2 Gulf of Maine Atlantic cod

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This assessment of the Gulf of Maine Atlantic cod (Gadus morhua) stock is an operational assessment of the existing benchmark assessment (NEFSC 2013). This stock was most recently assessed in 2015 (NEFSC 2015). This assessment updates commercial and recreational fishery catch data, research survey indices of abundance, and the analytical ASAP assessment models through 2016. Additionally, stock projections have been updated through 2020. In what follows, there are two population assessment models brought forward from the most recent benchmark assessment (2012), the M=0.2 (natural mortality = 0.2) and the M-ramp (M ramps from 0.2 to 0.4) assessment models (see NEFSC 2013 for a full description of the model formulations).

State of Stock: Based on this updated assessment, the stock status for the Gulf of Maine Atlantic cod (*Gadus morhua*) stock is overfished and overfishing is occurring (Figures 10-11). Retrospective adjustments were not made to the model results (see Special Comments section of this report). Spawning stock biomass (SSB) in 2016 was estimated to be 3,046 (mt) under the M=0.2 model and 3,262 (mt) under the M-ramp model scenario (Table 9) which is 8% and 5% (respectively) of the biomass target, SSB_{MSY} *proxy* (40,604 (mt) and 59,714 (mt); Figure 10). The 2016 fully selected fishing mortality was estimated to be 0.228 and 0.237 which is 131% and 134% of the F_{MSY} *proxy*($F_{40\%}$; 0.174 and 0.177; Figure 11).

Table 9: Catch and status table for Gulf of Maine Atlantic cod. All weights are in (mt), recruitment is in (000s), and F_{Full} is the fishing mortality on fully selected ages.

	2009	2010	2011	2012	2013	2014	2015	2016
				Data				
Recreational discards	142	188	164	48	69	85	80	176
Recreational landings	1,399	1,803	1,813	571	705	528	4	95
Commercial discards	752	171	99	93	52	26	14	8
Commercial landings	5,953	5,356	4,598	2,759	951	832	227	320
Catch for Assessment	8,247	7,517	6,673	3,472	1,777	1,471	325	599
				Model Results (M=0.2)				
Spawning Stock Biomass	10490	8881	5703	2836	1661	1449	1897	3046
F_{Full}	1	1.045	1.542	1.844	1.673	1.634	0.21	0.228
Recruits $age1$	2025	1188	1233	1526	842	3129	1215	457
				Model Results (M-ramp)				
Spawning Stock Biomass	13390	10931	6805	3451	2118	1896	2366	3262
F_{Full}	0.824	0.886	1.335	1.585	1.412	1.361	0.188	0.237
Recruits $age1$	3955	2289	2405	3010	1606	5590	1999	699

Table 10: Comparison of reference points estimated in an earlier assessment and from the current assessment update. The overfishing threshold is the F_{MSY} *proxy* ($F_{40\%}$). The biomass target, (SSB_{MSY} *proxy*) was based on long-term stochastic projections of fishing at the F_{MSY} *proxy*. Median recruitment reflects the median estimated age-1 recruitment from 1982 - 2012. Intervals shown reflect the 5^{th} and 95^{th} percentiles.

	2015 M=0.2	2015 M-ramp	M=0.2	M-ramp
F_{MSY}	0.185	0.187	0.174	0.177
SSB_{MSY} (mt)	40,187 (27,551 - 58,228)	59,045 (44,976 - 76,525)	40,604 (27,631 - 58,553)	59,714 (44,732 - 77,611)
MSY (mt)	6,797 (4,608 - 9,990)	10,043 (7,560 - 13,130)	7,049 (4,699 - 10,380)	10,502 (7,734 - 13,822)
Median recruits age-1) (000s)	4,406 (1,458 - 14,450)	8,965 (2,489 - 15,908)	4,377 (1,161 - 14,434)	8,464 (2,353 - 15,934)
Overfishing	Yes	Yes	Yes	Yes
Overfished	Yes	Yes	Yes	Yes

