N. Gulf of Maine/Georges Bank Acadian redfish

by Timothy J. Miller, Ralph K. Mayo, Michelle L. Traver and Laurel A. Col

Additional details and supporting information can be found in the Appendix of the GARM-III Report (NEFSC 2008).

1.0 Background

The most recent stock assessment of Gulf of Maine-Georges Bank Acadian redfish was completed and reviewed at the 2005 Groundfish Assessment Review Meeting (GARM) (Mayo et al. 2005, Mayo et al. 2007). The assessment was based on several analyses including trends in catch/survey biomass exploitation ratios; a yield- and biomass-per-recruit analysis; an age-structured dynamics model which incorporates information on the age composition of the landings, size and age composition of the population, and trends in relative abundance derived from commercial CPUE and research vessel survey biomass indices (NEFSC 2001a, 2001b).

Based on the most recent assessment, estimates of redfish population biomass have been increasing in recent years. The increase in biomass estimates is produced by corresponding increases in both the NEFSC spring and autumn survey biomass indices which rose substantially during the mid-1990s and remained relatively high through 2005. The rapid increase in abundance and biomass was attributed to strong recruitment for some cohorts in the early-1990s. The state of this stock was reviewed at the 2005 GARM by comparing the estimated 2005 spawning biomass with spawning biomass at 50% maximum spawning potential (SB(50%MSP), estimated previously; NEFSC 2002). Estimates of fishing mortality derived from the age-structured dynamics model in the last assessment were less than 10% of F(50%MSP) between 2000 and 2004 (<0.004). The 2004 spawning biomass was estimated to be about 175,790mt (74% of SB(50%MSP)) and the 2004 fishing mortality rate estimate was 0.0024 (F(50%MSP) = 0.04). Thus, it was concluded that the stock was not overfished and overfishing was not occurring.

For the 2008 GARM on assessment models, we updated the catch and survey data to 2006 and provide estimates of discards between 1989 and 2006. Two versions of a statistical catch at age model (RED and STATCAM) were explored for the 2005 GARM, but the definitive results were ultimately based on the RED model. As such, for initial meetings of the 2008 GARM we had also used both RED and STATCAM to estimate assessment parameters and we also made estimates using landings data from 1913-1933 that we found primarily in annual reports of the U.S. Bureau of Fisheries (e.g., Fielder 1928). We also note that, for consistency, we used the same version of STATCAM as that used in the 2005 assessment. We had also explored an alternative finite-state continuous-time population dynamics model (FSCTPD) on a limited set of age measurements from surveys and landings between 1969 and 1985 to estimate recruitment, selectivity, survey catchability and annual fishing mortality (see Miller 2008). The statistical framework is the same as that described by Miller and Andersen (2008) for various types of tagging experiments. We compared the results from FSCTPD with corresponding results from the RED and STATCAM models for corroborative purposes.

There was concern raised at the 2008 GARM on assessment models about the problematic estimation of biomass levels prior to the substantial landings starting 1936 using RED and STATCAM. The review panel suggested implementing a Beverton-Holt stock-recruitment relationship. As ASAP (ASAP 2008) is also a statistical catch-at-age model with the stock-recruitment implementation readily available, we moved to this as the assessment model. We presented ASAP alternative models at the 2008 GARM on biological reference points and, ultimately, the panel recommended a model alternative where we assumed a 5 year linear ramp from 0.1 in 1964 to 0.8 in 1969 for the CVs of recruitment residuals. We also used revised estimates of maturity- and weight-at-age and CVs for survey biomass indices and we included discards with landings for total catch estimates between 1989 and 2006 with corresponding CVs.

2.0 The Fishery

Substantial exploitation of Gulf of Maine-Georges Bank Acadian redfish began in the late 1930s and was highest in the 1940s (Table N1, Figure N1). Landings declined drastically in the early 1950s, but continued to range from about 8,000 – 20,000mt annually until the early 1980s. Landings of redfish declined steeply throughout the1960s, but stabilized somewhat in the 1970s'. Finally landings dropped steeply again in the 1980s and remained below 1,000mt per year since1989, and at less than 600 mt per year until 2007 where landed biomass was 787mt.

As a consequence of the relatively low landings of redfish after the mid 1980s, age measurements from landings halted after 1985 (Tables N2). Authors of previous assessments derived estimates of catch at age between 1969 and 1985 (Figure N2).

Discards

We estimated discards between 1989 and 2007 using the d/k ratio (ratio of sums) method described in Wigley et al. (2006). The discard estimates are generally low (< 400mt), but are sometimes a substantial proportion of total removals during this period (discards and landings) (Table N1). One particularly high estimate in 1991 is roughly 3 times the corresponding landed biomass but the precision is estimated quite low (CV =0.74).

3.0 Research Survey Estimates

We estimated annual numbers and biomass per tow and mean fish weight and length for the NEFSC spring and autumn research vessel bottom trawl surveys (Tables N3 and N4, Figures N3-N4). For both surveys, the estimates of annual numbers and biomass per tow are generally low and have generally higher precision between the late 1970s and middle 1990s than annual estimates from years outside this range. This period roughly corresponds to the last decline in landings. The increase in annual estimates of numbers and biomass per tow since the middle 1990s is accompanied by increased estimates of uncertainty. Note that although there is increased uncertainty in higher estimates of numbers and biomass per tow, the relative uncertainty (CV) is fairly consistent across all years.

In a few of the yearly surveys, there were sampling deficiencies in some strata. For the spring survey in 1975 no trawls were made in stratum 1390 and this stratum is not included in estimation for that year. For the autumn survey, only one trawl was made in stratum 1300 in 1963 and in stratum 1400 in 2004 so that stratified sampling variance estimates over sets of strata where these are included is not possible.

Survey Age Composition

Age observations are available from 1975 through 2007 for the NEFSC autumn bottom trawl survey and from 1975-1980 and 1984-1990 for the NEFSC spring bottom trawl survey

(Figures N5 and N6). Estimates of proportions at age appear to show infrequent large recruitment pulses followed by periods of small recruitment between 1975 and the early 1990s. Several strong cohorts began to appear in the early 1990s and the biomass in the middle age classes appears to be building at present.

4.0 Assessment

Input data and Model Formulation

The reviewers at the 2008 GARM on assessment models, were concerned with the problematic estimation of biomass levels prior to the substantial landings starting 1936 using RED and STATCAM (O'Boyle et al. 2008a). The reviewers suggested implementing a Beverton-Holt stock-recruitment relationship with a steepness as estimated for Pacific Ocean Perch and assume low coefficient of variation (CV, ≤0.2) of recruitment residuals in years where age observations are not available and high CV (≥ 0.4) of recruitment residuals where age observations are available. The reviewers were also interested in relaxing the constant selectivity assumption (i.e., the separability assumption).

In the revised assessment, we have used ASAP (ASAP 2008) as the assessment model because it is also a statistical catch-at-age model and it has options for assuming a Beverton-Holt stock-recruitment relationship. Prior to the 2008 GARM on biological reference points, we fit three ASAP models assuming the suggested CVs for recruitment residuals (0.2 and 0.4, alternative 1) assuming more drastic differences in the CVs for periods with and without age sampling (0.1 without age observations and 0.8 with age observations, alternative 2) and assuming the same CVs as alternative 2 except with a 5 year linear ramp from 0.1 in 1964 to 0.8 in 1969 (alternative 3) (Miller et al. 2008). However, we estimated both the steepness and unexploited spawning biomass for the stock-recruitment function. In addition, we revised the maturity-at-age (Figure N7) and weight-at-age (Figure N8) estimates and assumed CVs for survey biomass indices. The CVs for the biomass indices were estimates provided by the sampling design used in the autumn and spring bottom trawl surveys when available. In years where design-based CV estimates were not possible, we assumed CV = 0.3. Finally, we also included discards with landings for total catch estimates between 1989 and 2007 with corresponding CVs provided by variance estimates for the annual discards. Further assumptions in the ASAP models were intended to mimic those used previously in STATCAM and RED models where possible (Table N5). However, we did not attempt to relax the constant selectivity assumption because the time span over which age composition data are available from landings (1969-1985) is short relative to the entire time span of landings (1913-2007) and, as such, there is no ability to estimate different selectivity patterns in the periods prior to and after age observations from landings.

Model Selection Process

Overall, the diagnostics of the three ASAP alternatives presented at the 2008 GARM on biological reference points were similar and estimation of initial annual spawning biomass estimates were better behaved than those from any of the STATCAM alternatives. ASAP alternative 3 was deemed the best of the alternative assessment models to use for this assessment and determination of stock status (O'Boyle et al. 2008b).

Since the 2008 Groundfish Assessment meeting on Biological Reference Points, we updated the landings and discard estimates (Table N1), NEFSC survey indices and age composition for the NEFSC autumn survey for 2007 and investigated retrospective patterns in the model. We quantified retrospective pattern of a given parameter (spawning biomass, recruitment or fishing mortality in the terminal year) using the average relative differences of estimates from 7 fits of the ASAP model to data where terminal years were removed. Specifically, we fit models to data up to 2000, 2001, …, 2007 and we averaged the relative differences between estimates from the models using data up to 2000, …, 2006 and the model using all data (up to 2007).

We found retrospective pattern in spawning biomass and fishing mortality in the terminal year using the model chosen at the 2008 GARM meeting on biological reference points. Because the reviewers were interested in exploration of the sensitivity of the results to alternative values of natural mortality, we calculated the retrospective statistics described above for a suite of models assuming different natural mortality rates as well as an alternative model where catchability and selectivities were allowed to be different for both autumn and spring surveys up to 1994 and afterward. We also report the total and component values of the optimized objective function for the models fit to all data (Table N6). The alternative model where M=0.1 provided the least retrospective pattern for spawning biomass and fishing mortality as measured by the average relative differences whereas the alternatives with M = 0.05 and 0.075 provided least retrospective pattern for recruitment. The total objective function is best for the model where M=0.04, but the measures of retrospective pattern for this model were worse than the base model (M = 0.05). The model with survey catchability and selectivities different in the two time periods provided very strong retrospective patterns in spawning biomass and fishing mortality.

We chose to provide assessment results for two models: the Base model (M = 0.05) and the alternative where M = 0.1 because the total objective function value for the base model (M = 0.05) is nearly as good as that of the alternative where M = 0.04 and the retrospective patterns were lessened when M = 0.1. However the fit for the alternative model as measured by the objective function value is so much worse than the Base model and the retrospective pattern was not entirely eradicated (Figure N9). In addition, M=0.05 has been used in assessment of Icelandic redfish (*Sebastes marinus*; Stefánsson and Sigurðsson 1997) and the age composition of the spawning biomass as estimated from the 2007 fall survey and corresponding selectivity-, weight- and maturity-at-age is different than that predicted at equilibrium using a spawning biomass-per-recruit analysis when spawning biomass is nearly twice its reference point as the alternative model estimates (Figure N10; see Section 4.3 below). Given these results, we recommend the Base model (including 2007 data) for determining stock status and catch and biomass projections.

The review panel at this final 2008 GARM accepted the base model as the Final model for determining stock status. However, the panel also recommended that stock status be determined by adjusting the 2007 spawning biomass and fishing mortality rate for the corresponding retrospective patterns exhibited by this model (see Section 8.0 below for panel recommendations). The adjustments we made to determining stock status are described in Section 5.0. The panel also recommended current numbers-at-age estimates be adjusted for catch and rebuilding projections and those adjustments are described in Section 6.0.

Assessment Results

The annual recruitments and spawning biomass estimates are similar for the base models excluding and including the 2007 data (Figure N11). The recruitments are substantially higher on average for the alternative where M = 0.1, but spawning biomass estimates in recent and initial years are similar to the base models. Similarly, the annual fishing mortality rate, survey catchabilties and fishery and survey selectivity estimates are similar for the base models, but often somewhat lower when M=0.1 is assumed (Table N7; Figures N12 and N13). The similar spawning biomass estimates of the base and alternative model reflect that the lower survey catchability and selectivity parameters in the alternative model are being balanced by the higher natural mortality rate. In addition, a much lower steepness for the stock-recruitment function was estimated by the alternative model than the base model, but the unexploited biomass estimates were similar. The worse fit of the lower steepness estimate in combination with higher recruitment estimates at lower spawning stock sizes is reflected in the higher objective function value for the component corresponding to recruitment deviations (Table N8; Figure N14).

Diagnostics

Residual patterns for catch and autumn and spring surveys are not noticeably different among the base and alternative models (Figure N15) which is also reflected in the similar values for the corresponding objective function components. Likewise, the recruitment residuals largest in magnitude are often slightly larger for the alternative model which results in a somewhat larger corresponding objective function component for that model.

Differences between predicted and observed landings and survey age composition are similar between the base and alternative models (Figure N16). In view of the objective function component for the survey age composition the alternative model fits these observations somewhat better (Table N8).

5.0 Biological Reference Points

For the 2008 GARM on biological reference points, we re-evaluated the reference points, the methods for calculating the reference points and the current status of the population relative to those reference points. We used AGEPRO (AGEPRO 2005) to determine median SB(50%MSP) under a few alternative scenarios. Ultimately, the review panel recommended using a projection approach that assumed future recruitment was drawn from the distribution of recruitments between 1969 and present as estimated using the base ASAP model where age composition data are available and the CV for recruitment residuals is assumed 0.8 (O'Boyle et al. 2008b). The same class of reference points, F(50%MSP) and SB(50%MSP), as the 2005 GARM were also recommended. We calculated the F(50%MSP) using a yield-per-recruit analysis (YPR 2007) with the same weight- and maturity-at-age estimates and natural mortality assumption used in the ASAP fits and the estimated fishery selectivity resulting from those fits (i.e., base and alternative models).

