APPENDIX 4. PRELIMINARY CASA MODELS FOR SEA SCALLOPS

CASA model results are for use by reviewers in evaluating CASA as a primary analytical tool for the next sea scallop stock assessment. At meetings during 2004, the Invertebrate Subcommittee opted to use methods from NEFSC (2001) to evaluate the official status of sea scallops for the 2004 stock assessment; results described in this appendix are therefore not intended by the Subcommittee for use by managers. The Subcommittee also decided, however, that the CASA modeling approach had considerable merit, provided information not otherwise available, and that it could be used as a primary stock assessment method in the next stock assessment if reviews and subsequent testing proved favorable.

To facilitate review work, this appendix describes CASA models and example results for sea scallops in the Mid-Atlantic Bight (MAB) and Georges Bank (GBK) regions.[3] In the interests of space, results for MAB sea scallops are emphasized. More data were available for MAB and the fishery in GBK is a bit more complicated (due to extensive closed areas during recent years where fishing is periodically allowed), but results were basically similar. See Appendix 5 for a general and technical description of the model.

Model structure

Length bins in the models for both regions were 20-155 mm in 5 mm increments. The 155 mm bin includes the best available estimates of L for both stocks (NEFSC 2001). Von Bertalanffy K values and length-weight parameters were fixed at the best available estimates for both regions (NEFSC 2001). The natural mortality rate M was assumed to be 0.1 y^{-1}. Based on examination of survey length composition data, scallops were assumed to recruit into the first 13 size bins (20-84.9 mm, see below) with probabilities for each bin from region-specific beta distributions (beta distribution parameters estimated in the model).

Growth probabilities were from gamma distributions with parameters estimated in the models for each region using length increment data from shells collected during the 2001 NEFSC scallop survey from the GBK and MAB regions. Minimum and maximum growth increments were specified based on a visual examination of the data (Appendix Table 4-1). In retrospect, higher values of maximum growth increments should have been used and minimum and maximum values should have been specified more carefully. Growth matrices estimated in the model for both areas were similar and seemed reasonable (Appendix Table 4-2). Length based selectivity in the NEFSC scallop survey was assumed fixed at the best available estimates, although selectivity parameters for the NEFSC scallop survey were estimated in some sensitivity analysis runs. Selectivity parameters for the commercial fishery and for other surveys in the MAB region were estimated in the models.

[3] See Appendix 5 for a technical description of the CASA model.

Mid-Atlantic Bight

Model runs for MAB sea scallops during 1979-2004 used a very wide range of data (Appendix Table 4-3). The last year in the analysis was 2004 because data from the NEFSC winter bottom trawl survey during 2004 was available and because information about scallop abundance and length composition during early 2004 should improve estimates for 2003. However, estimates for 2004 were based little information and are not presented. Landings in 2004 were assumed equal in calculations to the mean during 2001-2003.

Based on information about recent developments in the fishery and availability of fishery length composition data, the CASA model was configured to estimate ascending logistic selectivity curves for the MAB fishery during three periods: 1979-1998, 1999-2000 and 2001-2004. The latter two fishery periods correspond to years with closed areas in the MAB region when well-recognized changes in the fishery occurred. The fishery period 1979-1998 covered many changes in the fishery but too little fishery length composition data were available to estimate additional selectivity patterns.

Data from the sea scallop survey were supplemented by winter, spring and fall trawl survey data in the MAB. The winter survey uses a flounder trawl that is similar to those used by commercial scallop trawl vessels, while the spring and fall surveys use gear that is not optimal for catching scallops. Because the trawl surveys are mainly intended to survey finfish, they need to be employed cautiously in scallop assessments.

Double-logistic selectivity curves were estimated for MAB sea scallops in bottom trawl surveys. Double logistic selectivity curves are potentially dome shaped (highest selectivity at intermediate sizes) to accommodate the possibility that bottom trawls are less efficient for small and large scallops (Rudders et al., 2000). Double logistic curves tend to collapse towards ordinary logistic curves when there is no support for a domed selectivity pattern in the fishery length composition data.

Results

Trial runs with a preliminary version of the model for MAB sea scallops showed no evidence of retrospective bias in biomass or fishing mortality estimates (Appendix Figure 4-1). The Working Group's final "basecase" run converged readily with a full rank Hessian matrix (Appendix Table 4-4). CV's for fishing mortality and abundance were plausible and of reasonably magnitude indicating good model performance. Subjectively, and in comparison to experience with other stocks, the data for MAB sea scallop seemed consistent and relatively easy to model.

Fit to survey index information was good although residuals plots for the NEFSC winter bottom trawl survey showed a temporal pattern that may be related to the overall abundance level (Appendix Figures 4-2 to 4-5). Survey selectivity patterns seemed reasonable with domed patterns for bottom trawl surveys and relatively high selectivity for small scallops in the winter bottom trawl survey (which uses ground gear designed to catch flatfish that is probably relatively efficient for small scallops). Selectivity patterns were similar for the fall and spring bottom trawl surveys, which used the same gear in most years (Appendix Figure 4-6).

The NEFSC survey dredge efficiency estimate from the model fit was similar to the distribution of bootstrap estimates from an external analysis of SMAST video survey data and NEFSC survey data for scallops 80+ mm on the same grounds (Appendix Figure 4-6). Sensitivity analysis (not shown) indicated that the external efficiency estimates had almost no effect on abundance or fishing mortality estimates for MAB. Fit to LPUE and catch data was generally good, although predicted catches were substantially higher than catch data during 1989-1991 and 1995 (Appendix Figures 4-7 to 4-8) as the model tried to explain conflicting evidence in the catch and most of the survey abundance trends.

Fit to fishery and survey length composition data for MAB sea scallops was generally good (Appendix Figure 4-9). The estimated CV for errors in assigning lengths to scallops in the SMAST video survey was 7.6%. With 100 mm scallops, for example, a CV of 7.6% implies a 95% probability interval for assigned lengths of roughly 85-115 mm, or six length bins in the CASA model. The CASA model estimate for the measurement error CV was similar to estimates from a calibration experiment carried out by SMAST and NEFSC using survey video equipment in a tank with scallops and scallop shells of known size (Appendix 1).

In terms of population dynamics (Appendix Figure 4-10), CASA model runs showed widely recognized recent increases in abundance during recent years. Recruitment in 2003 was estimated imprecisely (CV 56%) but was apparently at record levels. Fishing mortality and exploitation levels were similar to rescaled-*F* estimates used for status determination in this assessment and were correlated with trends in fishing effort data (Appendix Figure 4-10). Based on model estimates, catch biomass generally equaled or exceeded surplus production until 1997 (Appendix Figure 4-11).

Model estimates show recent increases in mean weight (Appendix Figure 4-11) and stock abundance with more scallops at larger sizes and increases in numbers at all sizes (Appendix Figure 4-12). Estimates reflect changes in fishery length composition towards larger scallops during recent years (Appendix Figure 4-13). Estimated length composition of new recruits was reasonable in comparison to average length compositions form the NEFSC survey during 1979-2003 (Appendix Figure 4-14).

The very high fishing mortality estimate for MAB sea scallops during 1995 was likely exaggerated due to conflicting information in the fishery and survey data during those years. Sensitivity analysis (not shown) showed that reducing the assumed CV for catch measurement errors reduced F and the residual for catch data in 1995, while reducing goodness of fit to LPUE and most of the survey time series.

Likelihood profile analysis

A preliminary model for MAB was fit while fixing the model's estimate of efficiency for the NEFSC scallop survey dredge to a wide range of feasible values. The lower boundary of the range for efficiency (*e*=0.2) implies that the survey dredge captures 20% of the scallops in its path. The upper boundary implies that the dredge captures 100% of the scallops in its path. In comparison, the basecase run for MAB sea scallops estimated an efficiency of 0.59. Estimated fishing mortality increases and estimated abundance decreases at higher values of assumed efficiency.

Profile analysis results showed that the commercial fishery data (catch weight and LPUE) fit best at relatively high values (*e*=0.7-0.8) for survey dredge efficiency. With the exception of trends in the winter bottom trawl survey, survey data fit best at relatively low values (*e*=0.2-0.5) for survey dredge efficiency. Trend and length composition data from the scallop survey fit best at efficiency levels (*e*=0.5-0.6) near the basecase estimate of *e*=0.59. In considering profile analysis results for MAB sea scallops, it may be important to remember that selectivity parameters for the scallop survey were fixed at estimates obtained outside the model, while selectivity parameters for other surveys and the commercial fishery were estimated without constraint. Data from the scallop survey would likely fit well over a broader range of efficiency values if the corresponding selectivity parameters had been estimated in the model.

Sensitivity analyses

A preliminary model for MAB was used to perform a limited number of sensitivity analyses. The model was not able to estimate plausible values for the natural mortality rate *M* or von Bertalanffy growth parameter *K*. Scenarios in which NEFSC scallop survey selectivity parameters were estimated seemed to provide plausible results with implied efficiencies ranging 0.46-0.48. Preliminary runs that excluded bottom trawl survey trend and length composition data also seemed to provide plausible results.

Georges Bank

The CASA model for sea scallops in the Georges Bank was similar to the model for sea scallops in the Mid-Atlantic Bight except that trawl survey data were not used due to problems with the catchability of scallops in trawls in MAB, and that the time series starts in 1982 rather than 1979. Data used for GBK included commercial catch and length composition, LPUE and NEFSC scallop survey trend and length composition data. The condition of the fishery in Georges Bank differs from MAB, due to higher peak fishing mortality rates and the dynamics of the closed areas established in late-1994, and fished substantially afterward only during 1999-2000.

Four fishery periods were used in modeling GBK sea scallops to accommodate implementation of closed areas and periodic fishing in closed areas. An ascending logistic selectivity pattern was assumed for the commercial fishery during the first period (1979-1995) prior to the closed areas. A double-logistic selectivity curve (potentially domed) was assumed during the second period (1996-1998) when large scallops were accumulating in closed areas where they were protected from the fishery. The domed selectivity pattern mimics the action of the fishery operating in open areas and taking primarily intermediate-size scallops. A second double logistic selectivity curve was estimated for the third period (1999-2000) when substantial fishing occurred in closed areas. Finally, a third double logistic selectivity curve was estimated for the fourth period when closed areas again protected large scallops.

Results

Goodness of fit and residual patterns for GBK sea scallops was generally similar to results for MAB. The estimated efficiency of the NEFSC scallop survey dredge was lower for GBK (e=0.42) than for MAB, presumably due to rocky ground on Georges Bank.

Abundance and mortality estimates were similar to rescaled-F estimates used for status determination in this assessment, and were correlated with trends in fishing effort data (Appendix Figure 4-15). Fishery electivity estimates were plausible with ascending logistic selectivity patterns during 1979-1995 when all scallops were available to the fishery, and 1999-2000 when portions of the groundfish closed areas were reopened (Appendix Figure 4-16). In contrast, the CASA model estimated domed shaped fishery selectivity patterns for periods (1996-1998 and 2001-2003) when large scallops in the closed areas were protected. Selectivity curves for later years show a shift in the fishery towards larger scallops. The double logistic selectivity curve estimated for 1999-2000 collapsed to an ascending logistic pattern because fishery length composition data for this period include substantial proportions of large scallops.

Simulation analysis

The CASA model for sea scallops was fit to one simulated data set with no measurement errors as a preliminary test of model performance, and as a means of verifying validity of the computer code used to make calculations in CASA. The simulated data were generated in a separate program that is commonly used to simulate effects of different management options.