Projections: Short term projections of median total fishery yield and spawning stock biomass for Gulf of Maine Atlantic cod were conducted based on a harvest scenario of fishing at the FMSY proxy between 2018 and 2020. Catch in 2017 was estimated at 428 mt. Recruitment was sampled from a cumulative distribution function derived from ASAP estimated age-1 recruitment between 1982 and 2014. The projection recruitment model declines linearly to zero when SSB is below 6.3 kmt under the M=0.2 model and 7.9 kmt under the M-ramp model. The 2017 age-1 recruitment was estimated from the geometric mean of the 2012-2016 ASAP recruitment estimates. No retrospective adjustments were applied in the projections as the retrospective patterns are similar to the 2015 update for which no retrospective adjustments were made; however, the 2015 assessment review panel recommended that that M=0.2 projections with retrospective adjustments be brought forward to the SSC for consideration in the evaluation of uncertainty when setting catch advice (provided in the Supplemental Information Report, SASINF). Assumed weights are based on an average of the most recent three years. For the M-ramp model, projections are shown under two assumptions of short-term natural mortality: M=0.2 and M=0.4.

Table 11: Short term projections of total fishery catch and spawning stock biomass for Gulf of Maine Atlantic cod based on a harvest scenario of fishing at the F_{MSY} *proxy* ($F_{40\%}$) between 2018 and 2020. Catch in 2017 has been estimated at 428 (mt).

Year	Catch (mt)	SSB (mt)	F_{Full}	Catch (mt)	SSB (mt)	F_{Full}
	M=0.2			*Retrospective adjustment*		
2017	428	4,648	0.092	428	3041	0.142

Year	Catch (mt)	SSB (mt)	F_{Full}	Catch (mt)	SSB (mt)	F_{Full}
	M=0.2			*Retrospective adjustment*		
2018	1,084	5,574	0.174	693	3569	0.174
2019	1,181	6,553	0.174	758	4214	0.174
2020	1,326	8,401	0.174	855	5426	0.174

Year	Catch (mt)	SSB (mt)	F_{Full}	Catch (mt)	SSB (mt)	F_{Full}
	M-ramp(M=0.2)			*M-ramp(M=0.4)*		
2017	428	4,470	0.100	428	4,245	0.110

Year	Catch (mt)	SSB (mt)	F_{Full}	Catch (mt)	SSB (mt)	F_{Full}
	M-ramp(M=0.2)			*M-ramp(M=0.4)*		
2018	1,066	5,558	0.177	791	4,312	0.177
2019	1,215	7,070	0.177	741	4,572	0.177
2020	1,505	10,046	0.177	769	5,529	0.177

Special Comments:

- What are the most important sources of uncertainty in this stock assessment? Explain, and describe qualitatively how they affect the assessment results (such as estimates of biomass, F, recruitment, and population projections).

  An important source of uncertainty is the estimate of natural mortality. Past investigations into changes in natural mortality over time have been inconclusive (NEFSC 2013). Different assumptions about natural mortality affect the scale of the biomass, recruitment, and fishing mortality estimates, though terminal estimates (2016) of biomass, fishing mortality and recruitment are similar under both models. Other areas of uncertainty include the retrospective error in the M=0.2 model, residual patterns in the model fits to some of the survey series, stock structure, and the veracity of fishery catch data. A recent report indicated that contemporary commercial landings of Gulf of Maine cod may have been underestimated (Palmer 2017). Additional work is needed to investigate the accuracy and completeness of not only of commercial landings, but all sources of anthropogenic removals (e.g., commercial discards, recreational catch, scientific removals).

- Does this assessment model have a retrospective pattern? If so, is the pattern minor, or major? (A major retrospective pattern occurs when the adjusted SSB or F_{Full} lies outside of the approximate joint confidence region for SSB and F_{Full}; see Table 8).

