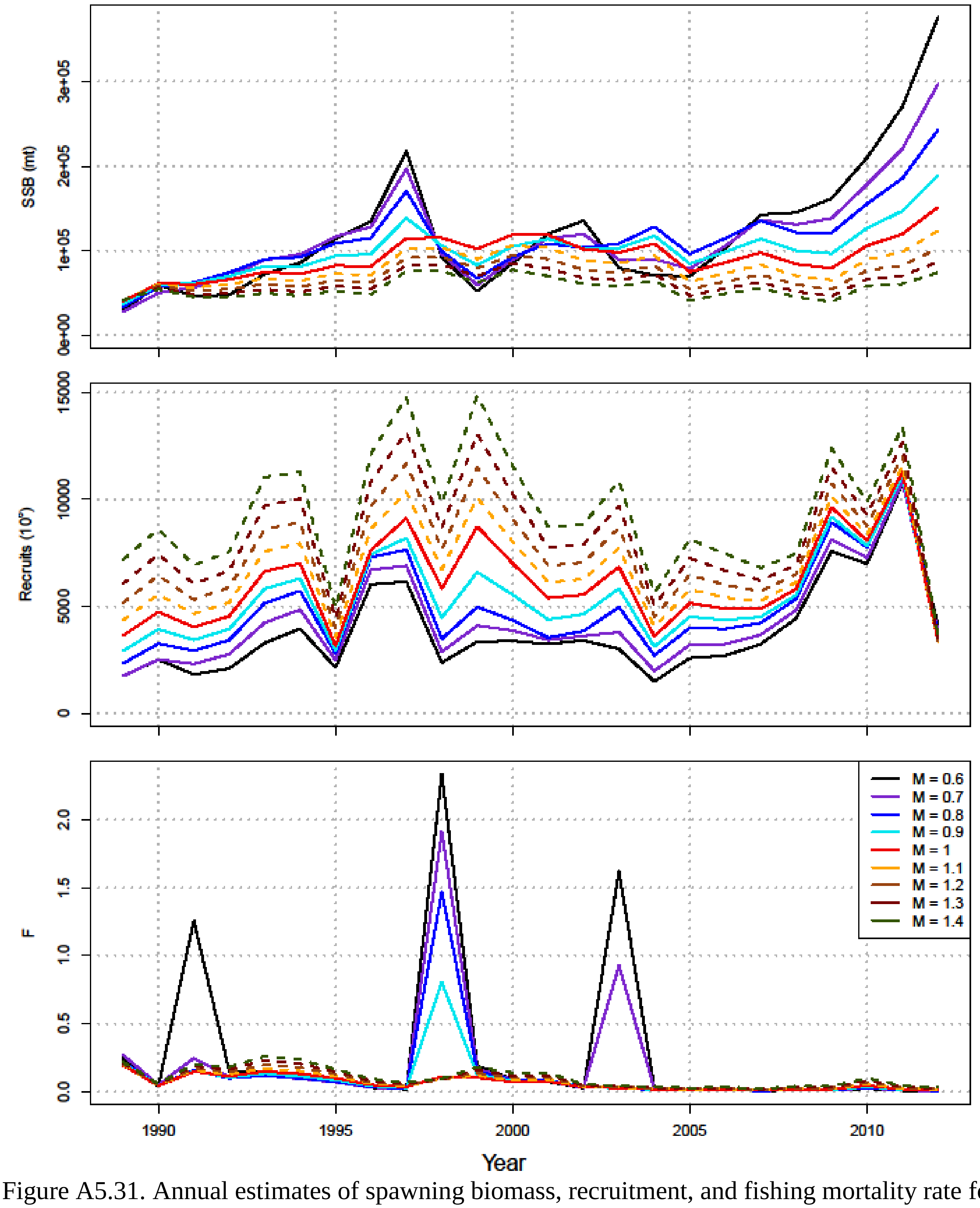


Figure A5.31. Annual estimates of spawning biomass, recruitment, and fishing mortality rate for models with a range of assumed natural mortality rates.

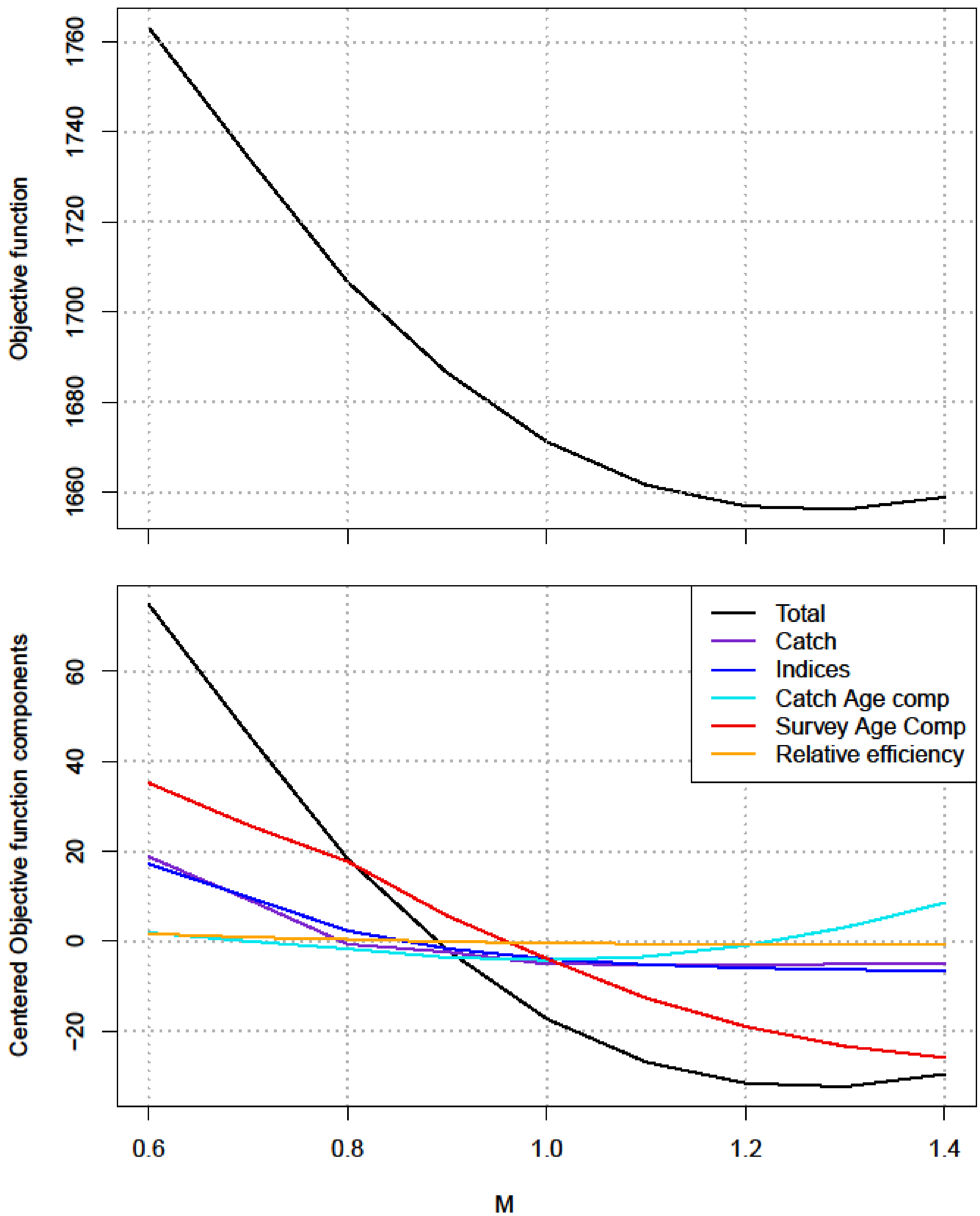


Figure A5.32. Minimized objective function and components for models with a range of assumed natural mortality rates.

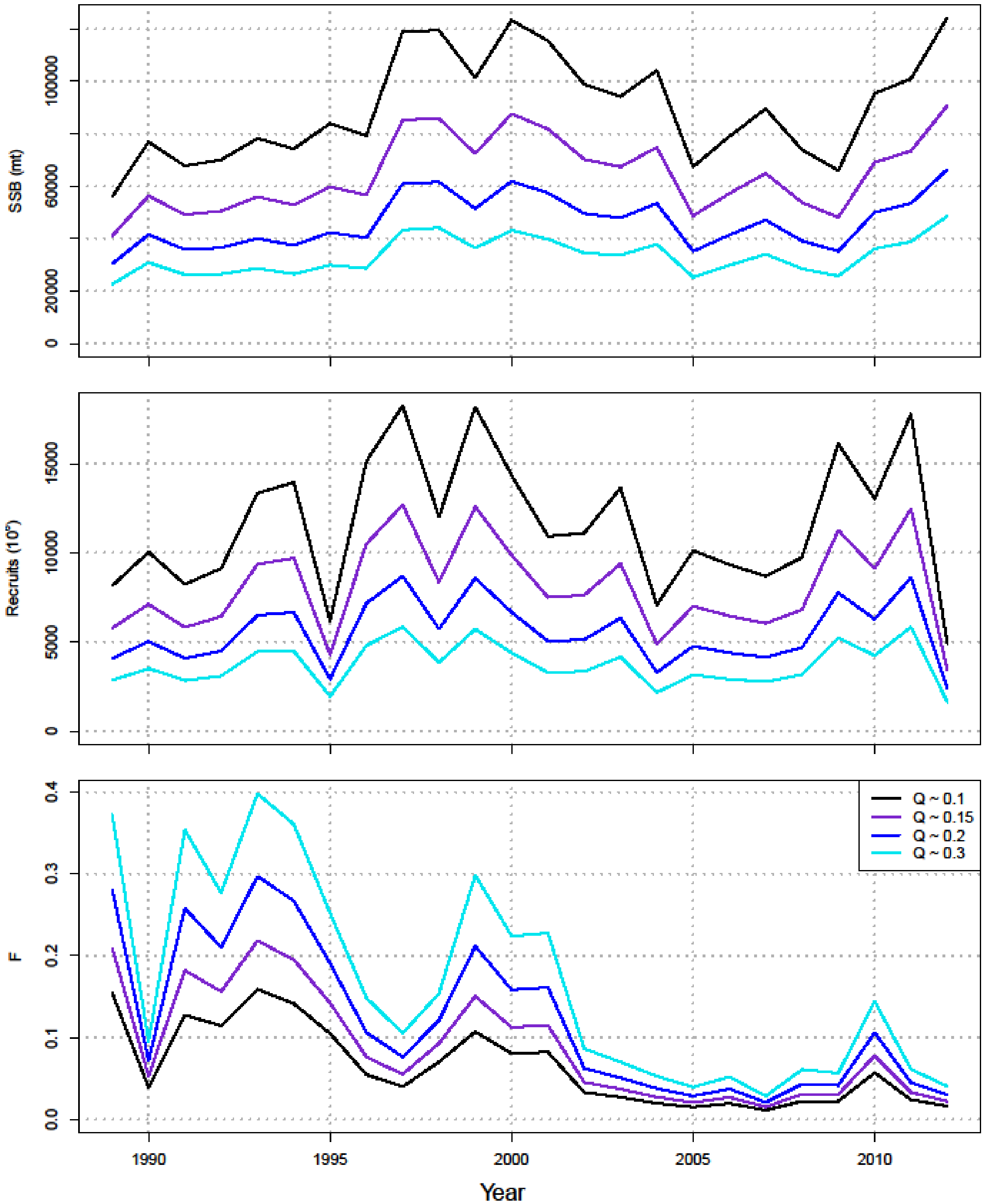


Figure A5.33. Annual estimates of spawning biomass, recruitment, and fishing mortality rate for models with a range of assumed NEFSC fall offshore survey catchabilities.

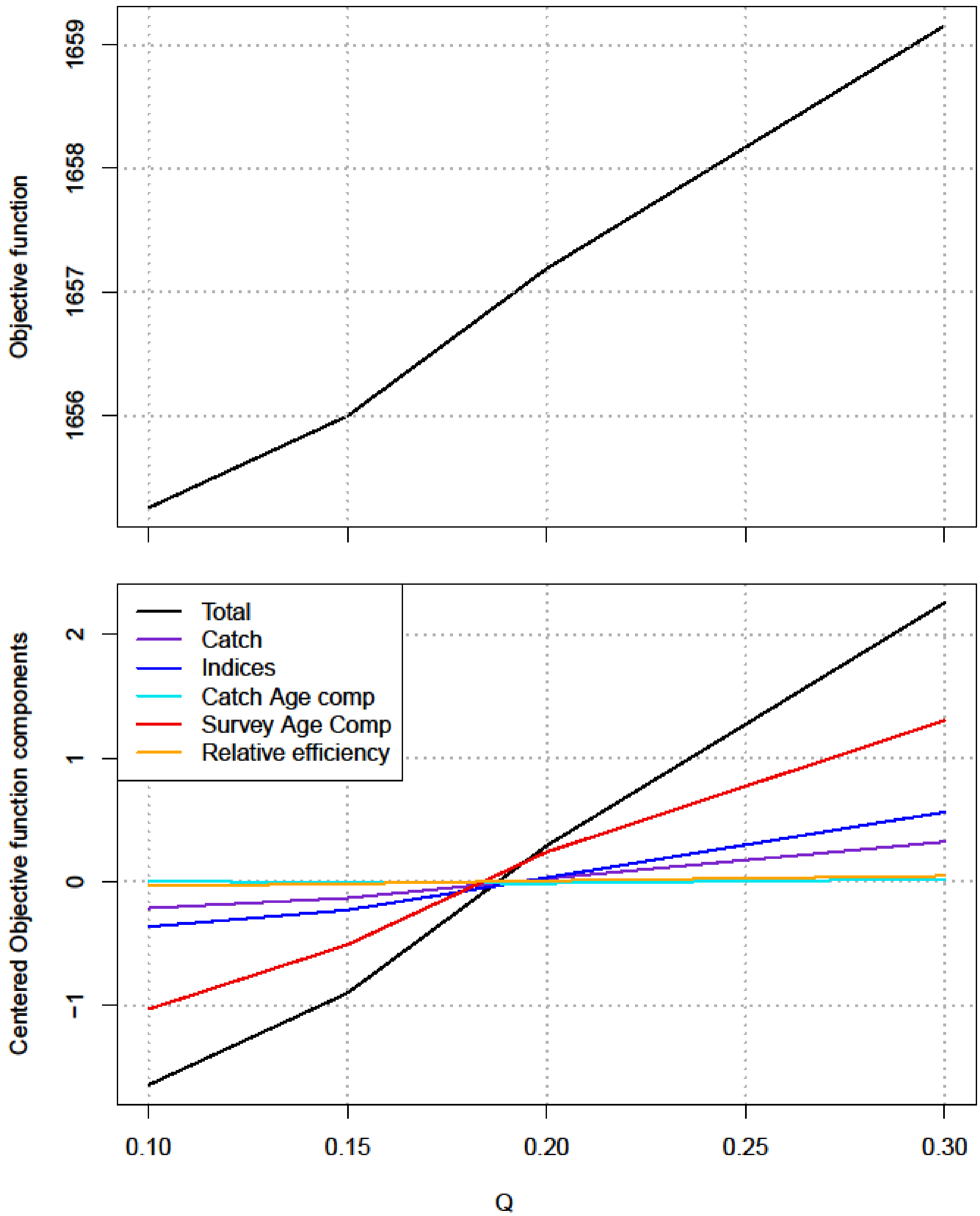


Figure A5.34. Minimized objective function and components for models with a range of assumed NEFSC fall offshore survey catchabilities.

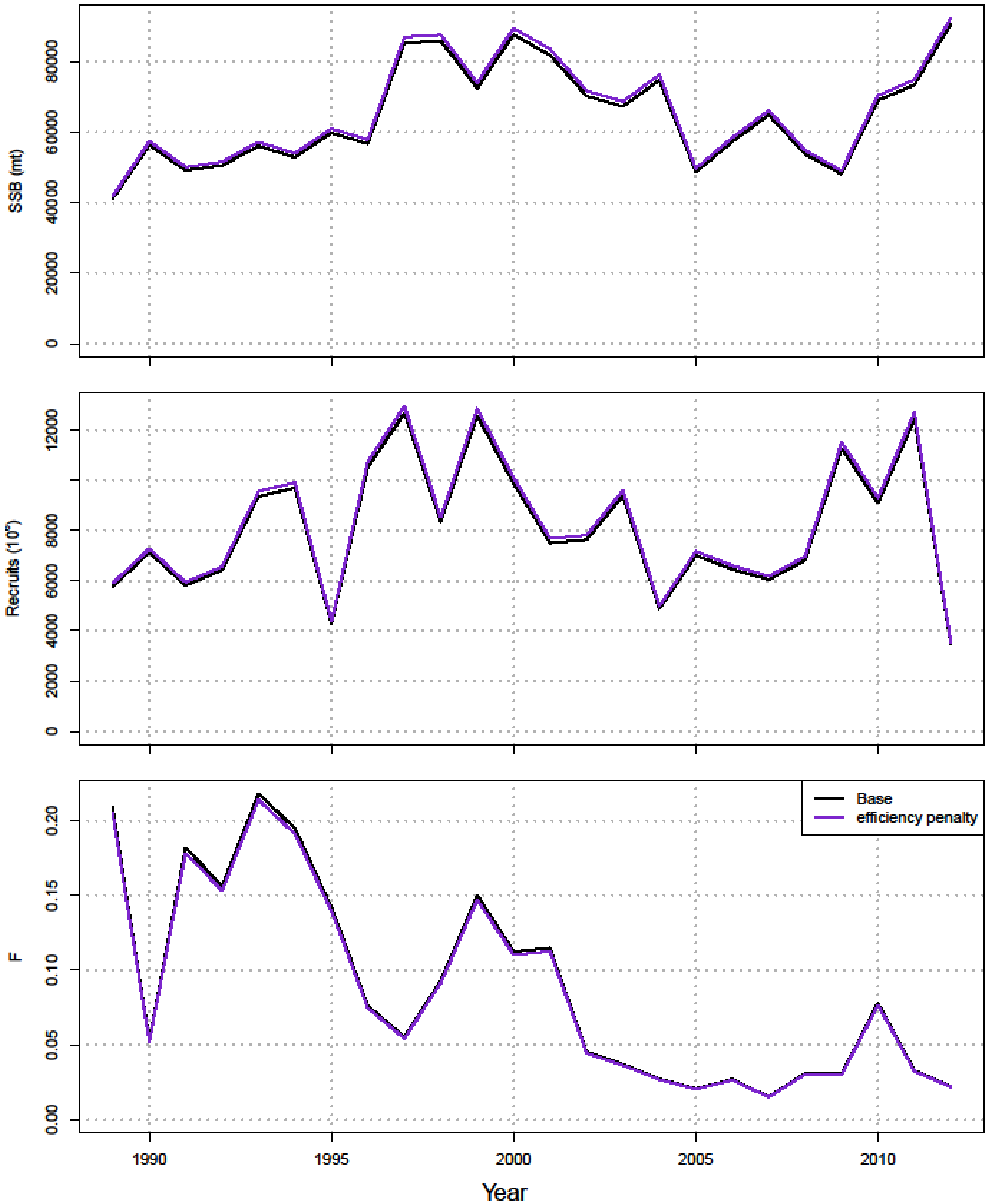


Figure A5.35. Annual estimates of spawning biomass, recruitment, and fishing mortality rate for the base model and alternative with penalized estimation of NEFSC fall offshore survey efficiency.