Population dynamics in the simulator were like those for MAB sea scallops. The simulation model and CASA were alike in general terms, except that shorter time steps were used in the simulator and growth was handled in a simpler, more deterministic fashion. A single fishery period with an ascending logistic fishery selectivity pattern was assumed in both models. Selectivity of the NEFSC scallop survey was fixed at the same values in both models. Despite differences in model structure, CASA was able to reproduce the conditions assumed in generating the simulated data (Appendix Figure 4-17). The simulation results suggest that the CASA model was working properly, though more simulations are necessary to determine the effects of catch and survey errors and misspecified growth on model performance.

	Bin_22.5	Bin_27.5	Bin_32.5	Bin_37.5	Bin_42.5	Bin_47.5	Bin_52.5	Bin_57.5	Bin_62.5	Bin_67.5	Bin_72.5	Bin_77.5	Bin_82.5	Bin_87.5	Bin_92.5	Bin_97.5	Bin_102.5	Bin_107.5	Bin_112.5	Bin_117.5	Bin_122.5	Bin_127.5	Bin_132.5	Bin_137.5	Bin_142.5	Bin_147.5	Bin_152.5
Bin_22.5																											
Bin_27.5																											
Bin_32.5																											
Bin_37.5																											
Bin_42.5																											
Bin_47.5	4																										
Bin_52.5	1	9	6	3																							
Bin_57.5		7	40	35	5																						
Bin_62.5		6	47	149	86	5																					
Bin_67.5		1	37	214	175	17	8	1																			
Bin_72.5			8	105	190	54	11	24	8																		
Bin_77.5			2	23	91	70	22	31	61	16	3																
Bin_82.5				1	16	49	36	27	105	94	22	4															
Bin_87.5					2	9	14	14	69	157	84	40	8														
Bin_92.5							3	7	28	98	127	77	65	13													
Bin_97.5					2				5	24	62	80	118	71	8	1											
Bin_102.5										4	27	36	52	132	102	19											
Bin_107.5											2	6	13	46	129	117	24	1									
Bin_112.5													2	4	35	76	106	51	2								
Bin_117.5														1	5	12	82	112	50	3							
Bin_122.5																1	9	39	92	72	8						
Bin_127.5																1	2	5	21	58	77	6					
Bin_132.5																				10	36	70	9				
Bin_137.5																			1	1	4	28	50	9			
Bin_142.5																						2	10	41	9		
Bin_147.5																								4	32	6	
Bin_152.5																									2	21	5
N increments	5	23	140	530	567	204	94	104	276	393	327	243	258	267	279	227	223	208	166	144	125	106	69	54	43	27	5
Effective N	2	6	35	100	100	51	24	26	69	98	82	61	65	67	70	57	56	52	42	36	31	27	17	14	11	7	3

Appendix Table 4-1. Growth increment data used in the CASA model for sea scallops in the GBK and MAB regions. Columns give the initial length bin and rows give the length bin one year later. Cells below the black area are feasible for each starting length (i.e. growth >= zero). "N increments" is the number of observations in each row. "Effective N" is the effective number of observations assumed in fitting the CASA model. The effective number of observations was meant to approximate the number of scallops observed in each starting bin. Assuming that the number of increments observed per scallops was about five, the effective number of observations was the number of increments divided by five.

	Bin_22.5	Bin_27.5	Bin_32.5	Bin_37.5	Bin_42.5	Bin_47.5	Bin_52.5	Bin_57.5	Bin_62.5	Bin_67.5	Bin_72.5	Bin_77.5	Bin_82.5	Bin_87.5	Bin_92.5	Bin_97.5	Bin_102.5	Bin_107.5	Bin_112.5	Bin_117.5	Bin_122.5	Bin_127.5	Bin_132.5	Bin_137.5	Bin_142.5	Bin_147.5	Bin_152.5
Bin_22.5	0																										
Bin_27.5	0	0																									
Bin_32.5	0	0	0																								
Bin_37.5	0	0	0	0																							
Bin_42.5	0	0	0	0	0																						
Bin_47.5	0.145808	0	0	0	0	0																					
Bin_52.5	0.308495	0.811802	0.077018	0.017455	0	0	0																				
Bin_57.5	0.307618	0.077811	0.2438	0.124626	0.033278	0	0	0																			
Bin_62.5	0.174422	0.065755	0.329143	0.30291	0.168435	0.055223	0	0	0																		
Bin_67.5	0.063656	0.033306	0.239973	0.338605	0.322072	0.213942	0.086245	0.016956	0	0																	
Bin_72.5	0	0.011327	0.110066	0.216404	0.30368	0.328912	0.256713	0.134985	0.032124	0	0																
Bin_77.5	0	0	0	0	0.172534	0.265945	0.323551	0.313741	0.180385	0.0536	0.005506	0															
Bin_82.5	0	0	0	0	0	0.135978	0.227631	0.329827	0.330584	0.227786	0.092409	0.011805	0														
Bin_87.5	0	0	0	0	0	0	0.10586	0.204491	0.294328	0.335248	0.300955	0.134347	0.0207	0													
Bin_92.5	0	0	0	0	0	0	0	0	0.162578	0.256148	0.361453	0.332145	0.184466	0.036588													
Bin_97.5	0	0	0	0	0	0	0	0	0	0.127217	0.239677	0.330029	0.352102	0.239675	0.062301	0											
Bin_102.5	0	0	0	0	0	0	0	0	0	0	0	0.191674	0.292756	0.358172	0.295578	0.100748	0.001895										
Bin_107.5	0	0	0	0	0	0	0	0	0	0	0	0	0.149976	0.251414	0.349617	0.346718	0.16037	0.00485									
Bin_112.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0.114152	0.208442	0.327029	0.402636	0.229942	0.011394								
Bin_117.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.084062	0.166069	0.30384	0.419868	0.314504	0.024867							
Bin_122.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.059436	0.131258	0.252972	0.415712	0.410472	0.051932						
Bin_127.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.092369	0.198091	0.386589	0.518678	0.10021					
Bin_132.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.060299	0.142735	0.336688	0.599827	0.187147				
Bin_137.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.035338	0.092703	0.251757	0.641391	0.341102			
Bin_142.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.048206	0.153561	0.593833	0.604383		
Bin_147.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.017901	0.061764	0.387159	0.944204	
Bin_152.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.003301	0.008458	0.055796	1
N increments	0.999999	1	1	1	0.999999	1	1	1	0.999999	0.999999	1	1	1	1.000001	1	1	0.999999	1.000001	0.999999	1.000001	1	1	1	1	1	1	1
Effective N	2	6	35	100	100	51	24	26	69	98	82	61	65	67	70	57	56	52	42	36	31	27	17	14	11	7	3

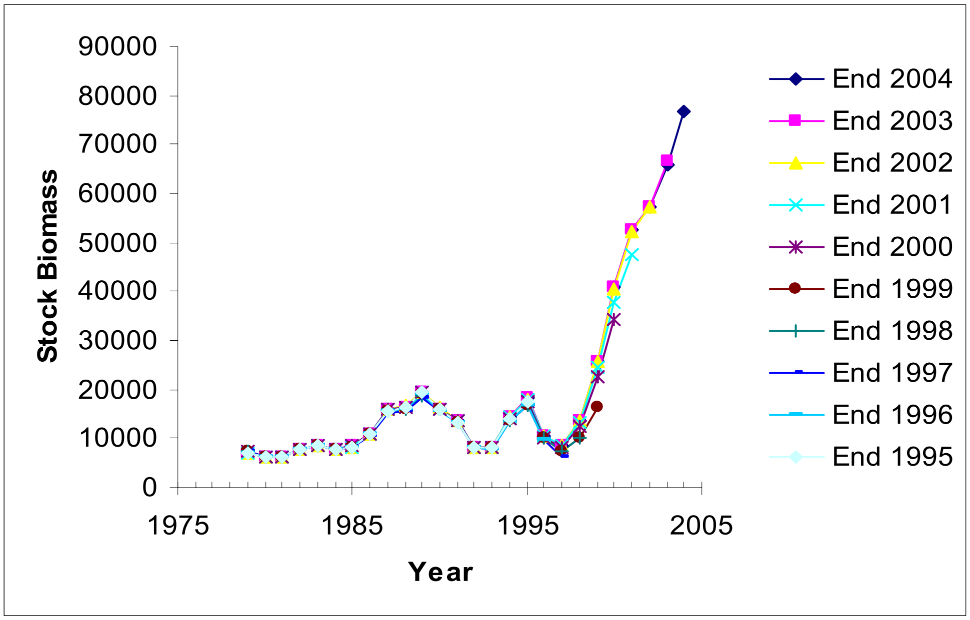
Appendix Table 4-2. Growth probabilities estimated in the CASA model for sea scallops in the MAB region (estimates for GBK were similar). Columns give the initial length bin and rows give the length bin one year later. Cells below the black area are feasible for each starting length (i.e. growth >= zero). Formatting as in Appendix Table 4-1.

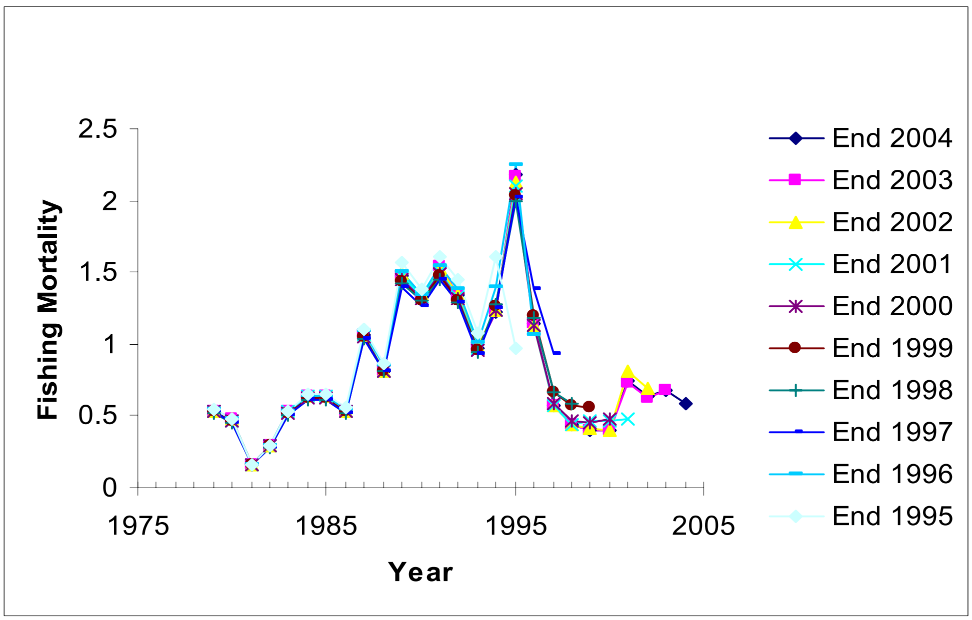
Appendix Table 4-3. Data for MAB sea scallops used in CASA model.

