A. GULF OF MAINE ATLANTIC COD ASSESSMENT SUMMARY FOR 2012

In what follows, there are two population assessment models and a result is presented for each model. The first number is from the $M_{0.2}$ (natural mortality, M=0.2) assessment model and the second number is from the M_{Ramp} (M ramps from 0.2 to 0.4) assessment model (see Data and Assessment section below for a description of the models).

State of Stock: The Gulf of Maine Atlantic cod (*Gadus morhua*) stock is overfished and overfishing is occurring (Figure A1). Spawning stock biomass (SSB) in 2011 is estimated to be 9,903 mt or 10,221 mt which is 18% or 13% of the SSB_{MSY} proxy (54,743 mt or 80,200 mt) in the $M_{0.2}$ or M_{Ramp} models, respectively (Figure A2). The 2011 fully selected fishing mortality is estimated to be 0.86 or 0.90 which is about 4 or 5 times the F_{MSY} proxy (0.18 for both models) (Figure A3).

Projections: Based on recommendations made in 2011 by the SARC 53 Panel, the short term projection method samples from a cumulative density function derived from ASAP estimated age-1 recruitment between 1982 and 2009. Recruitments in 2010 and 2011 were not included due to their greater variance. No retrospective adjustment is applied in the projections. The model adjusts projected recruitment when SSB falls below the lowest spawning stock biomass estimate (6.3 kmt or 7.9 kmt) based on a linear function that declines to zero when spawning stock biomass equals 0 mt. There are two sets of projections for the M_{Ramp} assessment in addition to the single projection for the $M_{0.2}$ assessment (Table A1).

One of the consequences of going forward with multiple models is there are a different set of conditions and reference points that come out of these models. General proposals are outlined to construct projections and provide some interpretation as to how they might be used. This results in at least four cases.

1. $M_{0.2}$ model with M=0.2 for projections: standard procedures
2. M_{Ramp} model with M=0.2 for projections: standard procedures
3. M_{Ramp} model with M=0.4 for some period then reverting to M=0.2
4. M_{Ramp} model with M=0.4 in perpetuity (regime shift scenario)

Cases 1-3 are compared to an M=0.2 reference point whereas for Case 4 the reference point would change and be based on M=0.4. Case 4 has not been examined. Cases 1-3 are relevant for short term (3 years) catch projections. Case 3 cannot be evaluated for $F_{rebuild}$ because the timing of change in M from 0.4 to 0.2 is unknown. Cases 1-2 can be used to calculate $F_{rebuild}$. Case 4 could be done as well, however this would indicate that the stock would never rebuild to historical levels. The SARC Panel was not willing to conclude that M would remain at 0.4 in perpetuity and so did not provide reference points for Case 4.

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

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Min[1]	Mean[1]	Max[1]
Commercial landings	3.6	3.9	3.8	3.6	3.0	4.0	5.4	6.0	5.4	4.6	1.4	7.4	18.0
Commercial discards	1.3	0.7	0.6	0.3	0.3	0.2	0.3	0.8	0.2	<0.1	<0.1	0.6	1.6
Recreational landings	1.3	1.6	1.2	1.3	0.7	1.0	1.3	1.4	1.8	1.8	0.2	1.4	3.5
Recreational discards	0.3	0.3	0.2	0.3	0.2	0.3	0.3	0.3	0.4	0.3	<0.1	0.1	0.4
Catch used in assessment	6.5	6.5	5.8	5.4	4.3	5.5	7.4	8.4	7.7	6.8	3.1	9.6	21.0
ASAP ($M_{0.2}$)													
Spawning stock biomass	12.0	10.0	8.6	7.2	6.8	8.7	10.3	11.5	11.1	9.9	6.3	11.0	22.0
F_{full}[2]	0.57	0.67	0.68	0.92	0.78	0.75	0.94	0.98	0.87	0.86	0.48	0.89	1.53
Recruitment (age 1)	5.2	1.9	6.3	3.9	6.6	5.3	4.5	3.5	2.2	1.2	1.2	6.8	27.9
ASAP (M_{Ramp})													
Spawning stock biomass	17.2	14.0	11.9	9.8	9.3	11.7	13.3	14.3	13.0	10.2	7.9	12.7	21.5
F_{full}[2]	0.40	0.48	0.50	0.70	0.60	0.60	0.77	0.83	0.79	0.90	0.35	0.80	1.46
Recruitment (age 1)	11.5	4.3	14.3	8.7	14.5	11.0	8.7	6.3	3.5	1.7	1.7	9.7	30.1

[1] years 1982-2011
[2] F_{full} is the fishing mortality on fully selected ages

Stock Distribution and Identification: Atlantic cod is a demersal gadoid species whose range in United States (US) waters extends from Cape Hatteras north to the Canadian border. Within the United States Exclusive Economic Zone (EEZ) there are two recognized stocks of cod: Gulf of Maine and Georges Bank. The current Gulf of Maine management unit extends from the northern tip of Cape Cod east to the US/Canadian border and north to the coast of Maine (Figure A4). The regional stock structure of cod is in the process of being reviewed, but alternate stock structures were not evaluated in this assessment.

