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Gulf of Maine-Georges Bank Acadian Redfish

by

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1.0 Background

The most recent stock assessment of Acadian redfish in Subarea 5 was completed and reviewed at the 2005 Groundfish Assessment Review Meeting (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 have 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 Groundfish Assessment Review Meeting 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 have been less than 10% of F(50%MSP) since 2000 (<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 deemed not overfished and overfishing is not occurring.

For the 2008 Groundfish Assessment Review Meeting on Assessment models, we updated the catch and survey data to 2006 and provide estimates of discards between 1989 and 2006. In the 2005 Groundfish Assessment Review Meeting, two versions of a statistical catch at age model (RED and STATCAM) were explored, but the definitive results were ultimately based on the RED model. As such, in initial meetings for 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 Groundfish Assessment Review Models Meeting about the problematic estimation of biomass levels prior to the substantial landings starting 1936 using RED and STATCAM. The reviewers 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 Groundfish Assessment Review Biological Reference Point meeting 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 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 1970. 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).

2.1 Discards

We estimated discards using the d/k ratio method described in Wigley et al. (2006). The discard estimates are generally low (< 400mt), but are sometimes a substantial proportion of total removals (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.

3.1 Survey Age Composition

Age samples from the NEFSC autumn bottom trawl survey are available from 1975 through 2007. Estimates of proportions at age appear to show infrequent large cohort recruitment pulses followed by periods of small cohort recruitment between 1975 and the early 1990s (Figures N5 and N6). 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

4.1 Input data and Model Formulation

The reviewers at the 2008 Groundfish Assessment Review Models Meeting, 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, approximately 0.2) of recruitment residuals in years where age samples are not available and high CV (approximately 0.4) of recruitment residuals where age samples 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 Groundfish Assessment Review Meeting 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 samples and 0.8 with age samples, 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.

4.2 Model Selection Process

Overall, the diagnostics of the three ASAP alternatives presented at the 2008 Groundfish Assessment Review Meeting 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 mild retrospective pattern in spawning biomass and fishing mortality in the terminal year using the model chosen at the GARM III 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, corresponding selectivity and weight- and maturity-at-age is different than that predicted at equilibrium using a yield 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 this, we recommend the base model for determining stock status and catch and biomass projections.

4.3 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).

4.4 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 Groundfish Assessment Review Biological Reference Point Meeting, 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 Recruitment 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 Groundfish Assessment Review Meeting were also recommended. We calculated the F(50%MSP) using a yield-per-recruit analysis 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.

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 estimated reference points. To determine stock status, the spawning biomass and fishing mortality estimates in the terminal year from the ASAP fits are compared to the corresponding estimates at 50%MSP provided by AGEPRO and yield-per-recruit analyses.

The fishing mortality rate and spawning biomass per recruit at 50%MSP provided by the yield-per-recruit analyses are similar whether 2007 data are included or not and the fishing mortality rate is also similar to that provided at the 2005 Groundfish Assessment Review Meeting, 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. When comparing the the spawning biomass and fishing mortality rate estimates for 2007 to the corresponding reference point estimates, the status of the stock is the same whether the base or alternative models are used (Table N8; Figure N18). In all cases, the stock is not overfished and overfishing is not occurring.

6.0 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.

Projected median 2009 catch biomass under base ASAP model with status quo fishing mortality (F = 0.005) is 1,732mt and the spawning biomass will be rebuilt with greater than 50% probability by 2008, greater than 95% probability in 2009 and greater than 99% probability in 20010. At F(50%MSP) = 0.0377, the median 2009 catch biomass is 11,713mt and the spawning biomass will be rebuilt with nearly 50% probability by 2008, greater than 95% probability by 2009 and greater than 99% probability by 2010.

Under the alternate (M=0.1) ASAP model with status quo fishing mortality (F = 0.005), projected median 2009 catch biomass is 1,323mt and when F(50%MSP) = 0.069 is used median 2009 catch biomass is 17,733mt. Under the alternate model, the current spawning biomass is already nearly twice the SB(50%MSP) and thus rebuilt.

7.0 Summary

8.0 Panel Discussion

<by Review Panel>

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 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	*

* Preliminary
** 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 biological 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. Assumptions made for ASAP model implementation for Gulf of Maine-Georges Bank Acadian Redfish.

Unestimated Parameter	Assumed Value
CV Recruitment residuals	0.2 for years with no age sampling and 0.4 for years without age sampling (Alternative 1) or 0.1 for years with no age sampling and 0.8 for years without age sampling (Alternative 2)
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
Natural mortality	0.05
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 Mohn's Rho values for spawning biomass, recruitment, and fully selected fishing mortality for the base and alternate (M = 0.1) ASAP models.

	M = 0.025	M = 0.03	M = 0.04	M = 0.05	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 models using data prior to 2007 (left) and including 2007 data (middle) and the ASAP alternate (M = 0.1) model using 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 from ASAP models. Spawning biomass per recruit and fishing mortality at 50% maximum spawning potential (MSP) as estimated using a 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) from yield per recruit analysis.

	2005 Assessment	Without 2007 Data M = 0.05	With 2007 Data M = 0.05	M = 0.1
SB(2006)	NA	215,722mt	199,012mt	197,242mt
SB(2007)	NA	NA	234,609mt	222,619mt
F(2006)		0.003	0.003	0.004
F(2007)	NA	NA	0.005	0.005
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

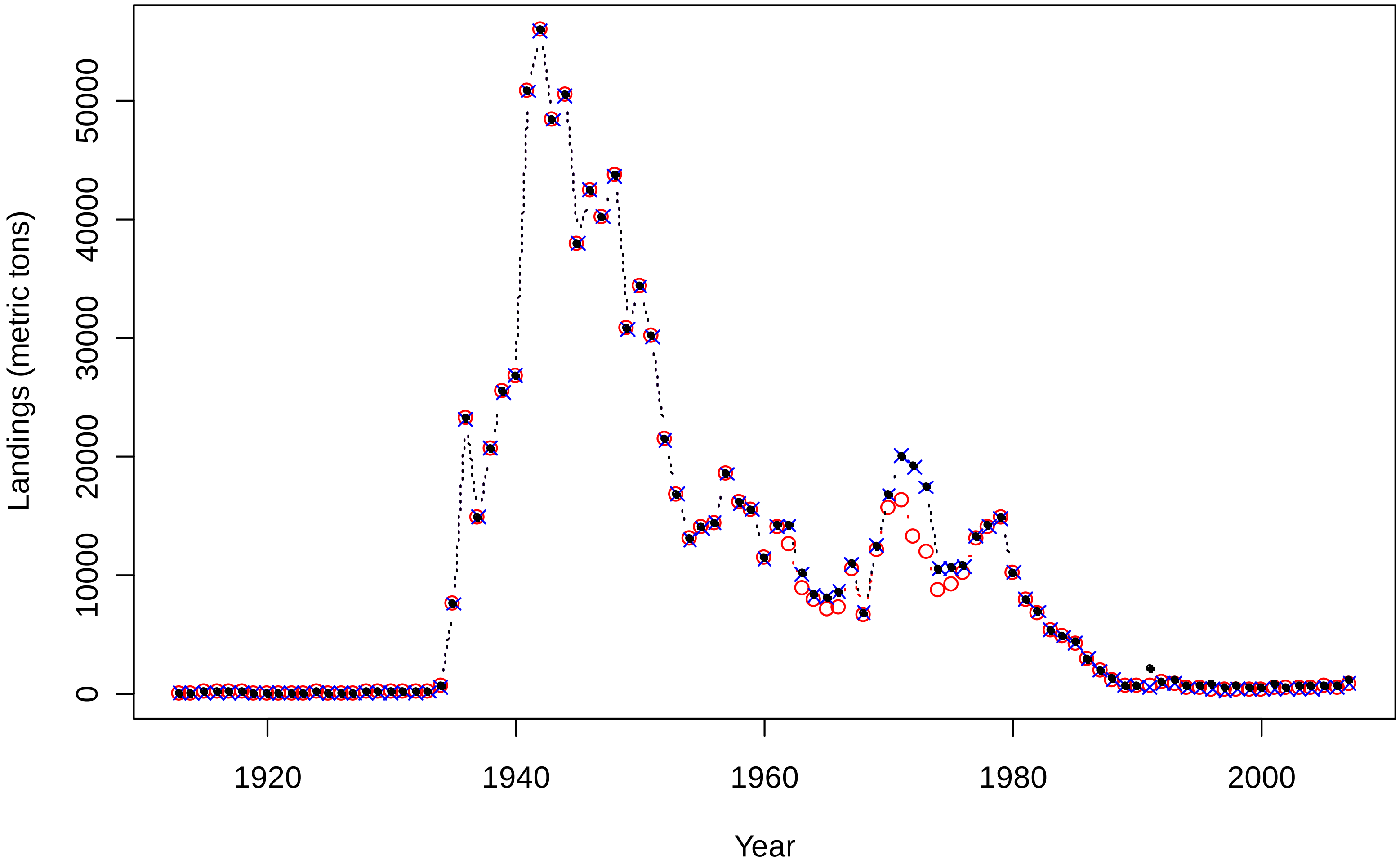

Figure N1. Annual landings (mt) of Gulf of Maine-Georges Bank Acadian redfish between 1913-2006 for US fleet only (red), US and foreign fleets combined (blue) and total landings combined with annual discard estimates between 1989-2006 (black).