Data Type	Years in Model	Distribution for Measurement Errors	Comments
Commercial landed weight	1979-2004 (mean 2001-03 used for 2004)	Normal, CV=10%	MT, not adjusted for discard or incidental mortality
Landings per unit effort	1980-2003	Normal, CV=25%	MT landed / days absent for large (Type 4) scallop dredge vessels based on port interview and dealer data (1993 and earlier) or VTR logbooks and dealer data (1994 and later). Data for 1979 omitted.
Length increments			Increment observations from sea scallop shells collected during 2002 sea scallop survey. There were 1,565 increment measurements from MAB and 3,551 measurements from GBK. After preliminary examination data for MAB and GBK were pooled for use in both areas.
NEFSC survey dredge efficiency	NA	Beta over 0,1	Beta prior with the same mean and CV as distribution of bootstrap estimates from SMAST and NEFSC scallop survey densities for sea scallops 80+ mm on same grounds.
Survey abundance data			
NEFSC scallop survey abundance index	1979-2003	Log normal, variances from survey CVs	N/tow for sea scallops 40+ mm. Survey selectivity assumed known.
NEFSC winter bottom trawl survey abundance index	1992-2004	Log normal, variances from survey CVs	N/tow for sea scallops 20+ mm. Logistic survey selectivity estimated.
NEFSC fall bottom trawl survey abundance index	1979-2003	Log normal, variances from survey CVs	N/tow for sea scallops 40+ mm. Logistic survey selectivity estimated.
NEFSC spring bottom trawl survey abundance index	1979-2003	Log normal, variances from survey CVs	N/tow for sea scallops 40+ mm. Logistic survey selectivity estimated.
SMAST Video Survey	2003	NA	Densities for sea scallops 80+ compared to densities in NEFSC scallop survey on same grounds to estimate efficiency of NEFSC scallop survey dredge.
Length composition			
Commercial length composition	1979-1984; 1995-2003	Multinomial, effective sample size = 10% N tows sampled	Data for 1979-1984 from port samples; data for 1995-2003 from observer data.
NEFSC scallop survey	1979-2003	Multinomial, effective sample size = N tows	Sea scallops 40+ mm in 5 mm bins
NEFSC winter bottom trawl survey	1979-2003	Multinomial, effective sample size = N tows	Sea scallops 20+ mm in 5 mm bins. Data originally by 10 mm bins split into adjacent 5 mm bins.
NEFSC fall bottom trawl survey	1979-2003	Multinomial, effective sample size = N tows	Sea scallops 40+ mm in 5 mm bins. Data originally by 10 mm bins split into adjacent 5 mm bins.
NEFSC spring bottom trawl survey	1979-2003	Multinomial, effective sample size = N tows	Sea scallops 40+ mm in 5 mm bins. Data originally by 10 mm bins split into adjacent 5 mm bins.
SMAST video survey	2003	Multinomial, effective sample size = 34	Sea scallops 20+ mm in 5 mm bins. Original numbers at length not adjusted for bias. CV for measurement errors estimated in model.

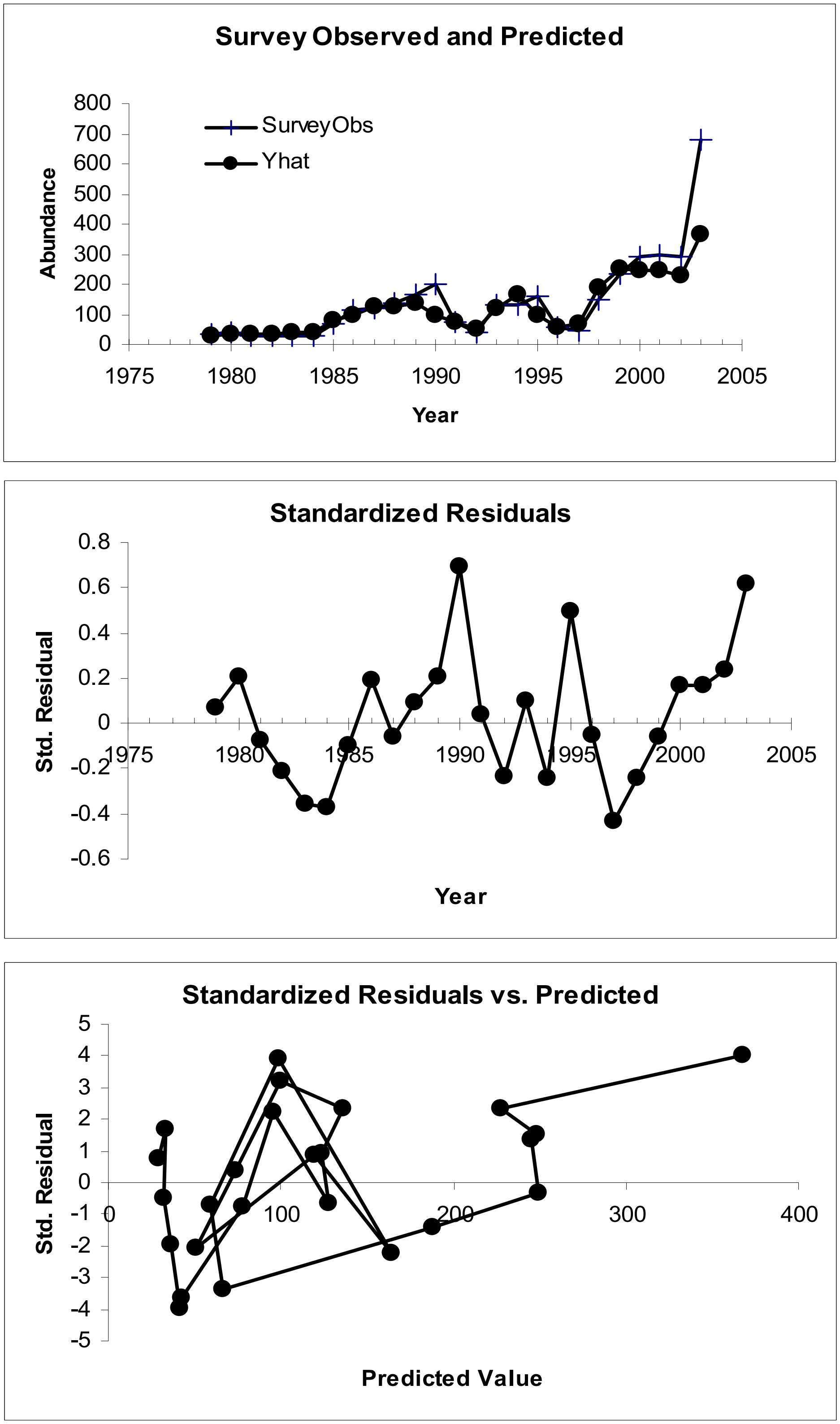
Appendix Table 4-4. Estimates, standard errors and CVs for parameters estimated in the CASA model for sea scallops in the Mid-Atlantic Bight region.

No.	Description	Estimate	SE	CV	No.	Description	Estimate	SE	CV
1	Log initial abundance	19.913	0.041	0.00	44	Log F dev 1989	0.762	0.150	0.20
2	Log beta distribution par new recruits	1.089	0.138	0.13	45	Log F dev 1990	0.643	0.143	0.22
3	Log beta distribution par new recruits	1.074	0.110	0.10	46	Log F dev 1991	0.798	0.103	0.13
4	Log mean recruitment	20.116	0.040	0.00	47	Log F dev 1992	0.655	0.097	0.15
5	Log Q scallop survey	-0.533	0.036	0.07	48	Log F dev 1993	0.319	0.130	0.41
6	Log Q winter BTS	-3.212	0.111	0.03	49	Log F dev 1994	0.539	0.137	0.25
7	Log Q fall BTS	-2.264	0.084	0.04	50	Log F dev 1995	1.148	0.103	0.09
8	Log Q spring BTS	-2.750	0.089	0.03	51	Log F dev 1996	0.503	0.098	0.19
9	Log intercept slx SMAST video survey	2.210	2.022	0.92	52	Log F dev 1997	-0.203	0.108	0.53
10	Log slope slx SMAST video survey	-1.186	1.844	1.55	53	Log F dev 1998	-0.479	0.108	0.23
11	Log slope slx winter BTS (ascending)	1.968	0.193	0.10	54	Log F dev 1999	-0.555	0.206	0.37
12	Log intercept slx winter BTS (ascending)	-2.540	0.136	0.05	55	Log F dev 2000	-0.559	0.189	0.34
13	Log slope slx winter BTS (descending)	-4.000	0.061	0.02	56	Log F dev 2001	0.037	0.187	5.05
14	Log intercept slx winter BTS (descending)	-3.045	0.273	0.09	57	Log F dev 2002	-0.125	0.183	1.46
15	Log slope slx fall BTS (ascending)	2.127	0.058	0.03	58	Log F dev 2003	-0.061	0.190	3.12
16	Log intercept slx fall BTS (ascending)	-2.285	0.102	0.04	59	Log F dev 2004	-0.229	0.211	0.92
17	Log slope slx fall BTS (descending)	2.879	0.191	0.07	60	Log recruitment dev 1980	-1.049	0.083	0.08
18	Log intercept slx fall BTS (descending)	-1.793	0.168	0.09	61	Log recruitment dev 1981	-1.482	0.113	0.08
19	Log slope slx spring BTS (ascending)	2.587	0.614	0.24	62	Log recruitment dev 1982	-1.370	0.122	0.09
20	Log intercept slx spring BTS (ascending)	-2.393	0.085	0.04	63	Log recruitment dev 1983	-1.030	0.099	0.10
21	Log slope slx spring BTS (descending)	2.703	0.093	0.03	64	Log recruitment dev 1984	-1.007	0.122	0.12
22	Log intercept slx spring BTS (descending)	-1.746	0.081	0.05	65	Log recruitment dev 1985	0.224	0.092	0.41
23	Log mean F	-0.363	0.047	0.13	66	Log recruitment dev 1986	0.085	0.101	1.19
24	Log intercept growth CV	-1.922	0.012	0.01	67	Log recruitment dev 1987	0.536	0.085	0.16
25	Slope growth CV	0.010	0.000	0.04	68	Log recruitment dev 1988	0.205	0.113	0.55
26	Log Q for LPUE	-2.443	0.167	0.07	69	Log recruitment dev 1989	0.670	0.090	0.13
27	Log shape parameter for LPUE	-0.401	0.241	0.60	70	Log recruitment dev 1990	-0.061	0.115	1.90
28	Log intercept fishery slx period 1	2.543	0.072	0.03	71	Log recruitment dev 1991	-1.008	0.146	0.15
29	Log slope fishery slx period 1	-1.846	0.079	0.04	72	Log recruitment dev 1992	-0.915	0.119	0.13
30	Log intercept fishery slx period 2	2.629	0.290	0.11	73	Log recruitment dev 1993	0.874	0.074	0.08
31	Log slope fishery slx period 2	-1.821	0.338	0.19	74	Log recruitment dev 1994	0.812	0.089	0.11
32	Log intercept fishery slx period 3	2.747	0.205	0.07	75	Log recruitment dev 1995	-0.317	0.120	0.38
33	Log slope fishery slx period 3	-1.871	0.236	0.13	76	Log recruitment dev 1996	-2.047	0.236	0.12
34	Log F dev 1979	-0.265	0.085	0.32	77	Log recruitment dev 1997	-0.136	0.093	0.69
35	Log F dev 1980	-0.388	0.103	0.26	78	Log recruitment dev 1998	1.272	0.075	0.06
36	Log F dev 1981	-1.474	0.112	0.08	79	Log recruitment dev 1999	1.125	0.088	0.08
37	Log F dev 1982	-0.863	0.110	0.13	80	Log recruitment dev 2000	0.671	0.113	0.17
38	Log F dev 1983	-0.271	0.093	0.34	81	Log recruitment dev 2001	0.728	0.110	0.15
39	Log F dev 1984	-0.101	0.084	0.84	82	Log recruitment dev 2002	0.387	0.146	0.38
40	Log F dev 1985	-0.106	0.093	0.88	83	Log recruitment dev 2003	1.999	0.112	0.06
41	Log F dev 1986	-0.277	0.099	0.36	84	Log recruitment dev 2004	0.833	0.531	0.64
42	Log F dev 1987	0.414	0.099	0.24	85	Logit length error SMAST video	-2.499	1.223	0.49
43	Log F dev 1988	0.138	0.134	0.97					

