Appendix 1. List of meeting attendees and working group participants (black box indicates attendance on the specific meeting day)

		Industry Meeting	Data Working Group Meeting			Models & Biological Reference Point Meeting				
Participant	Affiliation	8/16/2011	9/7/2011	9/8/2011	9/9/2011	10/17/2011	10/18/2011	10/19/2011	10/20/2011	10/21/2011
Chris Legault	NOAA - NEFSC					■	■	■	■	
Dvora Hart	NOAA - NEFSC							■	■	
Eric Robillard	NOAA - NEFSC		■							
Henry Milliken	NOAA - NEFSC				■					
Jessica Blaylock	NOAA - NEFSC		■		■			■		
Jon Hare	NOAA - NEFSC						■			
Katherine Sosebee	NOAA - NEFSC		■	■	■	■	■	■	■	■
Liz Brooks	NOAA - NEFSC (Working Group Chair)	■	■	■	■	■	■	■	■	■
Loretta O'Brien	NOAA - NEFSC	■			■	■	■	■	■	■
Michele Traver	NOAA - NEFSC		■		■					
Mike Palmer	NOAA - NEFSC (Assessment Lead)	■	■	■	■	■	■	■	■	■
Paul Nitschke	NOAA - NEFSC		■	■	■	■	■	■	■	■
Paul Rago	NOAA - NEFSC			■	■	■				
Susan Wigley	NOAA - NEFSC					■	■	■	■	■
Tim Miller	NOAA - NEFSC								■	■
Don Frei	NOAA - NERO	■								
Sarah Heil	NOAA - NERO	■				■				■
Tom Warren	NOAA - NERO	■				■				■
Steven Correia	MADMF		■	■	■			■	■	■
Annie Hawkins	NEFMC	■								
Tom Nies	NEFMC				■	■	■	■	■	■
Dan Goethel	SMAST	■								
David Martins	SMAST		■	■	■					
Lisa Kerr	SMAST			■	■					
Steve Cadrin	SMAST					■			■	
Yong Chen	UMAINE				■		■	■		■
Jonathon Peros	GMRI	■								
Michelle Loquine	GMRI	■								
Maggie Raymond	Industry (AFM)					■	■		■	
Eric Brazer	Industry (CCCHFA)				■					
Melissa Sanderson	Industry (CCCHFA)				■					
Tom Dempsey	Industry (CCCHFA)				■					
Tom Rudolph	Industry (CCCHFA)				■					
Aaron Dority	Industry (NCCS)				■					
Joe Ravcazzo	Industry (NEFS I)	■								
Vencenso Toorman	Industry (NEFS I)	■								
Al Cottone	Industry (NEFS II)	■								
David Lefeile	Industry (NEFS II)	■								
Joseph Orlando	Industry (NEFS II)	■								
Mario Orlando	Industry (NEFS II)	■								
Paul Vitale	Industry (NEFS II)	■								
Russell Sherman	Industry (NEFS II)	■								
Nick Brancaleone	Industry (NEFS III)	■								
Mike Walsh	Industry (NEFS VI)	■								
Elizabeth Etrie	Industry (NESSN)	■								
Jackie Odell	Industry (NSC)	■	■			■	■			
Vito Giacalone	Industry (NSC)	■								■
Ben Martens	Industry (Port Clyde Sector Manager)	■								
Doug Butterworth	Industry consultant					■	■	■	■	■
Rebecca Rademeyer	Industry consultant					■	■	■	■	

Appendix 2. Additional material presented during SARC 53 including ASAP sensitivity runs and an evaluation of biomass scale and estimates of ASAP-estimated survey catchability.

A2.1 Additional ASAP sensitivity runs

During the SARC 53 meeting, the Panel requested several additional sensitivity runs of the ASAP model to a) better understand the development of the base assessment model, and b) to better characterize overall model uncertainty. The types of sensitivity runs requested included:

1. A better description of some of the preliminary Age Structured Assessment Program (ASAP) models that were explored when transitioning from the previous Virtual Population Assessment (ADAPT-VPA) base model to the ASAP model.
2. Accounting for greater uncertainty in total catch by increasing the coefficients of variation (CVs) inputs in the model.
3. Limiting the survey indices to only those age classes that exhibited internal consistency in terms of correlations between successive ages (ages 1-6).
4. Start the assessment in 2000 so that the assessment is not confounded by changes in fishery selectivity and/or biology that may have occurred earlier on in the assessment period.
5. Run the assessment with each survey index individually to better understand the influences of each survey on the assessment.

A2.1.1. Preliminary development of an ASAP model

There were well over 20 different preliminary ASAP model configurations that were explored prior to the development of the ASAP base model (BASE). Many of these preliminary models attempted to take advantage of the complexity and flexibility of ASAP by partitioning fishery catch into its various fleet (commercial, recreational) and disposition (retained, discarded) components. These preliminary explorations, while informative in broad terms for demonstrating the robustness of the base model results with respect to the trend and magnitude of the resource, were untenable for consideration as a base model. This is primarily because the more complex model configurations tended to be over-parameterized (and therefore unstable to even minor perturbations) or the model diagnostics were poor.

Although there were many different model configurations and parameterizations considered, they can be categorized into three main configurations. When viewed in this way, it is more straightforward to trace the transition from a VPA-based assessment to development of the statistical catch-at-age model, ASAP. The first formulation explored was similar to the VPA model formulation (BASE_VPA). Two additional configurations, PRELIM_2FLEET and PRELIM_4FLEET, explored the possibility of decomposing the single VPA catch-at-age matrix into two or four subcomponents, respectively. Details of these three broad categories are discussed below in more detail.

In the BASE_VPA formulation, a single catch-at-age matrix with an age 11+ group was considered, and survey indices were fit to individual indices-at-age rather than tuning to the aggregate indices with the age compositions fit separately. A single fishery selectivity ogive was assumed to operate for the period 1982 to 2010. This selectivity assumption differs from the VPA, where fishery selectivity can vary annually. To estimate the single fleet selectivity, age six was assumed to be fully selected, and the remaining ages were freely estimated. The coefficient of variation (CV) on the aggregate fishery catch was set at 0.05. All survey indices used in the base VPA model (run 10) were incorporated including the MADMF fall survey (which was later dropped in the final BASE model). Unlike in the VPA, where fall survey indices were lagged forward an age and a year, ASAP can account for survey timing within the year, so survey indices-at-age were entered as true ages and years. The CVs on all survey indices-at-age were fixed at 0.3. Recruitment steepness was fixed at 1, so recruitment was estimated as deviations about the geometric mean rather that attempting to fit to a stock-recruit function. Unlike the base VPA model (run 10), the time of spawning was updated to April 1 in the BASE_VPA model similar to VPA run 10g.

The time series of spawning stock biomass (SSB) and average fishing mortality on ages 5-7 ($F_{5\text{-}7}$) was similar between the BASE and BASE_VPA runs from approximately 1998 onward (Appendix Fig. A2.1). There were large differences in the SSB time series early on (1982 – 1988) that are primarily the result of differences in the model estimates of age 9^+ fish (Appendix Fig. A2.2). The large amount of age 9+ fish in the BASE_VPA model is an artifact of the ASAP burn in period where a large pulse of older fish is necessary to support the strong doming of the fishery selectivity estimated in the BASE_VPA model (Appendix Fig. A2.3). While the doming of the fishery selectivity is quite strong, the selectivity at age 9 and older is imprecisely estimated with CVs exceeding 0.50 (Appendix Table A2.1). The selectivity for ages 1 through 7 is similar, though not identical to the selectivity of the BASE model in the 1991 – 2010 time block. Overall, the current perception of the Gulf of Maine cod stock based on the BASE_VPA model is similar in terms of current stock biomass and fishing mortality rates.

Subsequent formulations of the ASAP model did not tune to the survey indices-at-age separately, rather they tuned to the aggregate survey indices with age compositions fit assuming a multinomial error distribution. All preliminary ASAP runs used three survey indices (NEFSC spring, NEFSC fall, MADMF spring) with age compositions fit to ages 1 through 11^+. Survey selectivities were estimated assuming a double logistic fit. All preliminary ASAP runs attempted to break the fishery catch into separate fleets (commercial and recreational). Selectivity was fit as a double logistic with three separate selectivity blocks per fleet. The timing of the selectivity block varied slightly by fleet, but generally, there was a single selectivity block per decade. Two main categories of the two fleet formulations were explored in the preliminary runs: 1) catch was divided into two fleets and within each fleet, discards are accounted for assuming a release mortality option. Release mortality was set at 100% (PRELIM_2FLEET); and 2) for each fleet (commercial and recreational), catch was divided into retained and discarded catch, with each disposition constituting its own fleet such that there were 4 fleets total (PRELIM_4FLEET).

The results from these preliminary runs were not substantially different than the BASE run in terms of SSB or $F_{5\text{-}7}$ (Appendix Fig. A2.4). The PRELIM_2FLEET had slightly higher estimates of SSB and F owing to greater doming of the fleet selectivities. The effects of the doming are evident in the number of fish surviving to the age 9^+ group (Appendix Fig. A2.5). Recruitment was nearly identical in the preliminary runs relative to the BASE run. While the results of these preliminary runs were similar to the BASE run, the preliminary runs suffered from diagnostic issues. Specifically, the PRELIM_2FLEET model suffered from strong residual patterning in the fits to catch combined with generally poor fits to the discard components. For both the commercial and recreational fleet the retained catch tended to have strong positive residuals while the discarded catch had strong negative residuals (see Appendix Fig. A2.6 for an example from the commercial fleet). Alternate configurations of the PRELIM_2FLEET model were attempted to address the residual patterning with limited success.

The development of the PRELIM_4FLEET model was an attempt to provide greater model flexibility and reduce the tension between landings and discards leading to the strong residual patterning. The PRELIM_4FLEET configuration was successful in this regard, but still resulted in poor overall fits to the discard fraction of the catch (Appendix Fig. A2.7). Subsequent attempts to improve the fit of the PRELIM_4FLEET were largely unsuccessful. Moreover, the model appeared to be highly unstable and many of subsequent model formulations failed to converge. Given the problems experienced with these complex ASAP formulations, a decisions was made to simplify the model formulation. Subsequent formulations fit to the aggregate catch as was done in the BASE run rather than attempting to treat fleet catches explicitly.

A2.1.2. Accounting for additional catch uncertainty

The SARC Panel expressed some concern that the CVs on the aggregate catch used in the BASE model (CV=0.05) assumed higher precision than was warranted given the CV estimates of 0.11 – 0.38 for commercial discards (Table A.20) and recreational catch percent standard errors (PSE) around 20% (Table A.34). The Panel felt that CVs of 0.10 (BASE_CV10) or 0.15 (BASE_CV15) on the aggregate catch should be explored to examine the sensitivity of the BASE model to alternate assumptions. In these sensitivity runs only the CVs on the aggregate catch were adjusted; all model inputs and parameters were held constant. The results of the sensitivity runs showed little impact on overall results in terms of SSB, F, age-1 recruitment and total stock size (Appendix Fig. A2.8 and A2.9). The largest impacts, while small, occurred during the late 1980s and early 1990s when large catches of Gulf of Maine cod occurred. Increasing the CVs on aggregate catch reduced the overall fit on catch; models with higher CVs were less inclined to fit to the high catch estimates during this period (Appendix Fig. A2.10). Lower catches lead to lower model estimates of recruitment and subsequent stock size, thus accounting for the small discrepancies observed in the late 1980s and early 1990s.

Increasing catch CVs lead to slight improvements in the model fits to the survey indices, but only marginally (Appendix Fig. A2.11). The root mean square error on the NEFSC spring survey went from 1.05 under the BASE model to 1.00 in the BASE_CV15 model. There was no noticeable change in the NESFC fall survey. The MADMF spring survey improved from a RMSE of 1.07 in the BASE model to 1.04 under the BASE_CV15 model. Overall, increasing CVs on the aggregate catch had negligible impacts on the assessment results.

A2.1.3. Restricting the age range in the survey to those ages that exhibit internal consistency

The SARC Panel was interested in examining the sensitivity of the BASE model to inclusion of only those survey ages that showed internal consistency across time (i.e., ages for which cohorts were traceable across years). An examination of cohort tracking within the survey suggested that in general, cohorts could be tracked from one age to the next at ages 1-6 on average across all surveys (Appendix Table A2.2). The division was not distinct, but does provide a basis for restricting surveys to an age range where there is sufficient information. Additionally, at survey ages greater than age 6, there is a notable increase in the number of zero indices-at-age (Tables A.48, A.49 and A.53).

The SSB and F trends of the survey, age-6 truncated run (BASE_AGE6) were identical to the BASE run, though the scale of the BASE_AGE6 run was scaled up in terms of SSB and down in terms of F (Appendix Fig. A2.12). The estimated recruitment in both runs were nearly identical, but there were large differences in the estimates of age 9^+ fish between the two runs (Appendix Fig. A2.13). The large increase in the numbers of age 9+ fish in the BASE_AGE6 run are the result of the strong doming in the fleet selectivity at older ages in the BASE_AGE6 run compared to the BASE run (Appendix Fig. A2.14). The large doming in the BASE_AGE6 run is a likely product of the absence of survey age composition out beyond age 6. With no information to anchor the catch at age, the model tends to fit a much stronger dome to the catch selectivities, leading to a buildup of older age fish and increase in SSB relative to the BASE run.

A2.1.4. Exploration of a shorter assessment time series

Over the course of the BASE assessment time series (1982 – 2010) there have been documented changes in fishery regulations, including increases in mesh size and minimum fish size and though less well documented, possible changes in fish biology (e.g., distribution and size at age). Both regulatory changes and biological changes can alter fishery and survey selectivity. The BASE model attempts to account for these changes by creating two discrete fishery selectivity blocks; the first between 1982-1990 and the second between 1991-2010. While the selectivity blocks represented a 'best' attempt to account for changes affecting fishery selectivity, they likely do not account for all changes. A sensitivity run starting in 2000 was conducted (BASE_2000) to give the model greater flexibility in the most recent period such that it is not confounded by changes to fishery and biology over the last two decades (i.e., block 2, 1991-2010).

The assessment results of the BASE_2000 are similar to the BASE run between 2000 and 2007, but become increasingly divergent from 2008 onward (Appendix Fig. A2.15). The BASE_2000 run estimated increasingly lower SSB and higher fishing mortality between 2008 and 2010 relative to the BASE model. The 2010 estimates of SSB and F fell outside of the 90% probability intervals (PI) of the BASE model (SSB PI = 9,479 – 16,301 mt, F_{full} 90% PI = 0.79 – 1.54), with SSB estimated at 8,815 mt and F estimated at 1.59. The CVs on the terminal estimates of the two model runs are identical (SSB = 0.16, F = 0.21). The differences between the two models are primarily the result of the differences in selectivity, with the BASE_2000 run having greater selectivity on the age 9^+ group relative to the BASE model (Appendix Fig. A2.16).

A2.1.5. Exploring the impacts of individual survey indices on model results

To better understand how the model results are being influenced by each of the survey indices the BASE model was run using only one index at a time. The three sensitivity runs were BASE_INDEX1 (NEFSC spring survey), BASE_INDEX2 (NEFSC fall survey) and BASE_INDEX3 (MADMF spring survey). In all three sensitivity runs all other model configurations were left unchanged.

There are minor differences between the BASE_INDEX1, BASE_INDEX2 and the BASE run, notably in the early 1990s, but over the most recent five year period the three runs are similar with respect to SSB and F (Appendix Fig. A2.17). There are minor differences in the recruitment estimates and age 9^+ population estimates but there are no major differences beyond the initial burn in period of 1982 to 1990 (Appendix Fig. A2.18). The BASE_INDEX3 which tunes only to the MADMF spring survey exhibits large differences in SSB and F over the last decade compared to the BASE model, with the BASE_INDEX3 model estimating higher terminal SSB and lower F relative (Appendix Fig. A2.19). The recruitment estimates between the two models are similar, but there are large differences in the estimates of age 9^+ fish. The increase in older age fish is a product of the sharp dome that exists in block 2 of the BASE_INDEX3 run, with selectivity on age 9+ fish near 0.19 compared to 0.67 in the BASE run (Appendix Fig. A2.20). The CVs on the selectivity estimates of age 8 and age 9+ in block2 of the BASE_INDEX3 run are nearly double those of the BASE run, additionally, the age9+ selectivity in block1 appears to be hitting a bound of 1.0 (Appendix Table A2.3). These results suggest that the BASE_INDEX3 model has difficulty estimating the fleet selectivity at older ages. This is consistent with the results of the BASE_AGE6 run which illustrated the sensitivity of model estimated selectivity curves when there was limited survey information for older age classes. The MADMF spring survey, which encompasses only nearshore waters, catches few old fish as indicated by the estimated survey selectivity in the BASE run (Fig. A.126).

A2.1.6. Summary of ASAP sensitivity runs and how the results inform the perception of model uncertainty

Including the 10 ASAP sensitivity runs explored in this Appendix, there are 14 sensitivity runs presented in this report. In 7 (50%) of the sensitivity runs, the 2010 SSB was above the 11,868 mt estimate of the BASE run (Appendix Table A2.4). Estimates of F_{full} exceeded the BASE estimate of 1.14 in 9 of the 14 runs (64.3%) 2010. All but two of the sensitivity runs had 2010 terminal SSB and F_{full} estimates that fell within the 90% PIs of the BASE run. The two exceptions were the BASE_INDEX3 run which estimated substantially higher SSB and lower F and the BASE_2000 run which estimated lower SSB and higher F. Over the assessment time series, the majority of sensitivity runs have fallen within the 90% PI of the BASE run both with respect to SSB (Appendix Fig A2.22) and to a greater extent, F_{full} (Appendix Fig. A2.23). While approximately 5 of the sensitivity runs fell outside the SSB 90% PI at some point in the time series, they all follow the same general trends of the BASE model, with the differences resulting primarily due to scale. The scaling issues are primarily related to the estimated fleet selectivity in each of the models. Given the robustness of the assessment results to different model formulations, there is a high degree of confidence that the 90% PI of the BASE model adequately characterizes the uncertainty in the assessment results.

A2.2. Exploration of survey catchability and its implications on estimated biomass

The scale of model estimates of biomass is sensitive to the estimated fleet (fishery) selectivity as illustrated by the sensitivity runs. In addition to fishery selectivity, the relative scale of the estimated biomass can be affected by assumptions of the estimated efficiency of the surveys. Further work was conducted to 1) evaluate the sensitivity of the BASE model results to alternate assumptions of survey catchability (q), and 2) generate model-independent estimate of total biomass and compare to the model estimates to determine whether the BASE results are reasonable.

A2.2.1.1. Model profiling across a range of NEFSC spring survey q values

The sensitivity of the BASE model to alternate assumptions of survey catchability was evaluated by profiling across a range of q values from 0.1 to 1.0. Priors were specified for catchability ranging from 0.1 to 1.0 in 0.1 increments. The input CV on catchability was set to 0.1 and given lambda values of 1 (i.e., the initial q values were given little latitude to deviate from the initial conditions and a penalty was imposed for any deviations).

Results of the sensitivity runs are summarized in Appendix Fig. A2.24. On the basis of the objective function, the BASE model preferred q values in the range of 0.7 to 1.0. There was a general tendency for the model to estimate higher q values than inputted despite the low CV and a penalty was placed on deviations. Within the 0.7 to 1.0 range there was little impact in terms of SSB scaling (<5% difference from BASE run). Even when forcing q to a minimum believable range (≈0.4) the SSB scaling differences only amount to 10-20% differences from the base run q preference of 0.92. The tradeoff in lower q reduces the overall fit in the NEFSC spring survey and by necessity, reduces q on the NEFSC fall survey. Additionally, a lower q requires an approximate 22% decrease in the selectivity on the oldest age in the second fishery selectivity block (i.e., a considerable increase in the doming assumption). The profiling across a range of q values shows strong model preference for the BASE model results, with little impact in terms of SSB within the range of believable alternatives.

A2.2.1.2. Sensitivity of BASE results and estimates of survey q to area expansion factors

The Gulf of Maine cod stock boundary (Fig. A.1) encompasses a surface area of approximately 54.5 thousand km^2. The survey strata used in the Gulf of Maine cod stock assessment encompass 61.4

thousand km^2 which is approximately 17.1% larger than the stock area. Included in the survey strata set are three strata, 29, 30 and 36, that extend beyond the United States Exclusive Economic Zone (EEZ) into Canadian waters. A sensitivity analyses was conducted to evaluate whether using a survey strata set that included only survey strata contained entirely inside the US EEZ would affect model results and estimates of survey *q*.

NEFSC spring and fall survey indices, including indices at age, were recalculated using only strata 26-28 and 37-40 (exclude 29, 30 and 36). The revised survey area has a surface area of 34.2 thousand km^2 (37.2% smaller than the stock area).The recalculated aggregate abundance indices were nearly identical in terms of trends, but tended to be slightly higher (Appendix Fig. A2.25). The rescaling of the survey indices is a product of dropping survey strata that have historically not contained high abundances of cod, thus increasing the stratified mean number/tow without impacting overall survey trends. When converted to area swept indices by accounting for the survey trawl area and revised surface area, the indices tended to be lower than those that included in the full strata set (Appendix Fig. A2.26). The raising factor used to convert the mean number per tow to their area-swept equivalents was disproportionately smaller than the increases in the stratified mean number per tow. The revised survey indices were inputted into a revised ASAP model (BASE_revAS).

The BASE_revAS model is nearly identical to the BASE model with respect to the SSB, F and the age 1 recruitment time series (Appendix Fig. A2.27). There are small deviations early on in the time series, particularly in F, but over the last decade, the BASE and BASE_revAS are similar. The slight deviations in the two runs are likely due to the small differences in the survey indices when calculated using the reduced strata set. While there were no major differences in estimates of SSB and F, using the reduced strata sets resulted in q estimates that were much lower relative to the BASE model. The NEFSC spring q went from 0.92 to 0.57, NEFSC fall from 0.53 to 0.42 and the MADMF spring survey was unchanged at 0.16. The model estimates of *q* are highly sensitive to the estimated survey area used to expand mean number per tow survey indices to their area-swept equivalents. In addition to the assumptions about total survey area considered here, estimates of *q* are also likely to be sensitive to assumptions about the total trawl area, effective trawl sweep and the extent of cod herding that occurs in the survey net.

A2.2.2. Model independent estimates of total biomass

All previous analyses have examined the sensitivity of the biomass estimates to different assumptions on model parameters. While these analyses show that the model-based biomass estimates are robust to alternate model configurations, they do not provide a sense for whether the model-based estimates are realistic relative to model-independent estimates of total stock biomass. Several different model-independent approaches are taken below to evaluate whether the ASAP estimates of biomass are realistic.

A2.2.2.1. Model independent estimates of total biomass from the Bigelow survey years (2009-2011)

The conversion of Bigelow survey catches to Albatross equivalents is an uncertain, but necessary step in order to maintain a consistent time series and fully utilize the very short Bigelow time series. To avoid any confounding effects of the Bigelow conversion in deriving model-independent estimates of biomass, an attempt was made to use raw (i.e., unconverted) Bigelow time series data (2009 – 2011) to estimate total biomass. Total survey area-swept biomass can be estimated using Appendix Equation 1.

(1) $B_{AW} = I/1000 \cdot A/f \cdot 1/q$

where:

B_{AW} = Area swept biomass
I = survey index
A = survey area
f = trawl area
q = survey catchability

The survey area depends on the strata set included. For the purposes of these analyses, the inshore survey strata were included to better characterize total catch across all age classes (strata 57-69) in addition to the offshore survey strata (strata 26-30, 36-40). The nearshore area that makes up the inshore survey strata has higher abundance of juveniles relative to the offshore areas. The differences in availability of young age classes between the inshore and offshore regions is evident when comparing the selectivity of NEFSC offshore surveys to the MADMF survey in the BASE model (Fig. A.126). The total surface area of strata 26-30, 36-40 and 57-69 is 63.8 thousand km^2 and 36.5 thousand km^2 when strata 29,30 and 36 are excluded. The total trawl area of the Bigelow is 0.024 km^2 when using wing spread to define the effective trawl area and 0.061 km^2 when using door spread. Comparatively, the Albatross tow area in terms of wing spread is 0.038 km^2.

Assumptions on the effective trawl area and q can have large impacts on survey-based estimates of total biomass. Moving from a q of 1.0 to 0.2 will result in a fivefold increase in terms of biomass (Appendix Fig. A2.28). Assuming that the door spread best characterizes the effective trawl area results in biomass estimates less than half that compared to calculations made using wing spread. If there is herding between the doors and an assumption of wing spread is used to determine area swept biomass, biomass estimates may be inflated (or in the case of the model, *q* estimates, may be higher than reality). The true effective trawl area and survey catchability is not known, but an assumption that a wing spread-based estimate of effective trawl area and 80% efficiency (q=0.8) appears reasonable. Using these assumptions to estimate a survey-based estimate of total biomass yielded results similar to the BASE model estimates of total biomass at the time of the survey (i.e., total January 1 biomass decremented by total mortality, *z*, occurring before the survey; Appendix Fig. A2.29). In 2009 and 2010 the BASE biomass estimates are all within the 80% bootstrap CI of the Bigelow-based biomass estimates. Excluding the offshore survey strata does not impact the overall perception of Bigelow-based total biomass.

Given an assumption that the Bigelow survey q=0.8, it's reasonable to conclude that a comparative *q* for the Albatross survey is approximately 0.5 if the Bigelow to Albatross conversion coefficient of 1.602 on fish ≥ 54 cm is used as a rough estimate of differences in catchability (i.e., the Bigelow survey is 60% more efficient at catching cod compared to the Albatross survey). By performing a similar analysis on the Albatross survey series, but using a q assumption of 0.5, a time series of survey-estimated total biomass can be constructed. The survey-based time series is not inconsistent with the BASE model estimates of total biomass at the time of the survey (*z*-decremented to the time of the survey). The BASE biomass estimates generally fall within the 80% CI of both the NEFSC spring and fall survey-based biomass estimates (Appendix Fig. A2.30). While the estimates are not exact, they are all of the same relative scale, suggesting that the BASE model estimates are realistic.

A2.2.2.2. Thinking of q in terms of the catchability of 'survey-able' biomass

The BASE model estimate of NEFSC spring survey q (0.92) seems unreasonably high when thought of in terms of total survey efficiency. However, when interpreting the model *q* values, the impact of survey selectivity on the *q* estimates needs to be considered. Effectively, the BASE model *q* estimates represent the *q* in terms of fully selected fish (i.e., after accounting for survey selectivity). To examine whether the BASE *q* estimates were reasonable, the model estimates have been used to estimate survey-based total biomass as was done above. Unlike the previous analysis that incorporated the inshore survey strata, only the offshore survey strata are included here, as this is consistent with the NEFSC survey indices used in the BASE model. This maintains consistency between the survey index and model-based estimates of *q* and selectivity at age. Survey-based biomass indices were generated using both the full offshore strata set (26-30, 36-40) and with strata 29,30 and 36 excluded. The model estimates of *q* applied to estimate total biomass were: NEFSC spring = 0.92 (full strata set), 0.57 (exclude 29, 30 and 36) and NEFSC fall = 0.53 (full strata set), 0.42 (exclude 29, 30 and 36).

Total survey-based estimates of biomass were compared to the ‘survey-able’ biomass estimated from the BASE model. ‘Survey-able’ biomass was estimated by decrementing the January 1 biomass (Table A.63) by total *z* between January 1 and the time of the survey (spring vs. fall) and filtering the *z*-decremented biomass through the survey selectivity ogive. The BASE-estimated ‘surveyable’ biomass generally fell within the 80% survey CI on total biomass for both the spring (Appendix Fig. A2.31) and fall (Appendix Fig. A2.32) surveys. How *q* is defined, whether in terms of absolute efficiency (as was done in section A2.2.2.1) or in terms of only fully selected ages, does impacts the *q* value. However, when the *q* is properly applied in a model-independent exercise, the calculations yield biomass estimates that are comparable with those estimated by the BASE model.