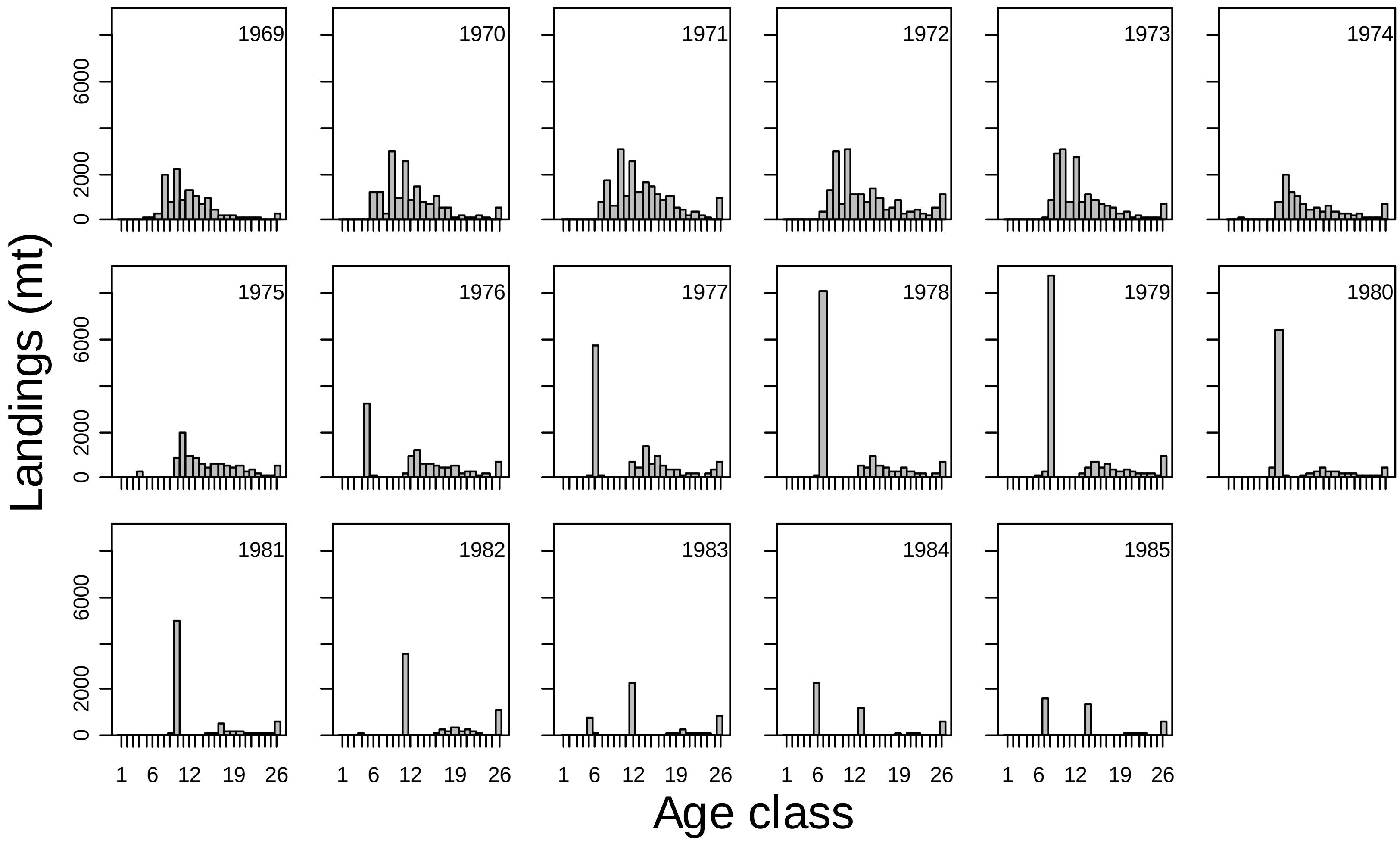

Figure N2. Estimated annual landings (mt) at age for Gulf of Maine-Georges Bank Acadian redfish between 1969-1985.

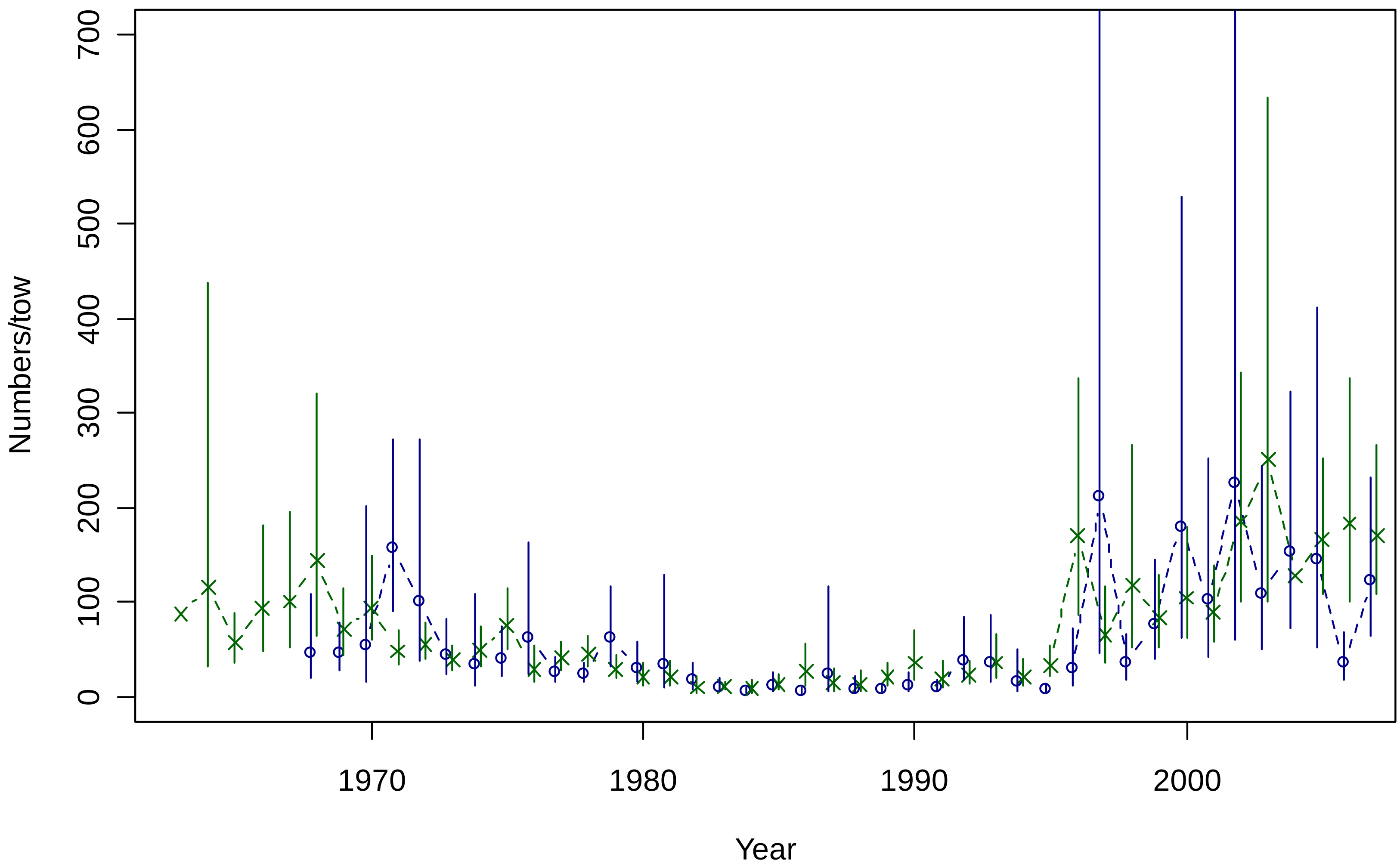

Figure N3. Estimated numbers per tow for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC spring (blue, circle) and autumn (green, x) survey over all inshore and offshore strata. Vertical bars represent approximate 95% confidence intervals.

