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 2014 assessment (Palmer 2014). This assessment updates commercial and recreational fishery catch data, research survey indices of abundance, and the analytical ASAP assessment models through 2014. Additionally, stock projections have been updated through 2018. 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 Gulf of Maine Atlantic cod (*Gadus morhua*) stock is overfished and overfishing is occurring (Figures 11-12). Retrospective adjustments were not made to the model results (see Special Comments section of this report). Spawning stock biomass (SSB) in 2014 was estimated to be 2,225 (mt) under the M=0.2 model and 2,536 (mt) under the M-ramp model scenario (Table 9) which is 6% and 4% (respectively) of the biomass target, SSB_{MSY} *proxy* (40,187 (mt) and 59,045 (mt); Figure 11). The 2014 fully selected fishing mortality was estimated to be 0.956 and 0.932 which is 517% and 498% of the F_{MSY} *proxy*($F_{40\%}$; 0.185 and 0.187; Figure 12).

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.

	2007	2008	2009	2010	2011	2012	2013	2014
				Data				
Recreational discards	154	153	142	188	164	48	69	85
Recreational landings	1,162	1,240	1,399	1,803	1,813	571	705	528
Commercial discards	178	349	752	171	99	93	52	26
Commercial landings	3,990	5,444	5,953	5,356	4,598	2,759	951	832
Catch for Assessment	5,485	7,186	8,247	7,517	6,673	3,472	1,777	1,471
				Model Results (M=0.2)				
Spawning Stock Biomass	8608	9716	10088	8638	5617	2954	2064	2225
F_{Full}	0.716	0.926	1.043	1.073	1.563	1.778	1.334	0.956
Recruits $age1$	4407	3087	2035	1281	1615	2269	1030	2042
				Model Results (M-ramp)				
Spawning Stock Biomass	11583	12649	12871	10645	6727	3599	2526	2536
F_{Full}	0.564	0.751	0.859	0.908	1.347	1.528	1.185	0.932
Recruits $age1$	9368	6307	4024	2486	3066	4114	1738	3211

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.

	2014 M=0.2	2014 M-ramp	M=0.2	M-ramp
F_{MSY}	0.18	0.18	0.185	0.187
SSB_{MSY} (mt)	47,184 (32,903 - 67,045)	69,621 (53,349 - 89,302)	40,187 (27,551 - 58,228)	59,045 (44,976 - 76,525)
MSY (mt)	7,753 (5,355 - 11,162)	11,388 (8,624 - 14,750)	6,797 (4,608 - 9,990)	10,043 (7,560 - 13,130)
Median recruits age-1) (000s)	4,665 (1,414 - 14,649)	9,173 (2,682 - 16,262)	4,406 (1,458 - 14,450)	8,965 (2,489 - 15,908)
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 2016 and 2018. Catch in 2015 was estimated at 279 mt. Recruitment was sampled from a cumulative distribution function derived from ASAP estimated age-1 recruitment between 1982 and 2012. 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 2015 age-1 recruitment was estimated from the geometric mean of the 2010-2014 ASAP recruitment estimates. No retrospective adjustments were applied in the projections as the retrospective patterns are similar to the 2014 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 2016 and 2018. Catch in 2015 has been estimated at 279 (mt).

Year	Catch (mt)	SSB (mt)	F_{Full}	Catch (mt)	SSB (mt)	F_{Full}	Catch (mt)	SSB (mt)	F_{Full}
	M=0.2			*M-ramp(M=0.2)*			*M-ramp(M=0.4)*		
2015	279	3045	0.111	279	3219	0.112	279	3057	0.123
2016	697	4400	0.185	748	4950	0.187	555	3841	0.187
2017	939	5852	0.185	1085	7062	0.187	662	4536	0.187
2018	1211	7601	0.185	1507	9674	0.187	765	5220	0.187

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).

  The largest 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. 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 (e.g., aggregate MADMF spring survey) and stock structure.

- 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=0.54, F=-0.31) and the M-ramp model has a minor retrospective pattern (7-year Mohn's rho SSB=0.20, F=-0.08). The 7-year Mohn's rho values from the current assessment are similar to those from the 2014 assessment (M=0.2: SSB=0.53, F=-0.33; M-ramp: SSB=0.17, F=-0.05) 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 and 2014 assessment review panels. The 2015 assessment review panel 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?