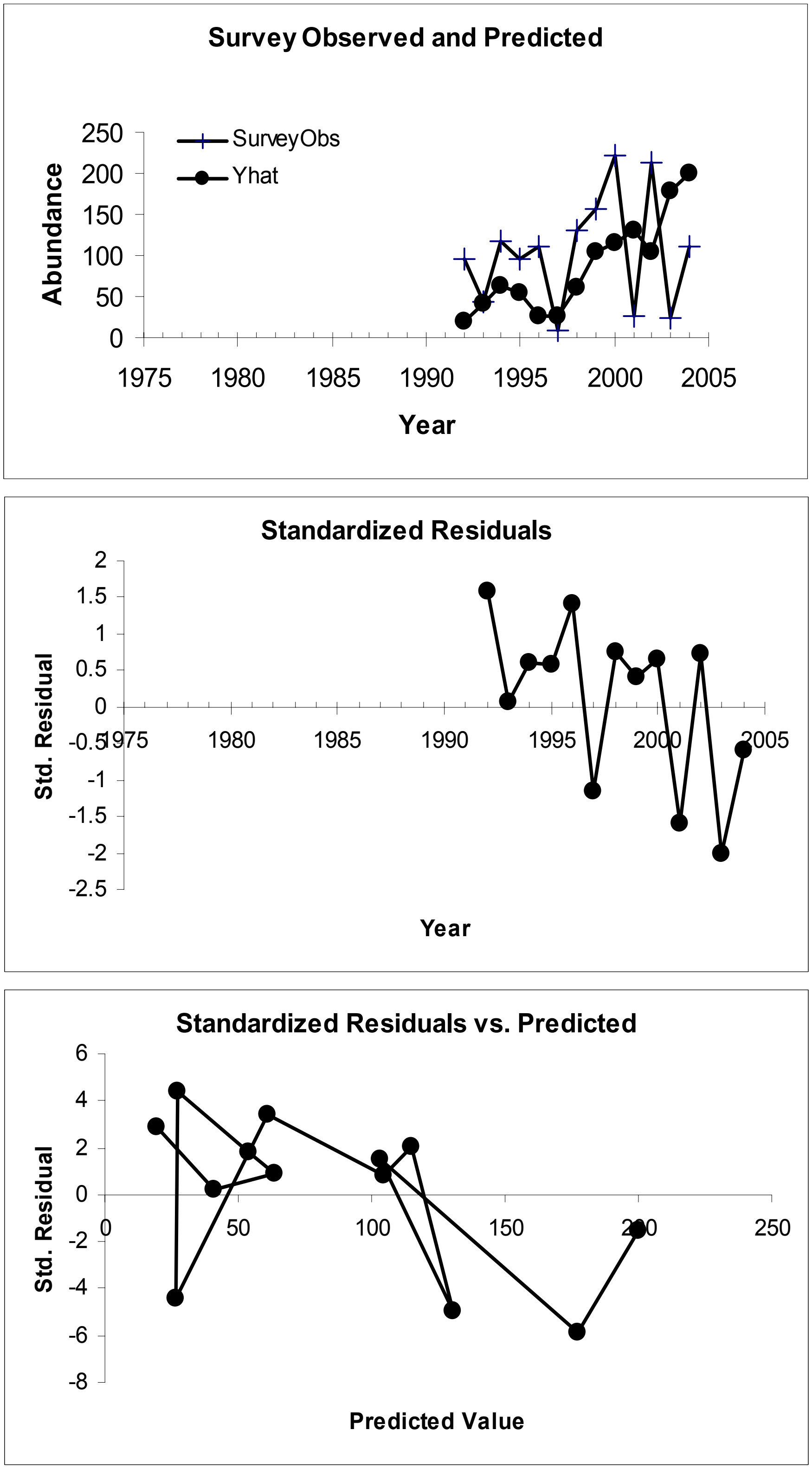




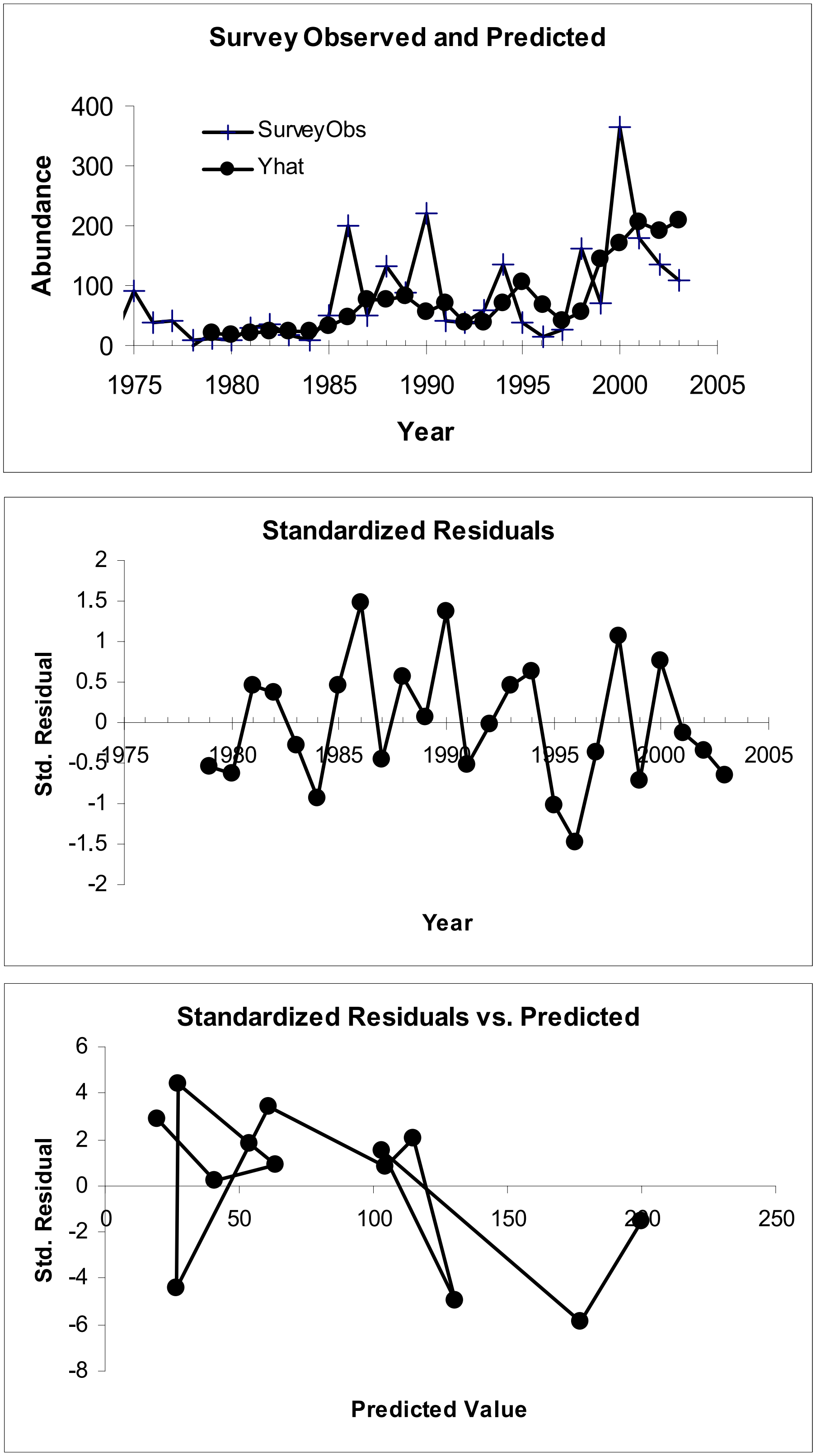
Appendix Figure 4-1. Retrospective analysis for biomass (top) and fishing mortality (bottom) estimates from a preliminary version of the CASA model for MAB sea scallops.



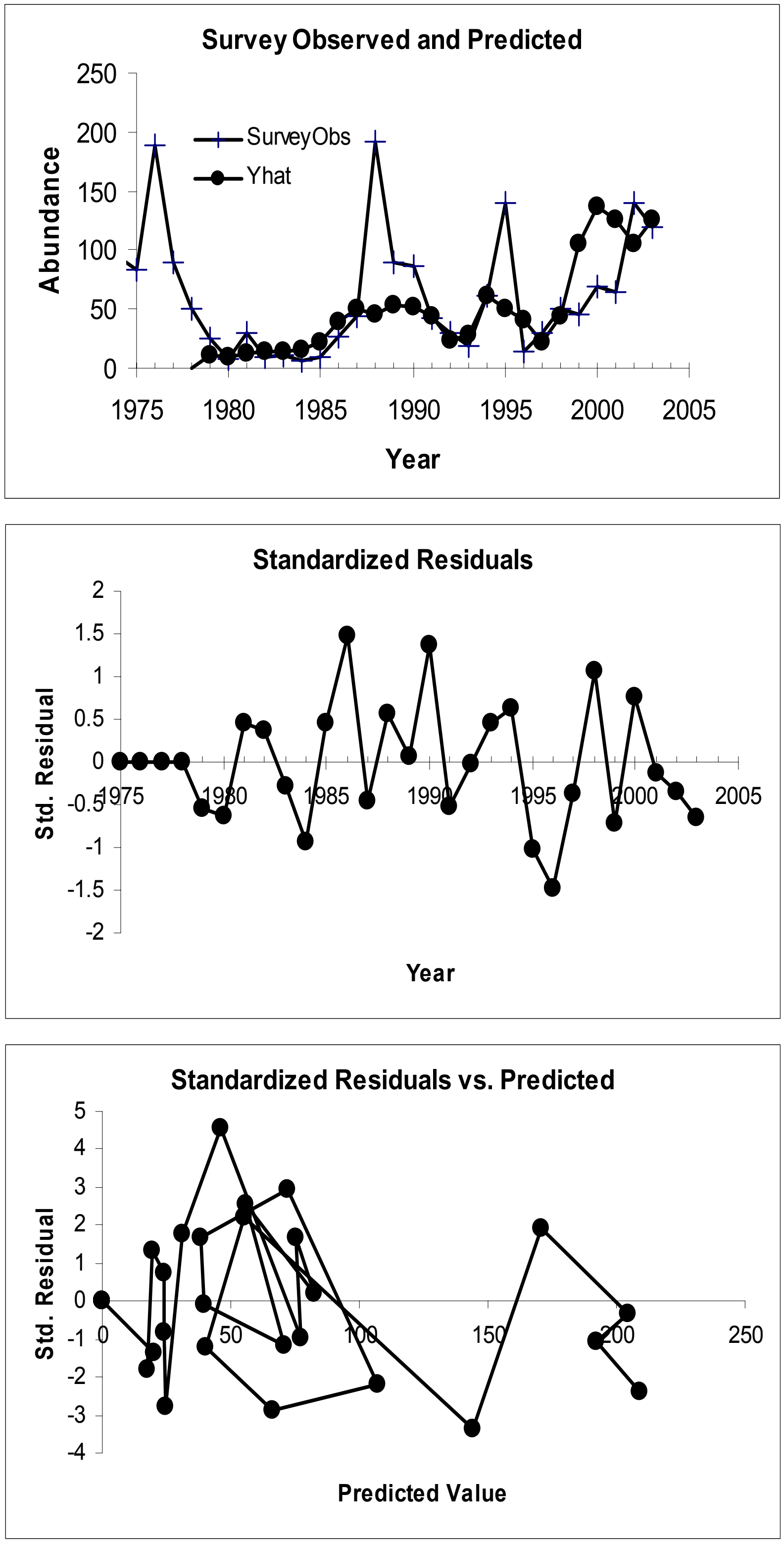
Appendix Figure 4-2. CASA model fit to NEFSC scallop survey data for MAB sea scallops.