Tables

Appendix Table A2.1. Coefficients of variation associated with the estimates of Gulf of Maine cod selectivity-at-age between block 2 (1991-2010) of the ASAP base (BASE) model run and the sensitivity run BASE_VPA. **The BASE_VPA run includes catch out to age 11$^+$ whereas the BASE run only includes catch out to age 9$^+$.*

AGE	BASE	BASE_VPA
AGE1	0.17	0.13
AGE2	0.10	0.09
AGE3	0.08	0.08
AGE4	0.08	0.08
AGE5	0.00	0.00
AGE6		
AGE7	0.20	0.20
AGE8	0.33	0.36
AGE9	0.54	0.65
AGE10		0.89
AGE11		1.41

Appendix Table A2.2. Significance (p-values) of Pearson correlation coefficients across survey cohorts for the NEFSC spring, fall and MADMF spring surveys. P-values > 0.05 are highlighted in bold.

NEFSC spring (Index 1)

Age	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8
Age2	0.37							
Age3	0.75	**0.00**						
Age4	0.58	0.35	0.20					
Age5	0.59	0.83	0.34	**0.00**				
Age6	0.49	0.21	0.95	**0.02**	**0.01**			
Age7	0.46	0.49	0.04	0.47	0.15	0.10		
Age8	0.90	0.42	0.97	0.22	0.34	0.68	0.11	
Age9	0.45	0.25	0.45	0.69	0.56	0.86	0.81	0.74

NEFSC fall (Index 2)

Age	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8
Age2	**0.00**							
Age3	**0.00**	**0.00**						
Age4	0.43	0.35	0.37					
Age5	0.90	0.64	0.63	**0.04**				
Age6	0.92	0.82	0.90	0.22	0.16			
Age7	0.58	0.60	0.35	0.05	**0.03**	**0.04**		
Age8	0.42	0.71	0.79	0.03	0.07	0.11	**0.00**	
Age9	0.39	0.15	0.77	0.74	0.35	0.35	0.63	0.68

MADMF spring (Index 3)

Age	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8
Age2	0.52							
Age3	0.91	**0.00**						
Age4	0.83	0.09	**0.00**					
Age5	0.68	0.87	0.12	**0.00**				
Age6	0.22	0.30	0.56	0.24	**0.00**			
Age7	0.85	0.26	0.53	0.75	0.08	**0.00**		
Age8	0.43	0.11	0.33	0.80	0.51	**0.04**	**0.00**	
Age9	0.45	0.11	0.38	0.69	0.04	0.26	0.06	0.02

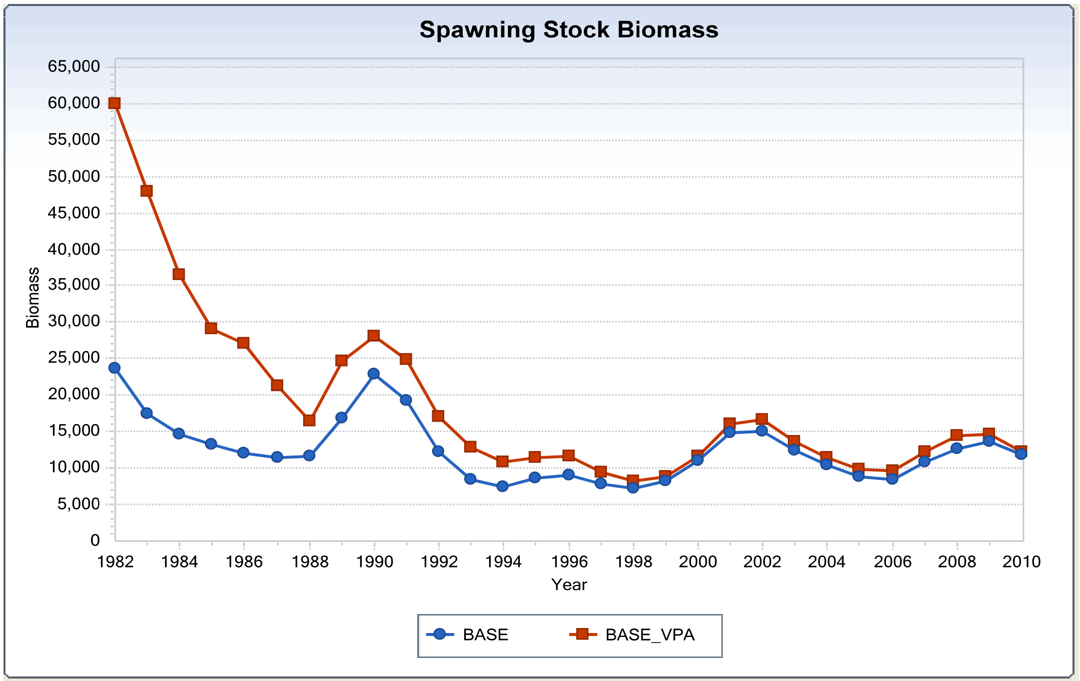
Appendix Table A2.3. Gulf of Maine cod fleet selectivities and coefficients of variation (CV) in blocks 1 (1982-1990) and block 2(1991-2010) for the sensitivity run tuned to only the MADMF spring survey index (BASE_INDEX3).

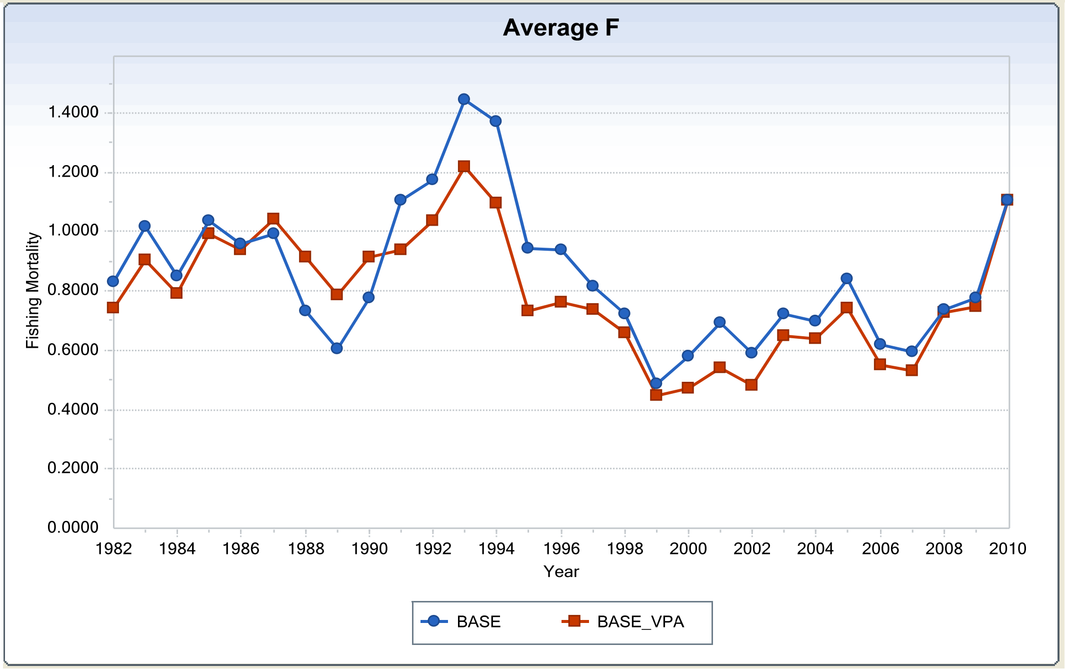
Block	Age	Selectivity	CV
1982-1990	Age1	0.05	0.18
	Age2	0.32	0.12
	Age3	0.64	0.11
	Age4	1.00	0.00
	Age5	1.00	
	Age6	0.83	0.30
	Age7	0.77	0.46
	Age8	0.70	0.66
	Age9	1.00	0.01
1991-2010	Age1	0.02	0.20
	Age2	0.12	0.15
	Age3	0.42	0.13
	Age4	0.89	0.11
	Age5	1.00	0.00
	Age6	1.00	
	Age7	0.66	0.32
	Age8	0.48	0.55
	Age9	0.19	0.95

Appendix Table A2.4. Summary of 2010 estimates of Gulf of Maine cod spawning stock biomass (SSB) and fully recruited fishing mortality (F_{full}) from 14 different ASAP sensitivity runs. Those runs that fell outside of the 90% probability intervals (PI) of the ASAP base run (BASE) are shown in bold; SSB 90% PI = 9,479 – 16,301 mt, F_{full} 90% PI = 0.79 – 1.54. **Note: PRELIM_2FLEET and PRELIM_4FLEET fishing mortalities are reported as the average fishing mortality on age 6, which is analogous to F_{full} for these two preliminary runs.*

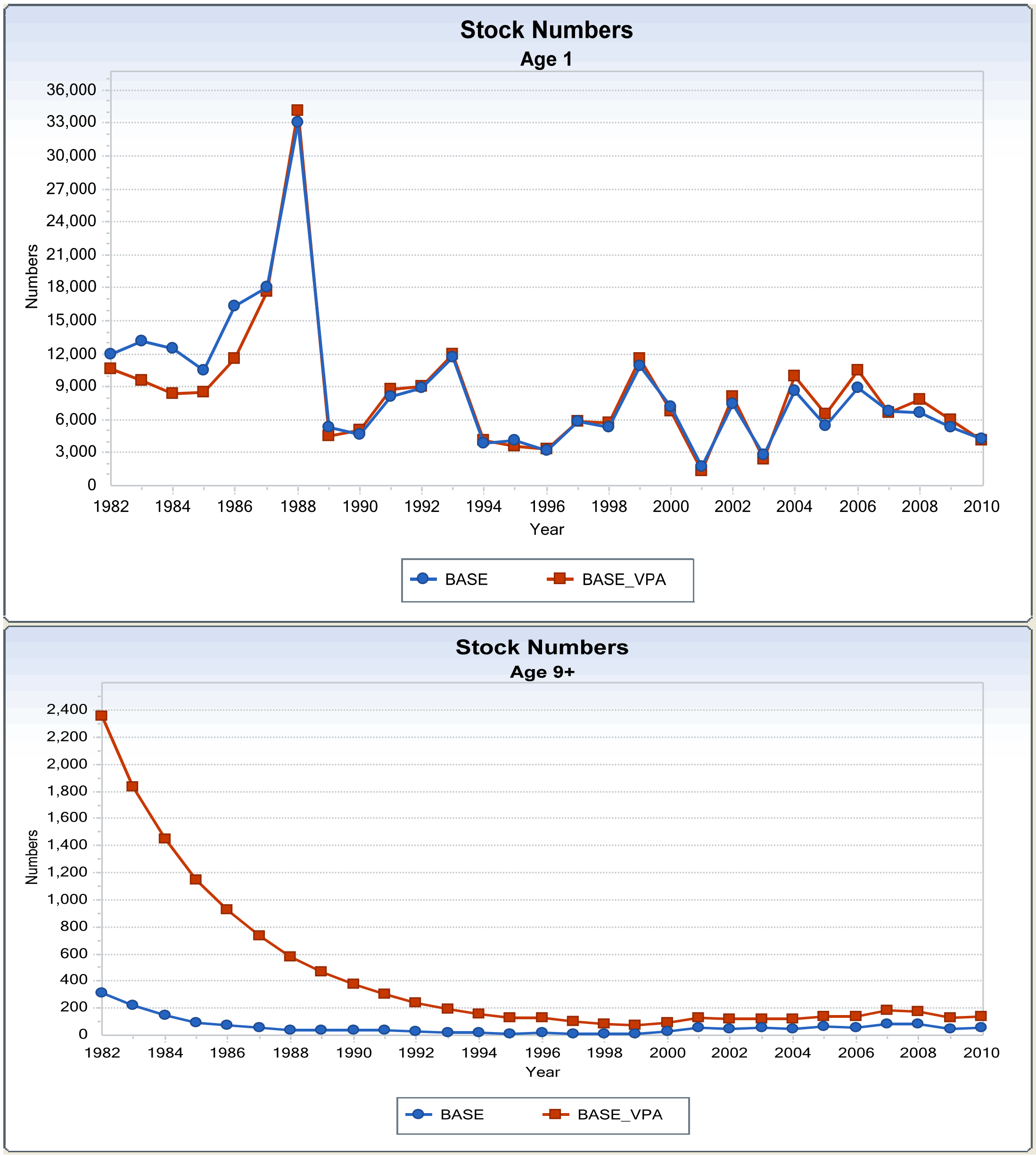
Model	**2010 SSB (mt)**	**2010 F_{full}**
BASE_11	11,777	1.15
BASE_DOME	14,476	1.04
BASE_1964	10,346	1.34
BASE_1970	9,664	1.46
BASE_VPA	12,318	1.21
PRELIM_2FLEET	15,488	*1.00*
PRELIM_4FLEET	12,134	*1.21*
BASE_CV10	11,635	1.16
BASE_CV15	11,347	1.16
BASE_AGE6	14,931	1.01
BASE_2000	**8,815**	**1.59**
BASE_INDEX1	10,726	1.28
BASE_INDEX2	12,144	1.13
BASE_INDEX3	**20,432**	**0.74**

Appendix A2 Figures

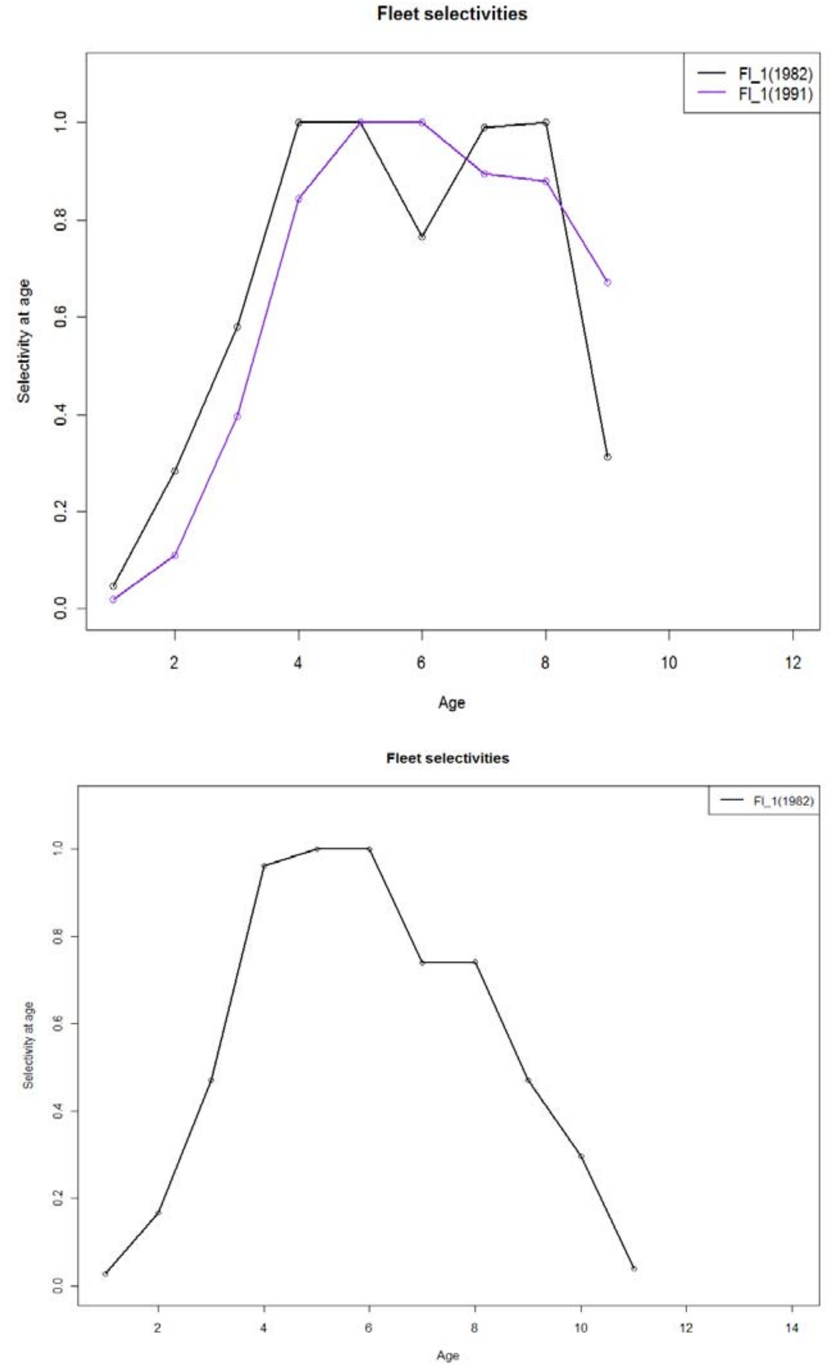




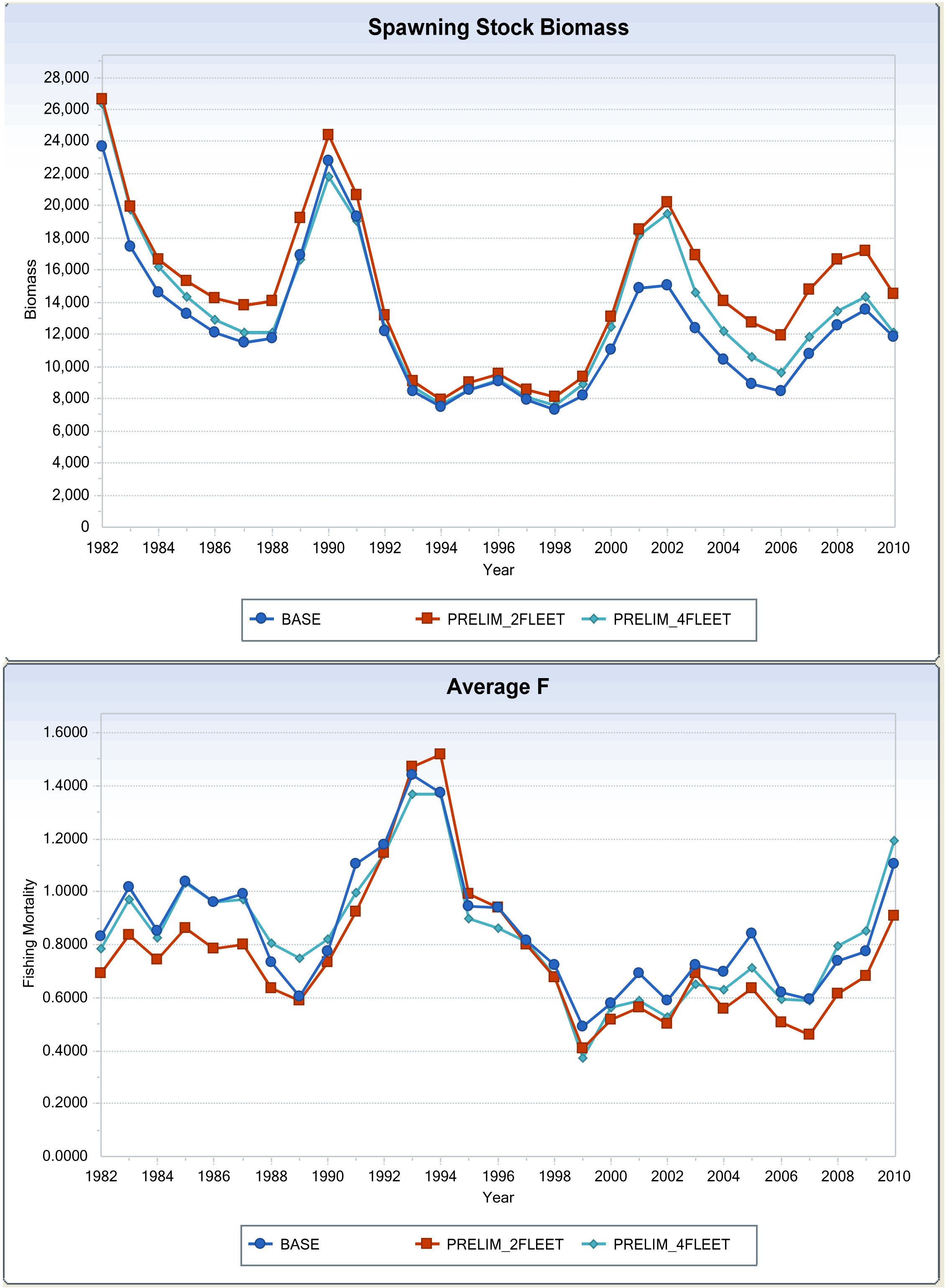
Appendix Figure A2.1. Comparison of the Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) and an ASAP sensitivity run configured similar to the updated base VPA model (BASE_VPA).



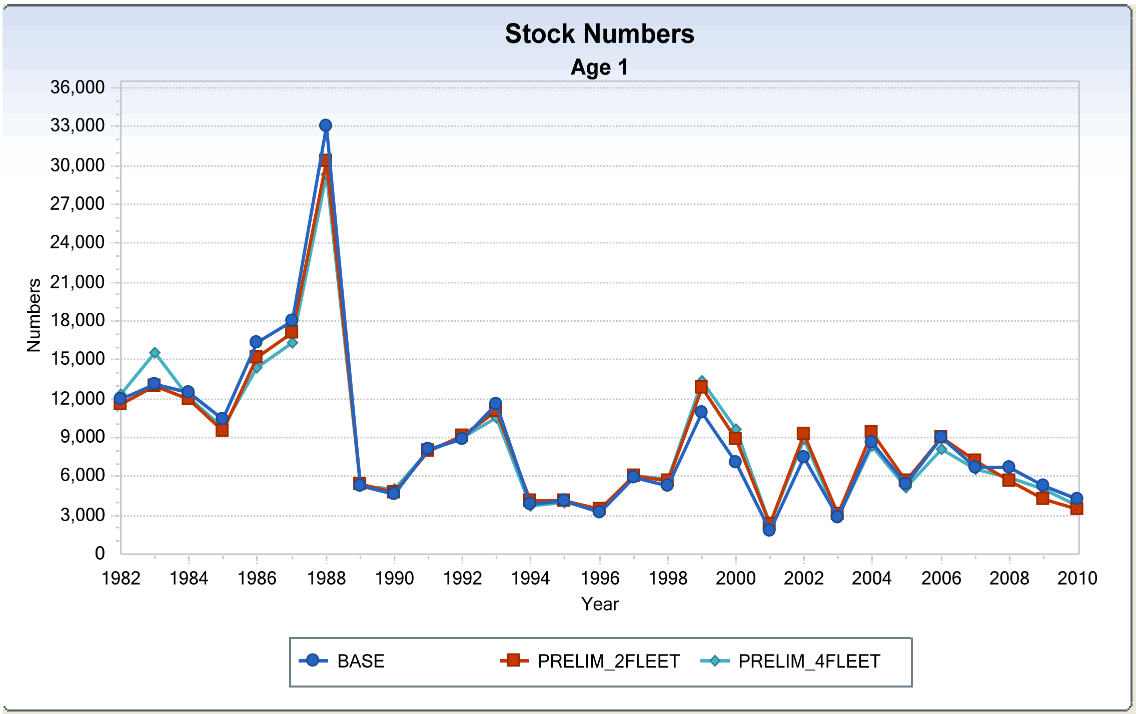
Appendix Figure A2.2. Comparison of the Gulf of Maine cod estimated age-1 recruitment in numbers (thousands of fish; top) and estimates of age 9^+ fish (thousands of fish; bottom) between the ASAP base run (BASE) and an ASAP sensitivity run configured similar to the updated base VPA model (BASE_VPA).

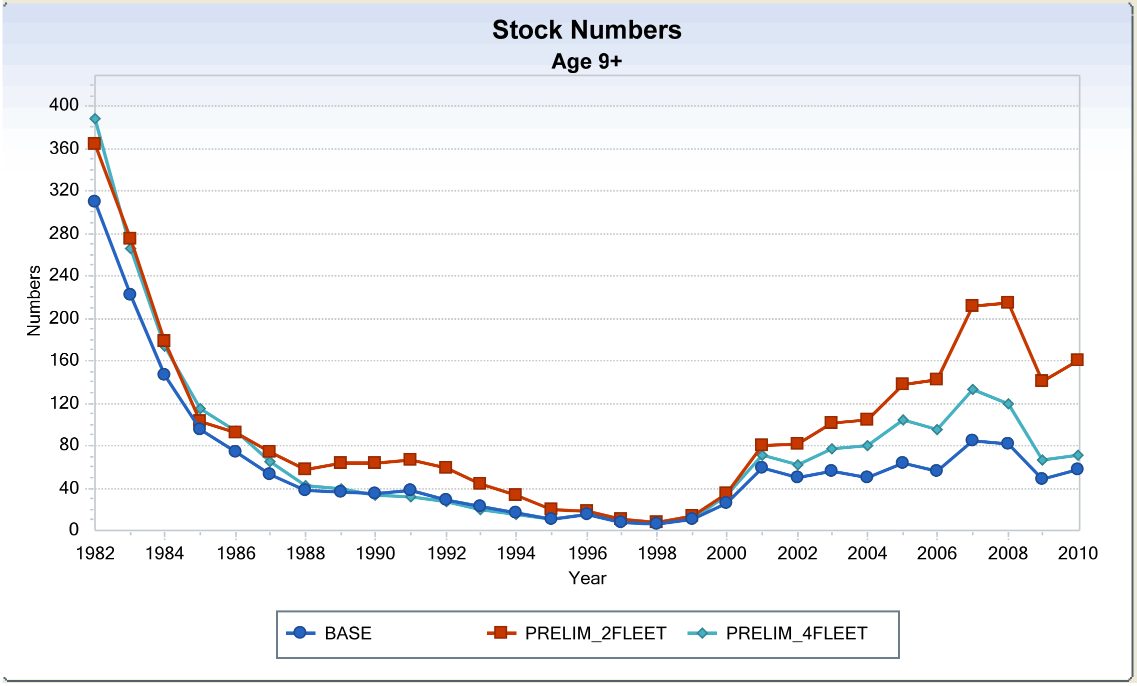


Appendix Figure A2.3. Comparison of the Gulf of Maine cod estimated fishery selectivity-at-age between the ASAP base run (BASE; top) and an ASAP sensitivity run configured similar to the updated base VPA model (BASE_VPA; bottom).

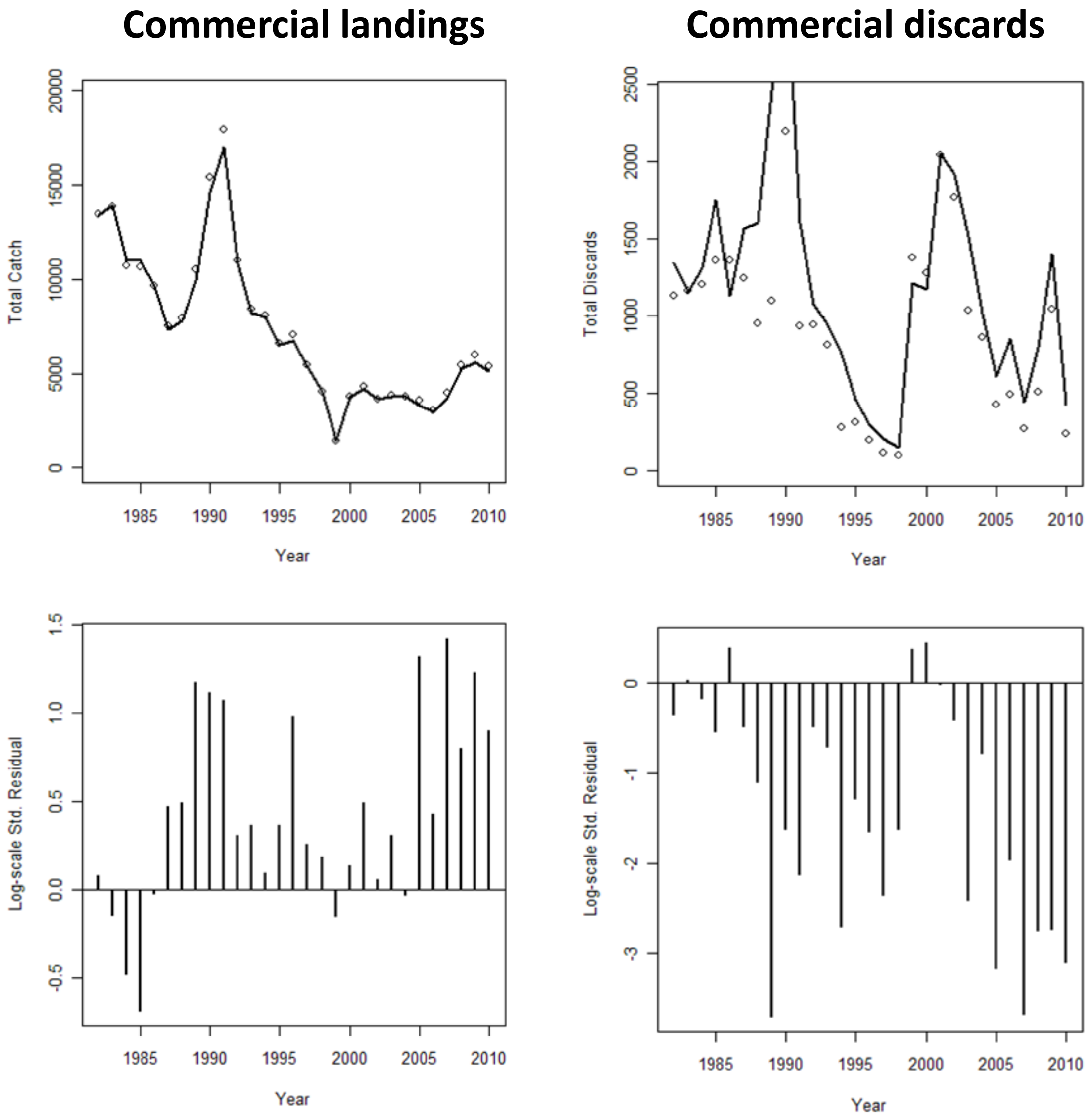


Appendix Figure A2.4. Comparison of Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) two preliminary configurations of the ASAP model, PRELIM_2FLEET and PRELIM_4FLEET.