Catches: Since 1982, fishery removals of Gulf of Maine Atlantic cod have ranged from 3,078 mt to 20,978 mt. Recent fishery removals over the past five years have ranged from approximately 5,500 mt to 8,400 mt. Prior to 1989 there are no direct estimates of commercial discards but discards were hindcast back to 1982 by gear and prior to 1981 there are no direct estimates of recreational removals. Since 1982, commercial landings have been the largest source of fishery removals, constituting 40-90% of the total catch. Commercial discards were a large fraction between 1998 and 2003 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 fishery removals but have ranged from 1-33% since 1982 (Figure A5). Recreational catch has varied annually from a low of 295 mt in 1997 to a high of 3,595 mt in 1987. Recreational catches have constituted between 5% and 31% of total annual removals, averaging 18% over the period 1982-2011.

Data and assessment: The previous assessment (i.e., SAW/SARC53) of Gulf of Maine cod was conducted using the statistical catch-at-age model (ASAP) that incorporated commercial and recreational landings and discards. In this SAW/SARC55 assessment, two of the models put

forward by the cod working group were used (see Special Comments section). In one model ($M_{0.2}$), natural mortality, M, was assumed to be 0.2 for all years. The other model (M_{Ramp}) was implemented with M=0.2 from 1982 to 1988, and M=0.4 between 2003 and 2011, with a linear ramp between 1989 and 2002. These values of M were applied to all ages.

The assessments include updated recreational catch estimates, revised discard mortality estimates and minor modifications to the Massachusetts Department of Marine Fisheries (MADMF) spring survey. Discard mortality was assumed to vary by gear type and fishery (commercial, recreational). This represents a change from the previous assessment that assumed 100% mortality of all discarded fish. The revised discard estimates range from 20-80% depending on gear type and fishery. The revision to the recreational discard mortality assumption had the largest impact on the assessment with respect to the data changes made since the previous assessment (NEFSC 2012).

The recreational catch estimation was changed from the previous assessment from MRFSS to MRIP.

The updated models used three fishery selectivity blocks instead of two blocks used in the previous assessment model. Finally, the new models assumed flat-topped selectivity for both the catch and NEFSC survey indices whereas the previous model (NEFSC 2012) assumed flat-topped selectivity for the NEFSC surveys only. All catch sources were combined into a single fleet.

Swept-area estimates of abundance from the NEFSC spring and autumn surveys (1982-2011), and the Massachusetts Department of Marine Fisheries (MADMF) spring survey (1982-2011) were used in the ASAP models along with associated estimates of uncertainty and annual age composition. The aggregate indices of abundance (numbers) have generally declined since time series highs in the 1960/1970s. Current indices are at, or near, all time lows (Figure A6).

Biological Reference Points: An MSY could not be derived directly from the two assessments. Therefore an MSY proxy must be used for reference points. $F_{40\%}$ is the proxy used for the overfishing threshold (F_{MSY}). This is consistent with the choice of proxy in the previous assessment and the SAW 55 working group's recommendation. A deterministic value of $F_{40\%}$ was calculated from a spawner per recruit analysis using 2009-2011 average SSB weights, catch weights, selectivity and maturity. Expressed as a fully selected fishing mortality, $F_{40\%}$ is 0.18.

Stochastic projections at $F_{40\%}$ were used to determine new recommended biomass-related reference points (proxies for both SSB_{MSY} and MSY). The projection methodology used to determine SSB_{MSY} and MSY proxies was identical to those used for short-term projections.

Proxy reference points	**$M_{0.2}$**	**M_{Ramp}**
F_{MSY}	0.18	0.18
SSB_{MSY} (mt)	54,743 (40,207 - 73,354)	80,200 (64,081 - 99,972)
MSY (mt)	9,399 (6,806 - 13,153)	13,786 (10,900 - 17,329)
Median age1 recruitment (000s)	5,254	9,446

Intervals shown are the 5th and 95th percentiles.

The biomass threshold is ½ SSB_{TARGET}.

The biological reference points estimated in the last assessment (NEFSC 2012) using a constant M=0.2 were $F_{MSY}=F_{40\%}=0.20$, $SSB_{MSY}=61{,}218$ mt, and MSY=10,392 mt.

Fishing Mortality: The lowest estimate of fully selected fishing mortality (F_{full}) over the assessment time series is 0.48 or 0.35 (1999). The 2011 F_{full} is lower than the time series high of 1.53 or 1.46 (1993); it is estimated at 0.86 (90% posterior probability interval 0.53 – 1.05) or 0.90 (90% posterior probability interval 0.57 – 1.09), but still 4.7 or 5.0 times higher than the F_{MSY} proxy (Figure A3).

Biomass: The estimates of spawning stock biomass (SSB) from both models have generally declined from a time series high of 22,036 or 21,531 mt in 1982. There were small increases in SSB in the early and late 2000s, but SSB has been declining since 2009 (Figure A2). SSB in 2011 is estimated to be 9,903 mt (90% posterior probability interval 7,644 – 13,503 mt) or 10,221 mt (90% posterior probability interval 7,943 – 13,676 mt). The spawning stock biomass is well below the SSB_{MSY} proxy and the biomass threshold in both models.

