

A. GULF OF MAINE COD ASSESSMENT SUMMARY FOR 2011

State of Stock: A new stock assessment model (ASAP) is proposed as the best scientific information available for determining stock status for Gulf of Maine Atlantic cod (*Gadus morhua*). Spawning stock biomass (SSB) in 2010 is estimated to be 11,868 mt and the fully recruited fishing mortality (F_{full}) is estimated to be 1.14 (Figure A1, Figure A2, Figure A3).

An MSY could not be derived directly from the ASAP model; therefore an MSY proxy must be used for reference points. $F_{40\%}$ is recommended as the proxy for F_{MSY} (the overfishing threshold). $F_{40\%}$, estimated on the fully selected age class, is 0.20. SSB_{MSY} (the biomass target) is calculated from projections at $F_{40\%}$ and is estimated to be 61,218 mt.

Comparing the current 2010 ASAP model estimates of SSB and fully recruited F to the newly accepted reference points, the Gulf of Maine cod stock is overfished and overfishing is occurring (Figure A1).

By the convention developed in GARM III, because the point estimate of current stock status with a five-year peel was within the confidence intervals of the base model (Figure A1), no correction for a retrospective pattern was used for stock status determination or applied in the stock projections.

All alternative parameterizations of the ASAP model led to the same conclusions regarding stock status. Moreover, all versions of the previously used VPA model also led to the same conclusions that the stock is overfished and overfishing is occurring.

Projections: The ASAP model results indicate that the stock is overfished and overfishing is occurring (Figure A1), and there was a moderate retrospective pattern. Projections were made for three constant F scenarios: $F = 0$ (no fishing), $F = 0.75 * F_{MSY \text{ Proxy}}$, and $F = F_{MSY \text{ Proxy}}$ (Table A1). Based on the recommendations of the SARC-53 Review Panel, a revised method was used to conduct short term projections relative to the methods used in the previous GARM III assessment. Similar to the previous method, the revised projection model samples from a cumulative density function derived from ASAP estimated age-1 recruitment between 1982 and 2008. Recruitment in 2009 and 2010 was not included due to general uncertainty in terminal estimates of recruitment. Unlike, the previous method, the revised approach adjusts projected recruitment when SSB falls below some specified SSB threshold based on a linear function that declines to zero when $SSB = 0$ mt. This revised method provides a better representation of the risk associated with alternative management policies. Under all projection scenarios, the stock does not rebuild by the current rebuilding date of 2014.

Catch and Status Table: Gulf of Maine Atlantic cod (weights in 000s mt, recruitment in millions, arithmetic means)

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Max ¹	Min ¹	Mean ¹
Commercial landings	4.3	3.6	3.9	3.8	3.6	3.0	4.0	5.4	6.0	5.4	18.0	1.4	7.5
Commercial discards	2.0	1.8	1.0	0.9	0.4	0.5	0.3	0.5	1.0	0.2	2.2	<0.1	0.9
Recreational landings	2.7	1.7	2.2	1.6	1.8	0.8	1.1	1.6	1.7	3.5	4.8	0.3	1.9
Recreational discards	1.0	1.3	1.2	0.8	1.1	0.6	1.1	1.3	1.2	2.3	2.3	<0.1	0.6
Catch used in assessment	10.0	8.4	8.3	7.1	6.8	5.0	6.4	8.8	9.9	11.4	22.3	3.9	10.9
Spawning stock biomass	14.9	15.1	12.4	10.4	8.9	8.4	10.8	12.6	13.6	11.9	23.7	7.3	12.5
Recruitment (age 1)	1.7	7.4	2.8	8.6	5.4	9.0	6.7	6.7	5.3	4.3	33.1	1.7	8.7
F ₅₋₇	0.69	0.59	0.72	0.70	0.84	0.62	0.59	0.74	0.77	1.10	1.44	0.49	0.85
F _{mult}	0.72	0.61	0.75	0.72	0.87	0.64	0.62	0.77	0.80	1.14	1.49	0.51	0.90