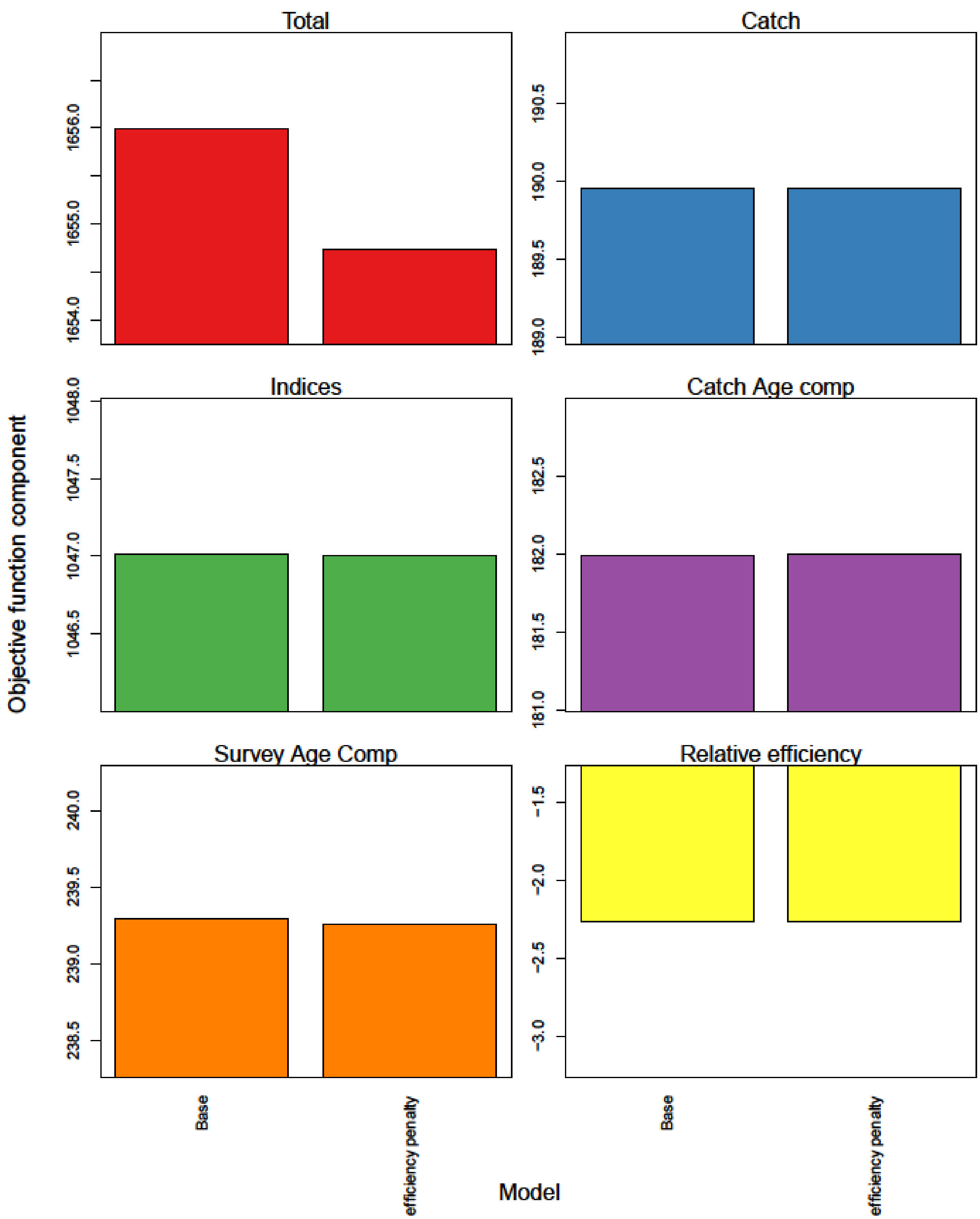


Figure A5.36. Minimized objective function and components for the base model and alternative with penalized estimation of NEFSC fall offshore survey efficiency.

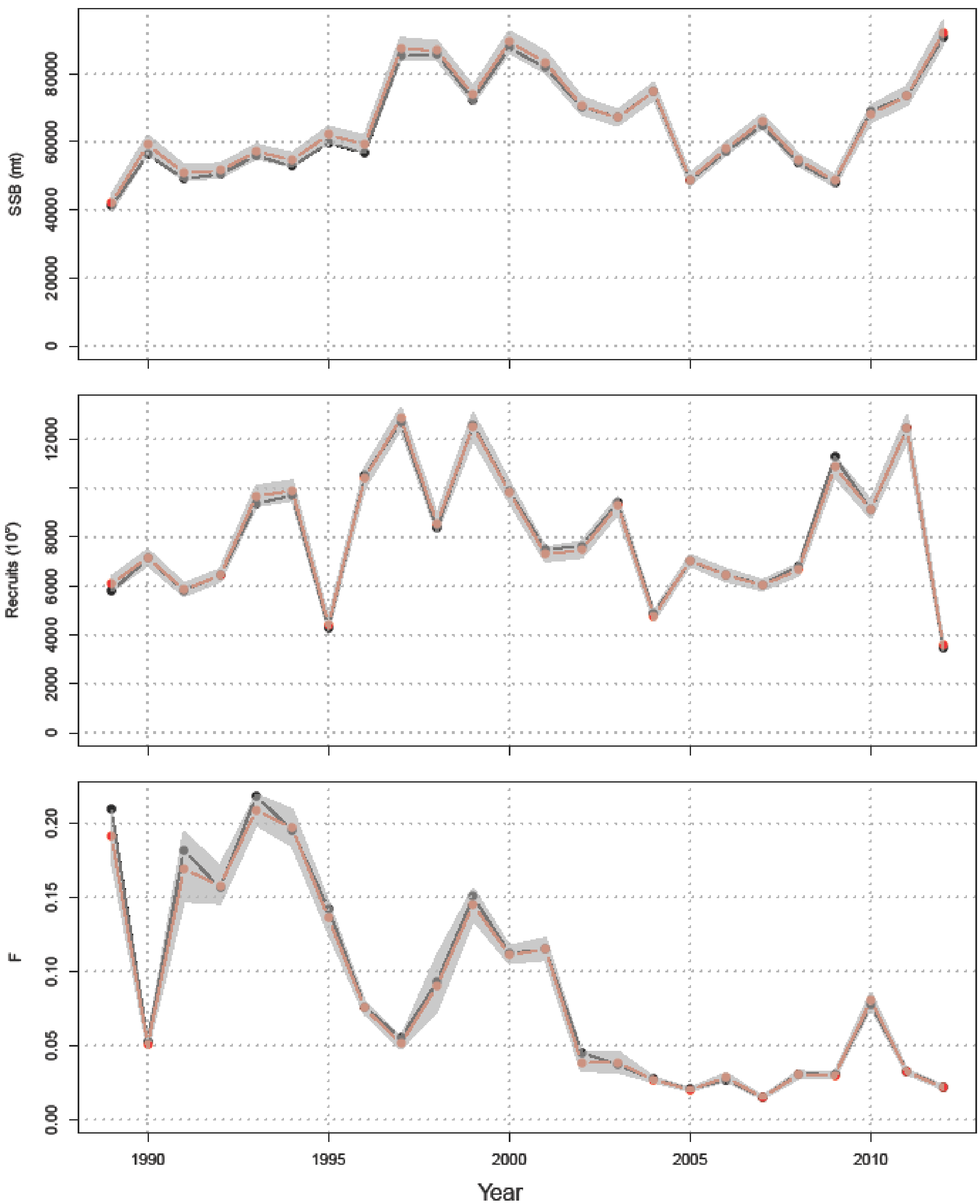


Figure A5.37. Annual spawning biomass, recruitment, and fishing mortality rate, estimated from the base model (black), and mean estimates from 100 simulations based on model estimates where observations of catch, indices and associated age compositions were randomly distributed. No length-based calibration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

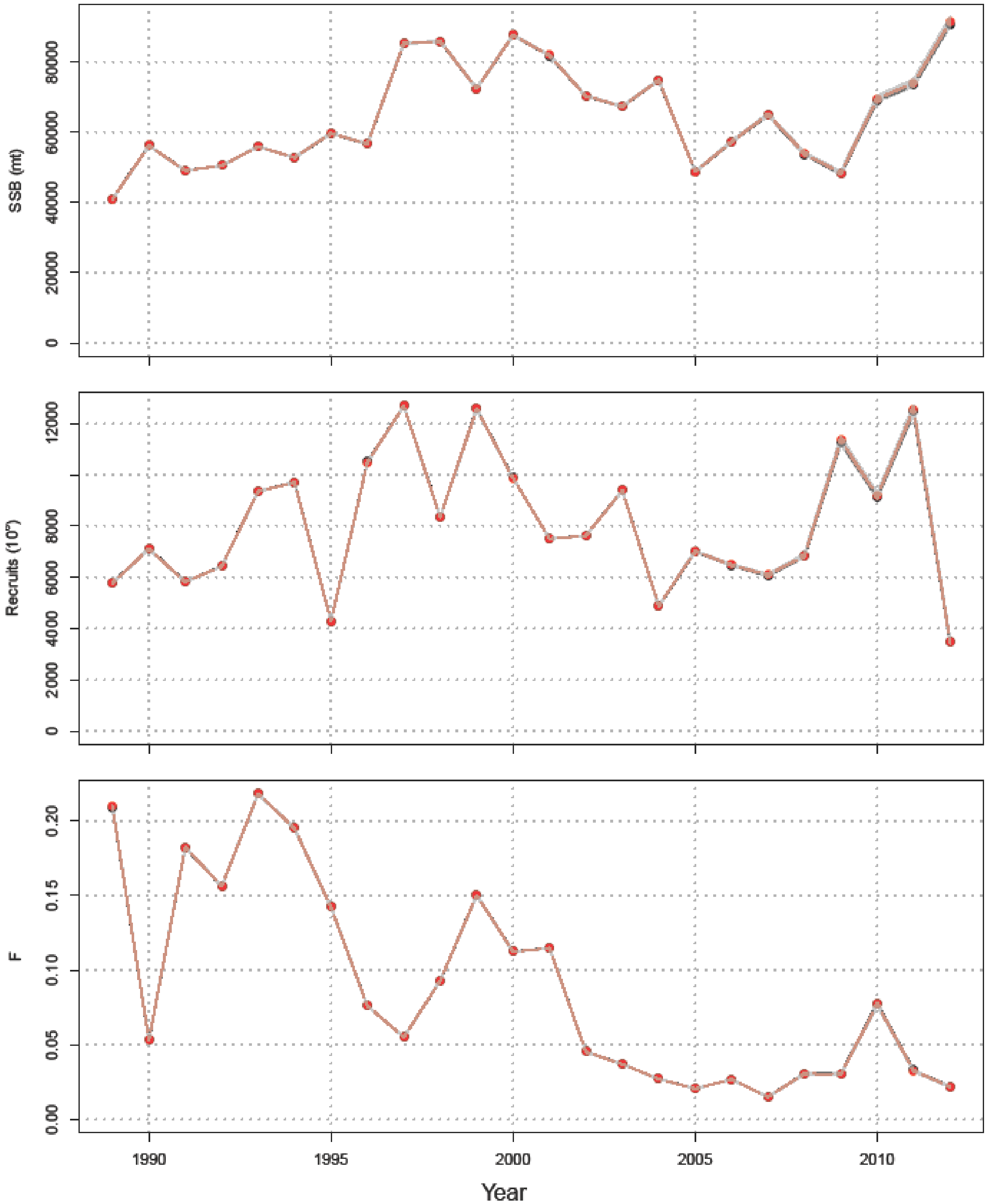


Figure A5.38. Annual spawning biomass (SSB), recruitment, and fishing mortality rate (F), estimated from the base model (black), and mean estimates from 100 simulations based on model estimates where length-based calibration parameters were drawn from a multivariate normal distribution with mean and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

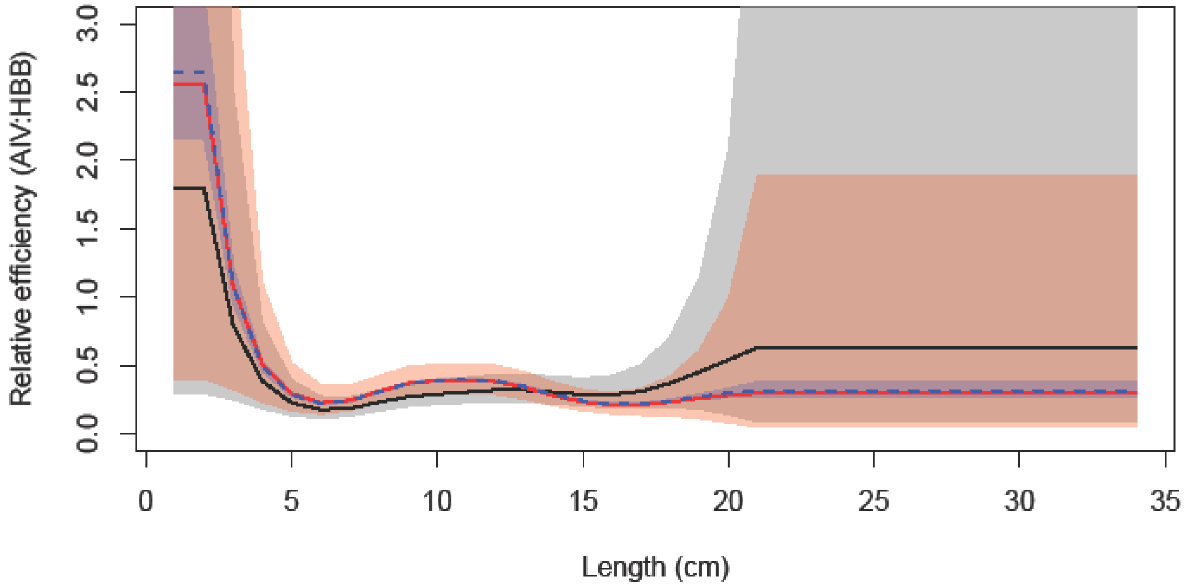


Figure A5.39. Relative catch efficiency from Miller (2013) (black, gray 95% confidence interval), from the base model with estimated deviations (red), and from average of predictions from fitting base model to simulated data (blue).

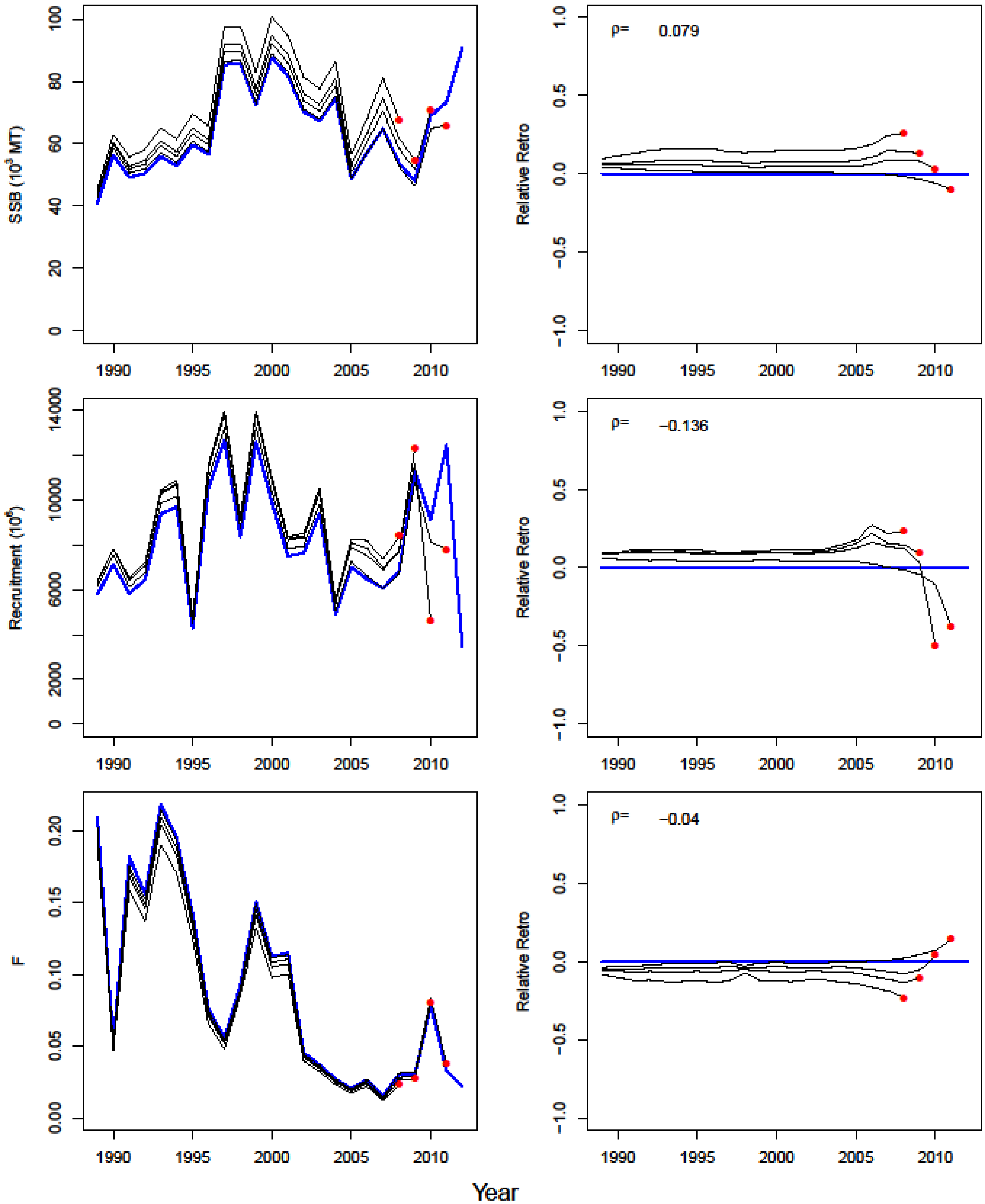


Figure A5.40. Retrospective patterns for spawning biomass, recruitment and fishing mortality in base model.

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.

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.