For AGEPRO projection scenarios, we used 10 draws of numbers-at-age vectors in 2007 from the posterior distribution provided by the ASAP fits and we projected 300 years forward with 100 simulations per numbers-at-age vector. In this approach, the annual spawning biomass and fishing mortality still vary to some degree after convergence, so we use the average of the yearly median values after convergence (over 200 yearly values) as the reference point estimates.

The fishing mortality rate and spawning biomass-per-recruit at 50%MSP are similar whether 2007 data are included or not and the fishing mortality rate is also similar to that provided at the 2005 GARM, but spawning biomass-per-recruit estimates were different from that in the previous assessment due primarily to the revised weight- and maturity-at-age estimates we have used (Table N8). For the alternate model when M=0.1, the fishing mortality reference point is greater and the spawning biomass-per-recruit is lower as would be expected. The spawning biomass reference point and corresponding yield are somewhat greater for the base model when the 2007 data are used which is primarily due to the increased average annual recruitment estimates used in the projection (Figure N17). The spawning biomass reference point using the alternate model (M=0.1) is less than half that of the base model.

The review panel at this final 2008 GARM recommended that the base model be used as the final assessment model for Gulf of Maine-Georges Bank Acadian redfish (see Section 8.0). The panel also recommended that the status of the stock be determined by adjusting the 2007 spawning biomass and fishing mortality rate estimates using the base model for the observed retrospective pattern. Specifically, the spawning biomass and fishing mortality estimates are adjusted for the average relative bias (see also Table N8) so that

$SB_{adjusted}(2007) = SB(2007)/(1+0.361) = 172{,}342$mt

and

$F_{adjusted}(2007) = F(2007)/(1-0.269) = 0.0068$.

When comparing the 2007 spawning biomass and fishing mortality rate estimates to the corresponding reference point estimates (Table N8; Figure N18),

SB(50%MSP) = 271,000mt

and

F(50%MSP) = 0.0377,

The stock is not overfished and overfishing is not occurring.

6.0 Catch and Rebuilding Projections

The same general approach as that for defining the spawning biomass reference point is used here. The exception is that we use 100 draws of numbers-at-age vectors in 2007 from the posterior distribution provided by the ASAP fits and we projected 44 years forward with 1000 simulations per numbers-at-age vector to ensure that estimates in the near term are precise. We also assume catch in 2008 equal to that in 2007. The review panel at this final 2008 GARM recommended that the 2007 numbers-at-age (and ultimately 2007 spawning biomass) be adjusted for the observed retrospective pattern in corresponding estimates in the same manner as the current spawning biomass and fishing mortality are adjusted for stock status (see Section 5.0).

Projected median 2009 catch biomass under the base (and final) ASAP model with status quo fishing mortality (F = 0.007) is 1,277mt and the spawning biomass will be rebuilt to 271,000mt with nearly 50% probability by 2010, greater than 90% probability by 2011 and greater than 99% probability in 2012. At $F(_{50\%MSP}=F_{REBUILD}) = 0.0377$, the median 2009 catch biomass is 8,631mt and the spawning biomass will be rebuilt with greater than 50% probability by 2011, greater than 95% probability by 2013 and greater than 99% probability by 2014.

7.0 Summary

We applied a completely revised forward-projecting statistical catch-at-age assessment model (ASAP) to data and inputs for Gulf of Maine-Georges Bank Acadian redfish stock. We extended the time series of total catch back to 1913 and included discards from 1989 to 2007. We weighted the influence of these data on the total objective function by yearly variance estimates associated with discards for years where these estimates are available. We also weighted yearly spring (1968-2007) and autumn (1963-2007) NEFSC survey indices by sampling design-based variance estimates. Finally, we also revised maturity-at-age and weight-at-age estimates used as inputs in the assessment model.

Due to moderate retrospective patterns exhibited by fits of the base ASAP model, we explored a suite of models where we assumed a range of alternative natural mortality rates and a change in survey catchability and selectivity after 1994. Based on those results, we went forward with estimation of reference points and stock status for the base ASAP model (M = 0.05) and an alternative where the natural mortality rate was assumed to be 0.1. At the final 2008 Groundfish Assessment Review Meeting the review panel recommended using the base model as the final model and adjusting current spawning biomass, fishing mortality and numbers-at-age estimates for the observed retrospective pattern when determining stock status and making catch and rebuilding projections.

The spawning biomass reference point (spawning biomass at 50% maximum spawning potential) estimate under the base model (271,000mt) is slightly greater than that used in the previous assessment (236,700mt). The fishing mortality rate reference point estimate under the base model (0.0377) is similar to that used in the previous assessment (0.04). The adjusted current (2007) spawning biomass estimate is 172,342mt and the adjusted current fishing mortality rate is 0.007. The Acadian redfish stock is not overfished and overfishing is not occurring (Figure N18).

8.0 Panel Discussion

Conclusions

This stock was assessed using a Statistical Catch at Age formulation consistent with the GARM 'models' review which the Panel found to be sufficient for management purposes. It displayed a moderate retrospective pattern which the Panel felt should be adjusted in the stock and rebuilding projections. Consequently, the Rho Adjustment was applied to the 2007 population numbers. This represents the Final formulation as accepted by the Panel, and it lowered the estimate of the 2007 SSB considerably although not enough to change the status from not-over fished.

Two large spikes in fishing mortality were estimated by the model around 1990. It was noted that these were likely due to discard estimates for which there are relatively large coefficients of variation (CV). The Panel considered that the impact of these estimates should be investigated and perhaps more restrictive CVs considered in future analyses.

As requested by the GARM III 'BRP' review, an exploration of the appropriate estimate of natural mortality (M) to use in the model was undertaken by observing how the model fit changes over a range of Ms. Based on goodness-of-fit criteria, M = 0.05 was chosen. It was noted that this is similar to the M used for Icelandic redfish while estimates of M for Pacific

Ocean Perch are slightly higher (0.5 – 1.0). While the Panel was concerned about the choice of a low estimate of M and encouraged further research on its estimation, it noted that the estimate of MSY was fairly robust to the assumption of M.

Research Recommendations

Dimorphic growth in this stock is fairly substantial with females growing faster than males. The use of female weights at age in the stock and rebuilding projections may result in overly optimistic rates of recovery although the implications for the BRPs would also have to be considered. The Panel recommends that the sensitivity of BRPs and stock projections to the weights at age should be investigated.

The Panel had difficulty interpreting the model residual plots and recommended alternative graphical approaches.

The Panel was concerned about this choice of a relatively low value for natural mortality and was suggested that consideration be given to M estimates from other redfish stocks as well as further exploration of existing data on this stock. Specifically, it noted that the data provide a unique opportunity to examine year – class specific M as recent catches have been very low.

9.0 References

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Table N1. Nominal redfish catches (metric tons), actual and standardized catch per unit effort, calculated standardized USA and total effort and estimated discards for the Gulf of Maine-Georges Bank Acadian redfish fishery.

	Nominal Catch (Metric tons)			USA Catch per Unit Effort (tons/day)		Calculated Standard Effort (days fished)		Estimated		Total
Year	USA	Others	Total	Actual	Standard	USA	Total	Discards (mt)	CV	Removals (mt)
1913	7		7							7
1914	30		30							30
1915	40		40							40
1916	53		53							53
1917	82		82							82
1918	73		73							73
1919	25		25							25
1920	31		31							31
1921	13		13							13
1922	9		9							9
1923	7		7							7
1924	40		40							40
1925	25		25							25
1926	30		30							30
1927	30		30							30
1928	57		57							57
1929	34		34							34
1930	54		54							54
1931	108		108							108
1932	60		60							60
1933	120		120							120
1934	519		519							519
1935	7549		7549							7549
1936	23162		23162							23162
1937	14823		14823							14823
1938	20640		20640							20640
1939	25406		25406							25406
1940	26762		26762							26762
1941	50796		50796							50796
1942	55892		55892	6.9	6.9	8100	8100			55892
1943	48348		48348	6.7	6.7	7216	7216			48348
1944	50439		50439	5.4	5.4	9341	9341			50439
1945	37912		37912	4.5	4.5	8425	8425			37912
1946	42423		42423	4.7	4.7	9026	9026			42423
1947	40160		40160	4.9	4.9	8196	8196			40160
1948	43631		43631	5.4	5.4	8080	8080			43631
1949	30743		30743	3.3	3.3	9316	9316			30743
1950	34307		34307	4.1	4.1	8368	8368			34307
1951	30077		30077	4.1	4.1	7336	7336			30077
1952	21377		21377	3.5	3.4	6287	6287			21377
1953	16791		16791	3.8	3.6	4664	4664			16791
1954	12988		12988	3.4	3.1	4190	4190			12988
1955	13914		13914	4.5	4.0	3479	3479			13914
1956	14388		14388	4.4	3.8	3786	3786			14388
1957	18490		18490	4.3	3.6	5136	5136			18490
1958	16043	4	16047	4.4	3.6	4456	4458			16047
1959	15521		15521	4.3	3.5	4435	4435			15521
1960	11373	2	11375	3.8	3.0	3791	3792			11375
1961	14040	61	14101	4.6	3.5	4011	4029			14101
1962	12541	1593	14134	5.4	4.0	3135	3534			14134

1963	8871	1175	10046	4.1	3.0	2957	3349			10046
1964	7812	501	8313	4.3	2.9	2694	2867			8313
1965	6986	1071	8057	7.0	4.4	1588	1831			8057
1966	7204	1365	8569	11.7	6.4	1126	1339			8569
1967	10442	422	10864	12.4	5.6	1865	1940			10864
1968	6578	199	6777	14.7	6.1	1078	1111			6777
1969	12041	414	12455	11.4	4.9	2457	2542			12455
1970	15534	1207	16741	9.0	4.0	3884	4185			16741
1971	16267	3767	20034	7.0	3.2	5083	6261			20034
1972	13157	5938	19095	5.7	2.9	4537	6584			19095
1973	11954	5406	17360	5.3	2.9	4122	5986			17360
1974	8677	1794	10471	5.0	2.6	3337	4027			10471
1975	9075	1497	10572	4.0	2.2	4125	4805			10572
1976	10131	565	10696	4.6	2.3	4405	4650			10696
1977	13012	211	13223	4.9	2.5	5205	5289			13223
1978	13991	92	14083	4.8	2.4	5830	5868			14083
1979	14722	33	14755	3.6	1.9	7748	7766			14755
1980	10085	98	10183	3.2	1.6	6303	6364			10183
1981	7896	19	7915	2.7	1.4	5640	5654			7915
1982	6735	168	6903	2.7	1.5	4490	4602			6903
1983	5215	113	5328	2.1	1.2	4346	4440			5328
1984	4722	71	4793	1.9	1.1	4293	4357			4793
1985	4164	118	4282	1.4	0.9	4627	4758			4282
1986	2790	139	2929	1.0	0.6	4650	4882			2929
1987	1859	35	1894	1.1	0.7	2656	2706			1894
1988	1076	101	1177	0.9	0.5	2152	2354			1177
1989	628	9	637	1.1	0.6	1047	1062	32	0.62	669
1990	588	13	601	**	**			38	0.49	639
1991	525		525	**	**			1514	0.74	2039
1992	849		849	**	**			129	0.30	978
1993	800		800	**	**			246	0.53	1046
1994	440		440	**	**			106	2.60	546
1995	440		440	**	**			191	0.47	631
1996	322		322	**	**			367	0.37	689
1997	251		251	**	**			181	0.44	432
1998	320		320	**	**			266	0.97	586
1999	353		353	**	**			30	0.51	383
2000	319		319	**	**			169	0.48	488
2001	360		360	**	**			368	0.33	728
2002	368		368	**	**			126	0.37	494
2003	361		361	**	**			203	0.19	564
2004	398		398	**	**			125	0.18	523
2005	564		564	**	**			101	0.15	665
2006	499		499	**	**			149	0.24	648
2007	787		787	**	**			373	0.34	1160

** CPUE and effort not calculated due to sharp reduction in directed redfish trips

Table N2. Number of length and age measurements by year and quarter and annual landings and number of samples for Gulf of Maine-Georges Bank Acadian redfish between 1969-1985.

	Number of length measurements				Number of age measurements						
Year	1	2	3	4	1	2	3	4	Annual Landings (mt)	Number of samples	Landings per sample
1969	200	1000	2000	0	40	178	398	0	12455	14	890
1970	200	900	1100	100	40	180	241	0	16741	18	930
1971	1196	2399	3201	1000	160	359	279	181	20034	34	589
1972	100	3026	1659	300	20	631	350	65	19095	16	1193
1973	1401	3141	1405	299	264	467	204	67	17360	23	755
1974	2407	2518	2217	803	263	335	251	162	10471	34	308
1975	2558	3097	916	300	411	494	198	46	10572	27	392
1976	1200	2747	2523	1624	234	278	252	261	10696	24	446
1977	3398	2148	2322	627	227	239	273	125	13223	31	427
1978	2470	1423	869	731	434	214	201	162	14083	30	469
1979	1132	1693	3569	2581	213	225	310	377	14755	35	422
1980	1308	1964	1385	201	292	418	354	45	10183	21	485
1981	800	1704	703	511	198	375	175	103	7915	21	377
1982	1262	1020	1321	613	246	186	284	131	6903	27	256
1983	1351	1020	1717	1012	295	195	284	220	5328	31	172
1984	1552	1959	624	609	353	448	84	133	4793	26	184
1985	931	1345	1808	1691	223	330	468	443	4282	37	116

Table N3. Estimated catch-per-tow, average weight and average length of Gulf of Main-Georges Bank Acadian redfish for all inshore and offshore strata (24, 26-30, 36-40) in the spring NEFSC bottom trawl survey.