  The M=0.2 model has a major retrospective pattern (7-year Mohn's rho SSB=0.53, F=-0.31) and the M-ramp model has a minor retrospective pattern (7-year Mohn's rho SSB=0.30, F=-0.17). The 7-year Mohn's rho values from the current assessment are similar to those from the 2015 assessment (M=0.2: SSB=0.54, F=-0.31; M-ramp: SSB=0.20, F=-0.08) where the M=0.2 model had a major retrospective pattern and the M-ramp model had a minor pattern. No retrospective adjustments have been applied to the terminal model results or in the base catch projections following the recommendations of the SARC 55 (NEFSC 2013) and 2014 assessment review panels (Palmer 2014). The 2015 assessment review panel (NEFSC 2015) supported this decision, noting that the most recent retrospective 'peel' suggested that an adjustment using the 7-year average may not be appropriate. However, the 2015 review panel highlighted the retrospective error in the M=0.2 model as a source of uncertainty - it should be noted that the retrospective error of the most recent peel is larger for the M-ramp model. Should the retrospective patterns continue then the models may have overestimated spawning stock size and underestimated fishing mortality.

- Based on this stock assessment, are population projections well determined or uncertain? If this stock is in a rebuilding plan, how do the projections compare to the rebuilding schedule?

  Population projections for Gulf of Maine Atlantic cod are reasonably well determined, though the projected biomasses from the last assessment did not fall within the confidence bounds of the biomass estimated in the current assessment. Multiple factors likely contributed to this including underestimation of the initial stock size and fishery catches in the projection bridge year (2015). This stock is not on target to rebuild by 2024.

- Describe any changes that were made to the current stock assessment, beyond incorporating additional years of data and the effect these changes had on the assessment and stock status.

  The only change to update was to use an automated procedure to fill holes in the survey age-legth keys rather than using visual imputation which was subjective and generally not

reproducible. The procedure relies on a multinomial logistic model to describe the proportions at age for a given length in situations where no age samples are available for that length bin (Gerritsen et al. 2006). This change had neglible impacts on the survey indices-at-age. A summary of the impacts of these changes are provided in the Supplemental Information Report (SASINF).

- If the stock status has changed a lot since the previous assessment, explain why this occurred.

  There has been no change in stock status since the 2014 udpate assessment.

- Provide qualitative statements describing the condition of the stock that relate to stock status.

  The Gulf of Maine Atlantic cod shows a truncated size and age structure, consistent with a population experiencing high mortality. Additionally, there are no positive signs of incoming recruitment, continued low survey indices, and the current spatial distribution of the stock is considerably less than its historical range within the Gulf of Maine.

- Indicate what data or studies are currently lacking and which would be needed most to improve this stock assessment in the future.

  The Gulf of Maine Atlantic cod assessment could be improved with additional studies on natural mortality, stock structure, a characterization of the overall uncertainty and possible biases in the fishery catch estimates, and research into potential causes of low stock productivity (i.e., low recruitment).

- Are there other important issues?

  When setting catch advice, careful attention should be given to the retrospective error present in both models, particularly given the poor performance of previous stock projections. Additionally, it is unclear which level of natural mortality (M=0.2 or 0.4) to assume for the short-term projections under the M-ramp model.

2.1 Reviewer Comments: Gulf of Maine Atlantic cod

Assessment Recommendation:

The panel concluded that the operational assessment with no adjustment for retrospective bias as per the Stock Assessment Review Committee (SARC) 55 recommendation was acceptable as a scientific basis for management advice, including the two-model approach (M fixed at 0.2 and M-ramp) as well as using the suite of projection approaches for the Scientific and Statistical Committee (SSC) to consider in their development of catch advice.

Alternative Assessment Approach:

Not applicable.

Status Recommendation:

Based on this updated assessment, the panel agreed with the recommendation that the stock status for the Gulf of Maine Atlantic cod stock is overfished and overfishing is occurring. The Gulf of Maine Atlantic cod stock shows a truncated size and age structure, consistent with a population experiencing high mortality. Additionally, there are no positive signs of incoming recruitment, continued low survey indices, and the current spatial distribution of the stock is considerably less than its historical range within the Gulf of Maine.