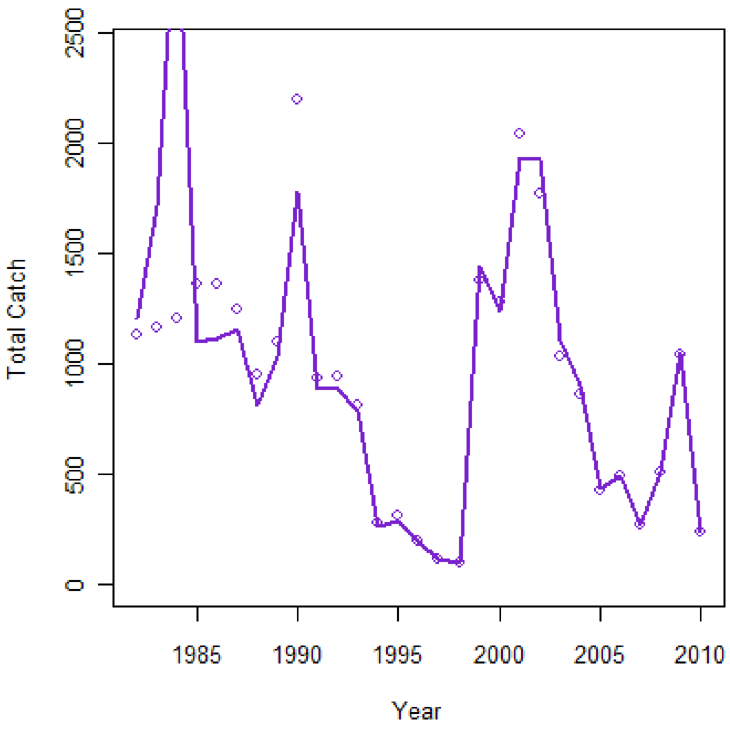


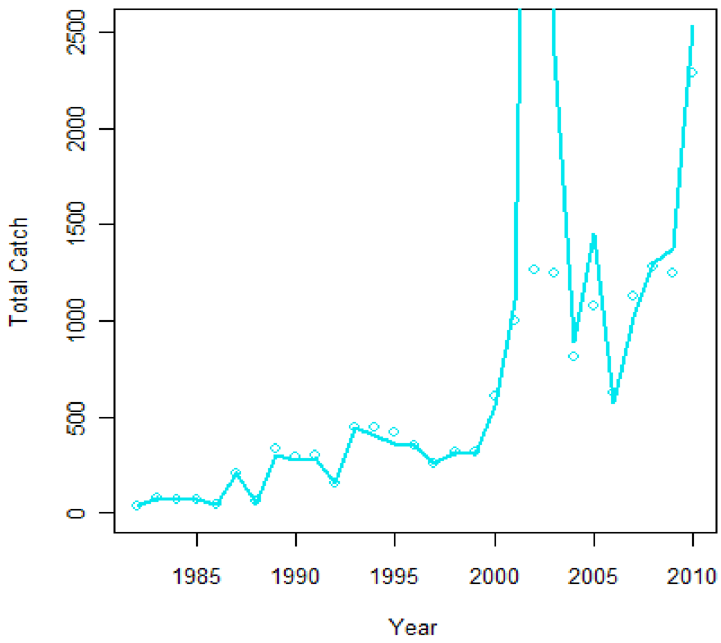
Appendix Figure A2.5. Comparison of Gulf of Maine cod age-1 recruitment (thousands of fish; top) and population estimates of age 9^+ fish (thousands of fish; bottom) between the ASAP base run (BASE) two preliminary configurations of the ASAP model, PRELIM_2FLEET and PRELIM_4FLEET.


Commercial landings

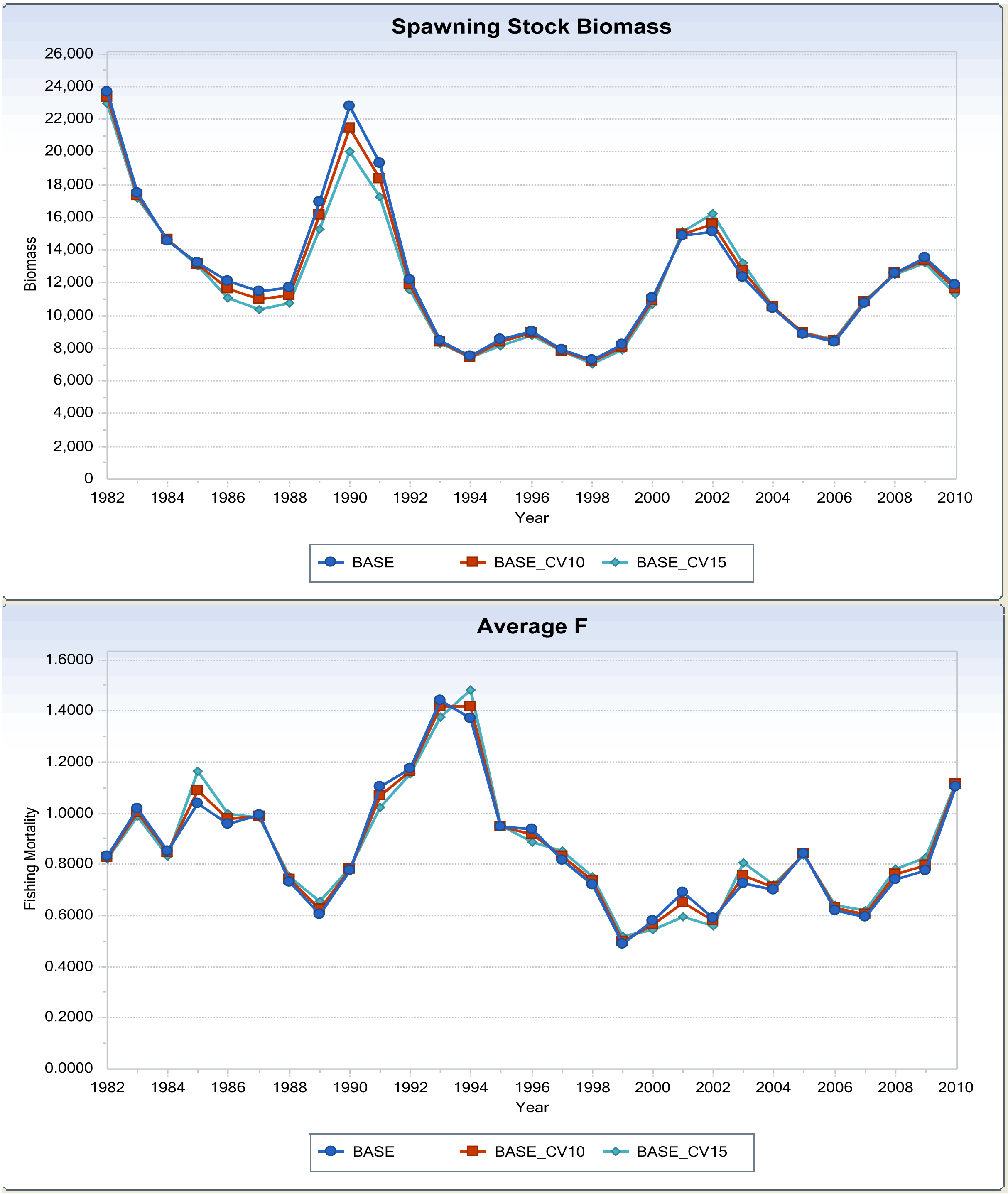
Commercial discards

Appendix Figure A2.6. Example of the residual patterns observed in the model fits to Gulf of Maine cod commercial landings (left) and commercial discards (right) from the preliminary ASAP model, PRELIM_2FLEET.

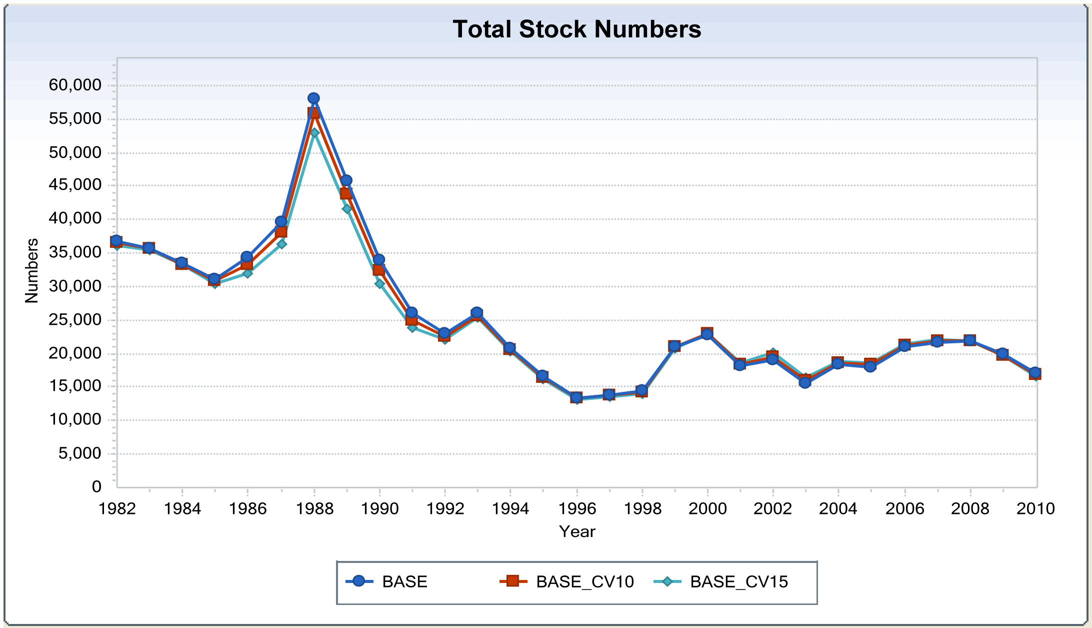


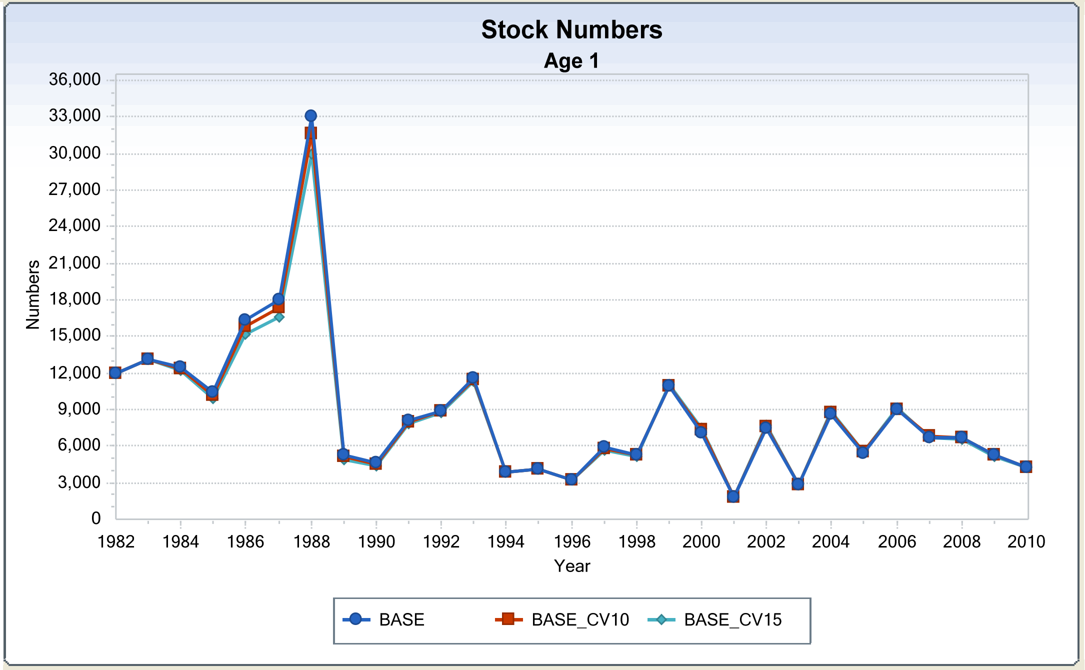


Appendix Figure A2.7. Example of poor model fits to Gulf of Maine cod commercial discards (top) and recreational discards (bottom) from a preliminary ASAP model run, PRELIM_4FLEET.

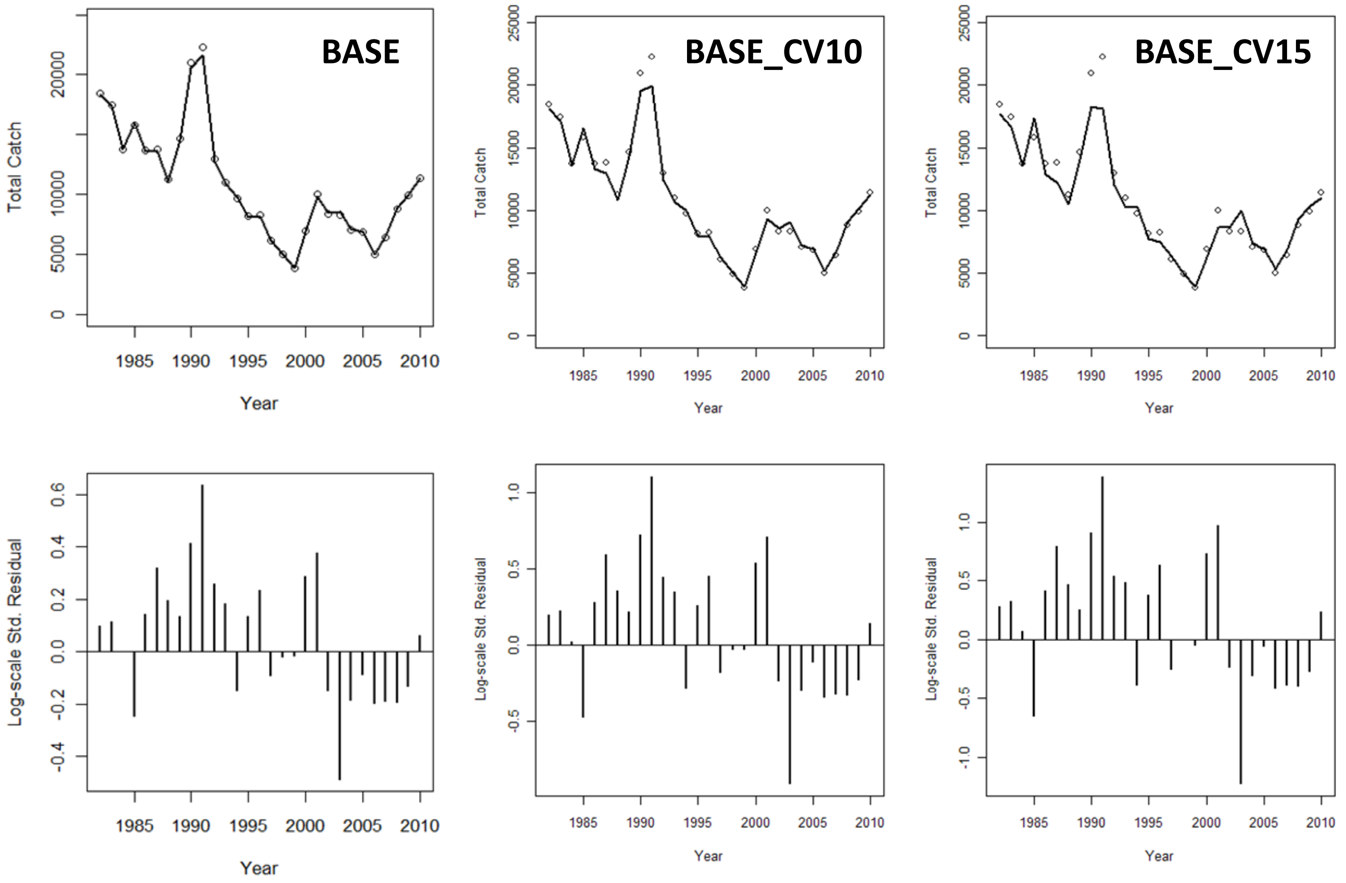


Appendix Figure A2.8. Comparison of Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) and two ASAP sensitivity runs where the coefficient of variation (CV) on total catch was increased to 0.10 (BASE_CV10) and 0.15 (BASE_CV15). The CV of the BASE run was set at 0.05.

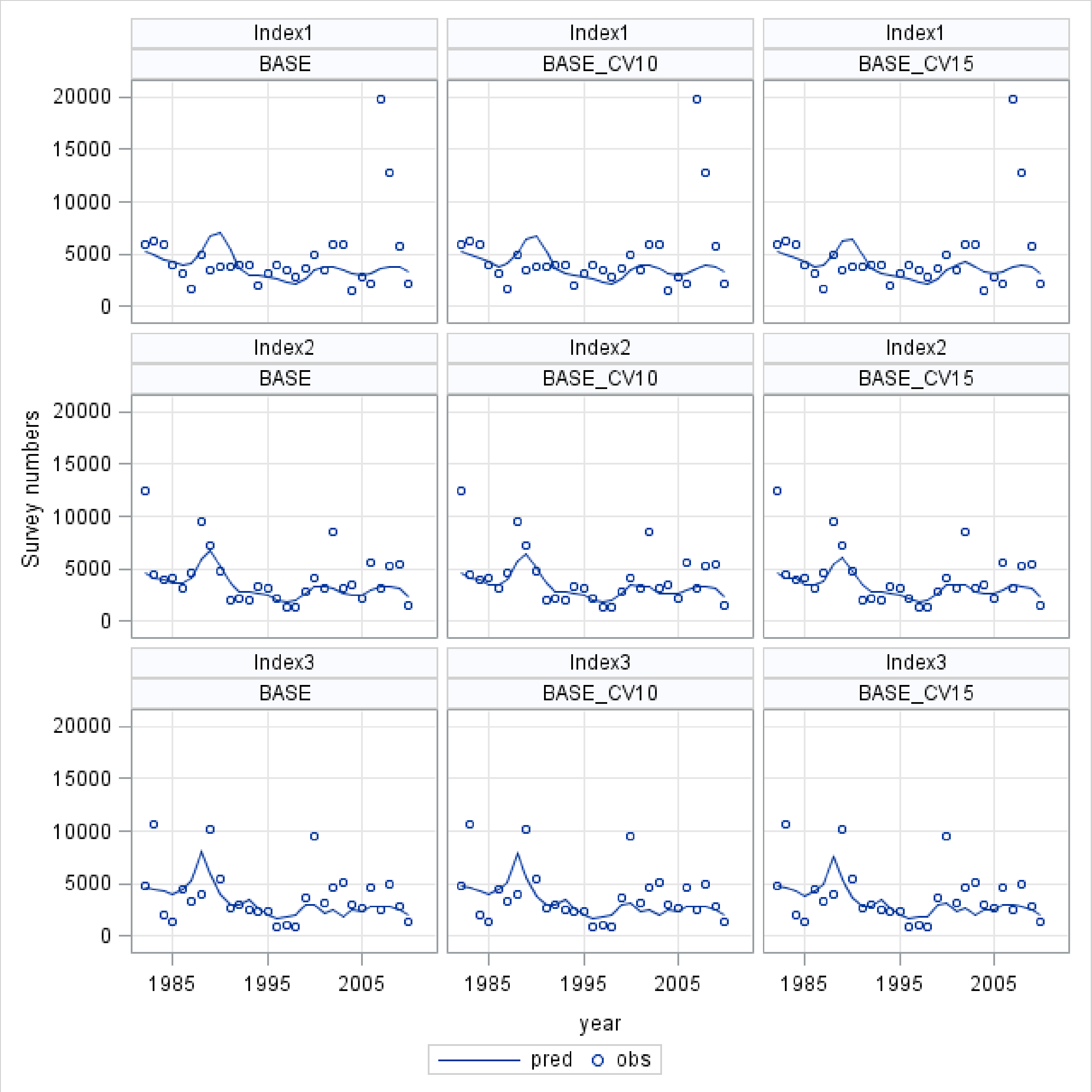




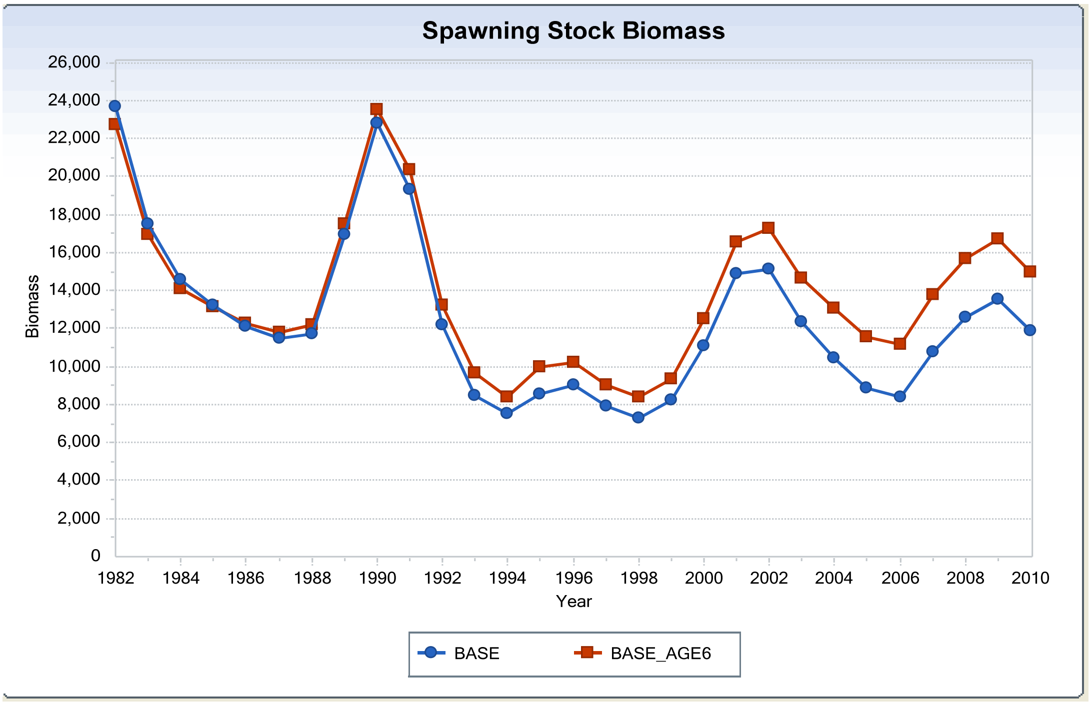
Appendix Figure A2.9. Comparison of Gulf of Maine cod total stock abundance (thousands of fish; top) and age-1 recruitment (thousands of fish; bottom) between the ASAP base run (BASE) and two ASAP sensitivity runs where the coefficient of variation on total catch was increased to 0.10 (BASE_CV10) and 0.15 (BASE_CV15). The CV of the BASE run was set at 0.05.

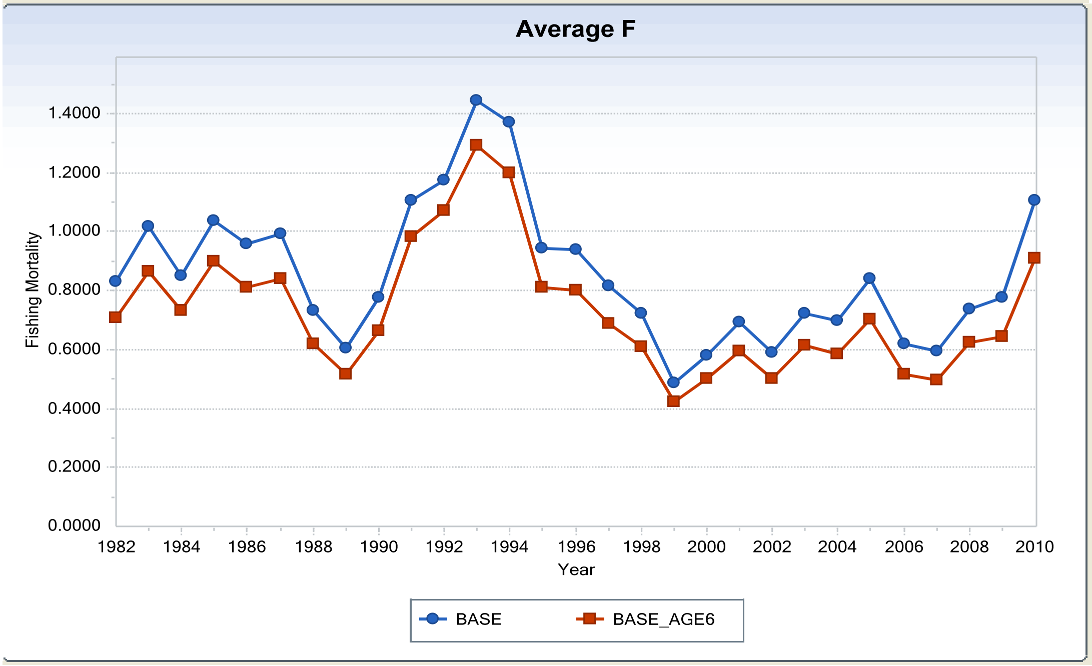


Appendix Figure A2.10. Model fits to the total catch of Gulf of Maine cod from three different ASAP model runs: BASE, BASE_CV10, and BASE_CV15. The differences in model runs are restricted to the inputted coefficient of variation on total catch; CVs were set at 0.05, 0.10 and 0.15, respectively, in each of the different model runs.

