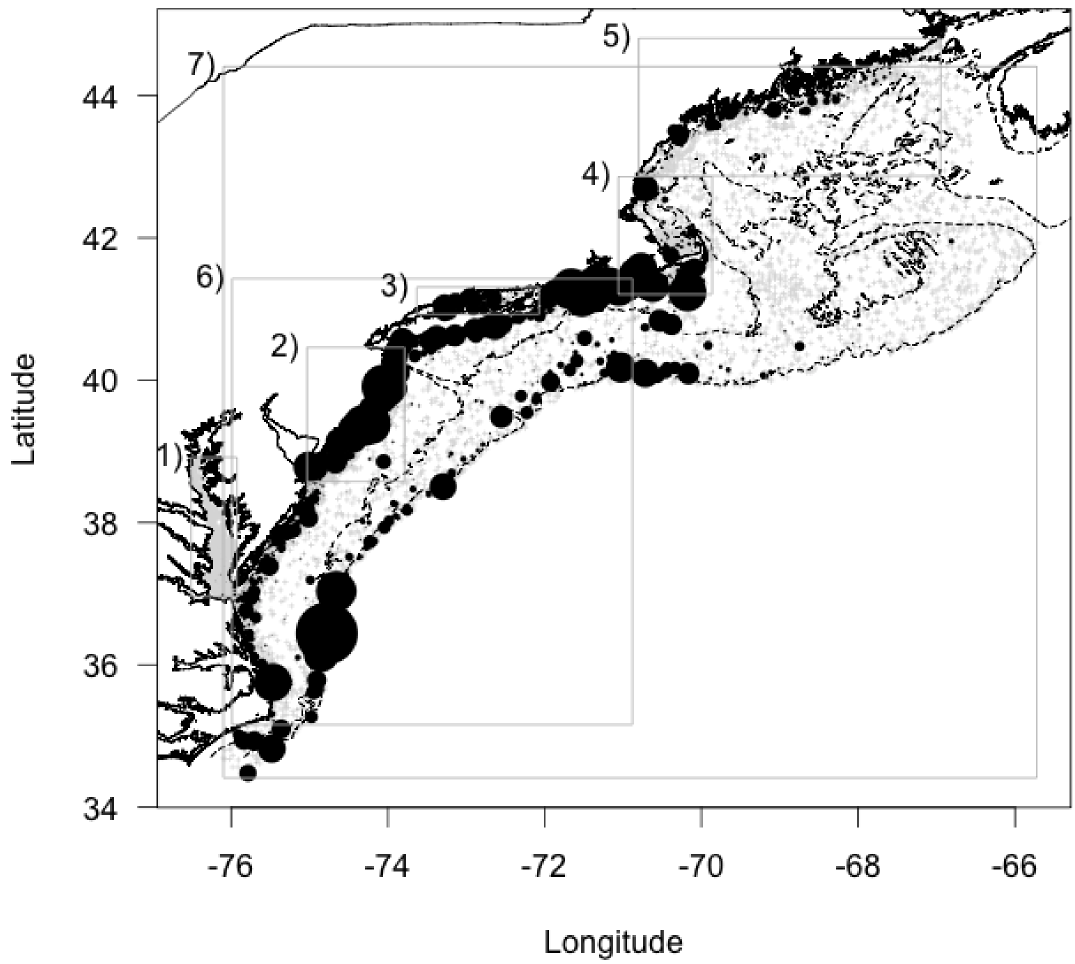
Butterfish App. A1. Habitat dependent species distribution shifts

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

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



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

Data & preliminary GAM analysis of effects on catch

Methods

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

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

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

C_{ij} = 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.

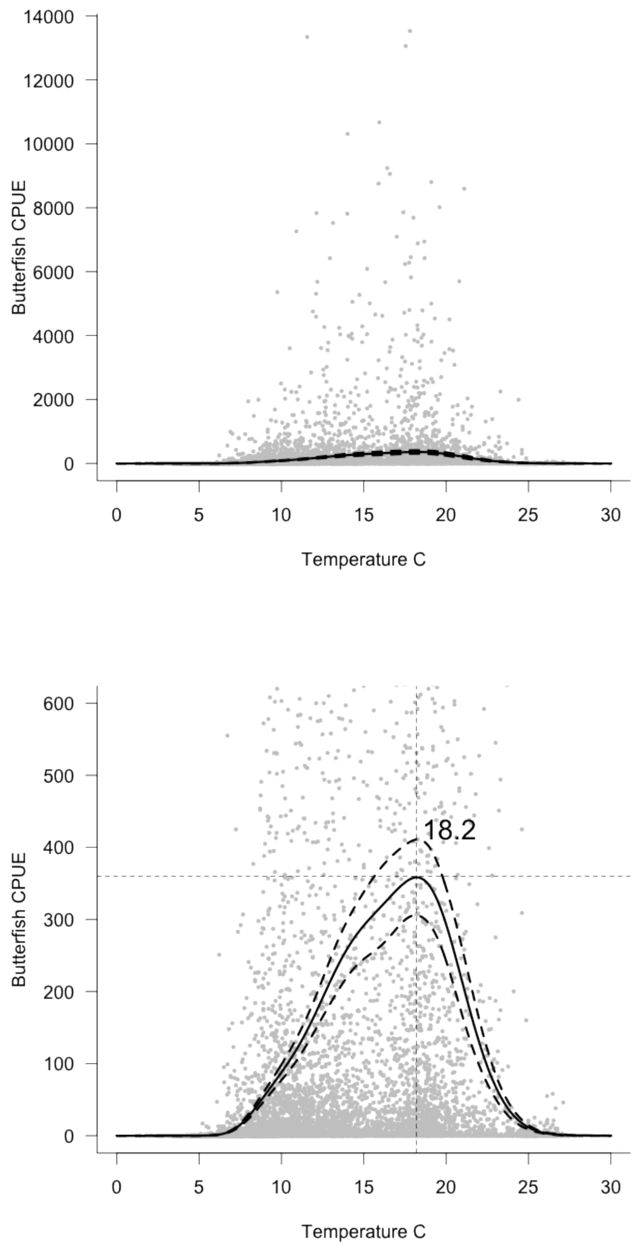
Although GAM indicated the model with the survey dependent temperature response had higher explanatory power (m8), response curves were only slightly different across the range of temperatures with positive effects on catch (not shown). Instead the strongest survey effects were associated with the northernmost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

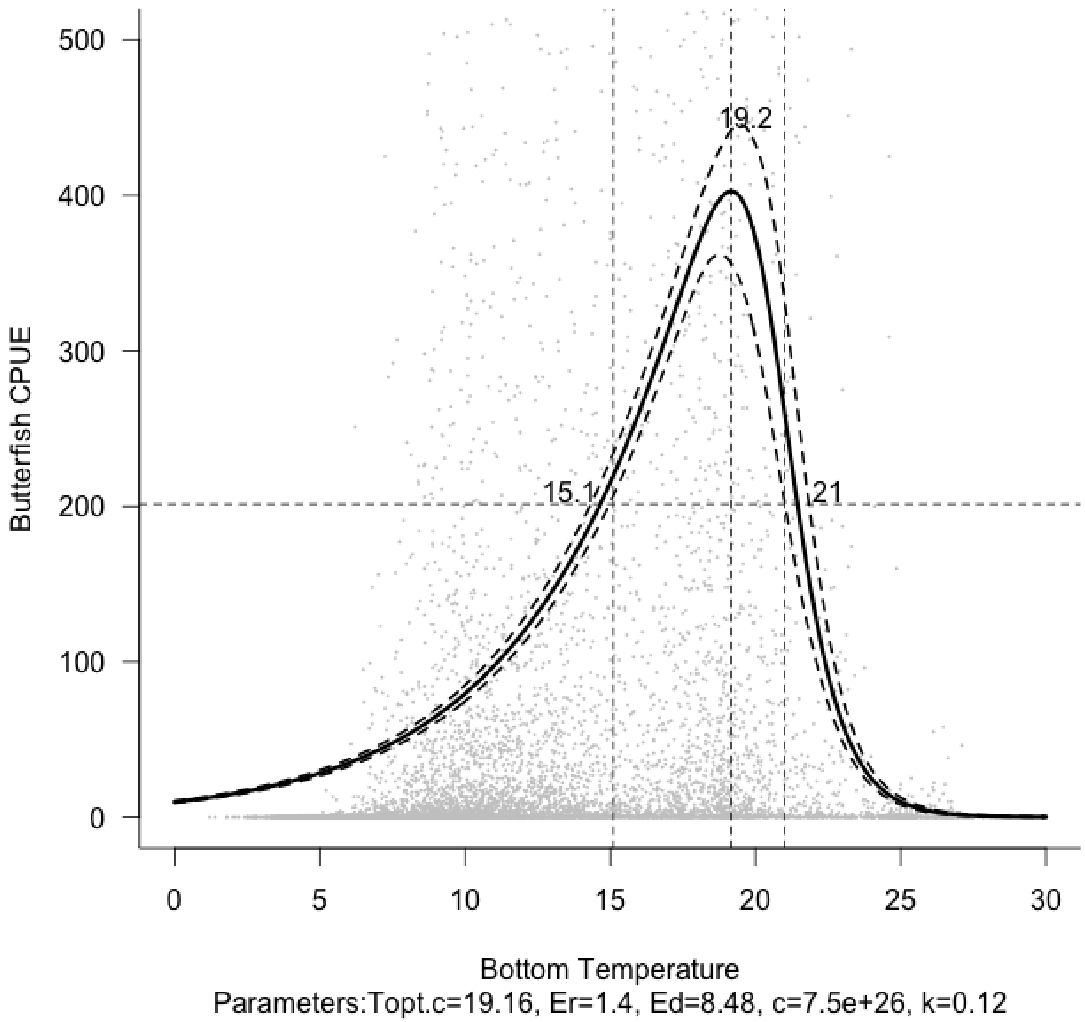
App. A1 Table 2a. Generalized additive models to determine effects of survey, year, and season on the response of butterfish catch to bottom water temperature in the 2008-2012 calibration data used to develop the parametric niche model. Number of butterfish per tow was the dependent variable. All models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

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



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

Maximum likelihood estimation (See main text for details)



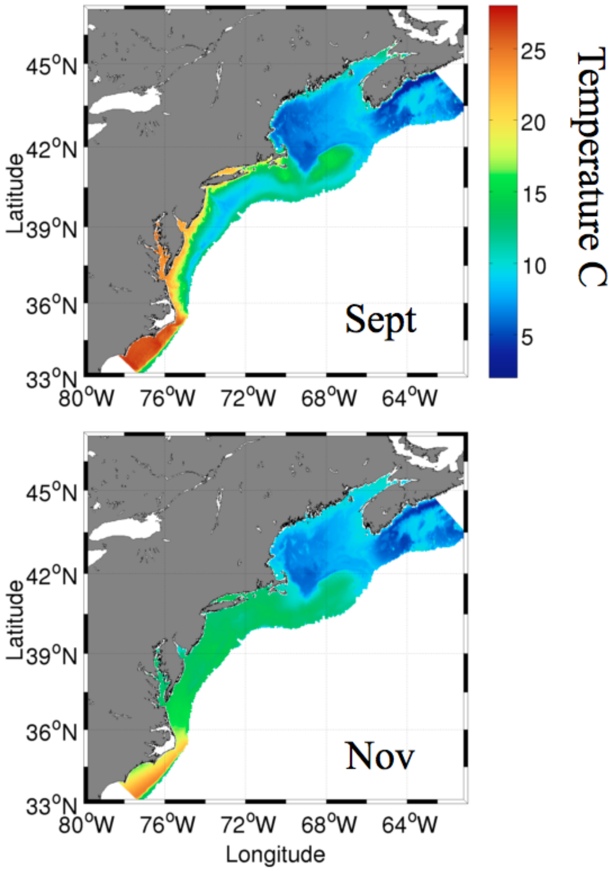
App A1 Figure 4. Plot of the thermal response curve for Atlantic butterfish constructed by estimating parameters of the Johnson and Lewin equation (solid black line) minimizing negative binomial likelihood using standardized butterfish catch as the response (h) and bottom water temperature as the independent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

Bottom temperature hindcast

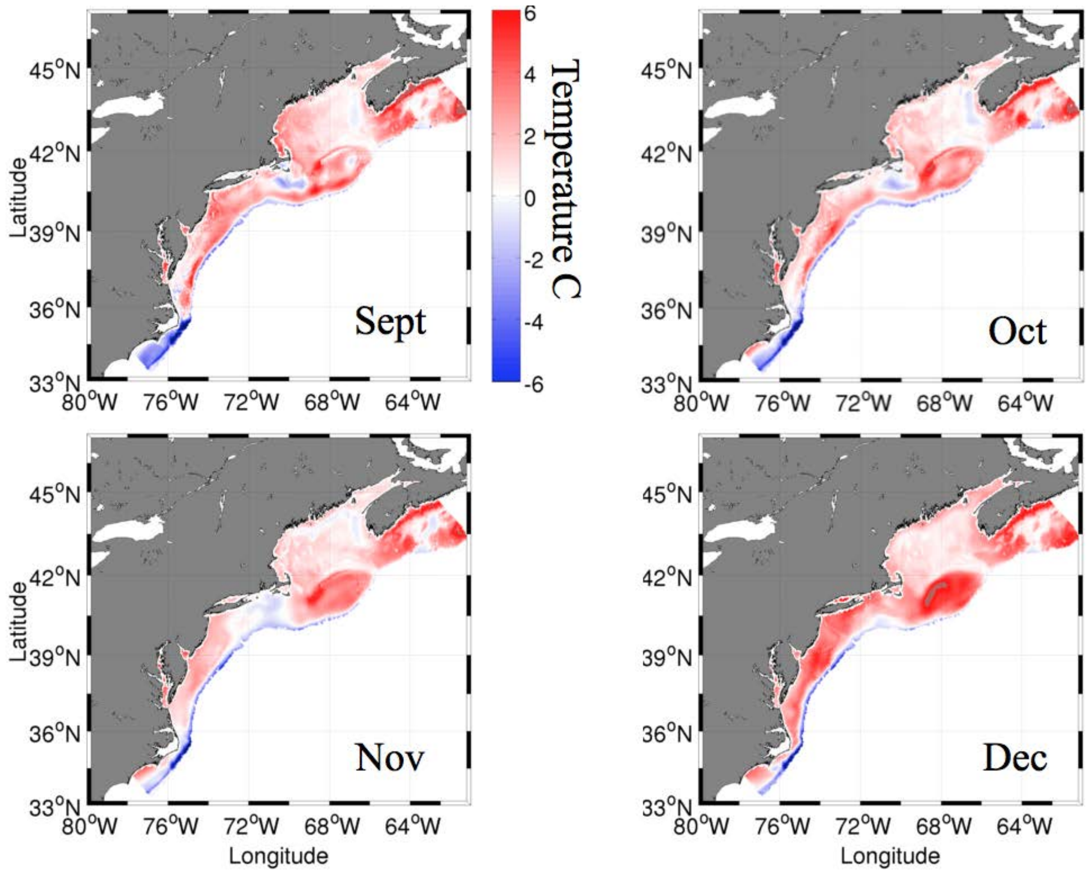
Methods

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

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



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



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

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

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

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

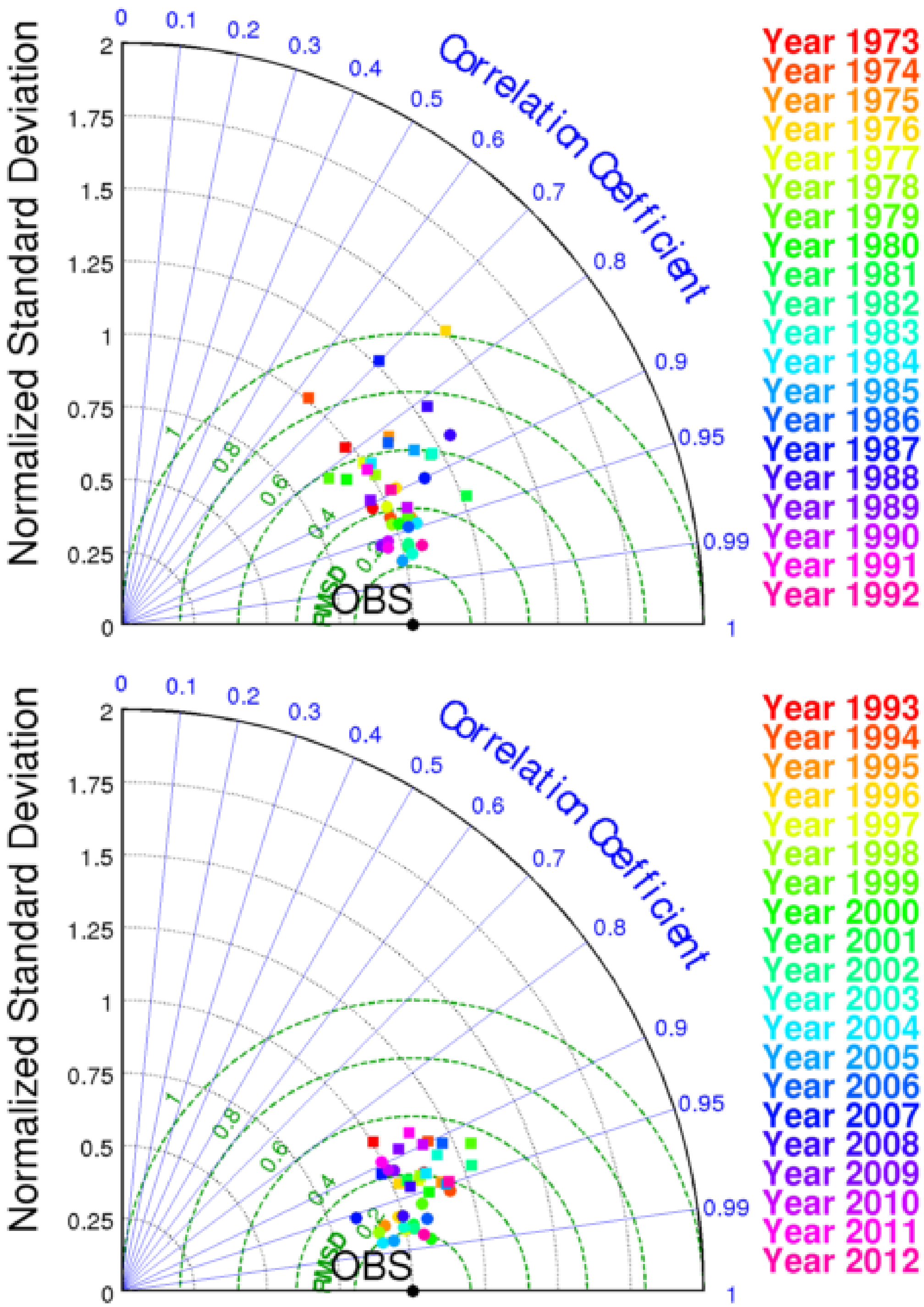
$$\boldsymbol{\sigma_o} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(o_i - \bar{o})^2}$$

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

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

Results

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



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

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

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

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

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

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

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

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

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

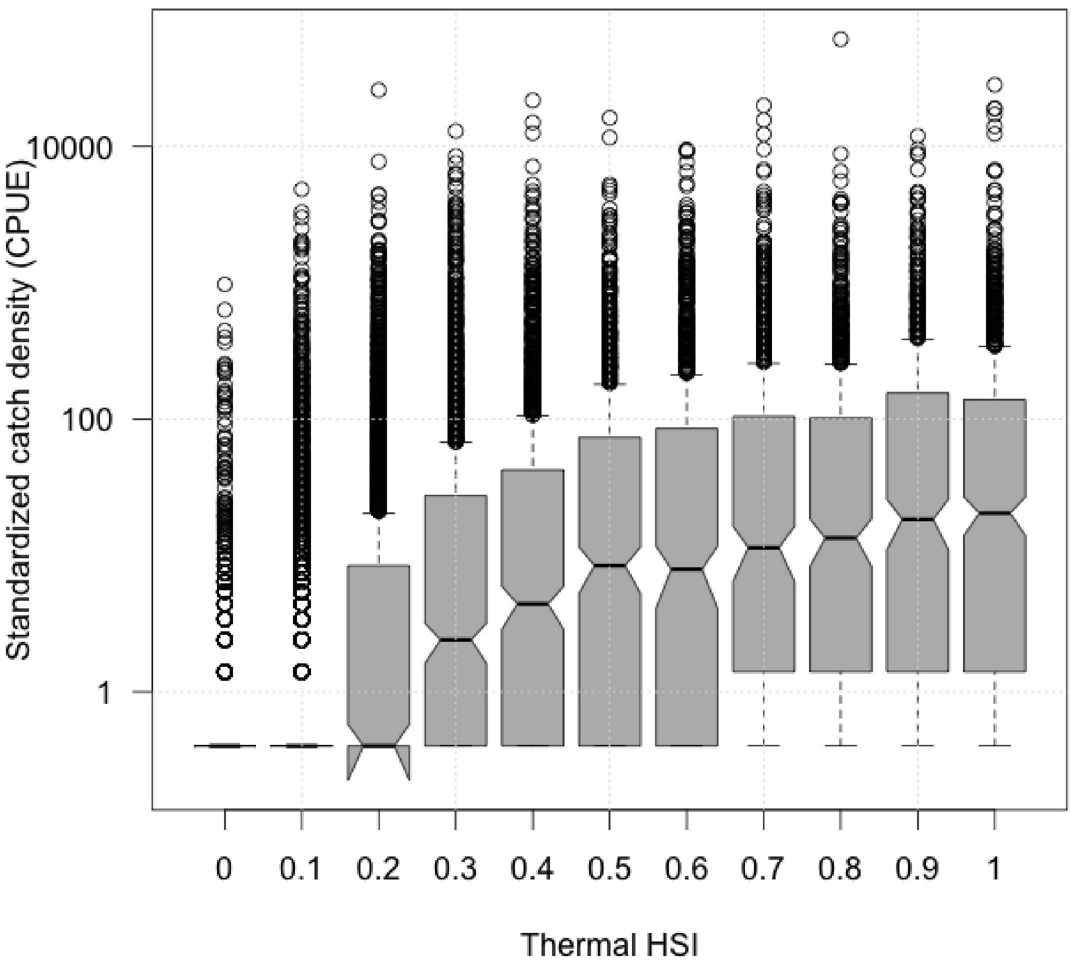
1987	8.48	8.66	10.85	8.51	2.89	2.93	3.27	2.70	2.70	1.21	1.04
1988	5.87	6.31	8.82	5.58	1.42	1.77	2.32	1.49	3.22	0.72	0.84
1989	9.27	8.76	12.21	9.06	3.79	3.45	3.85	3.46	3.26	1.97	1.33
1990	8.77	7.88	12.36	7.61	3.33	3.55	4.09	3.38	3.95	1.50	1.72
1991	9.87	7.47	12.25	7.47	4.71	3.25	4.69	3.48	2.87	3.24	3.10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