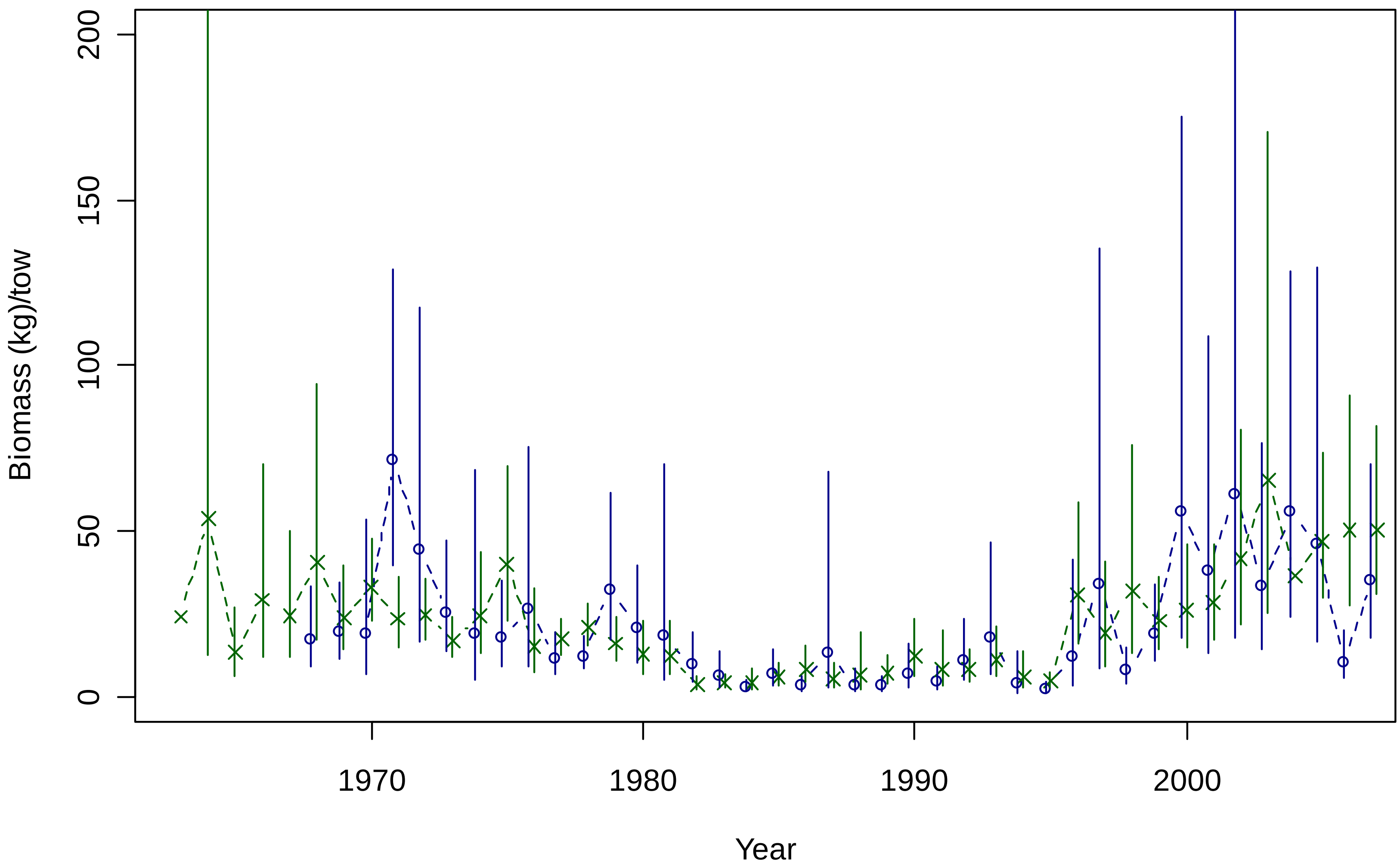

Figure N4. Estimated biomass (kg) per tow for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC spring (blue, circle) and autumn (green, x) survey over all inshore and offshore strata. Vertical bars represent approximate 95% confidence intervals.

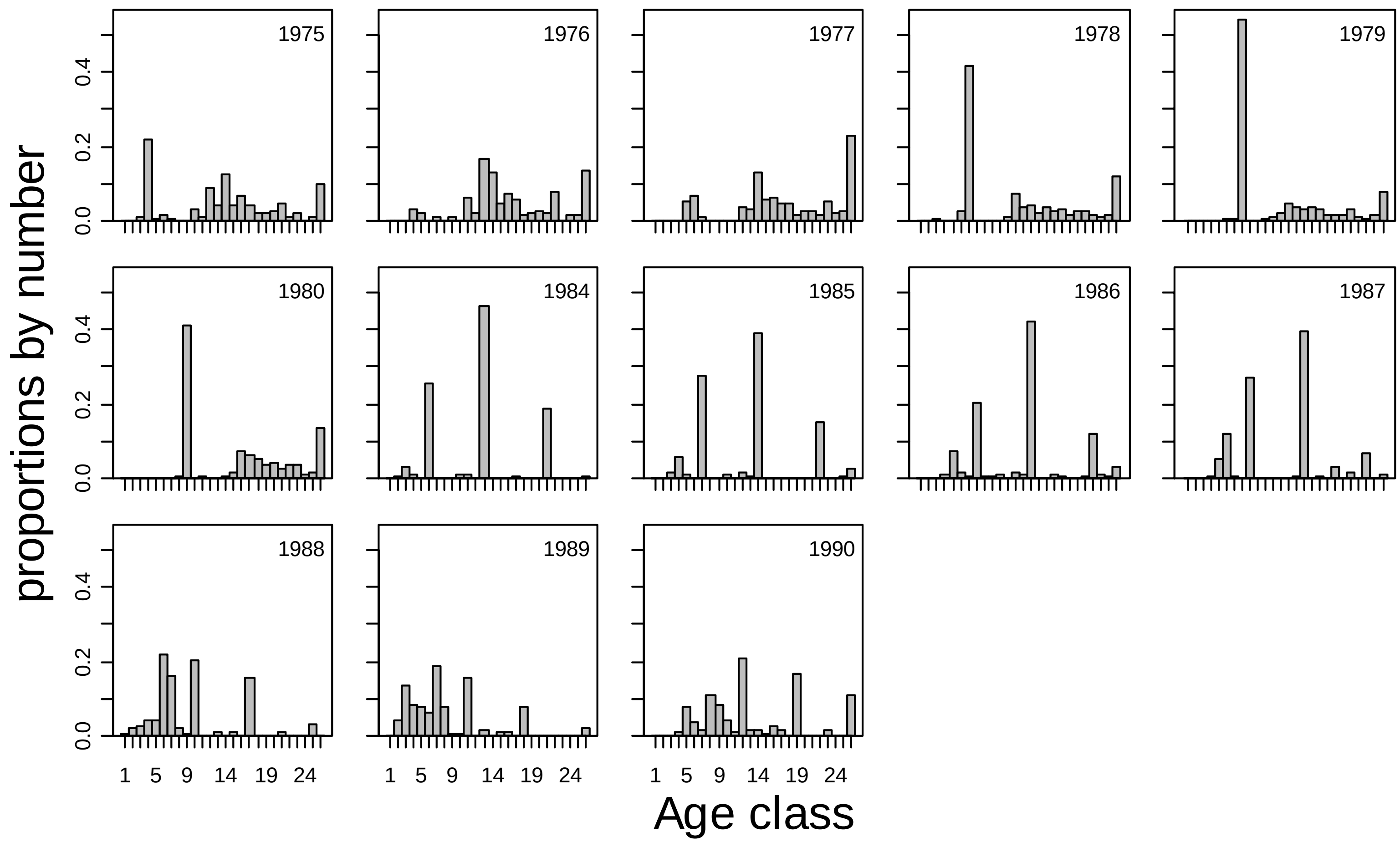

Figure N5. Estimated proportions at age for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC spring survey.

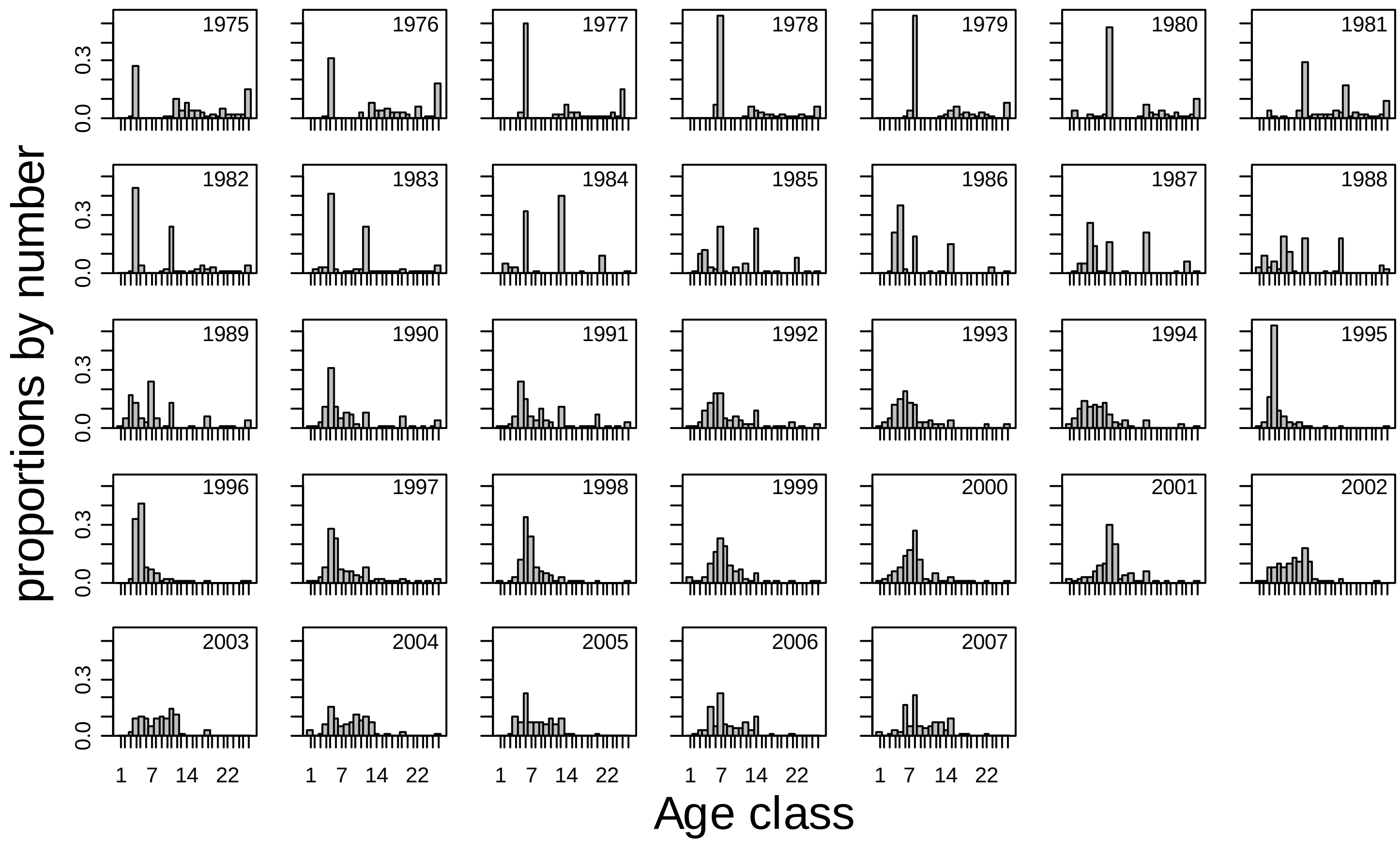

Figure N6. Estimated proportions-at-age for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC autumn survey.