Key Sources of Uncertainty:

An important source of uncertainty with this stock is the estimate of natural mortality. Other areas of uncertainty include the retrospective error in the M=0.2 model, residual patterns in the model fits to some of the survey series, stock structure, and the accuracy of fishery catch data.

Research Needs:

The panel recommends additional studies on natural mortality, stock structure, approaches to characterizing overall uncertainty, possible biases in the fishery catch estimates, and research into potential causes of low stock productivity (i.e., low recruitment). The uncertainty in catch should certainly be evaluated in the context of the retrospective pattern. Further, the panel recommends researching whether the M-ramp model continues to be useful as the retrospective bias is increasing.

References:

Gerritsen HD, McGrath D, Lordan C. 2006. A simple method for comparing age-length keys reveals significant regional differences within a single stock of haddock (Melanogrammus aeglefinus). ICES J. Mar. Sci. 63: 1096-1100.

Northeast Fisheries Science Center. 2013. 55^{th} Northeast Regional Stock Assessment Workshop (55^{th} SAW) Assessment Summary Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 13-11; 41 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026. CRD13-11

Palmer MC. 2014. 2014 Assessment update report of the Gulf of Maine Atlantic cod stock. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 14-14; 119 p. Available from: National Marine Fisheries Service,166 Water Street, Woods Hole, MA 02543-1026. CRD14-14

Palmer MC. 2017. Vessel trip reports catch-area reporting errors: Potential impacts on the monitoring and management of the Northeast United States groundfish resource. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 17-02; 47 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026. CRD17-02