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

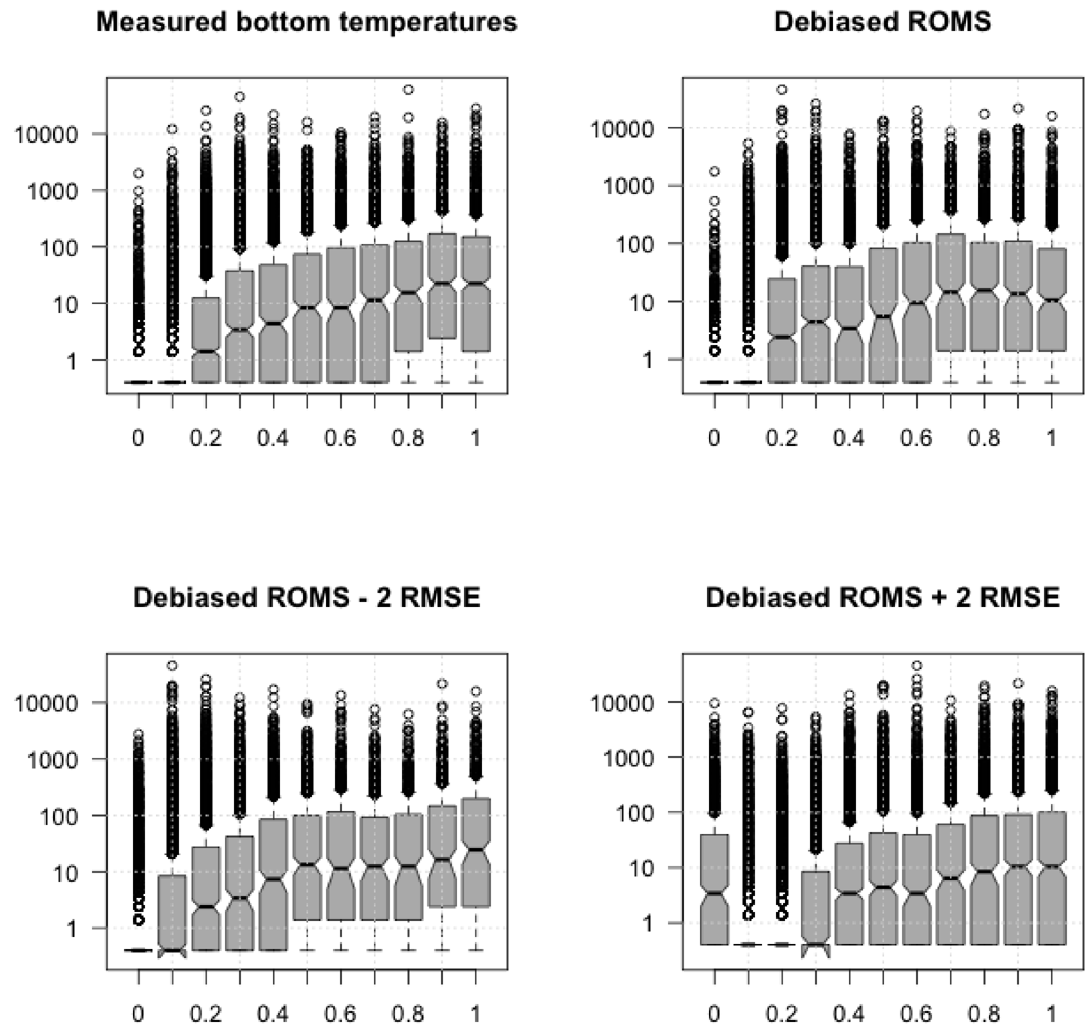
Year	Mean				Standard Deviation				RMSE		
	OBS	MOCHA	Model	Mode l SPA	OBS	MOCHA	Model	Model SPA	Mode l	MOCHA	Model SPA
1973	7.77	7.16	8.32	7.06	2.95	2.23	1.56	2.19	2.37	1.57	1.63
1974	8.12	7.18	8.42	7.18	2.75	2.42	1.82	2.47	2.63	1.59	1.64
1975	7.3	6.92	8.77	6.91	2.39	1.99	1.87	1.99	3.05	1.3	1.32
1976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

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

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



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



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

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

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

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

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

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

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

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

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A. Butterfish Appendix A2.

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

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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

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

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

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 $2M/3$.

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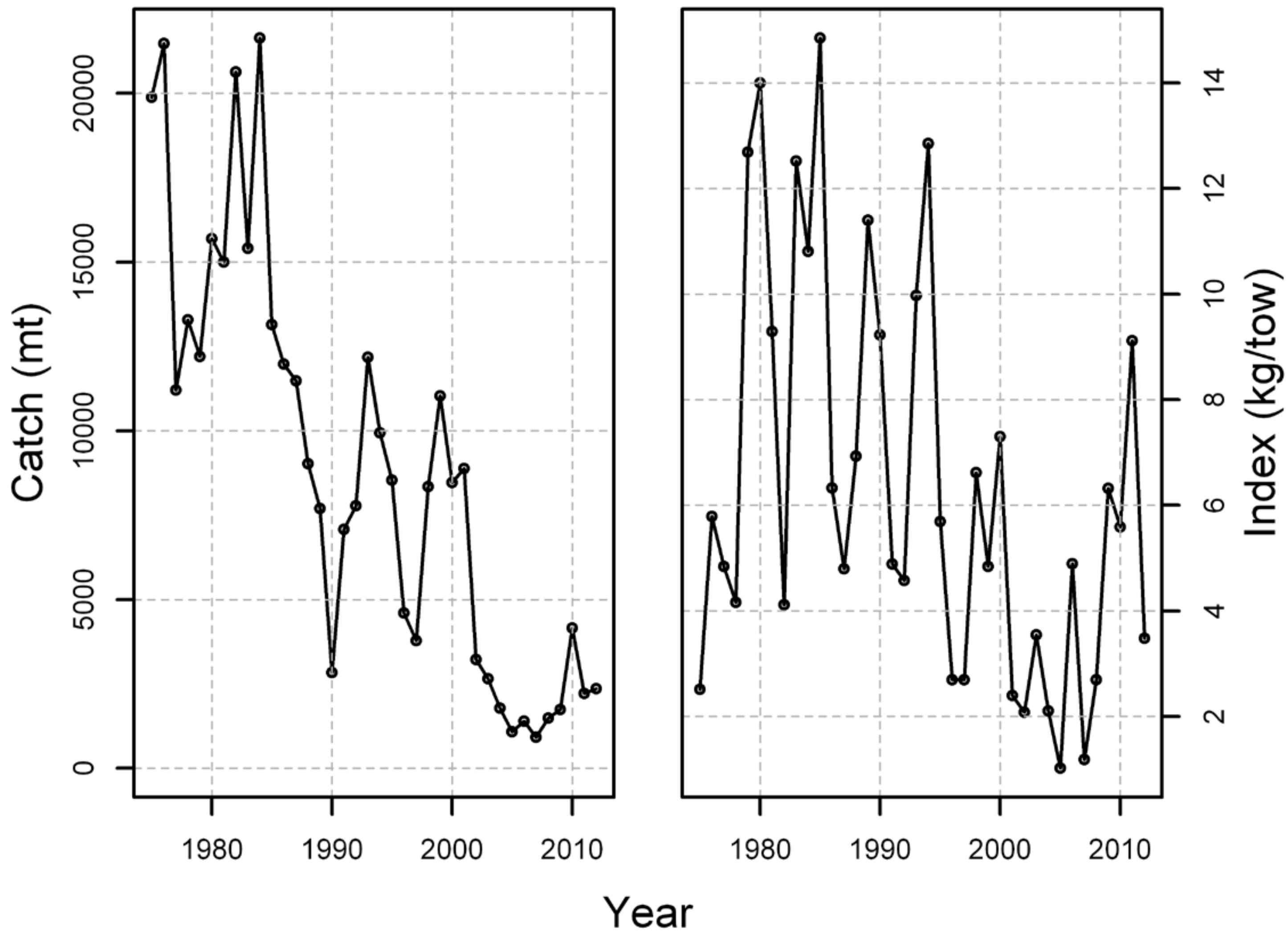
Miller, T. J., Das, C., Politis, P. J., Miller, A. S., Lucey, S. M., Legault, C. M., Brown, R. W., and Rago, P. J. 2010. Estimation of Albatross IV to Henry B. Bigelow calibration factors. NEFSC Ref. Doc. 10-05.

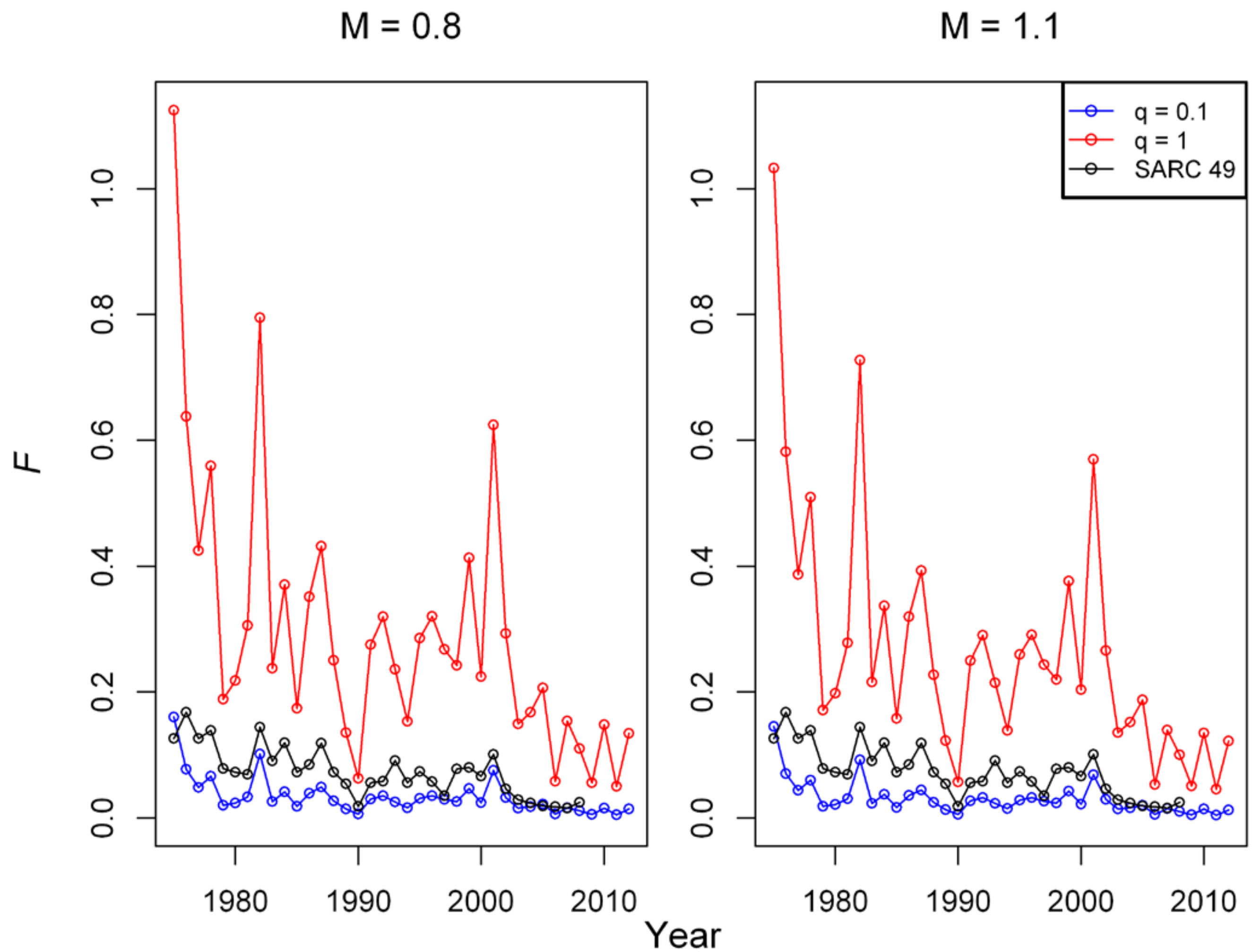
Miller, T., and P. Rago. 2012. Empirical exploration of feasible bounds on butterfish stock size and fishing mortality rates, 1975-2011. Report to the Mid-Atlantic Fishery Management Council Scientific and Statistical Committee. 14 pp.

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

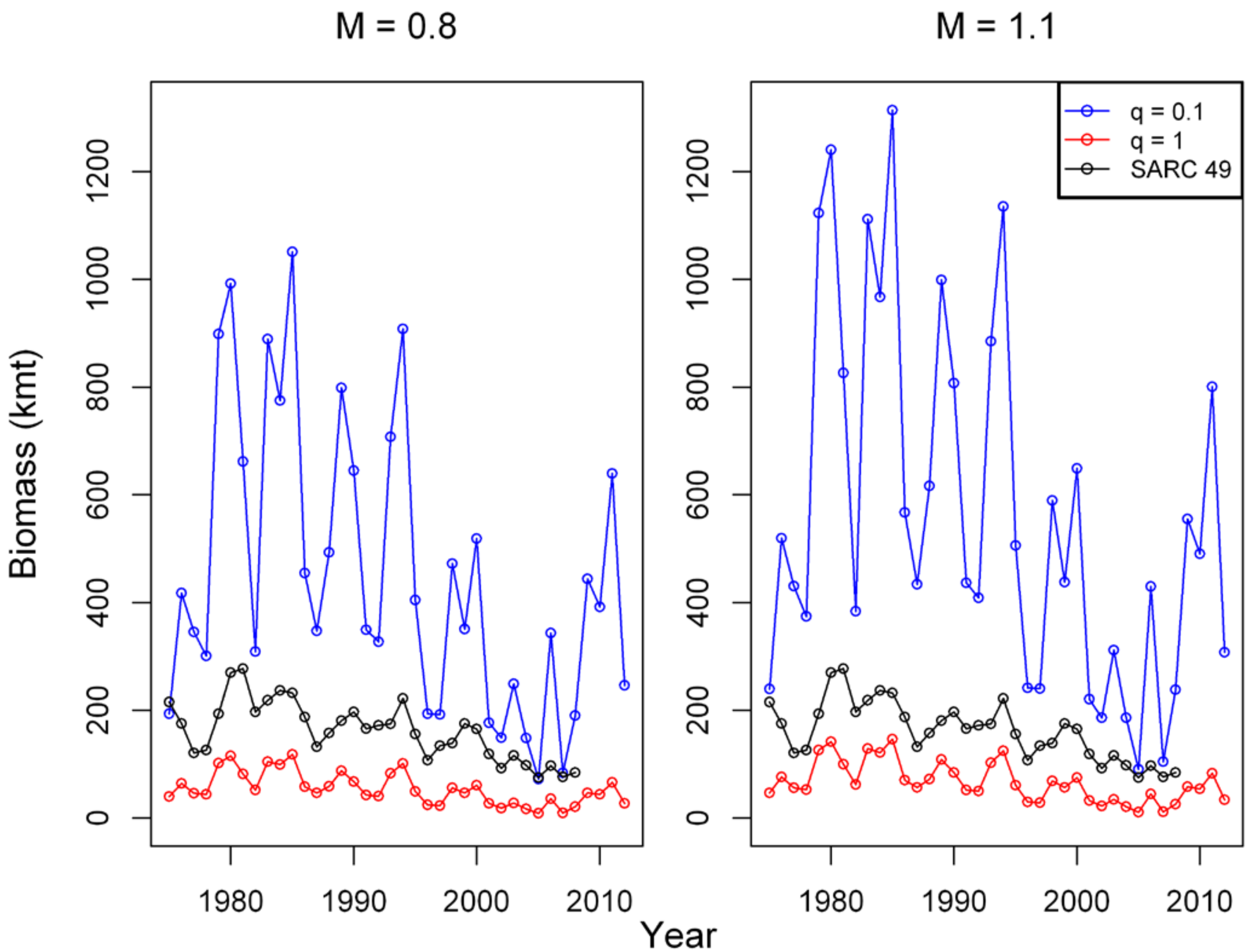
Patterson, K. 1992. Fisheries for small pelagic species: an empirical approach to management targets. Reviews in Fish and Fisheries 2:321-338.



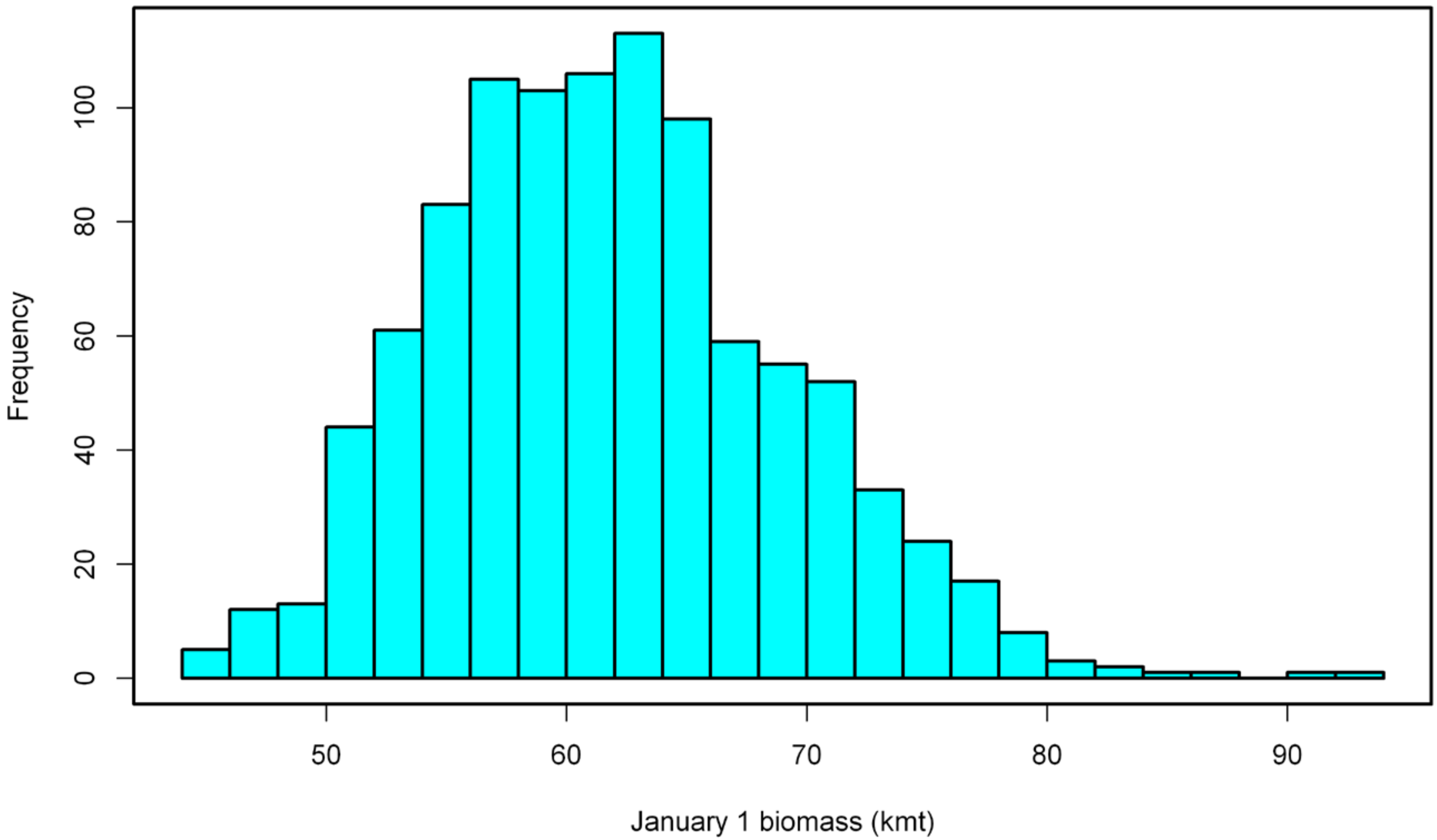
App. A2 Figure 1. Annual total catches and fall NEFSC biomass indices for Atlantic butterfish.