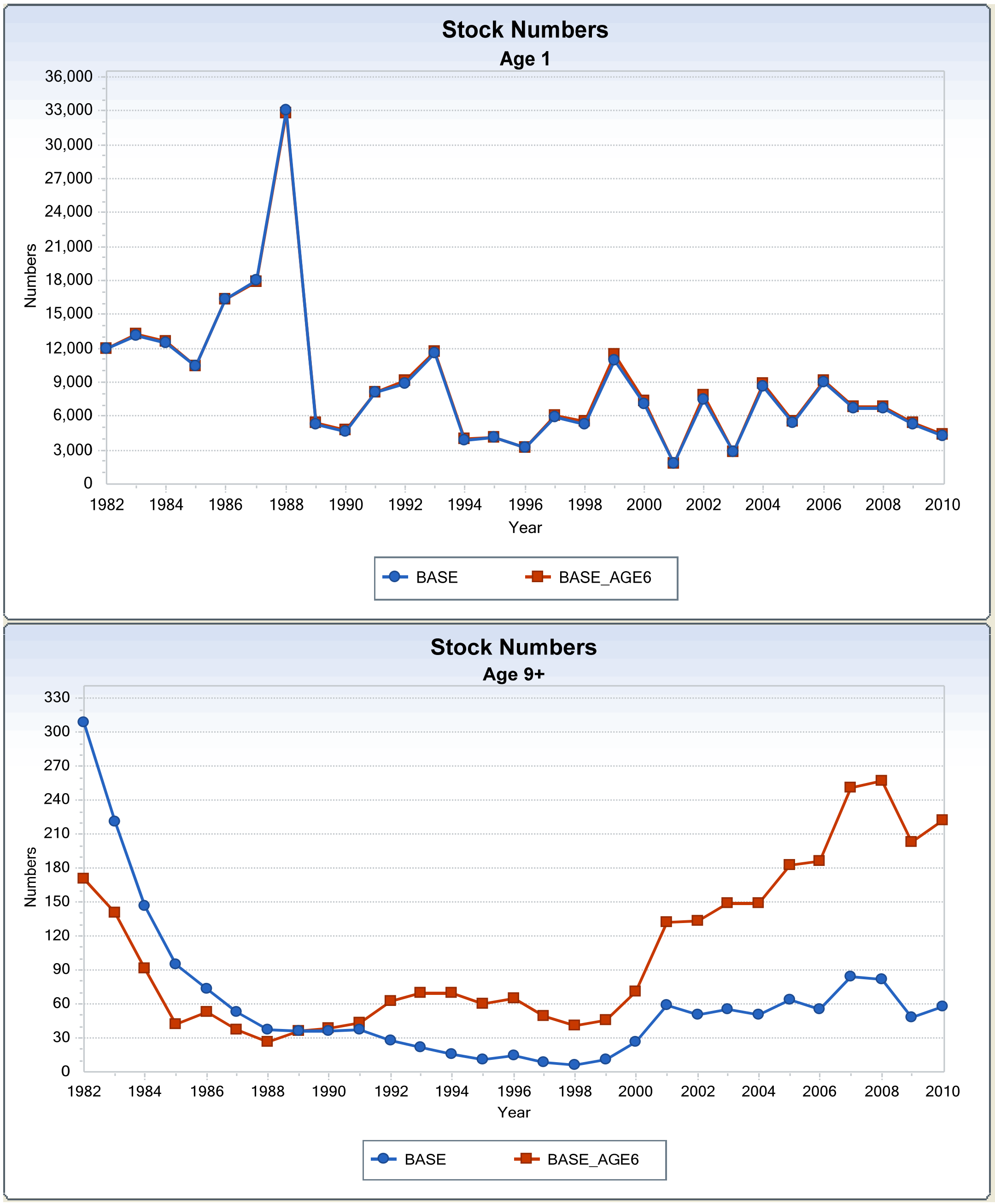


Appendix Figure A2.11. Model fits to the three Gulf of Maine cod survey indices from three different ASAP model runs: BASE, BASE_CV10, and BASE_CV15. The three survey indices are NEFSC spring (Index1), NEFSC fall (Index2) and MADMF spring (Index3). The differences in model runs are restricted to the inputted coefficient of variation on total catch; CVs were set at 0.05, 0.10 and 0.15, respectively, in each of the different model runs.

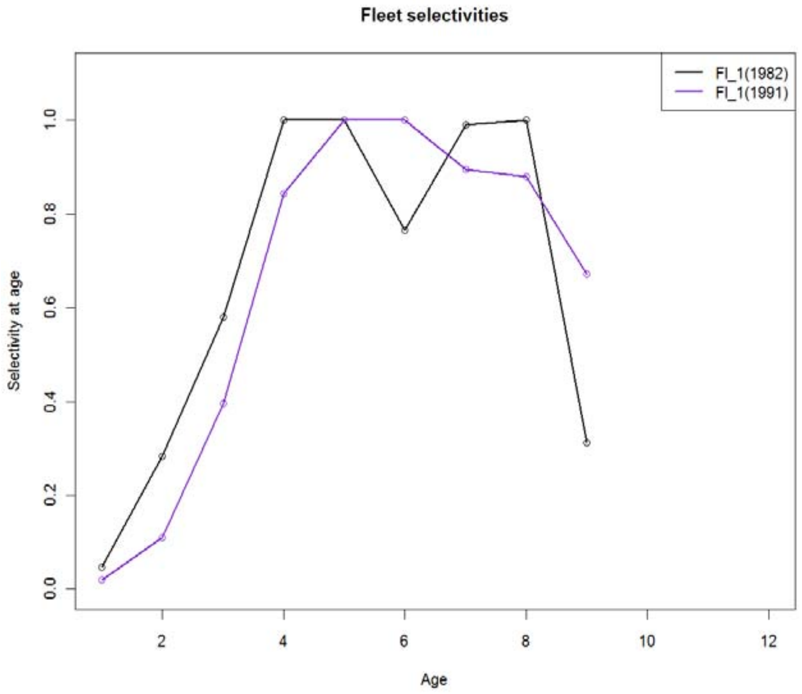


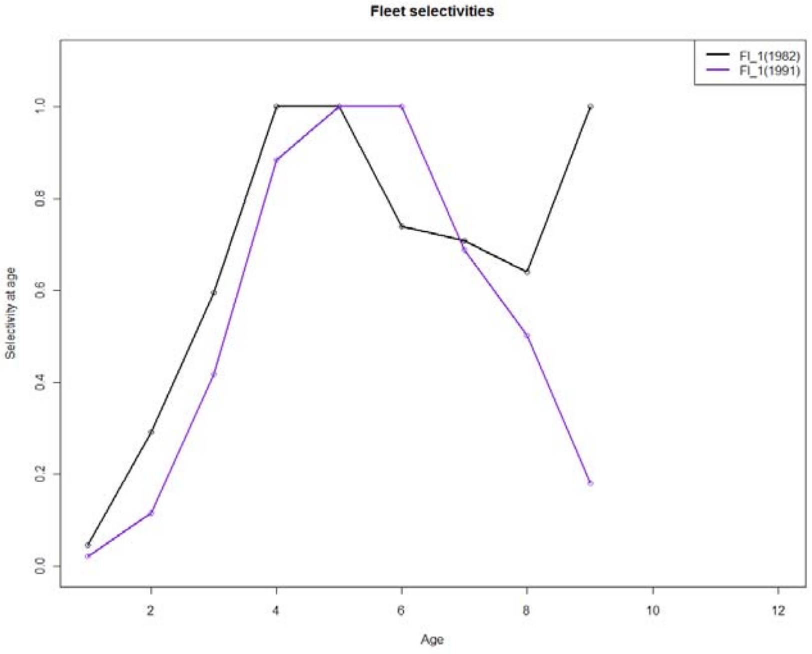


Appendix Figure A2.12. Comparison of the Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) and an ASAP sensitivity run where survey indices were restricted to ages 1-6 (BASE_AGE6).

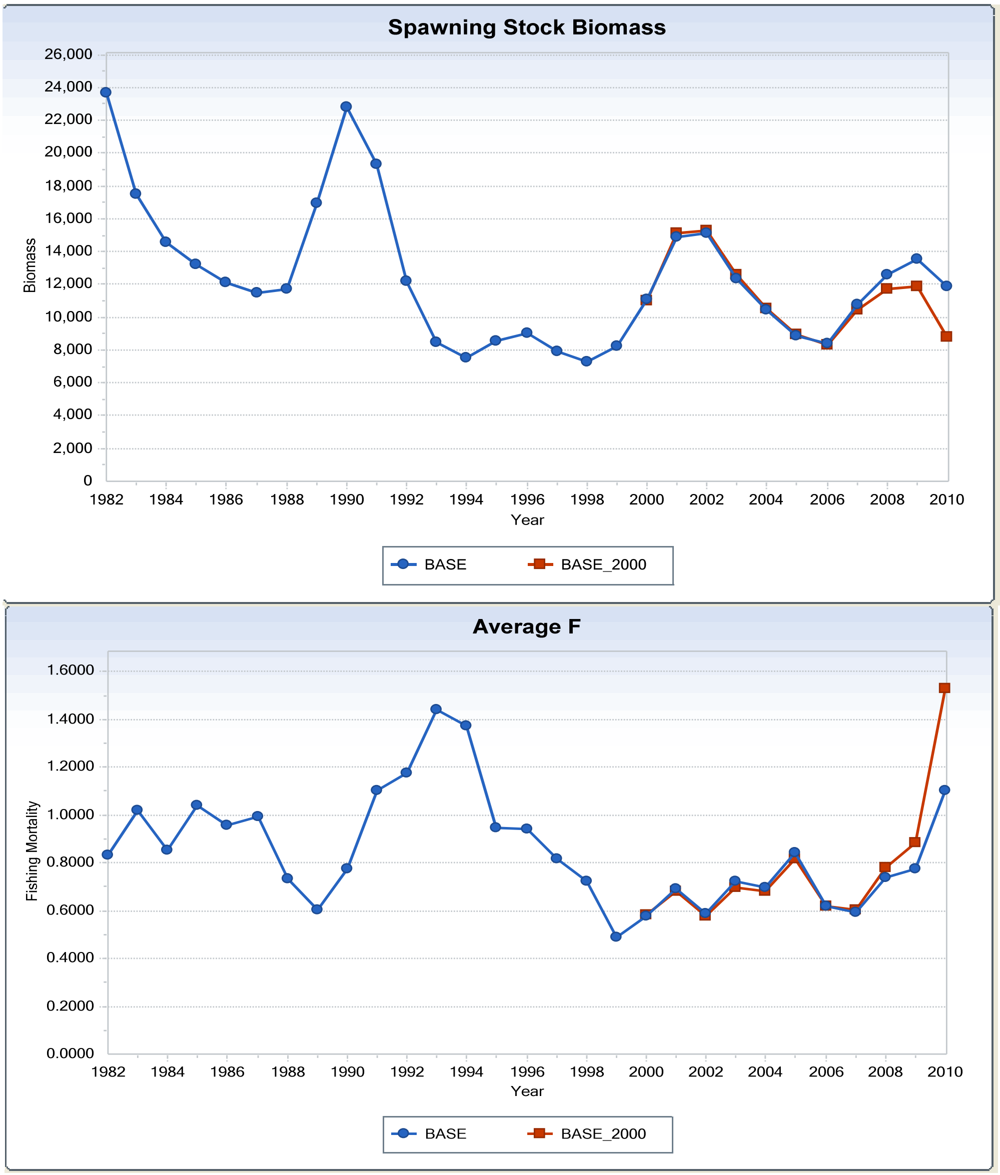


Appendix Figure A2.13. Comparison of Gulf of Maine cod age-1 recruitment (thousands of fish; top) and population estimates of age 9^+ fish (thousands of fish; bottom) between the ASAP base run (BASE) and an ASAP sensitivity run where survey indices were restricted to ages 1-6 (BASE_AGE6).

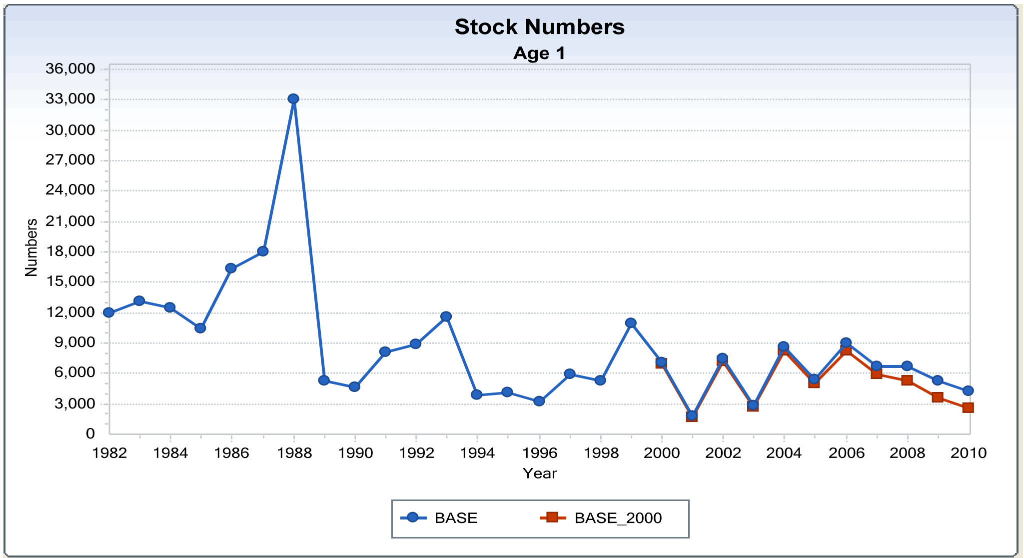


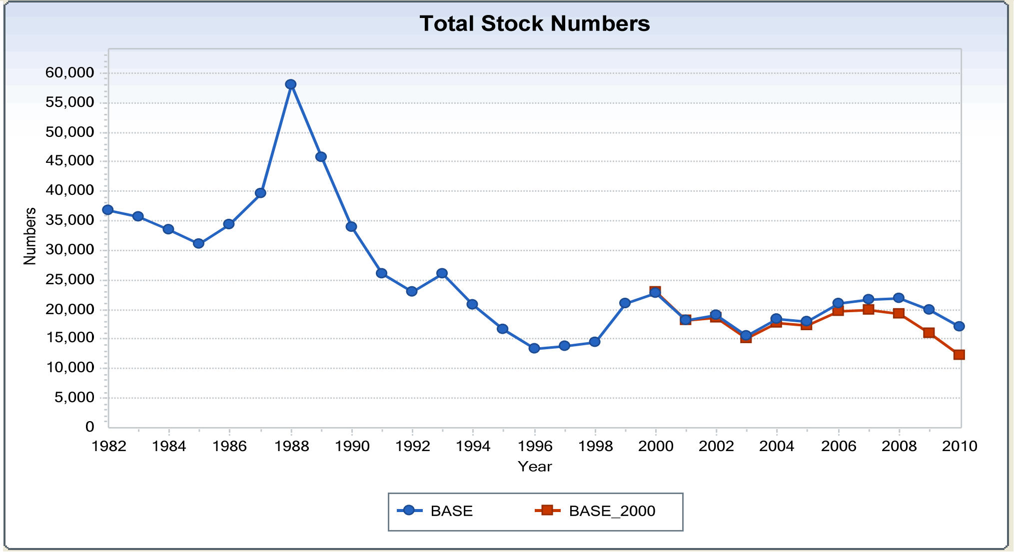


Appendix Figure A2.14. Comparison of the Gulf of Maine cod estimated fishery selectivity-at-age between the ASAP base run (BASE; top) and an ASAP sensitivity run where survey indices were restricted to ages 1-6 (BASE_AGE6; bottom).

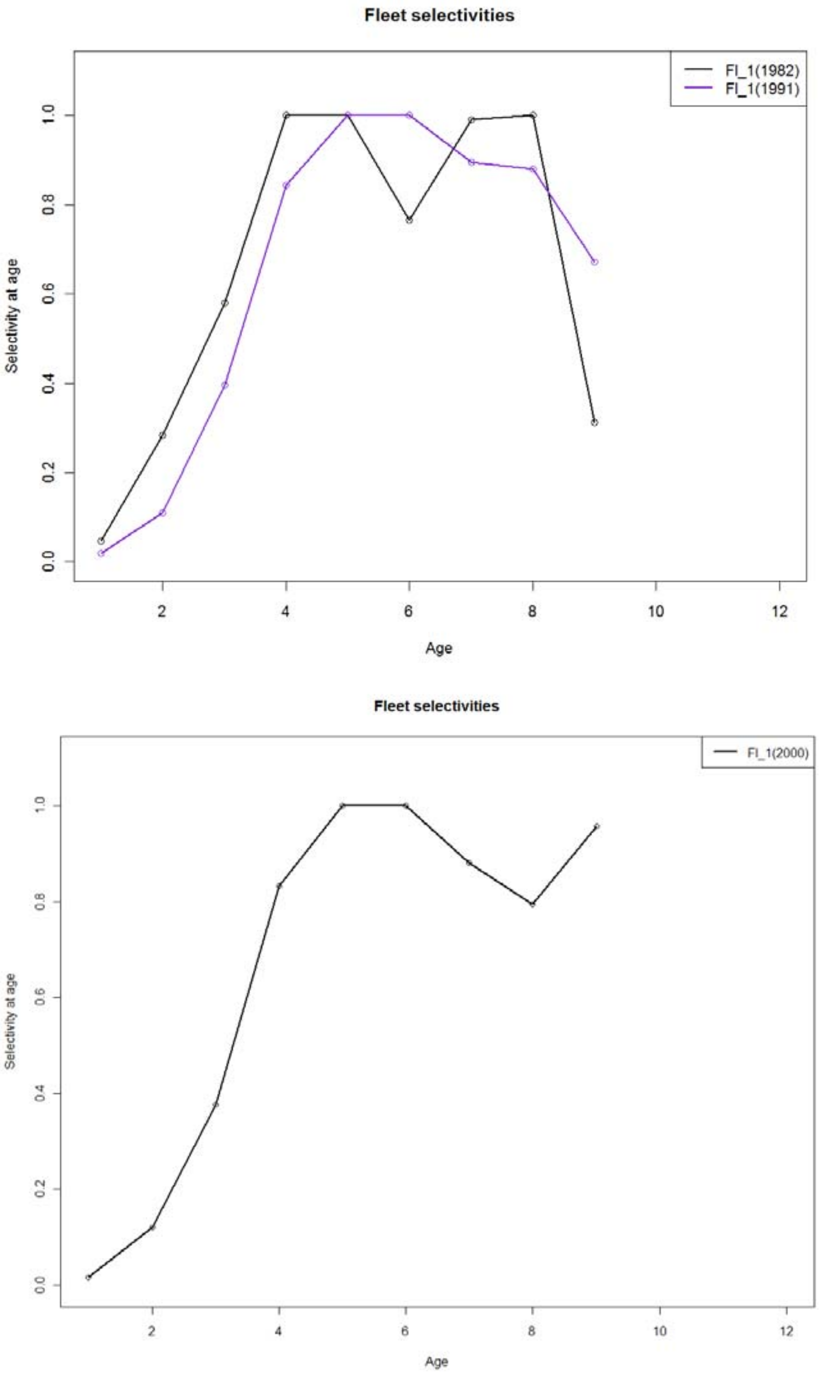


Appendix Figure A2.15. Comparison of the Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) and an ASAP sensitivity run where the assessment began in 2000 (BASE_2000).

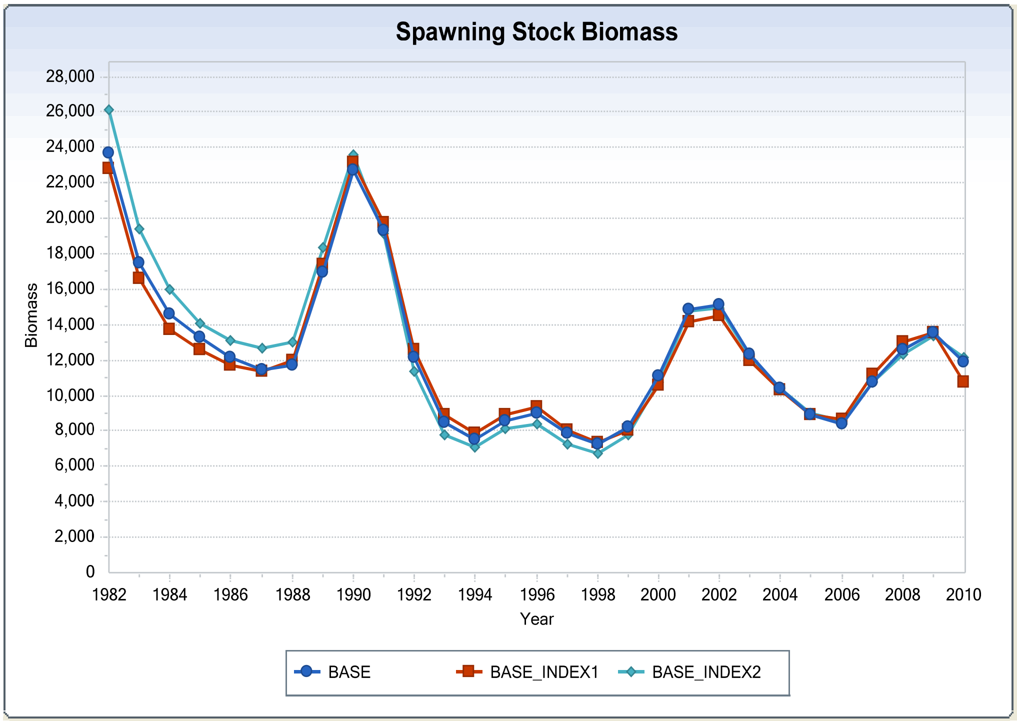


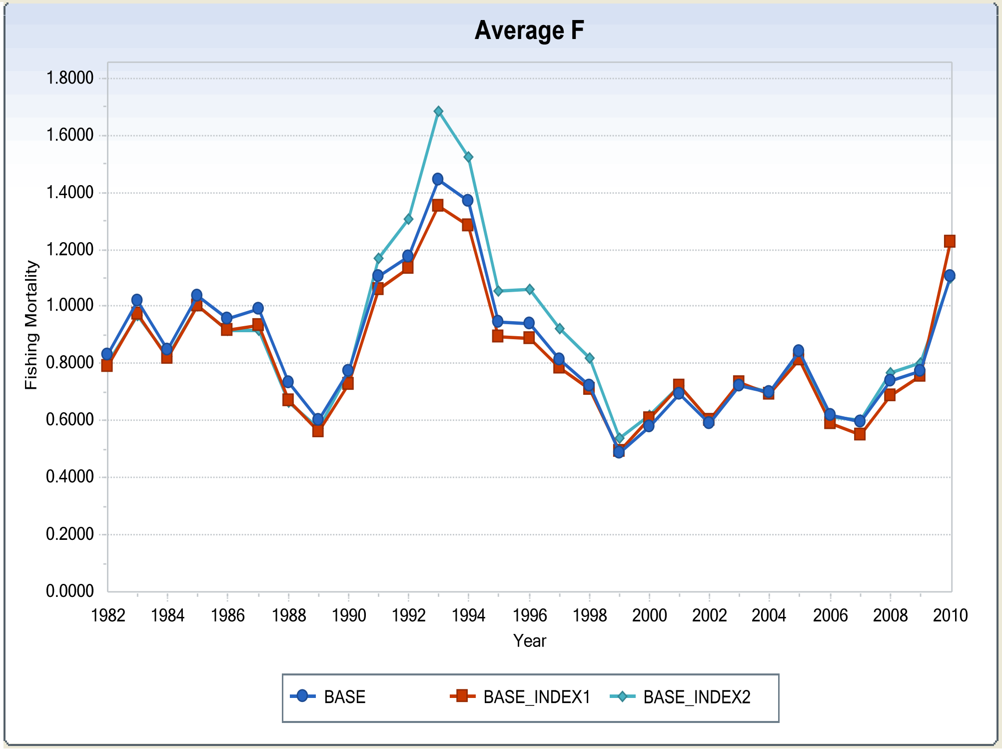


Appendix Figure A2.16. Comparison of Gulf of Maine cod age-1 recruitment (thousands of fish; top) and total population size (thousands of fish; bottom) between the ASAP base run (BASE) and an ASAP sensitivity run where the assessment began in 2000 (BASE_2000).

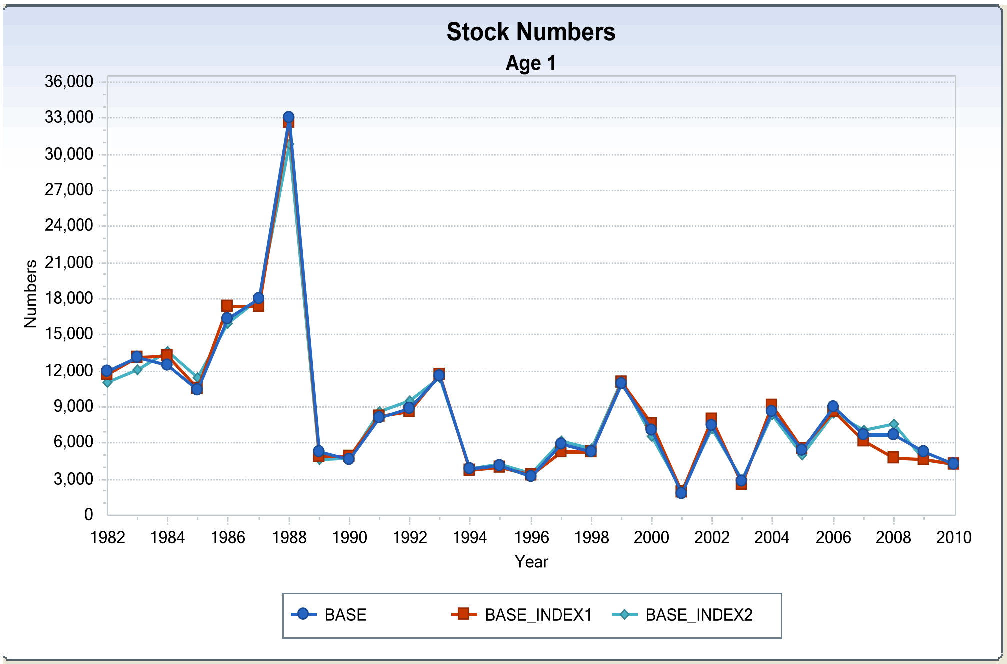


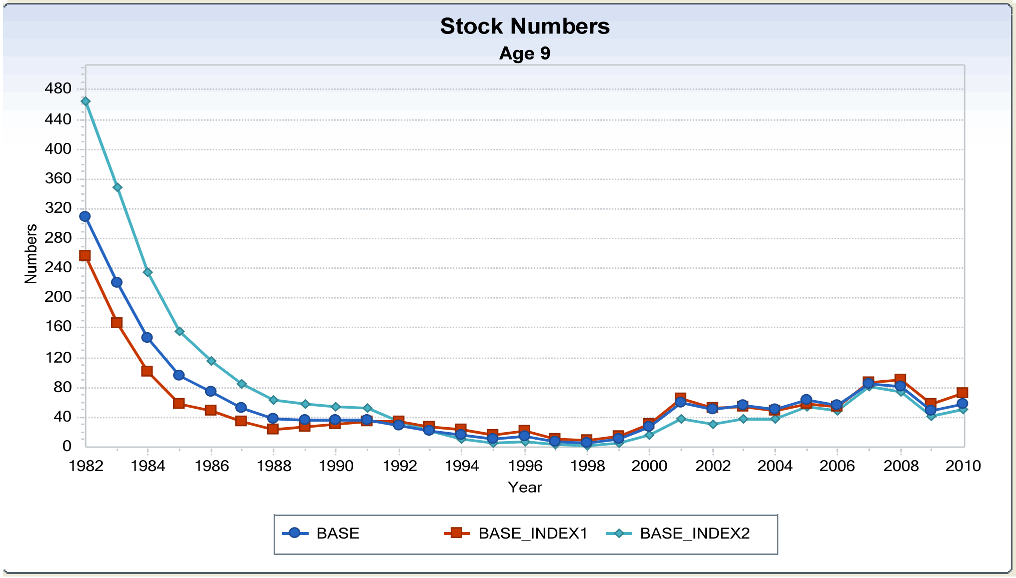
Appendix Figure A2.16. Comparison of the Gulf of Maine cod estimated fishery selectivity-at-age between the ASAP base run (BASE; top) and an ASAP sensitivity run where the assessment began in 2000 (BASE_2000).