¹Over the period 1982-2010

Stock Distribution and Identification: Within the Gulf of Maine the US EEZ splits statistical areas 464, 465 and 467. Prior to implementation of the Hague line in October 1984, United States (US) landings of fish from these statistical areas could have been either Gulf of Maine or Scotian Shelf cod. The operational definition of the stock area was changed for this assessment to be consistent with the management boundaries. Current management of Gulf of Maine cod includes catch from these areas against the fisheries ACLs. Since 1985, landings from these statistical areas have averaged less than 2% of total commercial landings. While previous assessments have not included these catches, their impact on the updated assessment is negligible.

Catches: Since 1964, catch of Gulf of Maine Atlantic cod has ranged from 3,242 mt to 22,272 mt. Recent catches over the past five years have ranged from approximately 5,000 mt to 11,000 mt. Catch estimates prior to 1981 do not include commercial discards or estimates of recreational removals. Since 1982, commercial landings have been the largest source of fishery removals, comprising 40-90% of the total catch. Commercial discards constituted a large proportion of the catch during the 1998 – 2003 period when trip limits ranged from 30-500 lb/day (13.6 – 226.8 kg/day). In the most recent five years, commercial discards have accounted for <10% of the catch (Figure A4).

Commercial discards were estimated for 1989 to 2010, and were hindcasted from 1988 back to 1982. Discard estimates ranged from 2% to 36% of catch, with an average of 9% for all years. The fleets that account for nearly all cod discards were longline, shrimp otter trawl, small-mesh otter trawl, large-mesh otter trawl, large-mesh gillnet, and extra-large mesh gillnet. Discards could not be estimated for any other commercial gear types.

Recreational catch has varied annually from a low of 574 mt in 1997 to a high of 5,795 mt in 2010. Recreational catches have constituted between 8 and 51% of total annual removals by weight, averaging 25% over the period 1982-2010. In terms of numbers of fish, estimates of recreational discards have increased from approximately 10% of recreational landings at the beginning of the time series to more than 200% of the recreational landings currently.

Discard mortality in all fleets was assumed to be 100%. The determination of stock status was not sensitive to this assumption.

Data and assessment: The previous assessment of Gulf of Maine cod was conducted with a VPA that accounted for total commercial landings, some commercial discards, and recreational landings. A new assessment model (ASAP) was developed that incorporated updated estimates of the length-weight equation, maturity at age, and weights at age. Commercial and recreational discards in all years were also included as inputs to the model.

The commercial fleet catch includes catch by all gear types, though Gulf of Maine cod are primarily caught using otter trawl and gillnet (with minor contributions from hook and line gear). Recreational catch was included for 1982 to 2010. These data were entered as a single time series of catch and catch-at-age.

Abundances (number/tow) from the NEFSC spring and fall surveys, and the MADMF spring survey (1982-2010) were used in the ASAP model along with estimated CV and annual age composition. The MADMF fall survey and the commercial landings per unit effort (LPUE) index were not included in this assessment.

Natural mortality rate was assumed to be 0.2 for all ages and years. Maturity at age was assumed constant for all years.

The assessment model was evaluated across a wide range of alternative assumptions regarding data inputs and was found to be robust to these different assumptions. In this assessment, inclusion of the discard weights at age into the overall weight at age estimates had a substantial impact on estimated model outputs. The estimated 2010 SSB ranged from 9,479 – 16,301 mt and F_{full} from 0.79 – 1.54.

Biological Reference Points: No basis was found to change the foundation of the biological reference points from the previous GARM III Assessment. $F_{40\%}$ is recommended as the proxy for the overfishing threshold (F_{MSY}). A deterministic value of $F_{40\%}$ was estimated from a spawner per recruit analysis using 2008-2010 average SSB weights, catch weights, maturity and selectivity at age. Expressed as a fully recruited fishing mortality, $F_{40\%}$ is 0.20.