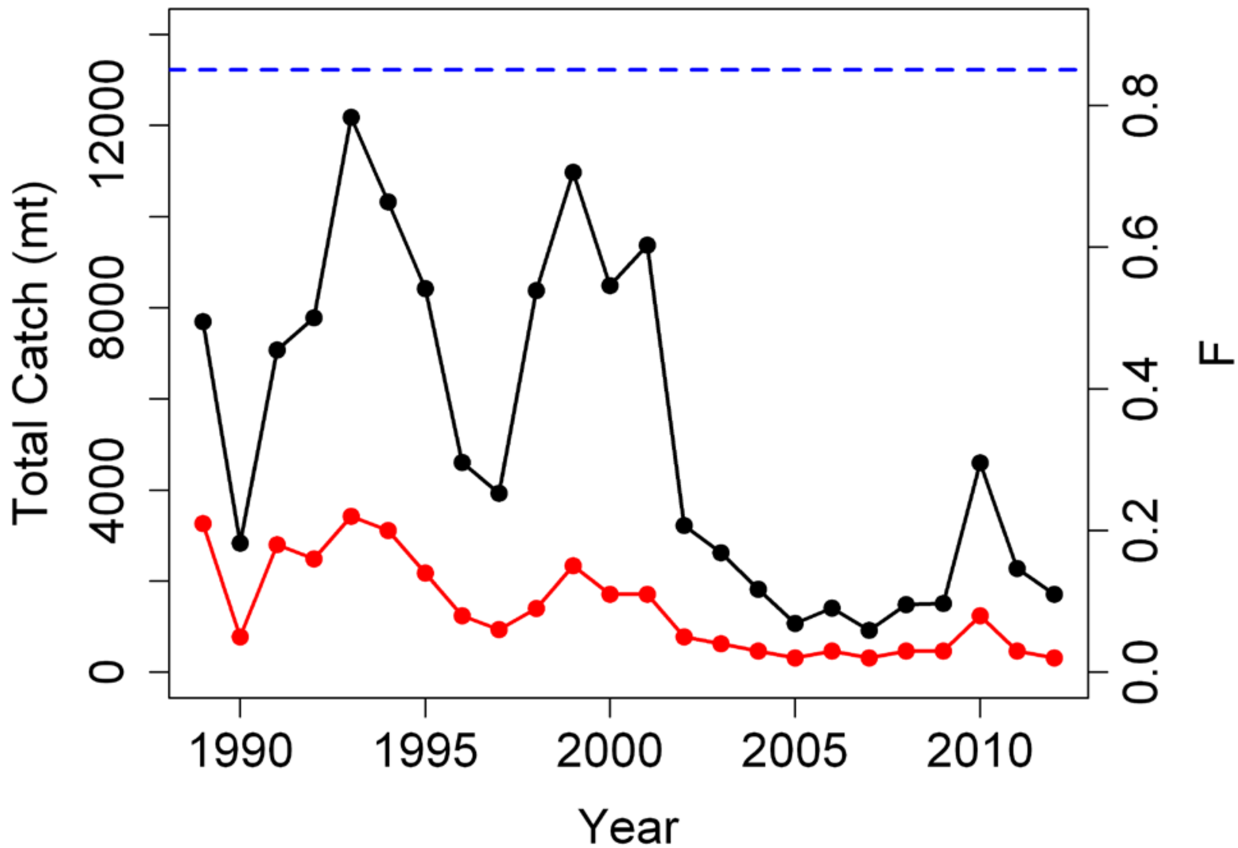


Figure A6.1. Butterfish total catch (mt) and fishing mortality (F). Dashed blue line is the 2014 SAW/SARC F_{MSY} proxy.

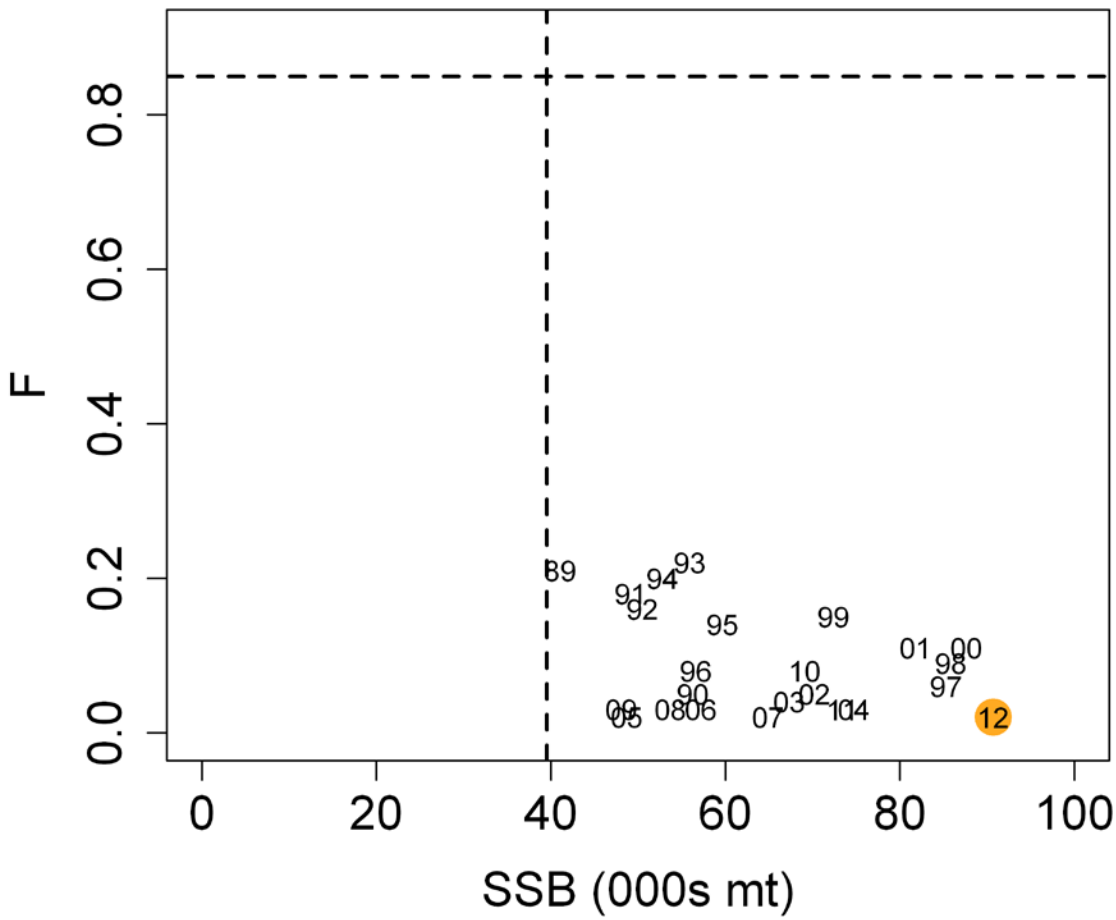


Figure A6.2. Butterfish spawning stock biomass (SSB) and fishing mortality (F) relative to the 2014 SAW/SARC biological reference points SSB_{MSY} proxy = 39,515 mt and F_{MSY} proxy = 0.85.

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.

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.

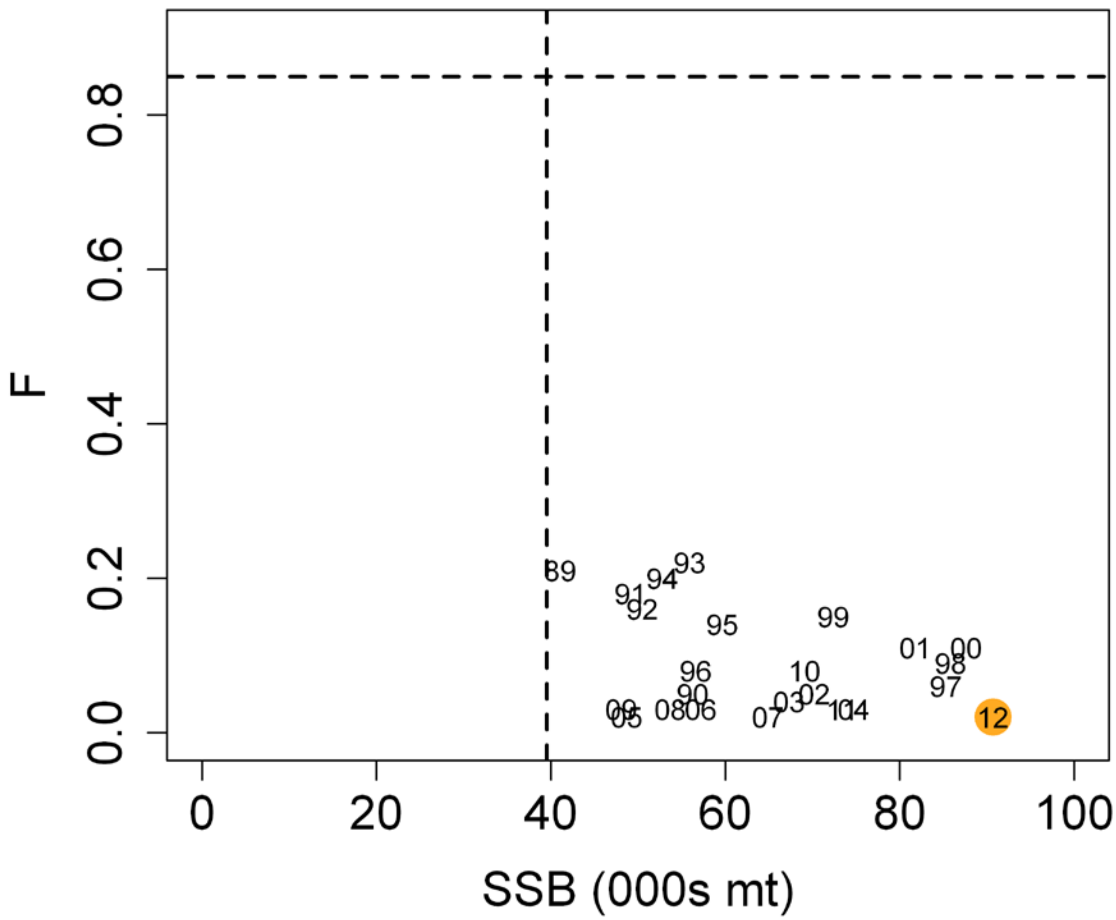


Figure A7.1. Butterfish spawning stock biomass (SSB) and fishing mortality (F) relative to the 2014 SAW/SARC biological reference points SSB_{MSY} proxy = 39,515 mt and F_{MSY} proxy = 0.85.

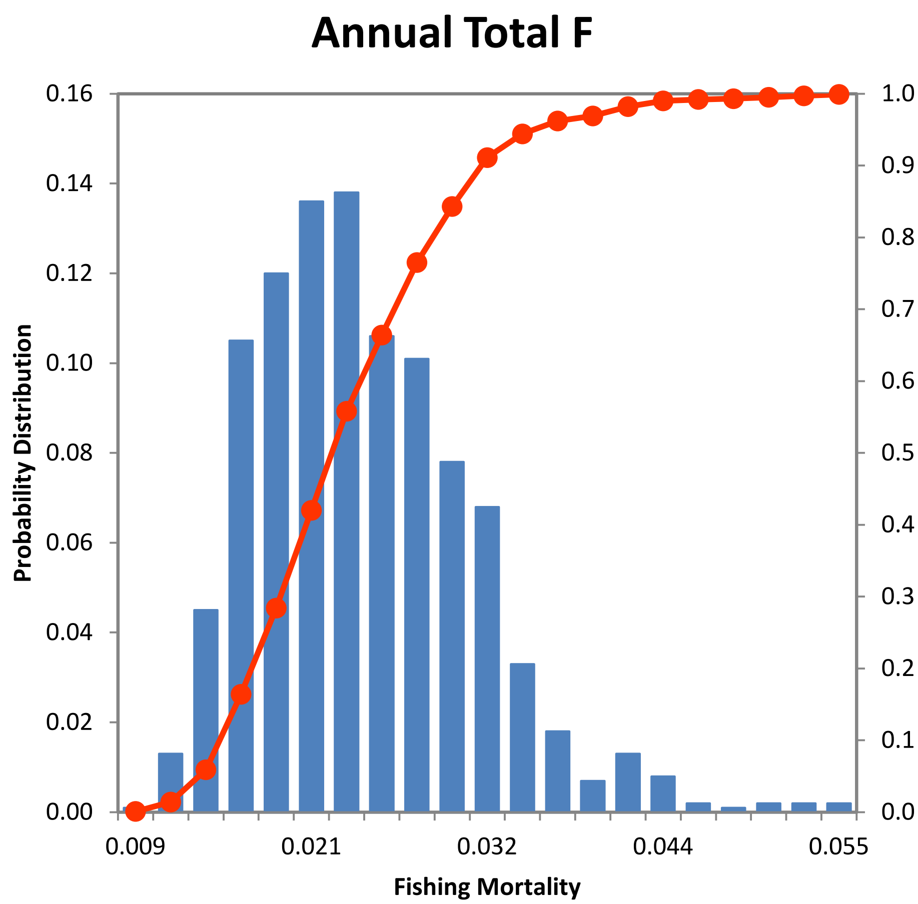


Figure A7.2. Markov Chain Monte Carlo distribution plots for annual total F

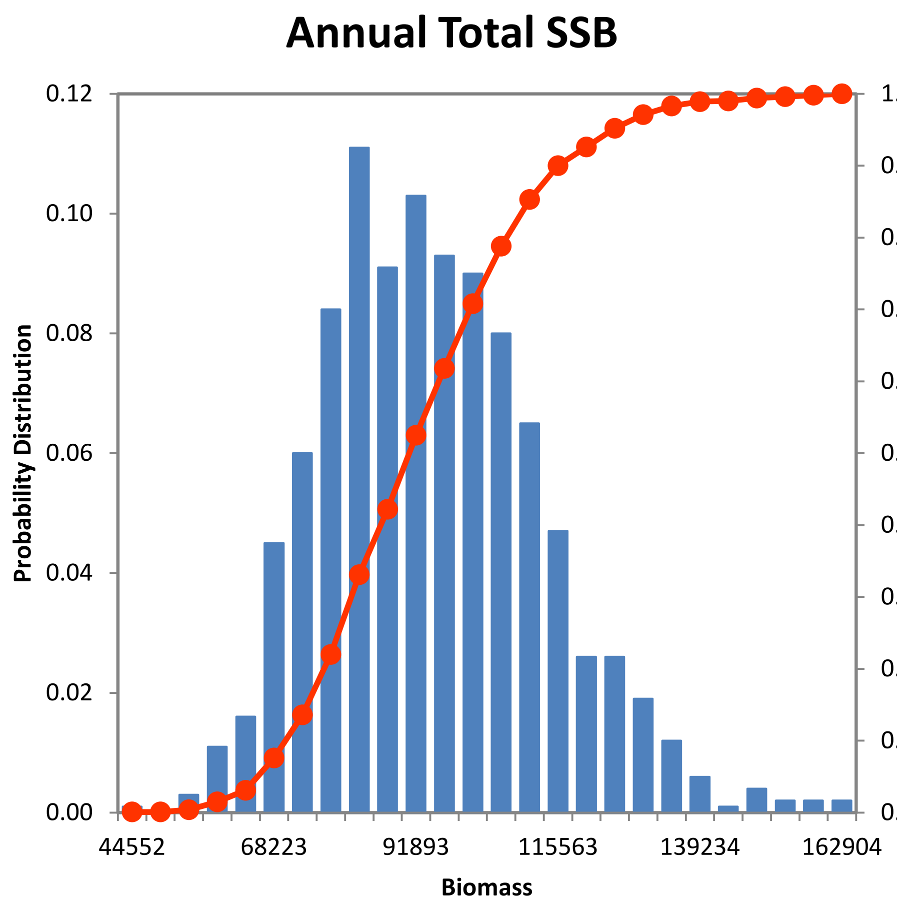


Figure A7.3. Markov Chain Monte Carlo distribution plots for annual total SSB.

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.

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

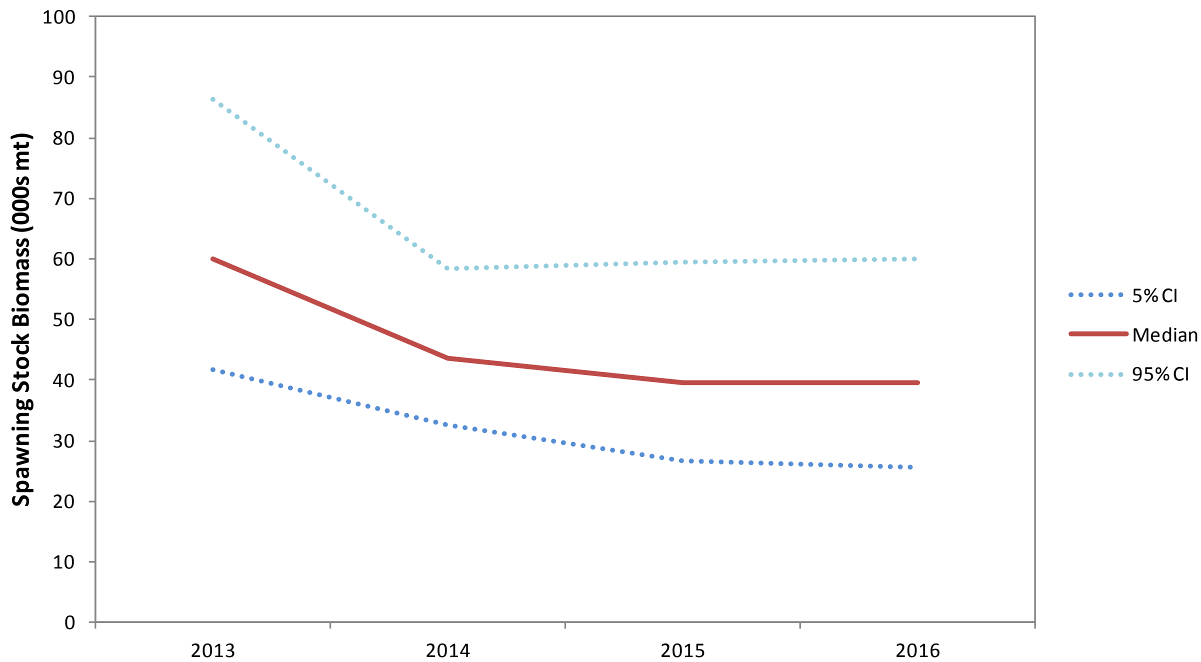


Figure A8.1. Projection of median butterfish spawning stock biomass (000s mt) $\pm$ 95% confidence interval with status quo F in 2013 and F_{MSY} in 2014 and beyond.