  Population projections for Gulf of Maine Atlantic cod are reasonably well determined and projected biomass from the last assessment was within the confidence bounds of the biomass estimated in the current assessment.

- 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.

  This update included several minor changes to model input data including: (1) re-estimation of recreational catch from 2004-2014 to account for recent updates to the MRIP data; (2) a revised assumption on recreational discard mortality from 30% to 15% following a Capizzano et al. 2015 study (unpublished); and (3) re-estimation of 2009-2014 NEFSC spring and fall survey time series using the TOGA station acceptance criterion. Additionally, the ASAP assessment model was run with the likelihood constants option turned off. All of these changes had minimal impacts on model results - summaries 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.

- 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 and stock structure. Additionally, future assessments should consider possible changes in recent fishery selectivity patterns and explore alternative methods for estimating recruitment. Potential causes of low stock productivity (i.e., low recruitment) should also be investigated.

- 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

Recommendation: The Panel concluded that the updated assessment with no retrospective adjustment was acceptable as a scientific basis for management advice. The minor changes to survey data and recreational catch statistics were acceptable and the revised assumption of discard mortality for the recreational fishery from 30% to 15% was well justified. The exclusion of likelihood constants from the assessment model's objective function is also reasonable.

The Assessment Oversight Panel recommended that retrospective adjustments should be applied to stock status determination and projections for stocks with major retrospective patterns. However, the SAW55 benchmark assessment did not apply a retrospective adjustment to the M=0.2 model results, and the retrospective pattern in the updated assessment was similar. The most recent retrospective 'peel' (i.e., with a terminal year of 2013) suggests that an adjustment using a 7-year average may not be appropriate. On the other hand, the panel noted that unadjusted projections from SAW55 were optimistic in retrospect. Therefore, short-term projections are provided with and without retrospective adjustment, so that they can be considered in the evaluation of uncertainty and catch advice.

Alternative Assessment Approach: Not applicable

Sources of Uncertainty: Major sources of uncertainty include the natural mortality assumption and retrospective error in the updated M=0.2 model. A pattern of residuals in fishery age compositions suggests that selectivity may have changed in the last two years, but a longer time series is needed to confirm the pattern. The panel concluded that the survey series are noisy and some residual patterns persist in the model (e.g., MADMF spring survey). The benchmark method cannot consider survey information in the current year (e.g., spring 2015 survey indices), but the two spring surveys have conflicting signals, with a substantial increase in the NEFSC survey (from two large tows in one stratum) and a near record-low index in the MADMF survey. Recently published research suggests that the stock area includes several distinct spawning groups, so stock boundaries may need to be re-considered.

Research Needs: The Panel recommends that the sources of the retrospective pattern in the M=0.2 model need to be addressed. Considering that retrospective patterns are a common problem, the generic problem may be most appropriately addressed in a research track topic, and all possible sources of the retrospective problem should be investigated (misspecified natural mortality, changes in natural mortality, under-reported catch, changes in survey catchability and misspecified selectivity, etc.).

The causes of low productivity, relative to historical productivity should be considered in the next benchmark assessment, including the investigation of ecosystem effects. In particular, information on natural mortality should be investigated. The implicit assumption that natural mortality will return to M=0.2 in the reference points associated with the Mramp model should be examined in the next benchmark assessment. Additional topics to be explored in future benchmark assessments include: alternative methods for estimating recruitment, possible changes in recent selectivity, and recent information on cod stock structure.

References:

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

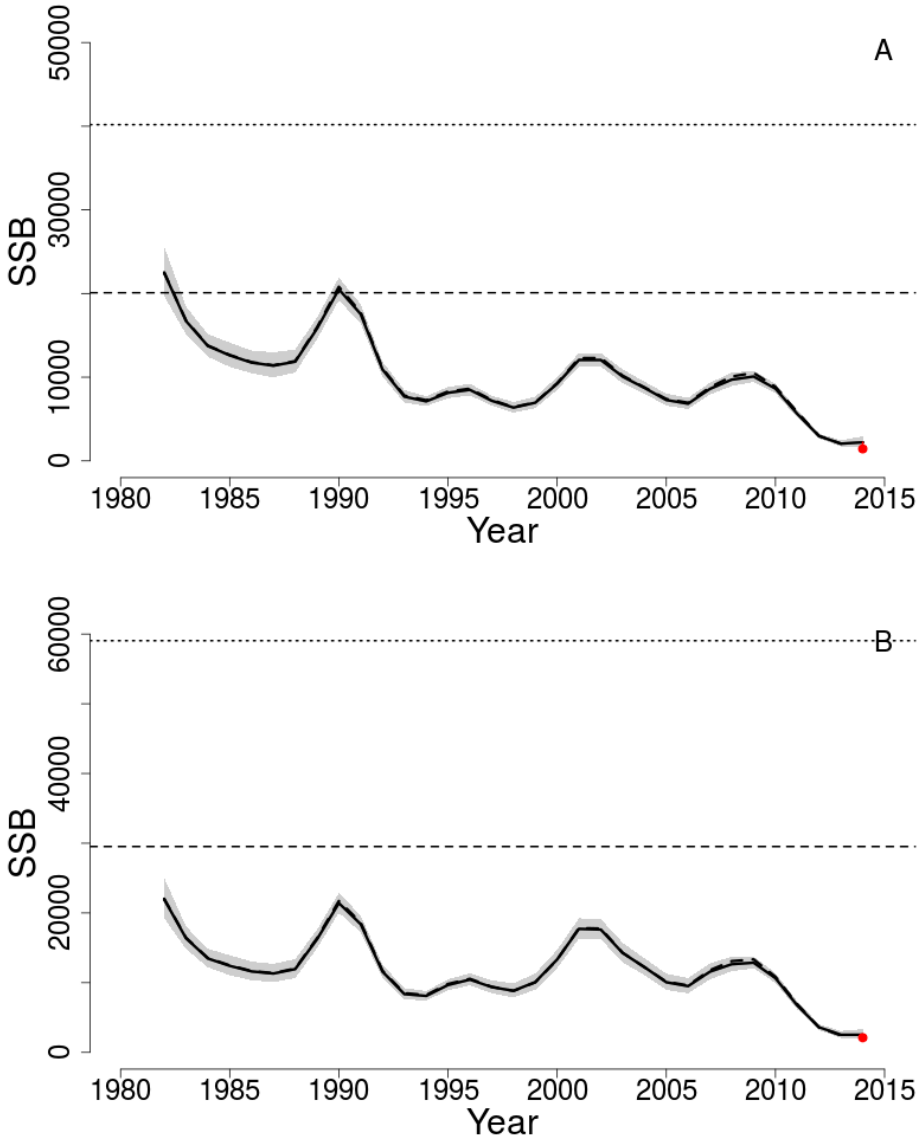

Figure 11: Estimated trends in the spawning stock biomass (SSB) of Gulf of Maine Atlantic cod between 1982 and 2014 from the current (solid line) and previous (dashed line) assessment and the corresponding $SSB_{Threshold}$ ($\frac{1}{2}$ SSB_{MSY}; horizontal dashed line) as well as SSB_{Target} SSB_{MSY}; horizontal dotted line) based on the 2015 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).