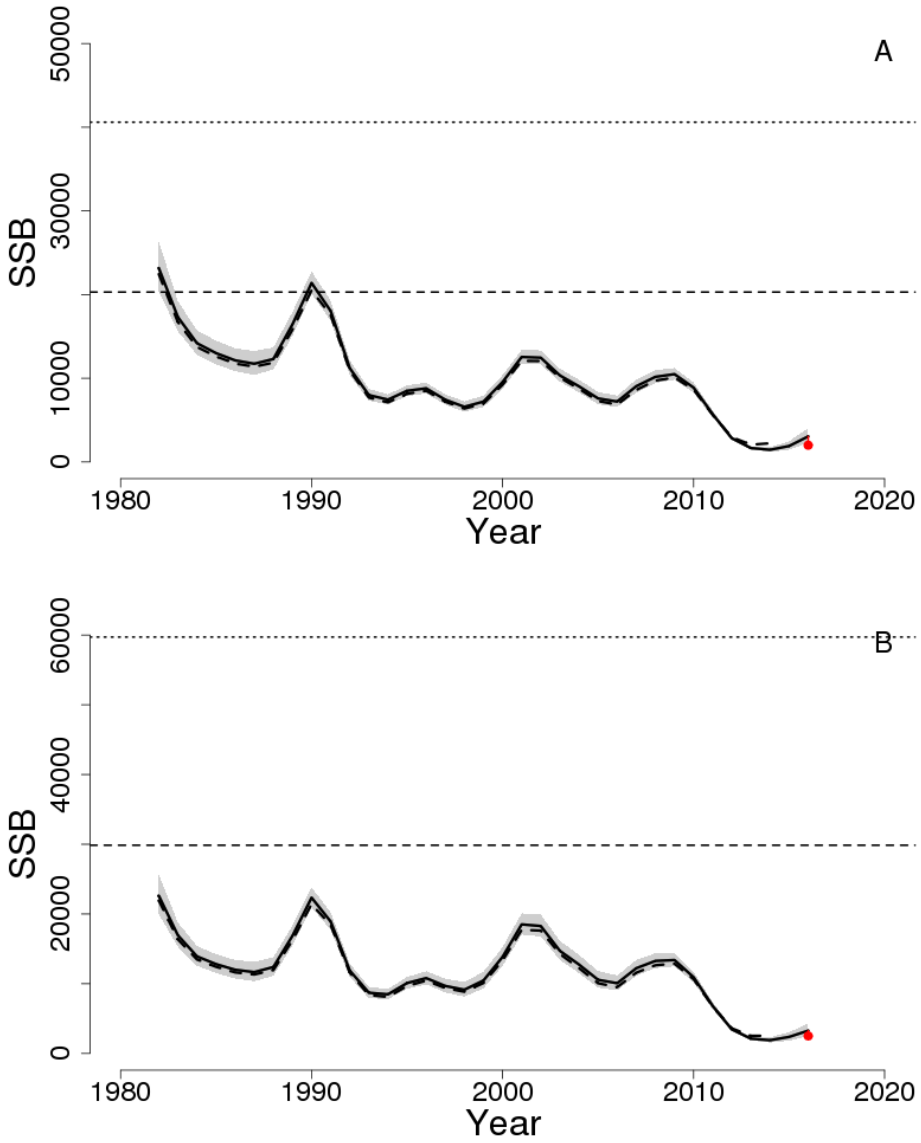

Figure 10: Estimated trends in the spawning stock biomass (SSB) of Gulf of Maine Atlantic cod between 1982 and 2016 from the current (solid line) and previous (dashed line) assessment and the corresponding $SSB_{Threshold}$ ($\frac{1}{2}$ SSB_{MSY}; horizontal dashed line) as well as SSB_{Target} SSB_{MSY}; horizontal dotted line) based on the 2017 M=0.2 (A) and M-ramp (B) assessment models. The 90% lognormal confidence intervals are shown. The red dot indicates the rho-adjusted SSB values that would have resulted had a retrospective adjusment been made to either model (see Special Comments section).