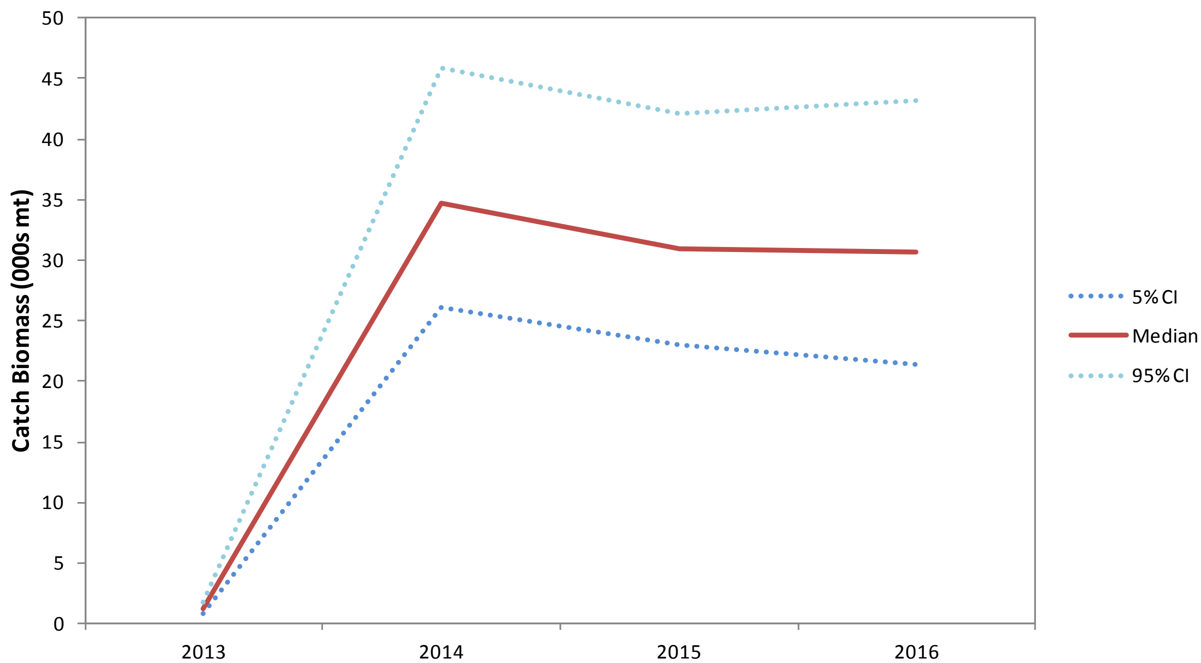


Figure A8.2. Projection of median butterfish catch (000s mt) $\pm$ 95% confidence interval with status quo F in 2013 and F_{MSY} in 2014 and beyond.

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:

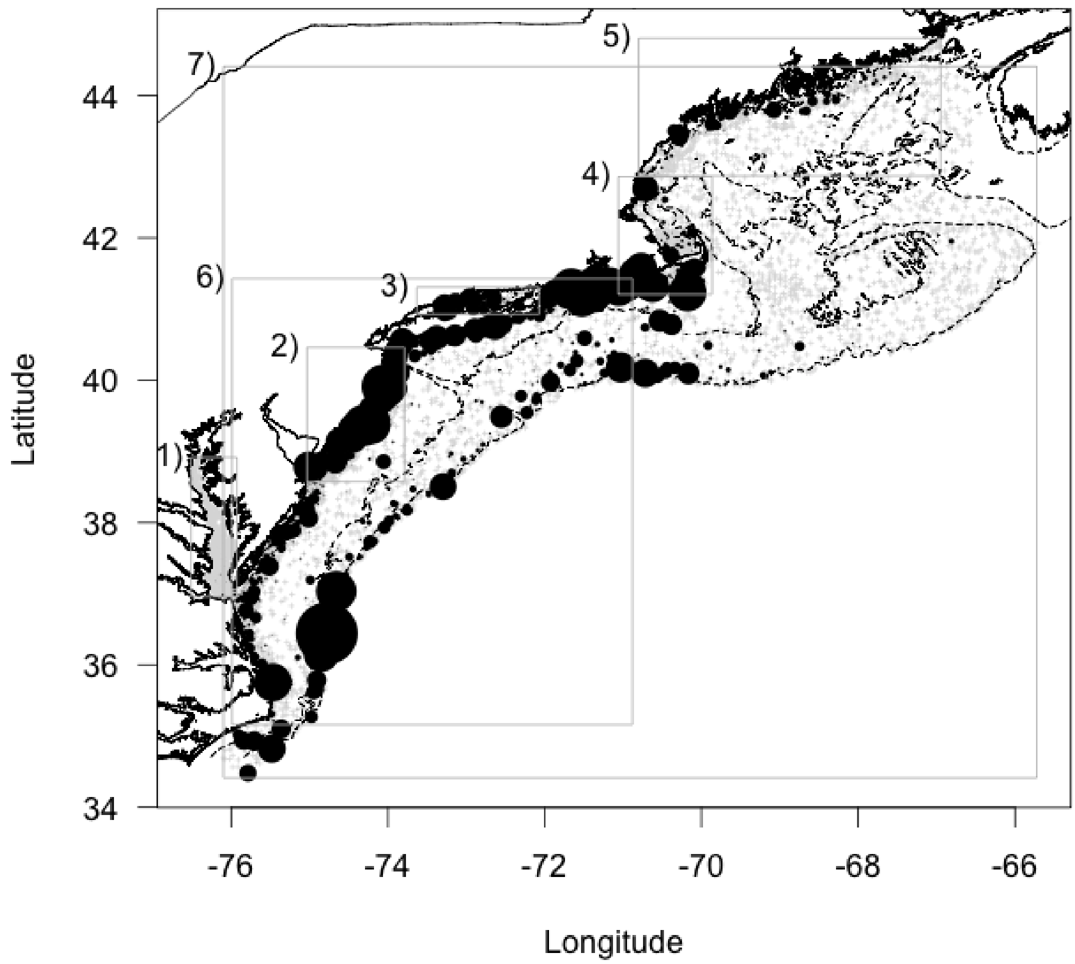
1. Encourage field experiments to examine efficiency and catchability of survey gear for the benefit of improving assessment models. Particular emphasis should be on the catchability of the Bigelow net configuration.
2. Explore the possibility of spawning south of Cape Hatteras, NC and potential contribution 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 Appendices

Butterfish Appendix 1. 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



Appendix 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} = offset(log[swept area km^2]) + s(Bottom water temperature) + $Survey_j$ +Season+ 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.

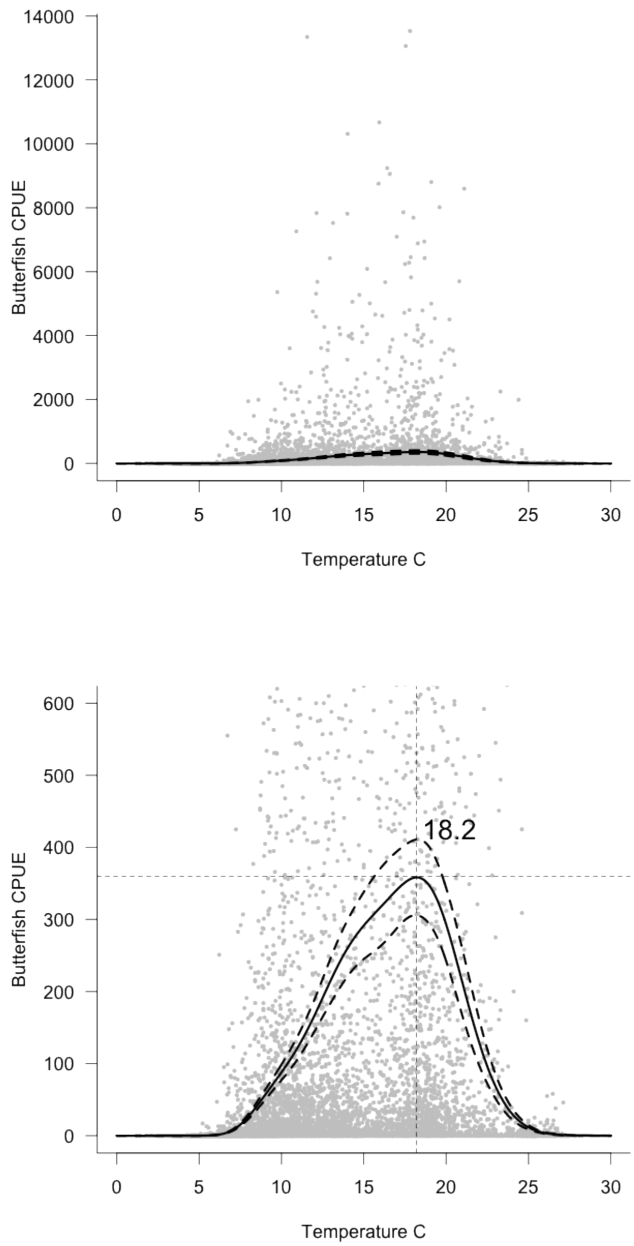
Although GAM indicated the model with the survey dependent temperature response had higher explanatory power (m8), response curves were only slightly different across the range of temperatures with positive effects on catch (not shown). Instead the strongest survey effects were associated with the northernmost 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.

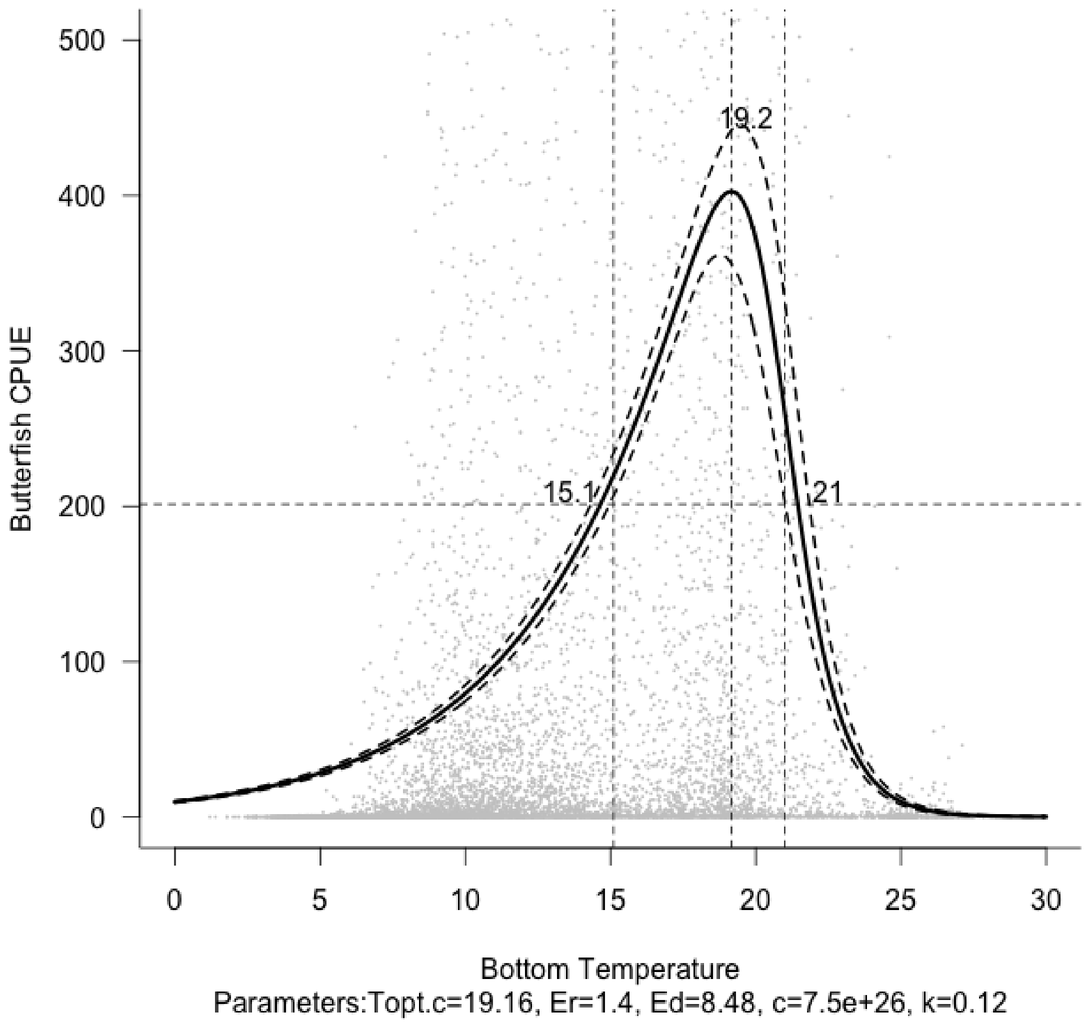
Appendix Table 2a. Generalized additive models to determine effects of survey, year, and season on the response of butterfish catch to bottom water temperature in the 2008-2012 calibration data used to develop the parametric niche model. Number of butterfish per tow was the dependent variable. All models 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



Appendix 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)



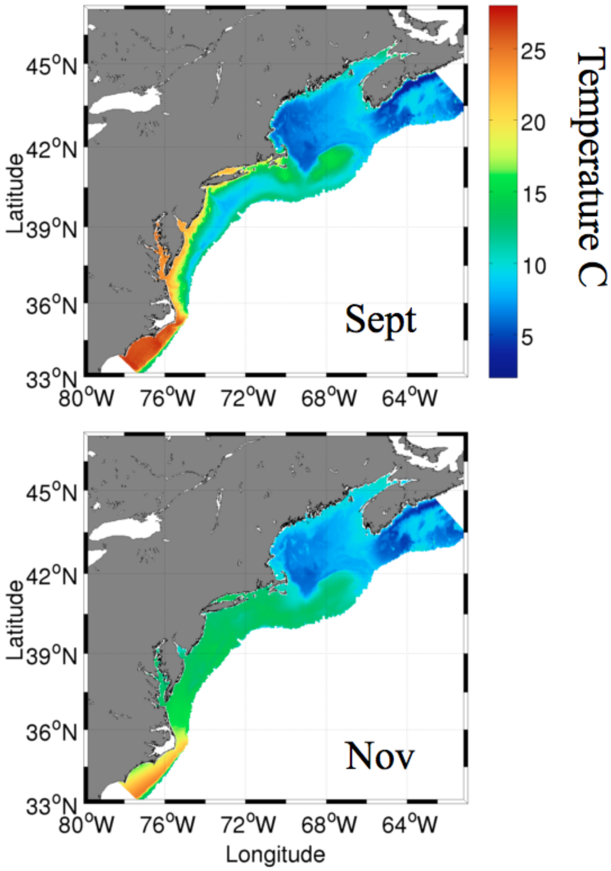
Appendix Figure 4. Plot of the thermal response curve for Atlantic butterfish constructed by estimating parameters of the Johnson and Lewin equation (solid black line) minimizing negative binomial likelihood using standardized butterfish catch as the response (h) and bottom water temperature as the independent 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

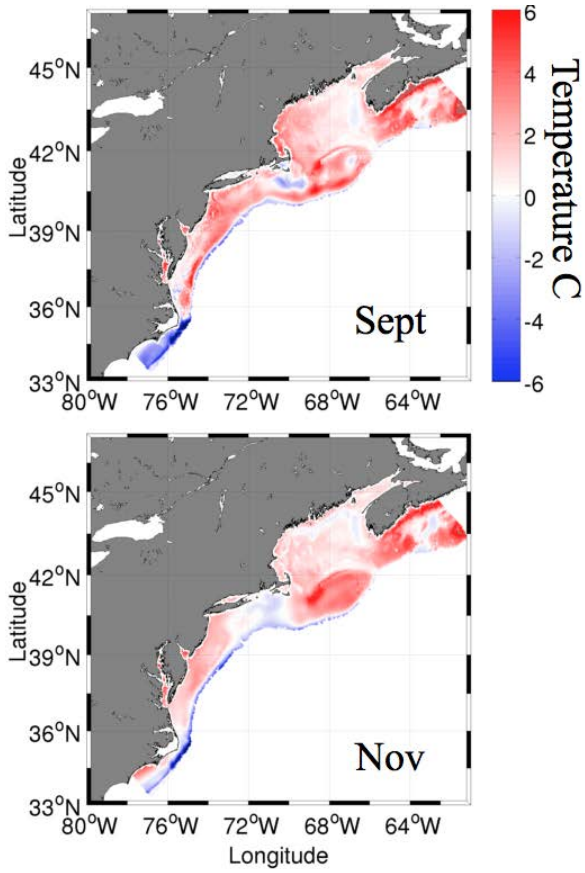
Methods

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.



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



Appendix 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.

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

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

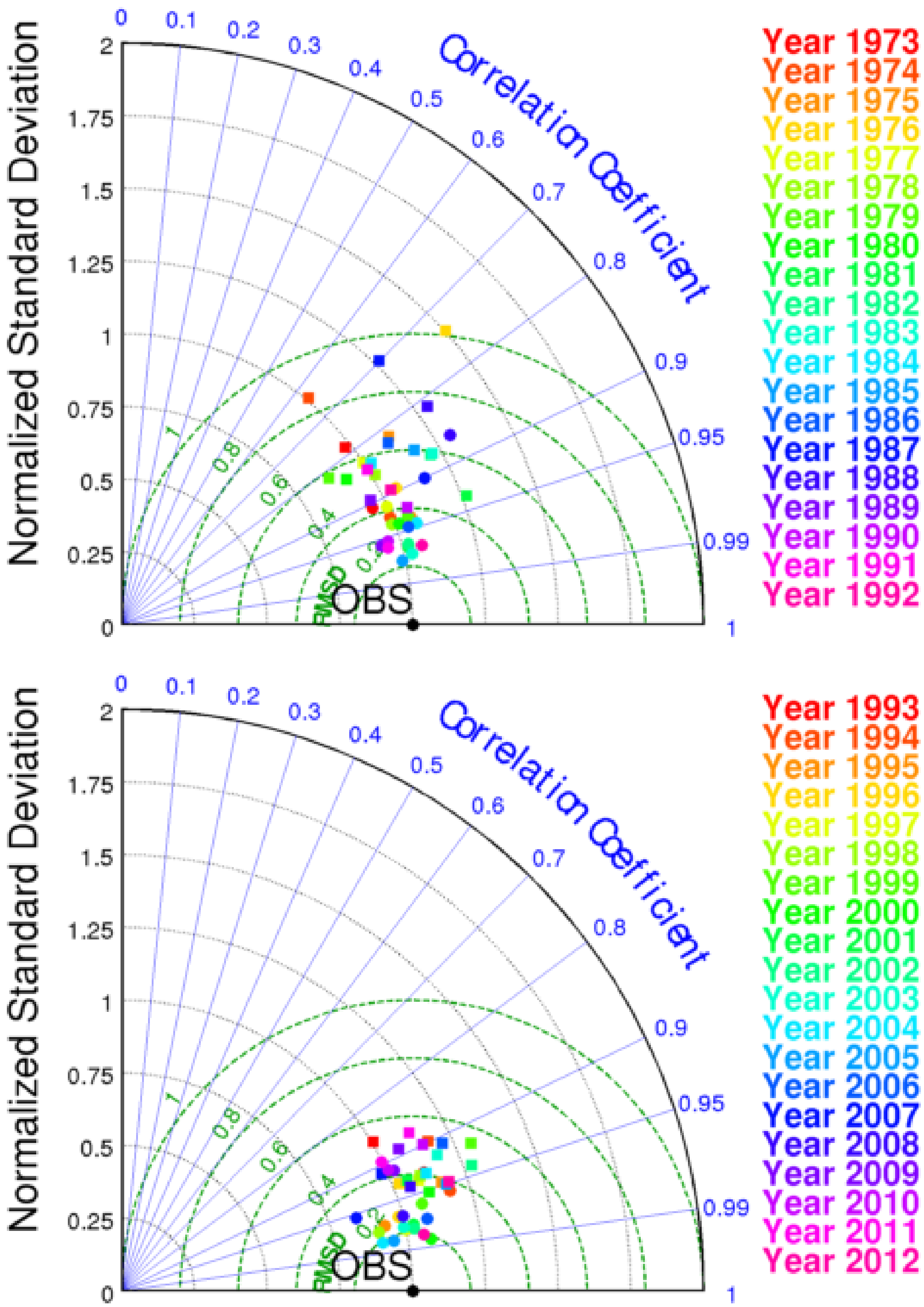
$$\boldsymbol{\sigma_o} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(o_i - \bar{o})^2}$$

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

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.