Recruitment: The time series mean recruitment (age 1) was around 6.8 million fish or 9.7 million fish. Strong year classes were produced in 1981-1987. Subsequently, the recruitment estimates differ due to the different assumptions about natural mortality (Figure A7). Over the last five years recruitment estimates have declined to a low level in both assessments.

Special Comments:

- Since the mid-1990s the distribution of cod has become increasingly concentrated in the western part of the Gulf, with a gradual loss of cod from the coastal and central Gulf.

- Since the mid-2000s, the fishing fleet has become particularly concentrated in a small region of the western Gulf due to the fine scale aggregation of cod in an area where their prey (sand lance) were increasingly available. This biases fishery CPUE as an indicator of the abundance of the stock as a whole.

- If recent weak recruitment of Gulf of Maine cod continues, productivity and rebuilding of the stock will be less than projected.

- The NEFSC 2011 fall and 2012 spring survey abundance indices were the 4th lowest and the lowest in their respective time series. The MADMF 2012 spring survey index was also the lowest in its times series. As the 2012 observations were not incorporated into the assessment formulations, the projections are likely to be optimistic.

- For both Georges Bank and Gulf of Maine cod stocks there is considerable uncertainty associated with natural mortality rates. With the **Georges Ban**k stock there were multiple assessments presented, but for the ones considered the projections and reference points were very similar. Furthermore, the results of the ramp mortality model that was considered could be taken to imply that the apparent changes in the system were likely due to changes in natural mortality when in fact this is uncertain. Consequently, a different approach was needed. In this circumstance the SARC Panel decided to work with a single model with constant natural mortality rate and a retrospective adjustment to better reflect an inability to identify the causal mechanisms of the changes in the system.

- In contrast, in the **Gulf of Maine** stock the biomass reference points and some of the projections showed a greater difference than the Georges Bank projections especially under alternative future natural mortality regimes. In the end, the set of projections considered in these comparisons differed between the two cod stocks. Given the pros and cons presented by the working group regarding natural mortality, the SARC Panel was unable to decide between two natural mortality assumptions. So a range of scenarios was selected and is being carried forward. A number of scenarios are being explored and the state of nature as reflected in the natural mortality rates included in the models is uncertain. Although it is not straightforward to determine the numeric values for stock status, the stock is overfished and overfishing is occurring based on both models.

- The SARC Panel concluded that if M is currently 0.4 then it seemed more reasonable to assume that in the short-term M would remain at 0.4 rather than reduce to 0.2.

- If M stays at 0.4 levels in the M_{Ramp} model (Case 4), then the stock could only return to levels much below those associated with an M=0.2 scenario.

- A Delphi method had been applied prior to the working group meetings to find alternative values of discard mortality rates for different gears. The retrospective pattern was worse with the lower discard mortality rates, implying that the ramp M approach could be partially aliasing fishing mortality. However returning all the discard mortality rates to 100% from those specified by the Delphi method resulted in marked differences in SSB estimates and a reduction in the retrospective pattern.

References:

Northeast Fisheries Science Center (NEFSC). 2012. Stock Assessment of Gulf of Maine Atlantic cod. 53th Northeast Stock Assessment Workshop. NEFSC Ref. Doc. 12-05.

Northeast Fisheries Science Center (NEFSC). In prep. Stock Assessment of Gulf of Maine Atlantic cod. 55th Northeast Stock Assessment Workshop.

Table A1. Short term projections of total fishery yield and spawning stock biomass for Gulf of Maine Atlantic cod based on a harvest scenario of fishing at 75% F_{MSY} between 2013 and 2015. Catch in 2012 has been estimated at 3,767 mt. There are two sets of projections for the M_{Ramp} assessment in addition to the single projection for the $M_{0.2}$ assessment. The two M_{Ramp} projections differ in the assumed natural mortality rate in subsequent years starting in 2012. One is set at M=0.2 while the other is set at M=0.4, to bracket the range of natural mortality rates used in the M_{Ramp} model.

Year	Input	ASAP, 1982 BASE			ASAP, 1982 M-RAMP					
		M=0.2			M=0.2			M=0.4		
		Fmsy = 0.18, Bmsy = 54,743 mt			Fmsy = 0.18, Bmsy = 80,200 mt			Fmsy = 0.18, Bmsy = 80,200 mt		
		Rebuild year at 75% F_{MSY} = 2022			Rebuild year at 75% F_{MSY} = 2022			NO REBUILD at 75% F_{MSY}		
		Catch (mt)	Spawning stock biomass (mt)	F_{full}	Catch (mt)	Spawning stock biomass (mt)	F_{full}	Catch (mt)	Spawning stock biomass (mt)	F_{full}
2011	Model result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	10,221	0.90
2012	Assumed catch	3,767	8,995	0.46	3,767	8,196	0.52	3,767	7,711	0.58
2013	Projection	1,249	9,406	0.14	1,142	9,163	0.14	822	6,927	0.14
2014	Projection	1,503	12,143	0.14	1,563	13,916	0.14	935	8,875	0.14
2015	Projection	2,030	16,802	0.14	2,582	22,124	0.14	1,313	12,234	0.14