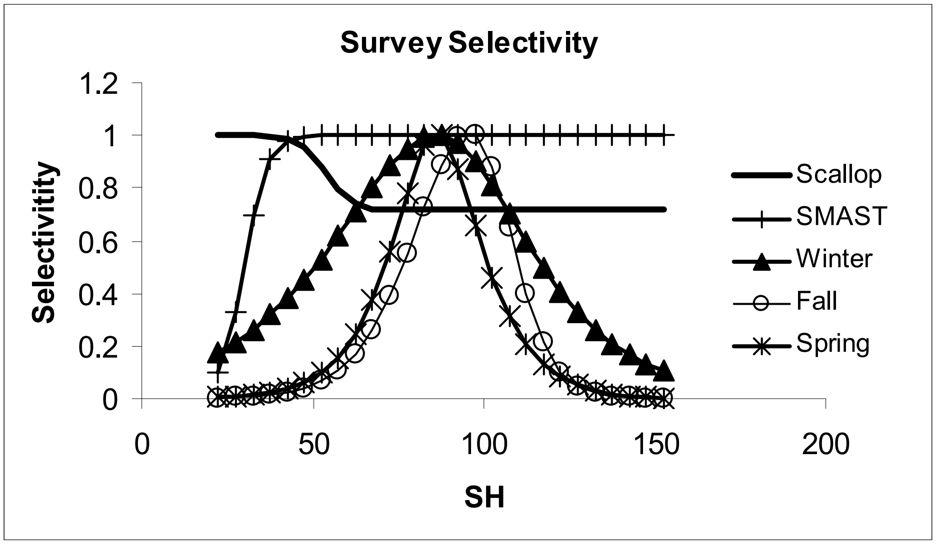
Appendix Figure 4-3. CASA model fit to NEFSC winter bottom trawl survey data for MAB sea scallops.

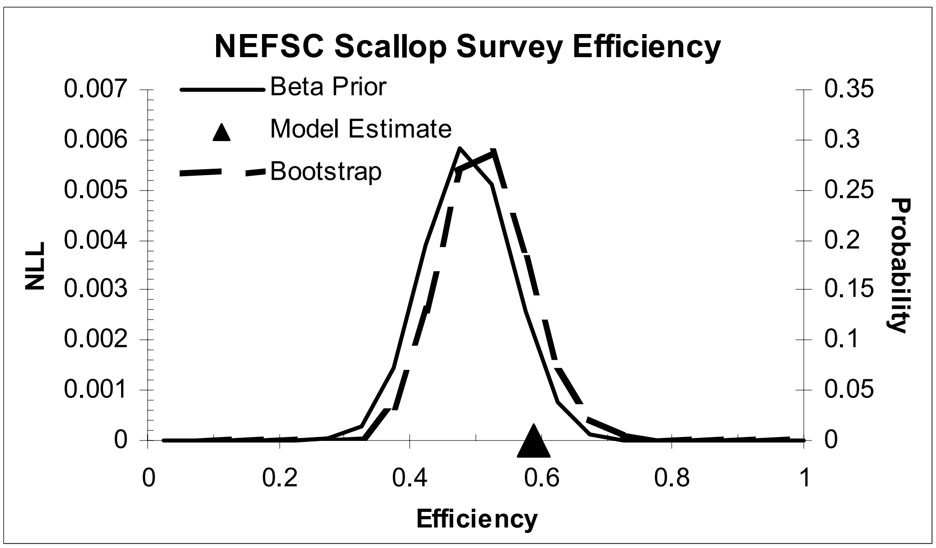


Appendix Figure 4-4. CASA model fit to NEFSC fall bottom trawl survey data for MAB sea scallops.

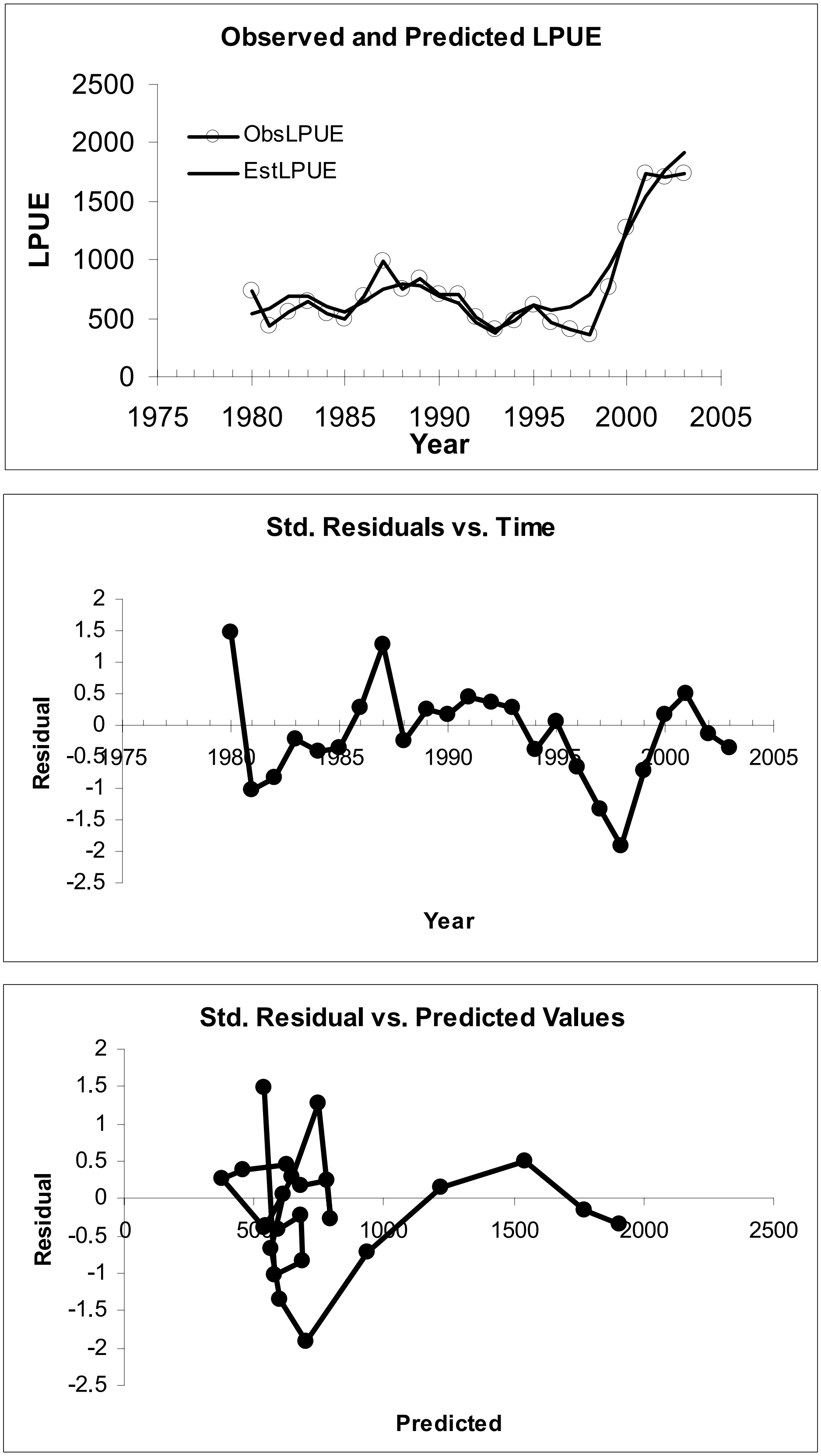


Appendix Figure 4-5. CASA model fit to NEFSC spring bottom trawl survey data for MAB sea scallops.