Year	Numbers/tow	CV	Biomass (kg)/tow	CV	Mean weight (kg)	CV	Mean length (cm)	CV
1968	45.18	0.45	17.09	0.34	0.38	0.29	26.22	0.09
1969	46.43	0.26	19.69	0.29	0.42	0.10	28.64	0.04
1970	54.72	0.67	18.93	0.53	0.35	0.15	26.24	0.04
1971	157.23	0.28	71.56	0.30	0.46	0.07	29.54	0.02
1972	101.22	0.51	44.36	0.50	0.44	0.03	28.56	0.01
1973	44.35	0.31	25.30	0.32	0.57	0.07	30.90	0.02
1974	34.31	0.59	18.84	0.66	0.55	0.09	30.21	0.05
1975	38.93	0.32	17.61	0.35	0.45	0.05	28.06	0.02
1976	62.22	0.49	26.19	0.54	0.42	0.11	28.16	0.06
1977	25.06	0.26	11.59	0.26	0.46	0.17	28.90	0.05
1978	23.98	0.20	12.17	0.20	0.51	0.08	29.12	0.03
1979	61.41	0.32	32.21	0.33	0.52	0.07	29.69	0.02
1980	29.81	0.34	20.34	0.34	0.68	0.06	32.11	0.02
1981	33.04	0.69	18.31	0.69	0.55	0.01	30.45	0.01
1982	16.96	0.39	9.41	0.37	0.55	0.15	29.84	0.06
1983	9.85	0.36	6.07	0.41	0.62	0.11	30.37	0.04
1984	4.96	0.32	2.68	0.33	0.54	0.12	29.41	0.04
1985	11.72	0.39	6.61	0.40	0.56	0.08	29.99	0.03
1986	5.27	0.27	3.22	0.32	0.61	0.09	31.00	0.04
1987	24.50	0.80	12.93	0.84	0.53	0.05	30.25	0.02
1988	8.09	0.49	3.27	0.47	0.40	0.10	27.23	0.04
1989	7.81	0.28	2.98	0.36	0.38	0.14	25.85	0.06
1990	12.34	0.36	6.81	0.43	0.55	0.08	30.18	0.03
1991	9.47	0.32	4.26	0.38	0.45	0.14	27.23	0.07
1992	37.86	0.41	10.67	0.41	0.28	0.11	25.30	0.03
1993	35.50	0.45	17.50	0.50	0.49	0.07	29.33	0.02
1994	16.14	0.58	3.92	0.63	0.24	0.10	23.50	0.05
1995	7.23	0.32	1.92	0.40	0.27	0.27	22.86	0.09
1996	28.74	0.46	11.89	0.64	0.41	0.21	27.19	0.08
1997	212.02	0.77	34.04	0.71	0.16	0.11	21.20	0.02
1998	34.67	0.33	7.84	0.33	0.23	0.04	23.40	0.01
1999	76.05	0.33	19.02	0.29	0.25	0.14	23.92	0.04
2000	180.09	0.55	56.01	0.58	0.31	0.07	25.88	0.02
2001	101.61	0.46	37.97	0.54	0.37	0.12	27.61	0.04
2002	225.18	0.68	61.21	0.63	0.27	0.10	25.32	0.03
2003	109.15	0.41	33.34	0.43	0.31	0.04	26.03	0.02
2004	152.30	0.38	55.67	0.43	0.37	0.07	27.14	0.02
2005	145.34	0.53	46.26	0.53	0.32	0.06	26.24	0.02
2006	34.70	0.35	10.33	0.34	0.30	0.13	25.58	0.04
2007	122.25	0.33	35.10	0.35	0.29	0.11	25.32	0.03

Table N4. Estimated catch-per-tow, average weight and average length of Gulf of Main-Georges Bank Acadian redfish for all inshore and offshore strata (24, 26-30, 36-40) in the autumn NEFSC bottom trawl survey.

Year	Numbers/tow	CV	Biomass (kg)/tow	CV	Mean weight (kg)	CV	Mean length (cm)	CV
1963	87.34	NA	24.11	NA	0.28	NA	25.04	NA
1964	116.26	0.68	53.64	0.75	0.46	0.09	29.66	0.06
1965	57.00	0.23	13.20	0.37	0.23	0.22	21.53	0.08
1966	93.84	0.34	29.27	0.45	0.31	0.16	24.27	0.07
1967	100.59	0.34	24.37	0.37	0.24	0.17	23.04	0.06
1968	143.45	0.41	40.43	0.43	0.28	0.07	24.76	0.03
1969	71.23	0.24	23.76	0.26	0.33	0.10	25.88	0.04
1970	93.98	0.23	32.96	0.19	0.35	0.12	26.12	0.04
1971	48.00	0.19	23.42	0.22	0.49	0.07	29.21	0.02
1972	55.57	0.17	24.63	0.19	0.44	0.05	28.40	0.02
1973	39.16	0.16	17.03	0.18	0.43	0.05	28.32	0.02
1974	48.30	0.22	24.16	0.30	0.50	0.13	28.47	0.05
1975	74.84	0.22	39.95	0.29	0.53	0.11	29.57	0.04
1976	28.85	0.31	15.29	0.39	0.53	0.12	29.71	0.05
1977	40.39	0.19	17.25	0.15	0.43	0.12	27.49	0.04
1978	45.21	0.17	20.74	0.16	0.46	0.05	28.67	0.02
1979	28.89	0.21	15.98	0.21	0.55	0.06	30.35	0.02
1980	20.58	0.28	12.63	0.31	0.61	0.10	30.68	0.03
1981	20.36	0.32	12.24	0.32	0.60	0.09	31.44	0.03
1982	9.18	0.46	3.48	0.27	0.38	0.27	26.31	0.09
1983	10.04	0.21	4.12	0.23	0.41	0.09	27.17	0.03
1984	7.77	0.42	3.93	0.38	0.51	0.08	28.86	0.02
1985	13.01	0.32	5.69	0.31	0.44	0.10	27.77	0.04
1986	26.05	0.39	8.01	0.34	0.31	0.13	25.04	0.04
1987	13.72	0.41	5.46	0.32	0.40	0.20	27.14	0.07
1988	12.43	0.41	6.33	0.57	0.51	0.19	27.50	0.06
1989	20.25	0.29	6.81	0.30	0.34	0.15	25.58	0.05
1990	35.53	0.34	12.16	0.33	0.34	0.11	26.01	0.03
1991	19.06	0.34	8.36	0.45	0.44	0.17	28.01	0.05
1992	22.37	0.26	8.09	0.29	0.36	0.09	26.90	0.03
1993	35.62	0.31	11.20	0.33	0.31	0.09	24.90	0.03
1994	20.86	0.32	5.94	0.43	0.28	0.16	24.24	0.05
1995	33.22	0.25	4.65	0.24	0.14	0.11	19.92	0.02
1996	169.64	0.35	30.63	0.33	0.18	0.11	21.83	0.03
1997	65.02	0.30	18.94	0.39	0.29	0.15	24.63	0.05
1998	116.95	0.42	31.72	0.45	0.27	0.08	24.47	0.03
1999	82.48	0.23	22.86	0.24	0.28	0.05	24.87	0.02
2000	104.43	0.27	26.16	0.29	0.25	0.07	24.22	0.03
2001	89.62	0.23	28.17	0.25	0.31	0.05	26.23	0.02
2002	185.19	0.31	41.88	0.33	0.23	0.09	23.77	0.04
2003	250.94	0.47	65.49	0.49	0.26	0.08	25.36	0.02
2004	127.29	NA	36.63	NA	0.29	NA	24.89	NA
2005	166.07	0.21	46.95	0.23	0.28	0.04	25.54	0.02
2006	183.43	0.31	50.22	0.30	0.27	0.05	24.96	0.02
2007	170.03	0.23	50.39	0.25	0.30	0.08	25.59	0.03

Table N5. Further assumptions made for ASAP model implementation for Gulf of Maine-Georges Bank Acadian Redfish.

Unestimated Parameter	Assumed Value
CV NAA in 1913	0.01
CV Catch	0.01 or estimate provided by variance estimation for discards where available
CV Survey Indices	Design-based estimates where available, 0.3 otherwise
CV of Survey/Fishery Selectivity Parameters	0.5
Fishery effective sample size (input)	200
Survey effective sample size (input)	100
Fraction of year at spawning	0.4
Fraction of year at spring survey	0.375
Fraction of year at autumn survey	0.875

Table N6. Objective function components and retrospective statistics for spawning biomass, recruitment, and fully selected fishing mortality for the suite of fitted ASAP models.

	M = 0.025	M = 0.03	M = 0.04	M = 0.05 FINAL MODEL	M = 0.075	M = 0.1	M = 0.15	Split Survey (1995)
Objective Function Components								
Catch (landings + discards)	432.0	432.2	432.9	433.8	436.6	440.0	421.6	437.2
Autumn survey index	523.0	520.6	516.7	513.5	506.7	502.7	506.3	506.2
Spring survey index	476.5	475.3	473.1	471.3	467.5	465.0	467.0	464.8
Landings age composition	916.8	907.6	898.0	893.2	887.9	884.8	883.1	888.8
Survey age composition	2048.5	2046.4	2041.1	2034.9	2022.9	2010.16	2005.0	2017.1
Catch selectivity penalties	106.4	106.8	108.3	110.2	115.8	121.9	132.0	112.5
Survey selectivity penalties	5.8	5.8	6.0	6.2	6.6	7.3	8.4	11.0
Initial numbers-at-age penalty	252.0	255.5	260.9	265.0	272.2	277.2	285.2	264.9
Recruitment deviations	1078.4	1078.8	1089.7	1104.2	1141.4	1177.1	1256.2	1116.0
Other	15.9	15.7	15.4	15.2	14.8	14.7	12.5	14.9
Total	5855.3	5844.9	5842.3	5847.5	5872.4	5900.8	5977.3	5833.3
Retrospective parameter								
Spawning biomass	0.837	0.487	0.419	0.361	0.244	0.147	0.172	0.933
Recruitment	0.288	0.086	0.086	0.053	-0.051	-0.163	0.539	-0.091
Fishing mortality	-0.453	-0.324	-0.295	-0.269	-0.208	-0.148	-0.157	-0.395

Table N7. Parameter estimates from the ASAP base (final) models using data prior to 2007 (left) and including 2007 data (middle) and the ASAP alternate (M = 0.1) model using data from all years (right).

Parameter	Without 2007 Data M = 0.05	With 2007 Data M = 0.05	M = 0.1
Steepness	0.64003	0.65873	0.34356
Unexploited spawning biomass (mt)	643,793	642,383	621,522
Autumn q	0.582012	0.594601	0.457688
Spring q	0.532395	0.542274	0.414501
MSY	10,237	10,491	8,042
SB_{MSY} (mt)	207,580	203,582	265,192
F_{MSY}	0.039110	0.040895	0.024285

Table N8. Recent spawning biomass and fishing mortality estimates (and standard errors in parentheses) from ASAP models. Spawning biomass-per-recruit and fishing mortality at 50% maximum spawning potential (MSP) as estimated using a spawning biomass- and yield-per-recruit analysis (fishery selectivity inputs are estimates from ASAP models). AGEPRO estimates of median spawning biomass (and 95% prediction interval) and yield at F(50%MSP). Spawning biomass and fishing mortality for 2007 for the base (final) model adjusted for retrospective pattern are also given.

	2005 Assessment	Without 2007 Data M = 0.05	With 2007 Data M = 0.05 (Final Model)	M = 0.1
SB(2006)	NA	215,722mt	199,012mt	197,242mt
SB(2007)	NA	NA	234,609mt (19,754mt)	222,619mt (19,177mt)
$SB_{adjusted}$(2007)	NA	NA	172,342mt	NA
F(2006)		0.003	0.0034 (0.0003)	0.0036 (0.0004)
F(2007)	NA	NA	0.0051 (0.0007)	0.0055 (0.0008)
$F_{adjusted}$(2007)	NA	NA	0.0068	NA
SB-per-recruit(50%MSP)	4.1073kg	6.1970kg	6.2021kg	1.9825kg
F(50%MSP)	0.04	0.0387	0.0377	0.0691
SB(50%MSP)	236,700mt	239,309mt	271,000mt	126,000mt
SB 95% prediction interval	NA	169,250-319,700mt	183,600-377,000mt	80,000-182,800mt
Yield(50%MSP)	8,235mt	8,951mt	10,139mt	8,329mt