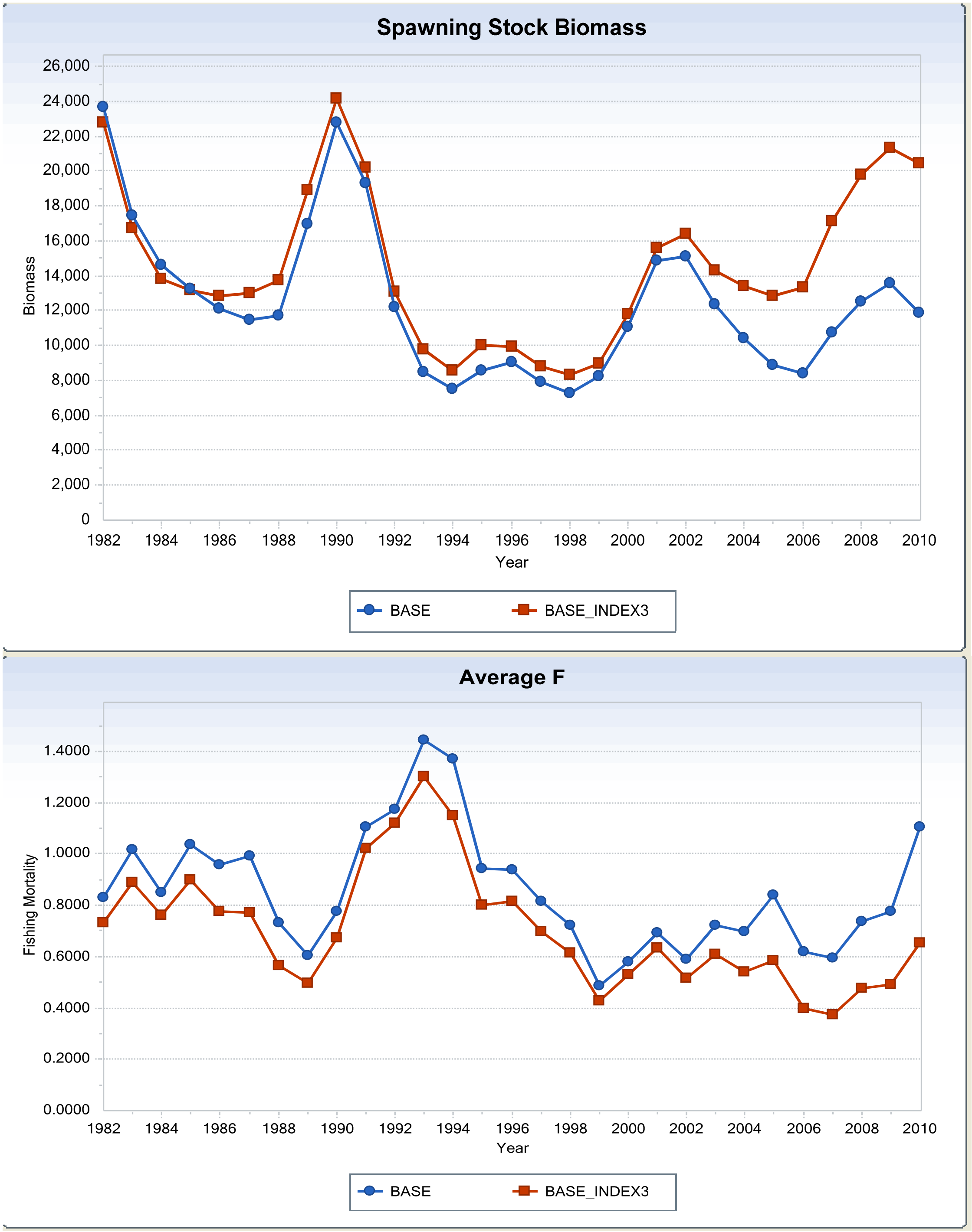


Appendix Figure A2.17. Comparison of the Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) and ASAP sensitivity runs that included only the NEFSC spring survey (BASE_INDEX1) or the NEFSC fall survey (BASE_INDEX2).

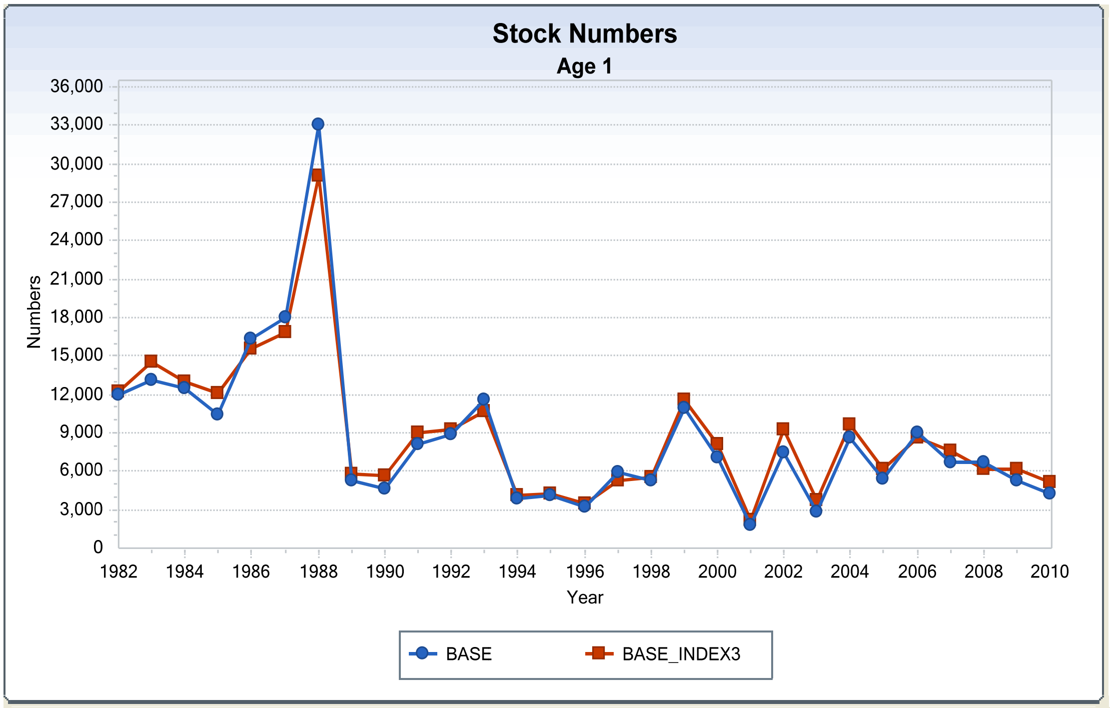


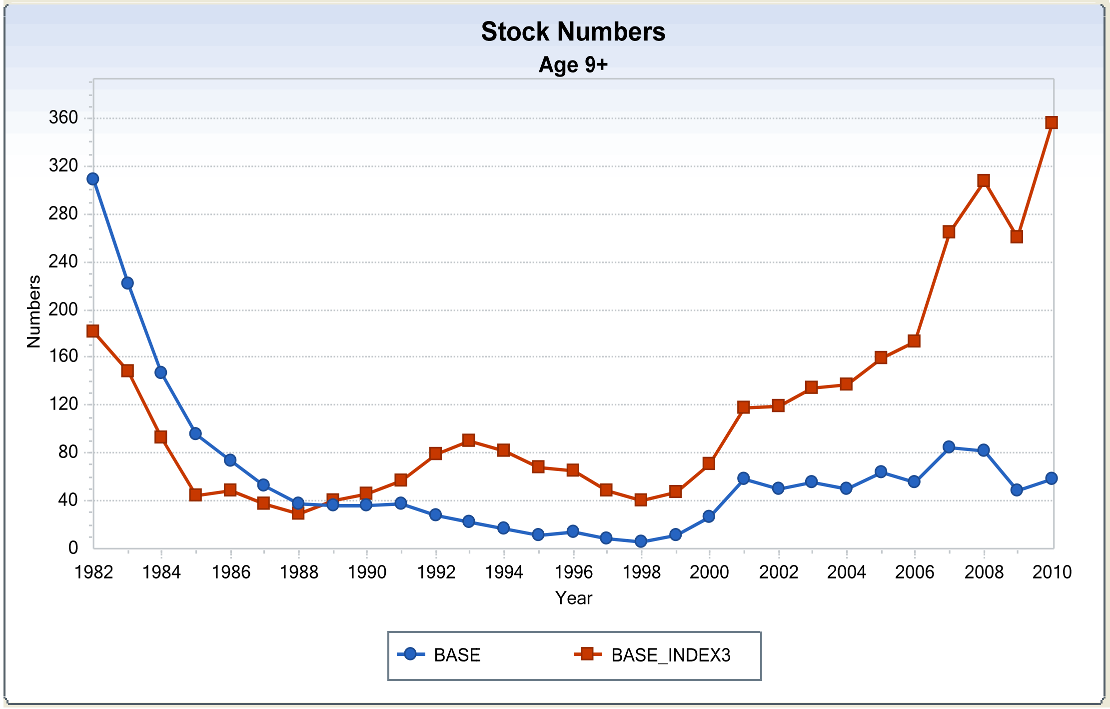


Appendix Figure A2.18. Comparison of Gulf of Maine cod age-1 recruitment (thousands of fish; top) and population estimates of age 9^+ fish (thousands of fish; bottom) between the ASAP base run (BASE) and ASAP sensitivity runs that included only the NEFSC spring survey (BASE_INDEX1) or the NEFSC fall survey (BASE_INDEX2).

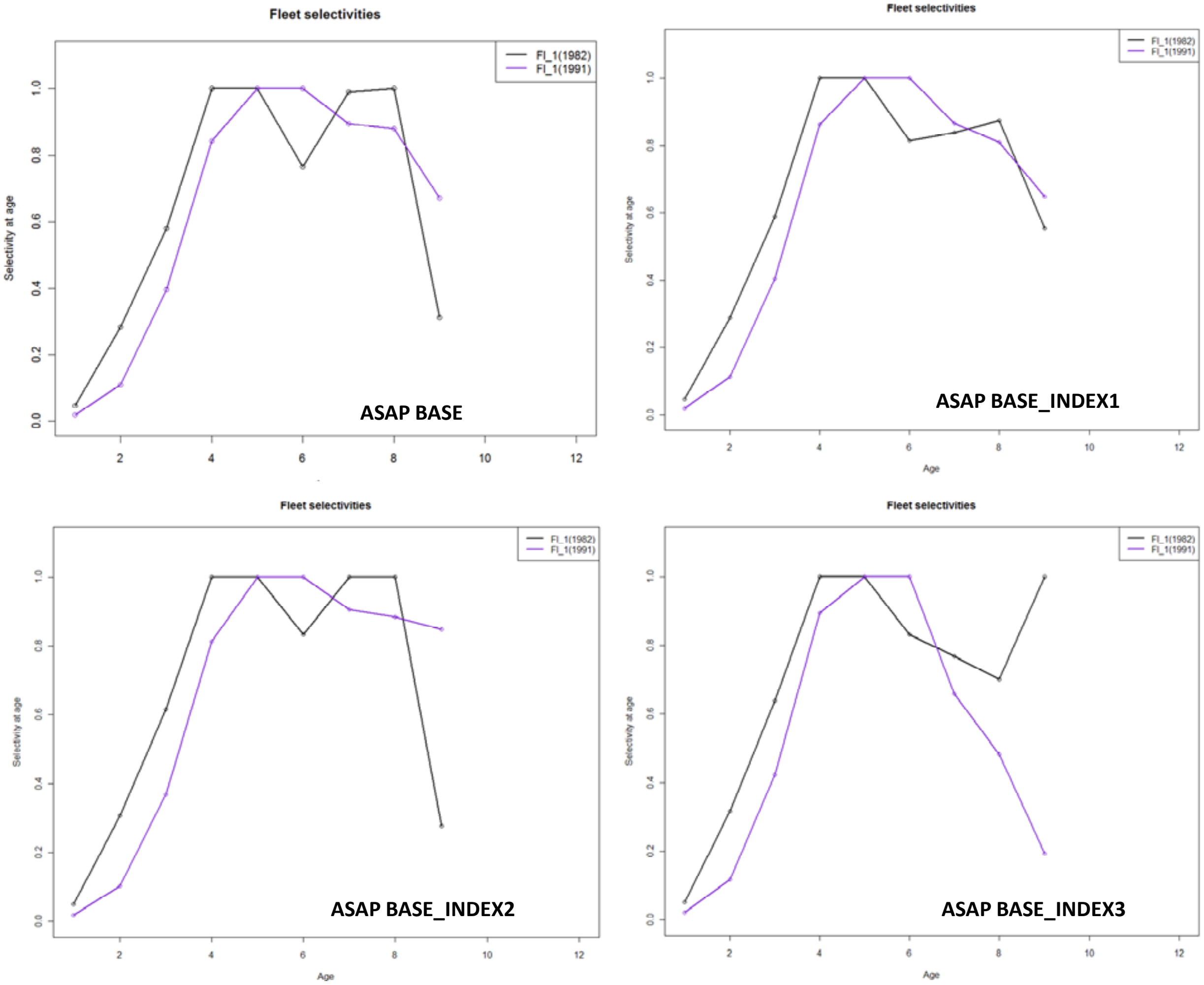


Appendix Figure A2.19. Comparison of the Gulf of Maine cod estimated spawning stock biomass (top) and average fishing mortality (F) on fish age 5-7 (bottom) between the ASAP base run (BASE) and an ASAP sensitivity run that includes only the MADMF spring survey (BASE_INDEX3).

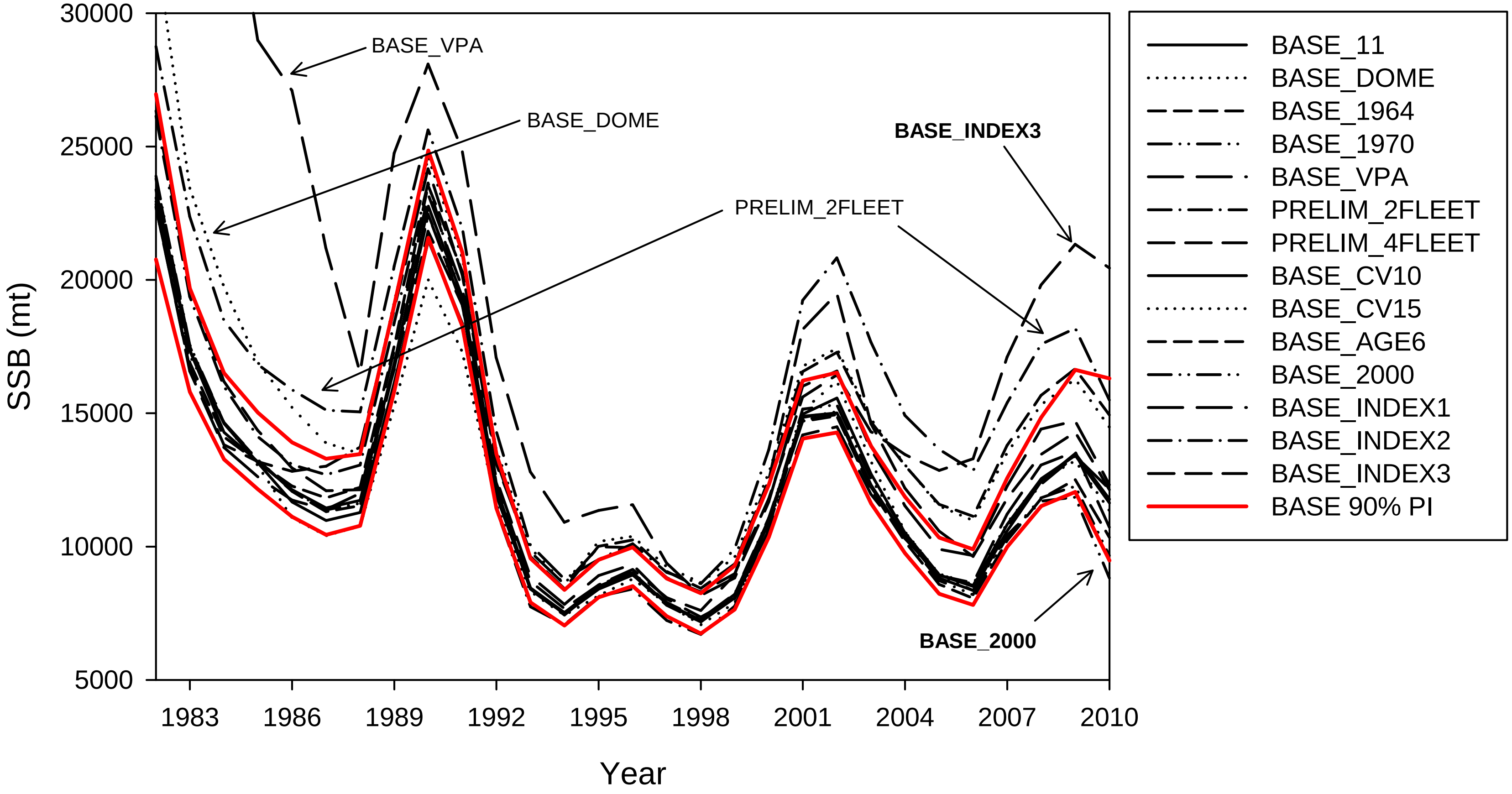




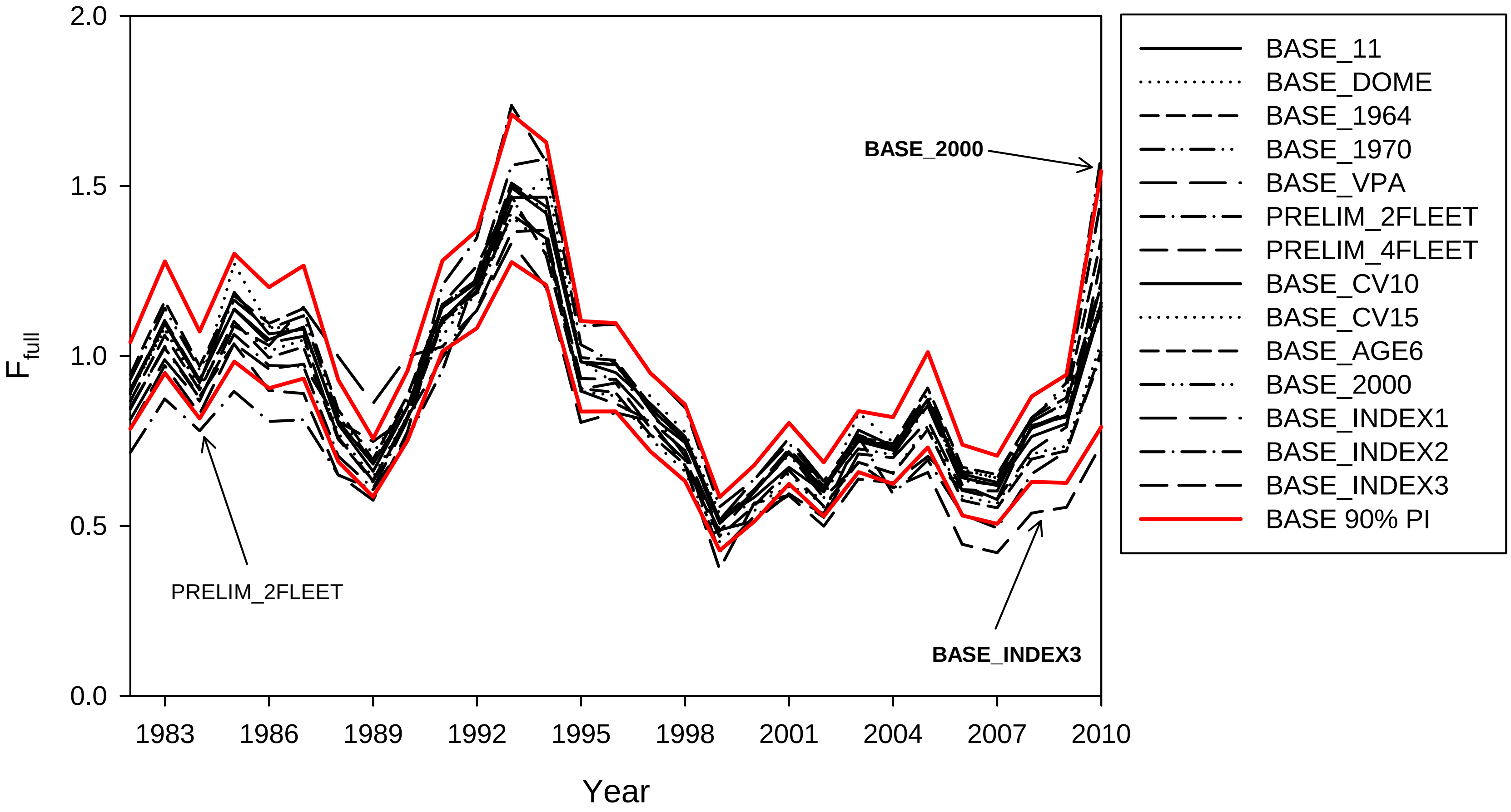
Appendix Figure A2.20. Comparison of Gulf of Maine cod age-1 recruitment (thousands of fish; top) and population estimates of age 9^+ fish (thousands of fish; bottom) between the ASAP base run (BASE) and an ASAP sensitivity run that includes only the MADMF spring survey (BASE_INDEX3).



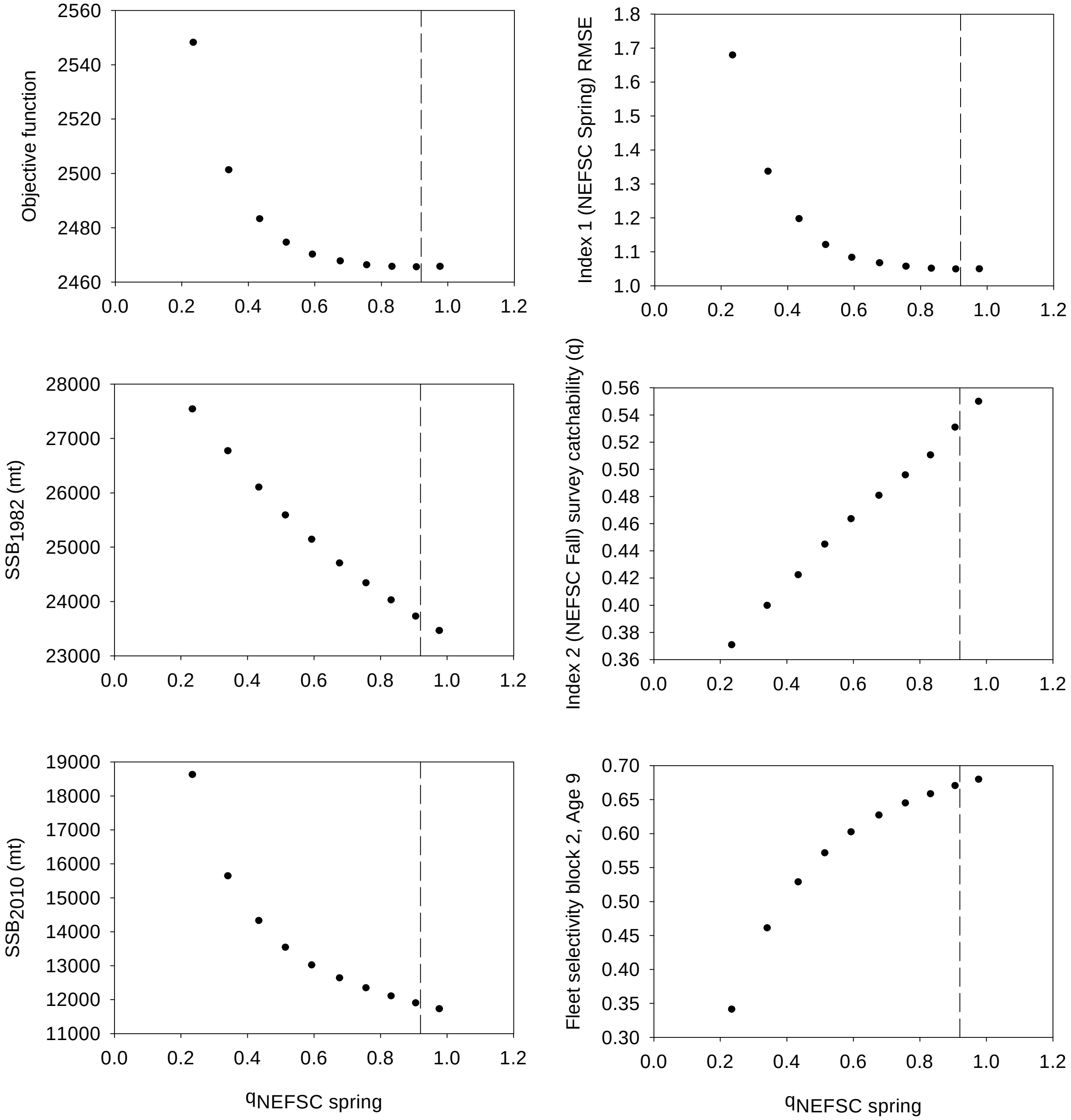
Appendix Figure A2.21. Comparison of the Gulf of Maine cod estimated fishery selectivity-at-age between the ASAP base run (BASE) and ASAP sensitivity runs that included only the NEFSC spring survey (BASE_INDEX1), the NEFSC fall survey (BASE_INDEX2), or the MADMF spring survey (BASE_INDEX3).



Appendix Figure A2.22. Estimates of Gulf of Maine cod spawning stock biomass (SSB) from 14 sensitivity runs of the ASAP model. The 90% probability intervals (PI) for the base ASAP model (BASE) are shown in red. The two sensitivity runs that fell outside the 90% PI in 2010 (BASE_INDEX3 and BASE_2000) are identified by bold text.

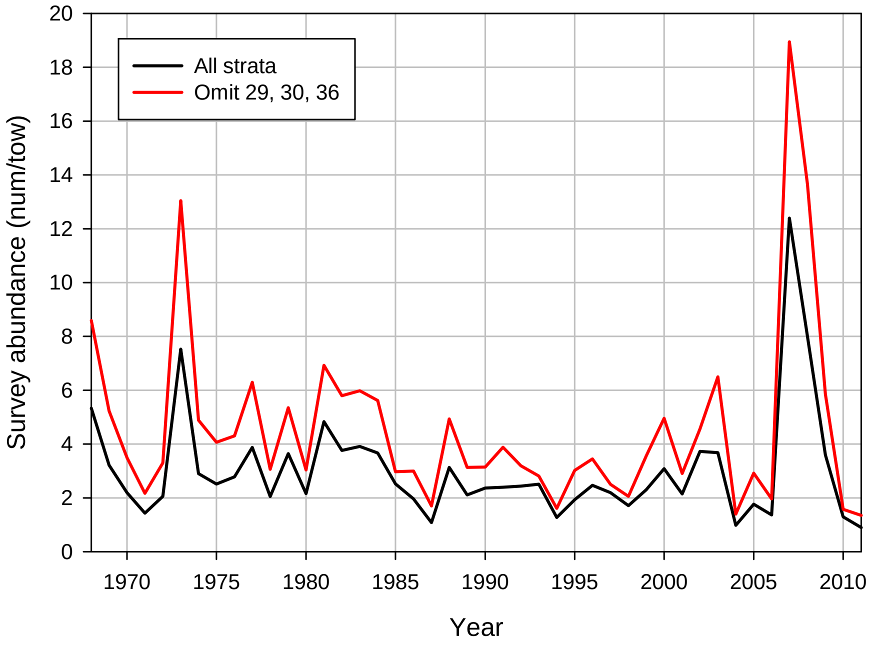


Appendix Figure A2.23. Estimates of Gulf of Maine cod fully recruited fishing mortality (F_{full}) from 14 sensitivity runs of the ASAP model. The 90% probability intervals (PI) for the base ASAP model (BASE) are shown in red. The two sensitivity runs that fell outside the 90% PI in 2010 (BASE_INDEX3 and BASE_2000) are identified by bold text.

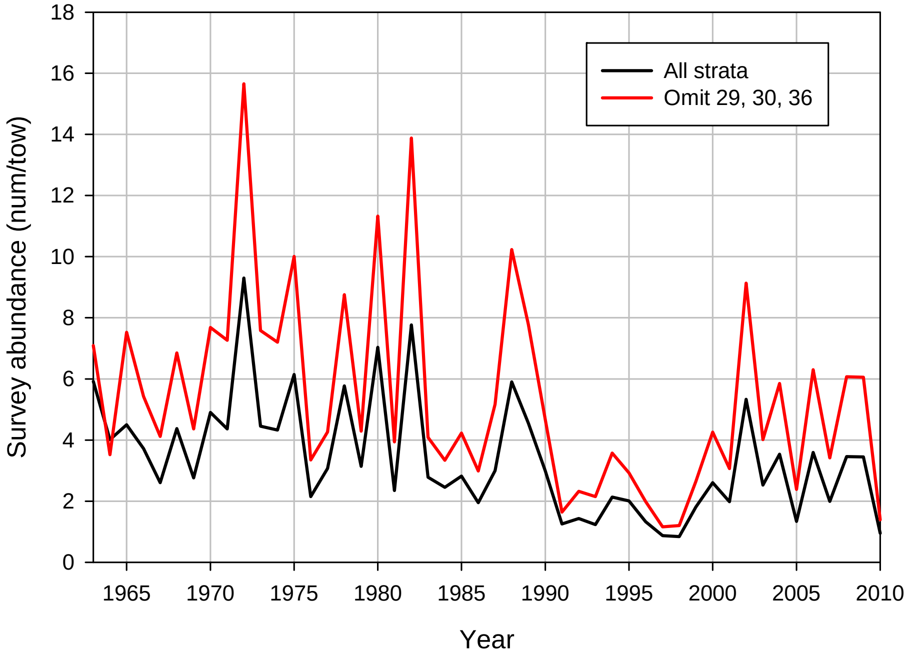


Appendix Figure A2.24. Sensitivity analysis showing the response of the ASAP base model (BASE) to different assumptions of Gulf of Maine Atlantic cod survey catchability (*q*) of the Northeast Fisheries Science Center spring survey.