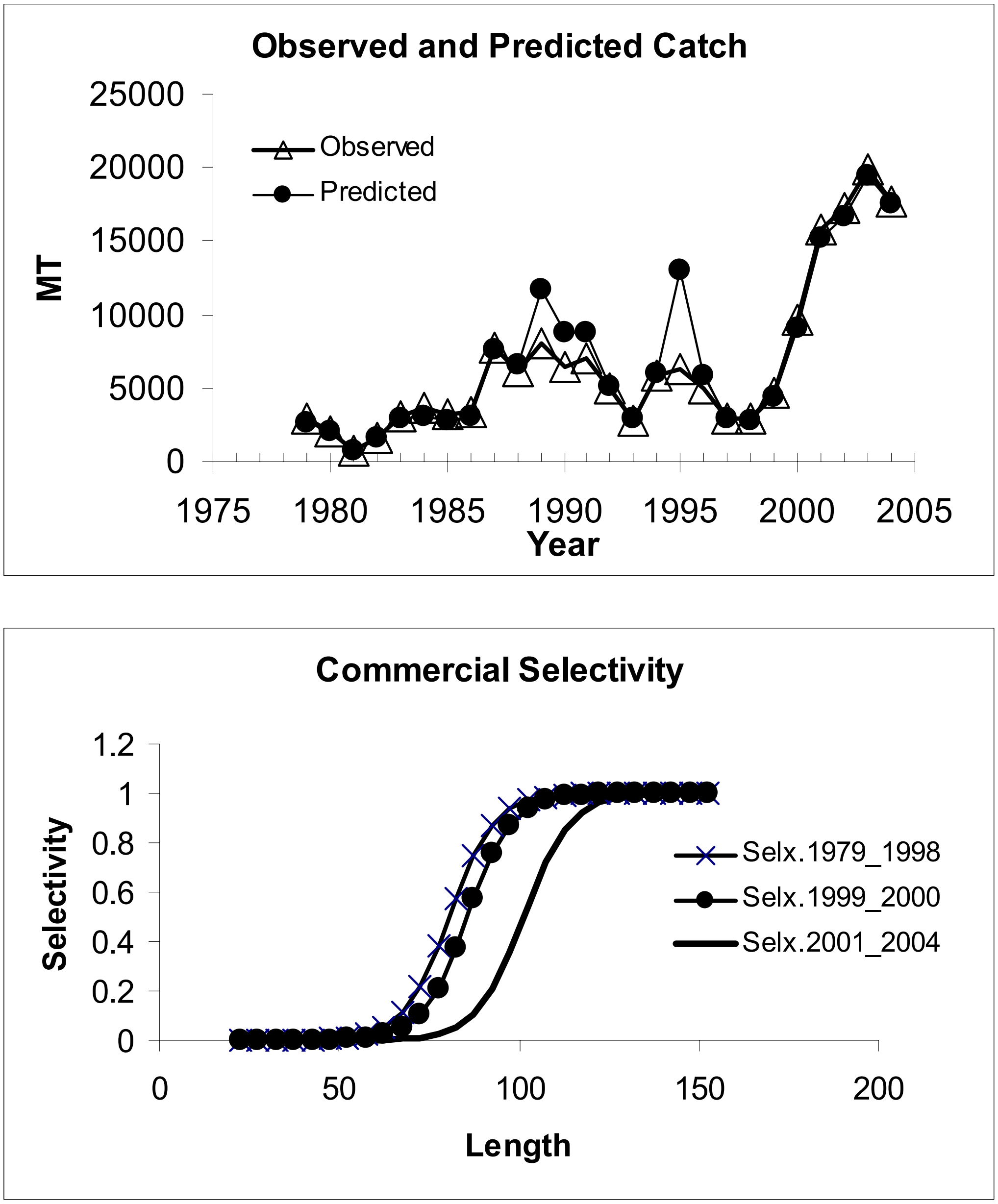




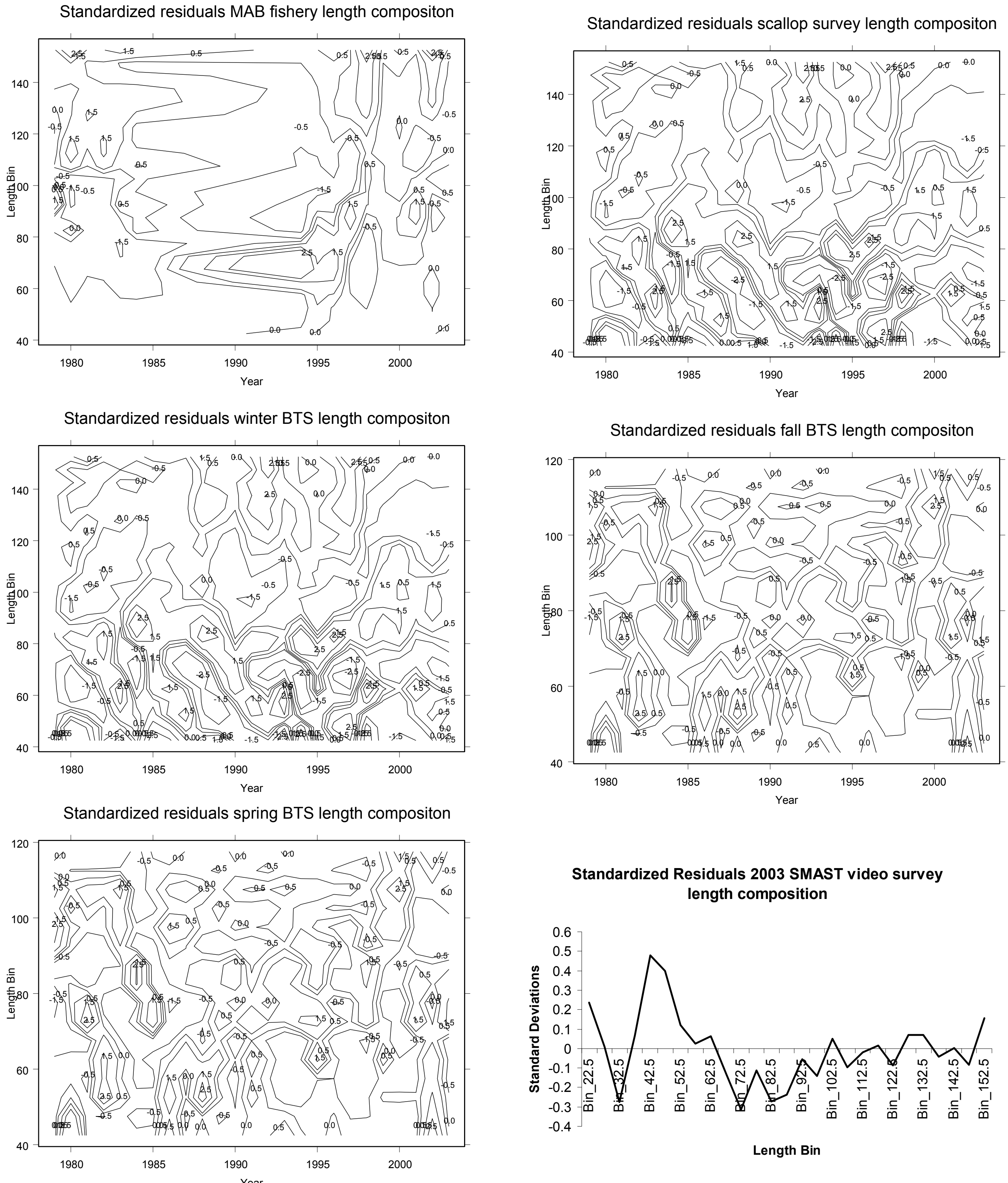
Appendix Figure 4-6. Survey selectivity patterns and NEFSC survey efficiency estimates for sea scallops in the MAB region.



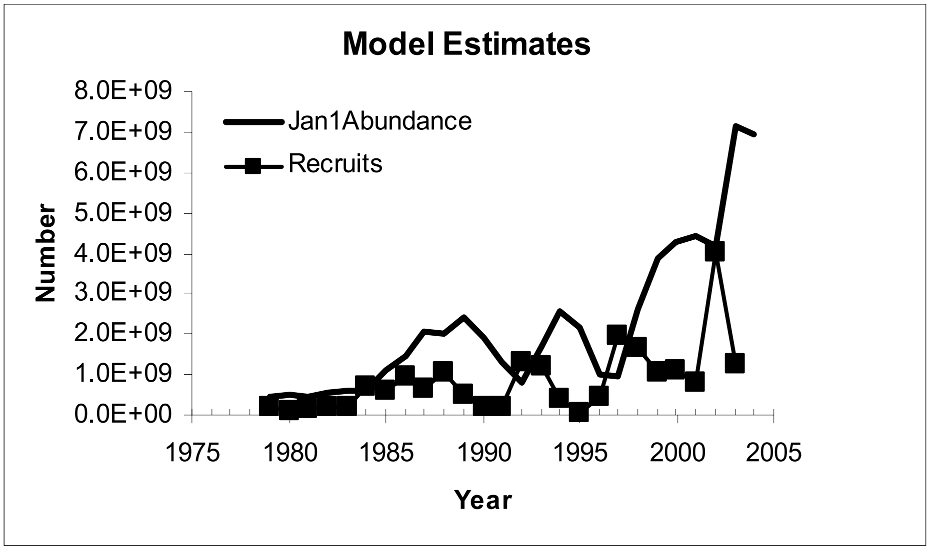
Appendix Figure 4-7. CASA model fit to LPUE data for MAB sea scallops.

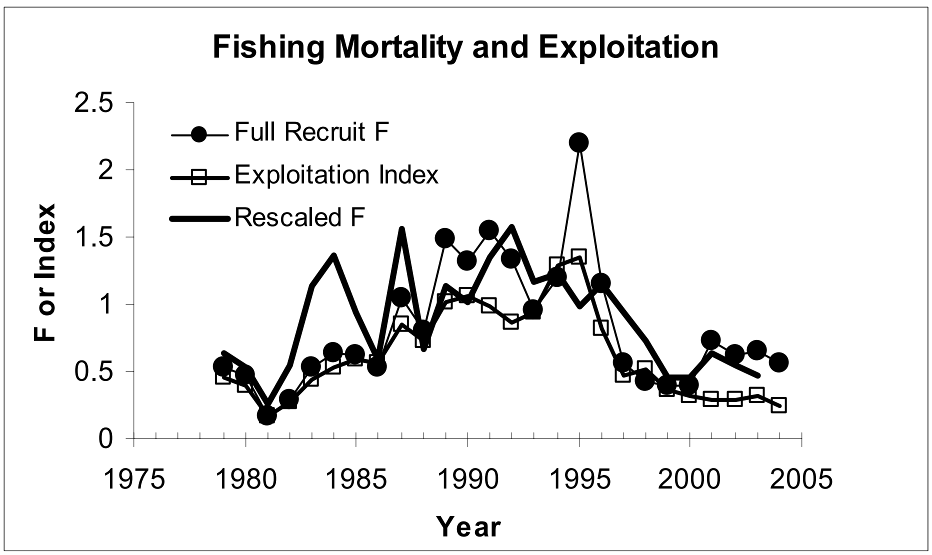


Appendix Figure 4-8. CASA model fit to landings data and estimated fishery selectivity patterns for MAB sea scallops.

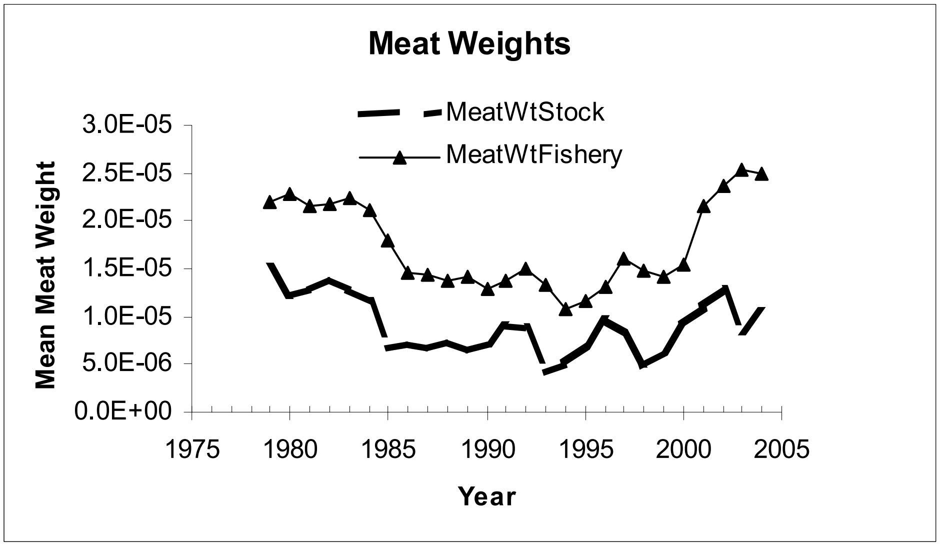


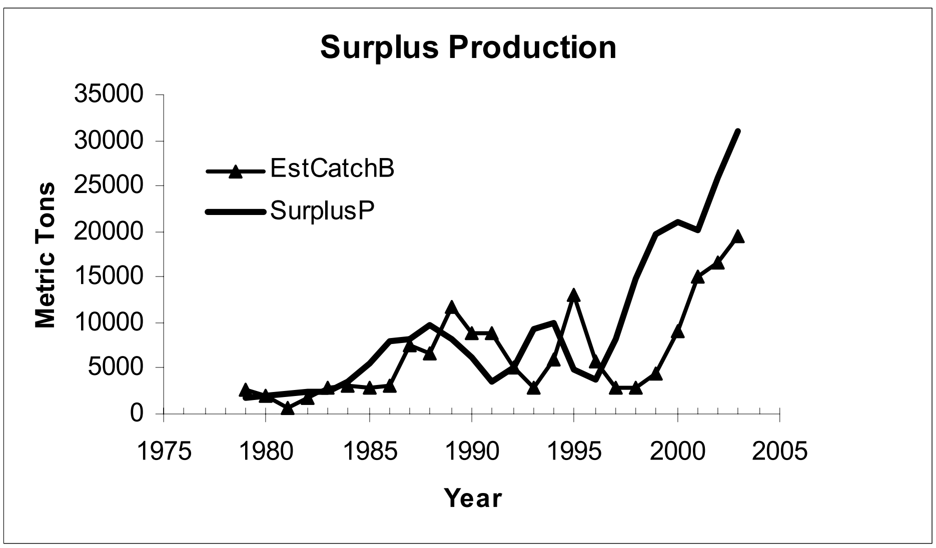
Appendix Figure 4-9. Standardized residuals by year and length bin for MAB sea scallop length composition data. Fishery length composition data were for 1979-1984 and 1994-2003. The apparent residual pattern for fishery data during 1985-1993 is an artifact due to no data.