Appendix 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.

Appendix 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

Appendix 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

Appendix 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

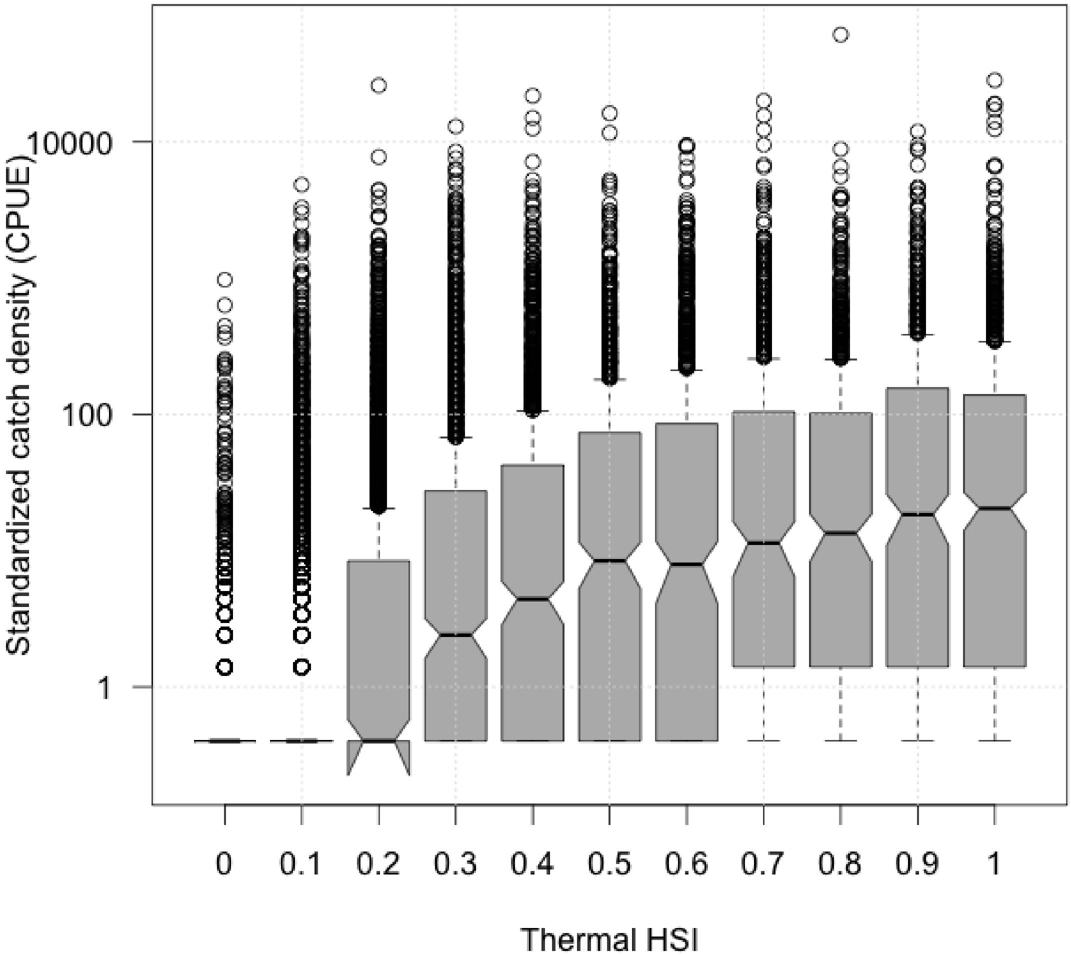
1987	8.48	8.66	10.85	8.51	2.89	2.93	3.27	2.70	2.70	1.21	1.04
1988	5.87	6.31	8.82	5.58	1.42	1.77	2.32	1.49	3.22	0.72	0.84
1989	9.27	8.76	12.21	9.06	3.79	3.45	3.85	3.46	3.26	1.97	1.33
1990	8.77	7.88	12.36	7.61	3.33	3.55	4.09	3.38	3.95	1.50	1.72
1991	9.87	7.47	12.25	7.47	4.71	3.25	4.69	3.48	2.87	3.24	3.10
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

Appendix 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).

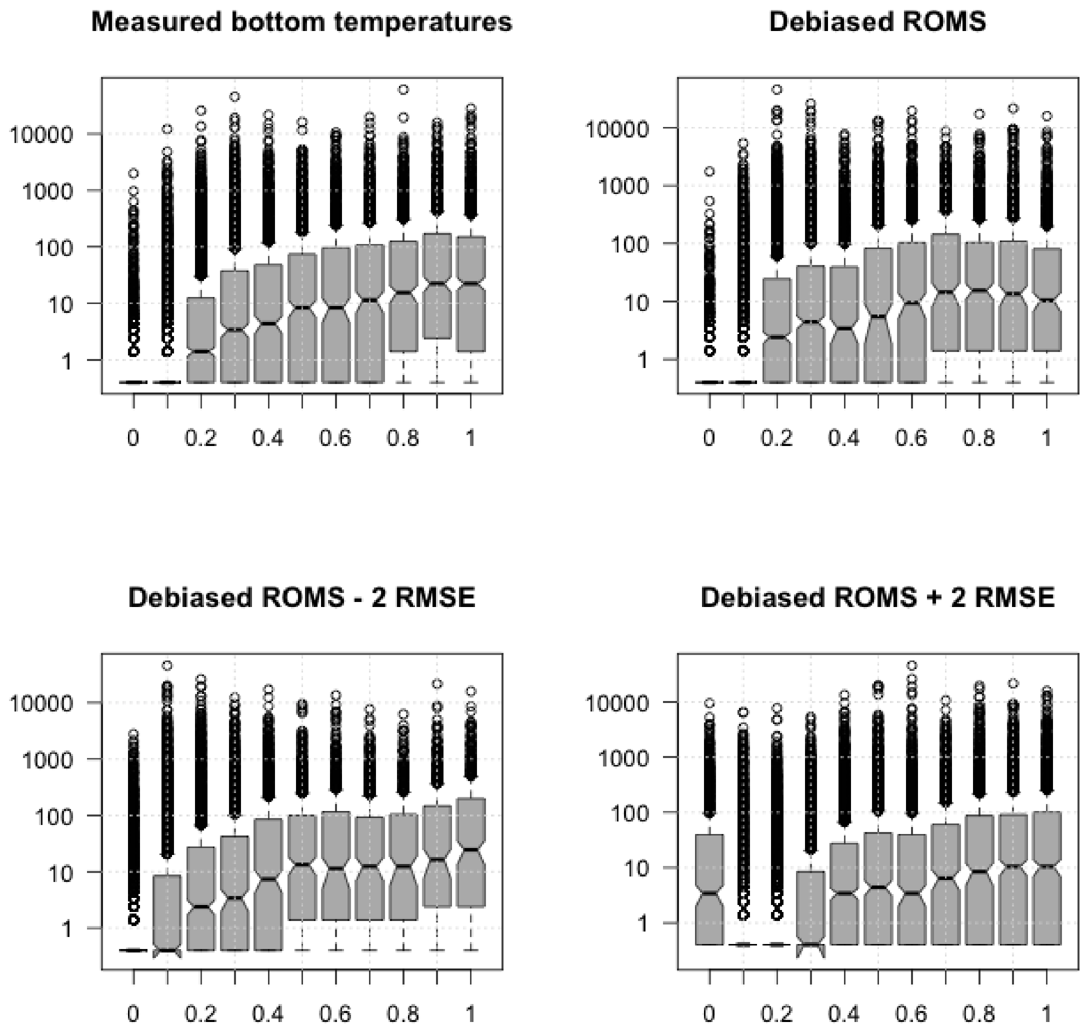
Year	Mean				Standard Deviation				RMSE		
	OBS	MOCHA	Model	Mode l SPA	OBS	MOCHA	Model	Model SPA	Mode l	MOCHA	Model SPA
1973	7.77	7.16	8.32	7.06	2.95	2.23	1.56	2.19	2.37	1.57	1.63
1974	8.12	7.18	8.42	7.18	2.75	2.42	1.82	2.47	2.63	1.59	1.64
1975	7.3	6.92	8.77	6.91	2.39	1.99	1.87	1.99	3.05	1.3	1.32
1976	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)



Appendix 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.



Appendix 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

Appendix 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)

Appendix 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)

Appendix 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)

Appendix 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)

Appendix 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)

Appendix 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)

Liturature cited:

Aarts, G., J. Fieberg, S. Brasseur, and J. Matthiopoulos. 2013. Quantifying the effect of habitat availability on species distributions. Journal of Animal Ecology DOI:10.1111/1365-2656.12061

Bacheler, N. M., L. Ciannelli, K. M. Bailey, and V. Bartolino. 2012. Do walleye pollock exhibit flexibility in where or when they spawn based on variability in water temperature? Deep Sea Research Part II: Topical Studies in Oceanography 65:208-216.

Bolker BM (2008) Ecological Models and Data in R. Princeton University Press, Princeton

Carton, J. A., and B. S. Giese. 2008. A reanalysis of ocean climate using Simple Ocean Data Assimilation (SODA). Monthly Weather Review, 136:2999-3017, doi 10.1175/2007MWR1978.1.

Ciannelli, L., K. M. Bailey, K.-S. Chan, A. Belgrano, and N. C. Stenseth. 2005. Climate change causing phase transitions of walleye pollock (Theragra chalcogramma) recruitment dynamics. Proceedings of the Royal Society B: Biological Sciences 272:1735-1743.

Ciannelli, L., P. Fauchald, K. S. Chan, V. N. Agostini, and G. E. Dings. 2008. Spatial fisheries ecology: Recent progress and future prospects. Journal of Marine Systems 71:223-236.

Egbert, G. D., and S. Y. Erofeeva. 2002. Efficient inverse modeling of barotropic ocean tides. Journal of Atmospheric and Oceanic Technology, 19:183-204.

Farr, T. G., P. A. Rosen, E. Caro, R. Crippen, R. Durn, S. Hensley, et al. 2007. The Shuttle Radar Topography Mission. Rev. Geophys., 45, RG2004, doi: 10.1029/2005RG000183.

Fleming, N. E. and J. Wilkin (2010). Mocha: A 3-d climatology of the temperature and salinity of the Mid Atlantic Bight. Eos Trans. AGU 91 (26). Ocean Sci. Meet. Suppl., Abstract PO35G-08.

Guisan, A., J. Edwards, Thomas C. and T. Hastie. 2002. Generalized linear and generalized additive models in studies of species distributions: setting the scene. Ecological Modeling 157:89-100.

Johnson FH, Lewin I (1946) The growth rate of E. coli in relation to temperature, quinine and coenzyme. Journal of Cellular and Comparative Physiology 28:47-75

Kang D, Curchitser EN (2013) Gulf Stream eddy characteristics in a high-resolution ocean model. Journal of Geophysical Research: Oceans 118:4474-4487

Lande R, Engen S, Sæther B-E (2003) Stochastic Population Dynamics in Ecology and Conservation. Oxford University Press, Oxford, UK.

Large, W. G., & S. G. Yeager. 2009. The global climatology of an interannually varying air-sea flux data set. Clim Dyn 33: 341-364.

Manderson J, Palamara L, Kohut J, Oliver MJ (2011) Ocean observatory data is useful for regional habitat modeling of species with different vertical habitat preferences. Marine Ecology Progress Series 438:1-17

Richardson, 2014. Empirical analysis of Q

Shchepetkin, A. F., and J. C. McWilliams. 2003: A method for computing horizontal pressure-gradient force in an oceanic model with a nonaligned vertical coordinate, J. Geophys. Res., 108 (C3), 3090, doi:10.1029/2001JC001047.

Shchepetkin, A. F., and J. C. McWilliams. 2005: The Regional Ocean Modeling System: A splitexplicit, free-surface, topography following coordinates ocean model, Ocean Modelling, 9:347-404.

Swartzman, G., C. Huang, and S. Kaluzny. 1992. Spatial analysis of Bering Sea groundfish survey data using generalized additive models. Canadian Journal of Fisheries and Aquatic Sciences 49:1366-1378

Taylor, K. E. (2001). Summarizing multiple aspects of model performance in a single diagram. J. Geophys. Res. 106 (D7), 7183–7192

Venables, W. N., and B. D. Ripley. 2002. Modern applied statistics with S-Plus., Springer-Verlag, New York.

Wood, S. 2006. Generalized Additive Models: An Introduction with R, Chapman & Hall.

Zuur, A. F., E. N. Ieno, N. Walker, A. A. Saveliev, and A. B. Smith. 2009. Mixed effects models and extensions in ecology with R, Springer, New York.

Zuur, A. F., A. A. Saveliev, and E. N. Leno. 2012. Zero inflated models and generalized linear mixed models with R, Highlands Statistics LTD, Newburgh, UK.

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

Tim Miller, Charles Adams, and Paul Rago
Northeast Fisheries Science Center
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.

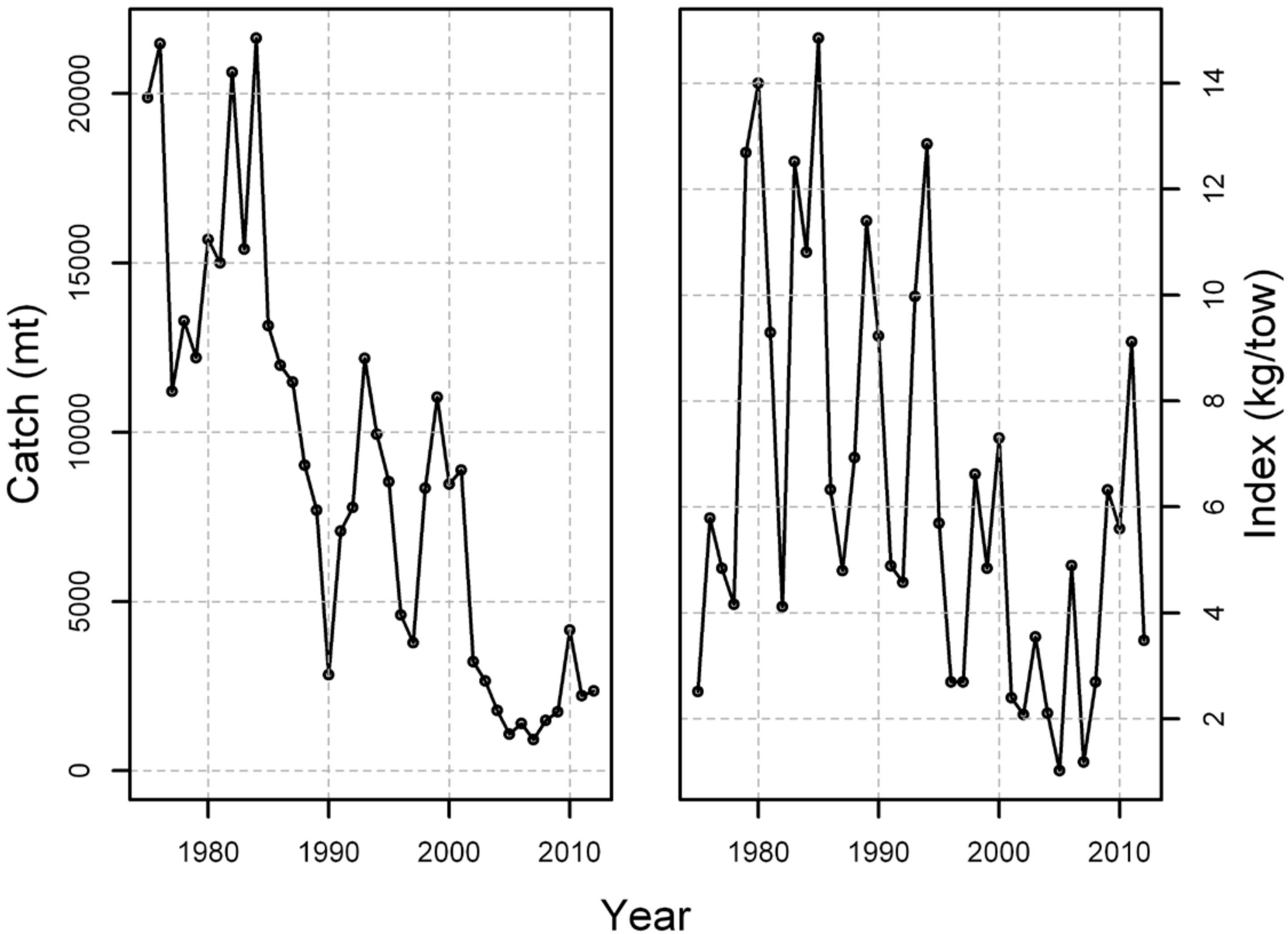


Figure 1. Annual total catches and fall NEFSC biomass indices for Atlantic butterfish.