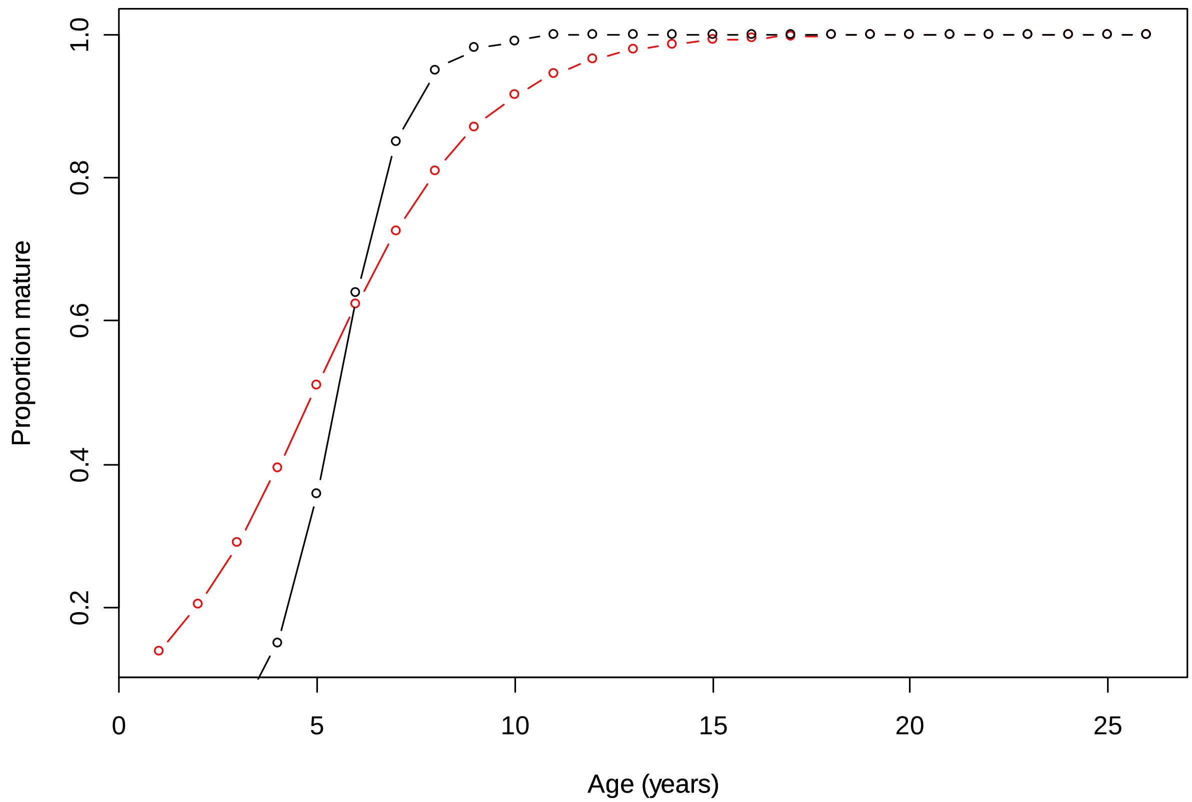

Figure N7. Proportion mature at age assumed in previous assessments (black) and estimated for females (red line) maturity and age data from Gulf of Maine-Georges Bank Acadian redfish caught in spring bottom trawl surveys.

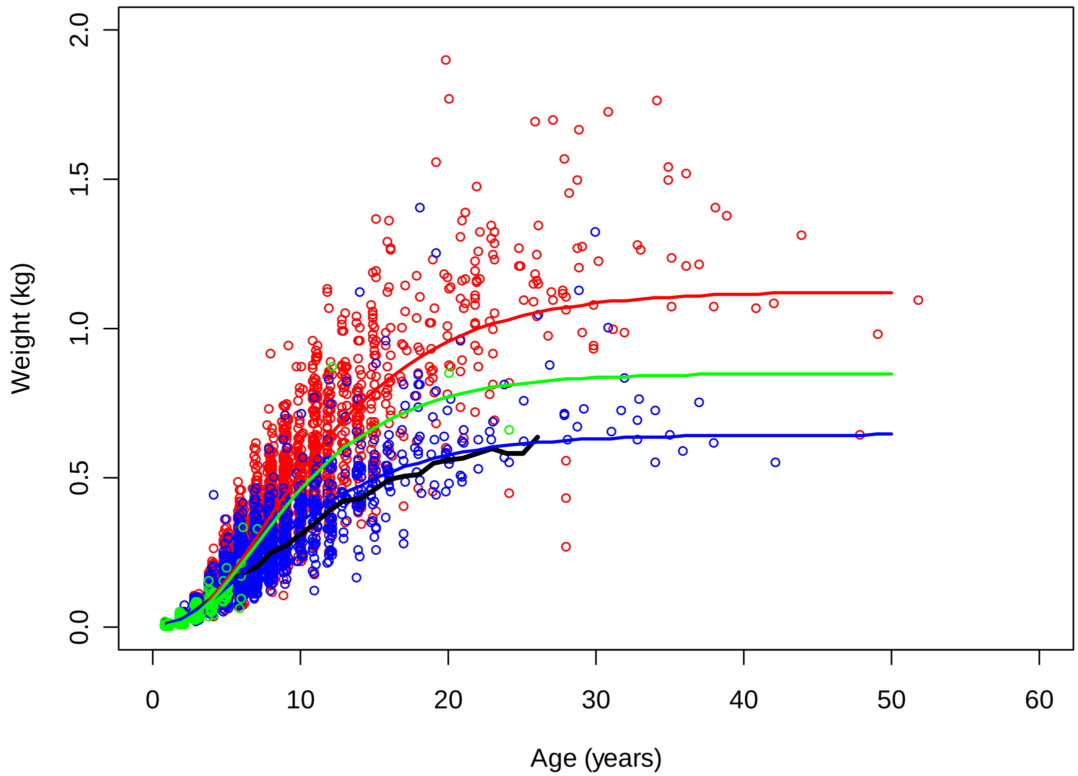

Figure N8. Weight at age assumed in previous assessments (black line) and estimated for females (red line), males (blue line) and combined (green line) from length, weight and age data from Gulf of Maine-Georges Bank Acadian redfish caught in bottom trawl surveys. Red, blue and green points represent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