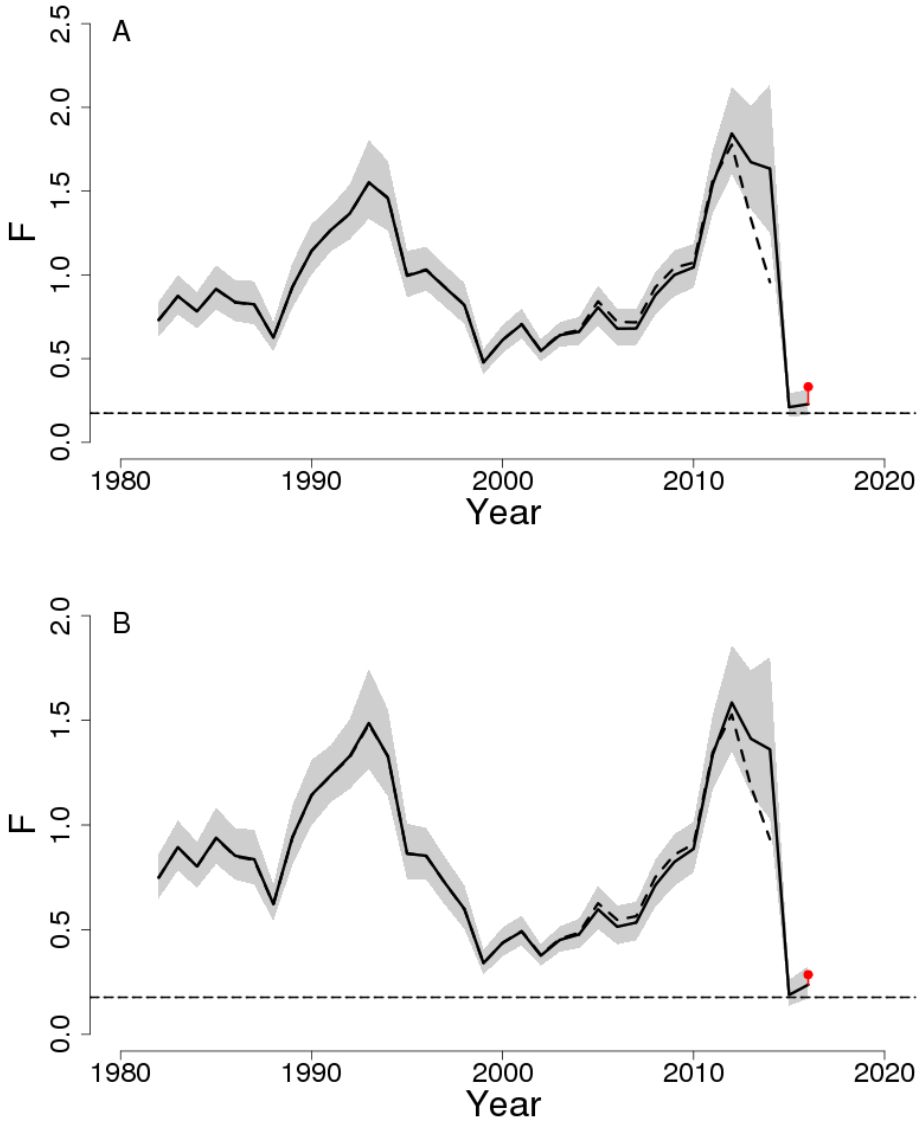

Figure 11: Estimated trends in the fully selected fishing mortality (F) of Gulf of Maine Atlantic cod between 1982 and 2016 from the current (solid line) and previous (dashed line) assessment and the corresponding $F_{Threshold}$ (0.174 (M=0.2), 0.177 (M-ramp); dashed line) based on the 2017 M=0.2 (A) and M-ramp (B) assessment models. The 90% lognormal confidence intervals are shown. The red dot indicates the rho-adjusted F values that would have resulted had a retrospective adjusment been made to either model (see Special Comments section).