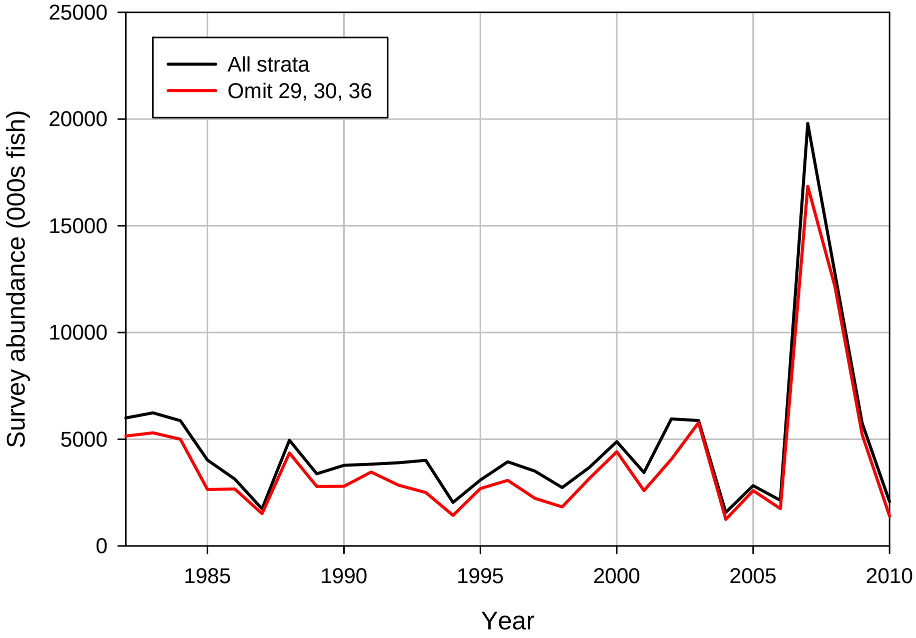
Spring abundance index



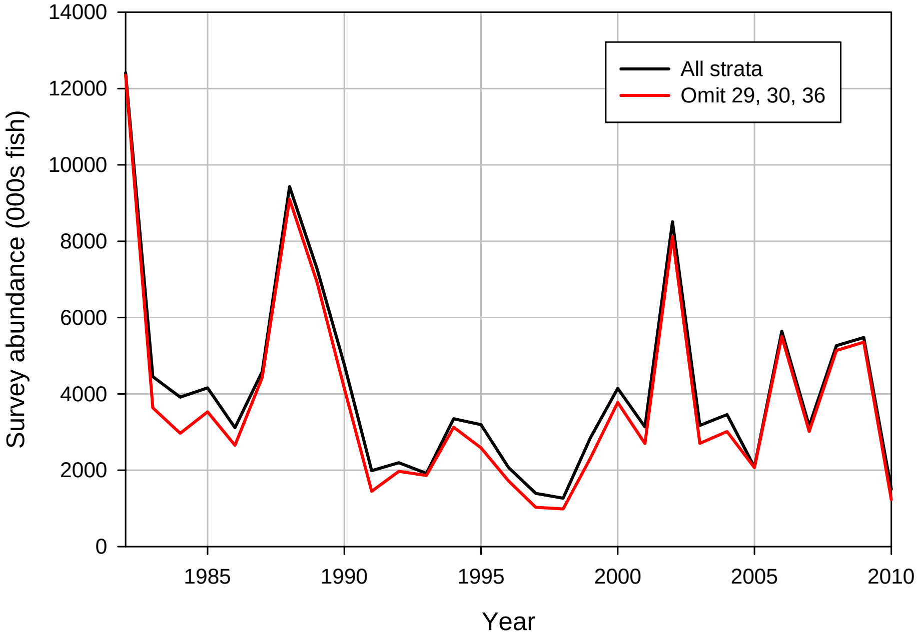
Fall abundance index



Appendix Figure A2.25. Gulf of Maine cod NEFSC spring (top) and fall (bottom) survey indices of abundance (numbers per tow) when estimated from all NEFSC offshore strata (26, 27, 28, 29, 30, 36, 37, 38, 39, 40; black line) and when strata 29, 30, and 36 are excluded (red line).

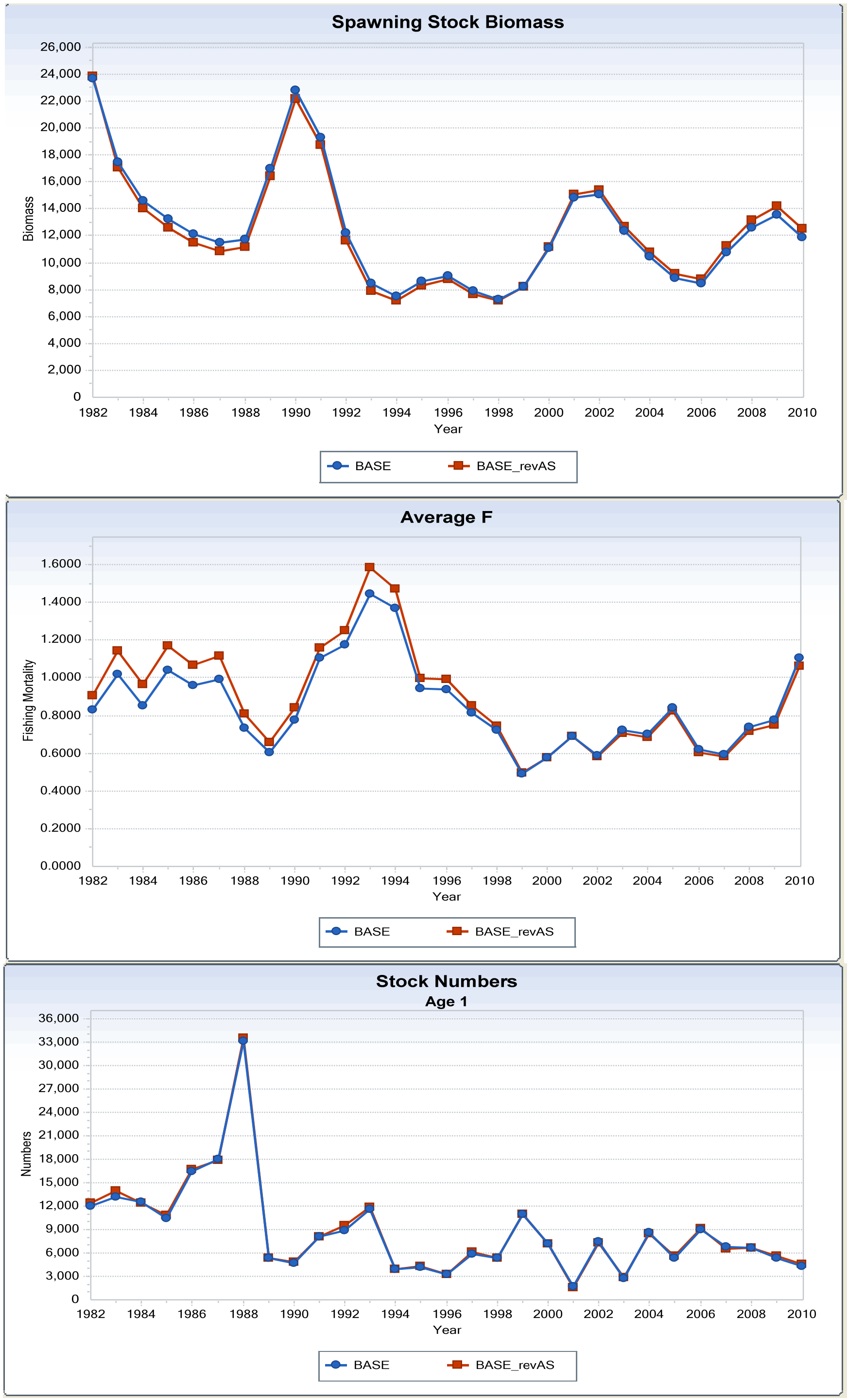


Spring area swept abundance index

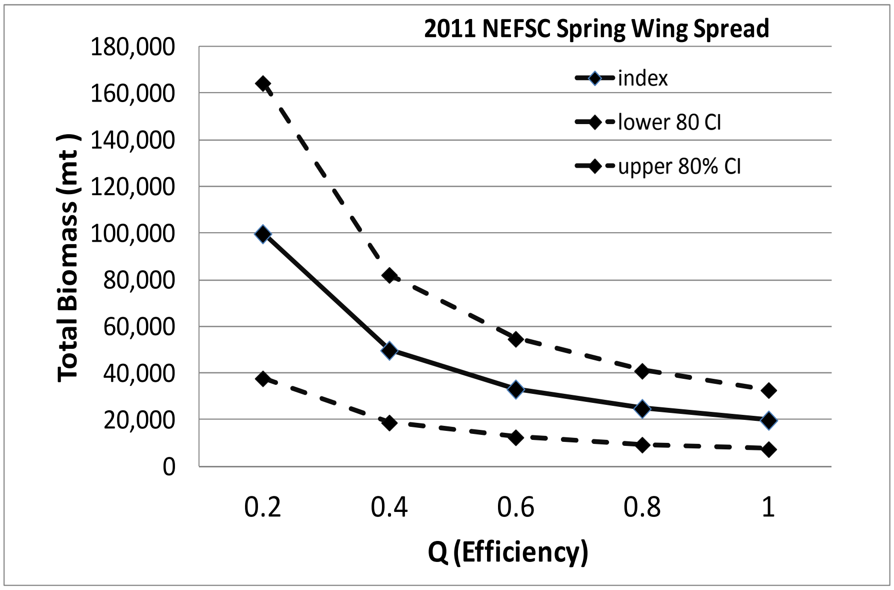


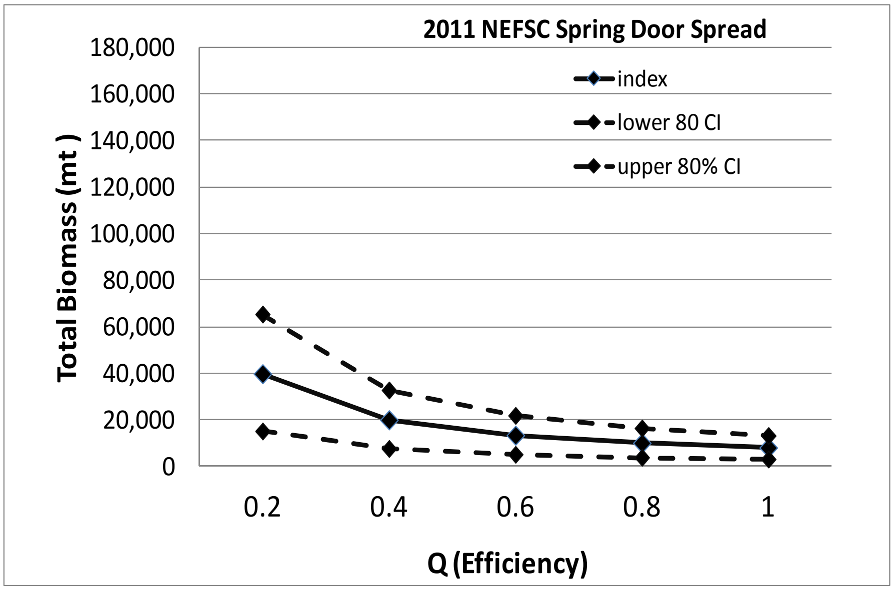
Fall area swept abundance index

Appendix Figure A2.26. Gulf of Maine cod NEFSC spring (top) and fall (bottom) survey indices of abundance in terms of area swept abundance (thousands of fish) when estimated from all NEFSC offshore strata (26- 30 and 36-40; black line) and when strata 29, 30, and 36 are excluded (red line).

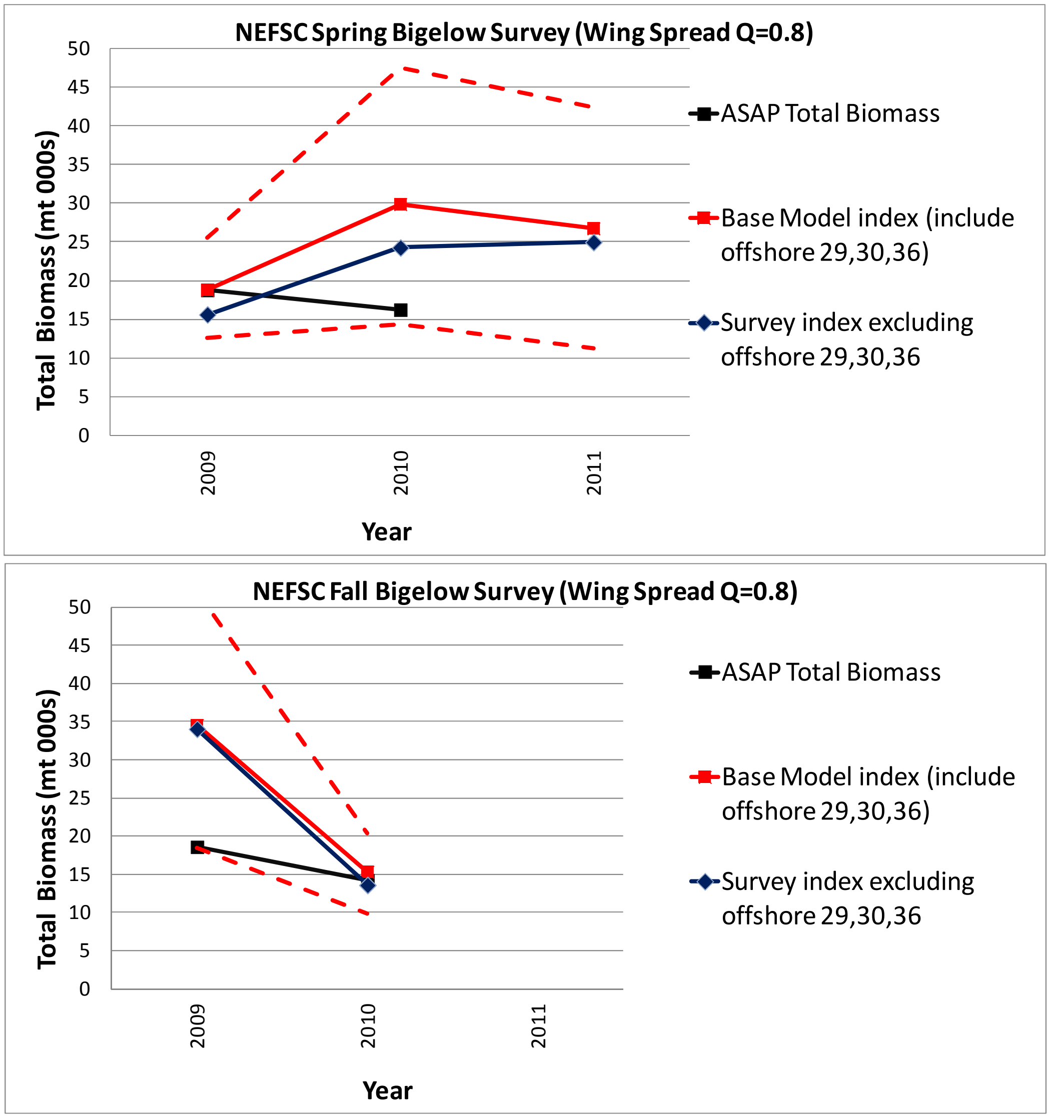


Appendix Figure A2.27. Comparison of Gulf of Maine cod spawning stock biomass (top), average fishing mortality (F) on ages 5-7 (middle) and age-1 recruitment (thousands of fish; bottom) between the ASAP base run (BASE) and a sensitivity run excluding NEFSC offshore survey strata 29, 30 and 36 (BASE_revAS).

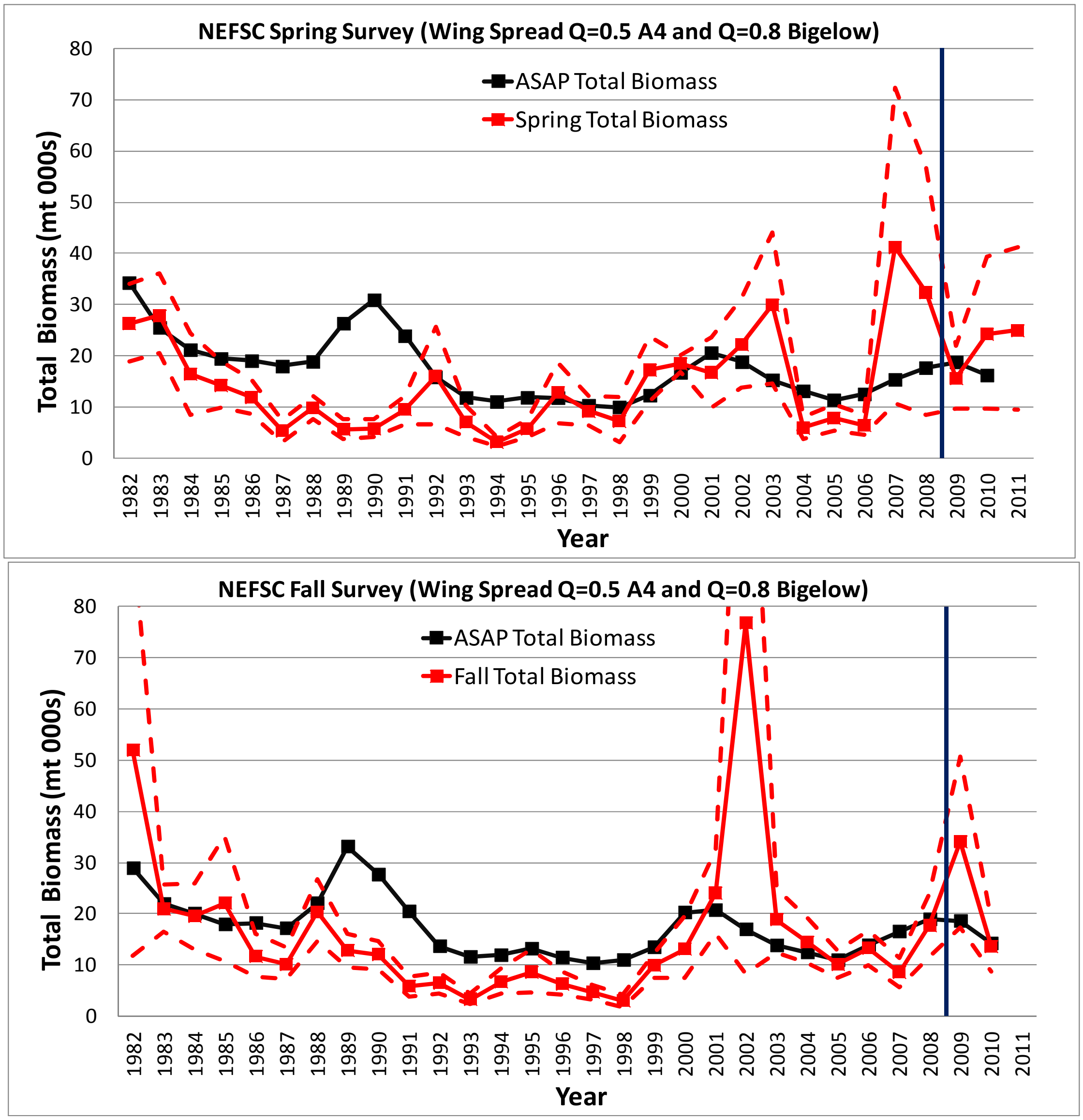




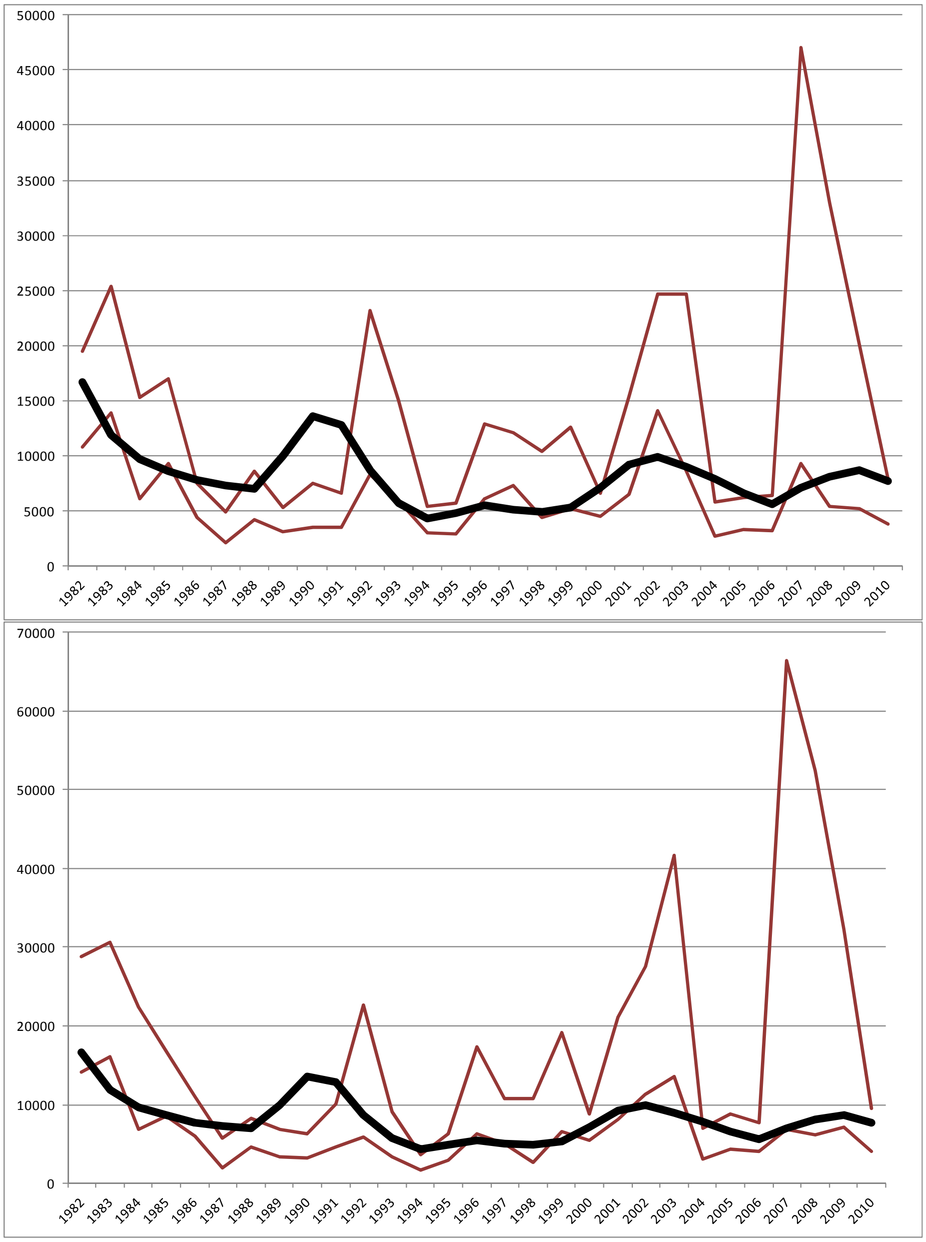
Appendix Figure A2.28. Area swept estimates of total Gulf of Maine cod biomass under different assumptions of NEFSC spring Bigelow survey catchability (*q*) and effective trawl area (wing spread vs. door spread). The 80% bootstrap confidence interval (CI) is shown by the dashed lines.



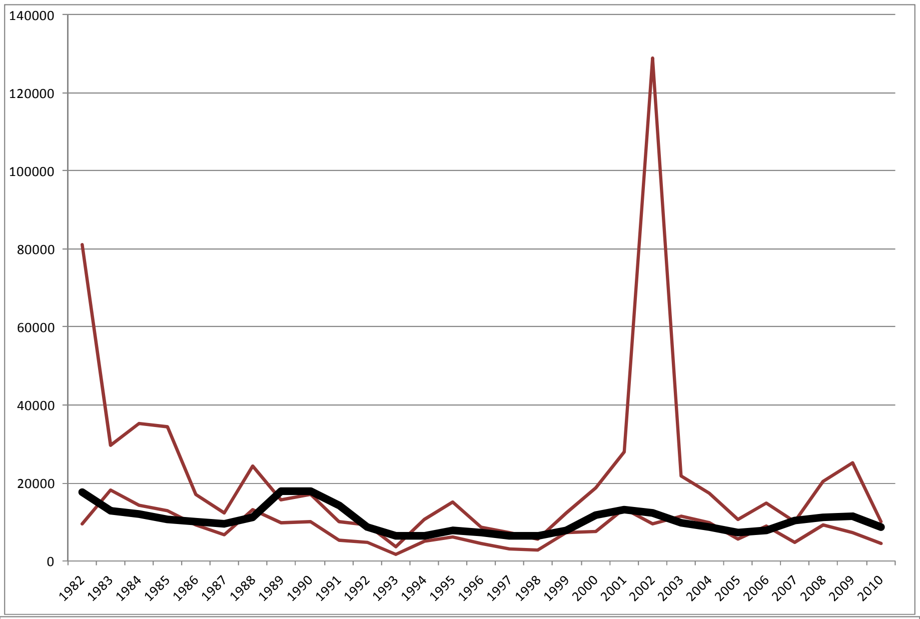
Appendix Figure A2.29. Area swept estimates of total Gulf of Maine cod biomass from 2009 to 2011 based on the NEFSC spring (top) and fall (bottom) Bigelow survey when the effective area is set equal to the wing spread and the survey is assumed to be 80% efficient (*q*=0.8). Biomass has been estimated using the full strata set (red line, with 80% bootstrap confidence intervals) and using a strata set that excludes strata 29,30 and 36 (blue line). In these analyses, the full strata set also includes inshore survey strata 57-69. Biomass estimates are compared to the annual total biomass estimated from the ASAP base model (black line) after accounting for total mortality between January 1 and the survey seasons. **NEFSC fall 2011 survey information were not available at the time of this report.*

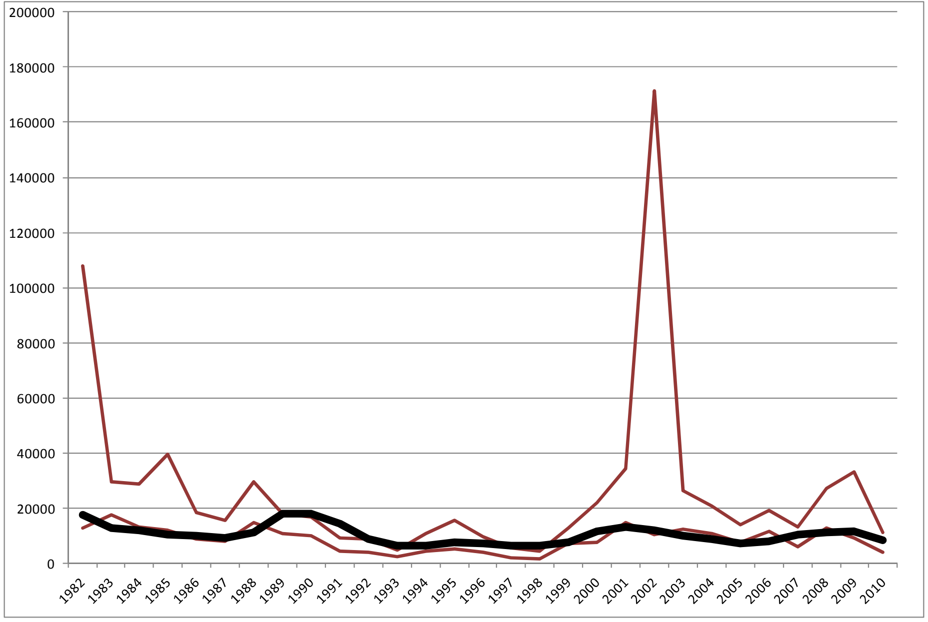


Appendix Figure A2.30. Area swept estimates of total Gulf of Maine cod biomass from 1982 to 2011 based on the NEFSC spring (top) and fall (bottom) survey when a the effective trawl area is set equal to the wing spread and strata set 29, 30 and 36 are excluded from the indices calculation. In these analyses, the full strata set also includes inshore survey strata 57-69. Survey efficiencies of 50% (q=0.5) and 80% (q=0.8) were assumed for the Albatross IV (1982-2008) and Bigelow (2009-2011) survey time series respectively (the vertical blue line delineates the split in survey time series). The 80% bootstrap confidence intervals of area swept estimates of biomass area shown by the dashed red lines. Biomass estimates are compared to the annual total biomass estimated from the ASAP base model (black line) after accounting for total mortality between January 1 and the survey seasons. **NEFSC fall 2011 survey information were not available at the time of this report.*



Appendix Figure A2.31. Comparison of the ASAP estimated total ‘survey-able’ biomass (metric tons; black line) and the 80% confidence intervals (red lines) of area swept estimates of total Gulf of Maine cod biomass from 1982 to 2011 based on the NEFSC spring survey. Area swept biomass indices have been calculated using all strata (strata 26- 30 and 36- 40; top) and excluding strata 29, 30 and 36 (bottom). Survey efficiency was set at ASAP model estimates of *q*=0.92 when using all strata and *q*=0.53 when excluding strata 29, 30 and 36. ASAP ‘survey-able’ biomass was derived from total biomass by accounting for both total mortality since January 1 and survey selectivity at age.