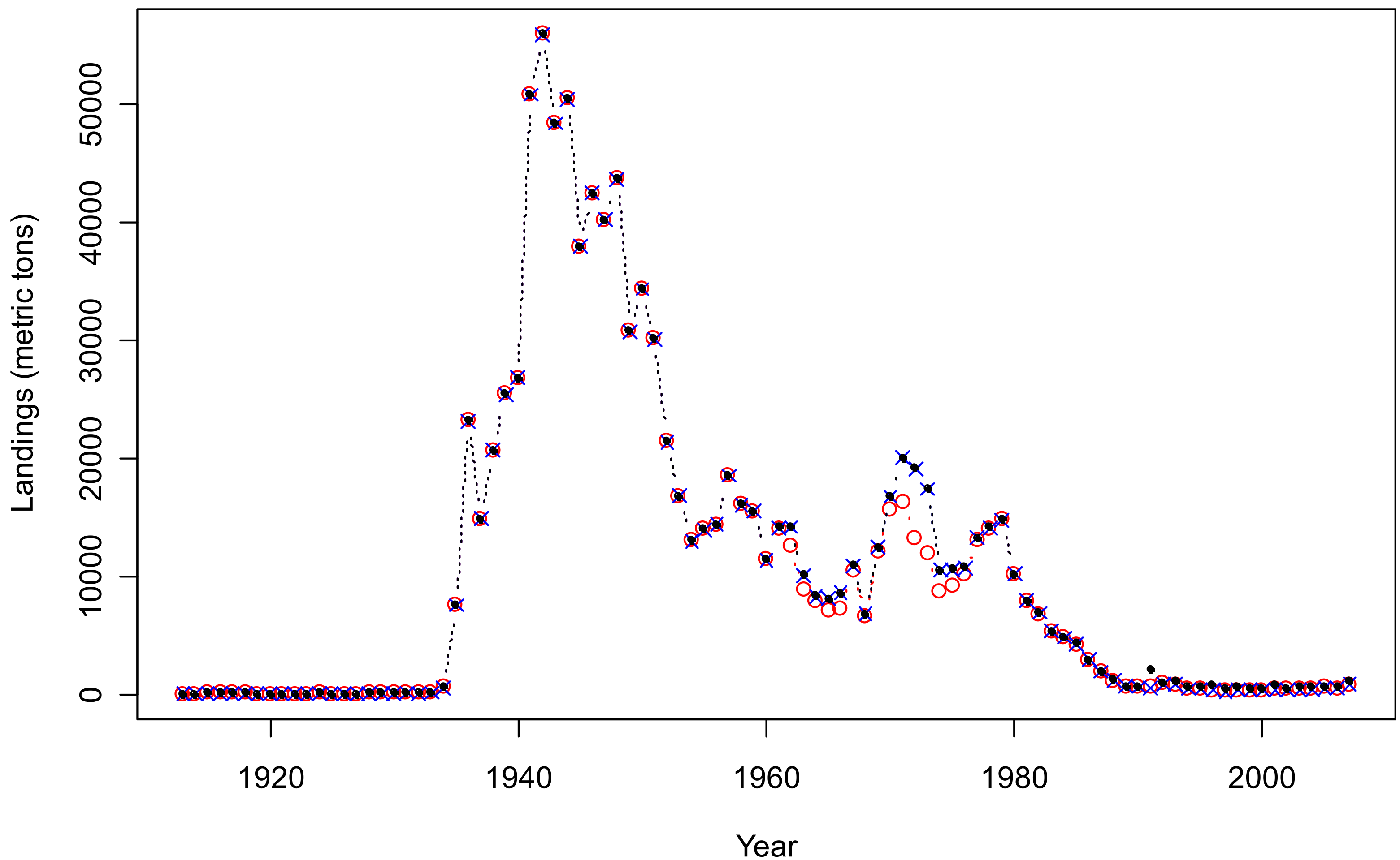

Figure N1. Annual landings (mt) of Gulf of Maine-Georges Bank Acadian redfish between 1913-2007 for US fleet only (red), US and foreign fleets combined (blue) and total landings combined with annual discard estimates between 1989-2007 (black).

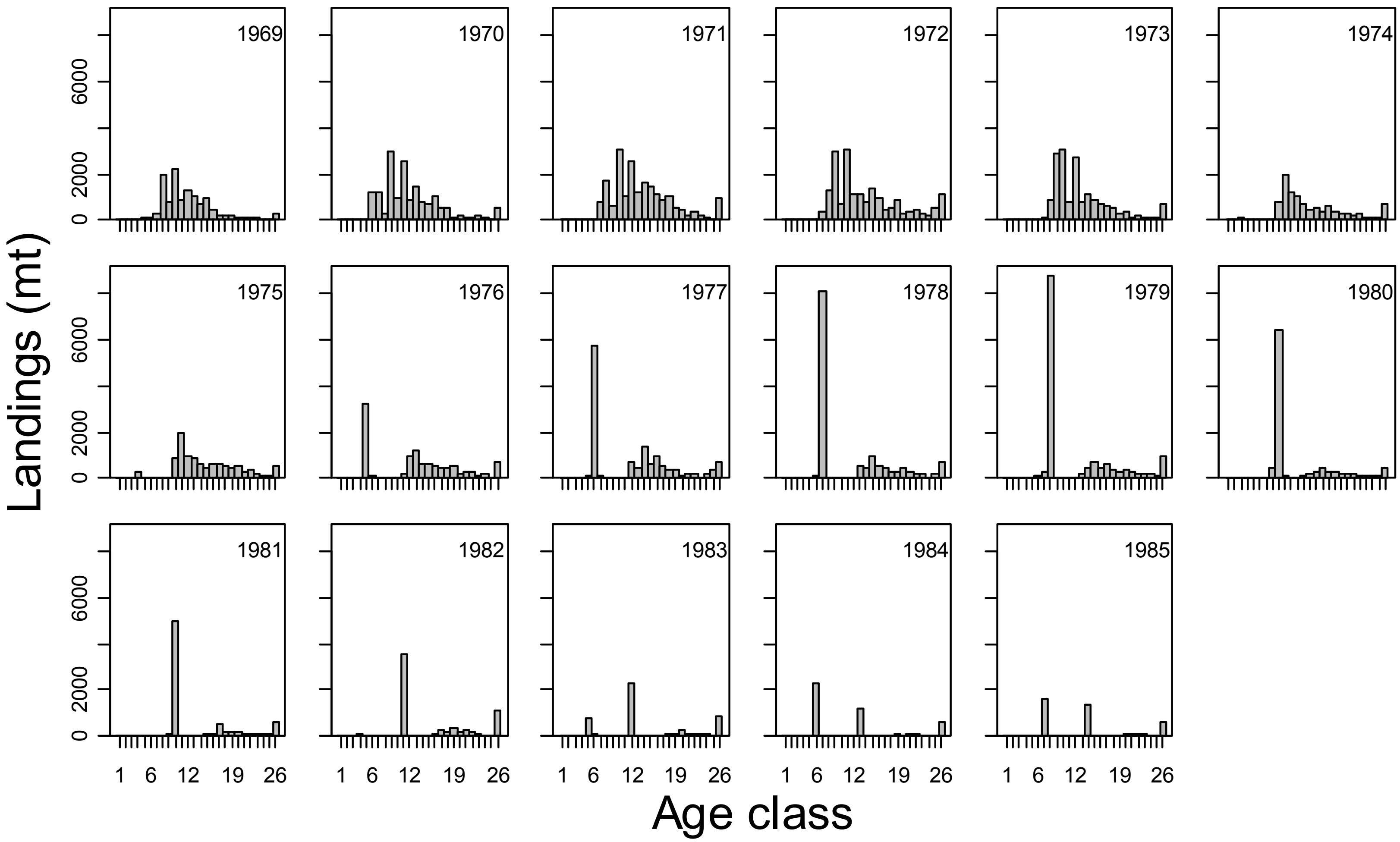

Figure N2. Estimated annual landings (mt) at age for Gulf of Maine-Georges Bank Acadian redfish between 1969-1985.

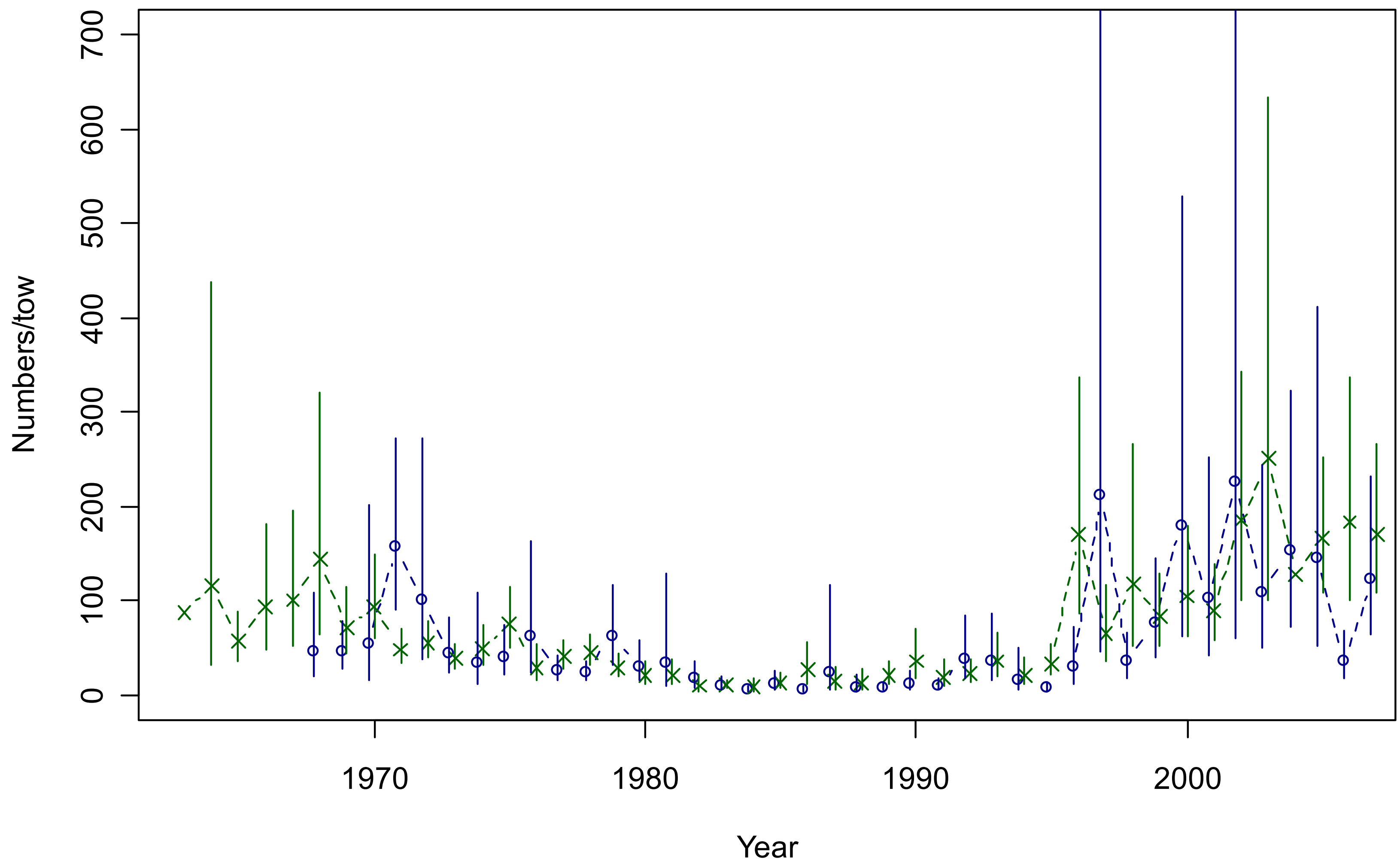

Figure N3. Estimated numbers-per-tow for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC spring (blue, circle) and autumn (green, x) survey over all inshore and offshore strata. Vertical bars represent approximate 95% confidence intervals.

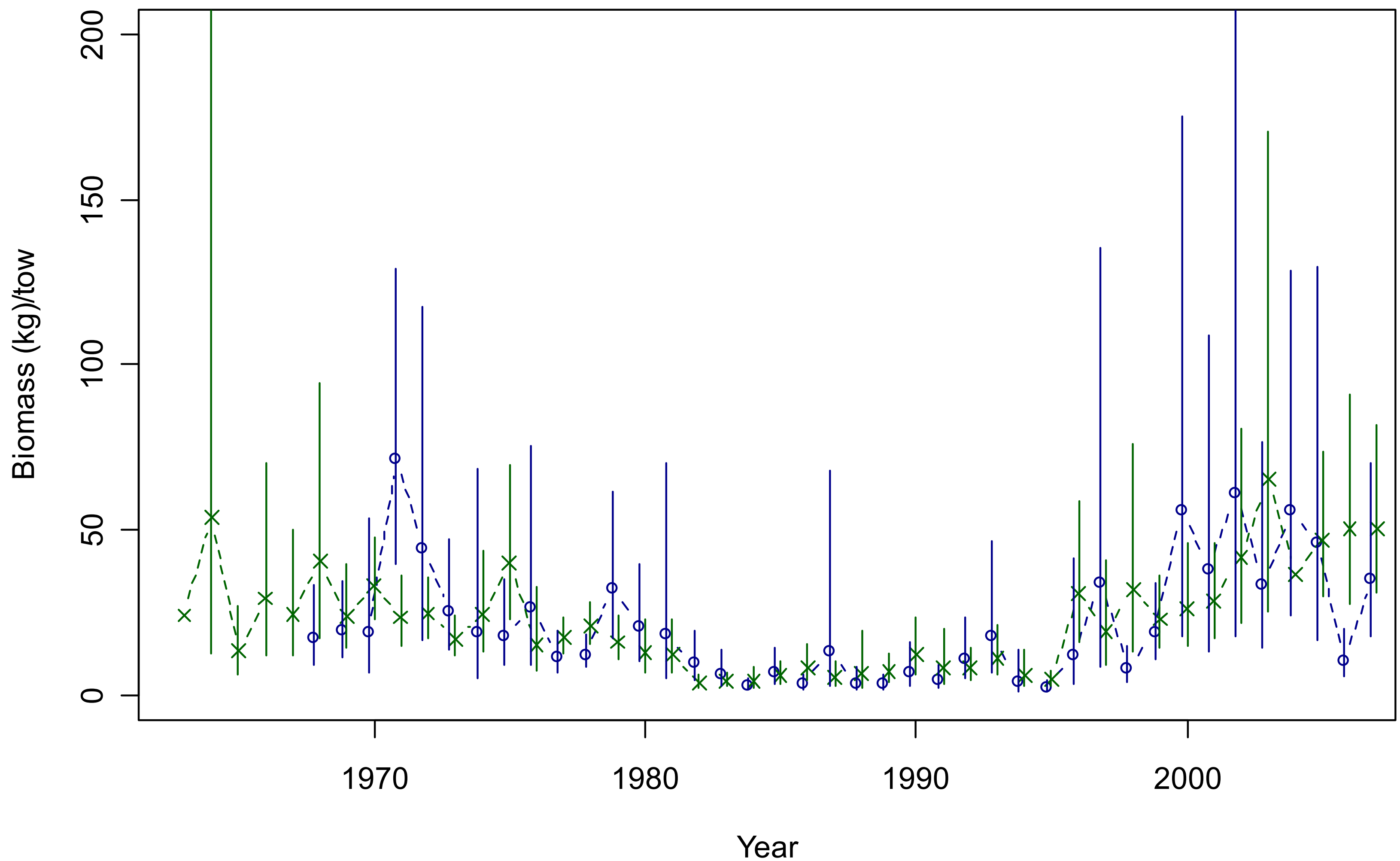

Figure N4. Estimated biomass-per-tow for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC spring (blue, circle) and autumn (green, x) survey over all inshore and offshore strata. Vertical bars represent approximate 95% confidence intervals.