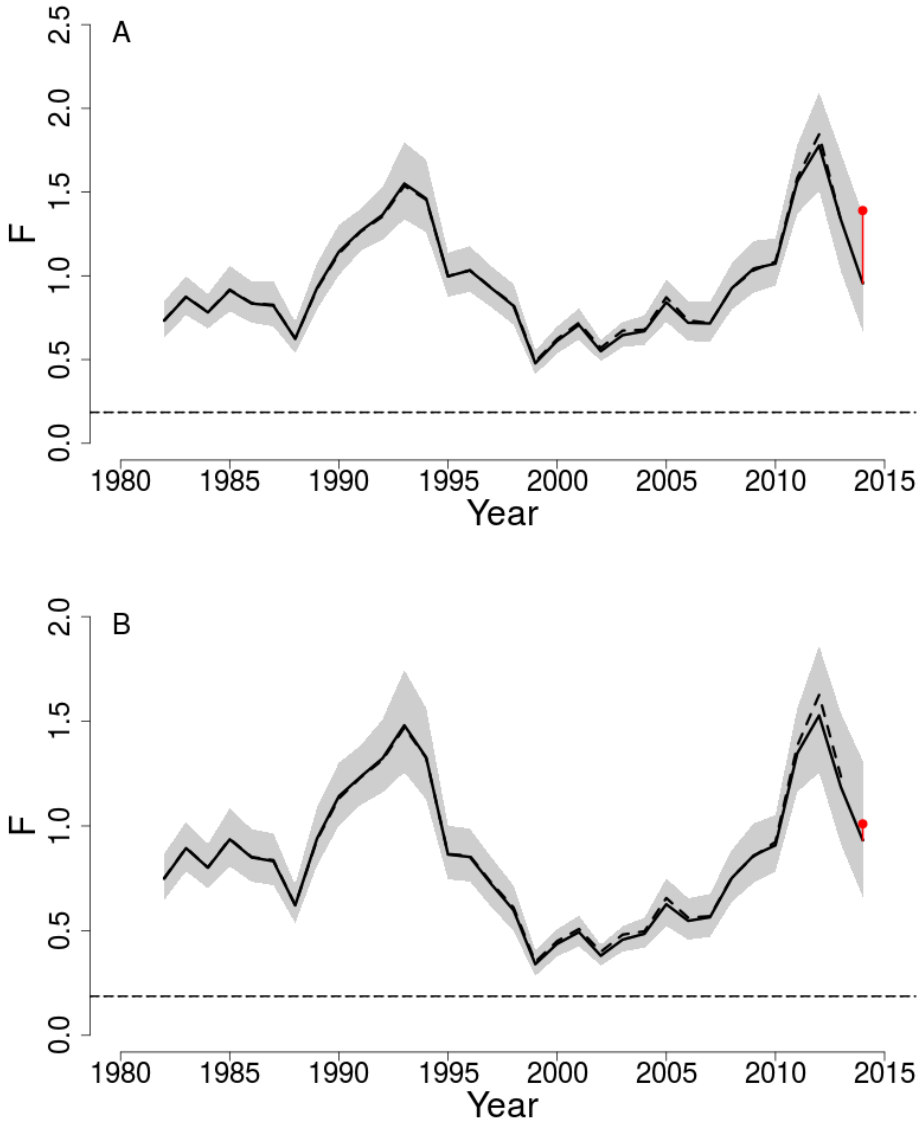

Figure 12: Estimated trends in the fully selected fishing mortality (F) of Gulf of Maine Atlantic cod between 1982 and 2014 from the current (solid line) and previous (dashed line) assessment and the corresponding $F_{Threshold}$ (0.185 (M=0.2), 0.187 (M-ramp); dashed line) based on the 2015 M=0.2 (A) 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).