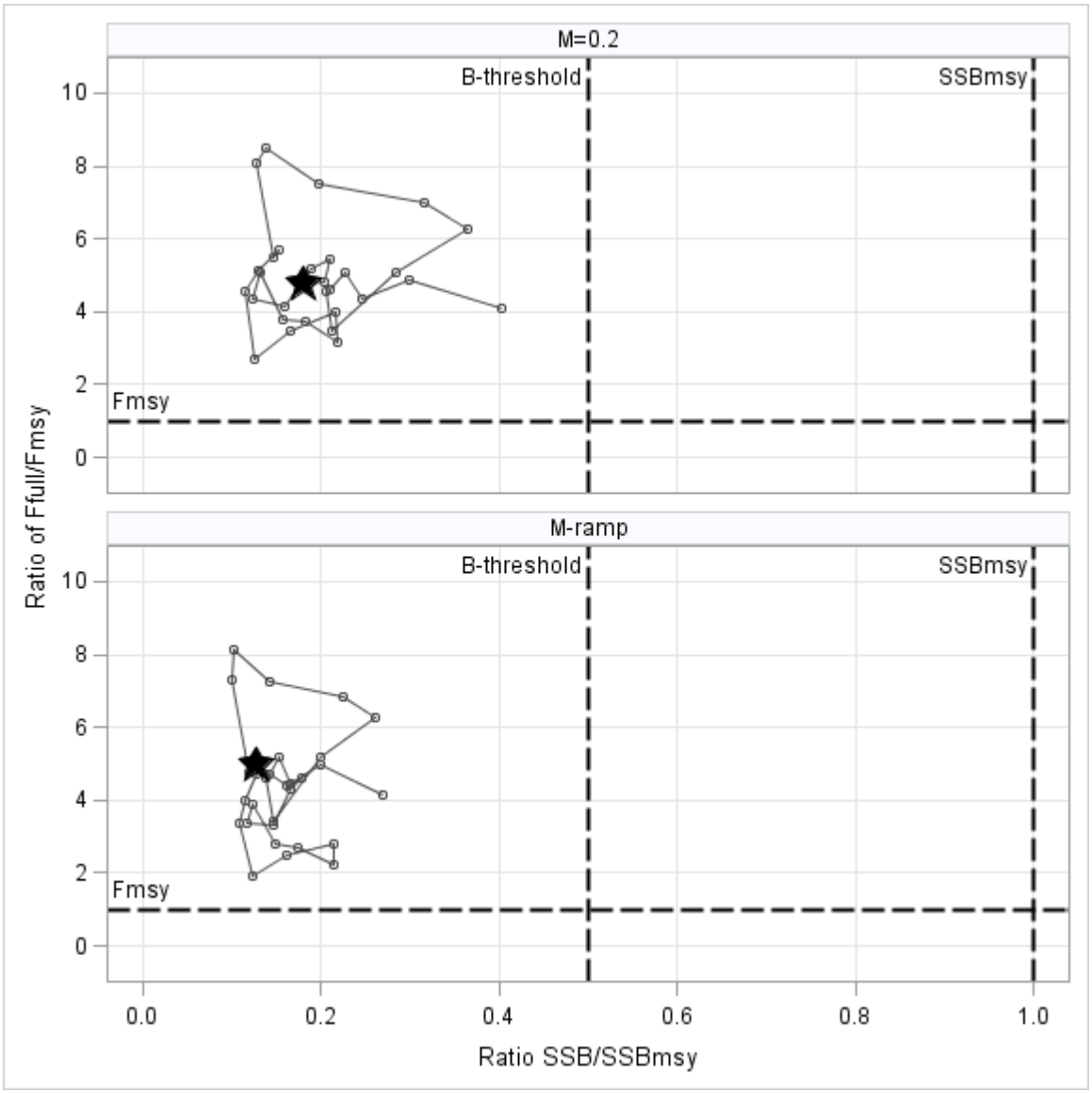


Figure A1. Time series plot of the Gulf of Maine Atlantic cod fully selected fishing mortality/2011 F_{MSY} ratio relative to the spawning stock biomass/2011 SSB_{MSY} ratio from 1982 to 2011. Results are shown for both the $M_{0.2}$ (top) and M_{Ramp} (bottom) models. Most recent value is indicated by a star.