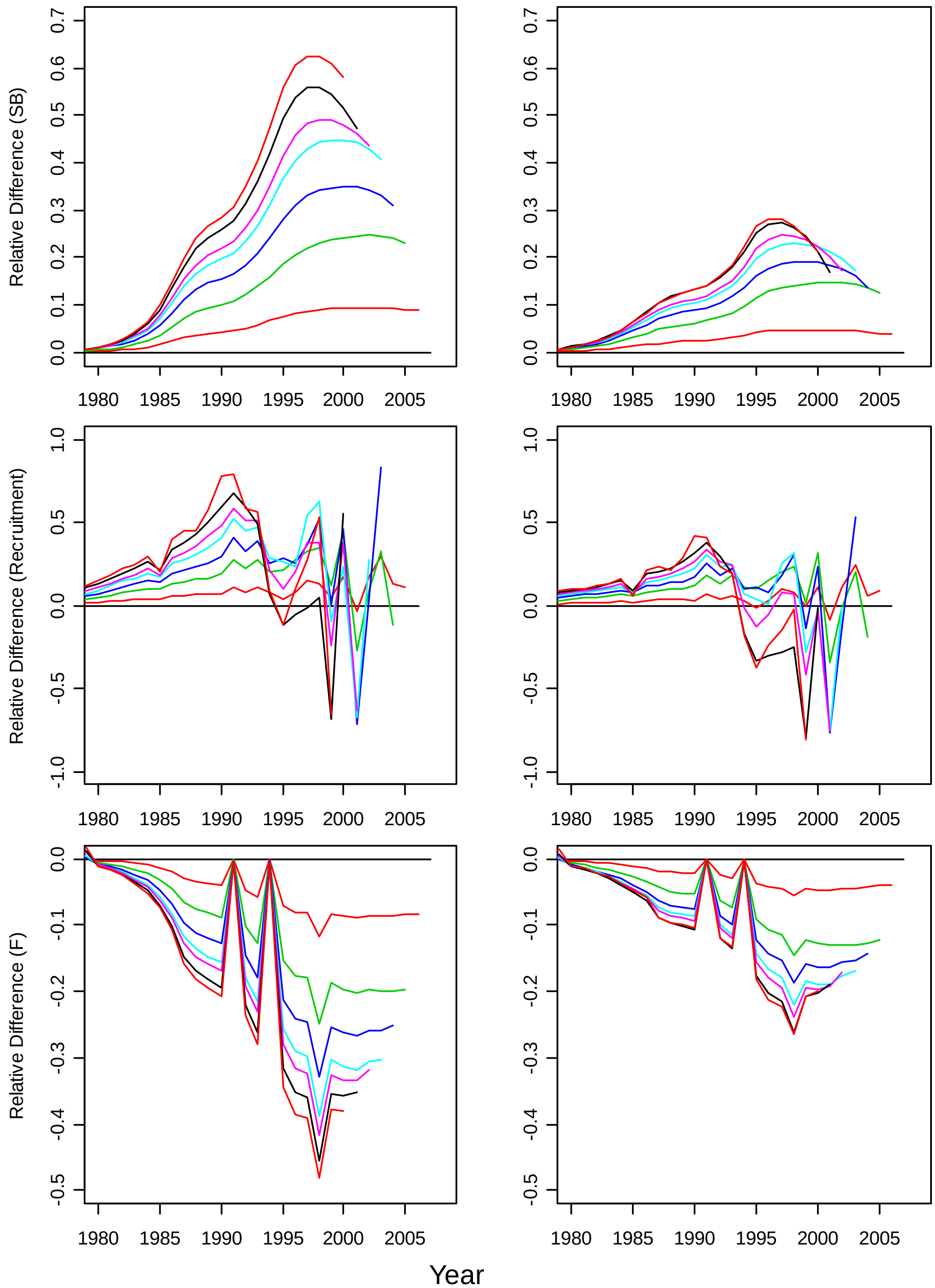

Figure N9. Retrospective patterns for relative differences in spawning biomass (top), recruitment (middle) and fishing mortality (bottom) from the ASAP base model including 2007 data (left) and the ASAP alternate (M = 0.1) model (right).

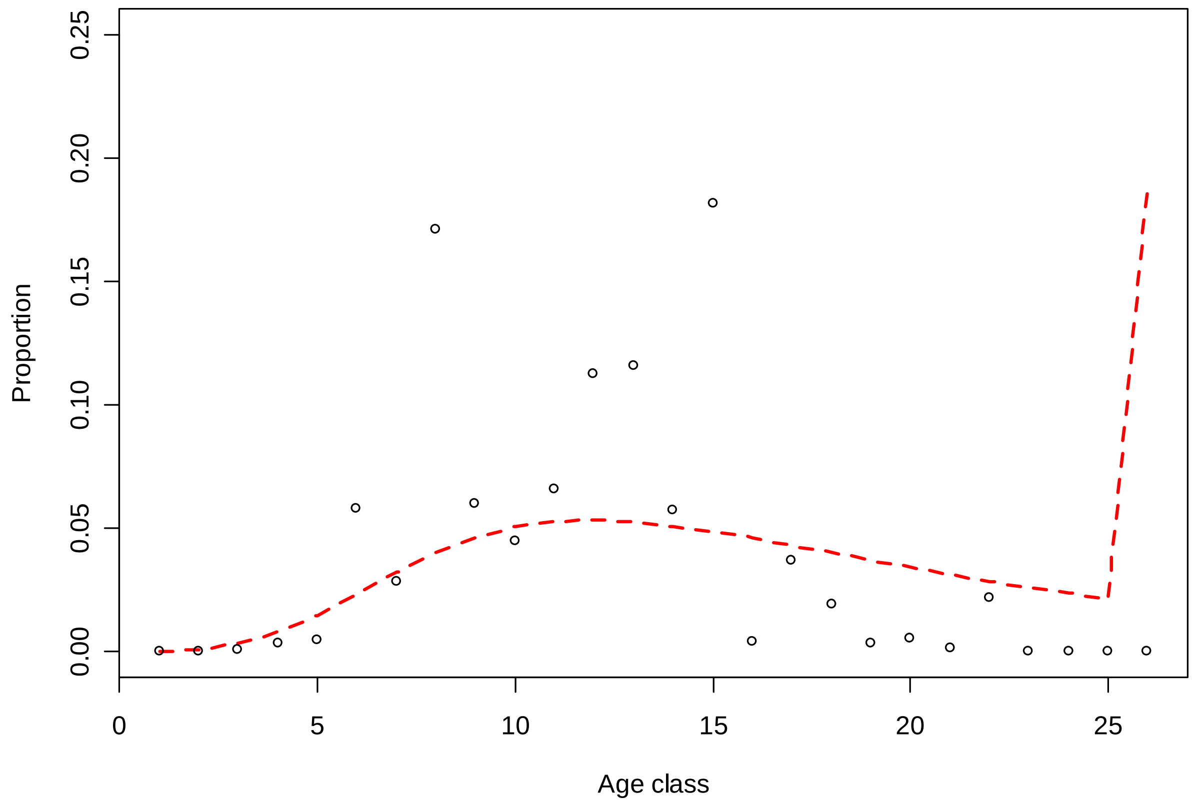

Figure N10. Estimated proportion of biomass at age for autumn survey in 2007 (circles) and at equilibrium with M = 0.1, F = 0.01 and selectivity at age as estimated under the ASAP model with M = 0.1 (red dashed line).

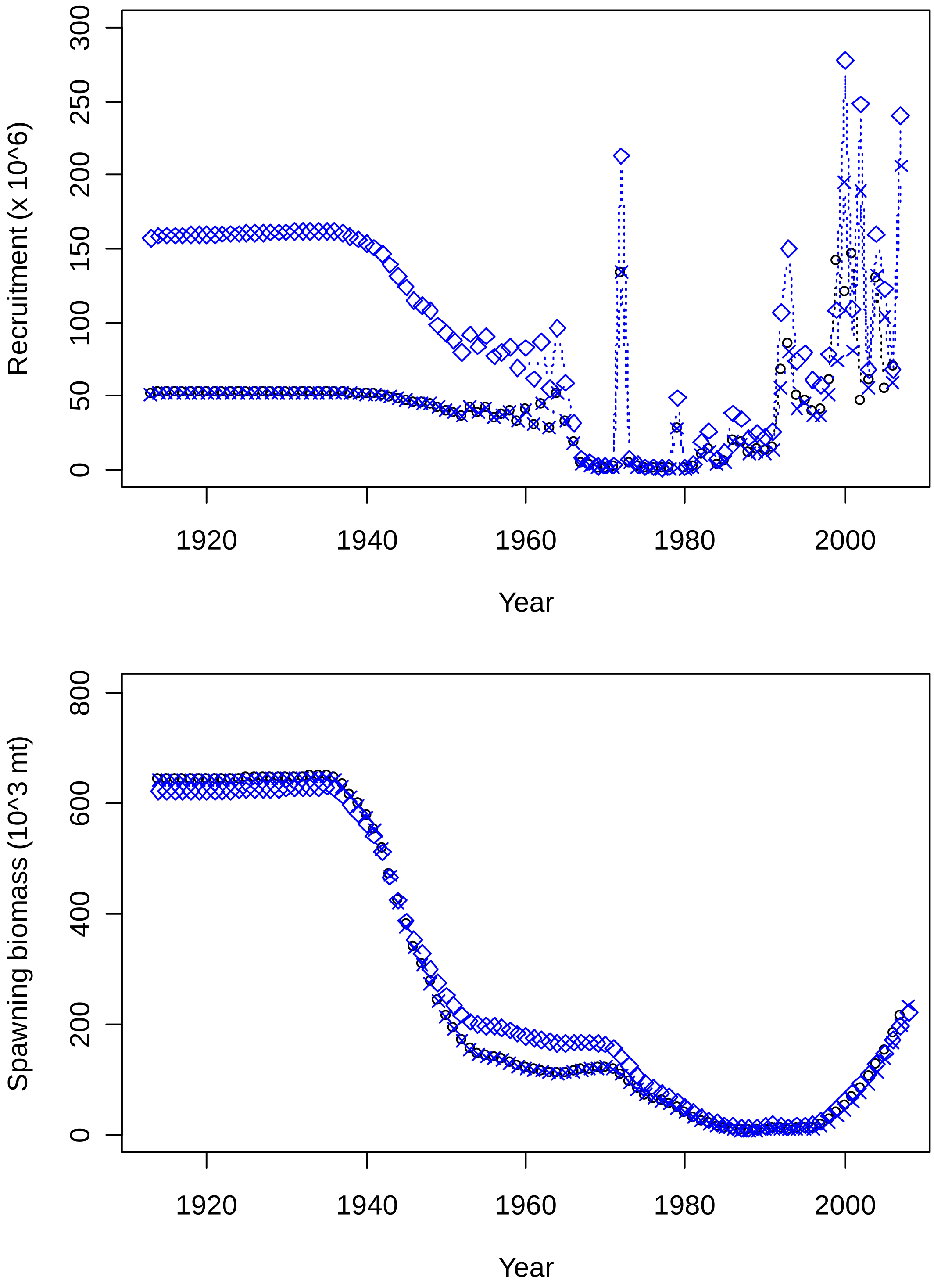

Figure N11. Recruitment (top) and spawning biomass estimates from the ASAP base models using only data prior to 2007 (black circle) and including 2007 data (blue x) and updated data with M = 0.1 (blue diamond).