Stochastic projections at $F_{40\%}$ were used to determine new recommended biomass-related reference points (SSB_{MSY} and MSY proxies). The projection methodology used to determine SSB_{MSY} and MSY proxies was identical to that used for short-term projections. The proxy for SSB_{MSY} , the B_{TARGET} , is estimated at 61,218 mt, with 5th and 95th percentiles spanning 46,905 - 81,089 mt. One half of SSB_{MSY} is proposed for $B_{THRESHOLD}$ (30,609 mt).

The proxy for MSY is 10,392 mt, with 5th and 95th percentiles spanning 7,825 - 14,146 mt. The median recruitment was 7.4 million age 1 fish, with 5th and 95th percentiles ranging from 2.9 to 17.5 million fish.

The biological reference points that had been used previously were $F_{MSY}=F_{40\%}=0.237$, $SSB_{MSY}=58,248$ mt, and $MSY=10,014$ mt.

Fishing Mortality: In 1982, the fully recruited F was 0.9, and over the next decade fishing mortality (F_{full} , also called F_{mult}) mostly increased, peaking in the early 1990s (1.10-1.49). It subsequently decreased through 1999, but has since increased to 1.14 in 2010 (Figure A5).

Biomass: The ASAP model estimates a 1982 spawning stock biomass (SSB) of 23,675 mt. Spawning biomass decreased to the time series low (7,270 mt) in 1998 (Figure A6). Spawning biomass then increased steadily through 2002, but has been fluctuating around 8,000-14,000 mt for the last eight years. Spawning biomass in 2010 is estimated to be 11,868 mt.

Total population biomass (January 1) follows the same trend as SSB (Figure A6). It has ranged from 41,575 mt in 1982 to a low of 11,885 mt in 1998. The current estimate of total biomass in 2010 is 20,589 mt.

Recruitment: Mean recruitment (age 1) was around 8.7 million fish. Strong year classes were produced in 1982, 1983, 1985, 1986, and 1987 with below average recruitment in recent years (Figure A7). The 2005 year class was believed to be very strong based on survey estimates in 2007 and 2008 (NEFSC 2008). However, as this year class recruited to the fishery and to the fishery-independent surveys, data through 2010 indicate that this year class was not as strong as previously believed, but still above the time series average.

Special Comments:

- The addition of three years of catch and survey data since the last assessment has altered the perception of the 2005 year class. Two anomalously large tows in the spring survey (2007 and 2008) produced an estimate of this year class of 23.9 million fish in the previous assessment. The additional recent observations of this year class in the surveys, and now in the catch, have revised this estimate downwards to 8.9 million fish. This has reduced estimates of stock biomass substantially.
- Previous estimates of fish weights at age were biased high as a result of their being derived only from landed catch. The current assessment re-estimated weights at age based on both the landed and discarded catch, and this has resulted in lower weights at age and lower stock biomasses.
- Based on the previous assessment (NEFSC 2008), the stock was predicted to be rebuilt by 2009-2010. The current re-evaluation of the stock indicates that this expectation was incorrect.