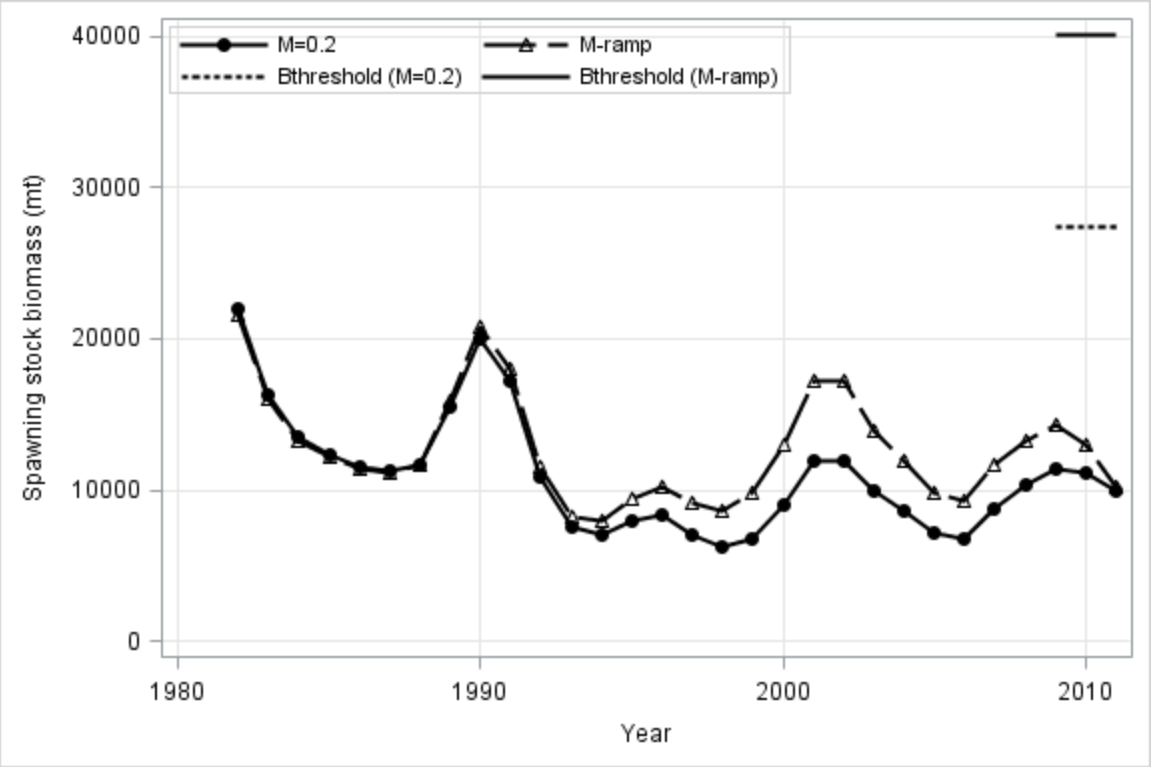


Figure A2. Estimated trends in the spawning stock biomass of Gulf of Maine Atlantic cod between 1982 and 2011 and the corresponding $SSB_{threshold}$ (1/2 SSB_{MSY}) based on the 2012 assessment. Results are shown for both the $M_{0.2}$ and M_{Ramp} models.