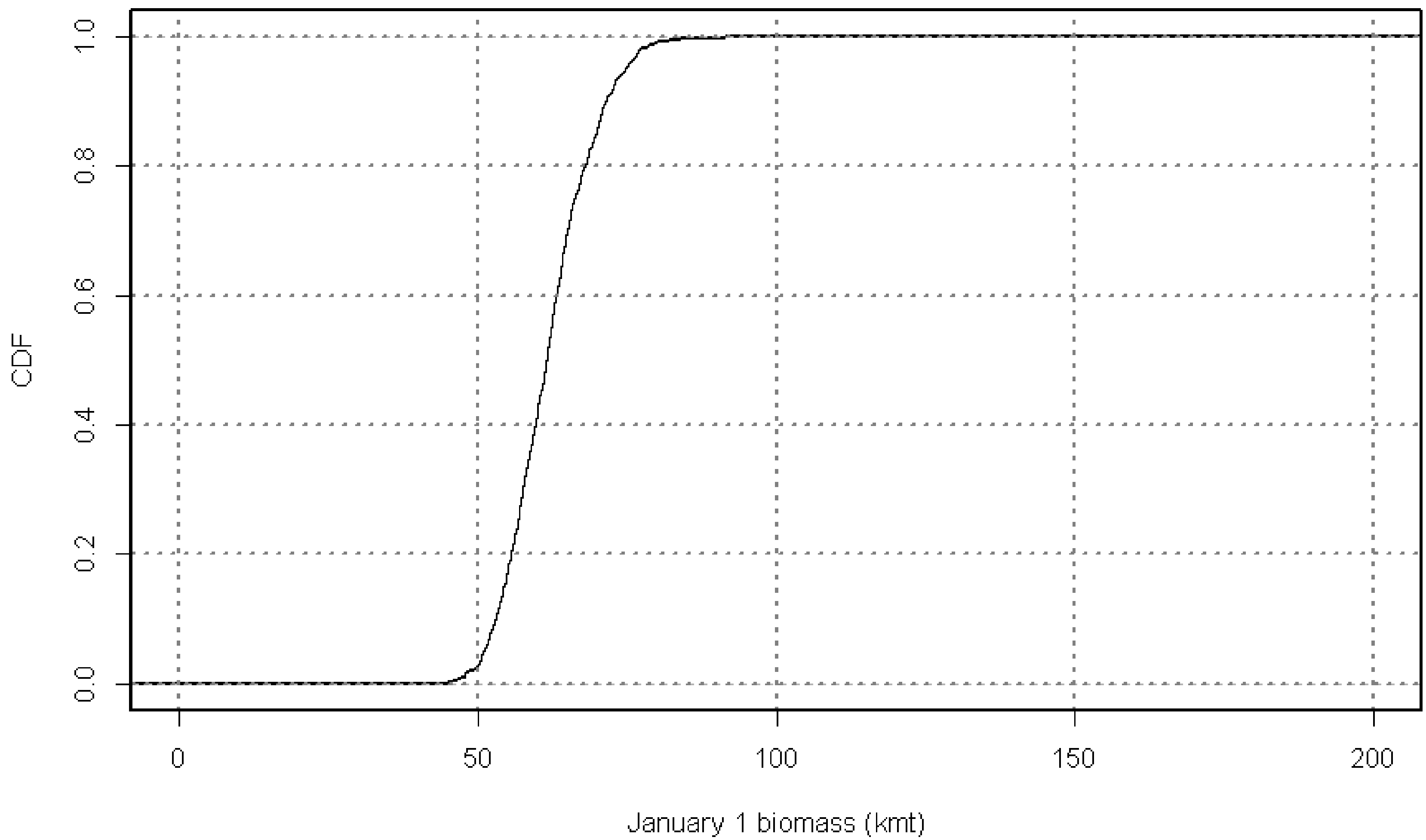
App. A2 Figure 2. Implied annual fishing mortality rates under two different survey efficiency and natural mortality assumptions and the fishing mortality rate estimates from SARC 49 (NEFSC 2010). See Equation 3.



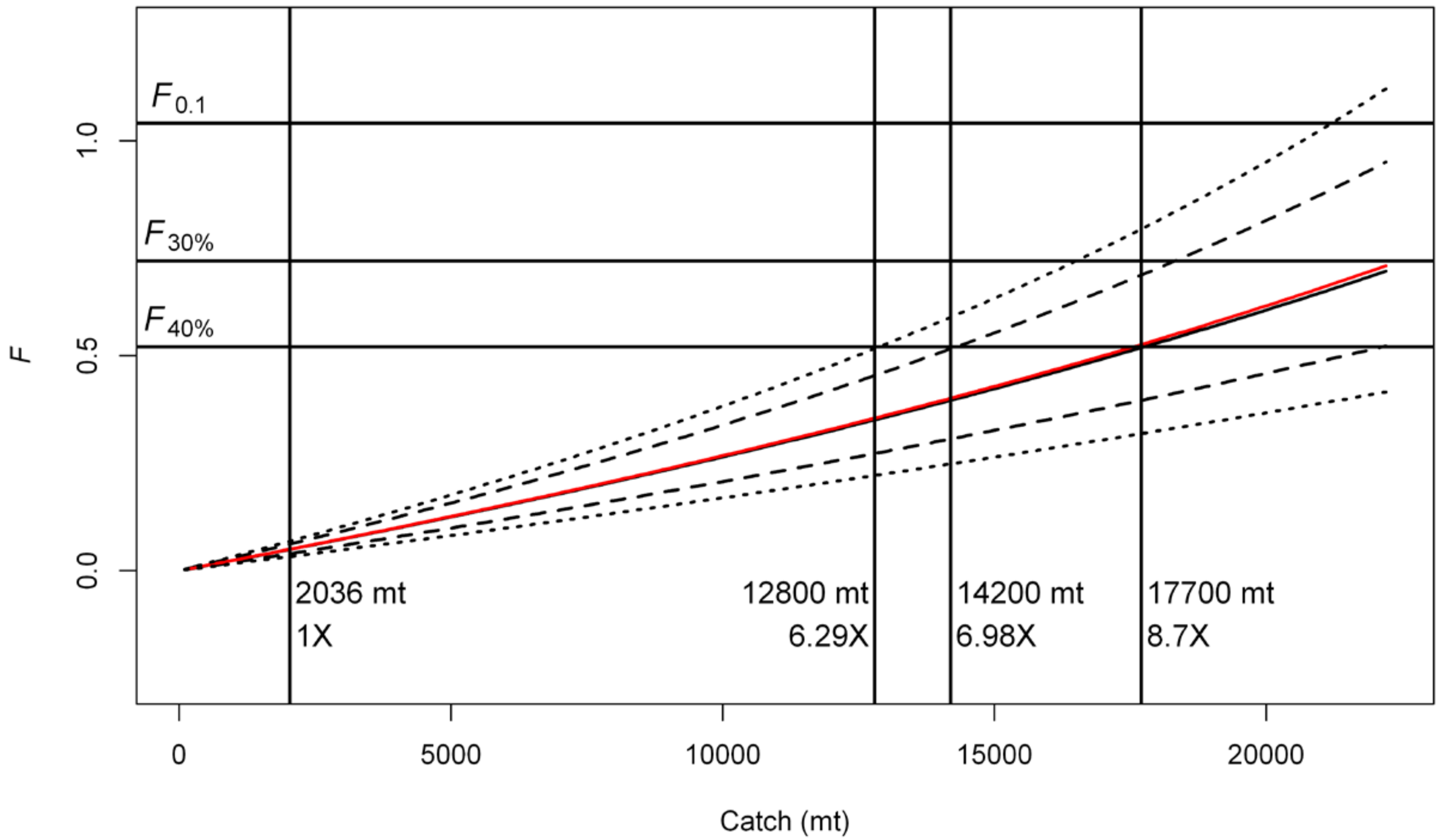
App. A2 Figure 3. Implied annual January 1 butterfish stock biomass under 2 different survey efficiency and natural mortality assumptions and the biomass estimates from SARC 49 (NEFSC 2010). See Equation 4.



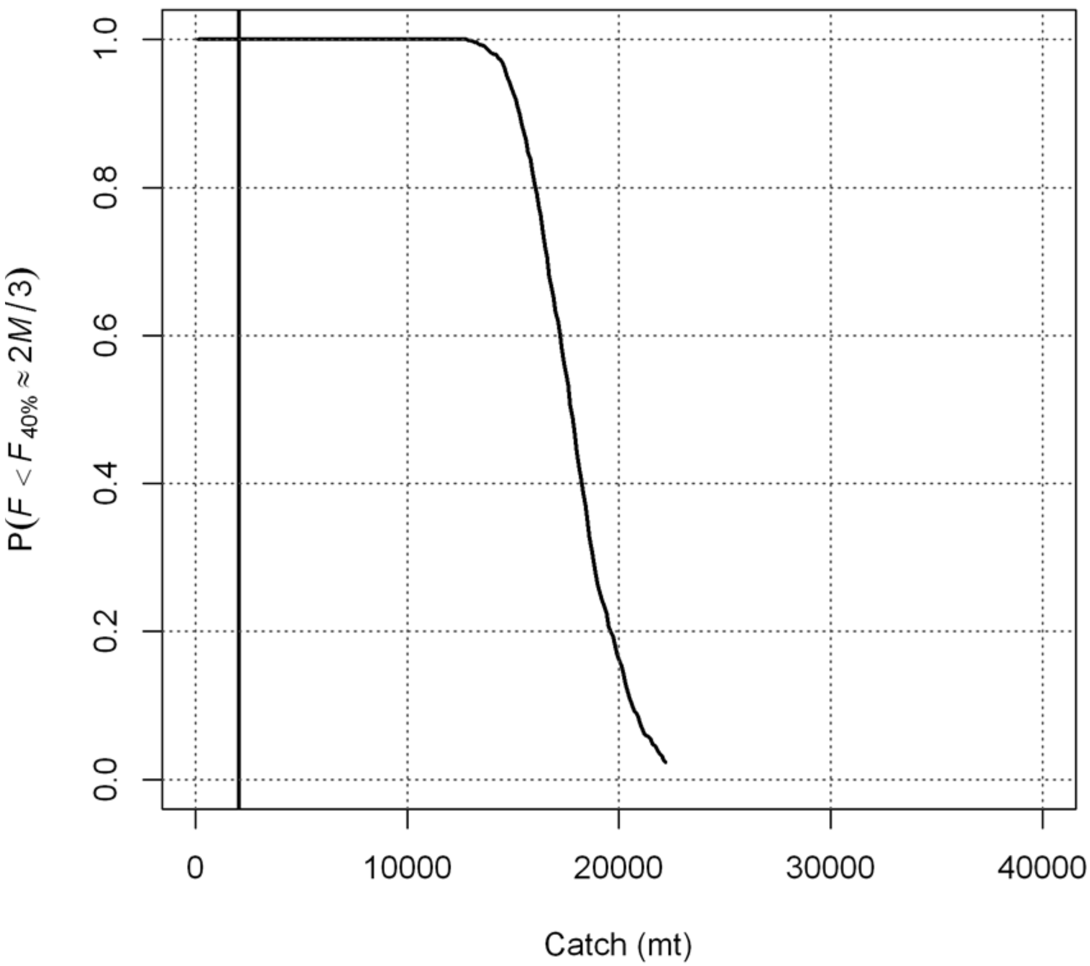
App. A2 Figure 4. Histogram of 1000 parametric bootstraps of average January 1 biomasses for Atlantic butterfish in 2006-2012.



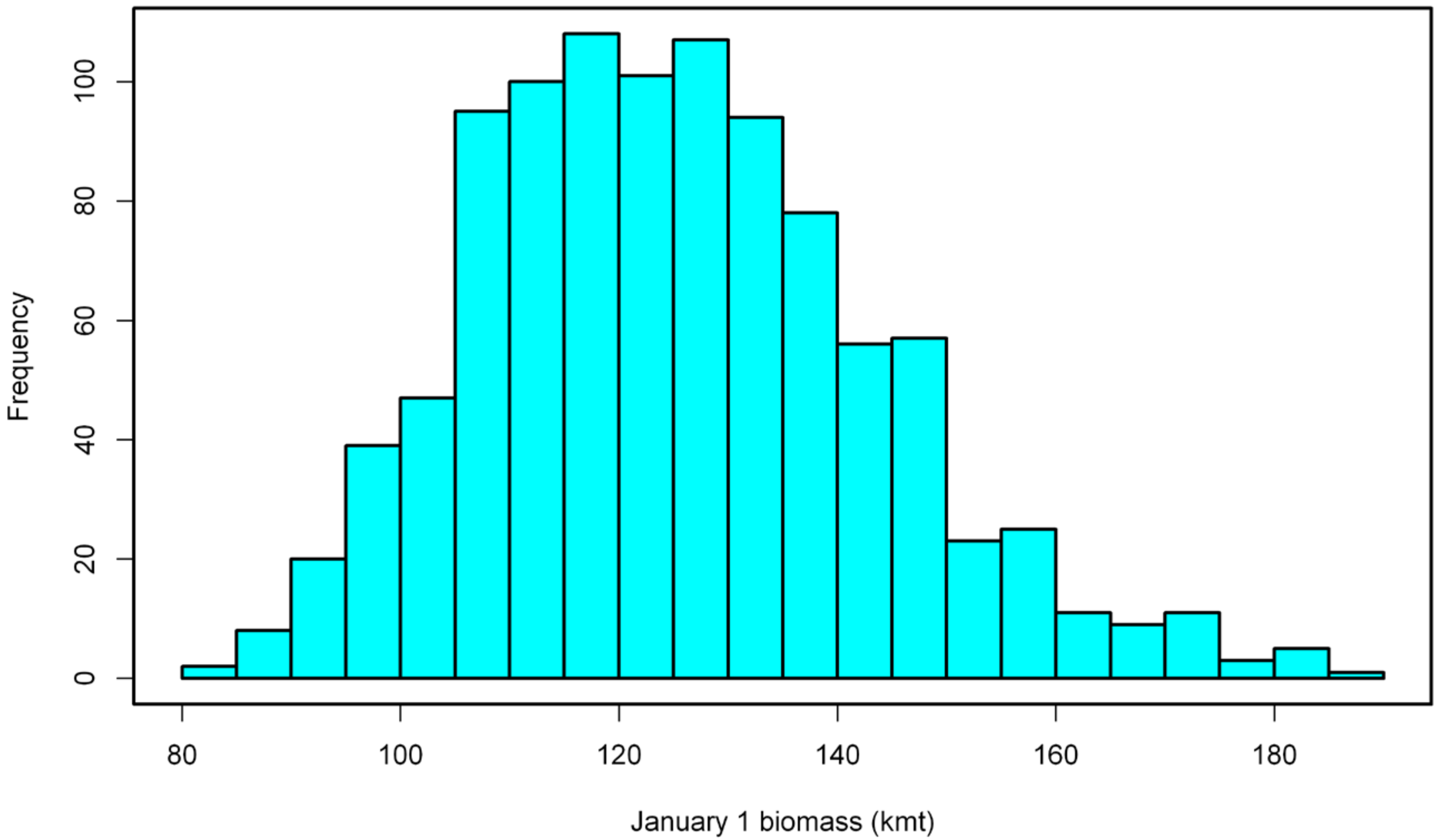
App. A2 Figure 5. Cumulative distribution of 1000 parametric bootstraps of average January 1 biomasses for Atlantic butterfish in 2006-2012.



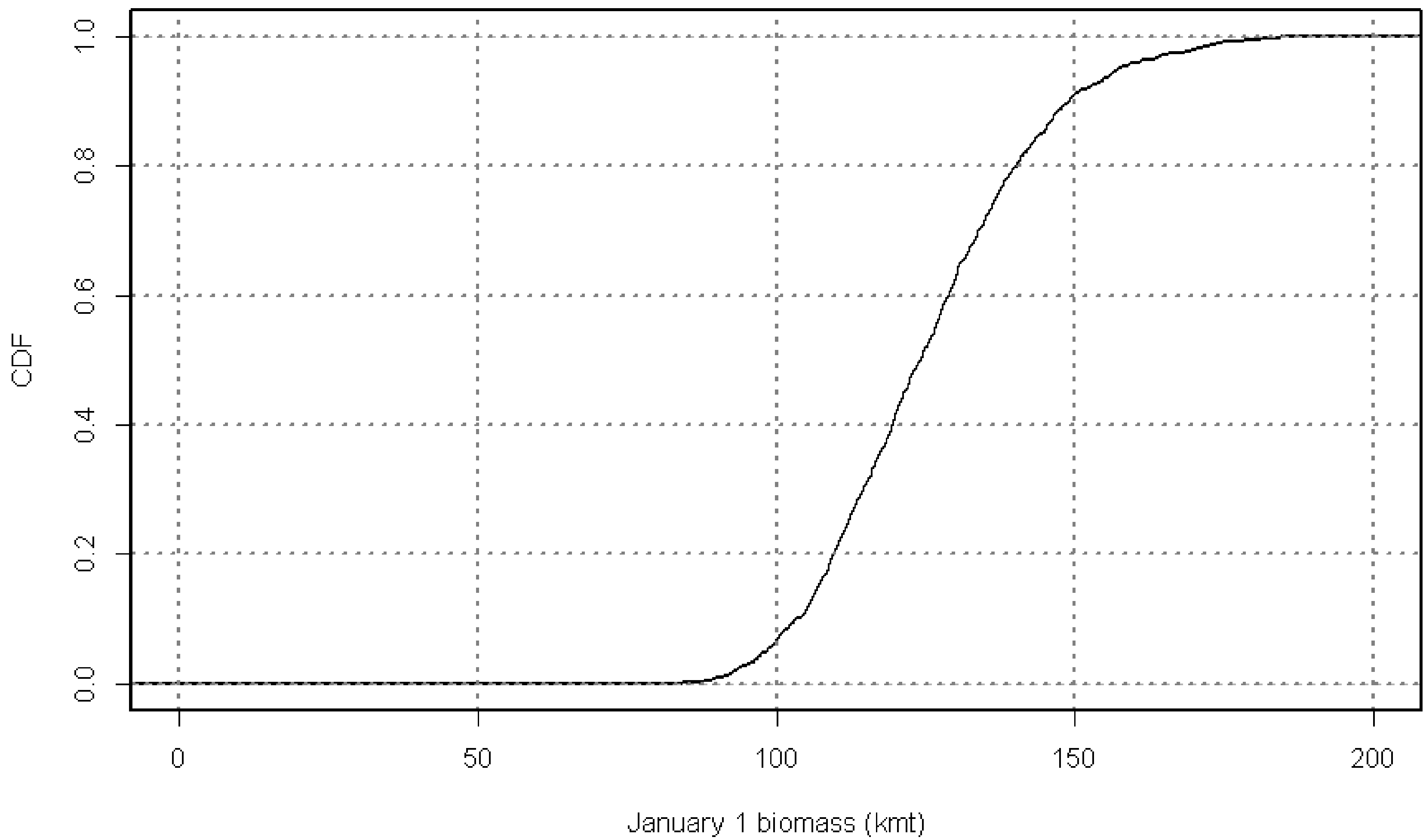
App. A2 Figure 6. Mean (solid red), median (solid black), 0.025 and 0.975 confidence limits (dashed), minimum and maximum (dotted) of F for 1000 bootstraps, based on average 2006-2012 January 1 biomasses. Overfishing reference points are from SARC 49 (NEFSC 2010). Vertical lines are for average 2006-2012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