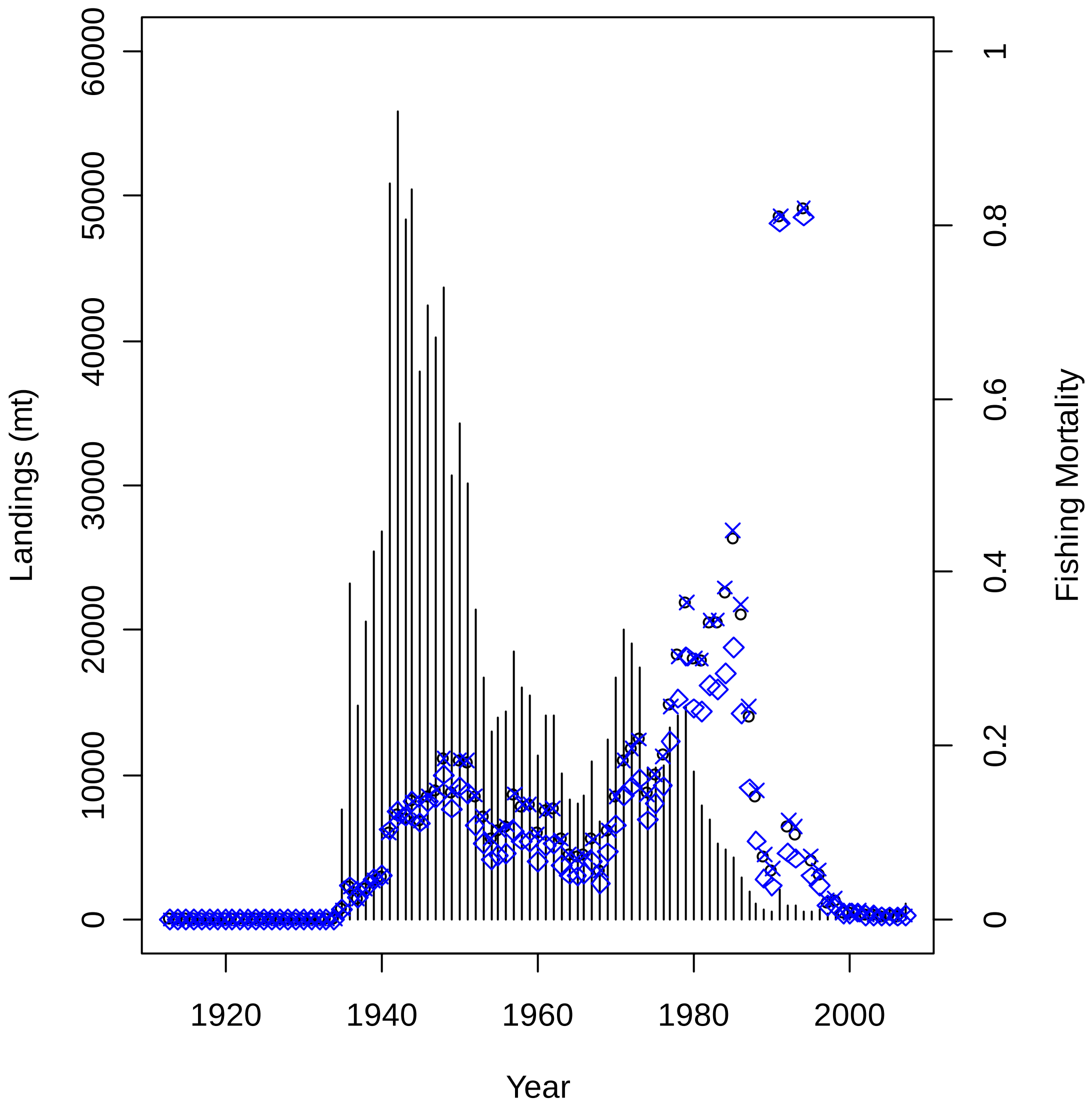

Figure N12. Landings and fully selected fishing mortality estimates from the ASAP base models using only data prior to 2007 (black circle) and including 2007 data (blue x) and updated data with M = 0.1 (blue diamond).

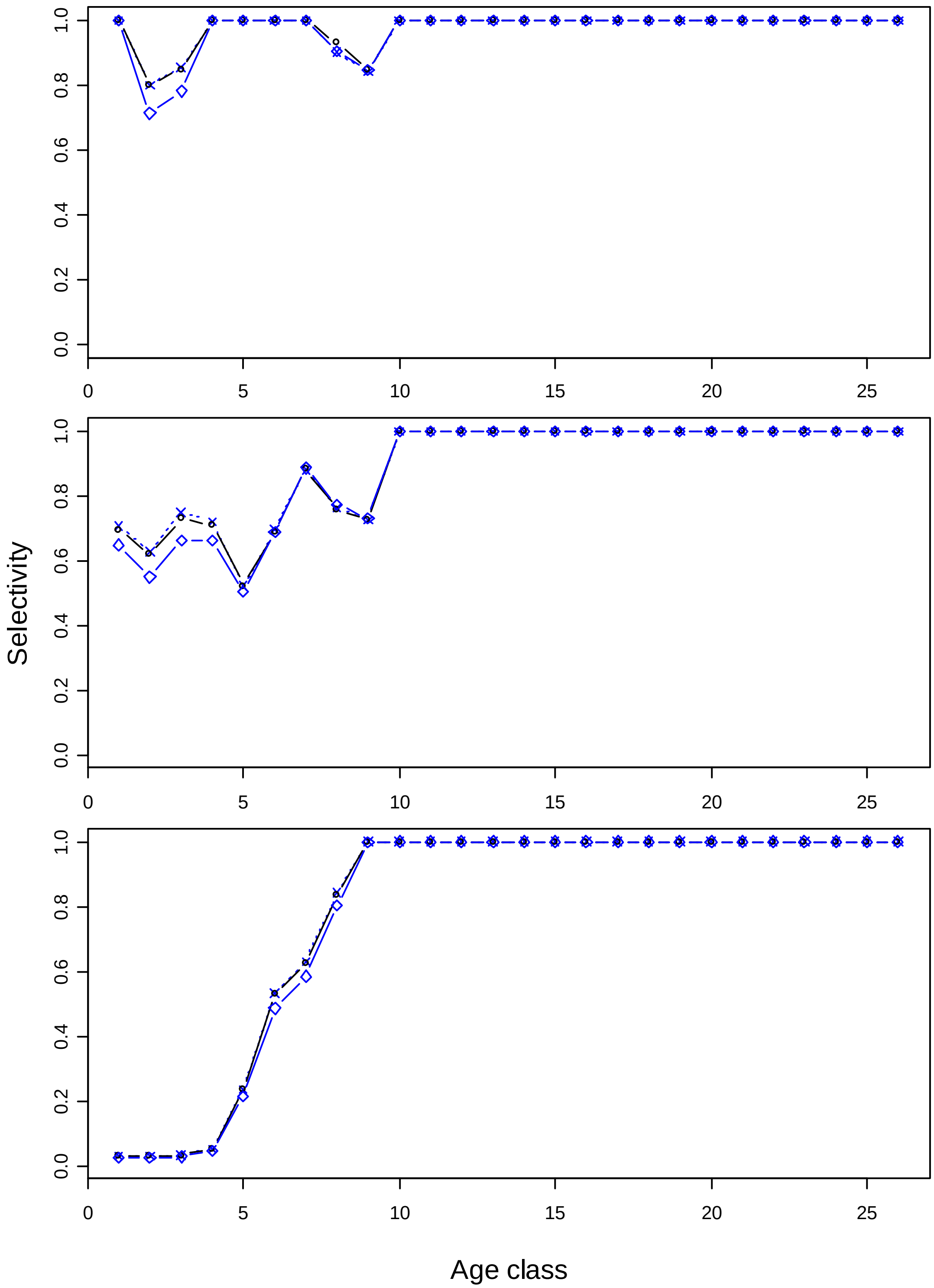

Figure N13. Selectivity-at-age for the NEFSC autumn (top) and spring (middle) surveys and the fishery (bottom) as estimated from the ASAP base models using only data prior to 2007 (black circle) and including 2007 data (blue x) and updated data with M = 0.1 (blue diamond).