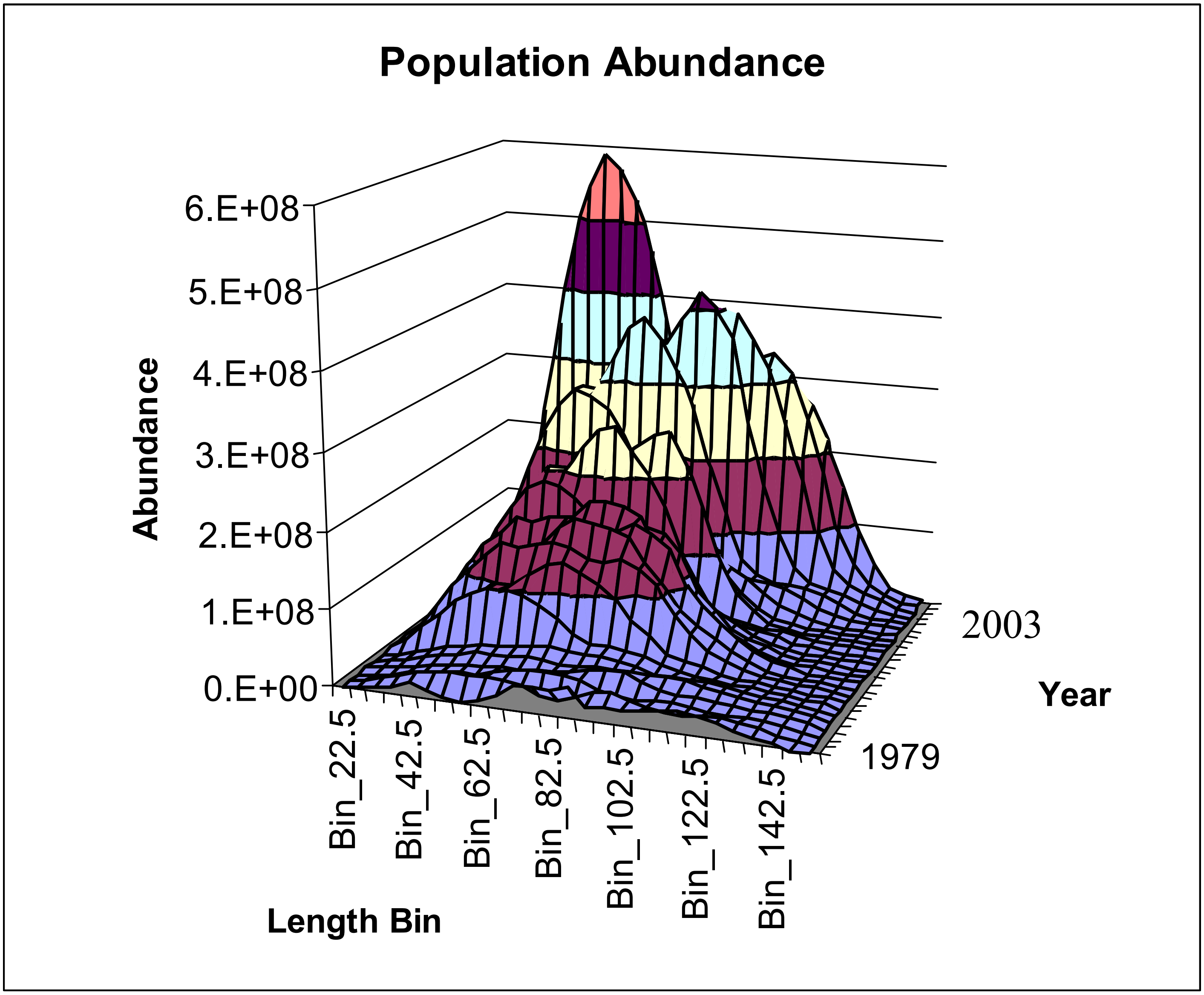


Appendix Figure 4-10. CASA model estimates of abundance, recruitment and fishing mortality for MAB sea scallops. In the lower panel, “Full Recruit F” is for length groups fully selected by the fishery and reflects changes in fishery selectivity, “Exploitation Index” is total catch number divided by abundance of scallops 90+ mm, and “Rescaled F” is for fishing mortality estimates by the method used for status determination.

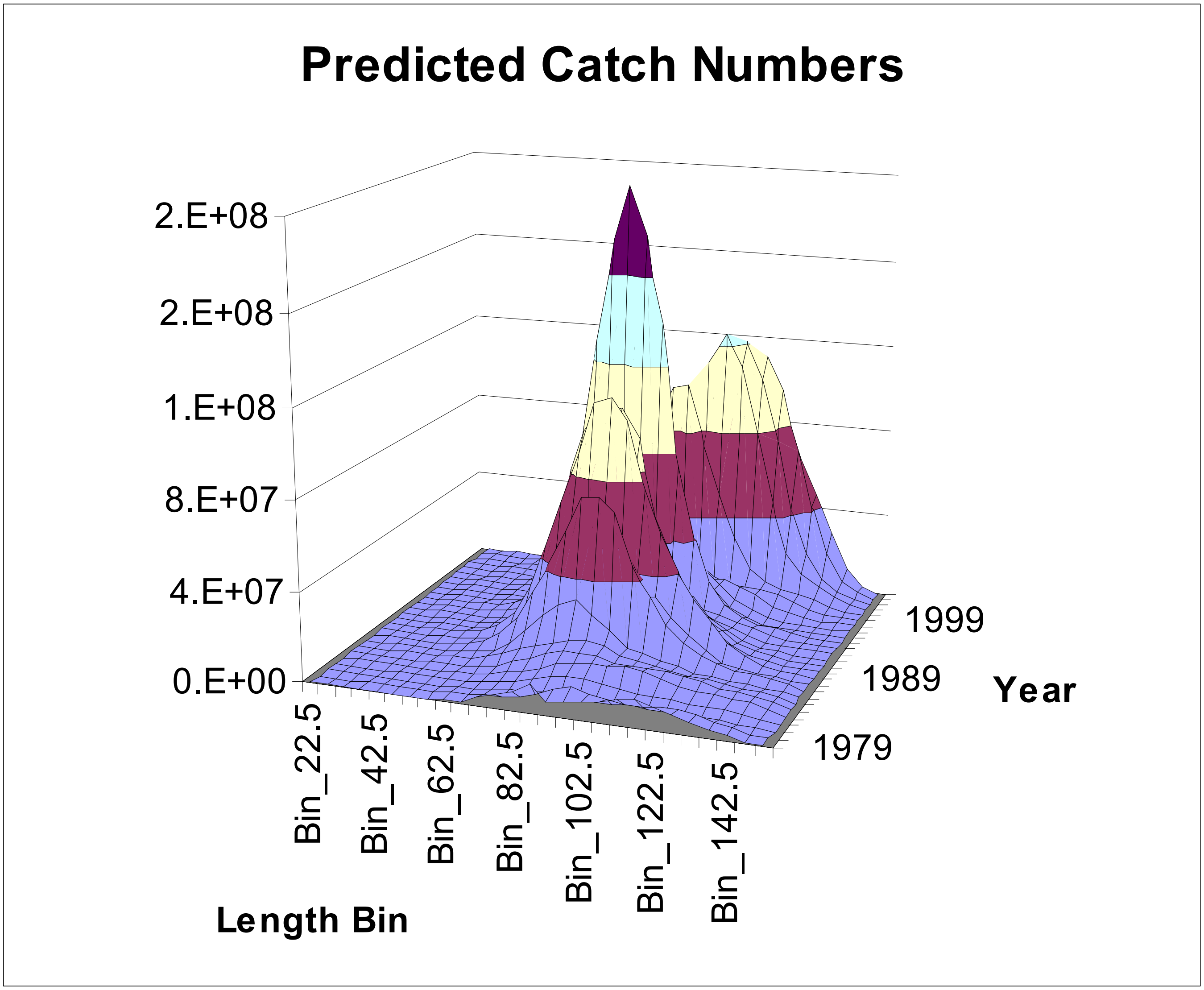




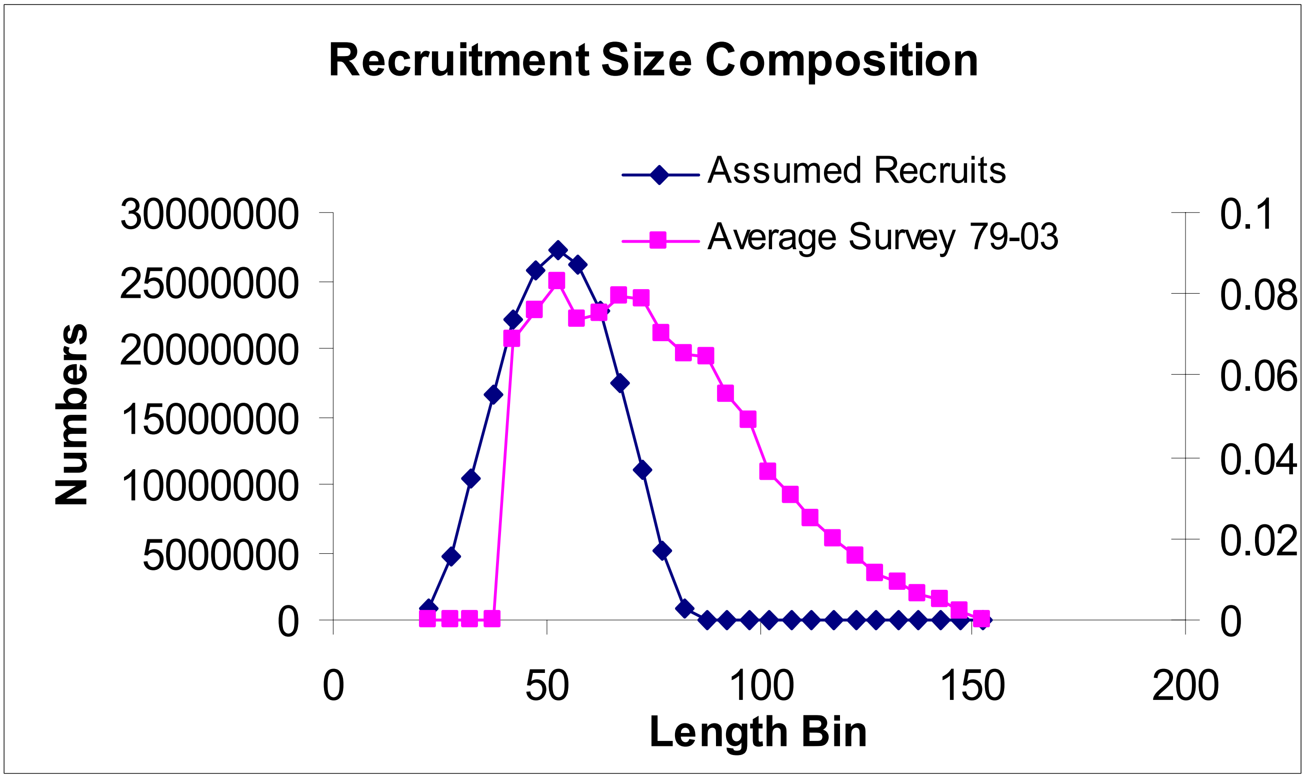
Appendix Figure 4-11. CASA model estimates of mean meat weights in the stock and fishery (top) and surplus production compared to catch of MAB sea scallops.