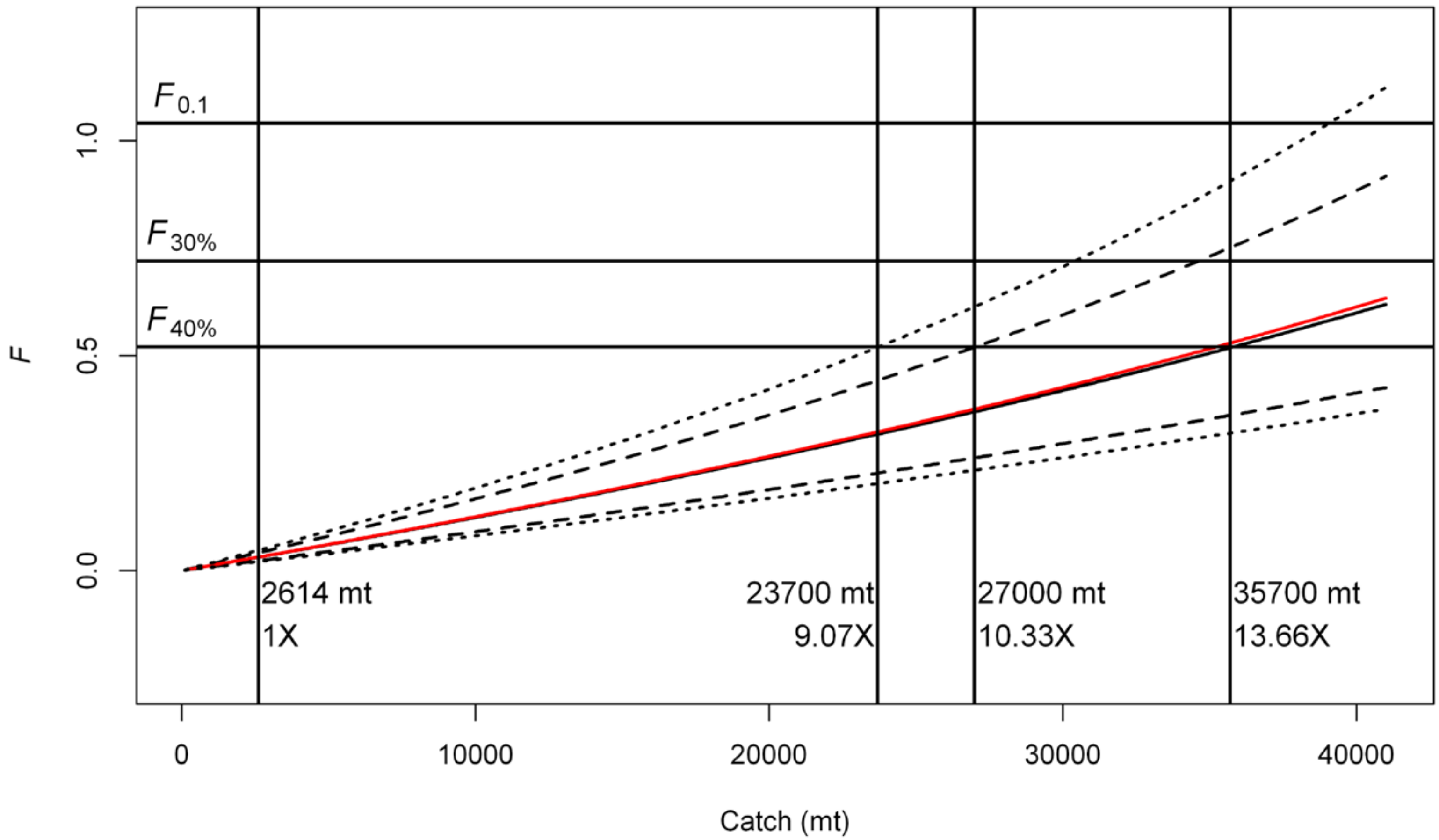
App. A2 Figure 7. Probability fishing mortality at specified catch is less than $F_{40\%} \approx 2M/3$ based on parametric bootstrap of average 2006-2012 January 1 biomasses. Vertical line represents average annual catch 2006-2012.



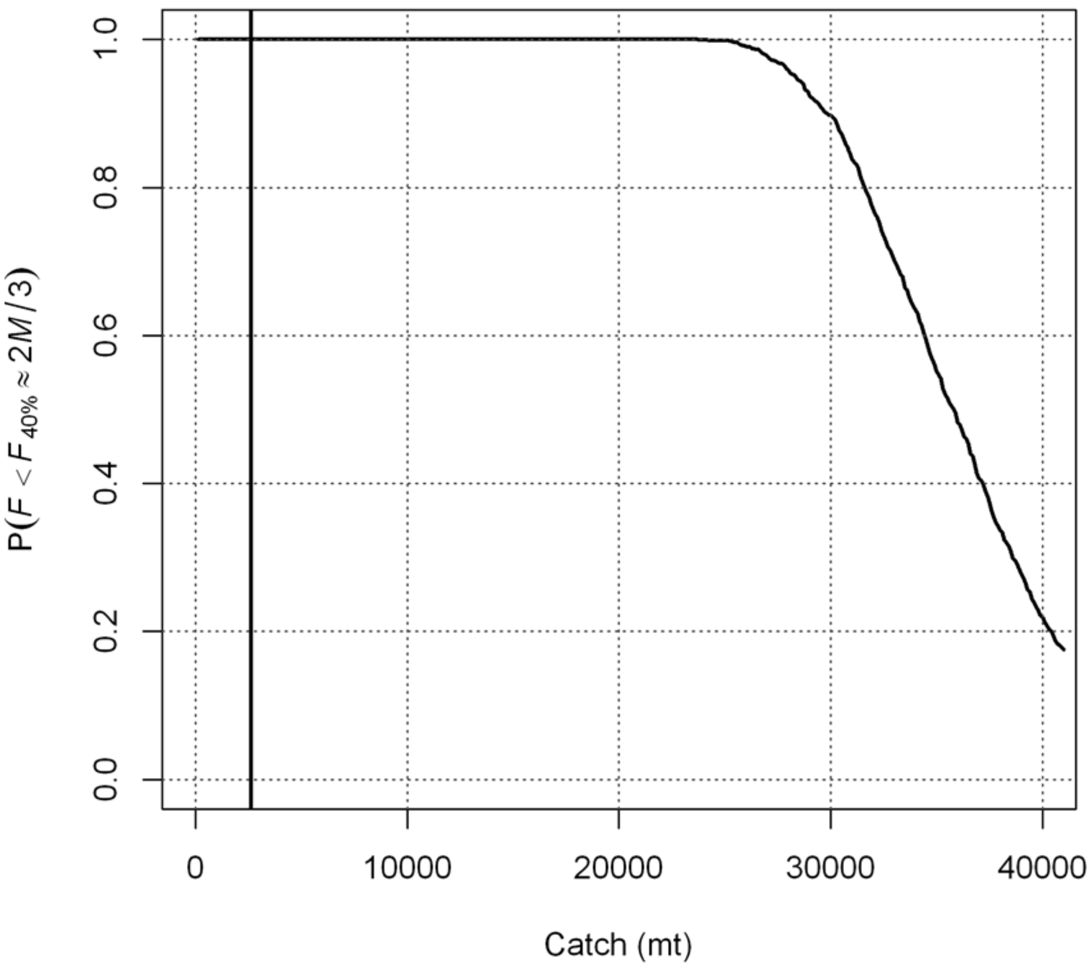
App. A2 Figure 8. Histogram of 1000 parametric bootstraps of average January 1 biomasses for Atlantic butterfish in 2009-2012.



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



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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

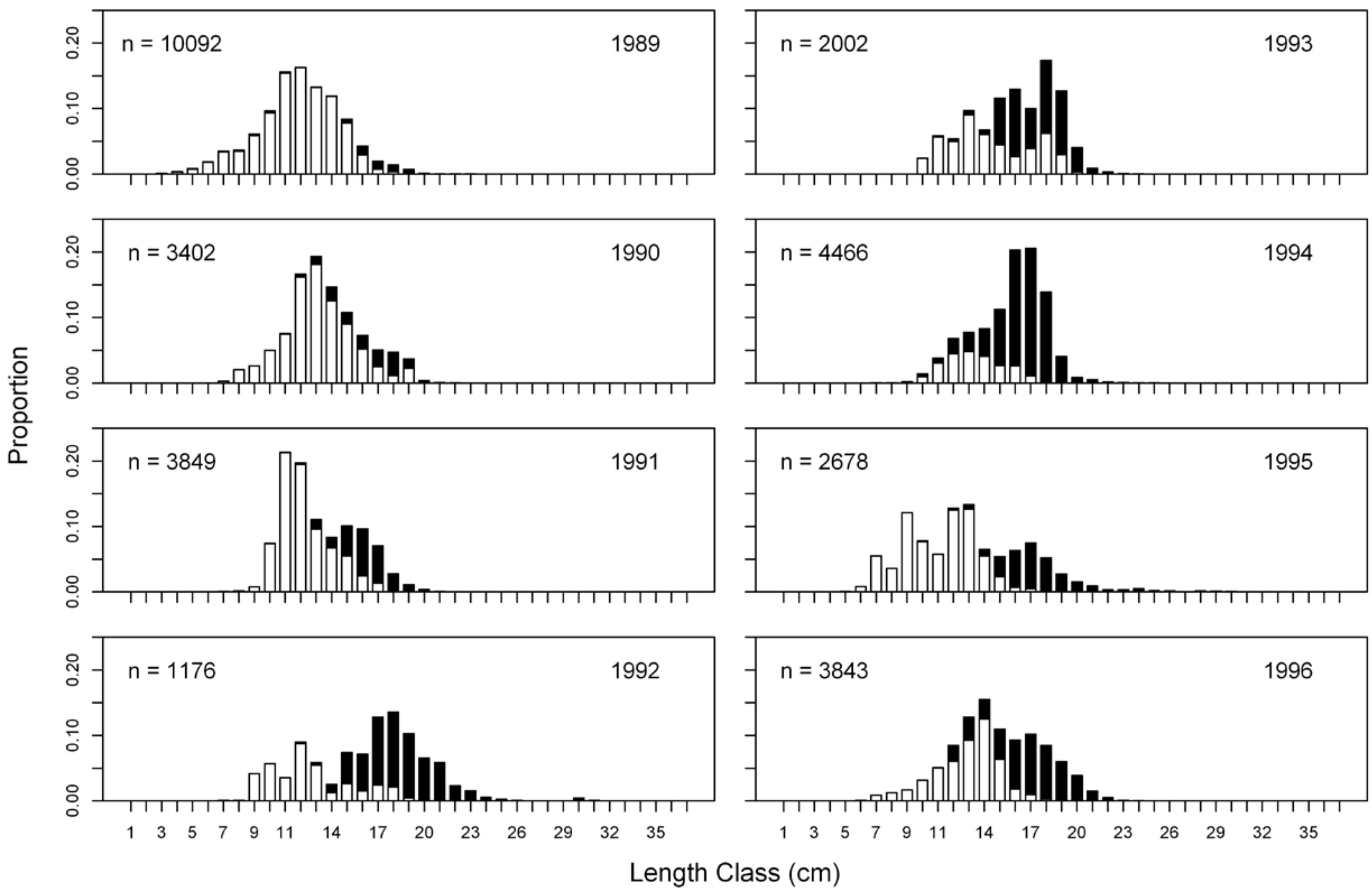
18800	0.16	0.39	0.18	0.24	0.34
18900	0.16	0.39	0.18	0.25	0.34
19000	0.16	0.40	0.18	0.25	0.34
19100	0.16	0.40	0.18	0.25	0.34
19200	0.16	0.40	0.18	0.25	0.34
19300	0.16	0.40	0.18	0.25	0.35
19400	0.16	0.41	0.18	0.25	0.35
19500	0.16	0.41	0.18	0.25	0.35
19600	0.16	0.41	0.18	0.26	0.35
19700	0.17	0.41	0.19	0.26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

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

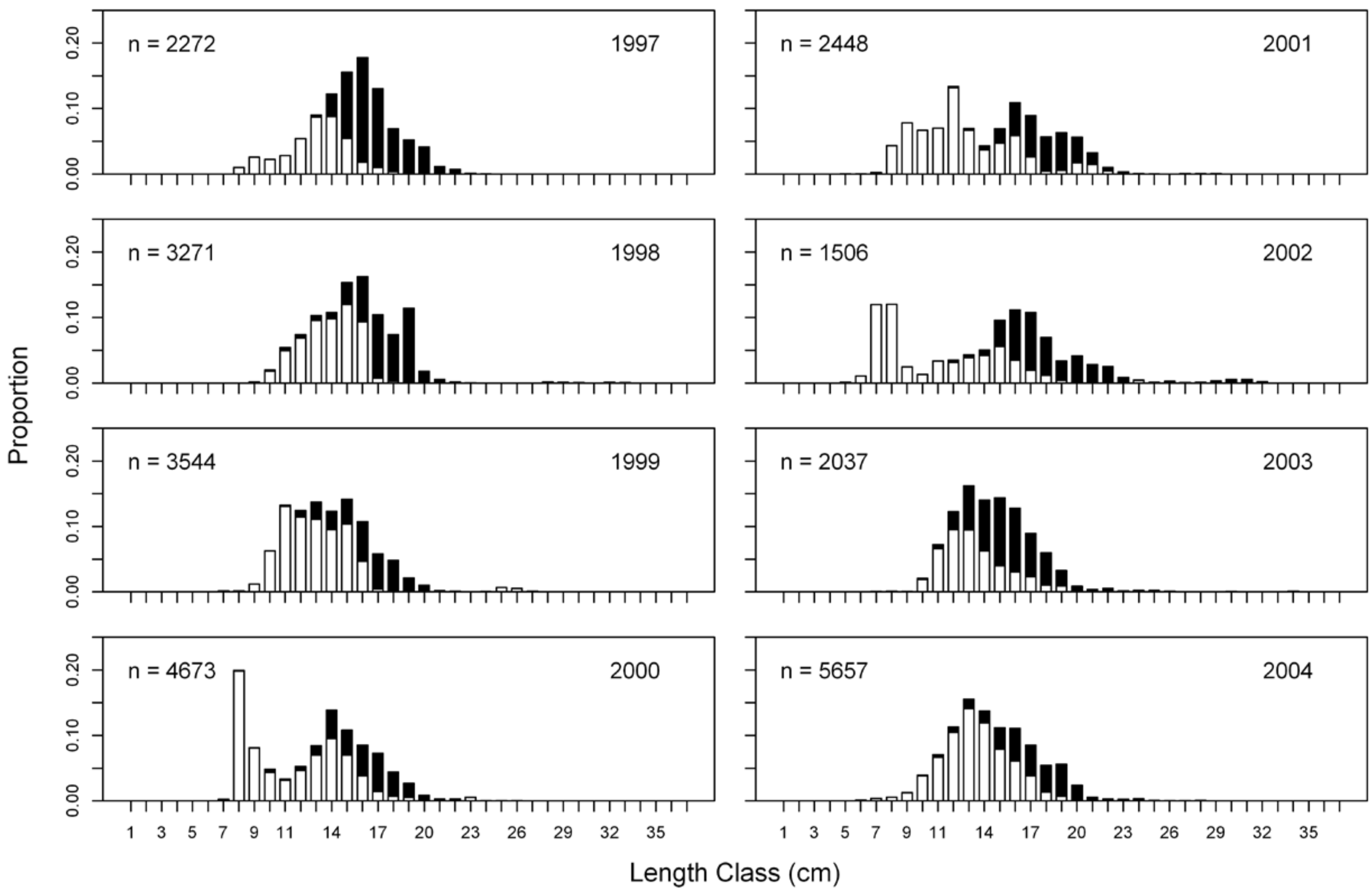
28400	0.25	0.66	0.28	0.39	0.55
28500	0.25	0.66	0.28	0.39	0.56
28600	0.25	0.66	0.28	0.40	0.56
28700	0.25	0.67	0.28	0.40	0.56
28800	0.25	0.67	0.28	0.40	0.56
28900	0.25	0.67	0.28	0.40	0.57
29000	0.25	0.67	0.28	0.40	0.57
29100	0.25	0.68	0.29	0.40	0.57
29200	0.25	0.68	0.29	0.41	0.57
29300	0.26	0.68	0.29	0.41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

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

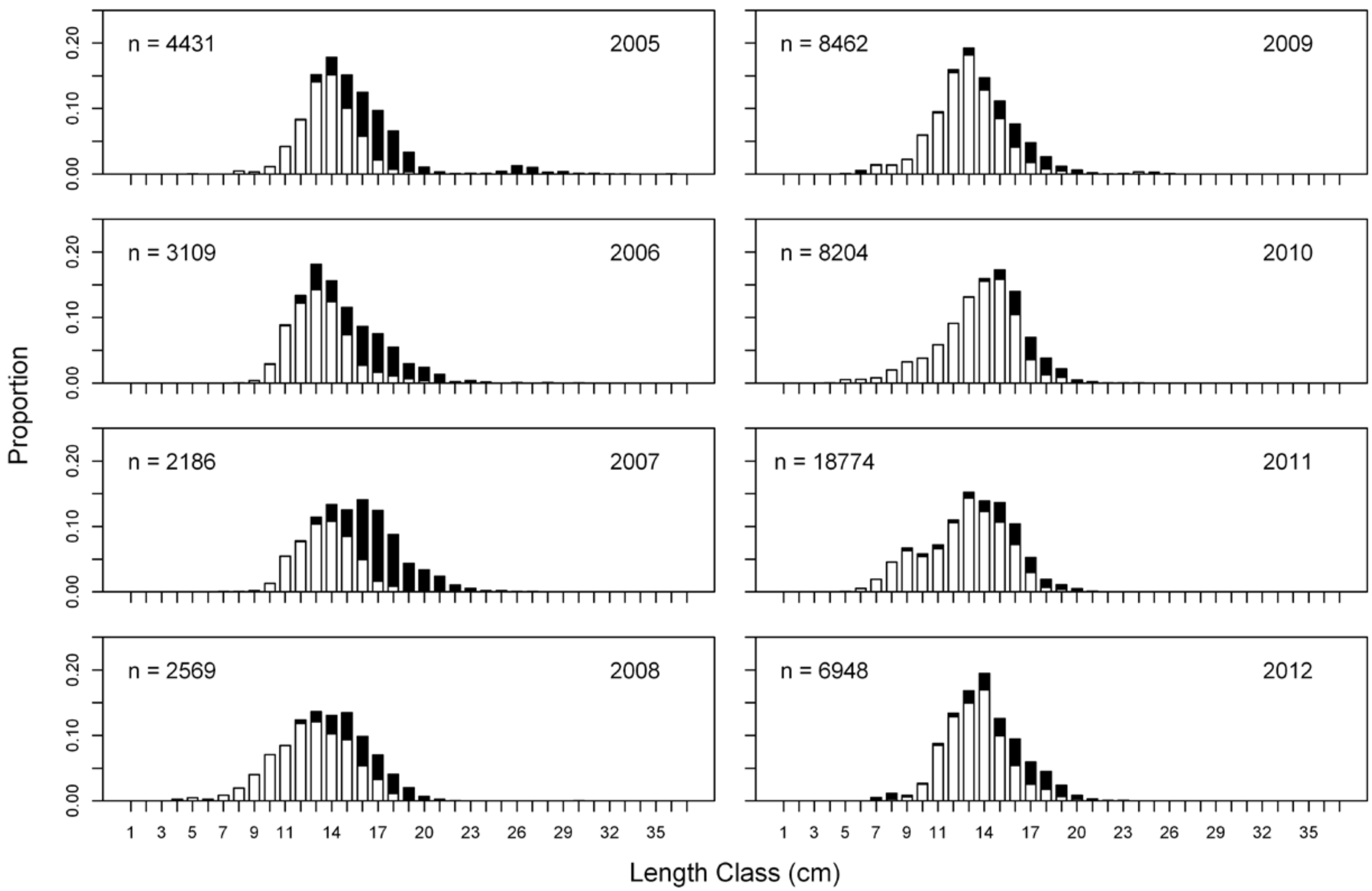
38000	0.34	1.00	0.39	0.56	0.82
38100	0.34	1.00	0.39	0.56	0.82
38200	0.35	1.00	0.39	0.56	0.83
38300	0.35	1.01	0.39	0.57	0.83
38400	0.35	1.01	0.39	0.57	0.83
38500	0.35	1.02	0.39	0.57	0.84
38600	0.35	1.02	0.40	0.57	0.84
38700	0.35	1.02	0.40	0.57	0.84
38800	0.35	1.03	0.40	0.58	0.85
38900	0.35	1.03	0.40	0.58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



App. A2 Figure A1. Length composition for NMFS Observer Program for butterfish between 1989 and 1996 with kept fish in black and discard in white. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.



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



App. A2 Figure A3. Length composition for NMFS Observer Program for butterfish between 2005 and 2012 with kept fish in black and discard in white. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

Appendix A2. Abundance indices for NEFSC fall surveys.

App. A2 Table B1. Abundance indices (number per tow) for NEFSC fall surveys in inshore strata (1-92) and offshore strata (1-14, 16, 19, 20, 23, 25, and 61-76) during 1982-2012 for ages 0-3 and 4+.