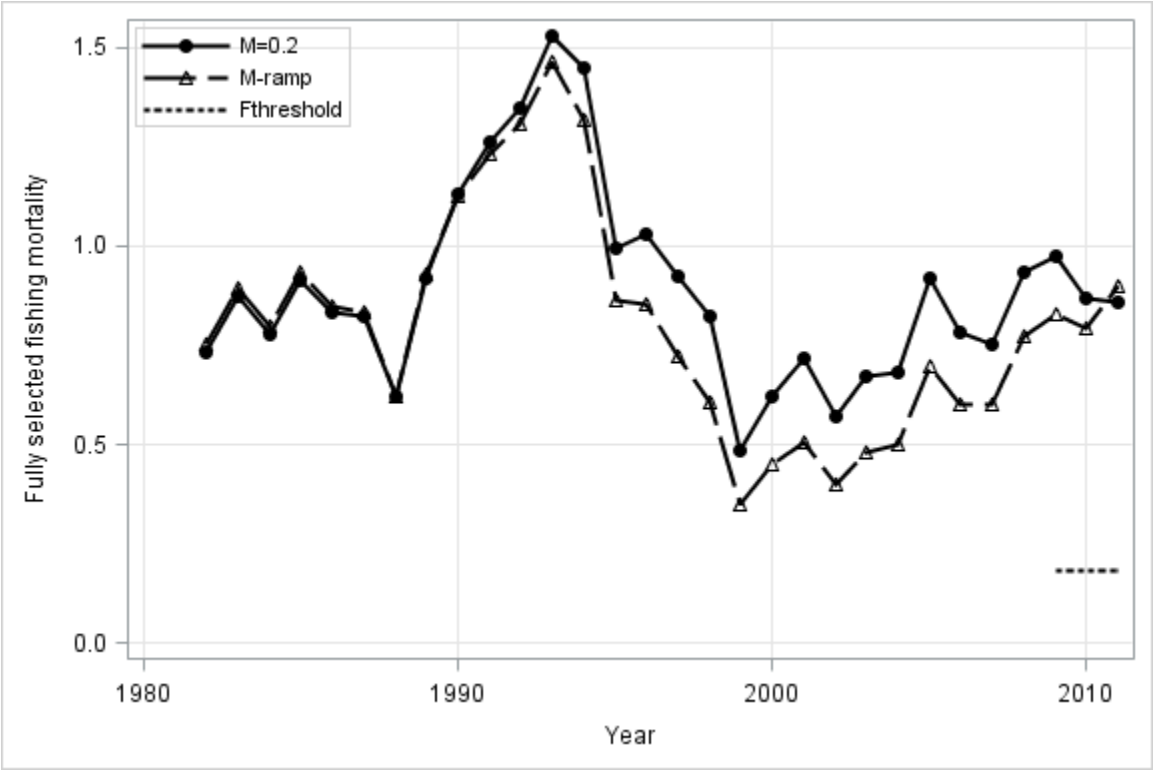
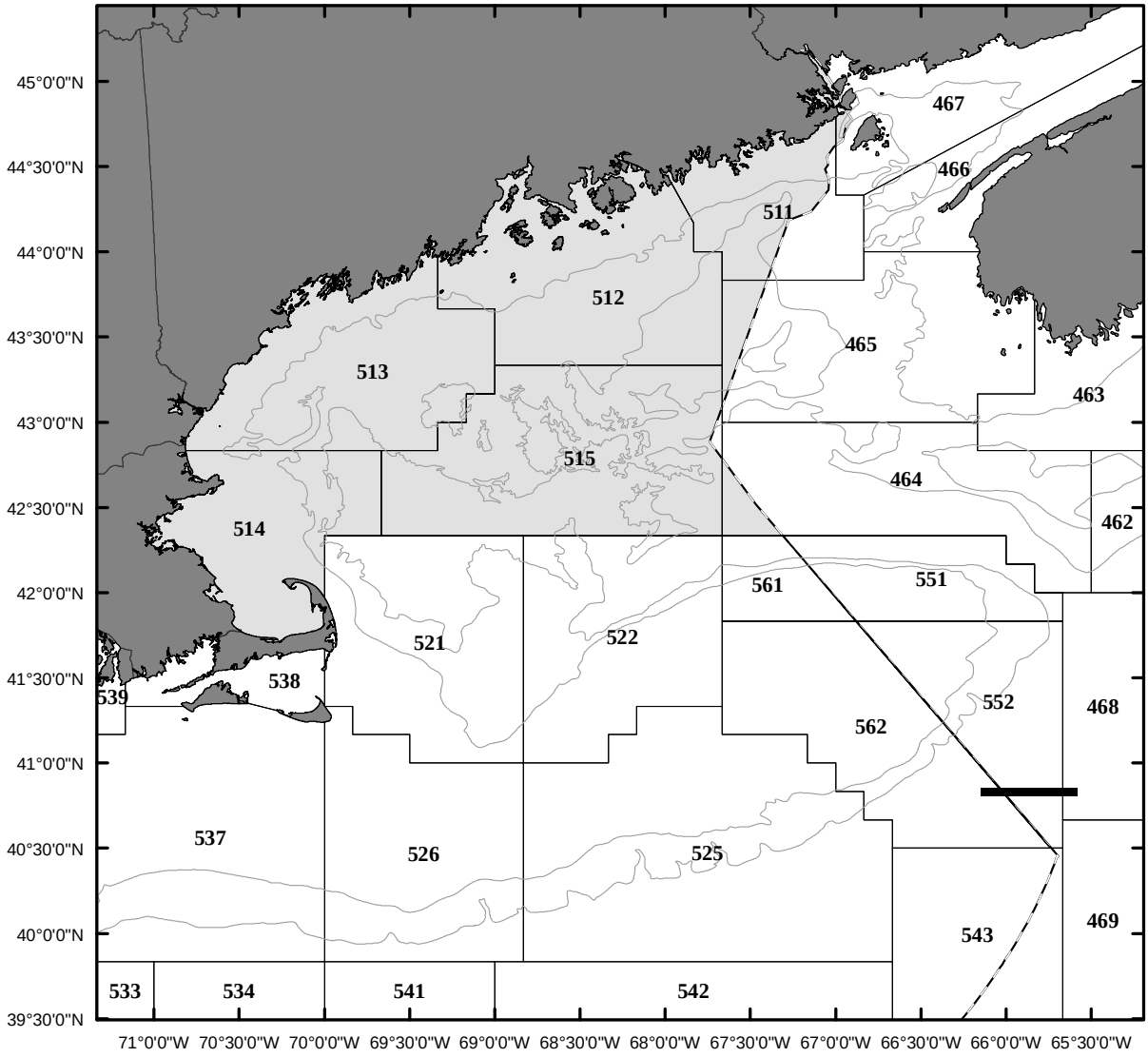


Figure A3. Estimated trends in the fully selected fishing mortality (F_{full}) of Gulf of Maine Atlantic cod between 1982 and 2011, and the corresponding F_{MSY} based on the 2012 assessment. Results are shown for both the $M_{0.2}$ and M_{Ramp} models. Both assessment models had identical F_{MSY} proxies. **Note that the time series includes three selectivity blocks (1982-1988, 1989-2004, 2005-2011) and the F_{full} values are not necessarily comparable between blocks.*



Figue A4. Map of the Gulf of Maine Atlantic cod (*Gadus morhua*) management and assessment area (shaded grey). The United States exclusive econic zone (EEZ) is defined by the dashed line.