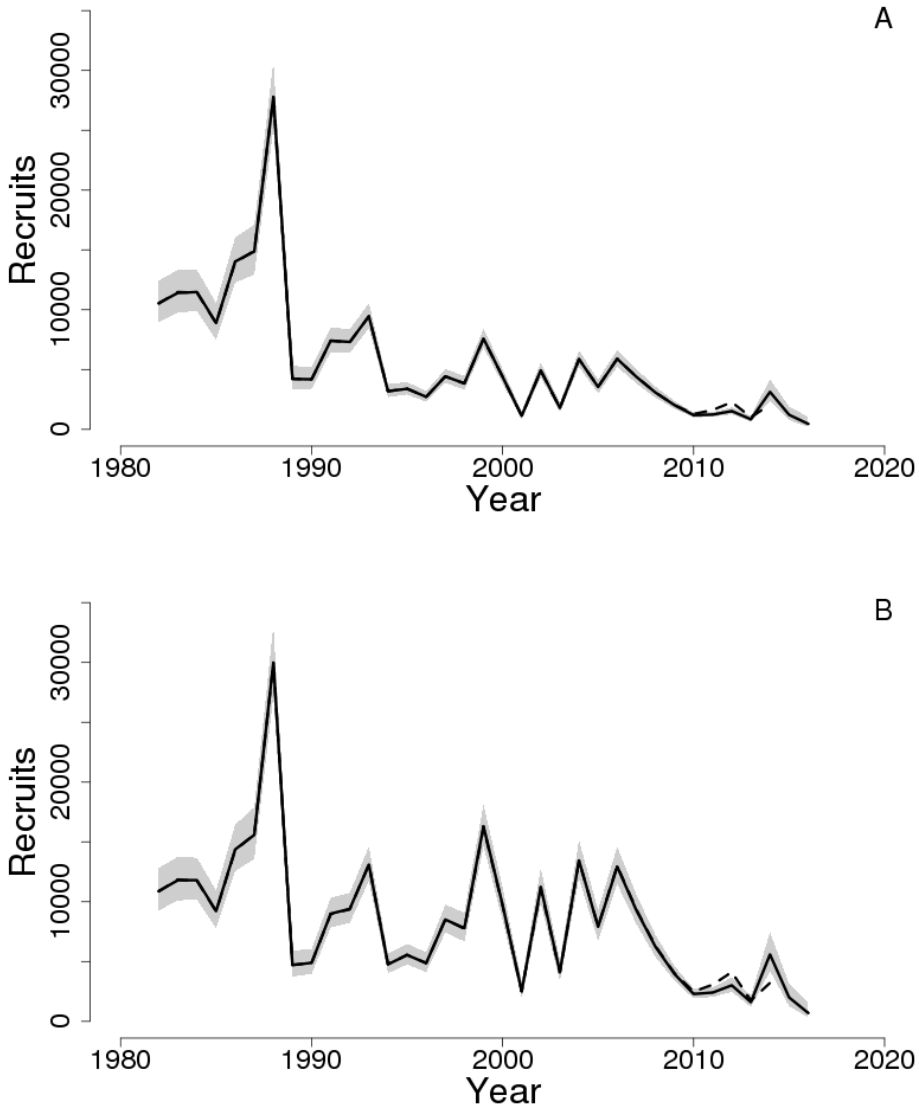

Figure 12: Estimated trends in age-1 recruitment (000s) of Gulf of Maine Atlantic cod between 1982 and 2016 from the current (solid line) and previous (dashed line) M=0.2 (A) and M-ramp (B) assessment models. The 90% lognormal confidence intervals are shown.

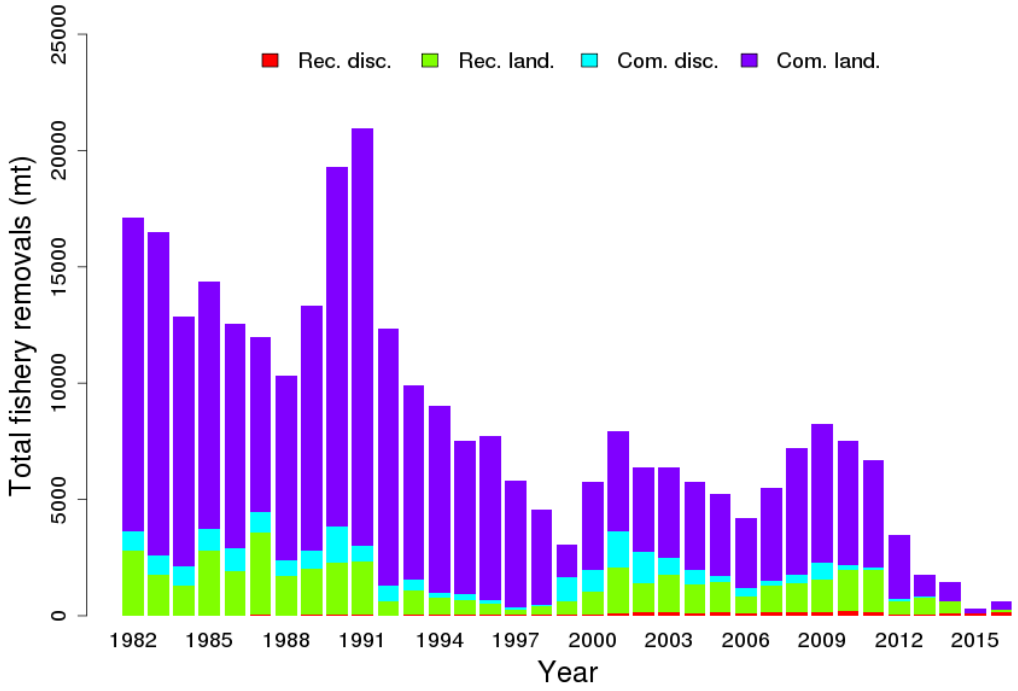

Figure 13: Total catch of Gulf of Maine Atlantic cod between 1982 and 2016 by fleet (commercial and recreational) and disposition (landings and discards).