Year	0	1	2	3	4+
1982	74.28	26.52	7.54	0.50	0
1983	341.34	83.41	13.43	2.29	0.03
1984	287.43	43.91	13.23	3.17	0.00
1985	281.25	80.31	11.85	2.28	0.09
1986	140.48	27.94	11.49	1.99	0.32
1987	77.32	29.95	6.54	0.22	0
1988	275.32	20.96	12.70	0.10	0
1989	329.46	47.26	14.85	0.92	0
1990	320.81	32.93	3.77	1.02	0
1991	163.50	19.94	3.65	0.34	0
1992	223.30	9.42	4.39	0.10	0
1993	192.53	49.56	9.49	0.83	0
1994	462.33	21.98	9.40	1.46	0.02
1995	45.63	41.67	24.13	0.08	0
1996	63.56	17.31	4.00	0.27	0
1997	231.46	16.92	2.51	0.14	0
1998	149.78	48.64	8.26	0.74	0
1999	226.15	15.28	2.09	0.03	0
2000	164.44	41.94	4.98	0.38	0
2001	62.60	14.81	8.53	0.22	0
2002	88.12	10.99	3.15	0.11	0
2003	178.35	12.78	1.68	0.40	0.21
2004	66.56	16.26	8.04	0.69	0.49
2005	45.68	5.23	1.71	0.81	0.02
2006	154.96	19.78	5.25	0.93	0.08
2007	39.12	13.76	1.94	0.02	0
2008	123.06	7.69	1.09	0.06	0
2009	158.31	20.06	3.88	0.17	0.01
2010	84.09	35.90	6.90	1.25	0
2011	218.26	26.86	4.76	0.42	0.06
2012	27.15	28.83	9.91	0.62	0.07

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

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

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

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

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

Estimates of the minimum bound on butterfish biomass

BACKGROUND

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

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

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

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

METHODS

The catchability equation

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

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

Where:

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

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

Analysis of detectability using day-night differences in catch levels

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

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

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:

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

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

Confidence intervals on the maximum bounds of catchability

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

Bigelow-Albatross calibration

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

RESULTS

Maximum bound on detectability

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

Maximum bound on availability using inshore trawl survey data

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

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

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

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

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

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

Estimates of Minimum bounds on Biomass

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

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

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

DISCUSSION

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

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

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

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

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

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

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

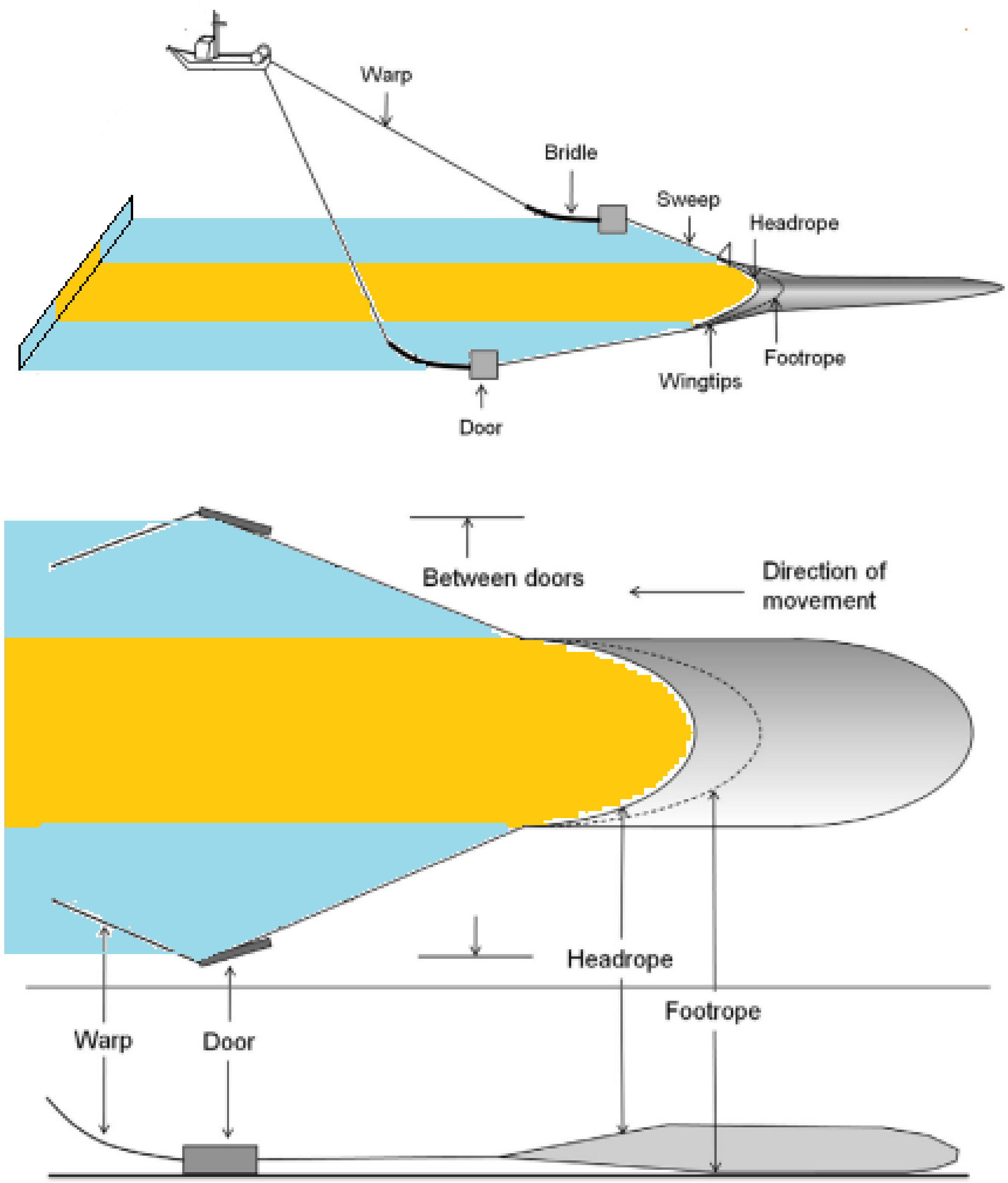
[4] Used 30 minute tow at 3.5 knots with a wing spread of 8 meters (26.24 ft).

[5] LIS Survey not complete for 2010

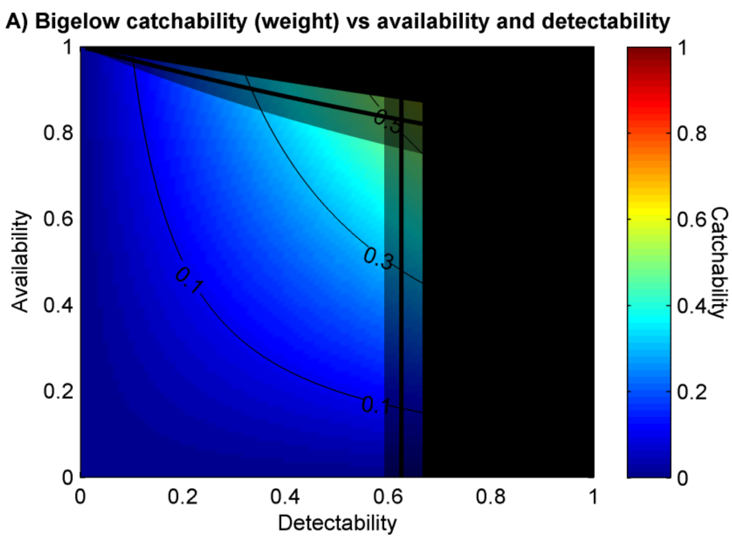
App. A3 Table 2: Estimates of the minimum bounds on total butterfish biomass during the fall survey period. The total biomass estimates using the door swept area assumes complete herding of butterfish into the trawl net, and also includes the upper 95% CI on catchability. The total biomass estimate using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

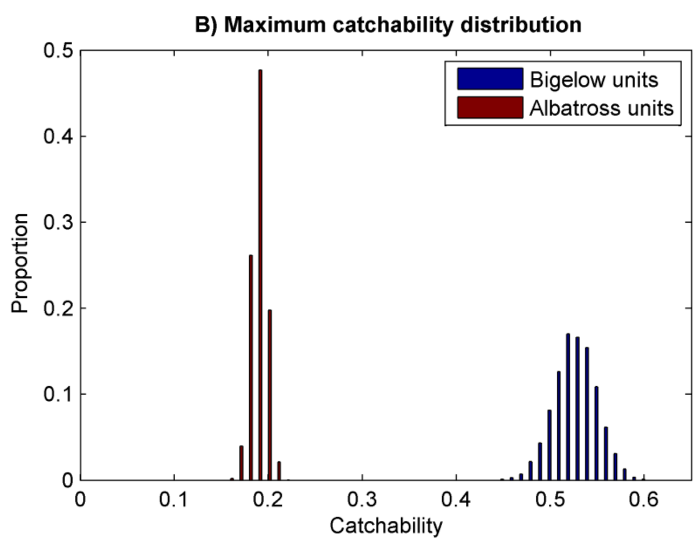
Year	$Weight\ Tow^{-1}$ Alb IV[1]	$Weight\ Tow^{-1}$ Bigelow	Total Biomass Fall metric ton- Doors	Total Biomass Fall metric ton Wings
1989	12	21.7	92,832	257,307
1990	8.74	15.8	67,613	187,405
1991	5.15	9.3	39,841	110,428
1992	4.38	7.9	33,884	93,917
1993	9.63	17.4	74,498	206,489
1994	12.51	22.6	96,778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

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

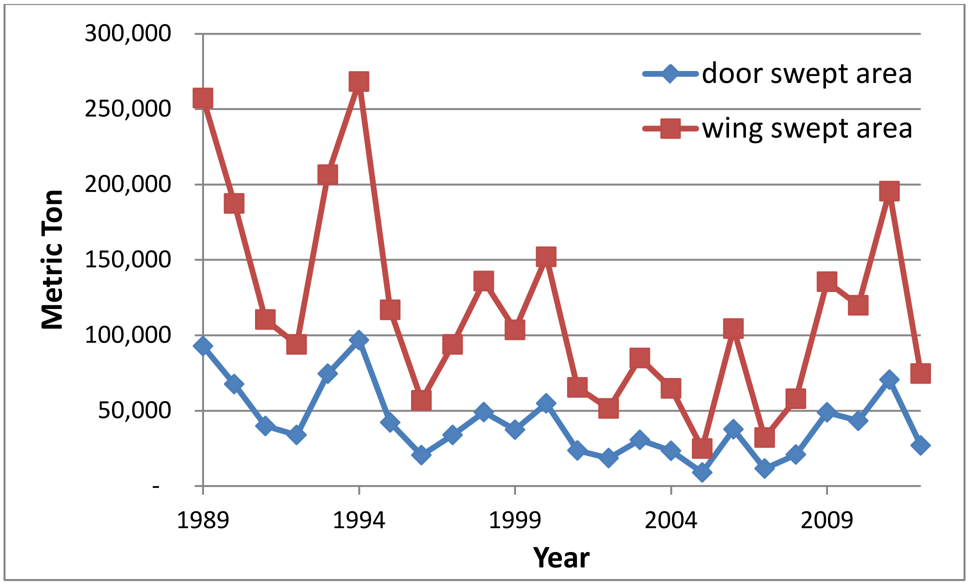


App. A3 Fig. 2. A) Plot of catchability different values of availability and detectability. The black shaded areas correspond to catchability values for the 24-hour Bigelow survey that are not possible given the analyses presented in this paper. Restrictions on detectability are due to the day:night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





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



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

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

Diagnostics for the final model

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

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

Results for the final model

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

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

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

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

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

Sensitivities

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

Retrospective patterns for the final model

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

SARC 58 biological reference points based on the final model

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

Stock status

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

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

Projections

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

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

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

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

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

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

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

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

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

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

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

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

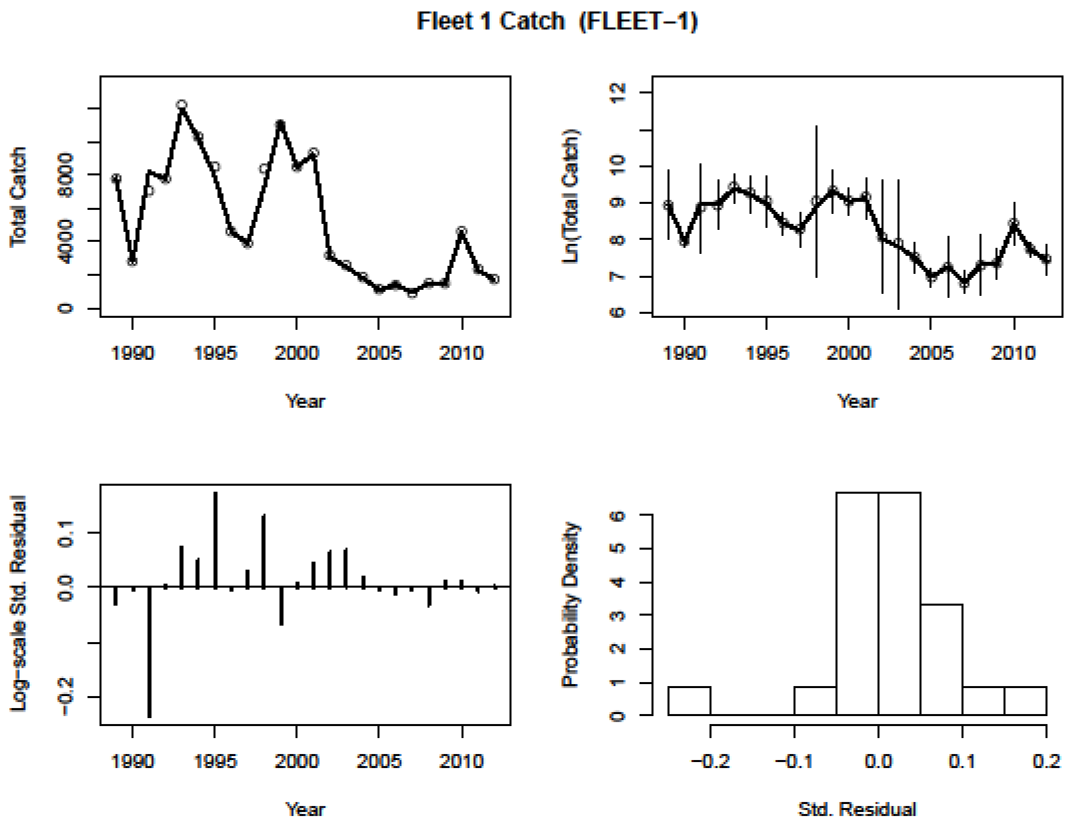
App. A4 Table 5. Estimated numbers at age (millions) on January 1 from the final model.

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

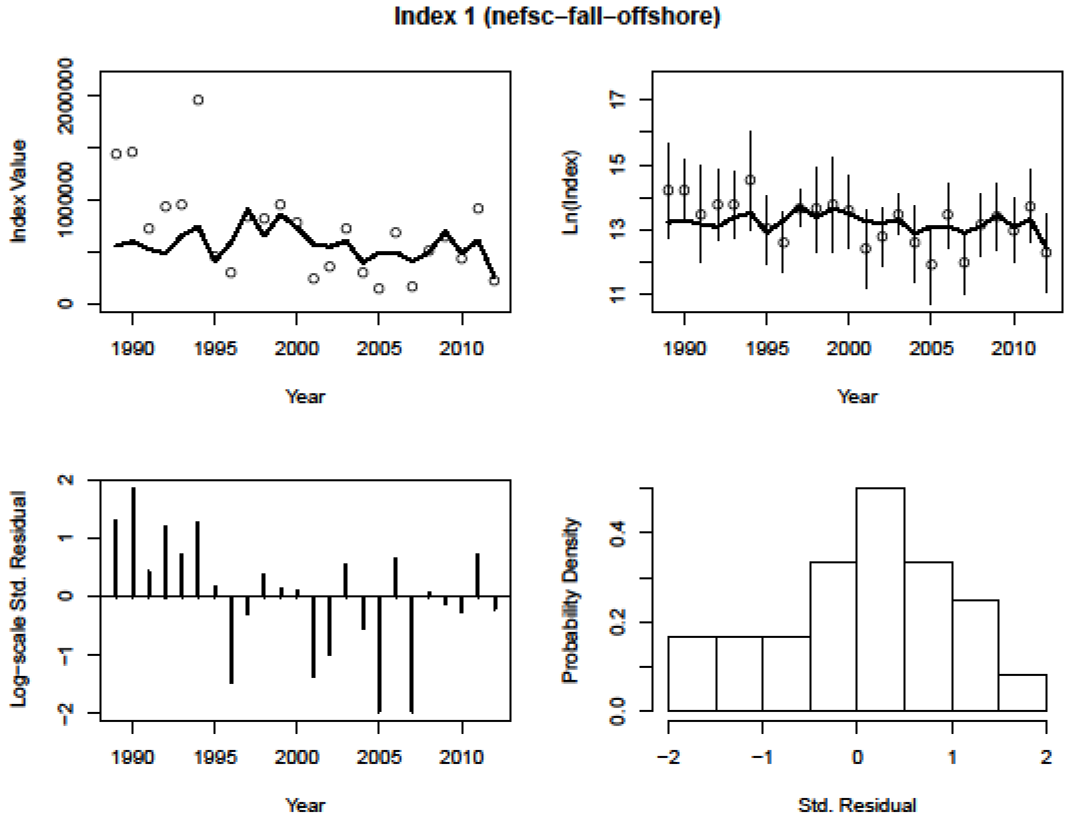
App. A4 Table 6. Accepted biological reference point for F_{MSY} and SSB_{MSY}, with 95% confidence interval, from the final model.

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

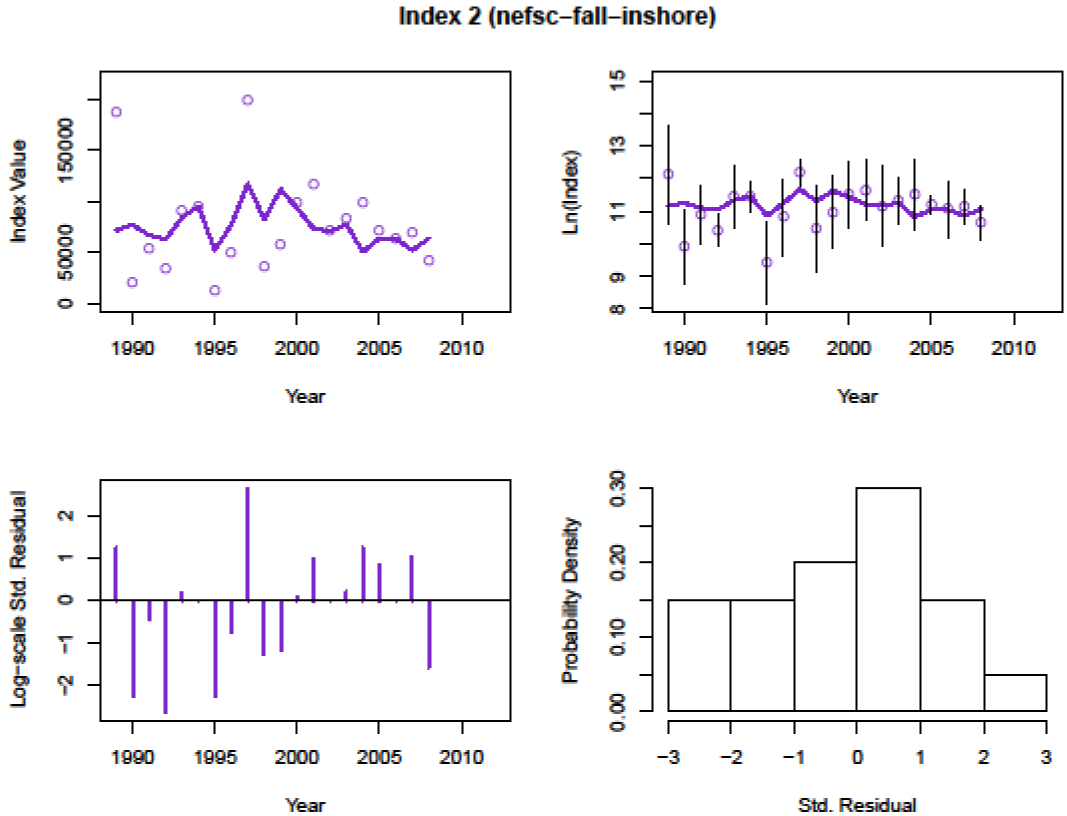
F_{MSY}	CV
0.81	0.05



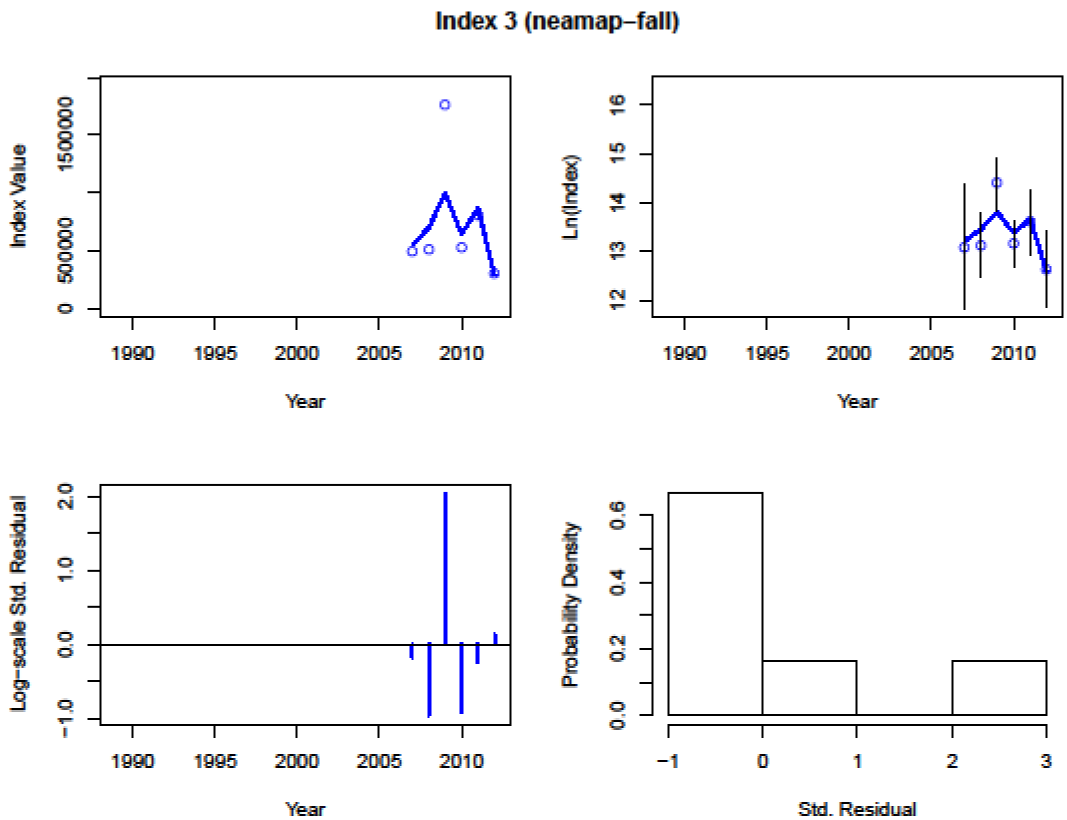
App. A4 Figure 1. Diagnostics for aggregate catch from the final model.