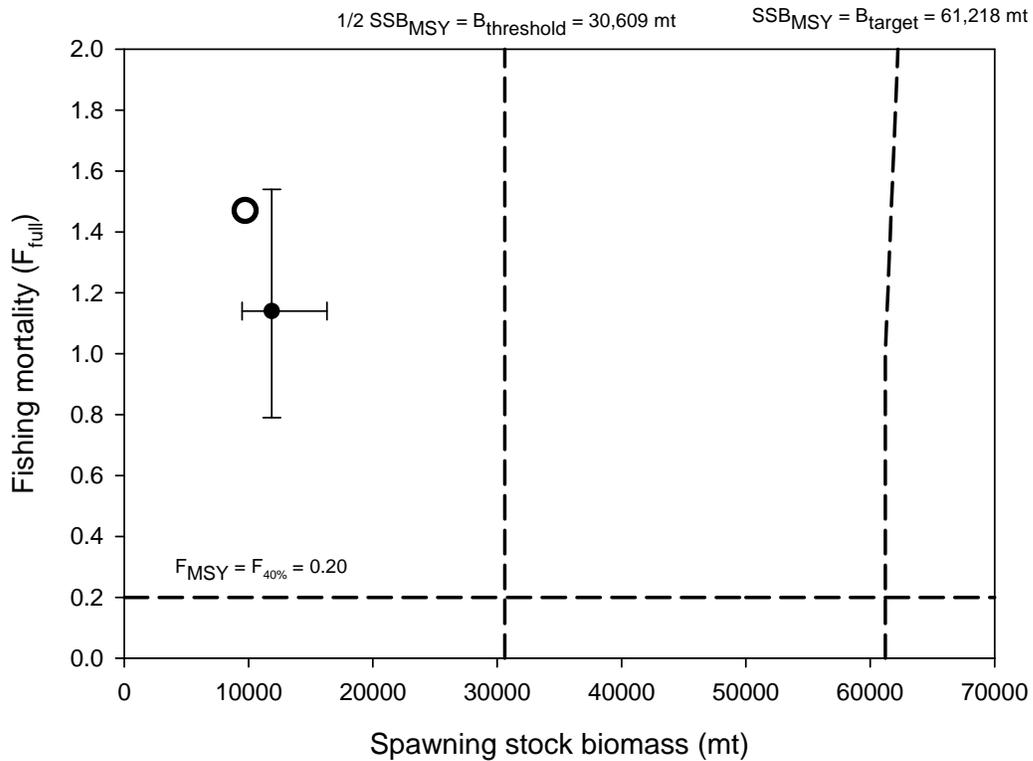
References:

- Northeast Fisheries Science Center. 2008. Assessment of 19 Northeast Groundfish Stocks through 2007: Report of the 3rd Groundfish Assessment Review Meeting (GARM III), Northeast Fisheries Science Center, Woods Hole, Massachusetts, August 4-8, 2008. US Dep Commer, NOAA Fisheries, Northeast Fish Sci Cent Ref Doc. 08-15; 884 p + xvii.
- Northeast Fisheries Science Center (NEFSC). (in prep. for 2012.) 53rd Northeast Regional Stock Assessment Workshop (53rd SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc.

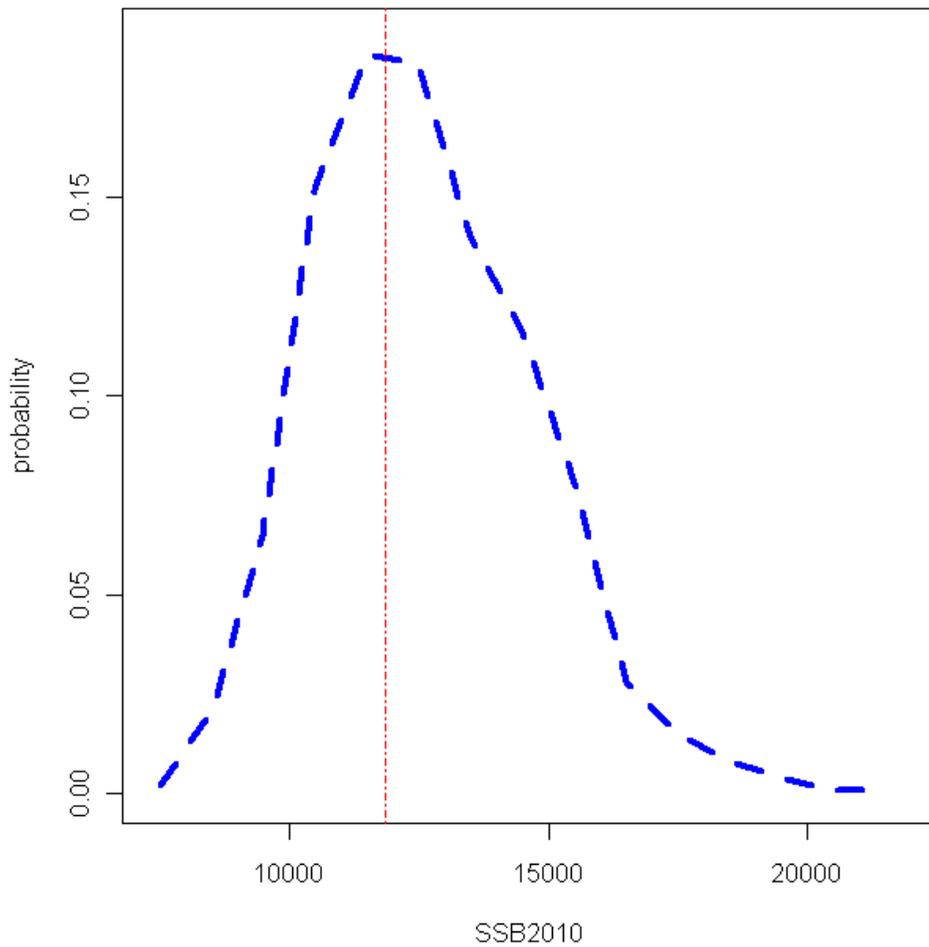
Table A1. Short term projections of total fishery yield and spawning stock biomass for Gulf of Maine Atlantic cod based on three different harvest scenarios: no fishing (F_0), fishing at 75% F_{MSY} , and fishing at F_{MSY} . The ‘Unadjusted’ notation indicates that these projections have not been adjusted to account for a retrospective pattern.