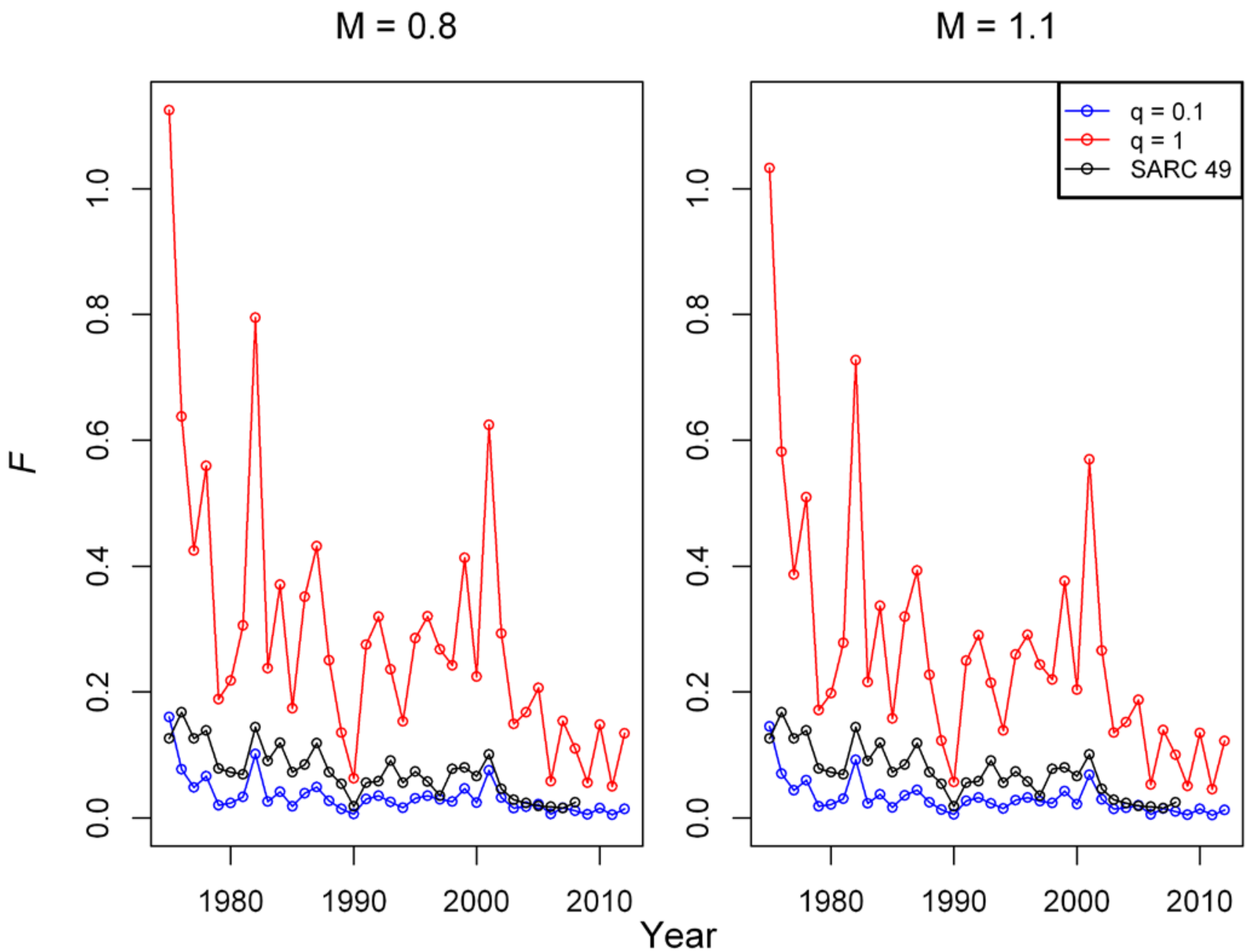


Figure 2. Implied annual fishing mortality rates under two different survey efficiency and natural mortality assumptions and the fishing mortality rate estimates from SARC 49 (NEFSC 2010). See Equation 3.

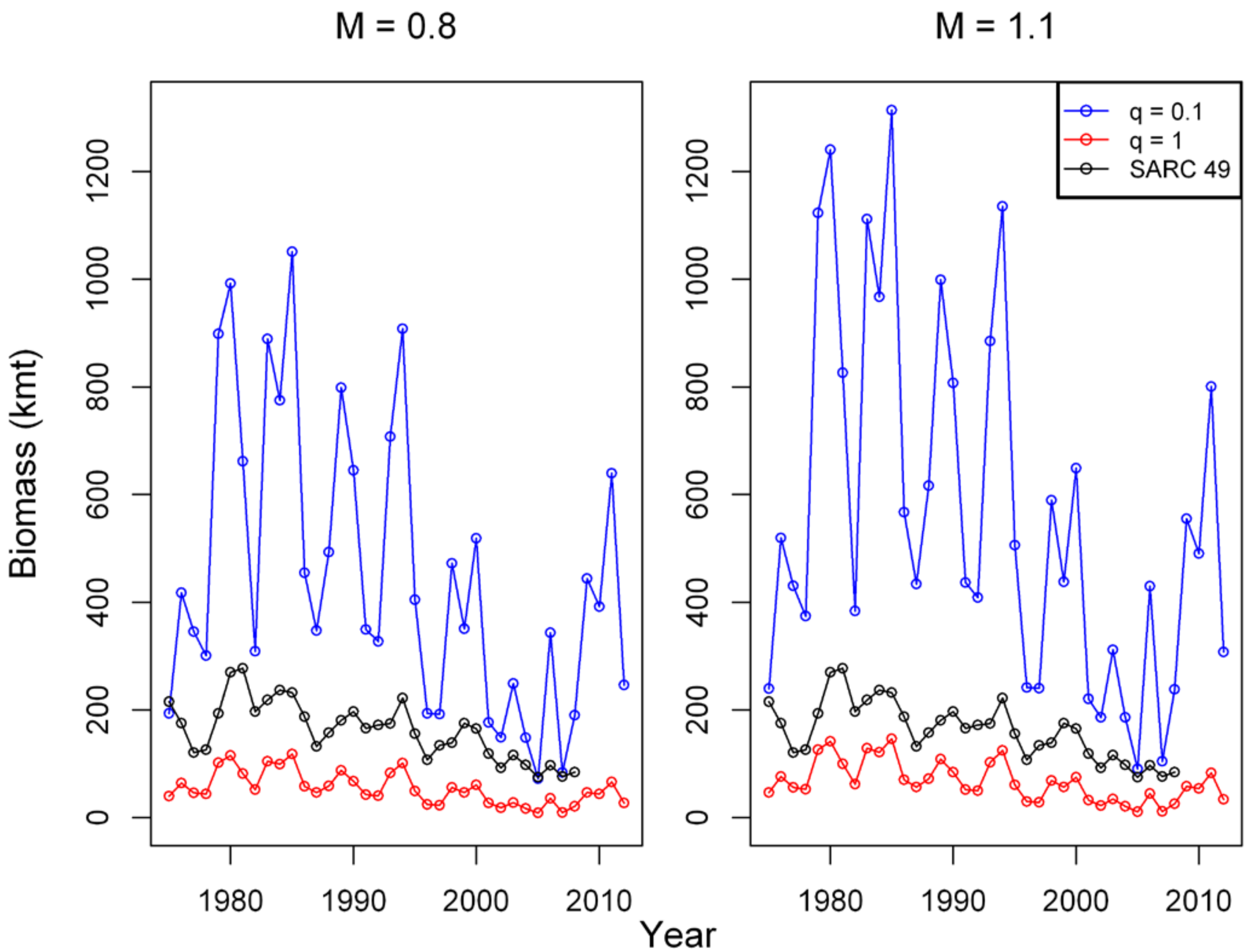


Figure 3. Implied annual January 1 butterfish stock biomass under 2 different survey efficiency and natural mortality assumptions and the biomass estimates from SARC 49 (NEFSC 2010). See Equation 4.

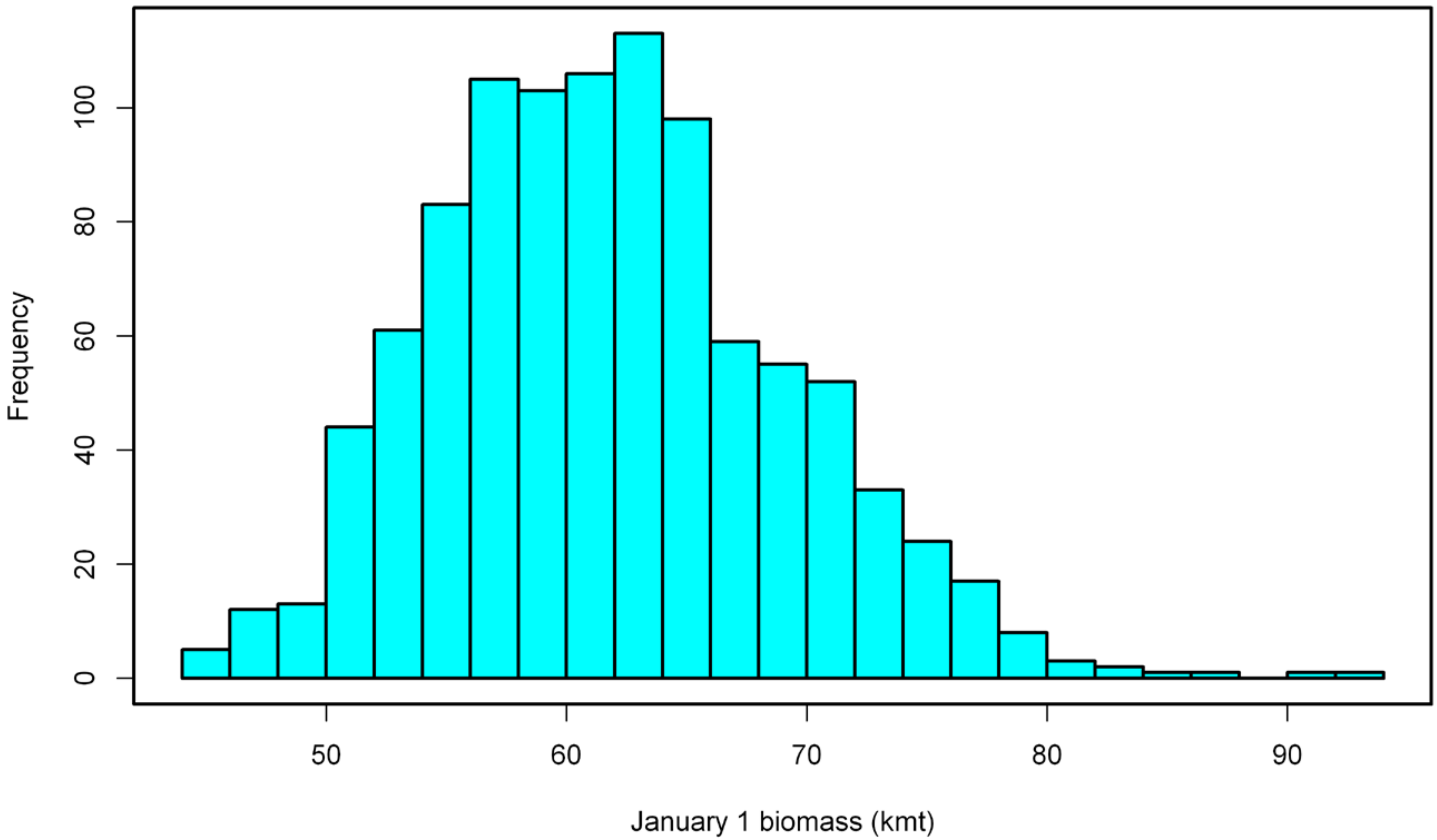


Figure 4. Histogram of 1000 parametric bootstraps of average January 1 biomasses for Atlantic butterfish in 2006-2012.

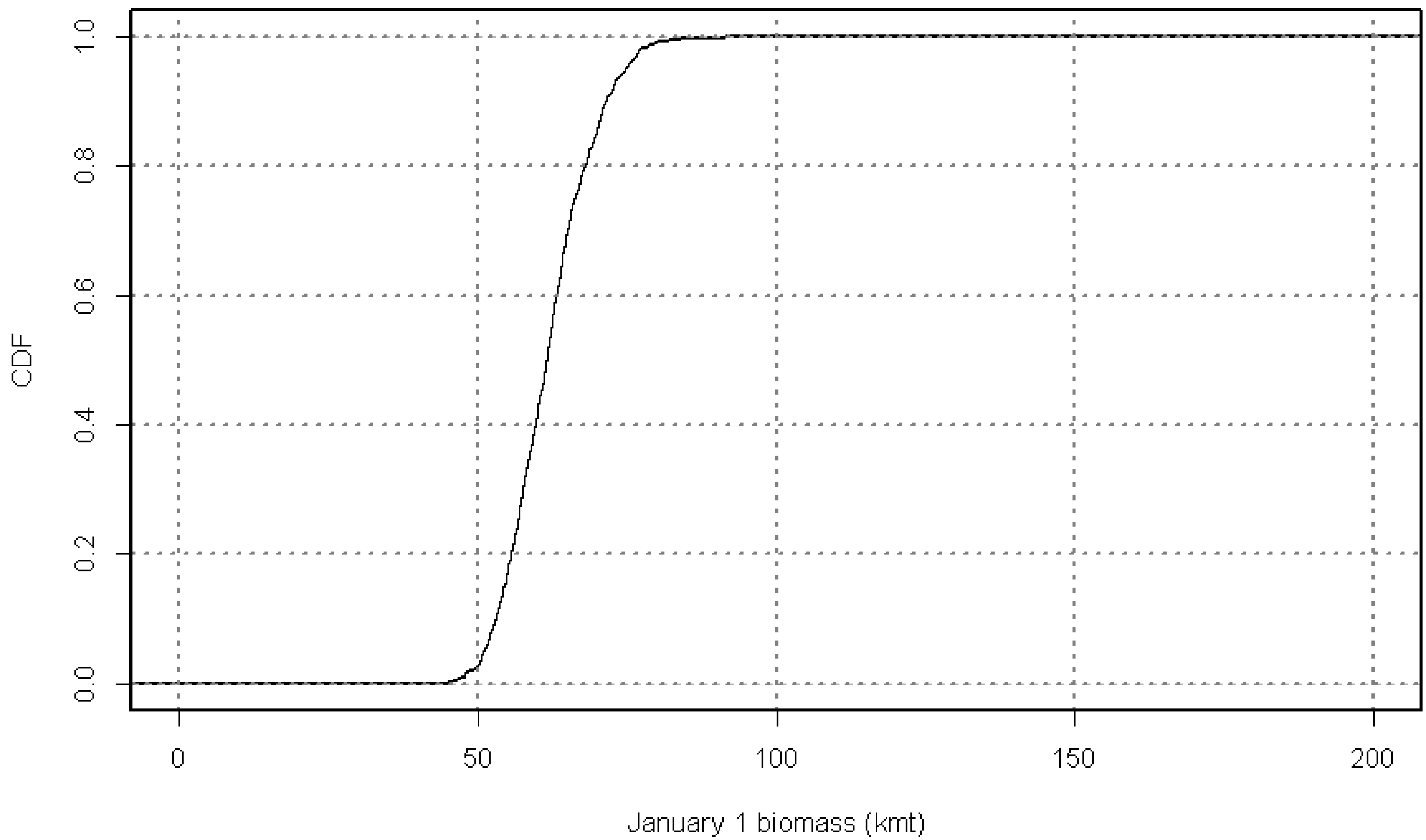


Figure 5. Cumulative distribution of 1000 parametric bootstraps of average January 1 biomasses for Atlantic butterfish in 2006-2012.

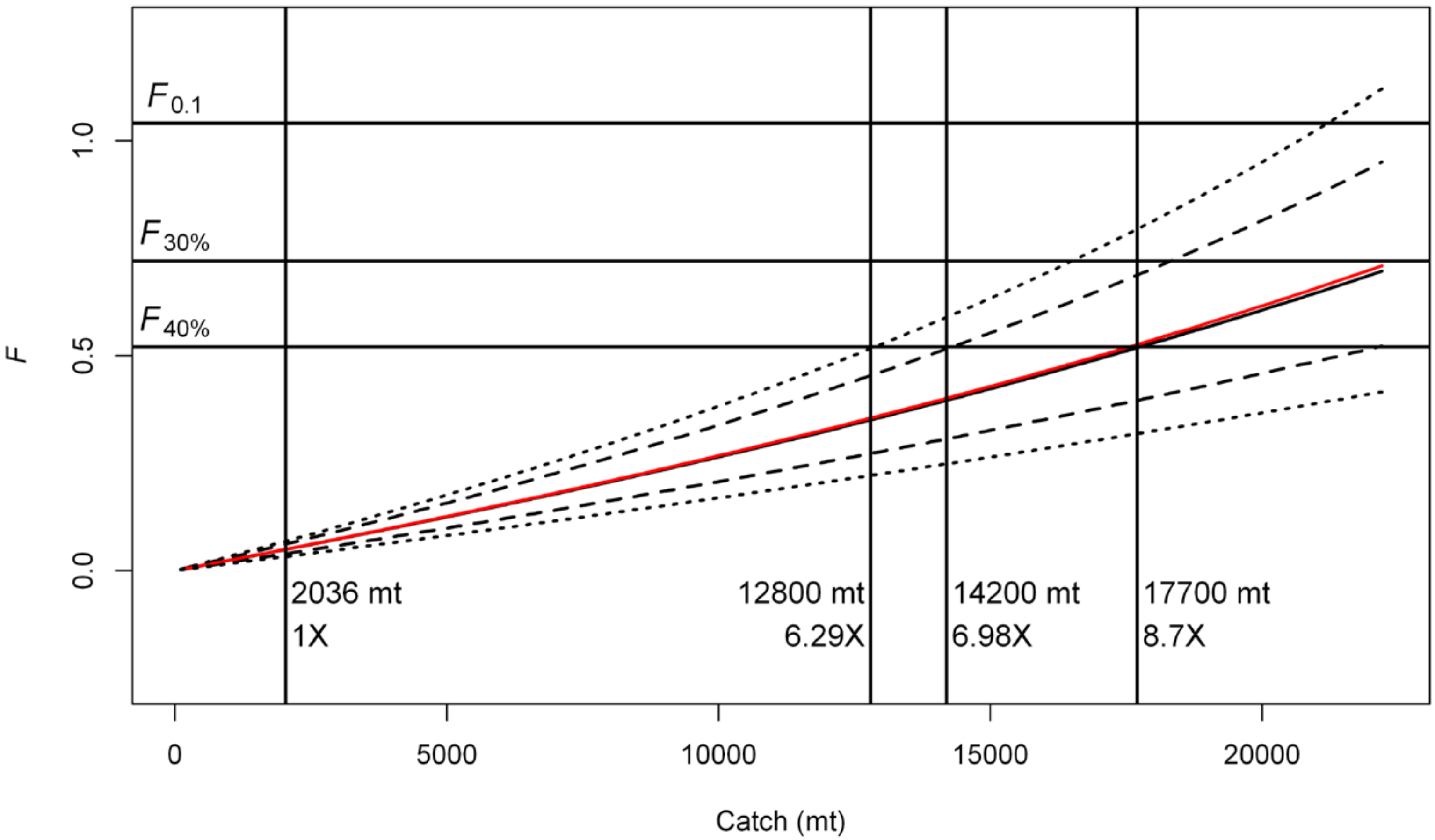


Figure 6. Mean (solid red), median (solid black), 0.025 and 0.975 confidence limits (dashed), minimum and maximum (dotted) of *F* for 1000 bootstraps, based on average 2006-2012 January 1 biomasses. Overfishing reference points are from SARC 49 (NEFSC 2010). Vertical lines are for average 2006-2012 total 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 ($F_{40\%} \approx 2M/3$).