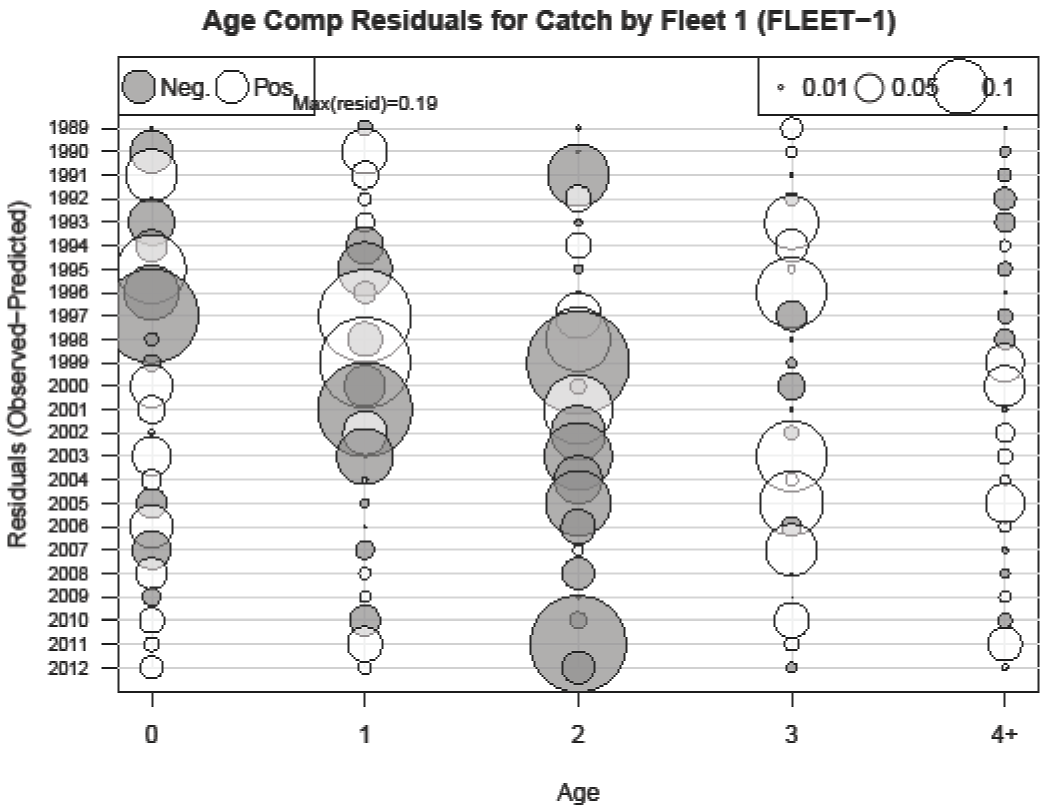
App. A4 Figure 2. Diagnostics for the NEFSC fall offshore survey from the final model.



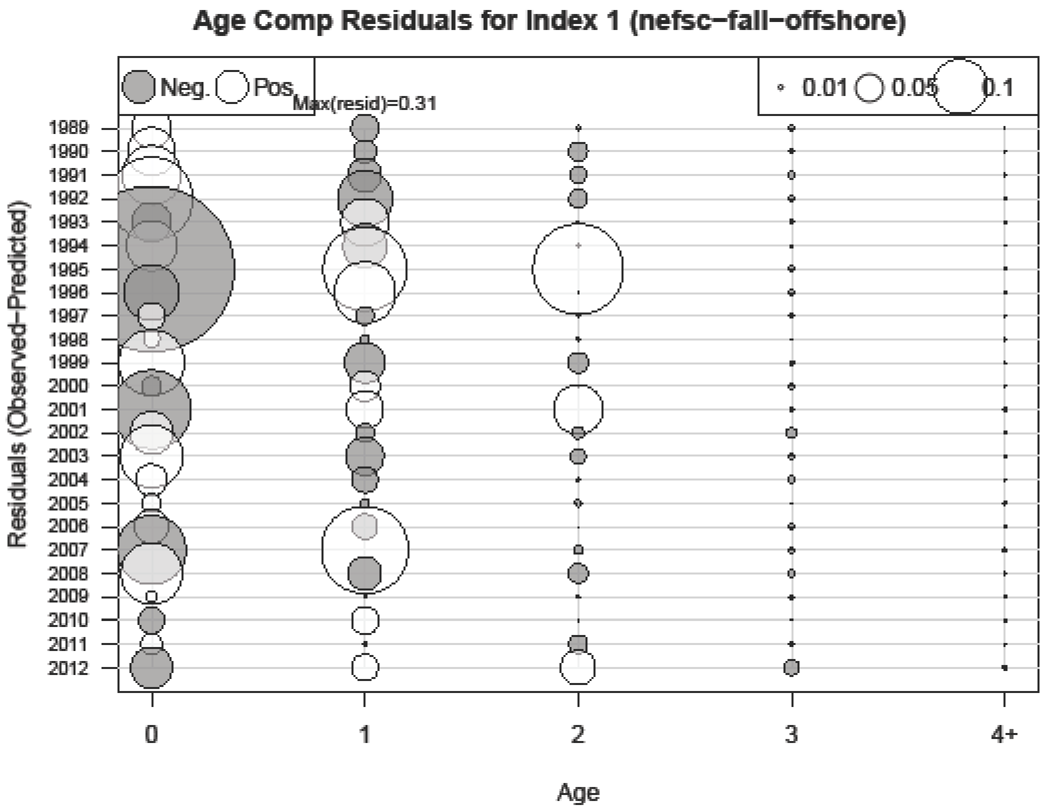
App. A4 Figure 3. Diagnostics for the NEFSC fall inshore survey from the final model.



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

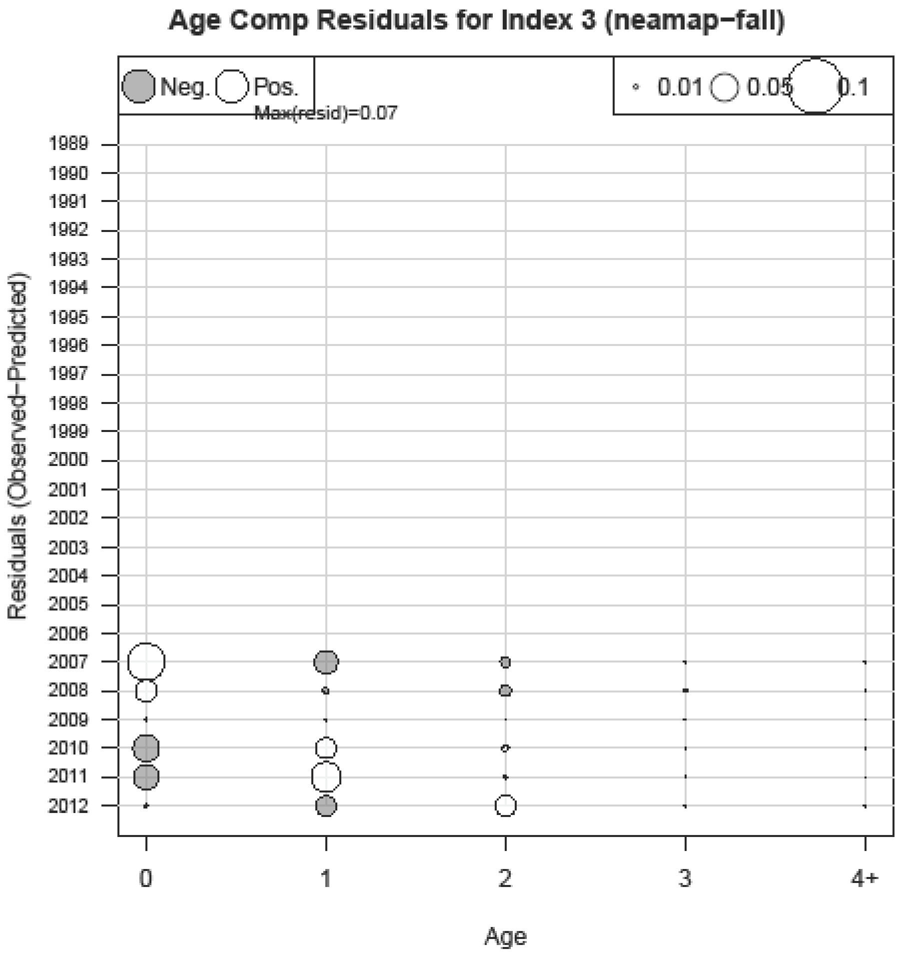


App. A4 Figure 5. Residuals for catch age composition from the final model.

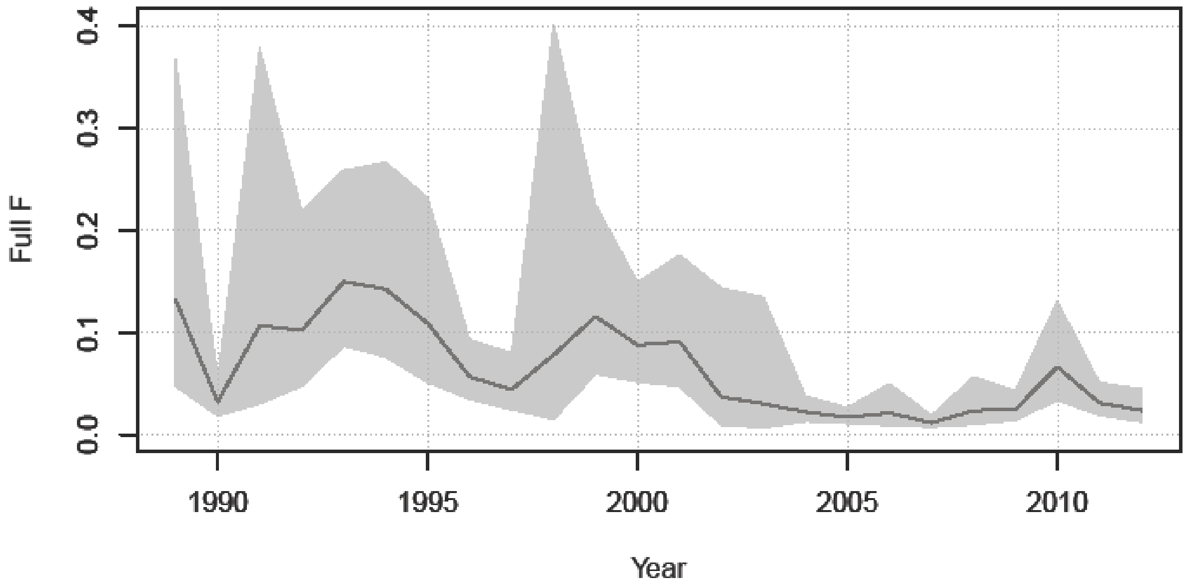


App. A4 Figure 6. Residuals for NEFSC fall offshore age composition from the final model.

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

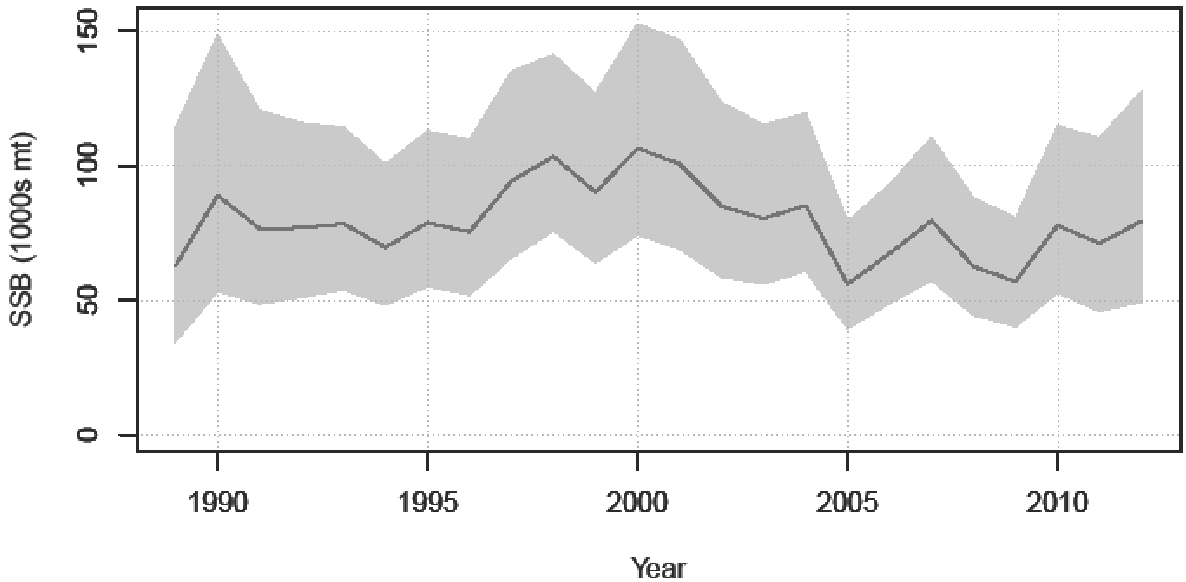


App. A4 Figure 8. Residuals for NEAMAP fall age composition from the final model

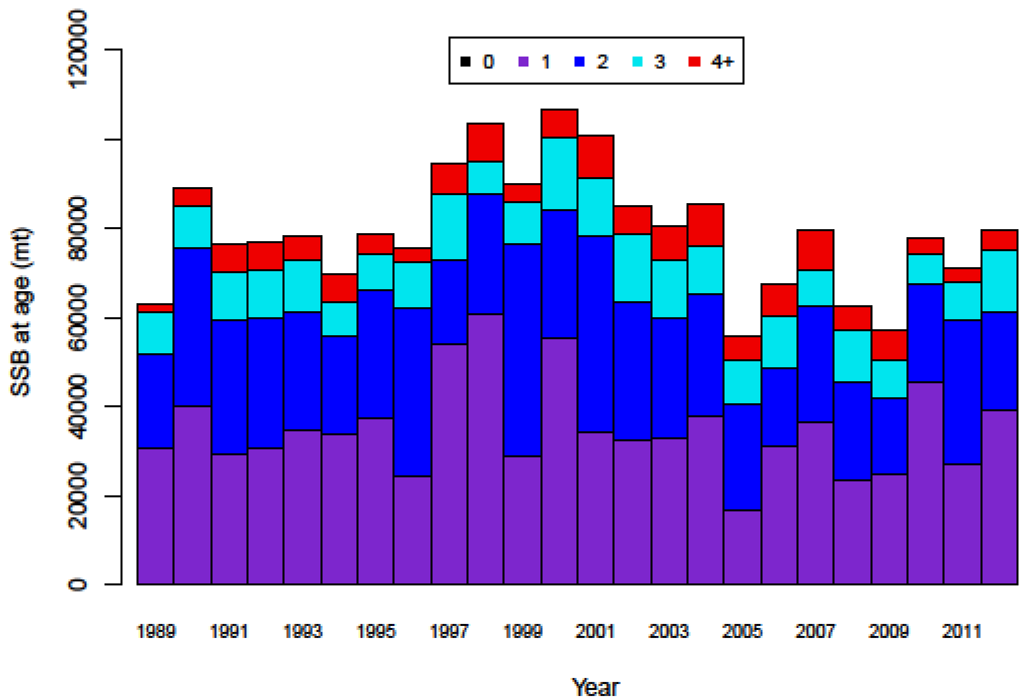


App.A4 Figure 9. Estimated fully selected fishing mortality rate and 95% confidence interval from the final model.

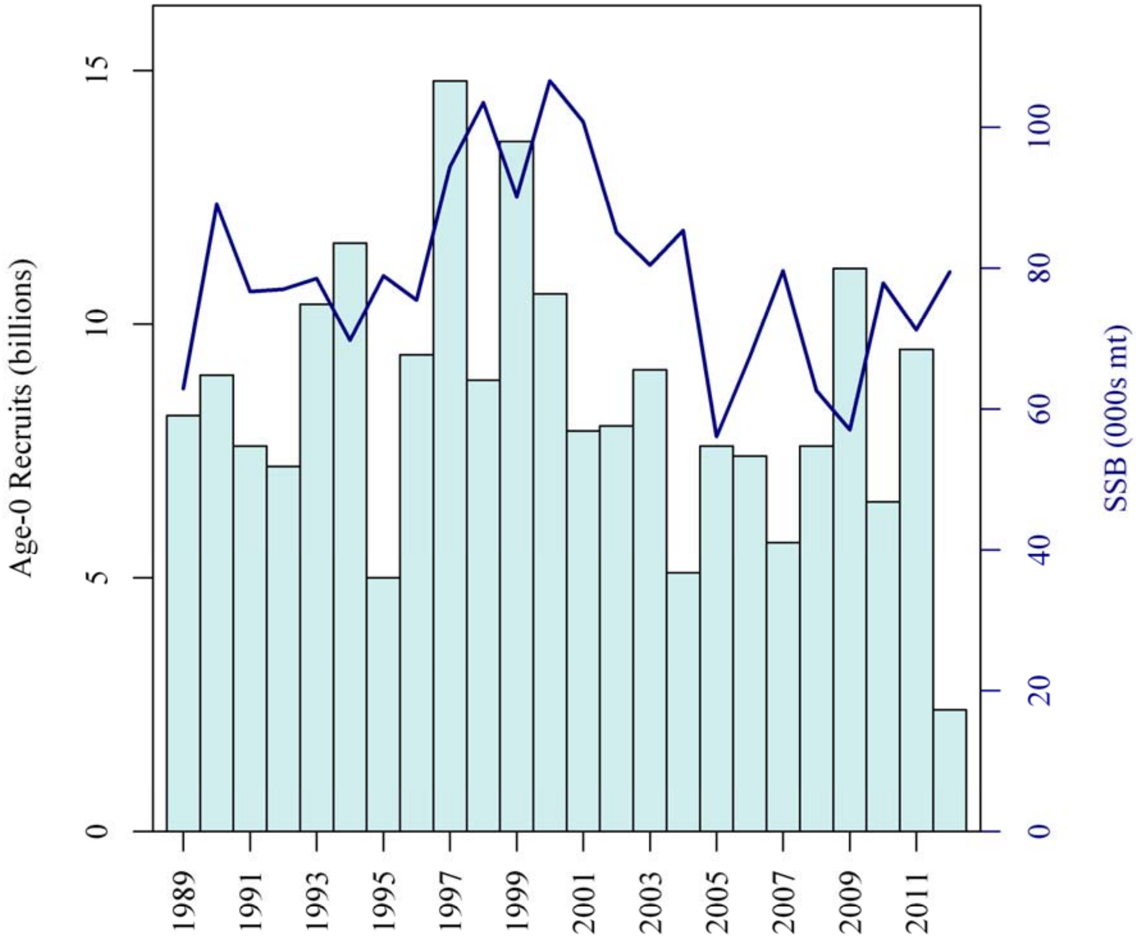
App. A4 Figure 10. Fleet selectivity at age from the final model.