Total fishery yield (mt)			
Year	F_0	75% F_{MSY} (0.15)	F_{MSY} ($F_{40\%} = 0.20$)
	<i>Unadjusted</i>	<i>Unadjusted</i>	<i>Unadjusted</i>
2011	11,392	11,392	11,392
2012	0	1,001	1,313
2013	0	1,746	2,232
2014	0	2,780	3,482
2015	0	3,740	4,584
2016	0	4,629	5,562
2017	0	5,526	6,541
2018	0	6,399	7,469
2019	0	7,115	8,213
2020	0	7,682	8,777
2021	0	8,133	9,202
2022	0	8,508	9,560
2023	0	8,781	9,811
2024	0	8,972	9,981
2025	0	9,116	10,100
Spawning stock biomass (mt)			
Year	F_0	75% F_{MSY} (0.15)	F_{MSY} ($F_{40\%} = 0.20$)
	<i>Unadjusted</i>	<i>Unadjusted</i>	<i>Unadjusted</i>
2011	8,178	8,178	8,178
2012	7,069	6,894	6,834
2013	13,073	11,838	11,463
2014	21,656	18,311	17,363
2015	31,565	24,809	23,014
2016	42,701	31,286	28,405
2017	55,765	38,067	33,884
2018	70,054	44,968	39,337
2019	85,801	51,811	44,599
2020	99,450	57,382	48,761
2021	110,811	61,576	51,821
2022	121,689	65,347	54,534
2023	130,611	68,136	56,370
2024	138,032	70,219	57,820
2025	144,000	71,759	58,819