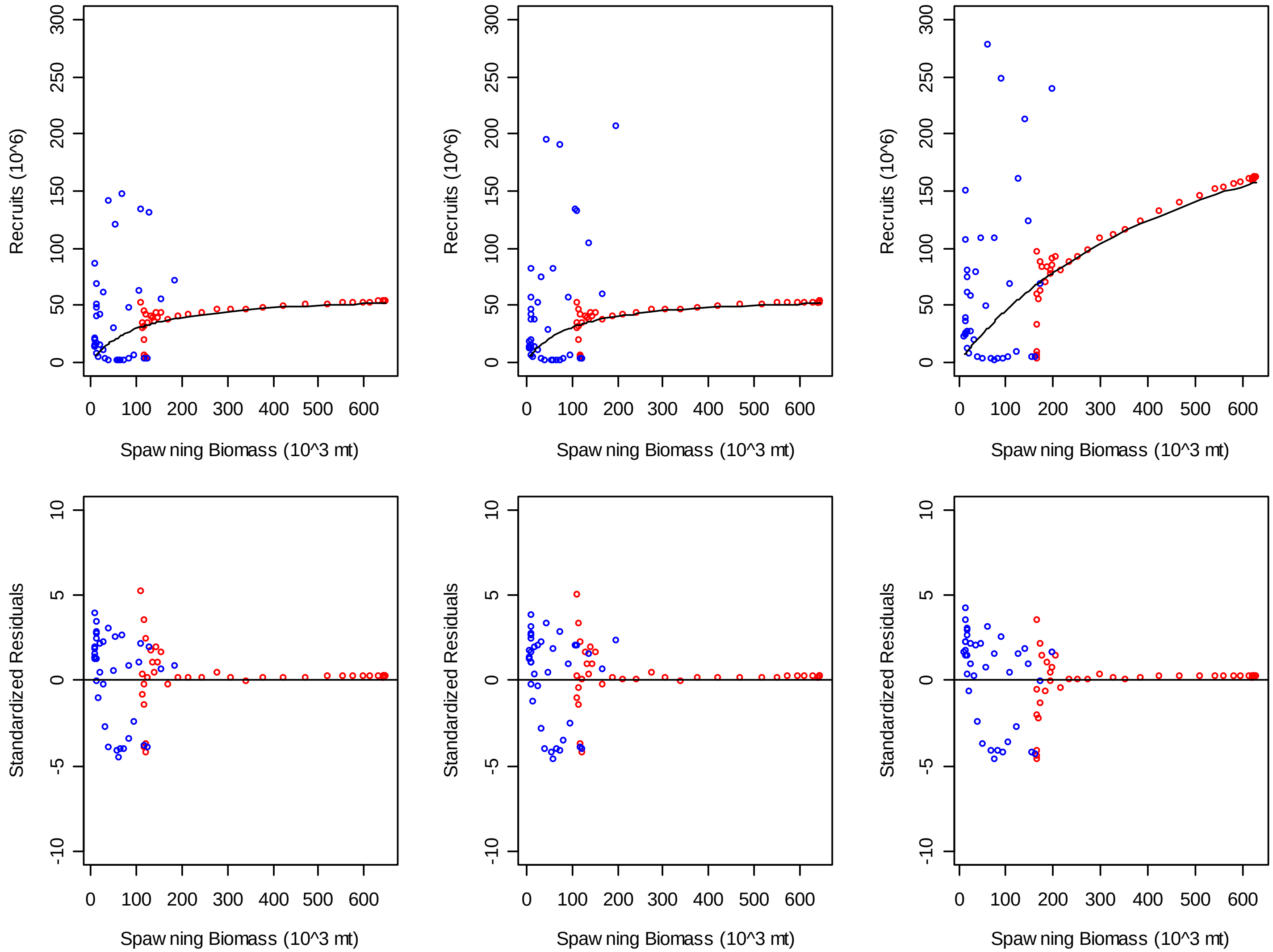

Figure N14. Spawning biomass and recruitment (top) and spawning biomass and standardized recruitment residuals (bottom) from the ASAP base models using data prior to 2007 (left) and including 2007 data (middle) and the ASAP alternate (M = 0.1) model using using data from all years (right). The blue and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

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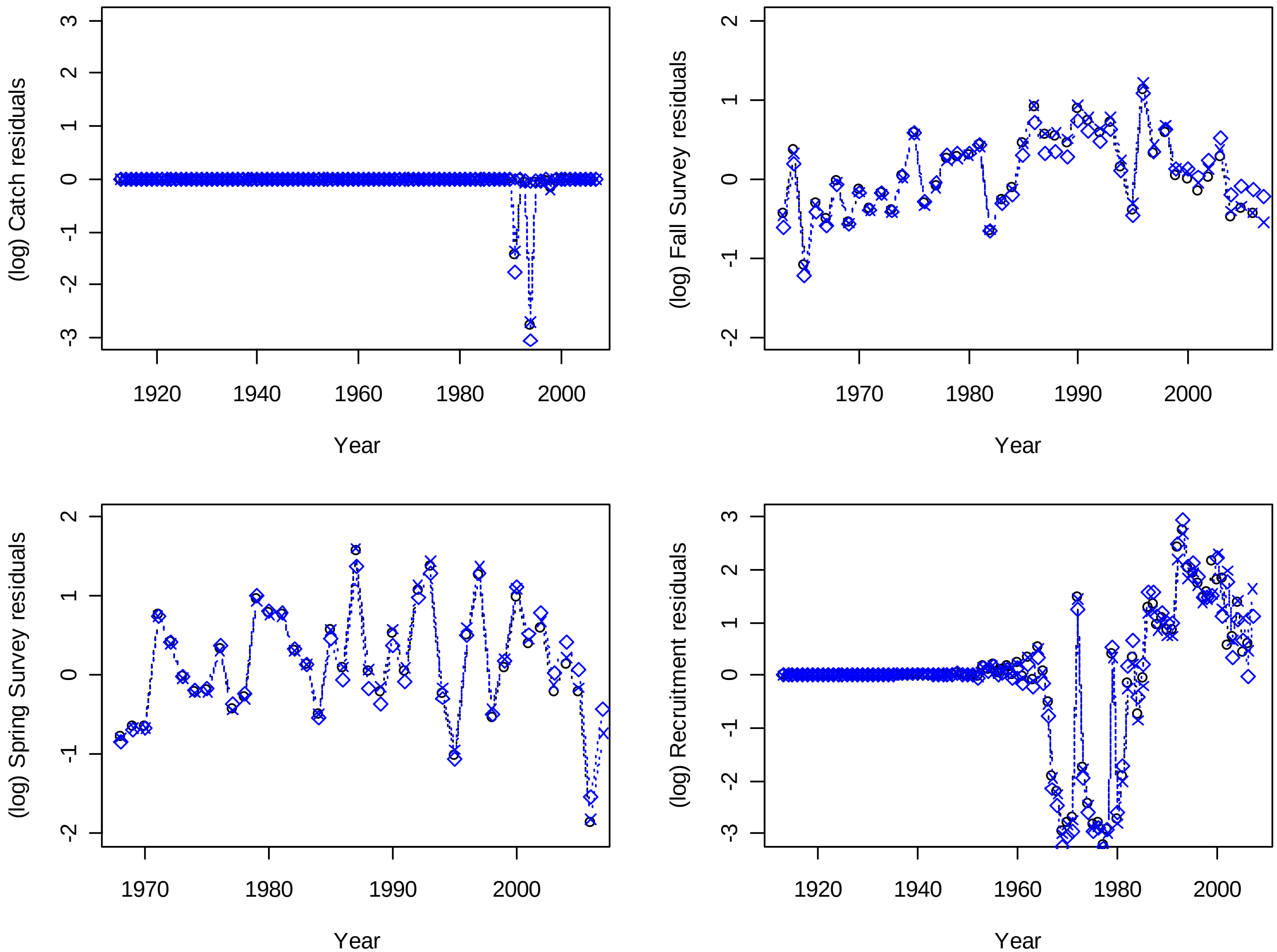

Figure N15. Model residuals for log catch, autumn and spring survey biomass per tow and recruitment produced by ASAP base models using only data prior to 2007 (black circle) and including 2007 data (blue x) and updated data with M = 0.1 (blue diamond).