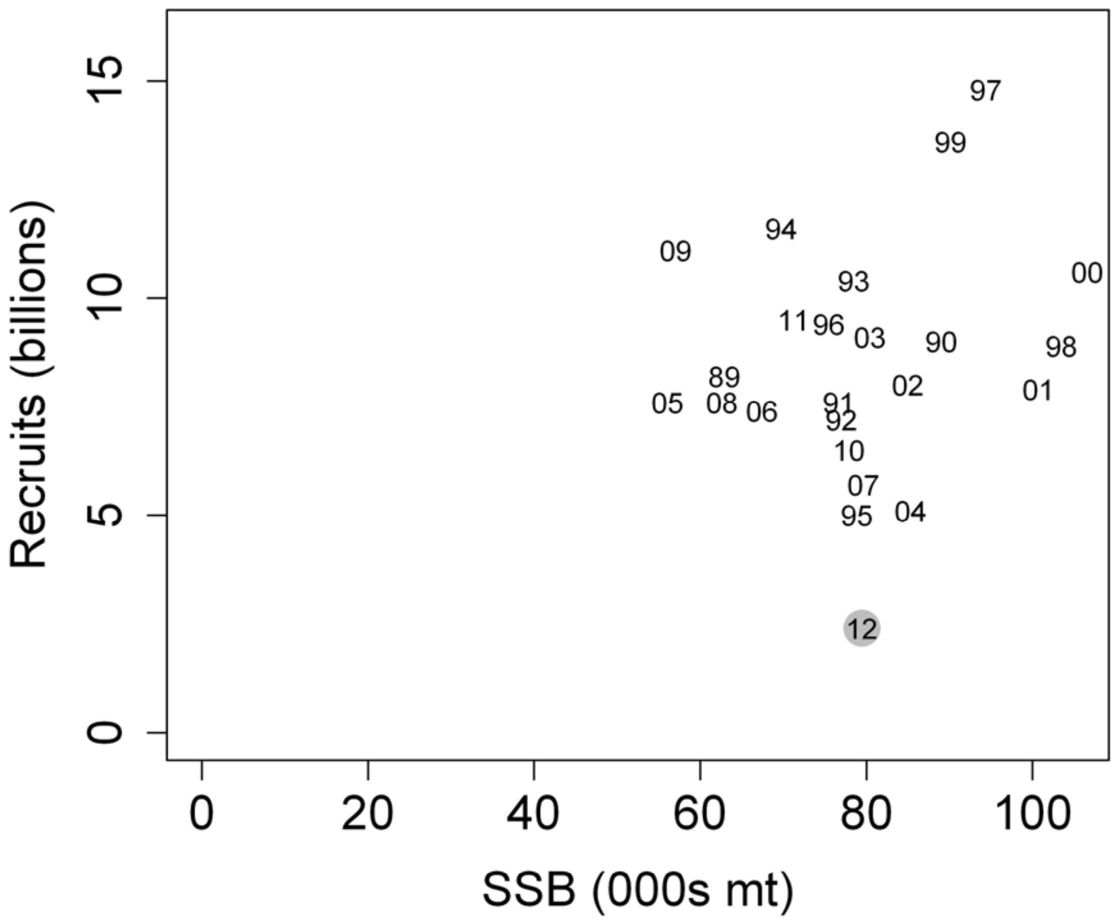
App. A4 Figure 11. Estimated spawning biomass and 95% confidence interval from the final model.



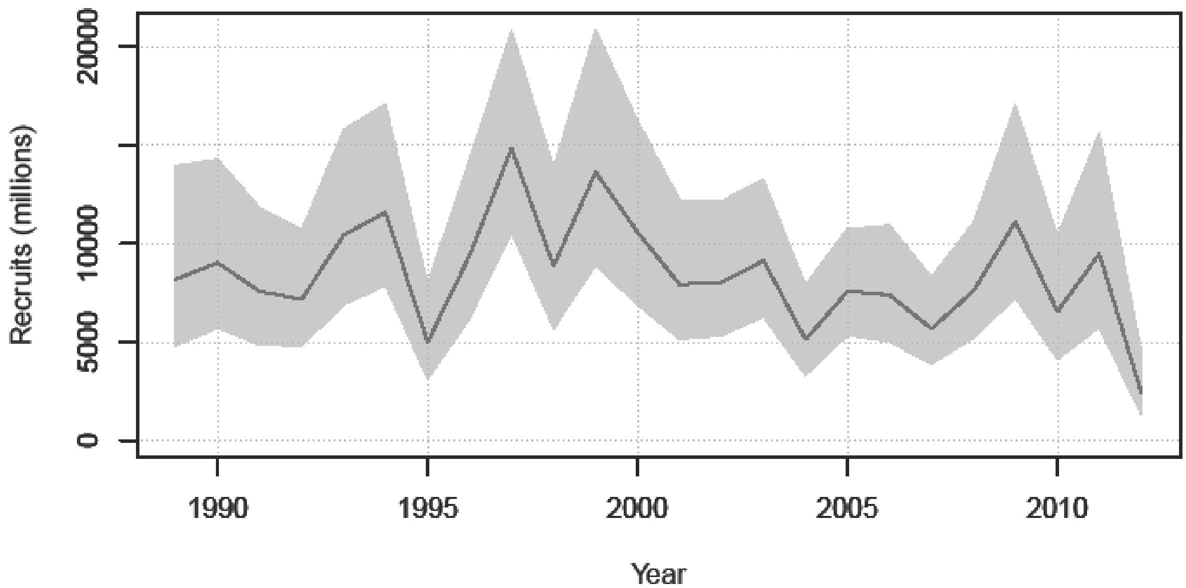
App. A4 Figure 12. Estimated annual spawning biomass at age from the final model.



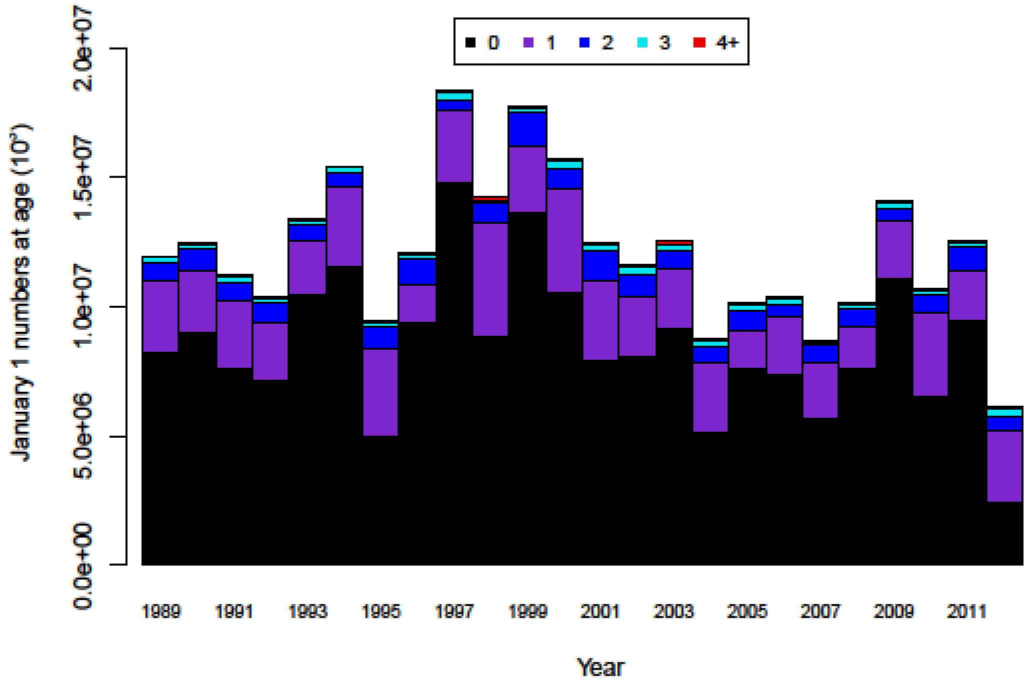
App. A4 Figure 13. Butterfish recruitment (vertical bars), and the spawning stock biomass (blue line) that produced the corresponding recruitment. Year refers to spawning year.



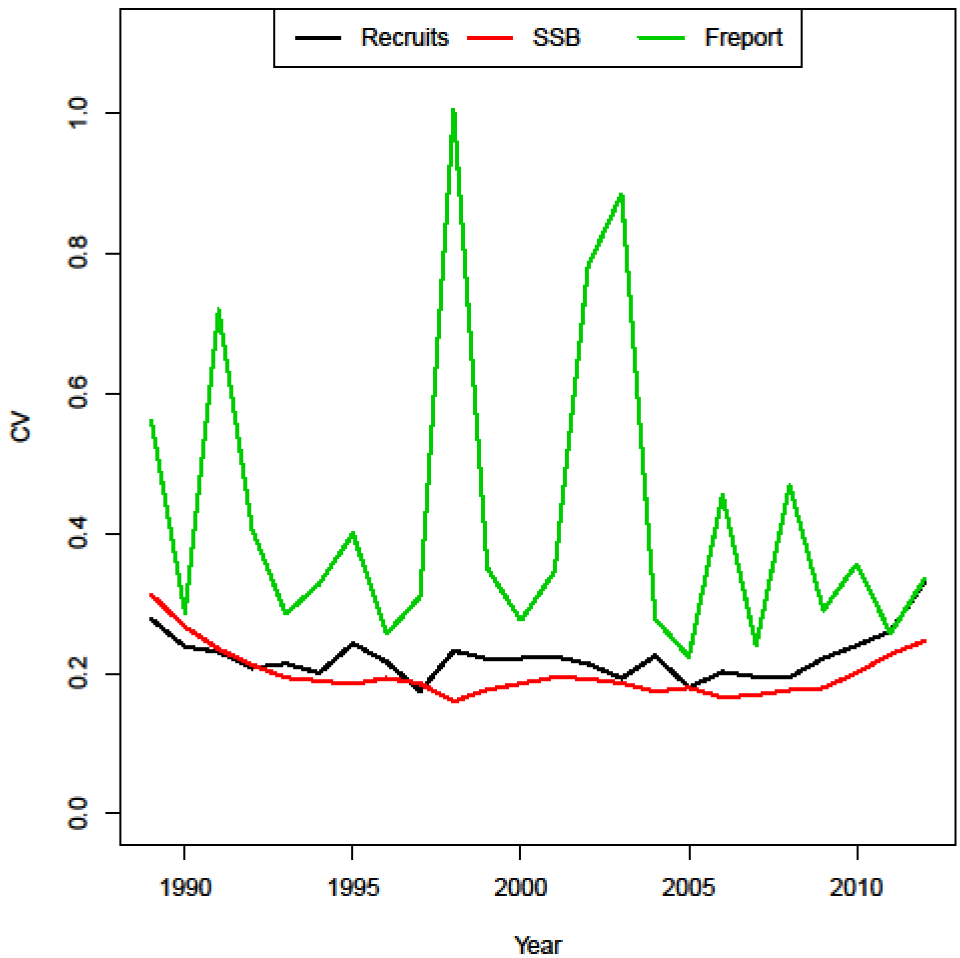
App. A4 Figure 14. Butterfish stock-recruitment scatter plot, with two digit indicator of model year.



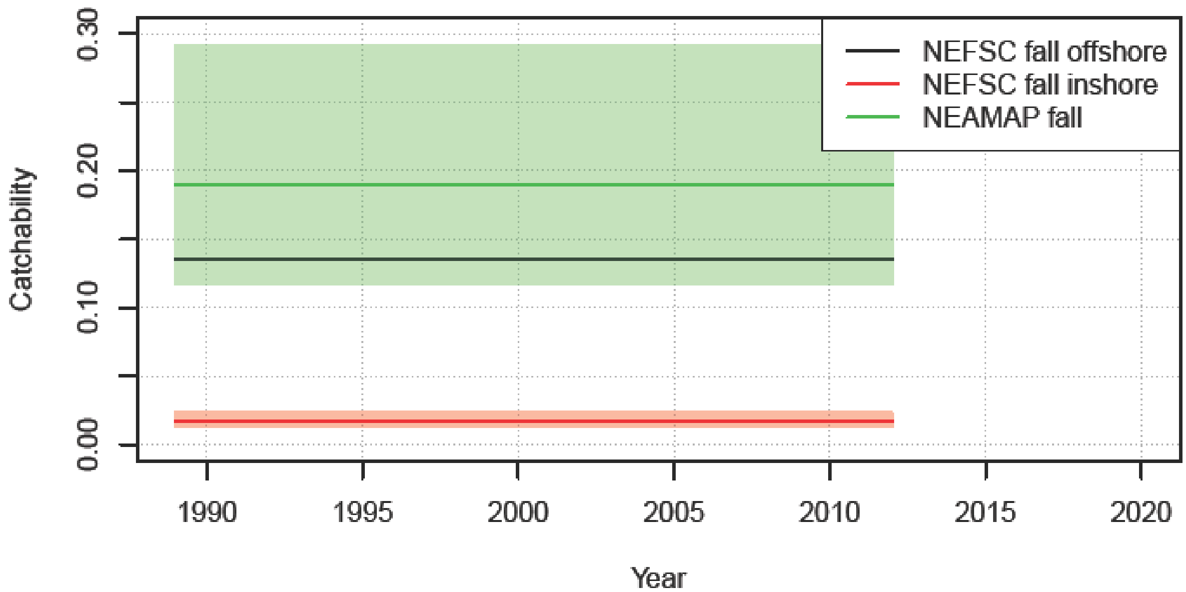
App. A4 Figure 15. Estimated recruitment and 95% confidence interval from the final model.



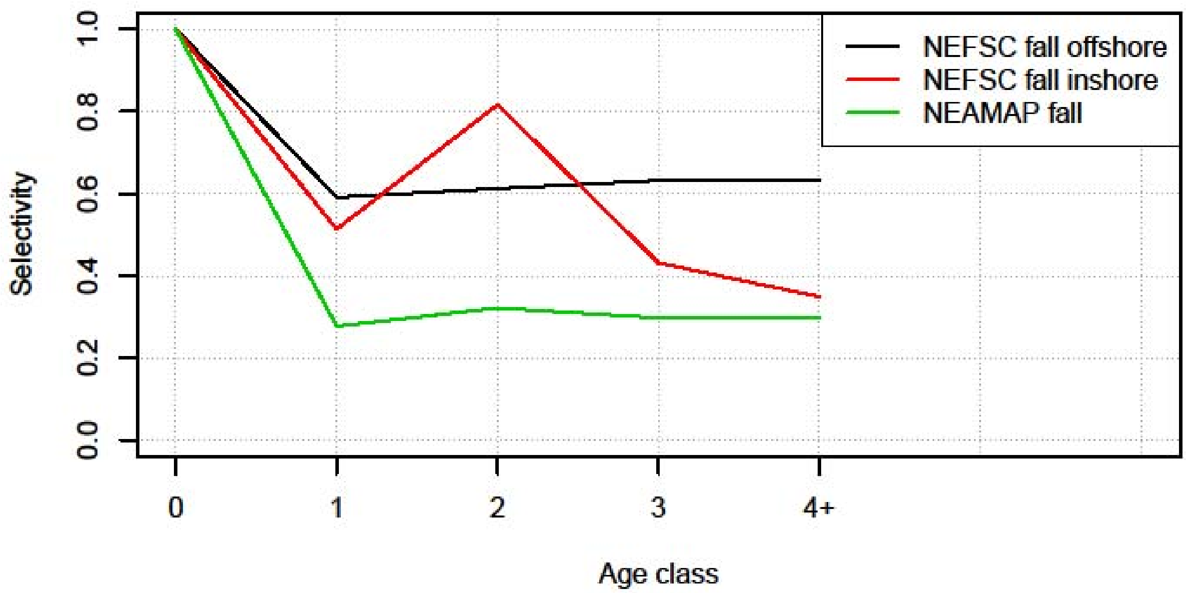
App. A4 Figure 16. Estimated numbers at age on January 1 from the final model.



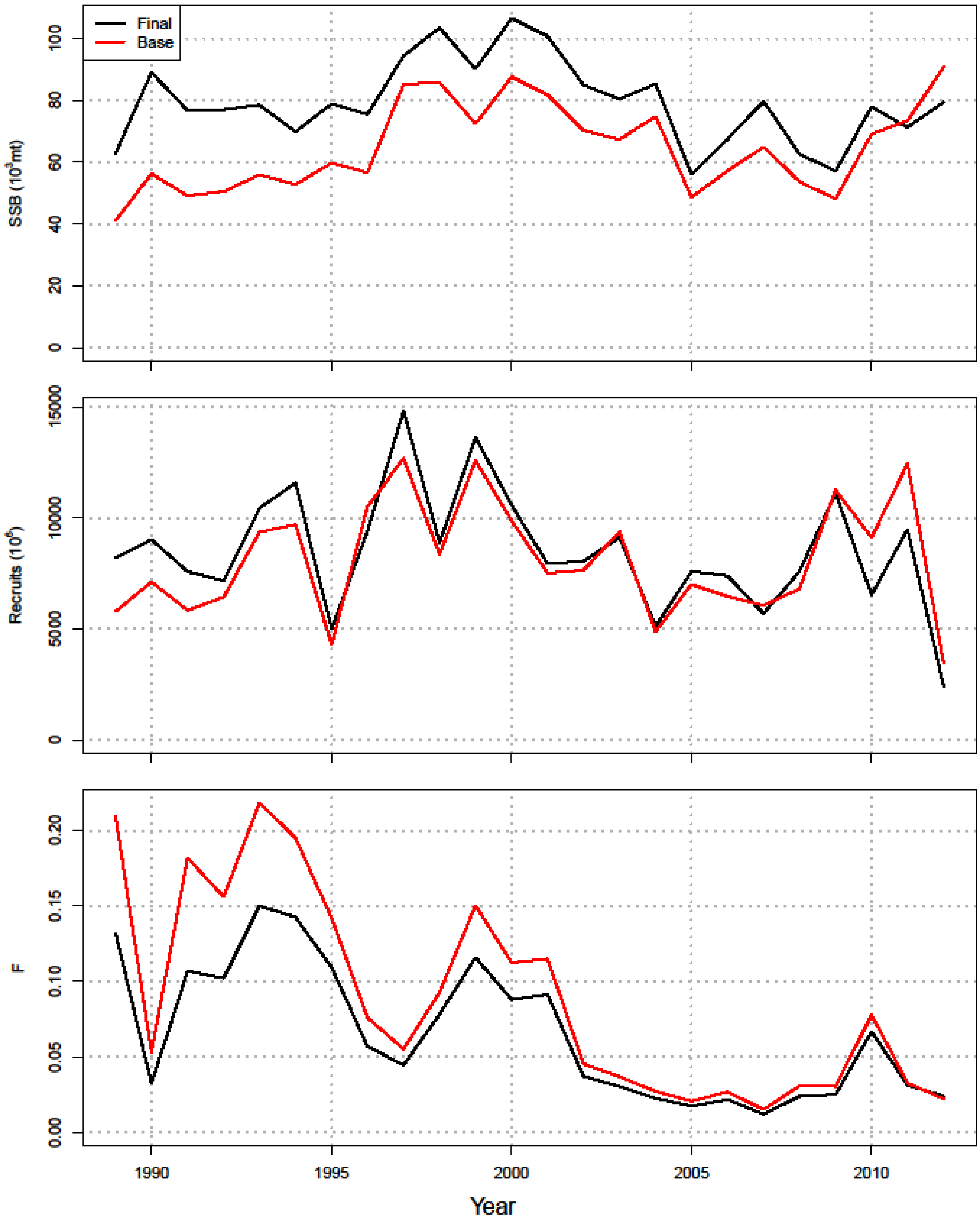
App. A4 Figure 17. Coefficients of variation for estimates of SSB, recruits and fully selected fishing mortality from the final model.