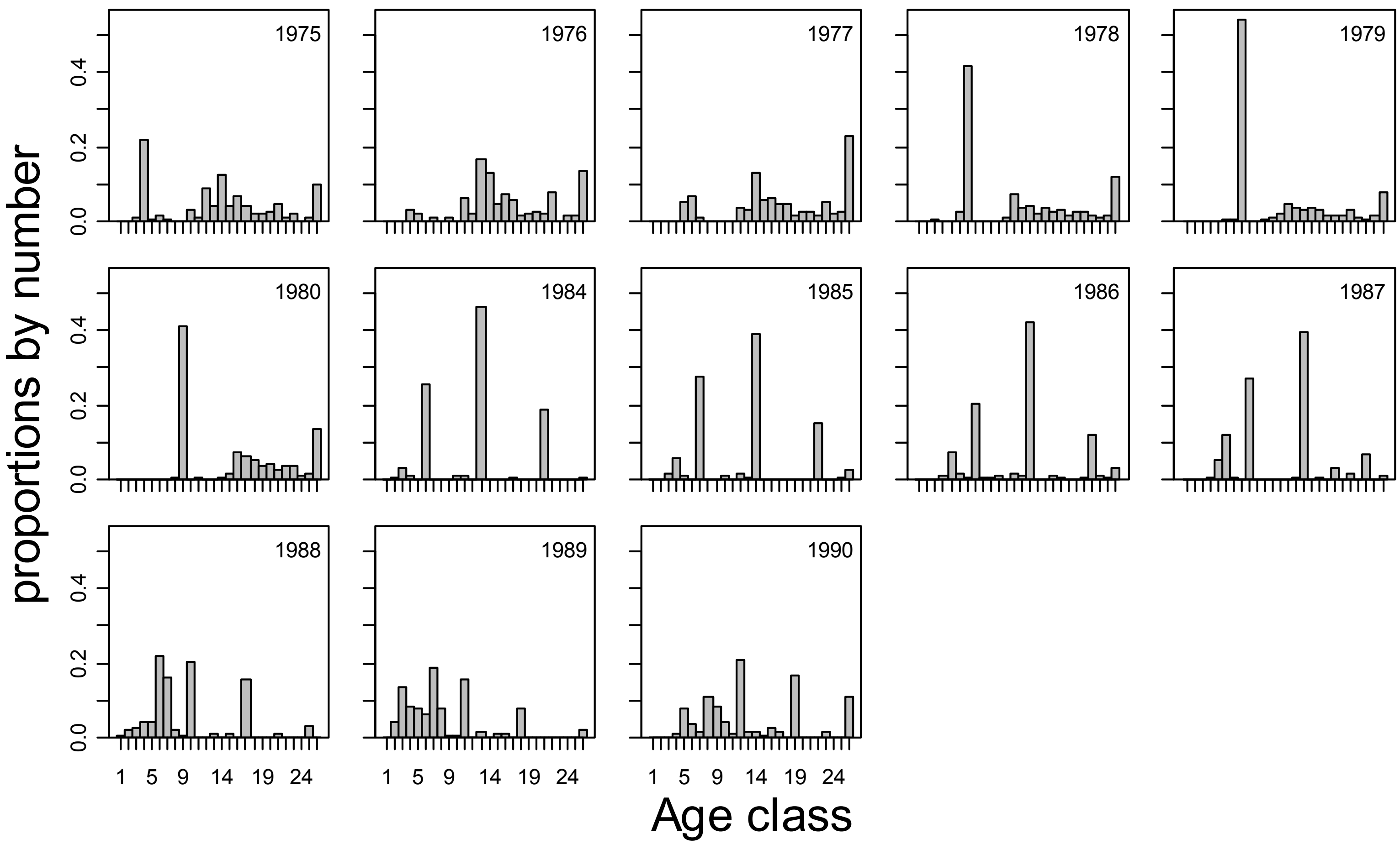

Figure N5. Estimated proportions at age for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC spring survey.

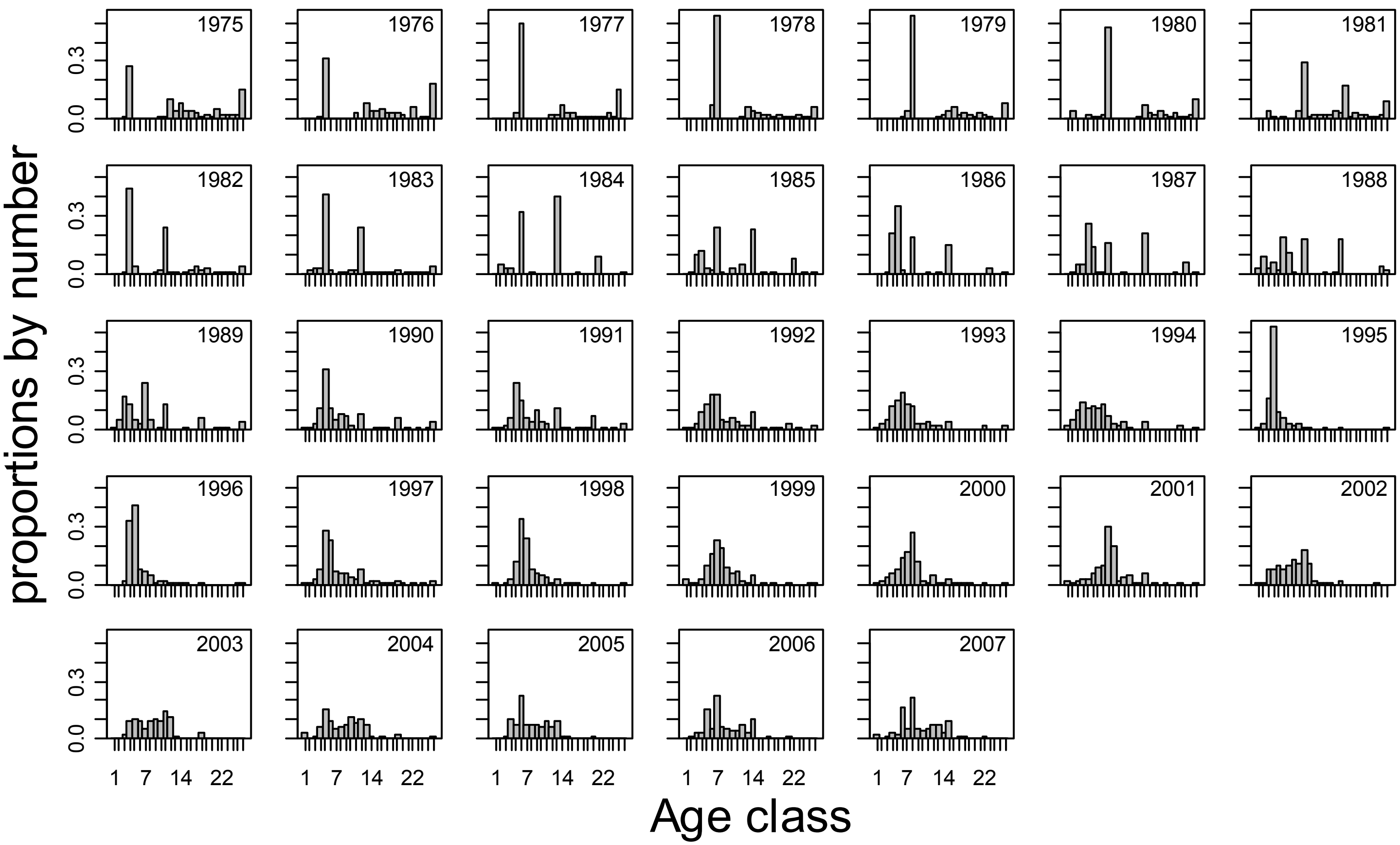

Figure N6. Estimated proportions-at-age for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC autumn survey.

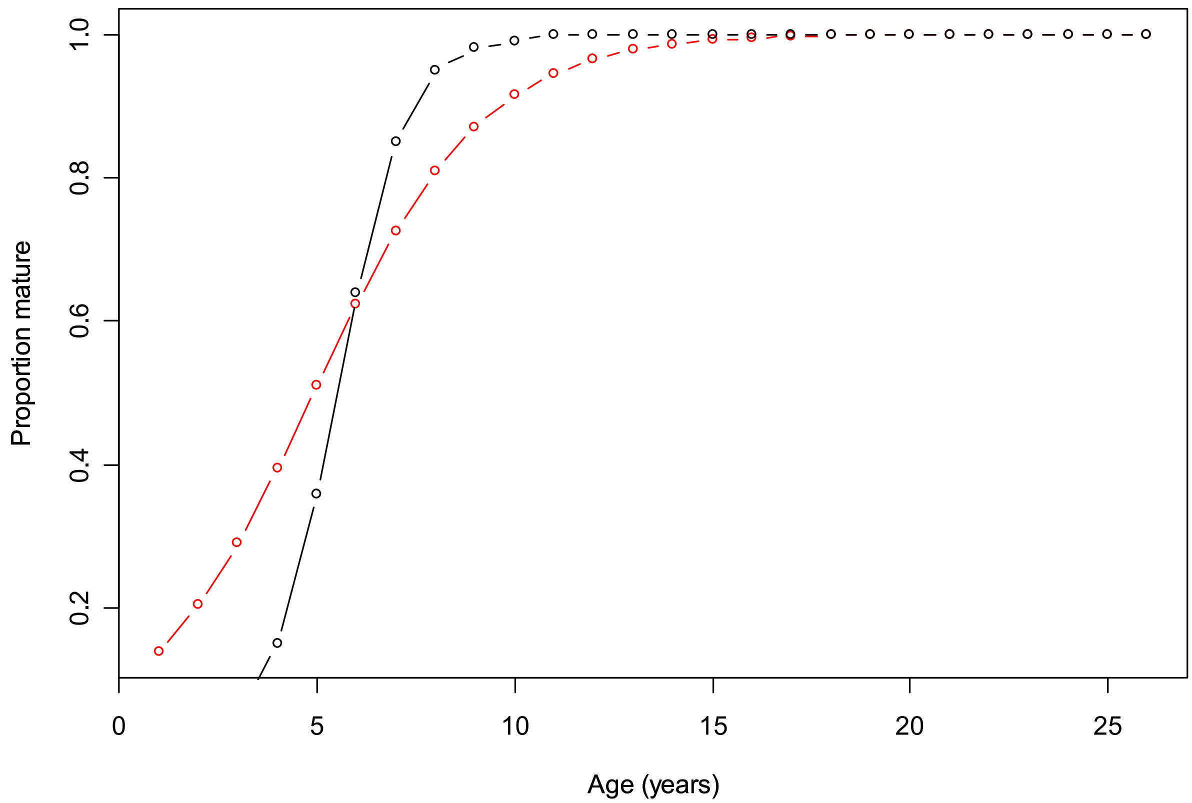

Figure N7. Proportion mature-at-age assumed in previous assessments (black) and estimated for females (red line) maturity and age data from Gulf of Maine-Georges Bank Acadian redfish caught in spring bottom trawl surveys.