Appendix Figure A2.32. Comparison of the ASAP estimated total 'survey-able' biomass (metric tons; black line) and the 80% confidence intervals (red lines) of area swept estimates of total Gulf of Maine cod biomass from 1982 to 2011 based on the NEFSC fall survey. Area swept biomass indices have been calculated using all strata (strata 26-30 and 36- 40; top) and excluding strata 29, 30 and 36 (bottom). Survey efficiency was set at ASAP model estimates of q=0.57 when using all strata and q=0.42 when excluding strata 29, 30 and 36. ASAP 'survey-able' biomass was derived from total biomass by accounting for both total mortality since January 1 and survey selectivity at age.

Appendix 3. ASAP BASE model input file.

```
# ASAP VERSION 2.0
# ASAP GoM cod 1982 start flat survey selectivity (no LPUE)
#
# ASAP GUI - 15 JAN 2008
#
# Number of Years
29
# First Year
1982
# Number of Ages
9
# Number of Fleets
1
# Number of Selectivity Blocks (sum over all fleets)
2
# Number of Available Indices
5
# Fleet Names
#$Catch
# Index Names
#$NEFSCspring
#$NEFSCfall
#$MAspring
#$MAfall
#$ComLPUE
#
# Natural Mortality Rate Matrix
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
```

```
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
# Fecundity Option
0
# Fraction of year that elapses prior to SSB calculation (0=Jan-1)
0.25
# Maturity Matrix
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
```

```
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
0.094  0.287  0.610  0.859  0.959  0.989  0.997  0.999  1.000
# Weight at Age for Catch Matrix
0.347  0.813  1.480  2.560  5.084  7.058  9.630  9.724  15.637
0.226  0.720  1.520  2.415  3.806  6.055  6.097  10.268  13.399
0.236  0.617  1.434  2.678  3.621  5.533  8.315  10.087  14.898
0.210  0.694  1.336  2.818  4.694  5.951  8.517  11.245  13.476
0.278  0.488  1.668  2.736  4.803  6.565  8.139  10.295  14.686
0.160  0.600  1.257  3.054  4.634  7.340  10.159  11.136  14.354
0.124  0.550  1.606  2.339  5.182  5.166  6.142  10.141  12.818
0.248  0.689  1.433  2.925  4.294  5.990  9.247  12.272  20.776
0.195  0.766  1.271  2.104  4.500  7.697  10.705  11.641  18.635
0.236  1.020  1.506  2.216  3.825  7.138  10.613  12.261  14.028
0.058  0.949  1.416  2.679  2.935  5.541  10.900  10.389  14.483
0.095  0.624  1.625  2.001  4.367  5.628  9.869  13.673  15.661
0.074  0.601  1.536  3.023  3.221  6.328  7.650  12.583  11.691
0.123  1.048  1.404  2.535  5.028  6.806  11.466  13.096  22.443
0.146  1.038  1.902  2.164  3.374  7.572  11.717  14.388  16.225
0.076  1.103  1.941  2.928  2.973  4.570  8.993  12.150  16.938
0.203  0.881  1.790  2.491  3.941  4.163  7.086  12.118  16.676
0.247  0.577  1.532  2.733  3.845  5.671  6.593  9.736  12.279
0.278  0.853  1.882  3.181  4.192  5.821  5.302  9.409  12.704
0.316  0.733  1.866  2.919  4.482  6.014  7.193  9.066  9.488
0.171  0.652  1.433  2.535  3.366  6.078  6.948  8.542  12.374
0.263  0.671  1.600  1.994  3.273  4.745  7.666  9.252  12.116
0.117  0.498  1.357  2.696  3.262  5.094  7.118  9.729  13.320
0.148  0.531  1.356  1.955  3.984  4.337  6.319  7.983  12.490
0.295  0.611  1.243  2.639  3.062  4.125  5.493  7.226  12.131
0.211  0.685  1.389  2.531  3.424  4.535  6.153  7.295  12.400
```

```
0.272  0.833  1.779  2.496  3.219  3.710  5.780  7.723  12.267
0.326  0.854  1.823  2.804  3.266  4.027  5.852  7.760  12.895
0.281  1.057  1.521  2.730  3.354  3.828  5.687  8.876  11.865
# Weight at Age for Spawning Stock Biomass Matrix
0.2409  0.5946  1.1586  2.0995  4.6586  7.5939  9.3260  9.6769  15.6370
0.1368  0.4998  1.1116  1.8906  3.1214  5.5483  6.5599  9.9439  13.3990
0.1376  0.3734  1.0161  2.0176  2.9571  4.5890  7.0956  7.8422  14.8980
0.1378  0.4047  0.9079  2.0102  3.5455  4.6420  6.8647  9.6697  13.4760
0.1892  0.3201  1.0759  1.9119  3.6790  5.5512  6.9595  9.3639  14.6860
0.0863  0.4084  0.7832  2.2570  3.5607  5.9375  8.1666  9.5203  14.3540
0.0526  0.2966  0.9816  1.7147  3.9782  4.8928  6.7143  10.1500  12.8180
0.1411  0.2923  0.8878  2.1674  3.1692  5.5714  6.9116  8.6819  20.7760
0.0853  0.4359  0.9358  1.7364  3.6280  5.7490  8.0077  10.3752  18.6350
0.1177  0.4460  1.0741  1.6783  2.8369  5.6675  9.0382  11.4566  14.0280
0.0177  0.4732  1.2018  2.0086  2.5503  4.6037  8.8207  10.5004  14.4830
0.0378  0.1902  1.2418  1.6833  3.4204  4.0643  7.3949  12.2080  15.6610
0.0197  0.2389  0.9790  2.2164  2.5387  5.2568  6.5616  11.1437  11.6910
0.0423  0.2785  0.9186  1.9733  3.8987  4.6821  8.5180  10.0092  22.4430
0.0531  0.3573  1.4118  1.7431  2.9246  6.1703  8.9301  12.8442  16.2250
0.0223  0.4013  1.4194  2.3599  2.5364  3.9267  8.2520  11.9315  16.9380
0.1204  0.2588  1.4051  2.1989  3.3969  3.5180  5.6906  10.4392  16.6760
0.1329  0.3422  1.1618  2.2118  3.0948  4.7275  5.2390  8.3060  12.2790
0.1712  0.4590  1.0421  2.2076  3.3848  4.7309  5.4834  7.8761  12.7040
0.2200  0.4514  1.2616  2.3438  3.7759  5.0210  6.4707  6.9331  9.4880
0.0863  0.4539  1.0249  2.1749  3.1345  5.2193  6.4642  7.8385  12.3740
0.1911  0.3387  1.0214  1.6904  2.8805  3.9965  6.8260  8.0177  12.1160
0.0549  0.3619  0.9542  2.0769  2.5504  4.0832  5.8116  8.6361  13.3200
0.0728  0.2493  0.8218  1.6288  3.2773  3.7613  5.6735  7.5381  12.4900
0.1936  0.3007  0.8124  1.8917  2.4467  4.0539  4.8809  6.7573  12.1310
0.1062  0.4495  0.9212  1.7737  3.0060  3.7264  5.0380  6.3302  12.4000
0.1535  0.4192  1.1039  1.8620  2.8543  3.5641  5.1198  6.8934  12.2670
0.1810  0.4820  1.2323  2.2335  2.8552  3.6004  4.6595  6.6972  12.8950
0.1345  0.5870  1.1397  2.2309  3.0667  3.5359  4.7856  7.2071  11.8650
# Weight at Age for Jan-1 Biomass Matrix
0.2409  0.5946  1.1586  2.0995  4.6586  7.5939  9.3260  9.6769  15.6370
0.1368  0.4998  1.1116  1.8906  3.1214  5.5483  6.5599  9.9439  13.3990
0.1376  0.3734  1.0161  2.0176  2.9571  4.5890  7.0956  7.8422  14.8980
0.1378  0.4047  0.9079  2.0102  3.5455  4.6420  6.8647  9.6697  13.4760
0.1892  0.3201  1.0759  1.9119  3.6790  5.5512  6.9595  9.3639  14.6860
0.0863  0.4084  0.7832  2.2570  3.5607  5.9375  8.1666  9.5203  14.3540
```

```
0.0526  0.2966  0.9816  1.7147  3.9782  4.8928  6.7143  10.1500  12.8180
0.1411  0.2923  0.8878  2.1674  3.1692  5.5714  6.9116  8.6819  20.7760
0.0853  0.4359  0.9358  1.7364  3.6280  5.7490  8.0077  10.3752  18.6350
0.1177  0.4460  1.0741  1.6783  2.8369  5.6675  9.0382  11.4566  14.0280
0.0177  0.4732  1.2018  2.0086  2.5503  4.6037  8.8207  10.5004  14.4830
0.0378  0.1902  1.2418  1.6833  3.4204  4.0643  7.3949  12.2080  15.6610
0.0197  0.2389  0.9790  2.2164  2.5387  5.2568  6.5616  11.1437  11.6910
0.0423  0.2785  0.9186  1.9733  3.8987  4.6821  8.5180  10.0092  22.4430
0.0531  0.3573  1.4118  1.7431  2.9246  6.1703  8.9301  12.8442  16.2250
0.0223  0.4013  1.4194  2.3599  2.5364  3.9267  8.2520  11.9315  16.9380
0.1204  0.2588  1.4051  2.1989  3.3969  3.5180  5.6906  10.4392  16.6760
0.1329  0.3422  1.1618  2.2118  3.0948  4.7275  5.2390  8.3060  12.2790
0.1712  0.4590  1.0421  2.2076  3.3848  4.7309  5.4834  7.8761  12.7040
0.2200  0.4514  1.2616  2.3438  3.7759  5.0210  6.4707  6.9331  9.4880
0.0863  0.4539  1.0249  2.1749  3.1345  5.2193  6.4642  7.8385  12.3740
0.1911  0.3387  1.0214  1.6904  2.8805  3.9965  6.8260  8.0177  12.1160
0.0549  0.3619  0.9542  2.0769  2.5504  4.0832  5.8116  8.6361  13.3200
0.0728  0.2493  0.8218  1.6288  3.2773  3.7613  5.6735  7.5381  12.4900
0.1936  0.3007  0.8124  1.8917  2.4467  4.0539  4.8809  6.7573  12.1310
0.1062  0.4495  0.9212  1.7737  3.0060  3.7264  5.0380  6.3302  12.4000
0.1535  0.4192  1.1039  1.8620  2.8543  3.5641  5.1198  6.8934  12.2670
0.1810  0.4820  1.2323  2.2335  2.8552  3.6004  4.6595  6.6972  12.8950
0.1345  0.5870  1.1397  2.2309  3.0667  3.5359  4.7856  7.2071  11.8650
# Selectivity Blocks (fleet outer loop, year inner loop)
# Sel block for fleet 1
1
1
1
1
1
1
1
1
1
2
2
2
2
2
2
```

```
2
2
2
2
2
2
2
2
2
2
2
2
2
2
# Selectivity Options for each block 1=by age, 2=logisitic, 3=double logistic
1  1
# Selectivity initial guess, phase, lambda, and CV
# (have to enter values for nages + 6 parameters for each block)
# Sel Block 1
0.1      1      0      1
0.3      1      0      1
0.5      1      0      1
0.8      1      0      1
1       -1      0      1
1        2      0      1
0.9      2      0      1
0.8      2      0      1
0.8      2      0      1
0        0      0      0
0        0      0      0
0        0      0      0
0        0      0      0
0        0      0      0
0        0      0      0
# Sel Block 2
0.1      1      0      1
0.3      1      0      1
0.5      1      0      1
0.8      1      0      1
0.9      1      0      1
```

```
1        -2       0        1
0.9       2       0        1
0.8       2       0        1
0.8       2       0        1
0        0        0        0
0        0        0        0
0        0        0        0
0        0        0        0
0        0        0        0
0        0        0        0
# Selectivity Start Age by fleet
1
# Selectivity End Age by fleet
9
# Age range for average F
5  7
# Average F report option (1=unweighted, 2=Nweighted, 3=Bweighted)
1
# Use likelihood constants? (1=yes)
1
# Release Mortality by fleet
1
# Fleet 1 Catch at Age - Last Column is Total Weight
604.400    3499.200    2513.900    1540.700    794.100    71.000    102.800    77.200    92.400    18442.6
853.200    3093.900    3084.300    1247.300    730.300    468.200    52.000    64.200    58.200    17493.8
514.700    2790.000    1834.200    1691.100    451.400    227.700    108.800    9.600    54.400    13707.7
705.400    2538.200    2757.300    1203.800    780.900    174.600    119.000    53.900    36.500    15807.1
1032.900    2345.800    2941.200    1053.800    293.200    217.200    51.300    42.000    52.700    13681.0
411.900    2927.100    1937.500    1734.700    372.500    98.100    93.300    17.600    43.500    13771.5
570.500    2076.600    2350.100    1243.200    464.100    70.400    26.900    28.300    9.900    11242.8
238.800    1787.400    2833.000    1760.400    544.700    92.800    74.200    9.900    20.300    14623.1
90.600    1076.500    6483.100    2910.300    572.100    202.000    31.300    40.500    44.000    20959.4
169.300    663.300    1128.200    6040.000    1094.500    154.800    59.900    26.000    16.000    22272.7
504.100    1081.500    1038.100    533.500    2281.400    231.300    81.100    6.100    5.500    12960.8
152.100    1009.100    2601.400    1106.400    107.000    508.500    42.900    11.300    0.000    10993.4
178.200    459.800    1949.800    1354.700    275.000    67.100    75.600    28.900    8.000    9727.3
116.800    495.200    1729.700    1379.400    228.100    30.400    6.500    18.300    2.800    8189.9
67.800    195.000    763.500    2207.600    427.000    37.100    4.100    0.500    1.800    8249.8
100.800    220.700    624.900    497.400    927.500    76.100    5.600    2.300    1.000    6120.9
18.100    312.500    606.500    710.800    158.200    216.500    29.100    5.300    2.300    4967.9
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143.700   265.100   517.200   401.600   213.200   64.200   71.700   13.900   1.100   3883.1
75.400   1033.700   795.600   949.400   196.900   91.500   13.600   11.900   0.000   6961.4
0.800   946.000   1778.300   882.300   457.000   120.300   63.100   9.100   12.100   10009.8
42.200   95.100   801.000   1359.500   440.700   182.700   74.100   34.500   24.200   8366.5
105.300   330.100   318.600   1041.100   946.900   226.100   83.500   32.400   30.300   8314.4
250.300   233.600   1136.700   347.000   522.600   290.900   74.300   35.400   29.200   7072.0
41.500   526.900   335.400   1568.500   103.300   278.500   117.700   30.700   34.500   6845.4
42.400   134.100   768.500   364.600   562.400   35.400   84.400   42.400   28.600   4996.5
19.400   262.900   615.200   1289.400   161.300   249.100   8.000   19.300   22.100   6447.8
31.300   358.000   1028.000   942.800   937.000   102.400   117.800   4.400   17.700   8817.5
28.300   263.900   1012.800   1400.100   581.100   367.900   22.500   33.900   10.600   9918.2
29.000   344.700   1138.800   1488.900   1046.800   249.100   88.200   14.300   11.000   11392.4
# Fleet 1 Discards at Age - Last Column is Total Weight
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

```
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
# Fleet 1 Release Proportion at Age
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
# Index Units
2  2  2  2  2
# Index Month
4  10  4  9  6
# Index Selectivity Choice
-1  -1  -1  -1  1
# Index Selectivity Option for each Index 1=by age, 2=logisitic, 3=double logistic
1  1  3  3  2
```

```
# Index Start Age
1  1  1  1  2
# Index End Age
9  9  9  9  6
# Use Index? 1=yes
1  1  1  0  0
# Index Selectivity initial guess, phase, lambda, and CV
# (have to enter values for nages + 6 parameters for each block)
# Index-1
0.05     1      0      1
0.2      1      0      1
0.4      1      0      1
0.79     1      0      1
0.9      1      0      1
1       -2      0      1
1       -2      0      1
1       -2      0      1
1       -2      0      1
1.5      1      0      1
1        2      0      1
0        0      0      0
0        0      0      0
0        0      0      0
0        0      0      0
# Index-2
0.05     1      0      1
0.2      1      0      1
0.4      1      0      1
0.79     1      0      1
0.9      1      0      1
1       -2      0      1
1       -2      0      1
1       -2      0      1
1       -2      0      1
1.5      1      0      1
1        2      0      1
0        0      0      0
0        0      0      0
0        0      0      0
0        0      0      0
```

```
# Index-3
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0.25	1	0	1
10	-1	0	1
2	2	0	1
1	3	0	1
# Index-4
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
11	-1	0	1
11	-1	0	1
2	2	0	1
0.1	3	0	1
# Index-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
0	0	0	0
```

```
0      0      0      0
0      0      0      0
1      -1     0      1
2      -3     0      1
0      0      0      0
0      0      0      0
0      0      0      0
0      0      0      0
# Index Data - Year, Index Value, CV, proportions at age and input effective sample size (only used if estimating parameters)
# Index-1
1982   5988.4   0.419   570.8000   1661.4000   794.8000   1177.7000   1355.0000   132.9000   215.8000   0.0000   80.0000   30
1983   6229.8   0.463   974.2000   1546.4000   1664.4000   723.2000   537.2000   399.1000   95.9000   0.0000   289.5000   30
1984   5858.4   0.643   241.2000   2091.3000   1576.9000   1363.0000   366.5000   75.2000   144.3000   0.0000   0.0000   30
1985   4020.7   0.402   45.7000   379.9000   1079.4000   978.3000   1129.4000   150.6000   174.6000   41.4000   41.4000   30
1986   3126.1   0.514   857.2000   413.1000   1224.8000   348.3000   120.3000   73.8000   59.9000   0.0000   28.8000   30
1987   1729.1   0.457   47.6000   752.1000   304.5000   354.6000   120.1000   0.0000   108.3000   18.1000   23.8000   30
1988   4949.9   0.411   1148.8000   1479.0000   1263.1000   452.7000   326.7000   157.8000   57.2000   32.3000   32.3000   30
1989   3374.2   0.384   39.8000   972.7000   1136.9000   1005.6000   110.7000   108.5000   0.0000   0.0000   0.0000   30
1990   3773   0.449   14.4000   371.9000   2116.4000   1068.4000   122.0000   51.3000   28.6000   0.0000   0.0000   30
1991   3823   0.451   45.0000   123.0000   371.6000   2796.3000   393.8000   64.7000   28.6000   0.0000   0.0000   30
1992   3889.6   0.517   80.2000   395.2000   355.9000   396.8000   2185.1000   340.7000   117.3000   0.0000   18.4000   30
1993   4004.8   0.423   321.3000   810.6000   1284.2000   581.5000   134.5000   711.7000   88.5000   36.3000   36.3000   30
1994   2030.6   0.423   24.6000   504.2000   649.4000   321.7000   133.1000   83.9000   227.2000   14.5000   72.0000   30
1995   3083.7   0.473   58.3000   298.7000   1860.6000   513.4000   234.8000   54.3000   0.0000   18.1000   45.4000   30
1996   3937   0.44   91.4000   34.3000   936.3000   2164.1000   614.9000   96.0000   0.0000   0.0000   0.0000   30
1997   3501.1   0.368   253.4000   222.5000   623.5000   432.1000   1395.6000   390.1000   183.9000   0.0000   0.0000   30
1998   2732.5   0.544   28.9000   364.9000   573.7000   819.2000   229.1000   651.1000   33.4000   32.3000   0.0000   30
1999   3675.5   0.442   264.5000   546.2000   1160.1000   560.1000   487.2000   214.5000   424.8000   0.0000   18.1000   30
2000   4883.9   0.421   1873.9000   1176.9000   700.0000   774.9000   158.2000   146.7000   18.1000   35.3000   0.0000   30
2001   3429   0.511   45.7000   566.8000   1091.1000   814.2000   547.0000   103.7000   155.0000   87.5000   18.1000   30
2002   5948.9   0.403   543.6000   72.4000   875.9000   2530.4000   967.8000   545.9000   295.7000   90.6000   26.7000   30
2003   5874.6   0.423   119.3000   1317.3000   93.8000   1147.5000   1711.7000   618.2000   542.4000   128.9000   195.5000   30
2004   1567.6   0.456   217.6000   71.1000   368.1000   185.2000   332.9000   340.6000   18.1000   18.1000   16.1000   30
2005   2818.6   0.441   45.7000   1181.0000   129.9000   995.9000   18.1000   220.3000   204.5000   23.3000   0.0000   30
2006   2131.5   0.403   293.5000   378.6000   693.6000   77.6000   314.5000   37.4000   201.4000   110.2000   24.6000   30
2007   19797.7   0.865   159.3000   5467.0000   4915.3000   7102.5000   698.4000   1271.1000   119.0000   65.0000   0.0000   30
2008   12763.4   0.916   126.7000   1860.6000   6278.5000   2527.1000   1755.0000   85.1000   130.4000   0.0000   0.0000   30
2009   5749.6   0.731   100.3000   446.2000   1677.4000   1813.2000   958.2000   700.0000   12.8000   35.8000   5.8000   30
2010   2070.2   0.443   94.9000   445.1000   534.4000   313.9000   365.8000   181.2000   69.3000   25.4000   40.3000   30
# Index-2
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1982   12410.2  0.736   1333.9000   5214.6000   3955.6000   1551.7000   354.5000   0.0000   0.0000   0.0000   0.0000   30
1983   4450.2   0.27    487.9000   1445.1000   1208.5000   426.7000   400.0000   350.2000   0.0000   0.0000   131.7940   30
1984   3912.1   0.32    819.4000   668.4000   936.5000   612.8000   313.1000   309.9000   99.2000   0.0000   152.8810   30
1985   4159.3   0.276   711.2000   1465.4000   1000.8000   321.3000   392.7000   101.9000   0.0000   54.3000   111.6650   30
1986   3115.6   0.33    628.8000   644.8000   999.7000   588.0000   116.1000   66.1000   0.0000   0.0000   72.0470   30
1987   4581.3   0.408   910.7000   2217.3000   936.6000   316.9000   199.7000   0.0000   0.0000   0.0000   0.0000   30
1988   9429.6   0.449   3018.2000   3778.9000   1707.4000   586.0000   233.1000   0.0000   70.0000   0.0000   36.1040   30
1989   7272.8   0.323   232.0000   3941.8000   2329.3000   451.3000   219.8000   84.2000   0.0000   14.4000   0.0000   30
1990   4770.5   0.29    90.9000   348.3000   2856.0000   975.6000   407.5000   77.0000   15.2000   0.0000   0.0000   30
1991   1985.7   0.367   229.2000   241.4000   367.4000   991.2000   120.3000   0.0000   36.1000   0.0000   0.0000   30
1992   2196.1   0.313   461.7000   716.3000   229.9000   64.7000   522.4000   201.1000   0.0000   0.0000   0.0000   30
1993   1919.1   0.359   334.8000   918.4000   577.2000   27.6000   0.0000   61.0000   0.0000   0.0000   0.0000   30
1994   3351.4   0.409   293.1000   1452.0000   1303.7000   148.6000   81.6000   0.0000   72.4000   0.0000   0.0000   30
1995   3194.2   0.401   108.6000   492.5000   1958.7000   485.2000   131.2000   18.1000   0.0000   0.0000   0.0000   30
1996   2074.7   0.354   195.4000   605.3000   369.7000   824.5000   79.9000   0.0000   0.0000   0.0000   0.0000   30
1997   1393.2   0.399   474.1000   145.7000   263.9000   268.5000   240.9000   0.0000   0.0000   0.0000   0.0000   30
1998   1267.1   0.446   135.8000   545.5000   176.4000   295.1000   65.3000   49.0000   0.0000   0.0000   0.0000   30
1999   2845.9   0.281   690.3000   599.4000   942.0000   389.0000   195.1000   30.2000   0.0000   0.0000   0.0000   30
2000   4146.5   0.406   862.8000   1566.8000   636.8000   786.6000   223.0000   16.1000   0.0000   54.3000   0.0000   30
2001   3135.3   0.371   0.0000   273.0000   1150.4000   763.8000   568.1000   197.5000   146.3000   0.0000   36.2630   30
2002   8511.8   0.678   429.9000   165.8000   531.6000   4286.1000   1709.8000   1197.5000   122.2000   68.9000   0.0000   30
2003   3175.2   0.407   737.1000   297.0000   344.4000   827.0000   721.0000   113.1000   99.5000   0.0000   36.1040   30
2004   3458.3   0.427   1056.3000   275.4000   922.1000   406.2000   399.4000   237.9000   90.6000   36.3000   34.1870   30
2005   2082.8   0.165   244.9000   604.3000   124.0000   728.0000   36.3000   143.8000   131.2000   36.3000   34.1870   30
2006   5640     0.401   1982.3000   956.6000   1609.2000   402.6000   467.4000   59.3000   83.9000   57.2000   21.5660   30
2007   3163.8   0.468   217.3000   1378.2000   631.7000   793.0000   36.6000   107.2000   0.0000   0.0000   0.0000   30
2008   5263.9   0.489   1038.1000   1960.3000   1693.0000   301.1000   222.1000   0.0000   0.0000   0.0000   49.3630   30
2009   5475.1   0.635   1053.9000   3348.5000   501.6000   442.0000   72.5000   56.6000   0.0000   0.0000   0.0000   30
2010   1501     0.333   150.5000   211.5000   463.4000   460.2000   147.1000   37.1000   21.1000   0.0000   10.0640   30
# Index-3
1982   4734.4   0.52    2599.6000   1326.1000   554.7000   184.8000   43.4000   9.1000   6.8000   9.8000   0.0000   15
1983   10611.8  0.46    6757.6000   2928.7000   544.0000   321.6000   29.6000   15.9000   14.3000   0.0000   0.0000   15
1984   1974.7   0.58    399.5000   963.6000   451.7000   114.1000   28.8000   16.9000   0.0000   0.0000   0.0000   15
1985   1399     0.51    297.4000   554.4000   432.2000   87.9000   7.5000   0.0000   19.6000   0.0000   0.0000   15
1986   4511.7   0.85    1704.3000   2414.3000   185.7000   183.3000   19.4000   4.5000   0.0000   0.0000   0.0000   15
1987   3230.8   0.52    1631.9000   940.1000   569.0000   35.6000   30.1000   10.4000   0.0000   0.0000   13.7420   15
1988   3991.5   0.5     1959.8000   1346.1000   363.1000   308.6000   0.0000   7.4000   6.4000   0.0000   0.0000   15
1989   10189.9  0.57    4214.0000   4498.4000   1348.4000   97.5000   22.1000   9.4000   0.0000   0.0000   0.0000   15
1990   5384.5   0.58    879.3000   1216.6000   2775.8000   443.5000   55.2000   14.1000   0.0000   0.0000   0.0000   15
1991   2615.9   0.52    1020.9000   544.5000   336.5000   651.4000   60.2000   2.4000   0.0000   0.0000   0.0000   15
```