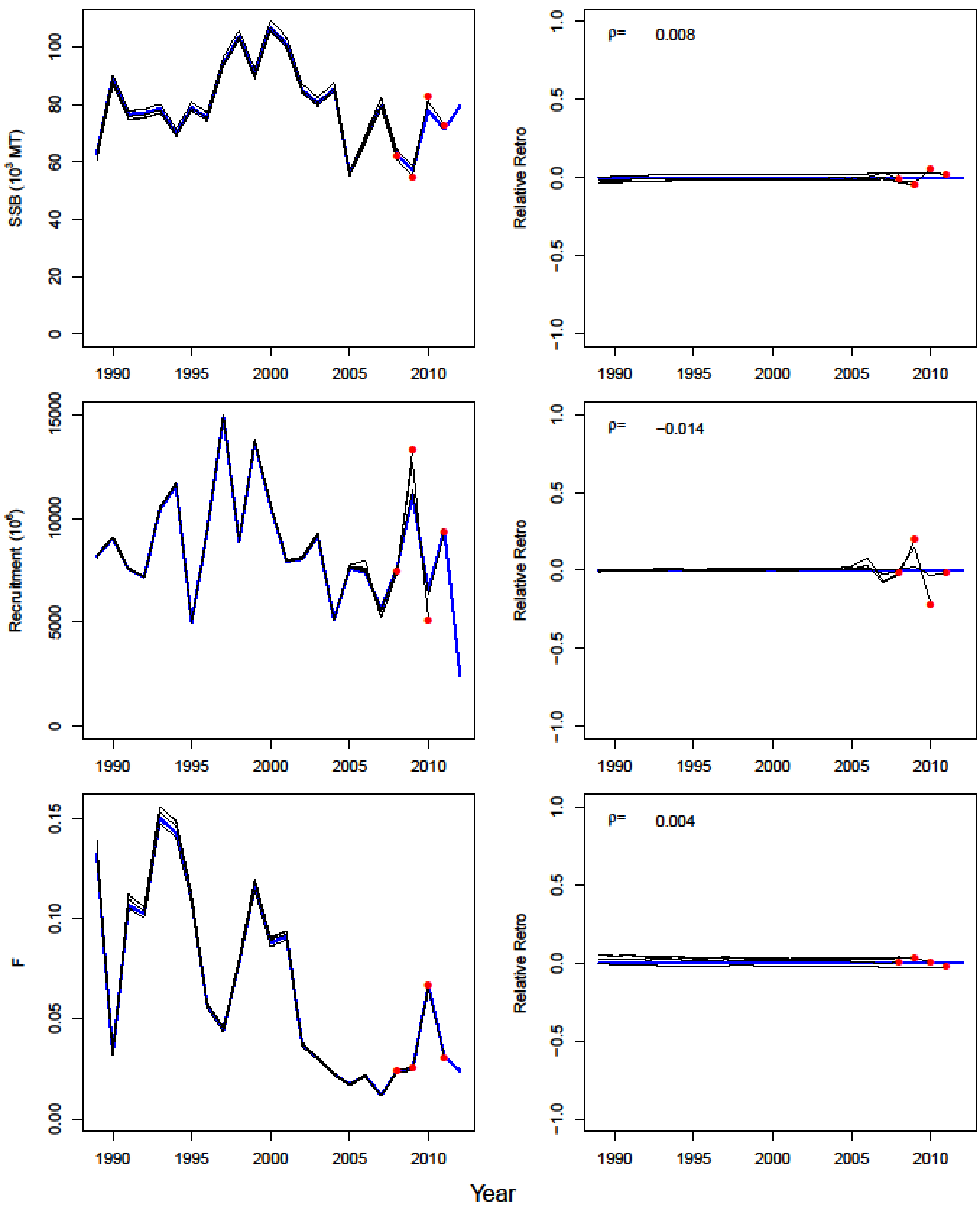
App. A4 Figure 18. Index catchability and 95% confidence interval from the final model.



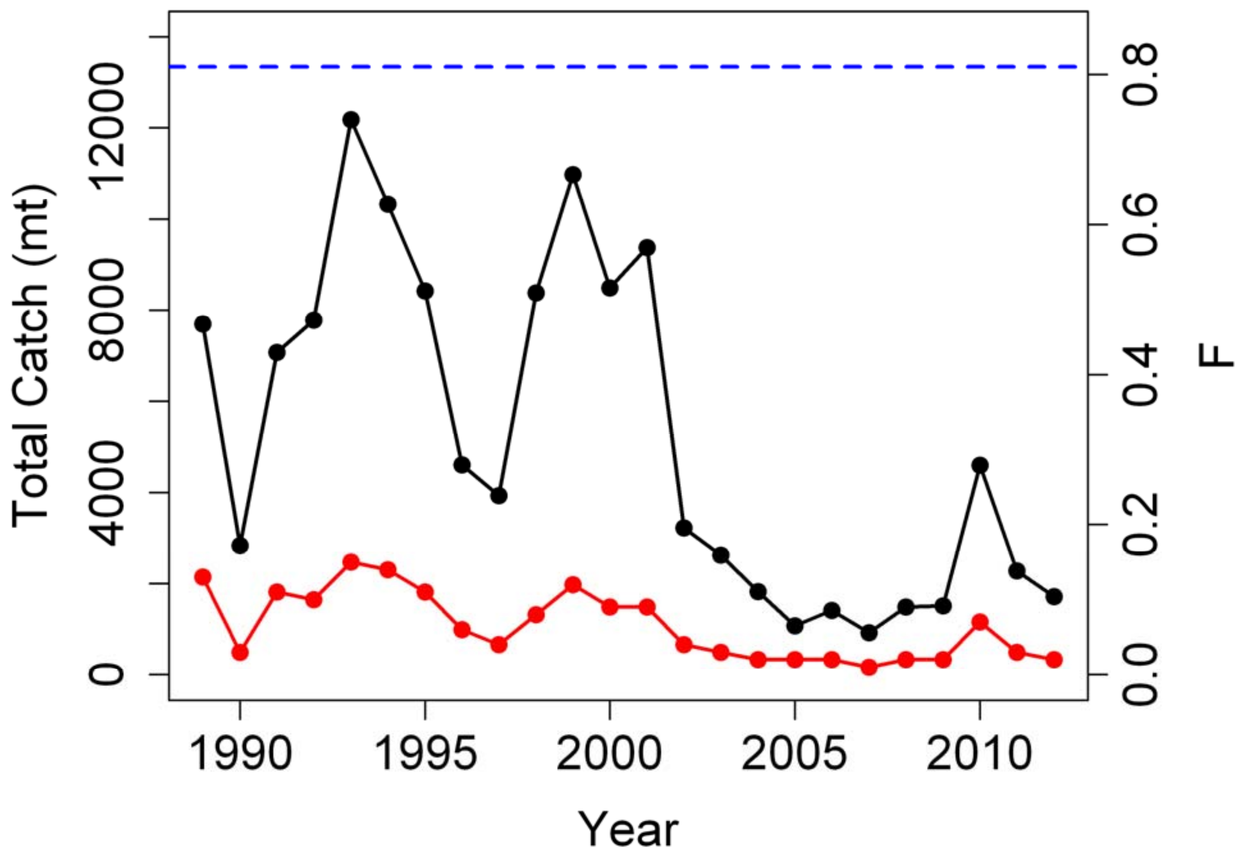
App. A4 Figure 19. Index selectivity from the final model.



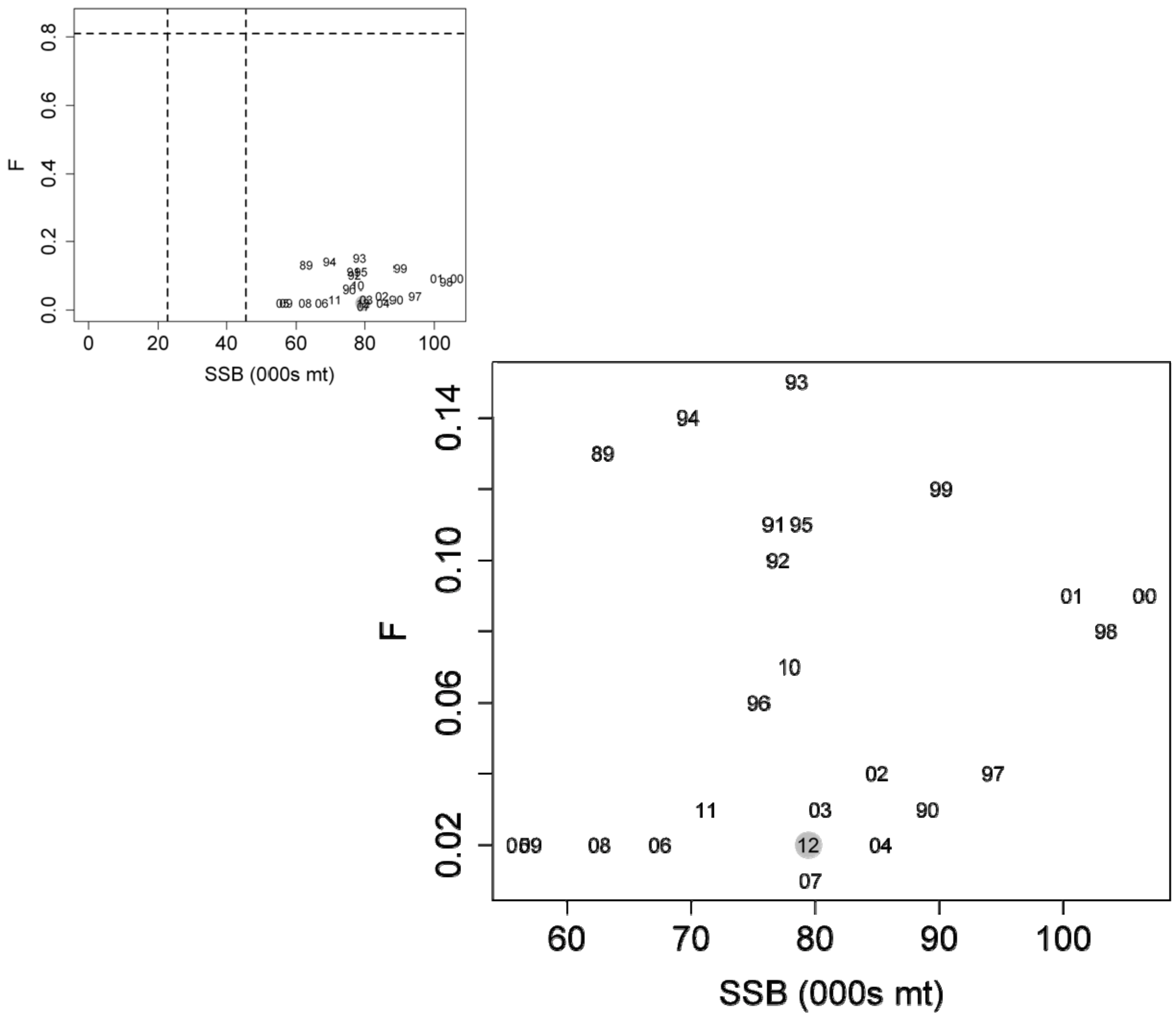
App. A4 Figure 20. Annual estimates of spawning biomass, recruitment and fishing mortality for the base and final models.



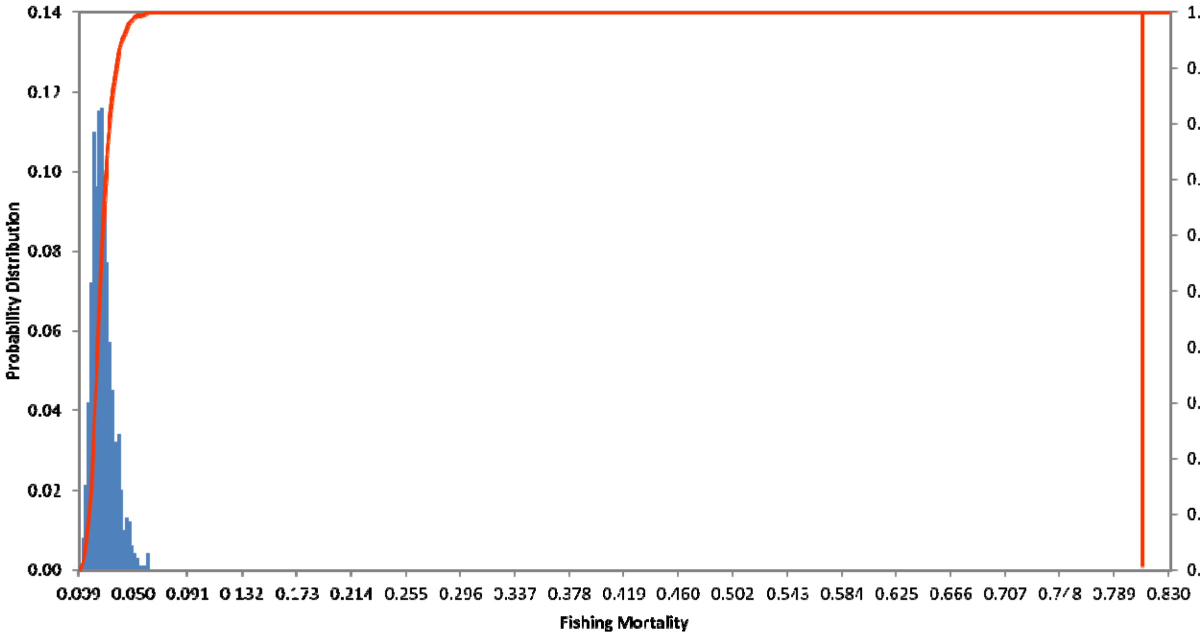
App. A4 Figure 21. Retrospective patterns for spawning biomass, recruitment and fishing mortality in the final model.



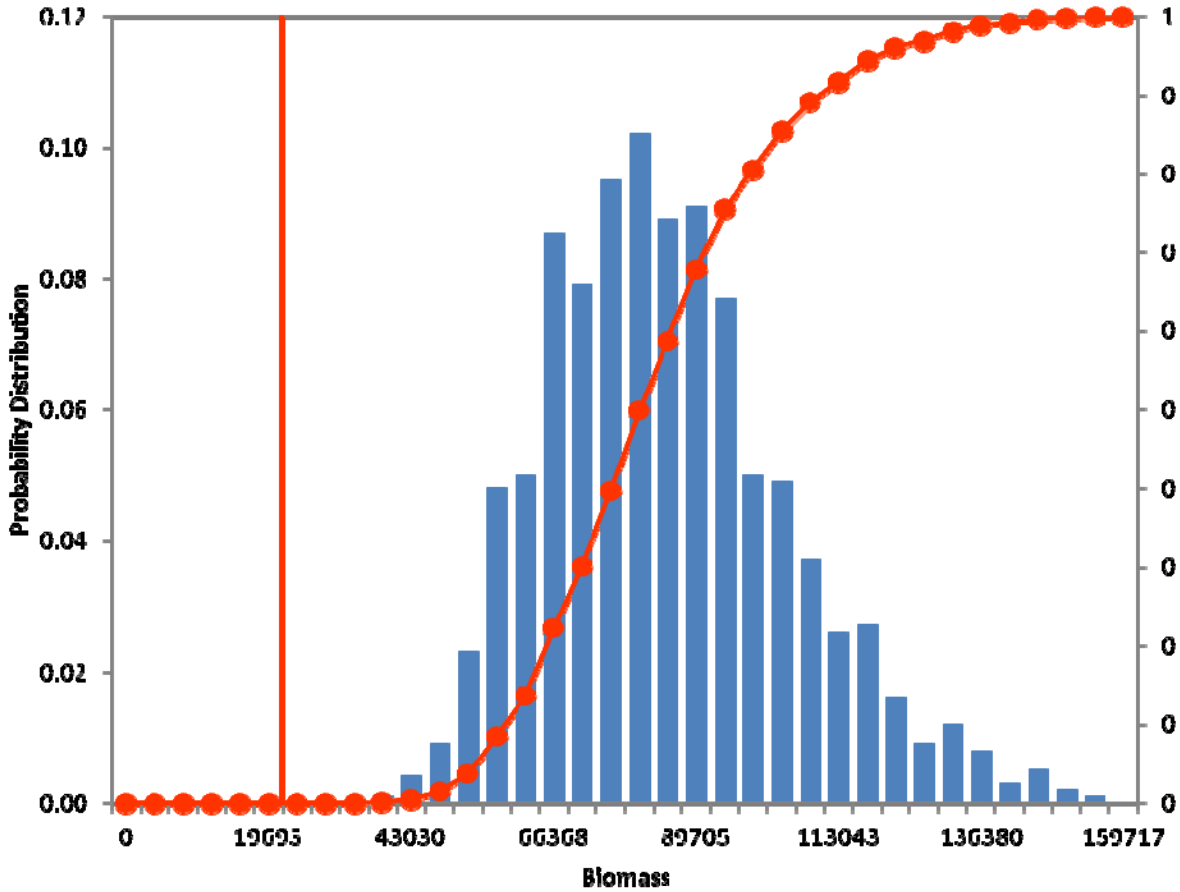
App. A4 Figure 22. Butterfish total catch (mt) and fishing mortality (F). Dashed blue line is the 2014 SAW/SARC F_{MSY} proxy = 0.81.



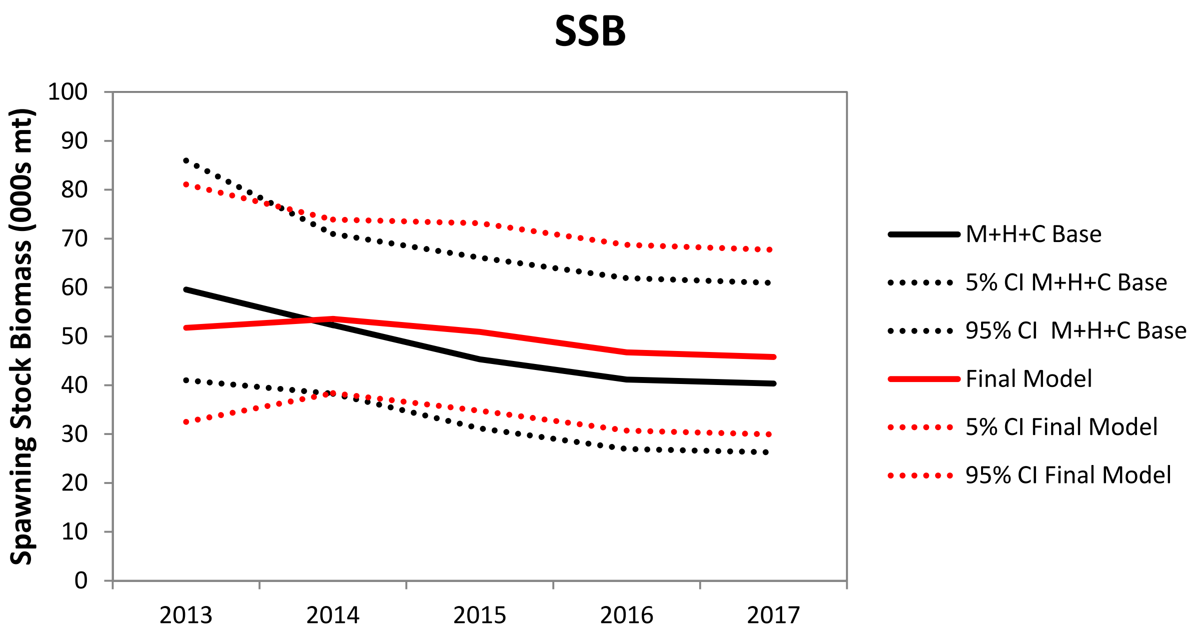
App. A4 Figure 23. Butterfish spawning stock biomass (SSB) and fishing mortality (F) relative to the 2014 SAW/SARC biological reference points $SSB_{threshold}$ = 22,808 mt, SSB_{MSY} proxy = 45,616 mt (100.6 million lb), and F_{MSY} proxy = 0.81 (upper left panel). Plot is expanded for clarity in lower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



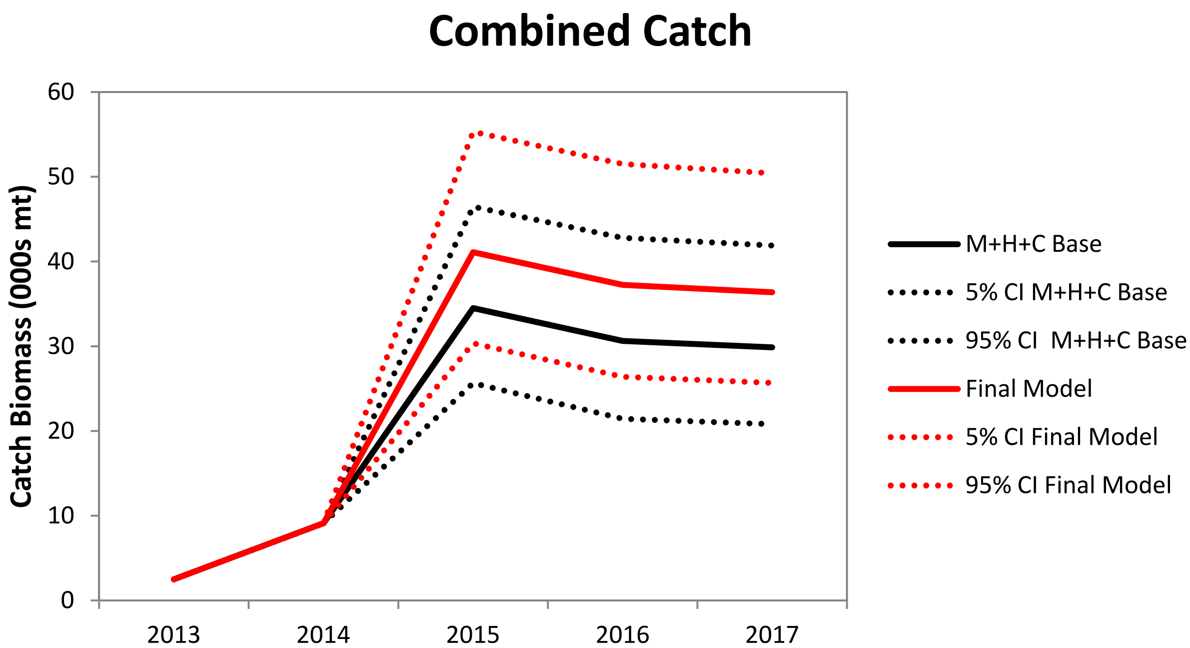
App. A4 Figure 24. Markov Chain Monte Carlo distribution plots for annual total F. Vertical line shows F_{MSY} proxy = 0.81.



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



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



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