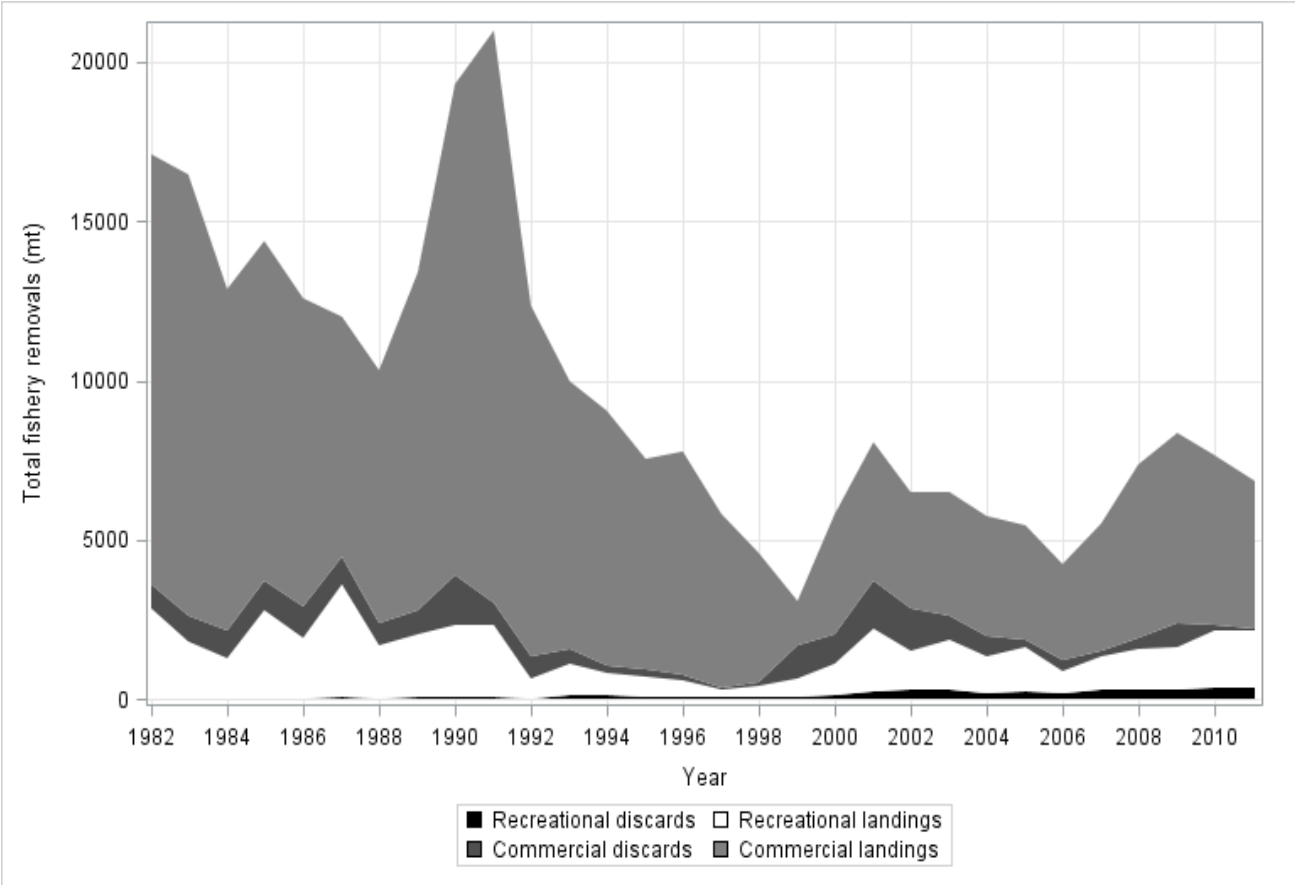


Figure A5. Total catch of the Gulf of Maine Atlantic cod between 1982 and 2011 by fleet (commercial and recreational) and disposition (landings and discards).