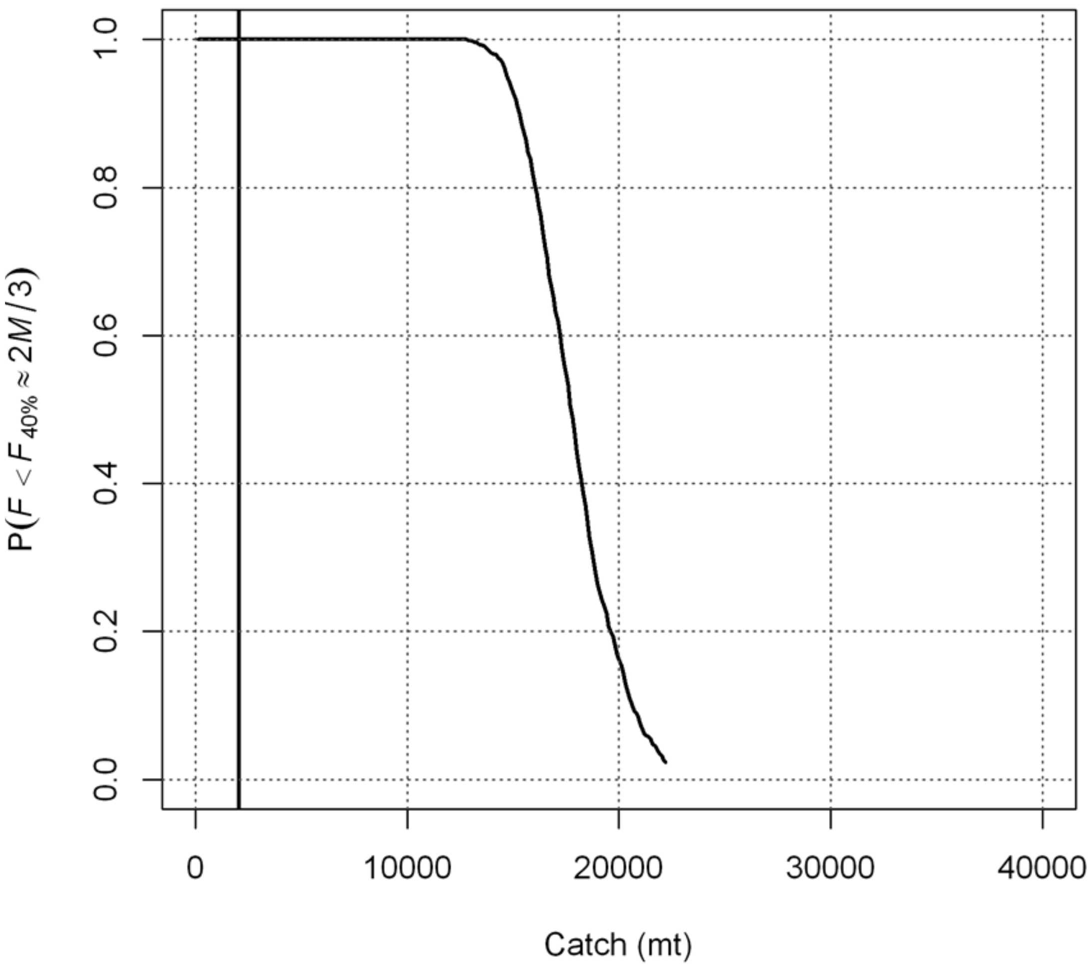


Figure 7. Probability fishing mortality at specified catch is less than $F_{40\%} \approx 2M/3$ based on parametric bootstrap of average 2006-2012 January 1 biomasses. Vertical line represents average annual catch 2006-2012.

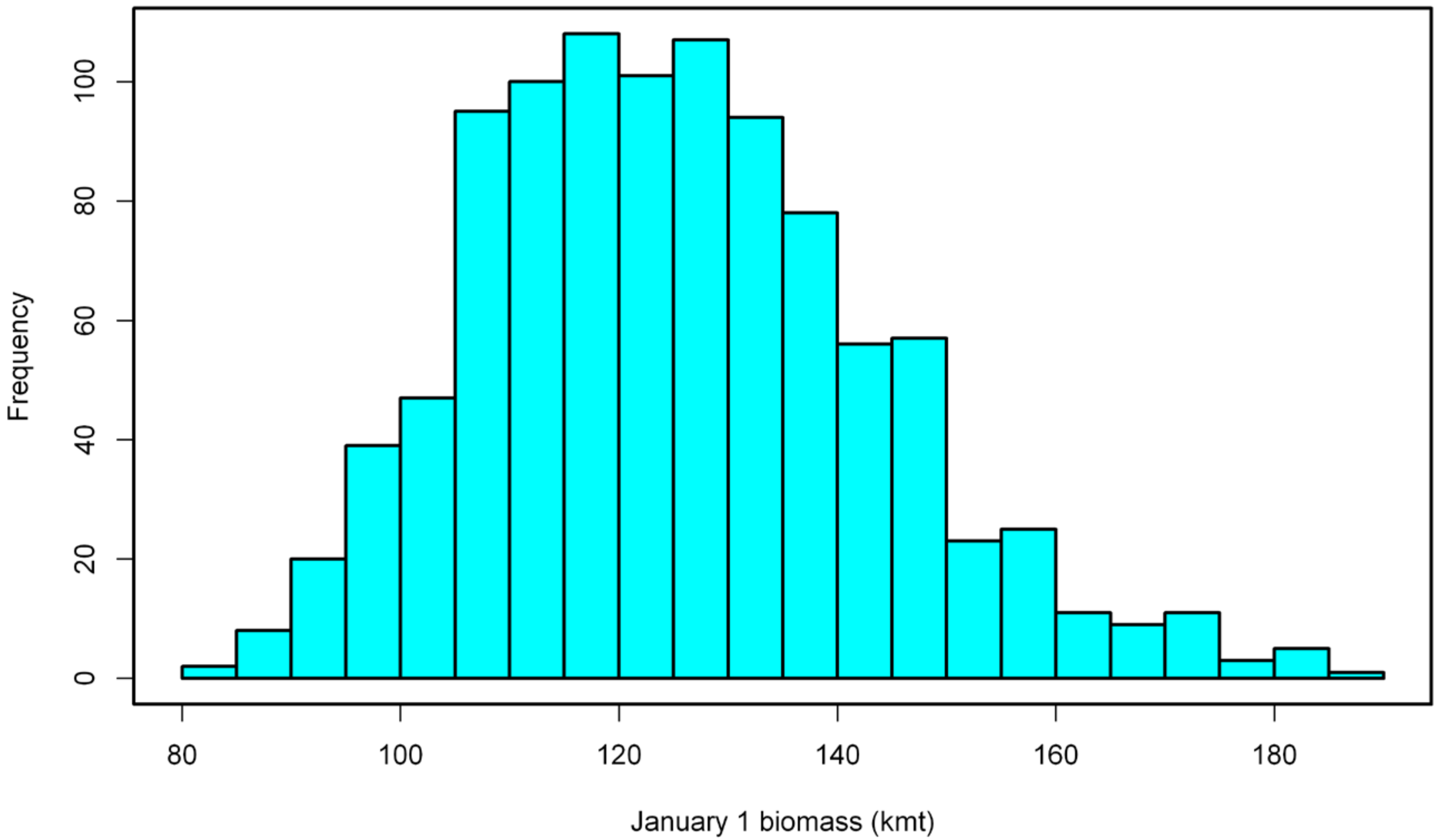


Figure 8. Histogram of 1000 parametric bootstraps of average January 1 biomasses for Atlantic butterfish in 2009-2012.

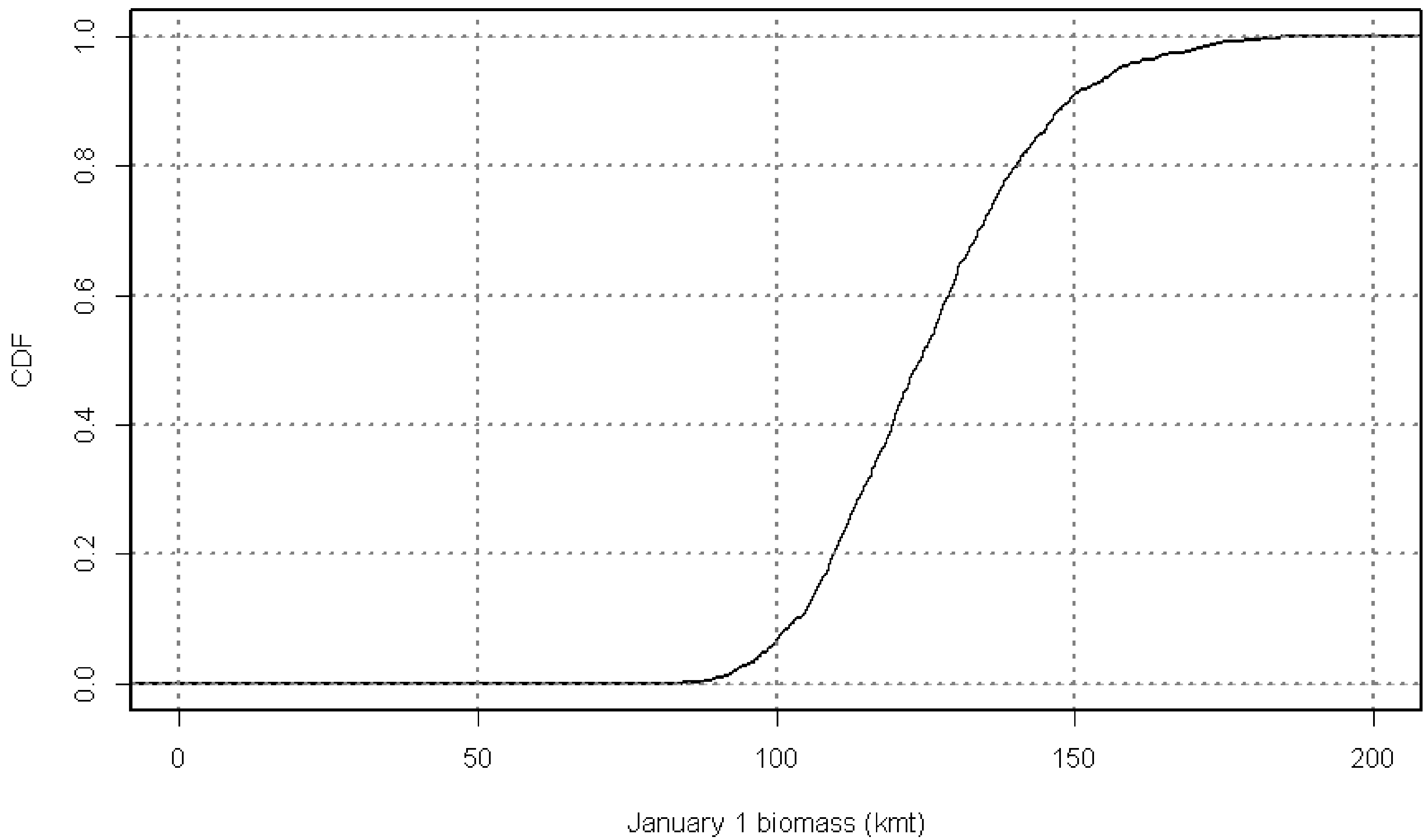


Figure 9. Cumulative distribution of 1000 parametric bootstraps of average January 1 biomasses for Atlantic butterfish in 2009-2012.

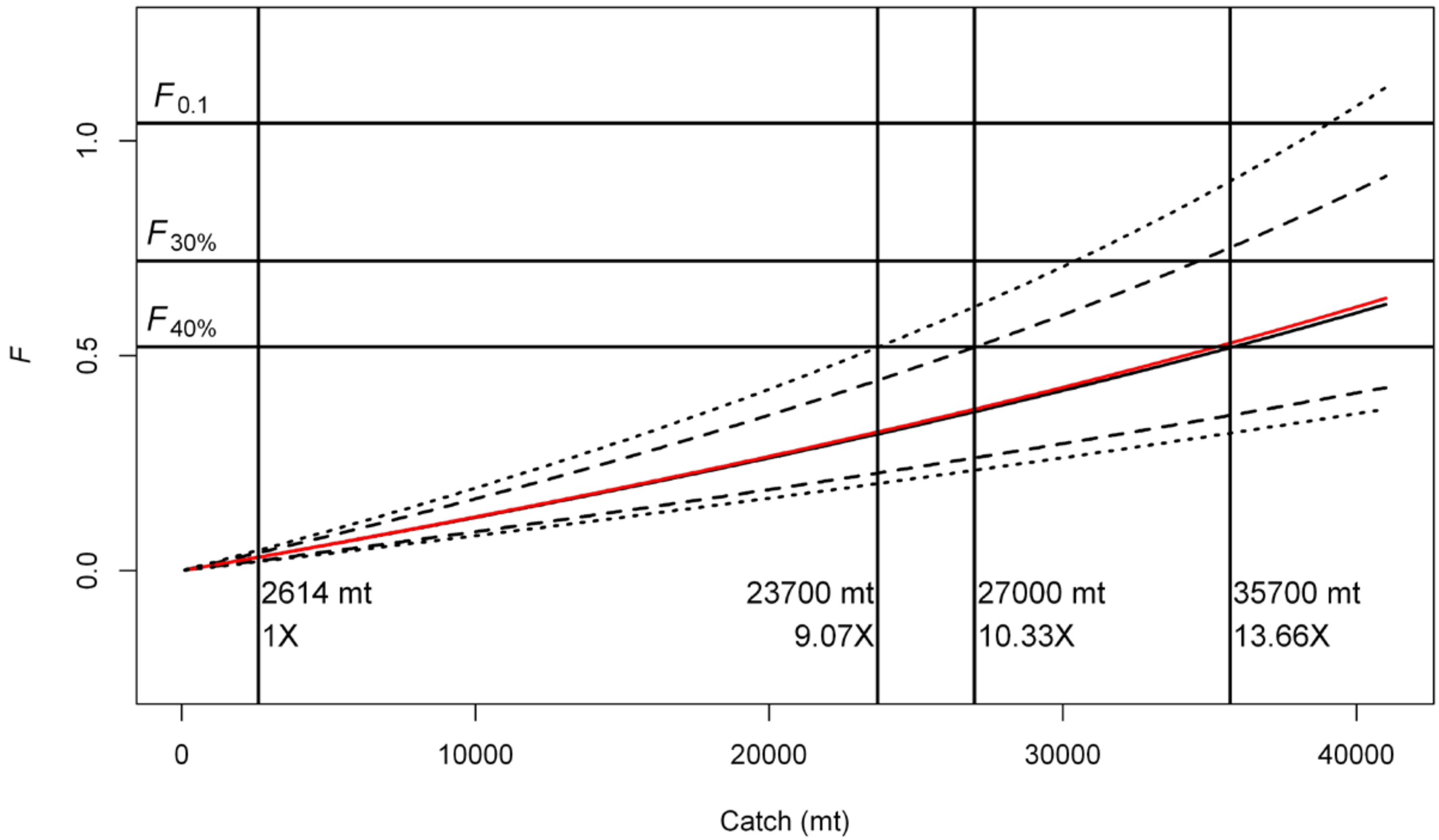


Figure 10. Mean (solid red), median (solid black), 0.025 and 0.975 confidence limits (dashed), minimum and maximum (dotted) of *F* for 1000 bootstraps, based on average 2009-2012 January 1 biomasses, and un-calibrated Bigelow data. Overfishing reference points are from SARC 49 (NEFSC 2010). Vertical 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 ($F_{40\%} \approx 2M/3$).

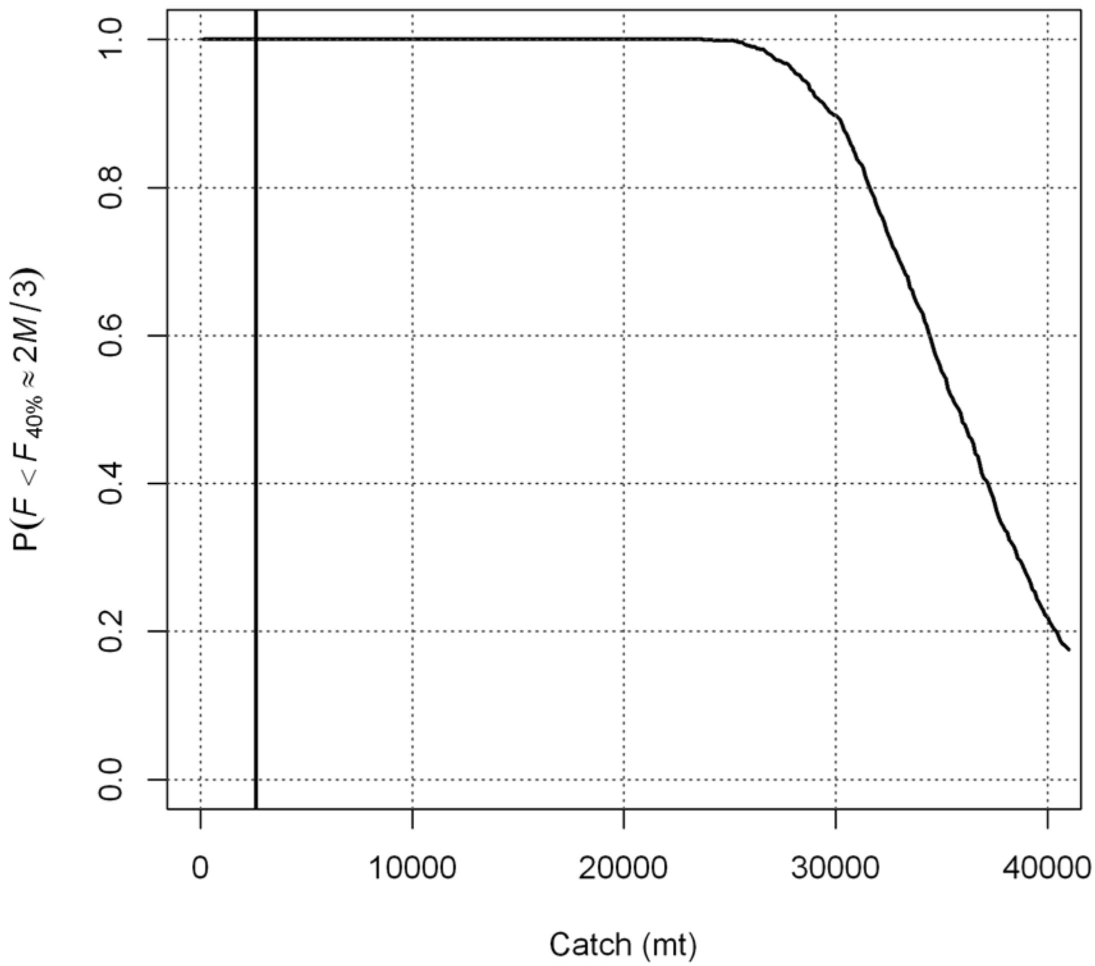


Figure 11. Probability fishing mortality at specified catch is less than $F_{40\%} \approx 2M/3$ based on parametric bootstrap of average 2009-2012 January 1 biomasses. Vertical line represents average annual catch 2009-2012.

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

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

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

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

Appendix A. Length composition of landings and discards from observer data.