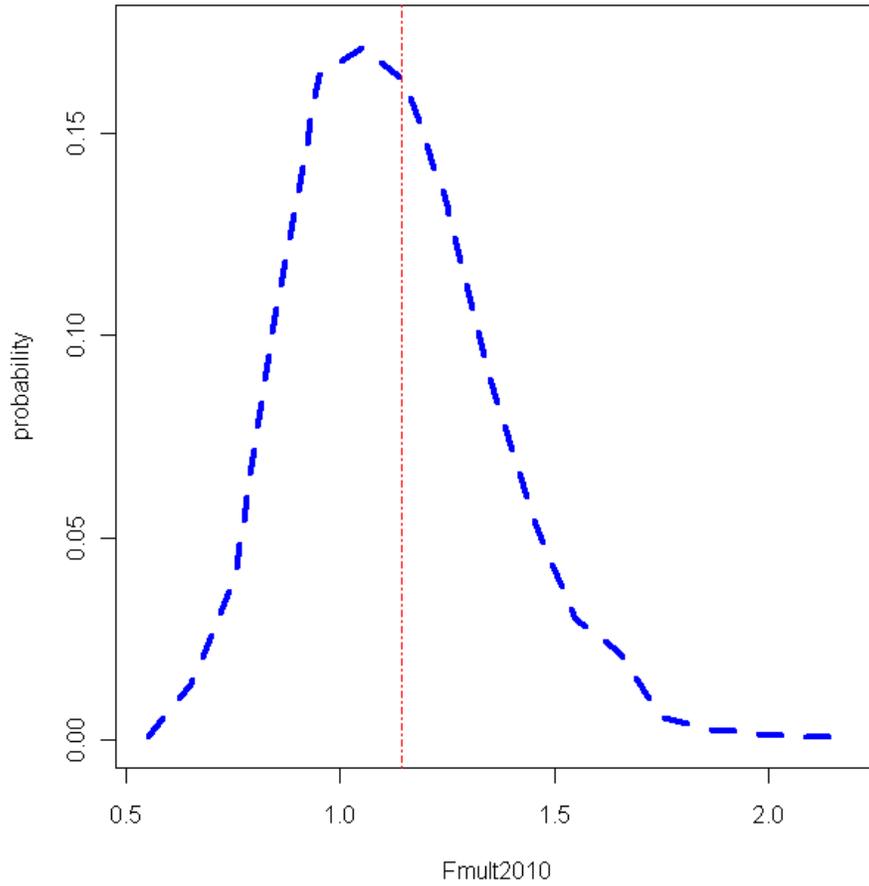
Gulf of Maine Atlantic cod stock status



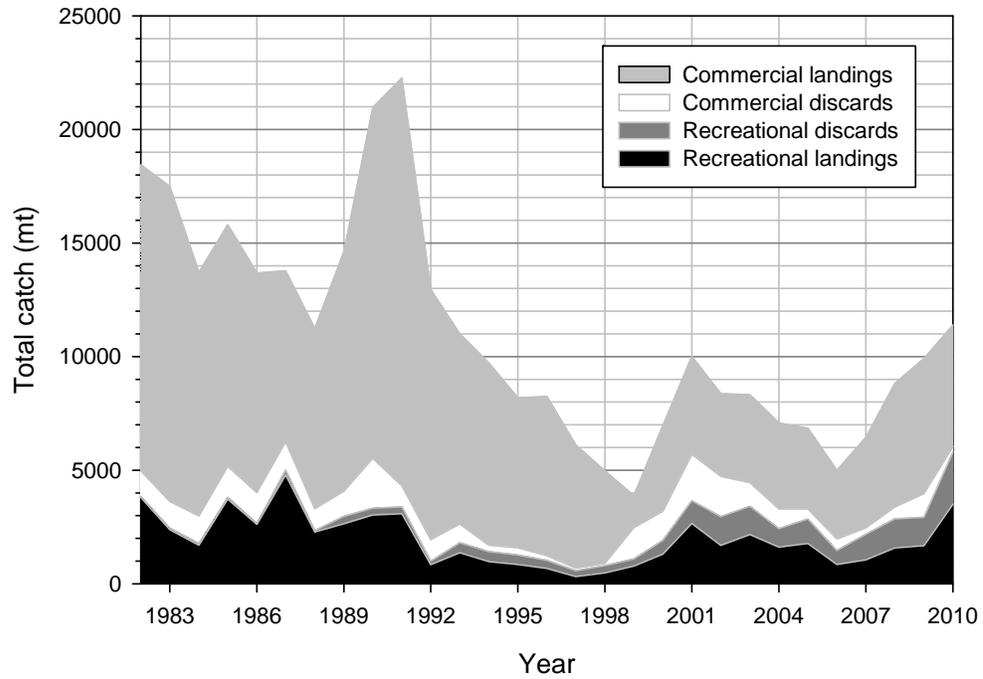
A1. Stock status based on estimates of F and SSB for 2010 for Gulf of Maine Atlantic cod with respect to biological reference points (solid circle); error bars represent 90% confidence intervals. The figure also shows fishing mortality and spawning stock biomass estimates that have been adjusted to account for retrospective pattern (open circle).