```
1992    3022.4   0.57    874.5000    1083.2000    670.3000    113.0000    252.8000    20.0000    8.6000    0.0000    0.0000    15
1993    2459     0.65    537.0000    1214.8000    440.7000    229.6000    19.9000    17.1000    0.0000    0.0000    0.0000    15
1994    2299.7   0.53    1008.0000    765.9000    372.7000    123.8000    29.3000    0.0000    0.0000    0.0000    0.0000    15
1995    2228     0.56    1154.7000    422.1000    527.1000    114.2000    9.9000    0.0000    0.0000    0.0000    0.0000    15
1996    807.5    0.52    152.2000    97.5000    214.0000    290.5000    53.3000    0.0000    0.0000    0.0000    0.0000    15
1997    1066.8   0.54    571.9000    189.5000    185.8000    39.2000    74.5000    5.9000    0.0000    0.0000    0.0000    15
1998    801.6    0.56    300.2000    161.3000    151.2000    138.5000    6.7000    40.2000    3.4000    0.0000    0.0000    15
1999    3540     0.67    2346.0000    440.7000    446.7000    138.5000    126.3000    14.7000    24.6000    2.5000    0.0000    15
2000    9531.4   0.68    6940.1000    1410.9000    508.1000    401.5000    139.6000    102.5000    11.5000    17.1000    0.0000    15
2001    3108.4   0.73    16.5000    893.9000    943.3000    661.7000    420.5000    101.2000    50.6000    20.8000    0.0000    15
2002    4590     0.39    3783.3000    50.0000    265.1000    252.3000    103.2000    52.9000    20.4000    46.0000    16.8200    15
2003    5141.8   0.81    3090.9000    1339.8000    87.0000    385.8000    178.2000    36.3000    13.3000    2.8000    7.6260    15
2004    3026.9   0.75    1755.5000    352.6000    521.6000    68.9000    196.0000    104.7000    19.2000    5.6000    2.8030    15
2005    2701.9   0.53    1034.0000    831.8000    169.4000    384.8000    59.2000    138.4000    49.3000    18.3000    16.7220    15
2006    4573.2   0.63    2084.6000    1294.1000    753.6000    111.0000    287.0000    20.7000    15.2000    0.0000    7.1160    15
2007    2402     0.57    825.4000    569.9000    435.2000    388.1000    67.5000    103.4000    6.5000    6.0000    0.0000    15
2008    4929.5   0.5     1407.6000    1963.9000    768.4000    411.1000    311.4000    36.7000    30.4000    0.0000    0.0000    15
2009    2826.3   0.67    1683.6000    511.7000    305.5000    207.0000    80.2000    32.8000    0.0000    5.5000    0.0000    15
2010    1354.6   0.54    514.8000    247.2000    274.0000    133.3000    128.5000    45.3000    1.4000    0.0000    10.0960    15
# Index-4
1982    300.2    0.32    197.8000    65.5000    25.8000    9.1000    0.0000    0.0000    2.1000    0.0000    0.0000    10
1983    70.5     0.34    58.8000    8.4000    3.2000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    10
1984    62.8     0.19    47.8000    11.8000    3.2000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    10
1985    76.7     0.3     66.1000    8.2000    2.4000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    10
1986    170.1    0.3     87.6000    76.9000    0.0000    5.6000    0.0000    0.0000    0.0000    0.0000    0.0000    10
1987    215.2    0.18    210.2000    5.1000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    10
1988    681.5    0.24    633.2000    46.2000    2.1000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    10
1989    53.5     0.06    19.3000    27.1000    1.6000    5.5000    0.0000    0.0000    0.0000    0.0000    0.0000    10
1990    989.7    0.27    840.3000    86.7000    52.6000    4.6000    5.4000    0.0000    0.0000    0.0000    0.0000    10
1991    483.1    0.27    375.7000    90.6000    2.6000    11.7000    2.6000    0.0000    0.0000    0.0000    0.0000    10
1992    232.4    0.08    214.3000    10.6000    0.0000    0.0000    7.4000    0.0000    0.0000    0.0000    0.0000    10
1993    427      0.25    317.1000    75.8000    29.0000    5.1000    0.0000    0.0000    0.0000    0.0000    0.0000    10
1994    1787.9   0.49    1102.4000    583.7000    99.4000    2.4000    0.0000    0.0000    0.0000    0.0000    0.0000    10
1995    362.3    0.3     235.9000    68.7000    56.4000    1.4000    0.0000    0.0000    0.0000    0.0000    0.0000    10
1996    16.8     0.37    11.5000    0.5000    1.2000    3.6000    0.0000    0.0000    0.0000    0.0000    0.0000    10
1997    5.2      0.24    5.2000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    10
1998    213      0.26    126.3000    65.1000    13.9000    7.7000    0.0000    0.0000    0.0000    0.0000    0.0000    10
1999    96.1     0.55    72.9000    20.0000    1.6000    1.6000    0.0000    0.0000    0.0000    0.0000    0.0000    10
2000    124      0.36    75.0000    38.7000    7.1000    3.2000    0.0000    0.0000    0.0000    0.0000    0.0000    10
2001    75.2     0.46    6.8000    26.4000    24.4000    12.4000    5.2000    0.0000    0.0000    0.0000    0.0000    10
```

```
2002   467.7    0.57    220.7000   9.0000    63.8000    52.7000    65.6000    32.5000    16.8000    6.7000    0.0000    10
2003   453.5    0.48    143.3000   229.0000    21.6000    32.1000    18.1000    9.3000    0.0000    0.0000    0.0000    10
2004   3390.9   0.29    2768.3000    127.4000    279.9000    48.5000    122.2000    41.3000    3.2000    0.0000    0.0000    10
2005   227.5    0.41    153.8000    69.7000    4.1000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    10
2006   1155.8   0.39    773.8000    238.5000    100.8000    14.4000    19.8000    8.4000    0.0000    0.0000    0.0000    10
2007   67.6     0.27    42.5000    18.9000    6.2000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    10
2008   1303.7   0.41    647.0000    466.9000    126.4000    29.6000    33.8000    0.0000    0.0000    0.0000    0.0000    10
2009   418.3    0.43    205.0000    143.6000    58.3000    8.1000    1.6000    1.7000    0.0000    0.0000    0.0000    10
2010   355.4    0.44    87.5000    125.3000    95.3000    33.4000    6.6000    7.3000    0.0000    0.0000    0.0000    10
# Index-5
1982   0.218    0.3    -999.0000    0.0740    0.0740    0.0450    0.0220    0.0030    -999.0000    -999.0000    -999.0000    -999
1983   0.233    0.3    -999.0000    0.0480    0.1100    0.0420    0.0210    0.0120    -999.0000    -999.0000    -999.0000    -999
1984   0.139    0.3    -999.0000    0.0330    0.0450    0.0440    0.0120    0.0060    -999.0000    -999.0000    -999.0000    -999
1985   0.106    0.3    -999.0000    0.0140    0.0420    0.0290    0.0180    0.0040    -999.0000    -999.0000    -999.0000    -999
1986   0.106    0.3    -999.0000    0.0040    0.0690    0.0230    0.0070    0.0040    -999.0000    -999.0000    -999.0000    -999
1987   0.06     0.3    -999.0000    0.0070    0.0190    0.0260    0.0060    0.0020    -999.0000    -999.0000    -999.0000    -999
1988   0.099    0.3    -999.0000    0.0150    0.0490    0.0240    0.0090    0.0020    -999.0000    -999.0000    -999.0000    -999
1989   0.133    0.3    -999.0000    0.0170    0.0640    0.0400    0.0110    0.0020    -999.0000    -999.0000    -999.0000    -999
1990   0.266    0.3    -999.0000    0.0110    0.1600    0.0780    0.0120    0.0050    -999.0000    -999.0000    -999.0000    -999
1991   0.221    0.3    -999.0000    0.0190    0.0400    0.1360    0.0220    0.0040    -999.0000    -999.0000    -999.0000    -999
1992   0.103    0.3    -999.0000    0.0150    0.0170    0.0140    0.0520    0.0050    -999.0000    -999.0000    -999.0000    -999
1993   0.094    0.3    -999.0000    0.0030    0.0500    0.0230    0.0040    0.0140    -999.0000    -999.0000    -999.0000    -999
1994   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
1995   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
1996   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
1997   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
1998   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
1999   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
2000   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
2001   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
2002   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
2003   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
2004   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
2005   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
2006   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
2007   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
2008   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
2009   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
2010   -999     1    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999.0000    -999
# Phase Control Data
```

```
# Phase for F mult in 1st Year
3
# Phase for F mult Deviations
3
# Phase for Recruitment Deviations
4
# Phase for N in 1st Year
1
# Phase for Catchability in 1st Year
1
# Phase for Catchability Deviations
-3
# Phase for Stock Recruitment Relationship
2
# Phase for Steepness
-3
# Recruitment CV by Year
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
```

```
0.5
0.5
0.5
0.5
0.5
0.5
#Lambda for Each Index
1  1  1  1  1
# Lambda for Total Catch in Weight by Fleet
1
# Lambda for Total Discards at Age by Fleet
0
# Catch Total CV by Year and Fleet
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
0.050
```

```
0.050
0.050
# Discard Total CV by Year and Fleet
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
# Input Effective Sample Size for Catch at Age by Year & Fleet
75
75
75
75
75
75
75
```

```
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
75
# Input Effective Sample Size for Discards at Age by Year & Fleet
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
```

```
0
0
0
0
0
0
0
0
0
0
0
0
# Lambda for F mult in first year by fleet
0
# CV for F mult in first year by fleet
1
# Lambda for F mult Deviations by Fleet
0
# CV for F mult deviations by Fleet
1
# Lambda for N in 1st Year Deviations
0
# CV for N in 1st Year Deviations
1
# Lambda for Recruitment Deviations
1
# Lambda for Catchability in first year by index
0  0  0  0  0
# CV for Catchability in first year by index
1  1  1  1  1
# Lambda for Catchability Deviations by Index
0  0  0  0  0
# CV for Catchability Deviations by Index
1  1  1  1  1
# Lambda for Deviation from Initial Steepness
0
# CV for Deviation from Initial Steepness
1
# Lambda for Deviation from Initial unexploited Stock Size
0
```

```
# CV for Deviation from Initial unexploited Stock Size
1
# NAA for Year 1
11397  13272  5773  3454  1941  212  296  163  103
# F mult in 1st year by Fleet
0.05
# Catchability in 1st year by index
0.3  0.3  0.1  0.05  0.0001
# Initial unexploited Stock Size
200000
# Initial Steepness
1.00
# Maximum F
3
# Ignore Guesses
0
# Projection Control Data
# Do Projections? (1=yes, 0=no), still need to enter values even if not doing projections
0
# Fleet Directed Flag
1
# Final Year of Projections
2011
# Year Projected Recruits, What Projected, Target, non- directed F mult
2011     0     0     0     0
# MCMC info
# doMCMC (1=yes)
0
# MCMCnyear option (0=use final year values of NAA, 1=use final year + 1 values of NAA)
1
# MCMCnboot
10000
# MCMCnthin
10
# MCMCseed
548623
# R in agepro.bsn file (enter 0 to use NAA, 1 to use stock-recruit relationship, 2 to used geometric mean of previous years)
2
# Starting year for calculation of R
1982
```

```
# Starting year for calculation of R
2008
# Test Value
-23456
#####
# ---- FINIS ----
```

Appendix 4. The Statistical Catch-at-Age Model (SCAA)

The text following sets out the equations and other general specifications of the SCAA followed by details of the contributions to the (penalised) log-likelihood function from the different sources of data available and assumptions concerning the stock-recruitment relationship. Quasi-Newton minimization is then applied to minimize the total negative log-likelihood function to estimate parameter values (the package AD Model Builder^{TM}, Otter Research, Ltd is used for this purpose).

4.1. Population dynamics

4.1.1 Numbers-at-age

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,0} = R_{y+1} \quad (4.1)$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_a/2} - C_{y,a}\right) e^{-M_a/2} \qquad \text{for } 0 \le a \le m-2 \quad (4.2)$$

$$N_{y+1,m} = \left(N_{y,m-1}\, e^{-M_{m-1}/2} - C_{y,m-1}\right) e^{-M_{m-1}/2} + \left(N_{y,m}\, e^{-M_m/2} - C_{y,m}\right) e^{-M_m/2} \quad (4.3)$$

where

$N_{y,a}$ is the number of fish of age *a* at the start of year *y* (which refers to a calendar year),

R_y is the recruitment (number of 0-year-old fish) at the start of year *y*,

M_a denotes the natural mortality rate for fish of age *a*,

$C_{y,a}$ is the predicted number of fish of age *a* caught in year *y*, and

m is the maximum age considered (taken to be a plus-group).

These equations reflect Pope's form of the catch equation (Pope, 1972) (the catches are assumed to be taken as a pulse in the middle of the year) rather than the more customary Baranov form (Baranov, 1918) (for which catches are incorporated under the assumption of steady continuous fishing mortality). Pope's form has been used in order to simplify computations. As long as mortality rates are not too high, the differences between the Baranov and Pope formulations will be minimal.

4.1.2. Recruitment

The number of recruits (i.e. new 0-year old) at the start of year *y* is assumed to be related to the spawning stock size (i.e. the biomass of mature fish) by either a modified Ricker or a Beverton-Holt stock-recruitment relationship, allowing for annual fluctuation about the deterministic relationship:

for the modified Ricker:

$$R_y = \alpha B_y^{\text{sp}} \exp\left[-\beta\left(B_y^{\text{sp}}\right)^{\gamma}\right] e^{(\varsigma_y - (\sigma_{\text{R}})^2/2)} \quad (4.4)$$

where

and for Beverton-Holt:

$$R_y = \frac{\alpha B_y^{\text{sp}}}{\beta + B_y^{\text{sp}}} e^{(\varsigma_y - (\sigma_{\text{R}})^2/2)} \qquad (4.5)$$

where

α, β and γ are spawning biomass-recruitment relationship parameters,

ς_y reflects fluctuation about the expected recruitment for year y, which is assumed to be normally distributed with standard deviation σ_R (which is input in the applications considered here); these residuals are treated as estimable parameters in the model fitting process.

B_y^{sp} is the spawning biomass at the start of year y, computed as:

$$B_y^{\text{sp}} = \sum_{a=0}^{m} f_{y,a} w_{y,a}^{\text{strt}} \left[N_{y,a} e^{-M_a/12} - C_{y,a}/6 \right] e^{-M_a/12} \qquad (4.6)$$

because spawning for the cod stocks under consideration is taken to occur two months after the start of the year and some mortality (natural and fishing) has therefore occurred,

where

$w_{y,a}^{\text{strt}}$ is the mass of fish of age a during spawning, and

$f_{y,a}$ is the proportion of fish of age a that are mature.

In order to work with estimable parameters that are more meaningful biologically, the stock-recruitment relationship is re-parameterised in terms of the pre-exploitation equilibrium spawning biomass, K^{sp}, and the "steepness", h, of the stock-recruitment relationship, which is the proportion of the virgin recruitment that is realized at a spawning biomass level of 20% of the virgin spawning biomass. In the fitting procedure, both h and K^{sp} are estimated with γ being either fixed on input or estimated as well.

4.1.3. Total catch and catches-at-age

The total catch by mass in year y is given by:

$$C_y = \sum_{a=0}^{m} w_{y,a}^{\text{mid}} C_{y,a} = \sum_{a=0}^{m} w_{y,a}^{\text{mid}} N_{y,a} e^{-M_a/2} S_{y,a} F_y^* \qquad (4.7)$$

where

$w_{y,a}^{\text{mid}}$ denotes the mass of fish of age a landed in year y,

$C_{y,a}$ is the catch-at-age, i.e. the number of fish of age a, caught in year y,

$S_{y,a}$ is the commercial selectivity (i.e. combination of availability and vulnerability to fishing gear)-at-age a for year y; when $S_{y,a} = 1$, the age-class a is said to be fully selected, and

F_y^* is the proportion of a fully selected age class that is fished.

The model estimate of the mid-year exploitable ("available") component of biomass is calculated by converting the numbers-at-age into mid-year mass-at-age (using the individual weights of the landed fish) and applying natural and fishing mortality for half the year:

$$B_y^{\text{ex}} = \sum_{a=0}^{m} w_{y,a}^{\text{mid}} S_{y,a} N_{y,a} e^{-M_a/2}(1 - S_{y,a} F_y^* / 2) \quad (4.8)$$

whereas for survey estimates of biomass in the beginning of the year (for simplicity spring and autumn surveys are treated as mid-year surveys):

$$B_y^{\text{surv}} = \sum_{a=0}^{m} w_{y,a}^{\text{strt}} S_a^{\text{surv}} N_{y,a} e^{-M_a/2}(1 - S_{y,a} F_y^* / 2) \quad (4.9)$$

where

S_a^{surv} is the survey selectivity for age *a*, which is taken to be year-independent.

4.1.4. Initial conditions

As the first year for which data (even annual catch data) are available for the cod stock considered clearly does not correspond to the first year of (appreciable) exploitation, one cannot necessarily make the conventional assumption in the application of ASPM's that this initial year reflects a population (and its age-structure) at pre-exploitation equilibrium. For the first year (y_0) considered in the model therefore, the stock is assumed to be at a fraction (θ) of its pre-exploitation biomass, i.e.:

$$B_{y_0}^{\text{sp}} = \theta \cdot K^{\text{sp}} \quad (4.10)$$

with the starting age structure:

$$N_{y_0,a} = R_{\text{start}} N_{\text{start},a} \qquad \text{for } 1 \le a \le m \qquad (4.11)$$

where

$$N_{\text{start},1} = 1 \ (4.12)$$

$$N_{\text{start},a} = N_{\text{start},a-1} e^{-M_{a-1}} (1 - \phi S_{a-1}) \qquad \text{for } 2 \le a \le m-1 \ (4.13)$$

$$N_{\text{start},m} = N_{\text{start},m-1} e^{-M_{m-1}} (1 - \phi S_{m-1}) \Big/ (1 - e^{-M_m}(1 - \phi S_m)) \qquad (4.14)$$

where ϕ characterises the average fishing proportion over the years immediately preceding y_0.

4.2. The (penalised) likelihood function

The model can be fit to (a subset of) CPUE and survey abundance indices, and commercial and survey catch-at-age data to estimate model parameters (which may include residuals about the stock-recruitment function, facilitated through the incorporation of a penalty function described below). Contributions by each of these to the negative of the (penalised) log-likelihood ($-\ell nL$) are as follows.

4.2.1 LPUE relative abundance data

The likelihood is calculated assuming that an observed CPUE abundance index for a particular fishing fleet is log-normally distributed about its expected value:

$$I_y = \hat{I}_y \exp(\varepsilon_y) \quad \text{or} \quad \varepsilon_y = \ell\text{n}(I_y) - \ell\text{n}(\hat{I}_y) \text{(4.15)}$$

where

I_y is the LPUE abundance index for year *y* for ages 2 to 6,

$\hat{I}_y = \hat{q}\ \widehat{N}_y^{\text{ex}}$ is the corresponding model estimate, where $\widehat{N}_y^{\text{ex}}$ is the model estimate of exploitable resource numbers for ages 2 to 6, given by

$$N_y^{\text{ex}} = \sum_{a=2}^{6} S_{y,a} N_{y,a} e^{-M_a/2} (1 - S_{y,a} F_y^* / 2) \quad (4.16)$$

$\hat{q}$ is the constant of proportionality (catchability) for the LPUE abundance series, and

ε_y from $N\left(0, (\sigma_y)^2\right)$.

The contribution of the LPUE data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell\text{n}\, L^{\text{LPUE}} = \sum_y \left\{ \ell\text{n}\left(\sqrt{(\sigma_y^2 + \sigma_{Add}^2)}\right) + (\varepsilon_y)^2 / \left[2(\sigma_y^2 + \sigma_{Add}^2)\right] \right\} \quad (4.17)$$

where

σ_y is the standard deviation of the residuals for the logarithm of index *i* in year *y* (which is input), and

σ_{Add} is the square root of the additional variance for the LPUE abundance series, which is estimated in the model fitting procedure, with an upper bound of 0.5.

The catchability coefficient q^i for CPUE abundance index *i* is estimated by its maximum likelihood value:

$$\ell n\, \hat{q}^i = 1/n_i \sum_y \left(\ln I_y^i - \ln \hat{B}_y^{\text{ex}}\right) \quad (4.18)$$

D2.2. Survey abundance data

In general, data from the surveys are treated as relative abundance indices in exactly the same manner to the CPUE series above, with survey selectivity function S_a^{surv} replacing the commercial selectivity $S_{y,a}$. Account is also taken of the time of year when the survey is held. For these analyses, selectivities are estimated as detailed in section 4.4.2 below.

4.2.3. Commercial catches-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood function under the assumption of an "adjusted" lognormal error distribution is given by:

$$-\ell\text{n} L^{\text{CAA}} = \sum_y \sum_a \left[\ell n\left(\sigma_{\text{com}} / \sqrt{p_{y,a}}\right) + p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / 2(\sigma_{\text{com}})^2 \right] \quad (4.19)$$

where

$p_{y,a} = C_{y,a} / \sum_{a'} C_{y,a'}$ is the observed proportion of fish caught in year y that are of age a,

$\hat{p}_{y,a} = \hat{C}_{y,a} / \sum_{a'} \hat{C}_{y,a'}$ is the model-predicted proportion of fish caught in year y that are of age a,

where

$$\hat{C}_{y,a} = N_{y,a}\, e^{-M_a/2} S_{y,a} F_y \qquad (4.20)$$

and

σ_{com} is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_{\text{com}} = \sqrt{\sum_y \sum_a p_{y,a} \left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / \sum_y \sum_a 1} \quad (4.21)$$

The log-normal error distribution underlying equation (4.19) is chosen on the grounds that (assuming no ageing error) variability is likely dominated by a combination of interannual variation in the distribution of fishing effort, and fluctuations (partly as a consequence of such variations) in selectivity-at-age, which suggests that the assumption of a constant coefficient of variation is appropriate. However, for ages poorly represented in the sample, sampling variability considerations must at some stage start to dominate the variance. To take this into account in a simple manner, motivated by binomial distribution properties, the observed proportions are used for weighting so that undue importance is not attached to data based upon a few samples only.

Commercial catches-at-age are incorporated in the likelihood function using equation (4.19), for which the summation over age a is taken from age a_{minus} (considered as a minus group) to a_{plus} (a plus group).

4.2.4. Survey catches-at-age

The survey catches-at-age are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-age, assuming an adjusted log-normal error distribution (equation (4.19)) where:

$p_{y,a} = C^{\text{surv}}_{y,a} / \sum_{a'} C^{\text{surv}}_{y,a'}$ is the observed proportion of fish of age a in year y,

$\hat{p}_{y,a}$ is the expected proportion of fish of age a in year y in the survey, given by:

$$\hat{p}_{y,a} = S^{\text{surv}}_a N_{y,a} \Big/ \sum_{a'=0}^{m} S^{\text{surv}}_a N_{y,a} \qquad \text{for begin-year surveys.} \quad (4.22)$$

4.2.5. Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be log-normally distributed and serially correlated. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell nL^{\text{pen}} = \sum_{y=y_1+1}^{y_2}\left[\left(\frac{\lambda_y - \rho\lambda_{y-1}}{\sqrt{1-\rho^2}}\right)^2 \bigg/ 2\sigma_{\text{R}}^2\right] \quad (4.23)$$

where

$\lambda_y = \rho\lambda_{y-1} + \sqrt{1-\rho^2}\,\varepsilon_y$ is the recruitment residual for year y, which is estimated for year y_1 to y_2 (see equation (4.4)),

ε_y from $N\left(0,(\sigma_R)^2\right)$,

σ_{R} is the standard deviation of the log-residuals, which is input, and

ρ is the serial correlation coefficient, which is input.

In the interest of simplicity, equation (4.23) omits a term in λ_{y_1} for the sensitivity when serial correlation is assumed ($\rho \neq 0$), which is generally of little quantitative consequence to values estimated.

The analyses conducted in this paper have however all assumed $\rho = 0$.

4.3. Estimation of precision

Where quoted, 95% probability interval estimates are based on the Hessian.

4.4. Model parameters

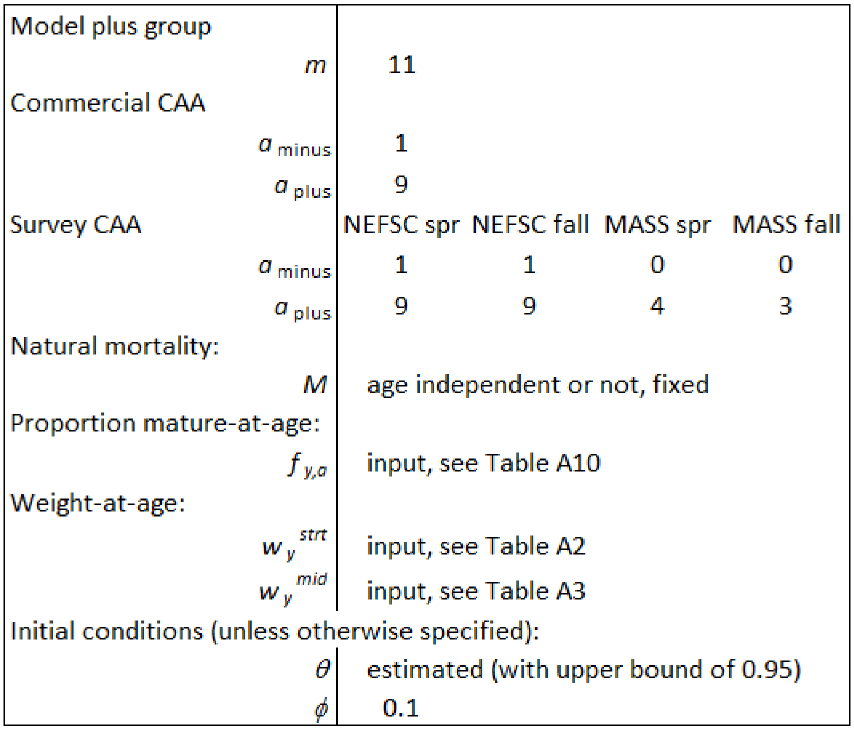
4.4.1. Fishing selectivity-at-age:

The commercial fishing selectivity, S_a, as well as the fishing selectivities for the NEFSC offshore and Massachusetts inshore spring and autumn surveys, are estimated separately for ages a_{minus} to a_{plus}. The estimated decrease from ages a_{plus}-1 to a_{plus}. is assumed to continue exponentially to age 11+ if otherwise not specified (see Table below for a_{minus} to a_{plus}.).

The commercial selectivity is taken to differ over the 1893-1991 and 1992+ periods. The decrease from ages a_{plus}-1 to a_{plus}. however is taken to be the same throughout the period. The decision to incorporate a change after 1991 was made to remove non-random residual patterns in the fit to the commercial catch-at-age data if time-independence in selectivity was assumed.

Selectivity is taken to differ for the surveys, but the decrease from ages a_{plus}-1 to a_{plus}. is taken to be the same for both spring and autumn surveys.

4.4.2. Other parameters



Model plus group					
	m	11			
Commercial CAA					
	a_{minus}	1			
	a_{plus}	9			
Survey CAA		NEFSC spr	NEFSC fall	MASS spr	MASS fall
	a_{minus}	1	1	0	0
	a_{plus}	9	9	4	3
Natural mortality:					
	M	age independent or not, fixed			
Proportion mature-at-age:					
	$f_{y,a}$	input, see Table A10			
Weight-at-age:					
	w_y^{strt}	input, see Table A2			
	w_y^{mid}	input, see Table A3			
Initial conditions (unless otherwise specified):					
	θ	estimated (with upper bound of 0.95)			
	ϕ	0.1			