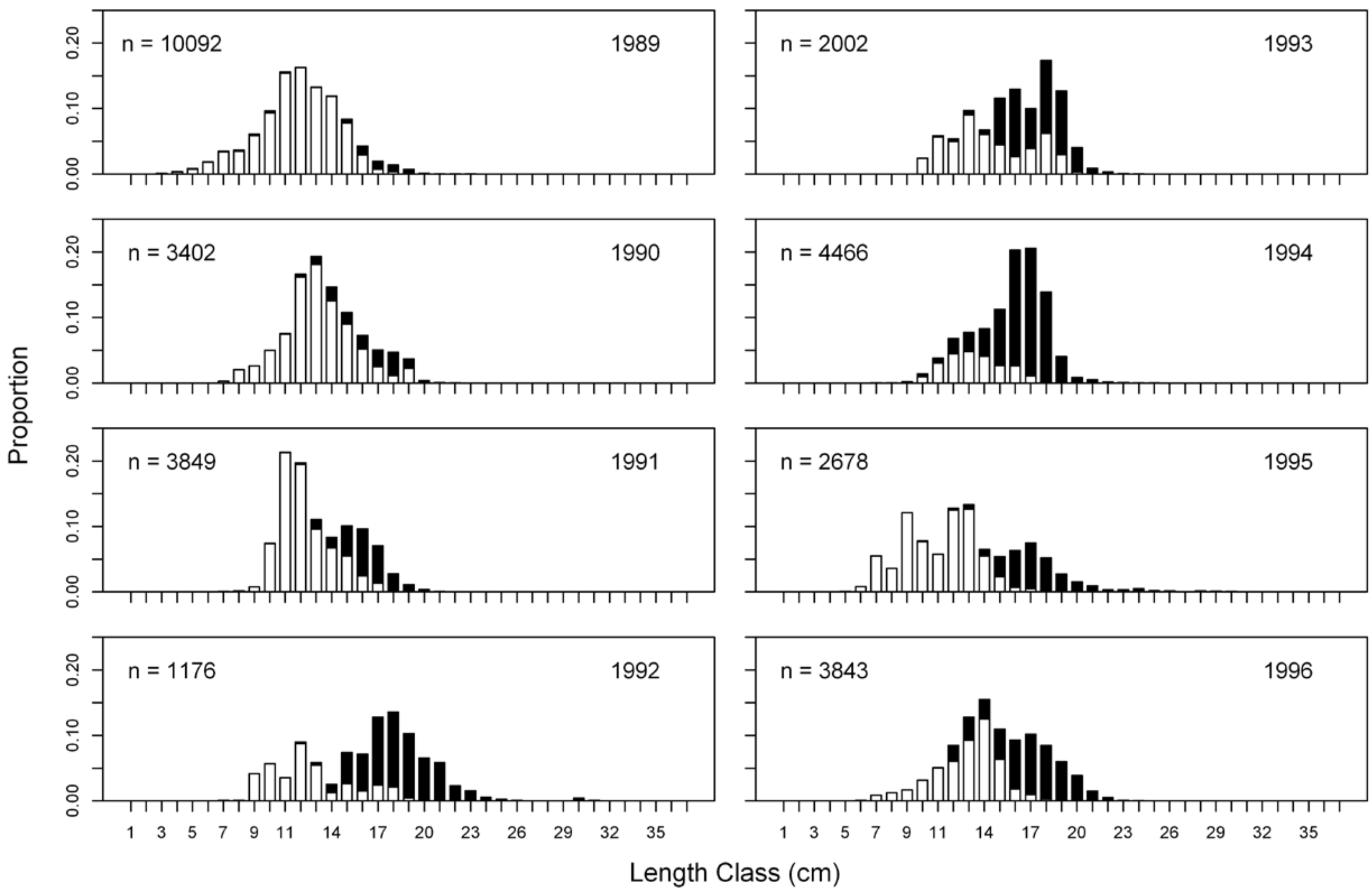


Figure A1. Length composition for NMFS Observer Program for butterfish between 1989 and 1996 with kept fish in black and discard in white. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

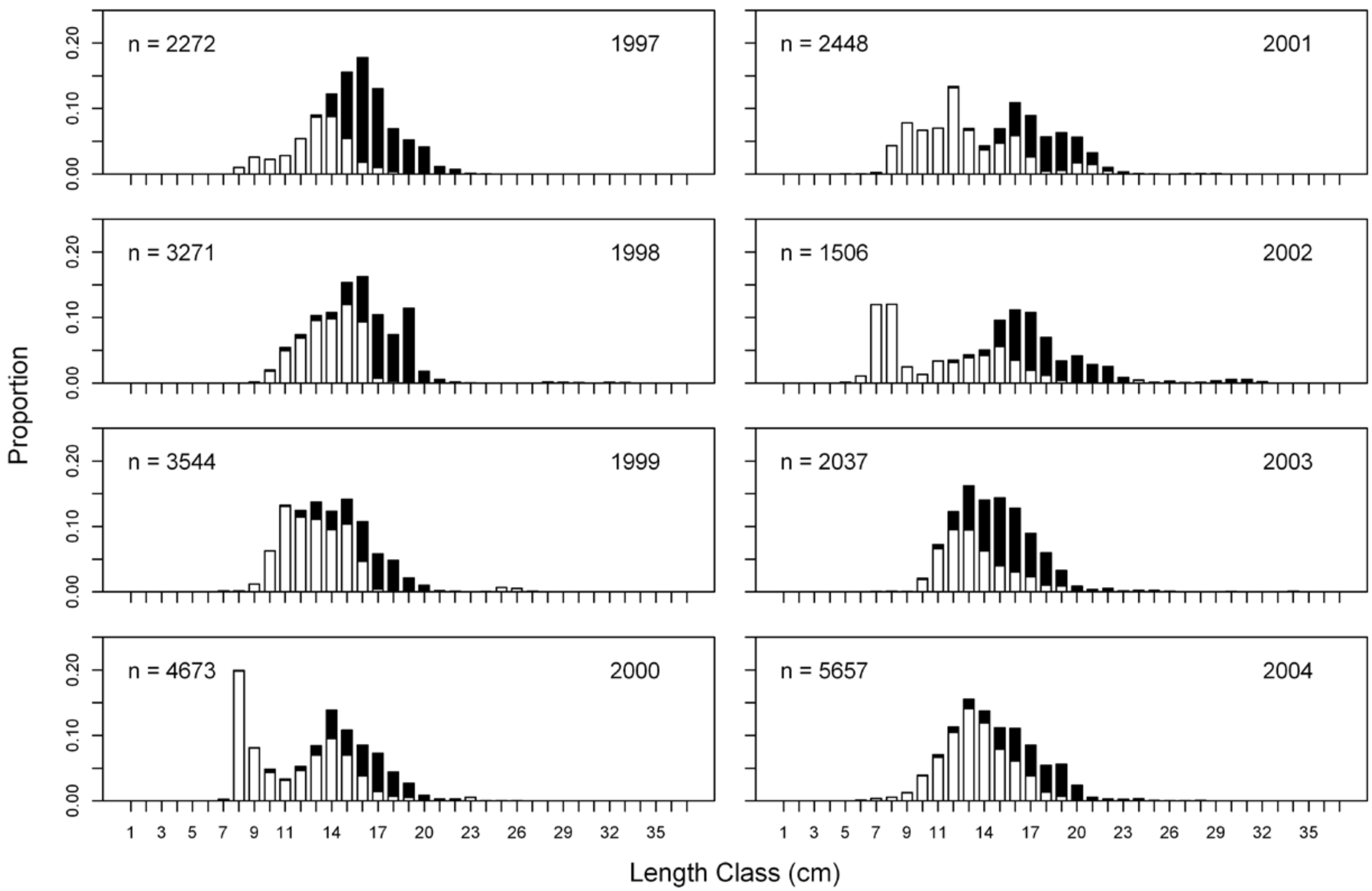


Figure A2. Length composition for NMFS Observer Program for butterfish between 1997 and 2004 with kept fish in black and discard in white. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

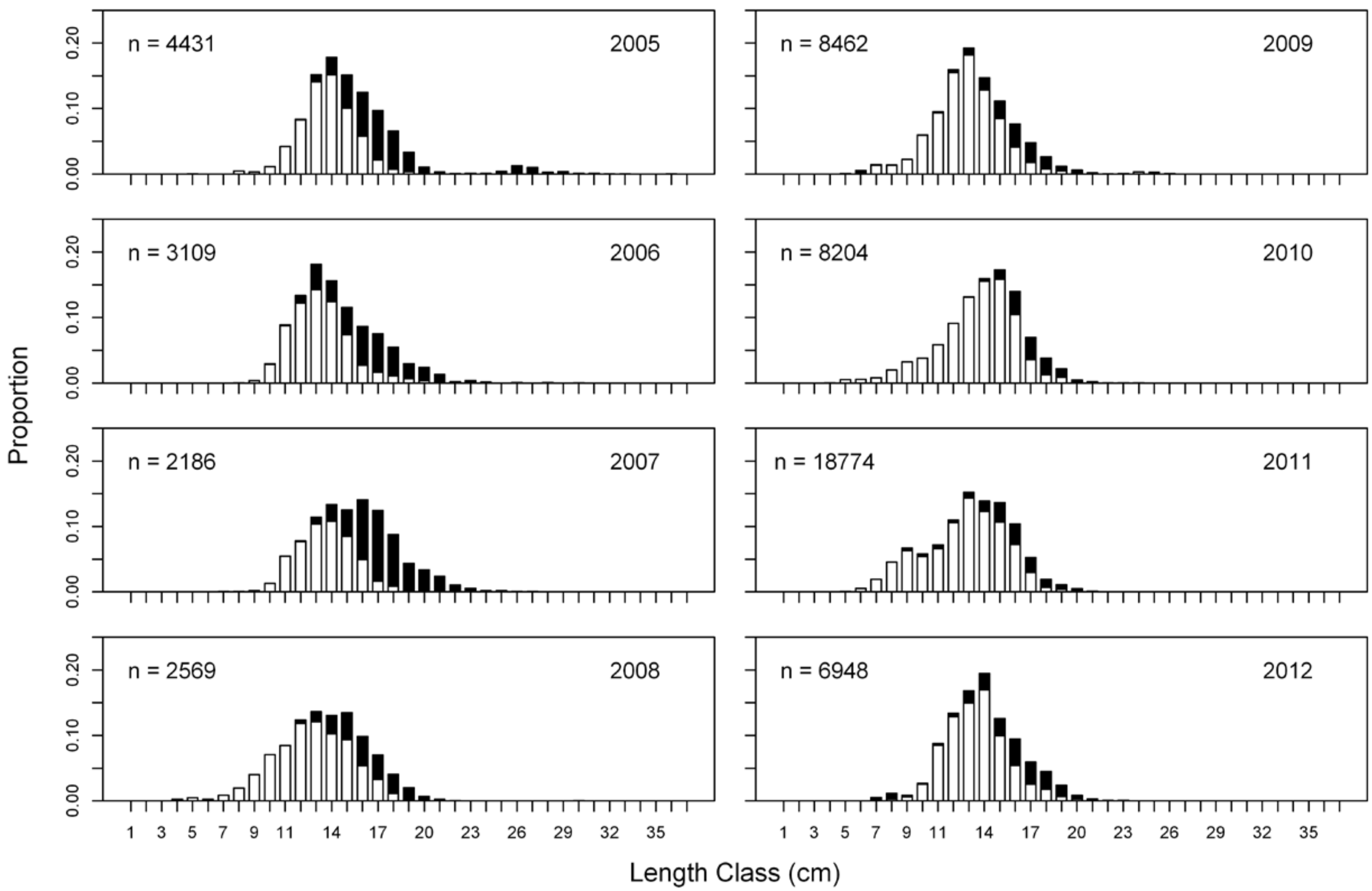


Figure A3. Length composition for NMFS Observer Program for butterfish between 2005 and 2012 with kept fish in black and discard in white. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

Appendix 2. Abundance indices for NEFSC fall surveys.

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 3. 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:

- $\mathbf{I_t}$**:** 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 [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:

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

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.

REFERENCES

Jacobson, L. J., Seaver, A., and Tang, J. 2011. AstroCalc4R: Software to Calculate Solar Zenith Angle; Time at Sunrise, Local Noon, and Sunset; and Photosynthetically Available Radiation Based on Date, Time, and Location. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 11-14, Woods Hole, MA.

Miller, T. and Rago, P. 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

Miller, T. J. 2013. A comparison of hierarchical models of relative catch efficiency based on paired-gear data for US Northwest Atlantic fish stocks. Can. J. Fish. Aquat. Sci. **70**:1306-1316.

Northeast Fisheries Science Center. 2009. 49th Northeast Regional Stock Assessment Workshop (49th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 10-03, Woods Hole, MA.

Northeast Fisheries Science Center. 2011. 51st Northeast Regional Stock Assessment Workshop (51st SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 11-02, Woods Hole, MA.

Smith, S. J. 1997. Boostrap confidence limits for groundfish trawl survey estimates of mean abundance. Can. J. Fish. Aquat. Sci. **54**:616-630.

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

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**

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.

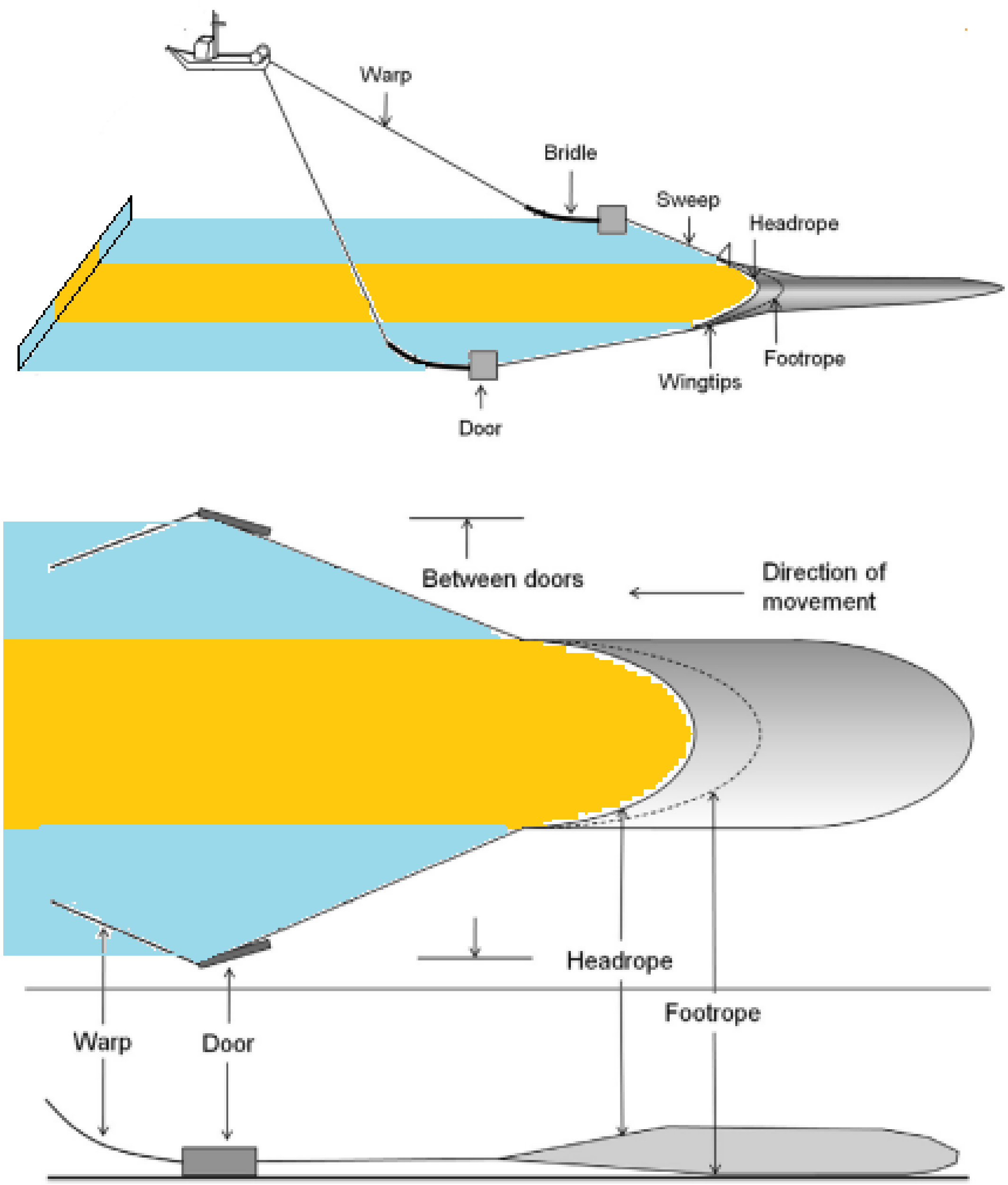
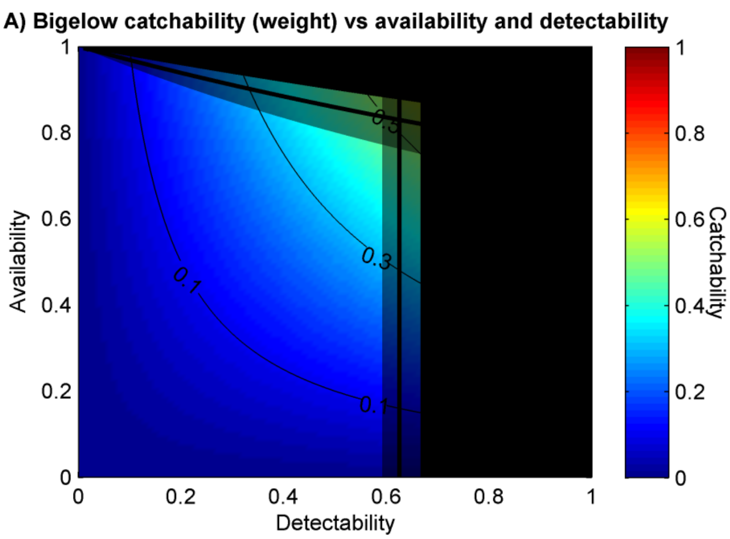


Fig. 2. A) Plot of catchability different values of availability and detectability. The black shaded areas correspond to catchability values for the 24-hour Bigelow survey that are not possible given the analyses presented in this paper. Restrictions on detectability are due to the day:night analyses 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.



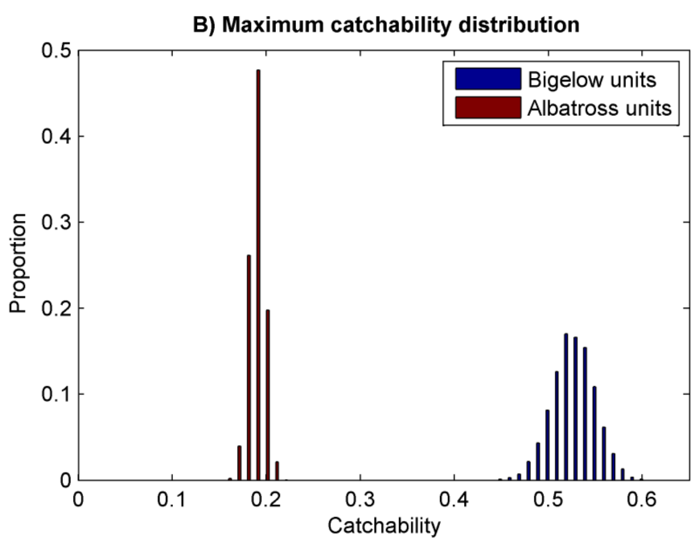


Figure 3. Time series of the minimum biomass estimates assuming that either the wings (red) or the doors (blues) are the appropriate measure of the area sampled by the trawl net.