A2. MCMC distribution of the estimate of the 2010 spawning stock biomass (SSB2010) for Gulf of Maine Atlantic cod. The final year point estimate is indicated by the dashed vertical red line.



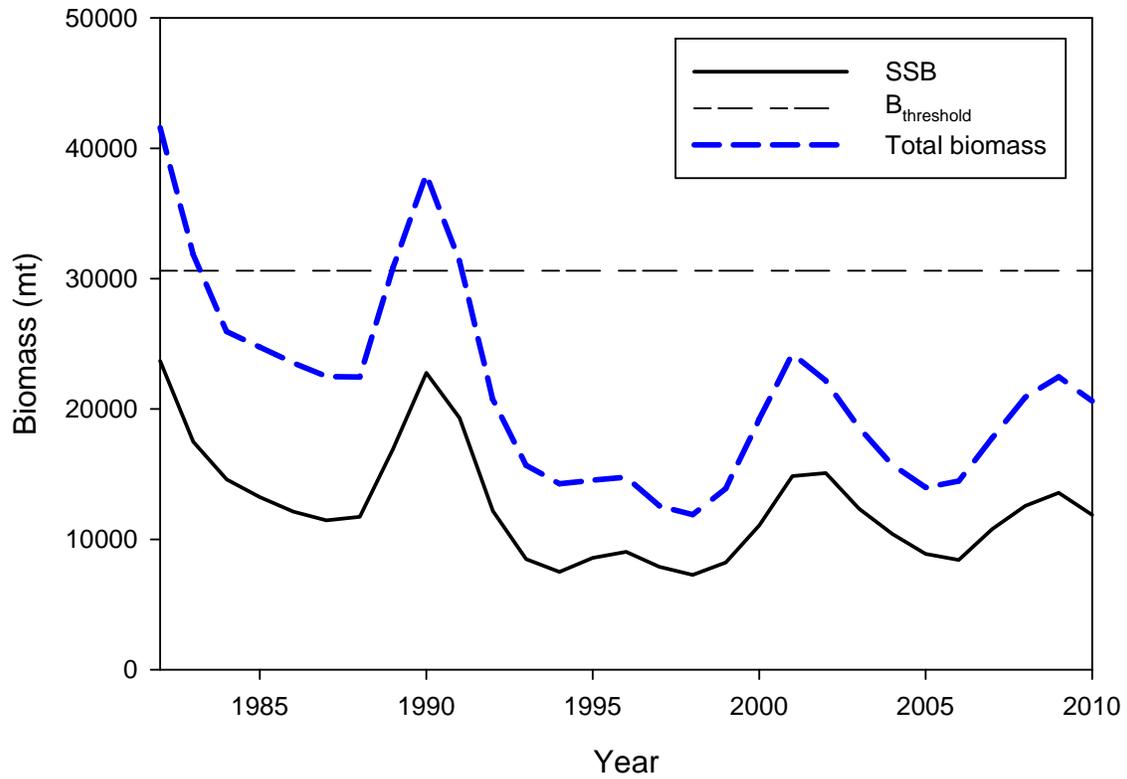
A3. MCMC distribution of the estimate of the 2010 fishing mortality for Gulf of Maine Atlantic cod ($F_{\text{mult}} = F_{\text{full}}$). The final year point estimate is indicated by the dashed vertical red line.