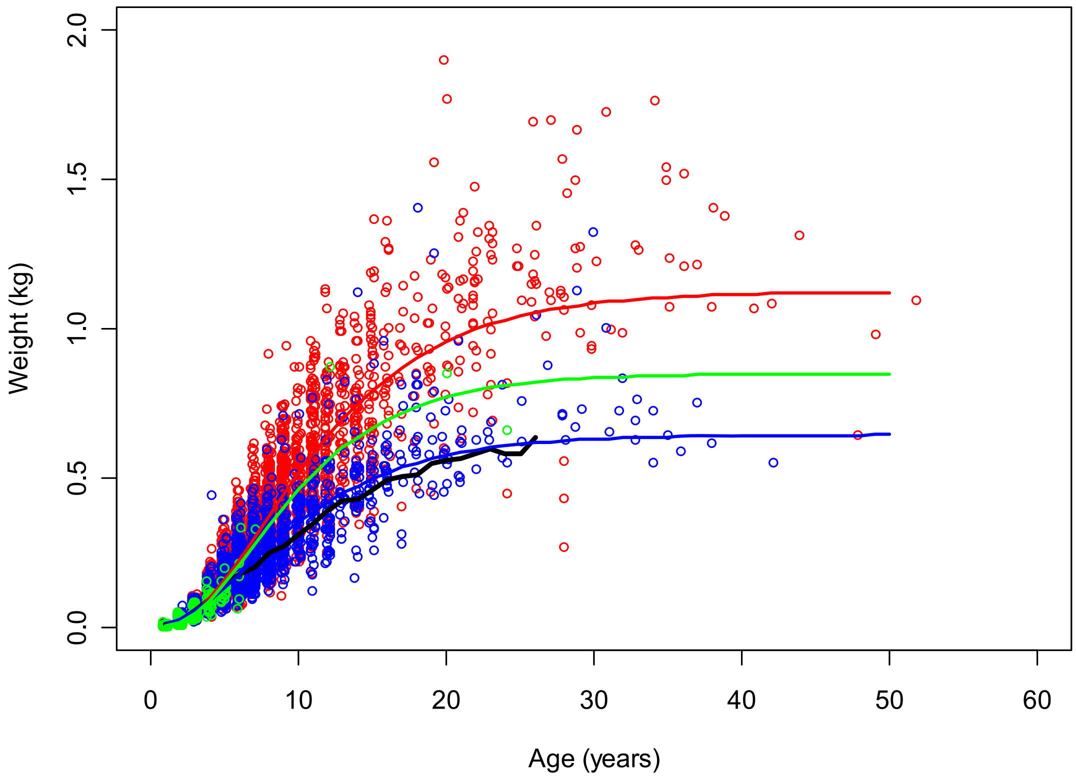

Figure N8. Weight-at-age assumed in previous assessments (black line) and estimated for females (red line), males (blue line) and combined (green line) from length, weight and age data from Gulf of Maine-Georges Bank Acadian redfish caught in bottom trawl surveys. Red, blue and green points represent female, male and unknown sex individuals.

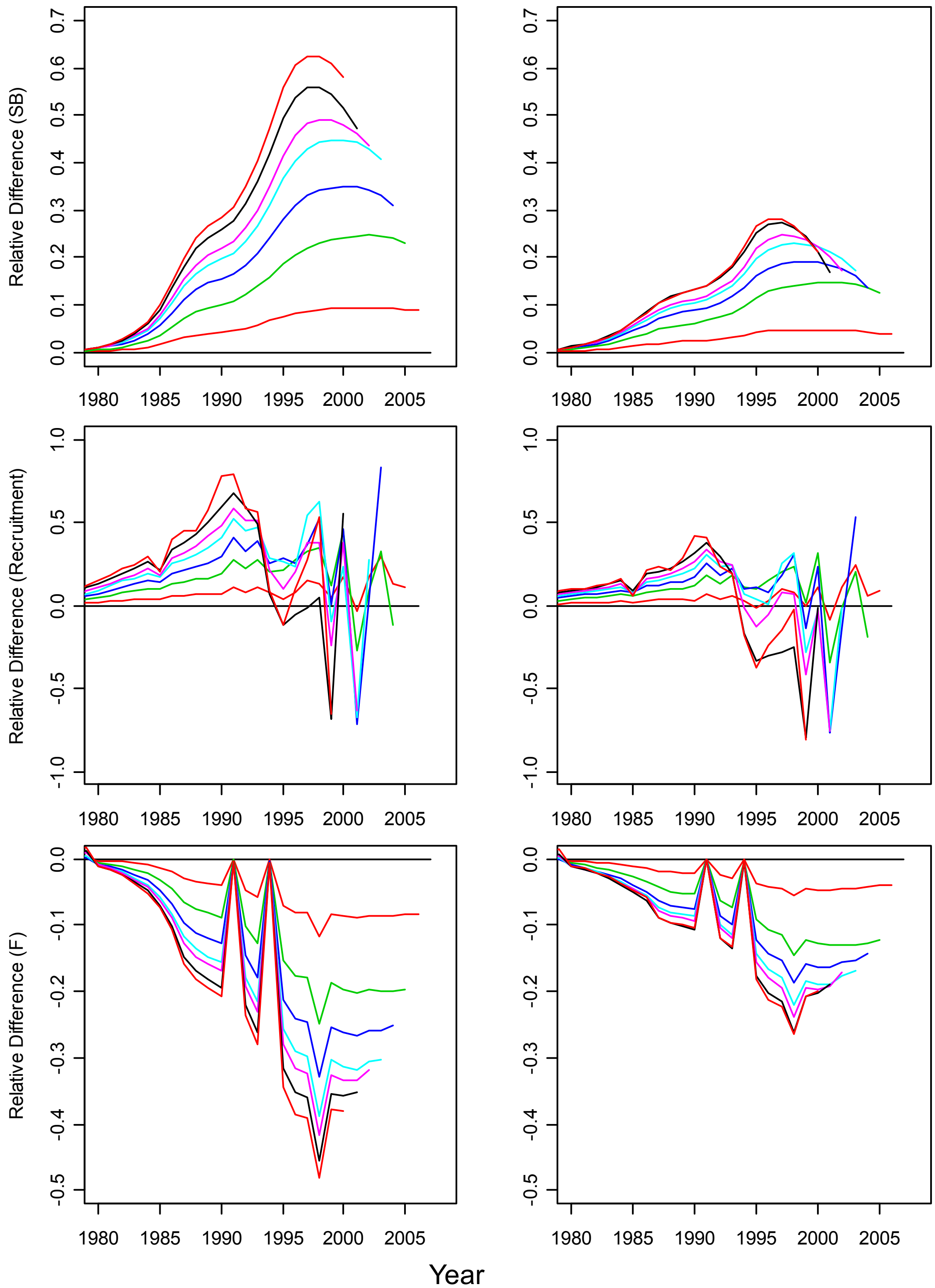

Figure N9. Retrospective patterns for relative differences in spawning biomass (top), recruitment (middle) and fishing mortality (bottom) from the ASAP base (final) model including 2007 data (left) and the ASAP alternate (M = 0.1) model (right).

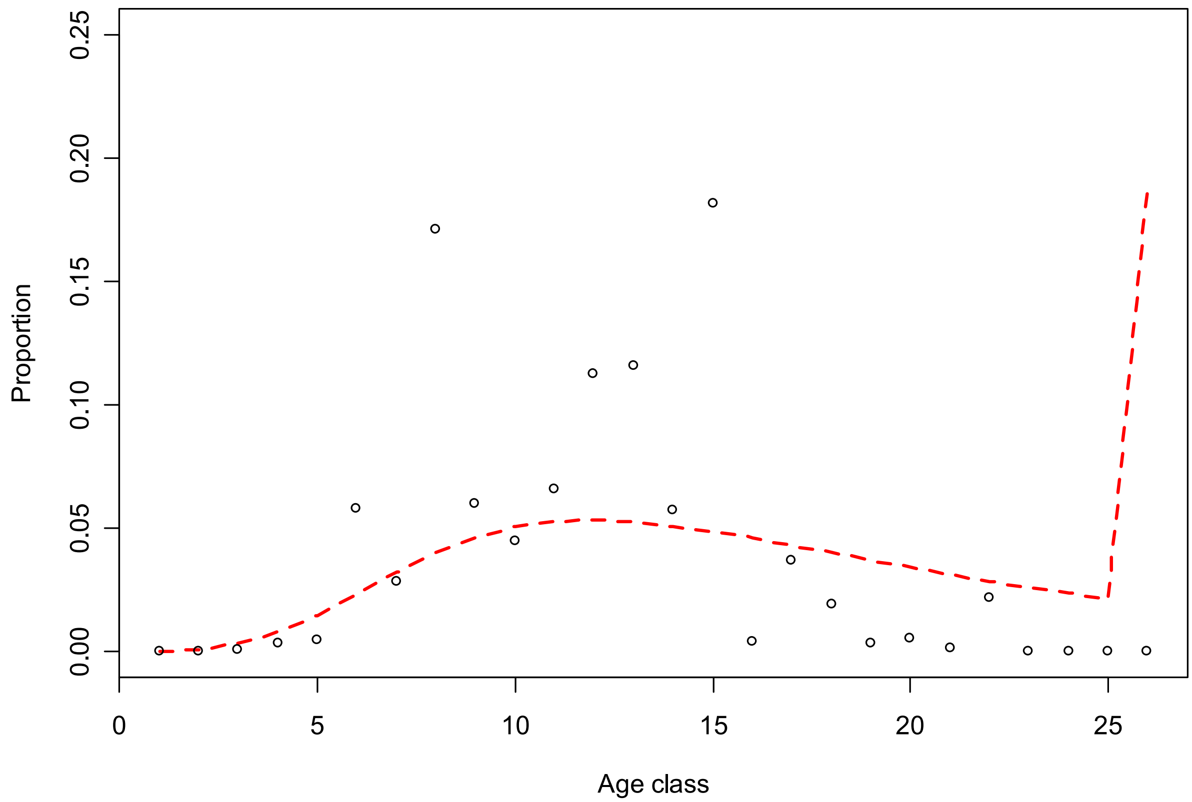

Figure N10. Estimated proportion of biomass-at-age for autumn survey in 2007 (circles) and at equilibrium with M = 0.1, F = 0.01 and selectivity-at-age as estimated under the ASAP model with M = 0.1 (red dashed line).

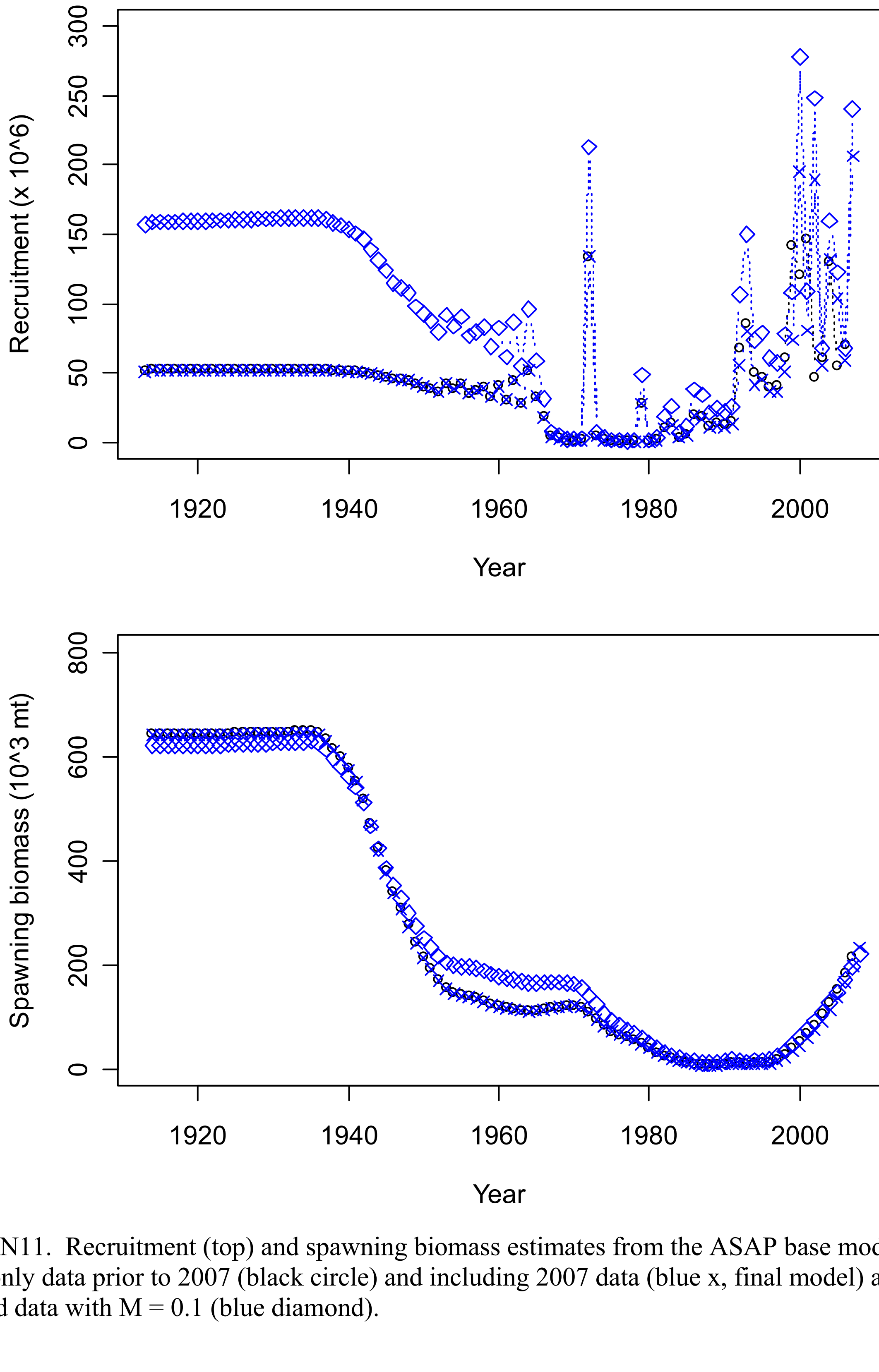

Figure N11. Recruitment (top) and spawning biomass estimates from the ASAP base models using only data prior to 2007 (black circle) and including 2007 data (blue x, final model) and updated data with M = 0.1 (blue diamond).