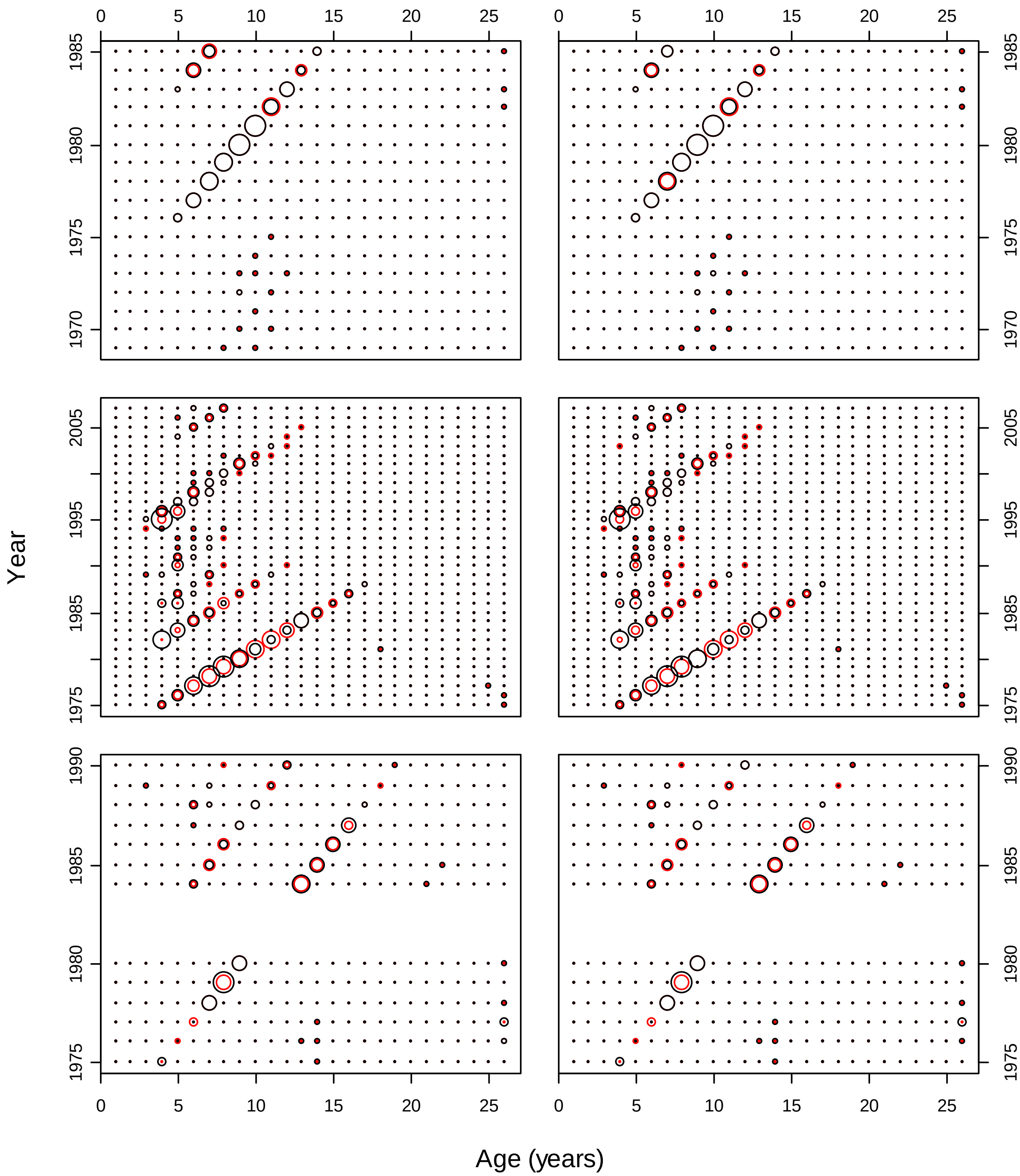

Figure N16. Observed (black) and predicted (red) proportions at age for ASAP base (left) and alternate (M = 0.1) (right) models in landings (top), autumn survey (middle) and spring survey (bottom).

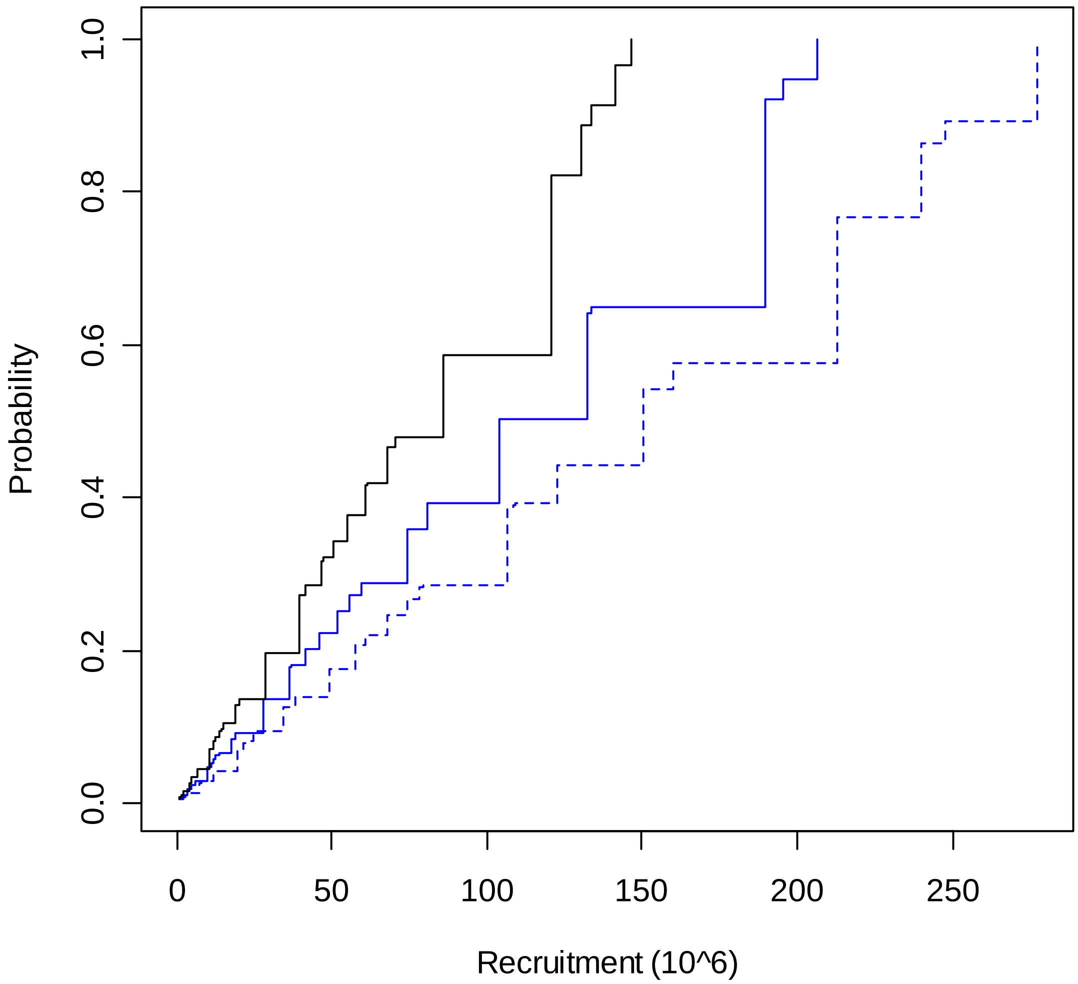

Figure N17. Cumulative distributions of the recruitment estimates from 1969 to present provided by the ASAP base models using data prior to 2007 (black) and including 2007 data (solid blue) and the ASAP alternate (M = 0.1) model using using data from all years (dashed blue).

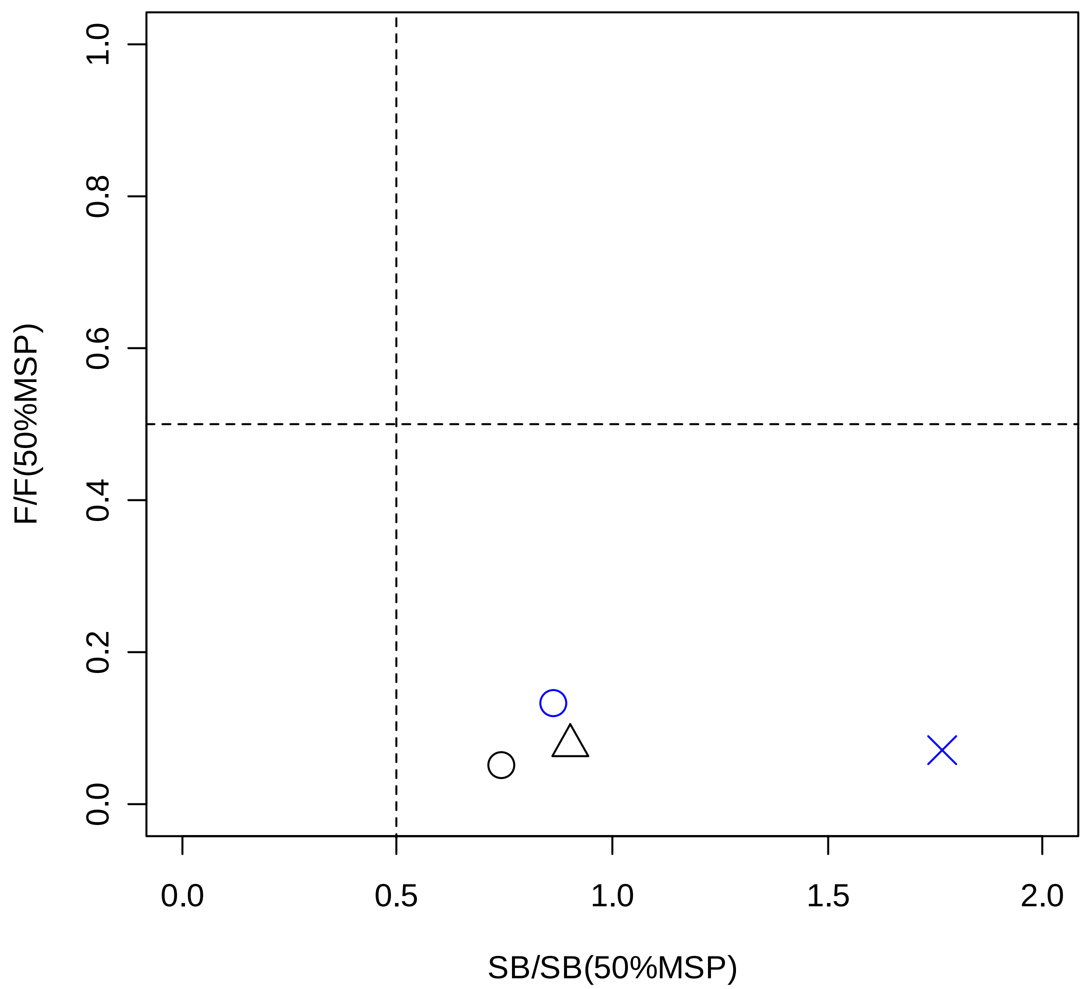

Figure N18. Stock status at the 2005 assessment (black circle), in 2006 using the base ASAP model and estimated recruitments in 1969 to 2005 (black triangle), in 2007 using the base ASAP model and recruits in 1969-2006 (blue circle) and in 2007 using the alternate ASAP model (M = 0.1) and recruits in 1969-2006 (blue x).