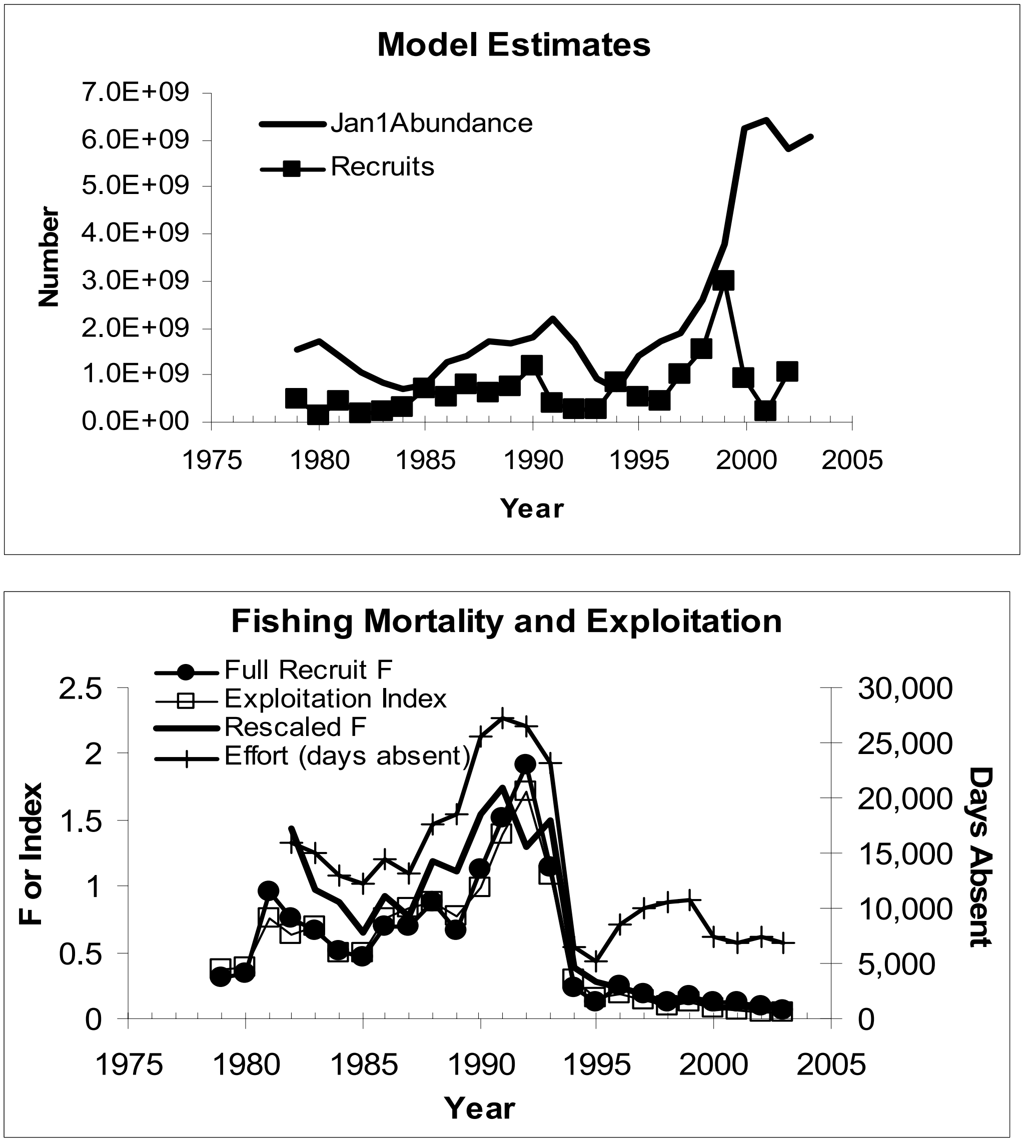
Appendix Figure 4-12. CASA model estimates of abundance at length by year for MAB sea scallops.



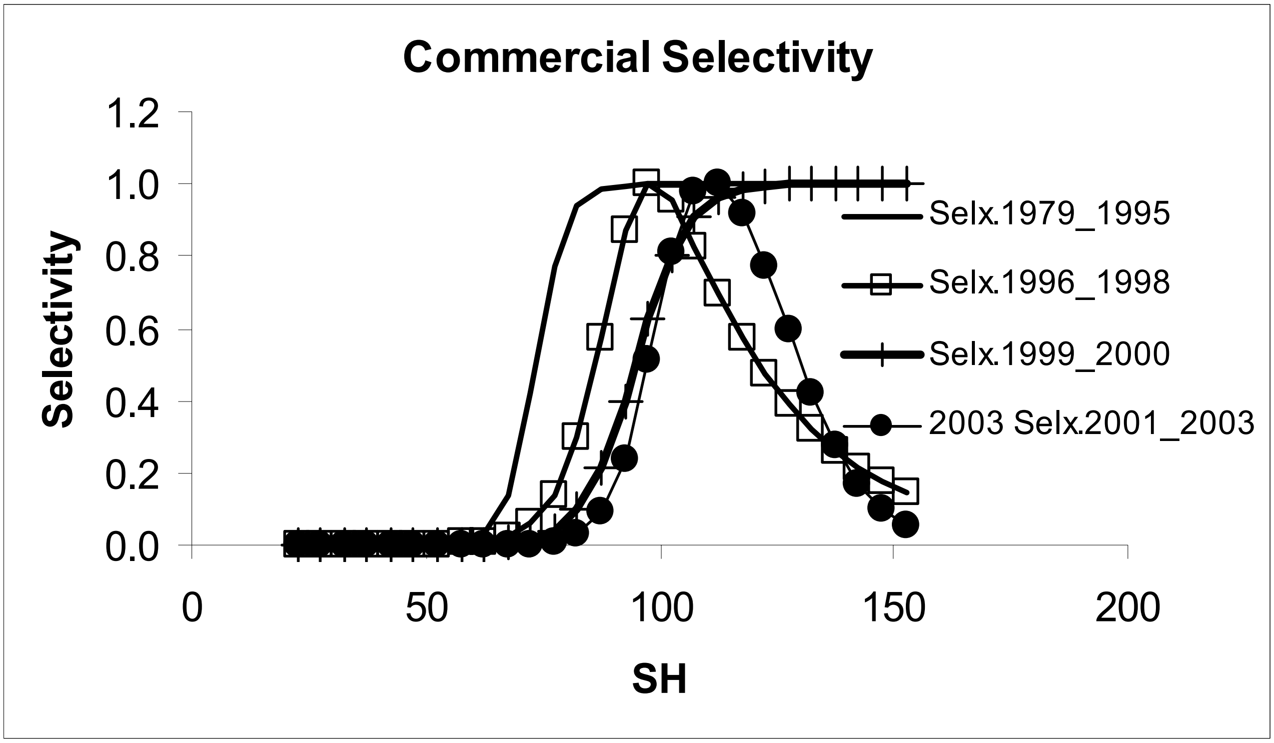
Appendix Figure 4-13. CASA model estimates of catch at length by year for MAB sea scallops.



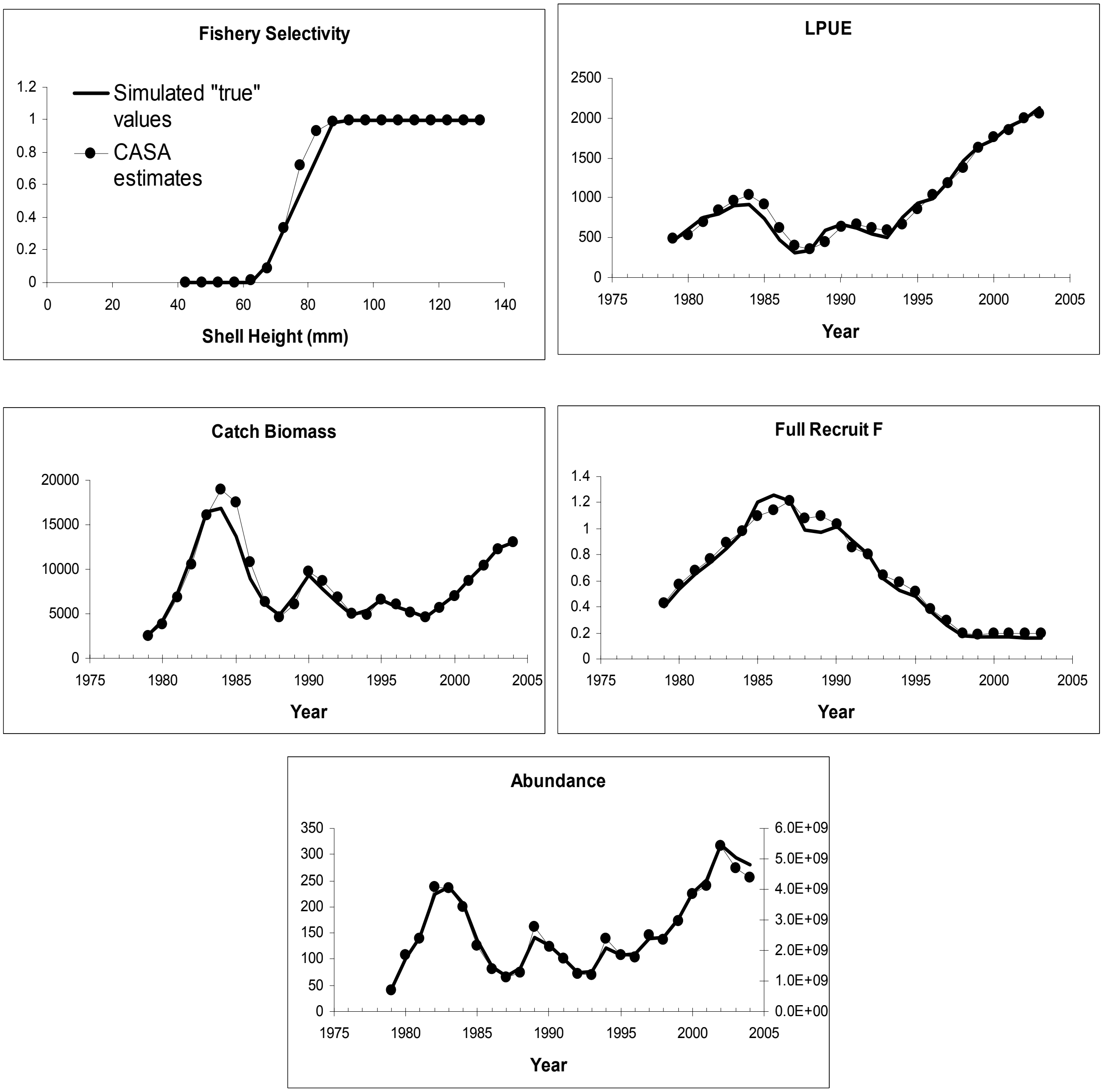
Appendix Figure 4-14. Assumed length composition of new recruits in the CASA model compared to average NEFSC scallop survey length composition data for 1979-2003. The steep ascending limb for the average survey length composition during 1979-2003 is an artifact due to using survey data for scallops larger than 40 mm.



Appendix Figure 4-15. CASA model estimates of abundance, recruitment and fishing mortality for GBK sea scallops. In the lower panel, "Full Recruit F" is for length groups fully selected by the fishery and reflects changes in fishery selectivity, "Exploitation Index" is total catch number divided by abundance of scallops 90+ mm, and "Rescaled F" is for fishing mortality estimates by the method used for status determination. Fishing effort is days absent from port.



Appendix Figure 4-16. Fishery selectivity patterns estimated in the CASA model for GBK sea scallops.



Appendix Figure 4-17. Results of simulation tests.