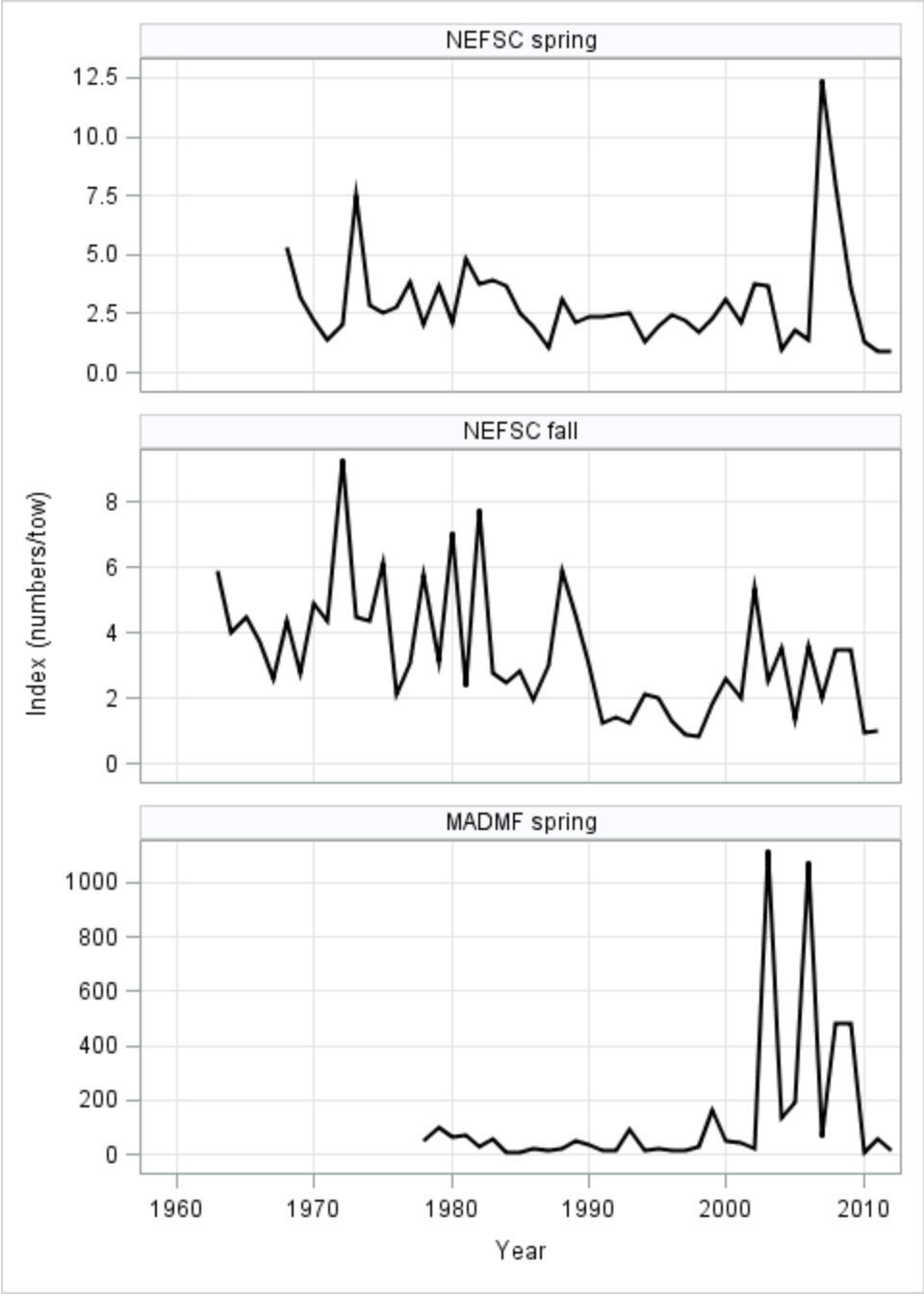


Figure A6. Indices of abundance for the Gulf of Maine Atlantic cod between 1963 and 2012 for the Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl surveys and the Massachusetts Department of Marine Fisheries (MADMF) spring bottom trawl survey.

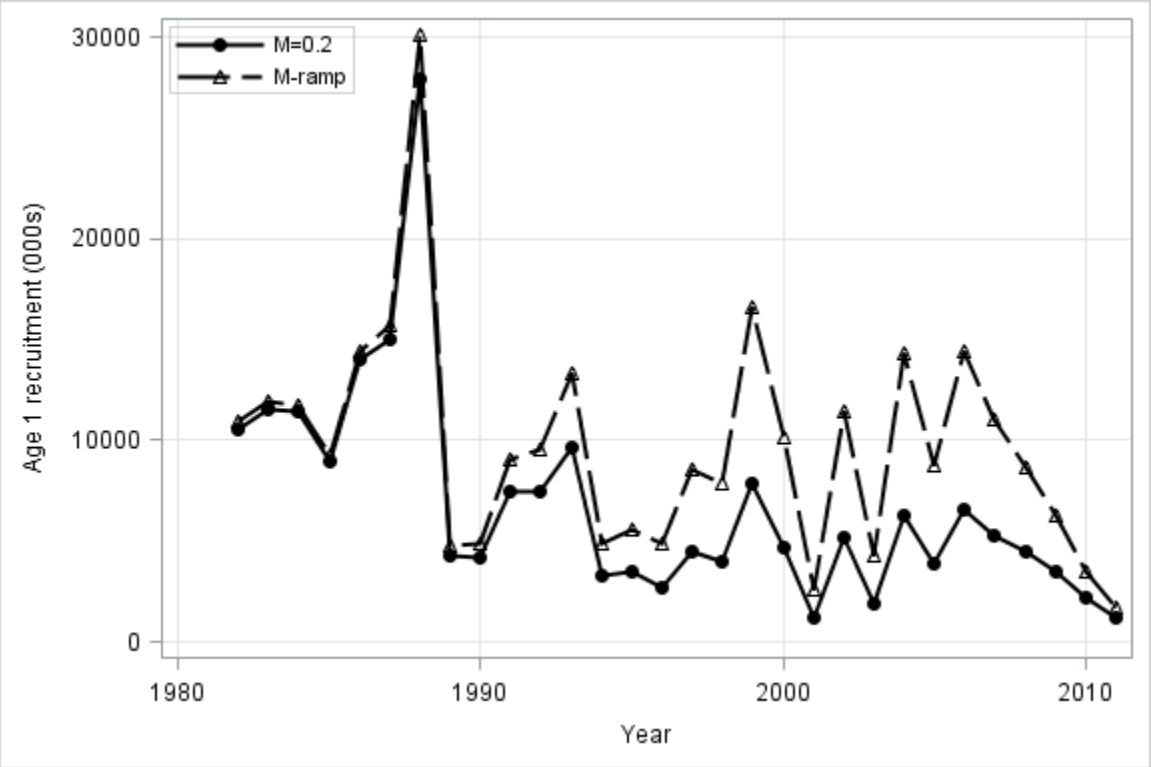


Figure A7. Estimated trends in age 1 recruitment (000s fish) of Gulf of Maine Atlantic cod between 1982 and 2011 based on the 2012 assessment. Results are shown for both the $M_{0.2}$ and M_{Ramp} models.