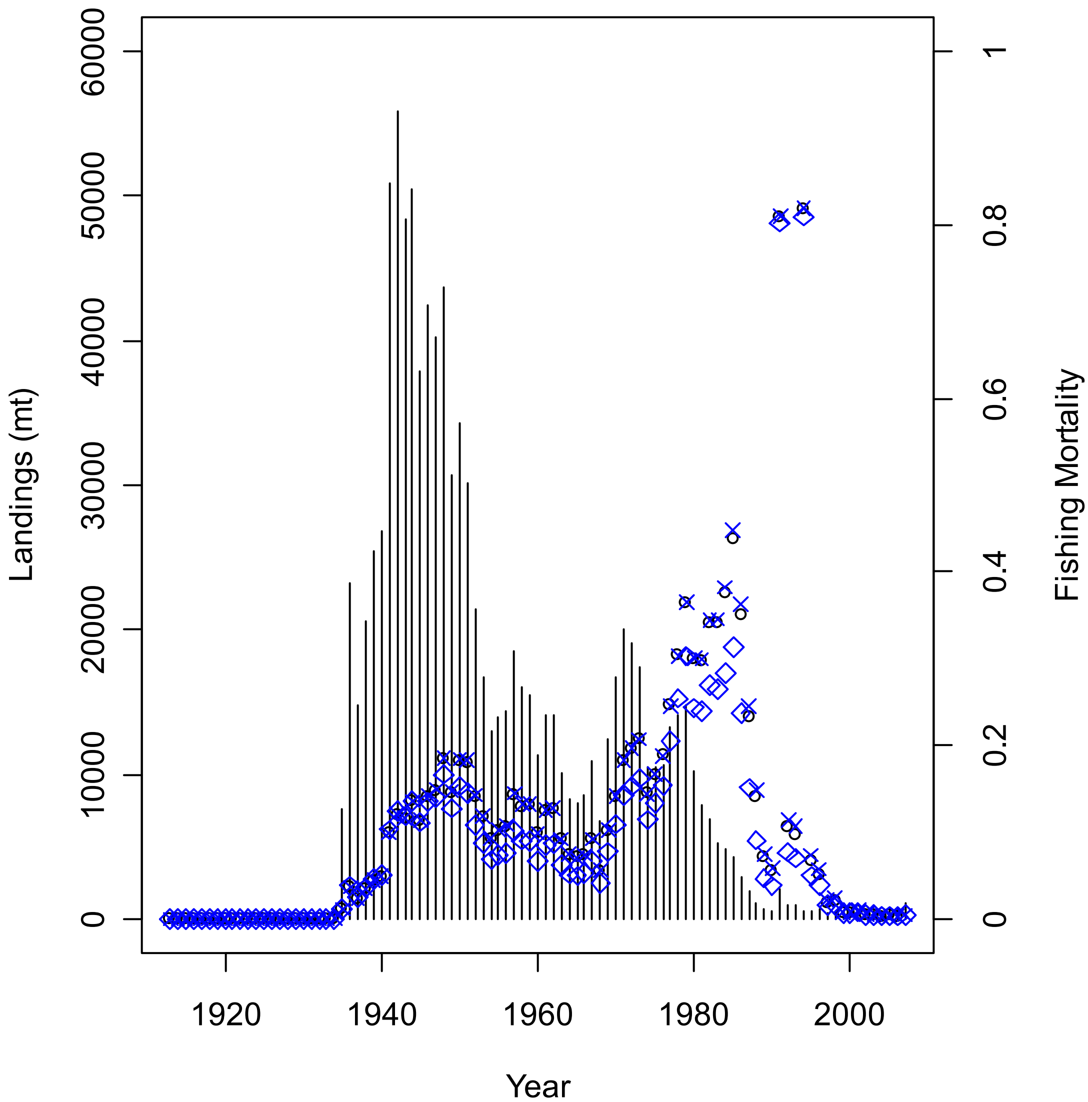

Figure N12. Landings and fully selected fishing mortality estimates from the ASAP base models using only data prior to 2007 (black circle) and including 2007 data (blue x, final model) and updated data with M = 0.1 (blue diamond).

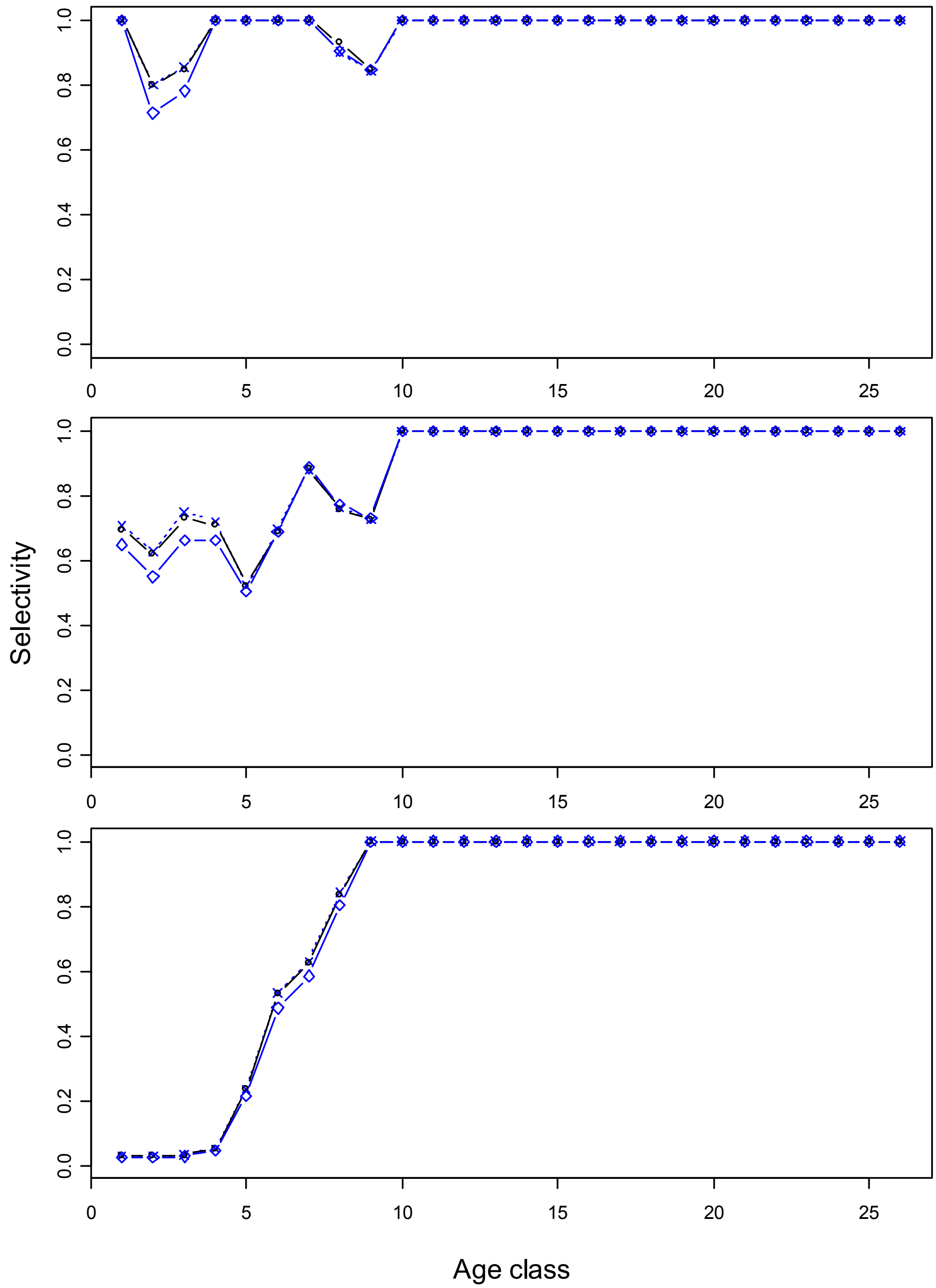

Figure N13. Selectivity-at-age for the NEFSC autumn (top) and spring (middle) surveys and the fishery (bottom) as estimated from the ASAP base models using only data prior to 2007 (black circle) and including 2007 data (blue x, final model) and updated data with M = 0.1 (blue diamond).

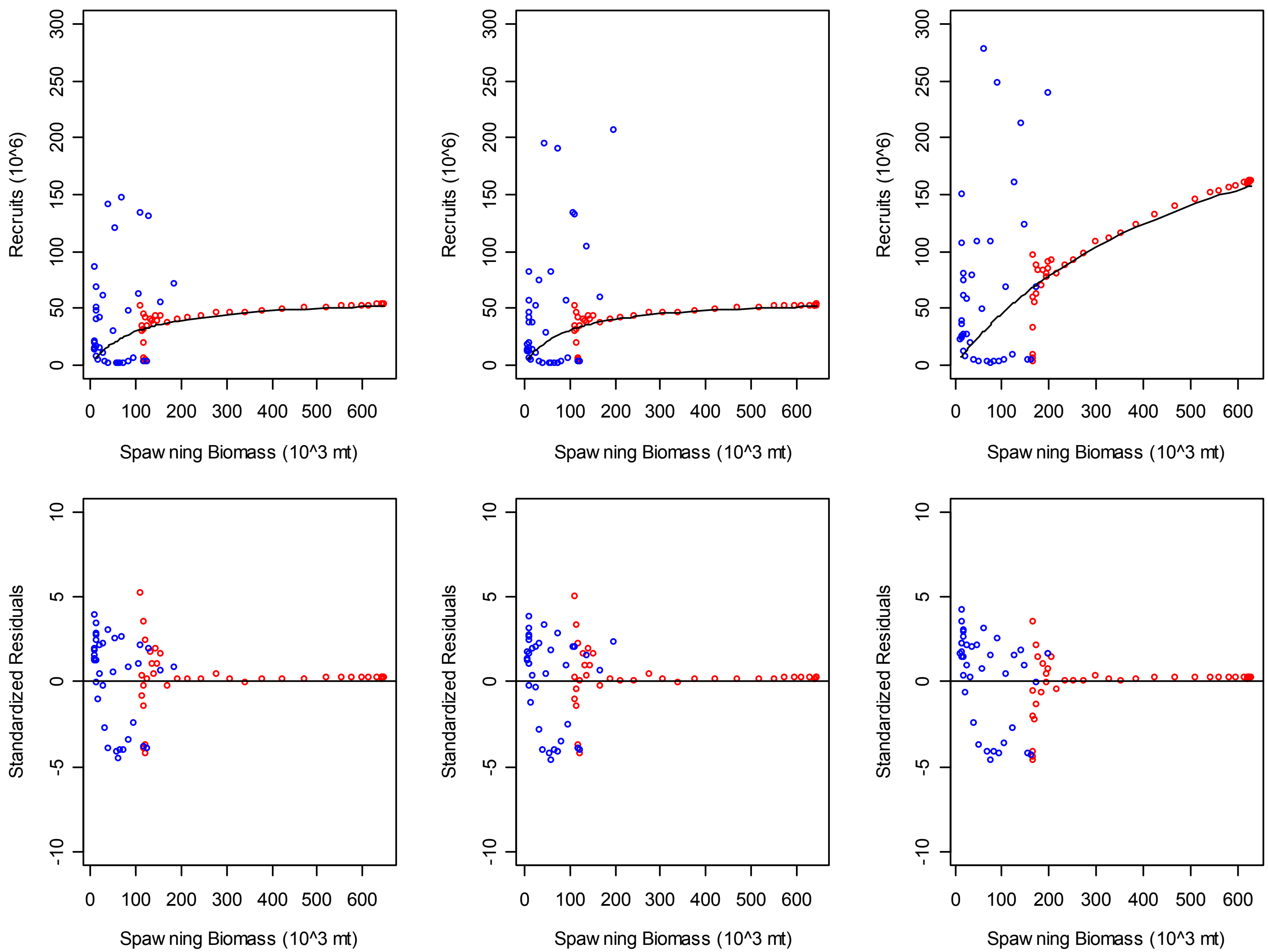

Figure N14. Spawning biomass and recruitment (top) and spawning biomass and standardized recruitment residuals (bottom) from the ASAP base models using data prior to 2007 (left) and including 2007 data (middle, final model) and the ASAP alternate (M = 0.1) model using data from all years (right). The blue and red points are for years where survey age observations are or are not available, respectively.