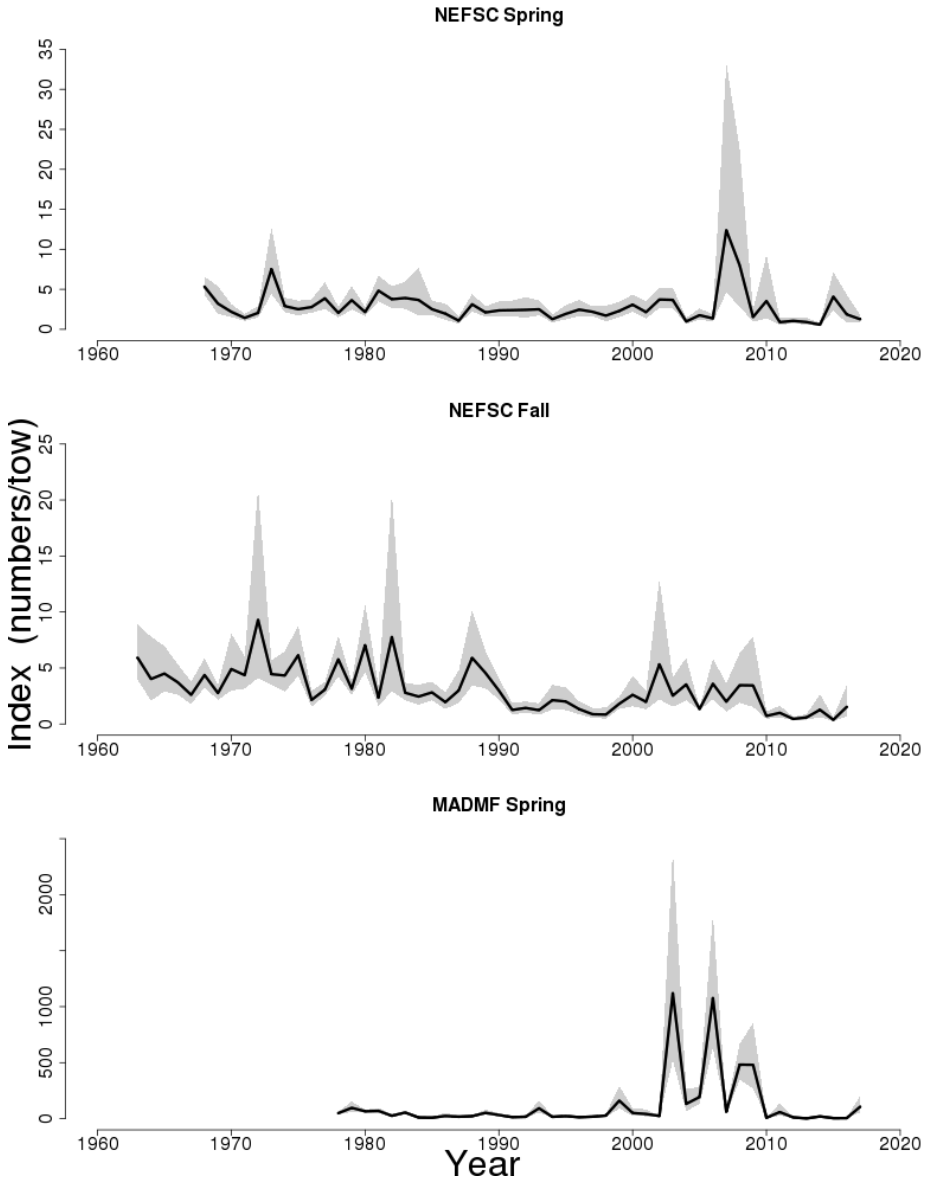

Figure 14: Indices of biomass for the Gulf of Maine Atlantic cod between 1963 and 2017 for the Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl surveys and Massachusetts Division of Marine Fisheries (MADMF) spring bottom trawl survey. The 90% lognormal confidence intervals are shown.