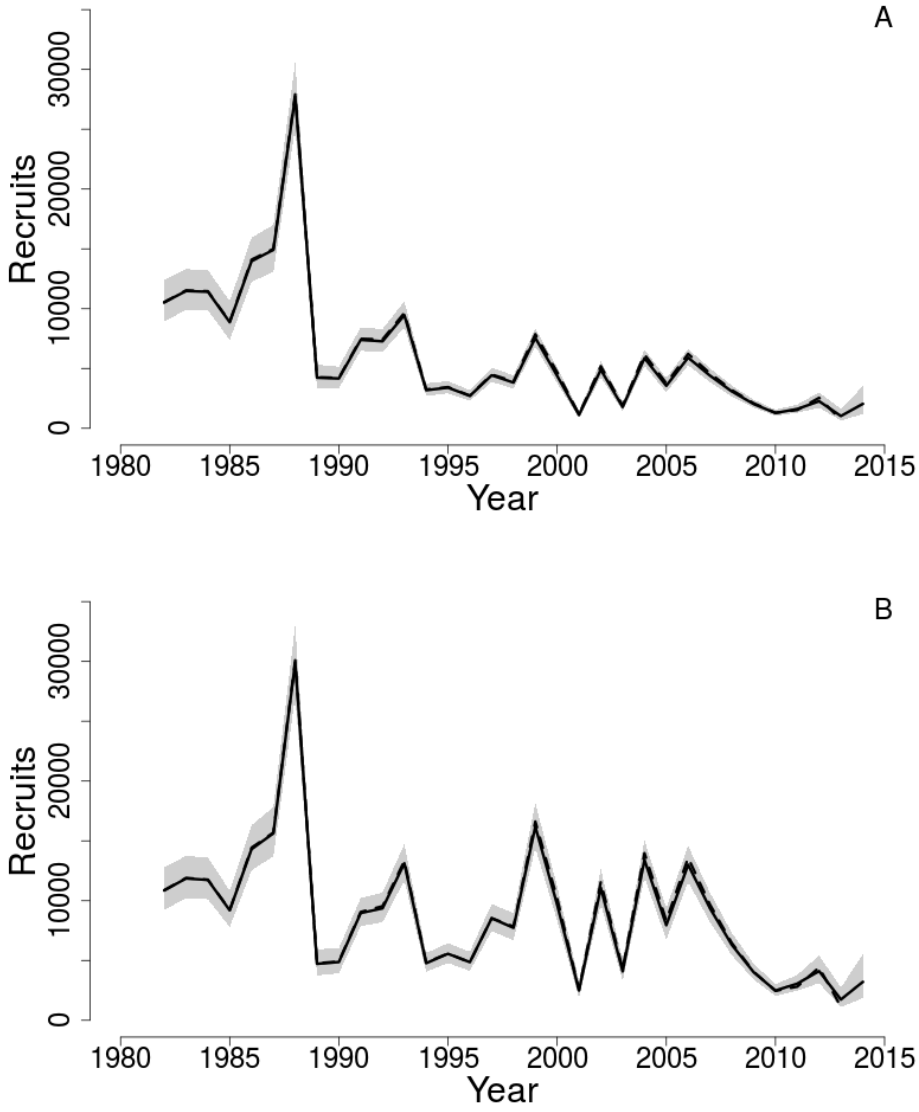

Figure 13: Estimated trends in age-1 recruitment (000s) of Gulf of Maine Atlantic cod between 1982 and 2014 from the current (solid line) and previous (dashed line) M=0.2 (A) and M-ramp (B) assessment models. The 90% lognormal confidence intervals are shown.

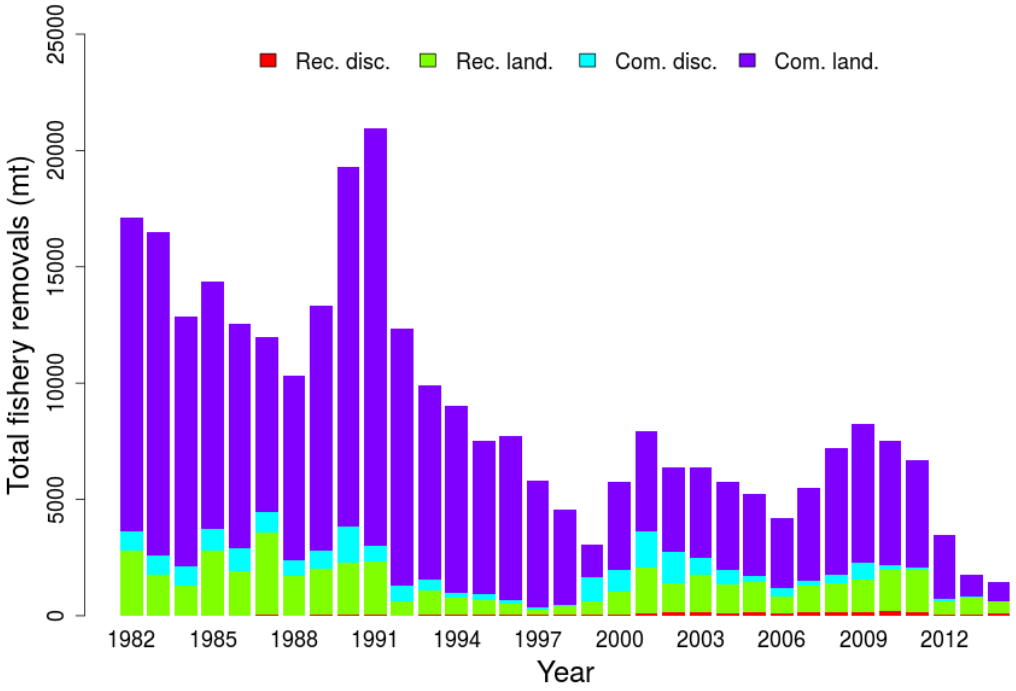

Figure 14: Total catch of Gulf of Maine Atlantic cod between 1982 and 2014 by fleet (commercial and recreational) and disposition (landings and discards).