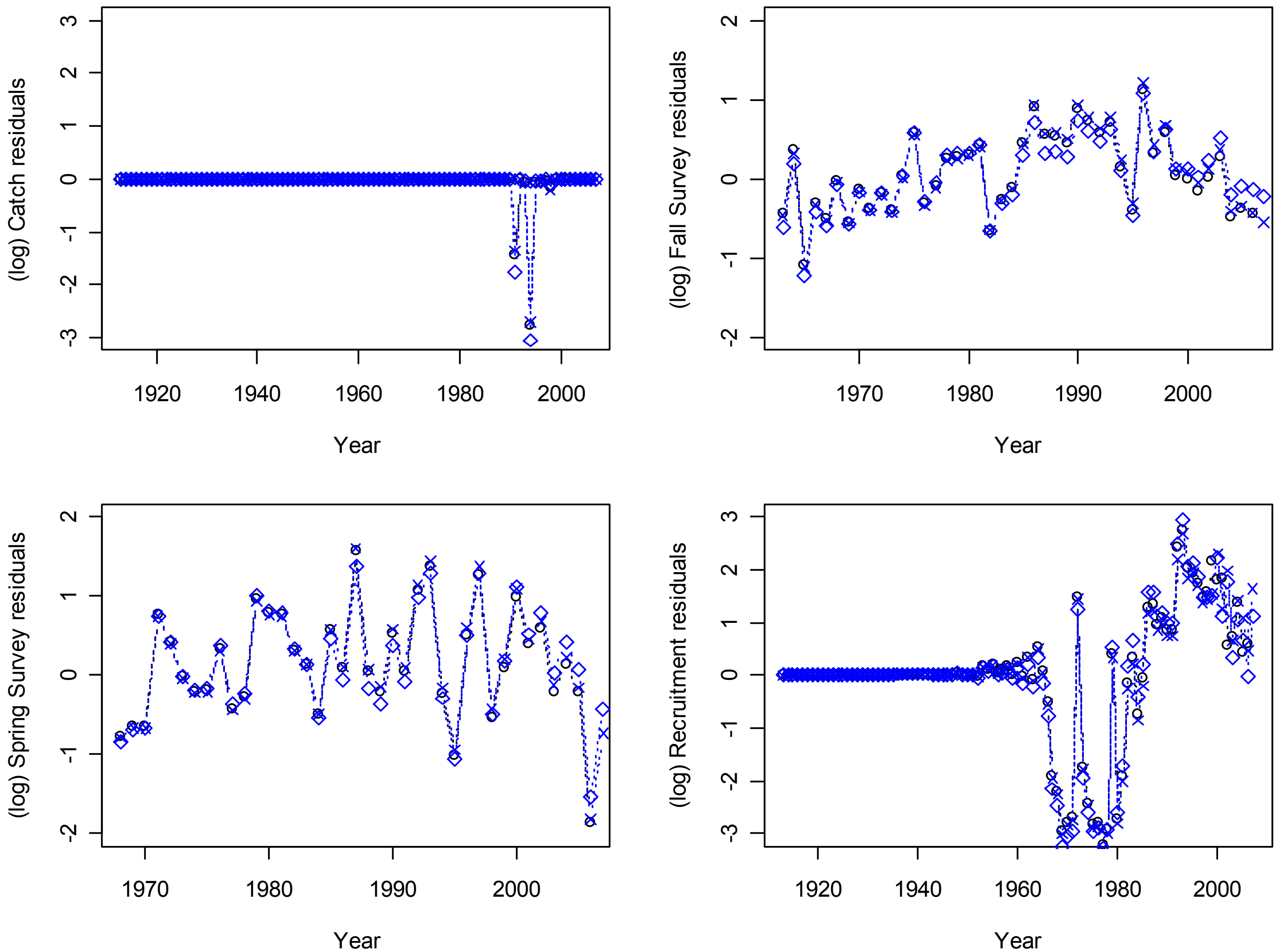

Figure N15. Model residuals for log catch, autumn and spring survey biomass-per-tow and recruitment produced by ASAP base models using only data prior to 2007 (black circle) and including 2007 data (blue x, final model) and updated data with M = 0.1 (blue diamond).

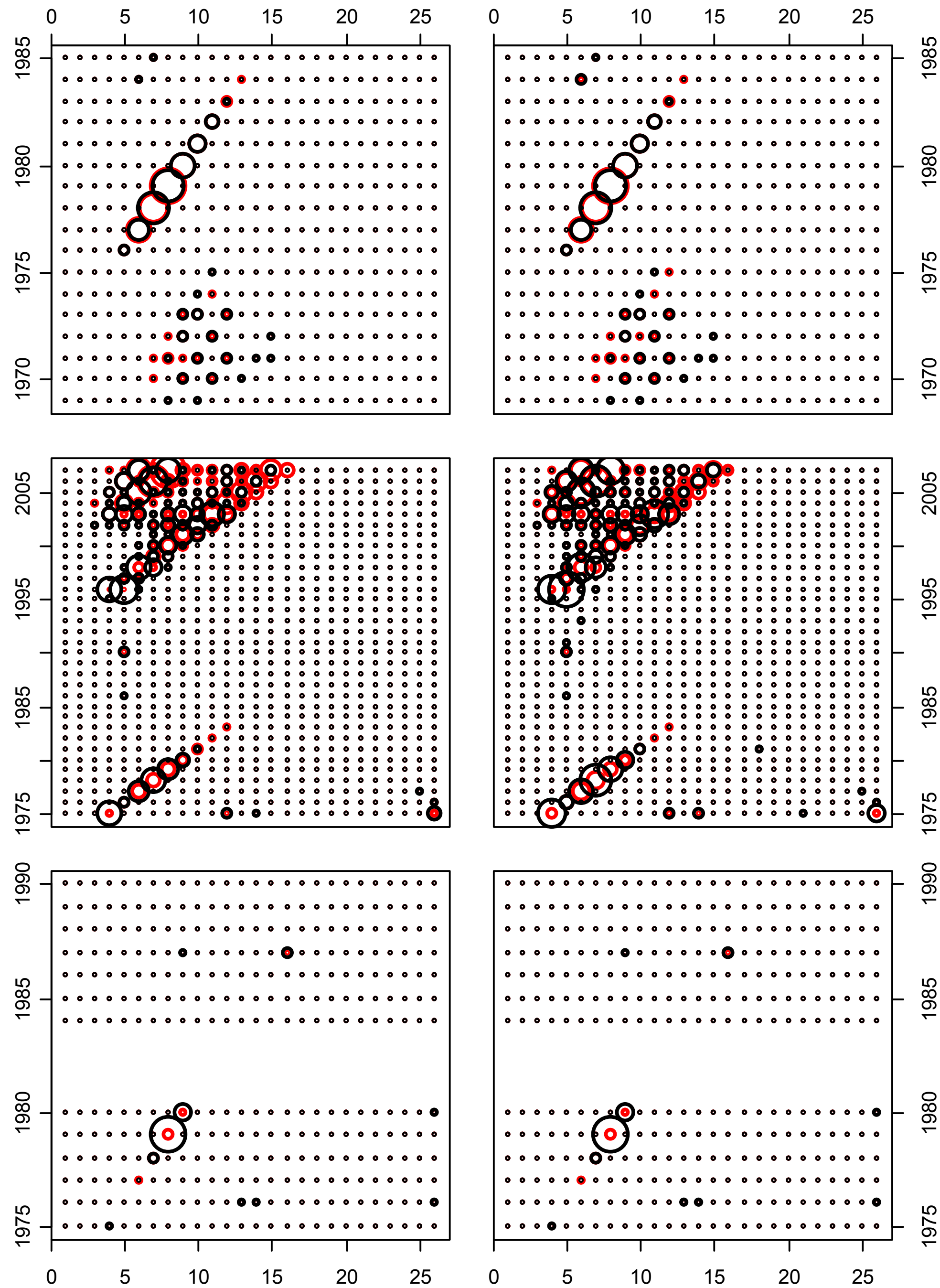

Figure N16. Observed (black) and predicted (red) numbers-at-age for ASAP base (left, final model) and alternate (M = 0.1) (right) models in landings (top), autumn survey (middle) and spring survey (bottom).

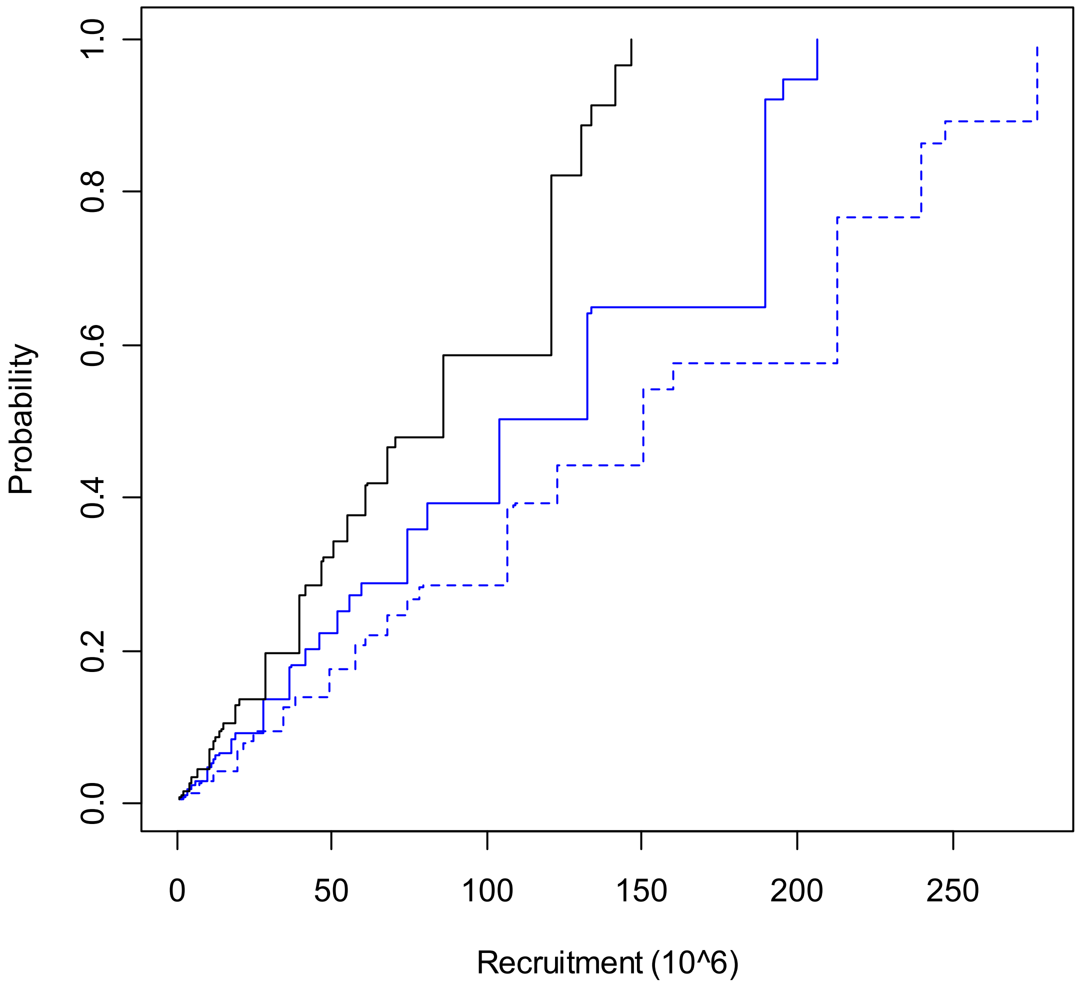

Figure N17. Cumulative distributions of the recruitment estimates from 1969 to present provided by the ASAP base models using data prior to 2007 (black) and including 2007 data (solid blue, final model) and the ASAP alternate (M = 0.1) model using data from all years (dashed blue).

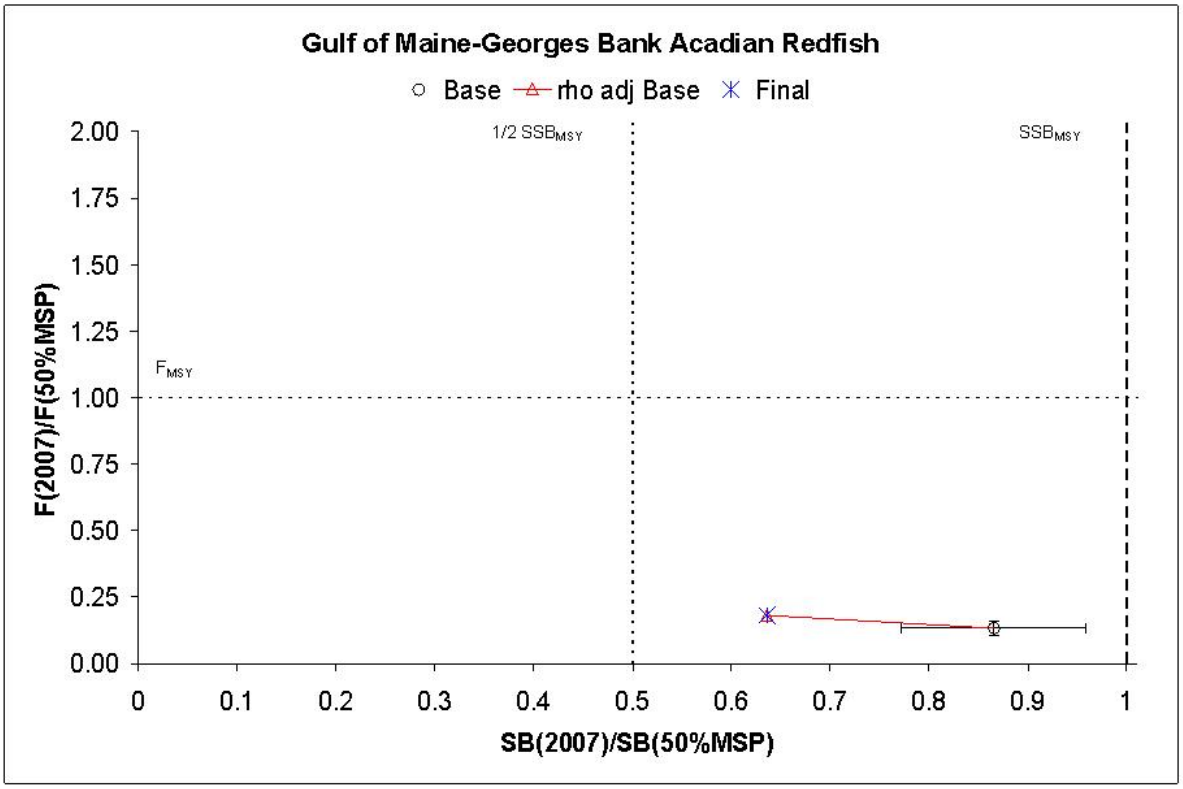

Figure N18. Stock status in 2007 using the base ASAP model and recruits in 1969-2006 (black open circle) and final status (black x and red triangle) given by adjusting status from base (final) model by the retrospective statistic. Vertical and horizontal bars around status points are 80% confidence intervals based on ASAP provided standard errors. Vertical and horizontal dotted lines represent MSY-proxy thresholds for defining whether the stock is overfished or overfishing is occurring, respectively.