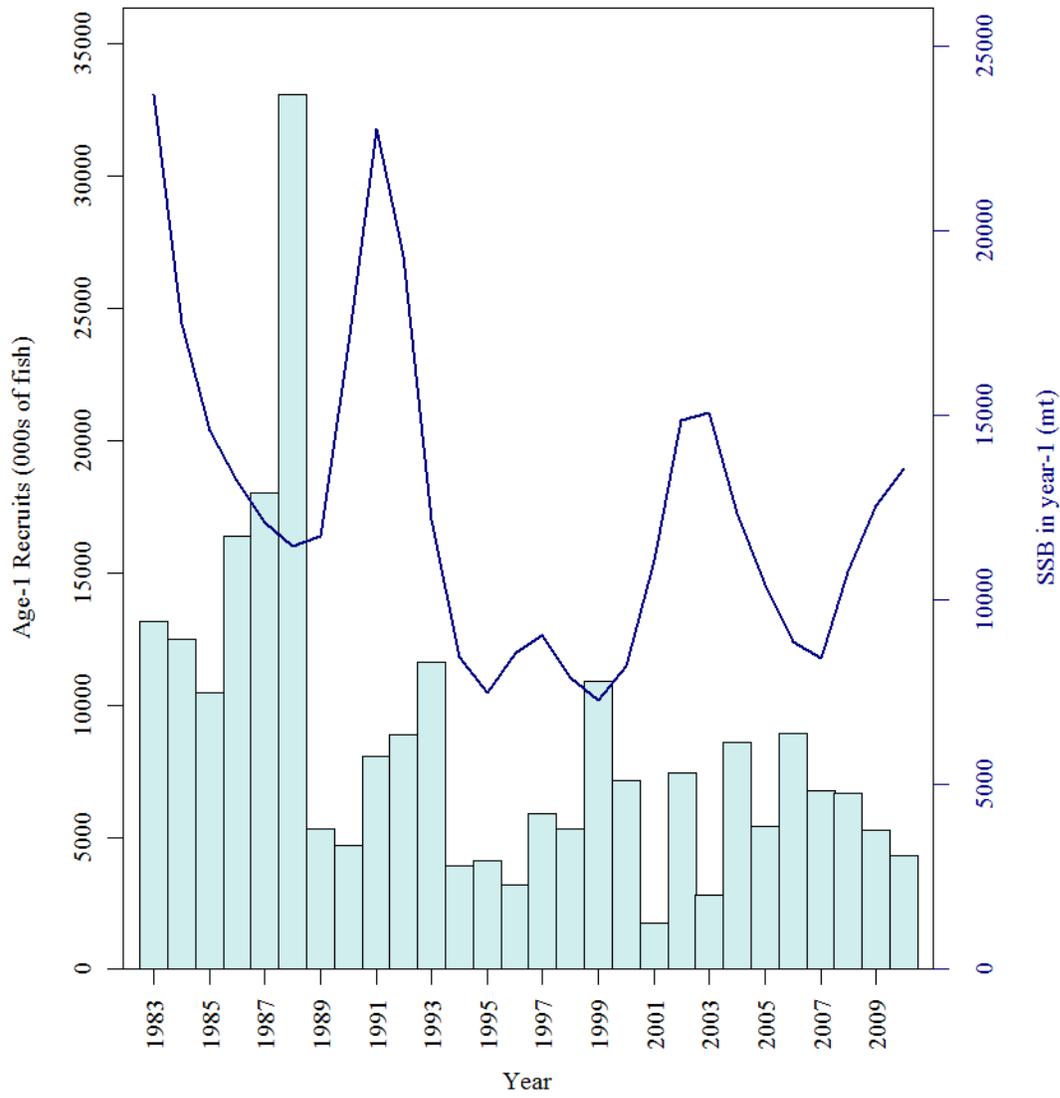
A4. Total catch of the Gulf of Maine Atlantic cod between 1982 and 2010 by fleet (commercial and recreational) and disposition (landings and discards).



A5. Estimated trends in fishing mortality (F_{full}) of Gulf of Maine Atlantic cod and associated overfishing level, $F_{Threshold}$.



A6. Estimated trends in total biomass and spawning stock biomass (SSB) of Gulf of Maine Atlantic cod and the associated overfished level, $SSB_{\text{threshold}}$.



A7. Time series plot of Gulf of Maine Atlantic cod spawning stock biomass in year t-1 (SSB, solid line) and recruitment of age-1 fish in year t (solid bars).