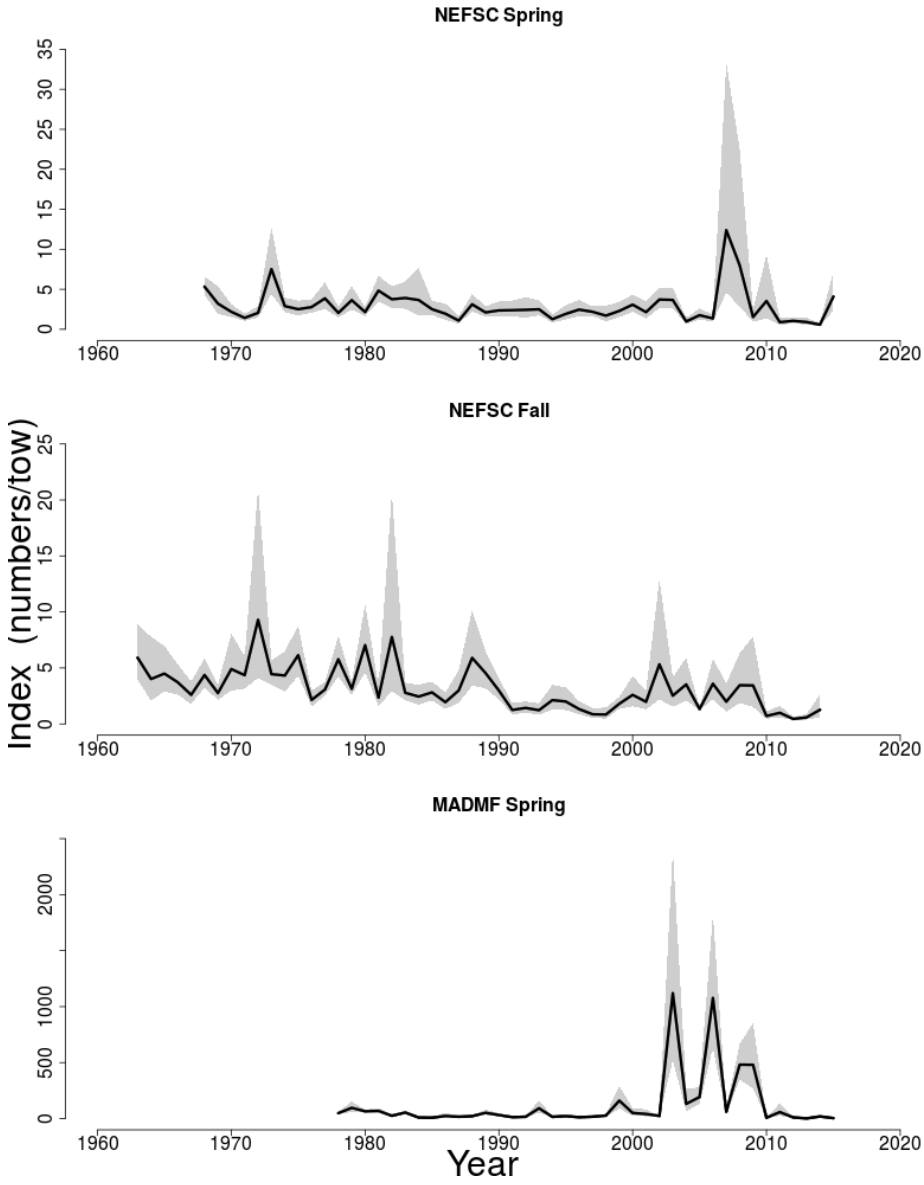

Figure 15: Indices of biomass for the Gulf of Maine Atlantic cod between 1963 and 2015 for the Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl surveys and Massachusetts Division of Marine Fisheries (MADMF) spring bottom trawl survey. The 90% lognormal confidence intervals are shown.