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MEMORANDUM

DATE: September 11, 2014

TO: Scientific and Statistical Committee (SSC)

FROM: Groundfish Plan Development Team (PDT)

CC: Groundfish Oversight Committee (OSC)

SUBJECT: **Gulf of Maine (GOM) cod ABCs and OFLs**

The Groundfish Plan Development Team (PDT) discussed and completed analyses for **Gulf of Maine (GOM) cod ABCs/OFLs for FY 2015- FY 2017.**

2014 Assessment Update

Overview

An updated assessment of the 2012 SARC 55 GOM cod benchmark assessment was peer reviewed in August 2014. The updated assessment included two additional years (2012-2013) of commercial and recreational fishery catch data and research survey abundance indices. No changes were made to the methods used to prepare the input data or in assessment model configurations.

The 2014 assessment update carried forward both of the two formulations of the statistical catch-at-age model, ASAP (NOAA Toolbox) accepted at SARC 55. The first of which, the M=0.2 model, holds natural mortality (M) constant at 0.2 across the time series. The second formulation, the M-ramp model, includes a linear ramp of natural mortality from M=0.2 pre-1989 to M=0.4 post-2002. In both model configurations, natural mortality is held constant across all ages. The overfishing reference points ($F_{40\%}$ assuming M=0.2) were estimated with minor changes to the data inputs (maturity, weights, selectivity). The values of $F_{40\%}$ were the same as those estimated at SARC 55 ($F_{40\%}$=0.18 for both the M=0.2 and M-ramp model). Long-term projections at F=0.18 and M=0.2 were updated using the 1982-2011 recruitment series, producing estimates of rebuilding targets (the SSB_{MSY} proxy) of 47,184 mt (using the ASAP M=0.2 recruitment series) and 69,621 mt (ASAP M-ramp recruitment series).

The GOM cod stock is overfished and overfishing is occurring. This conclusion is robust to both assessment models (M=0.2 and M-ramp), as well as exploratory approaches examined at the peer review to the M-ramp reference points. Spawning stock biomass (SSB) in 2013 is estimated to be below 2,500 mt under both models. The estimated 2013 SSB equates to 4% or 3% of the

SSB_{MSY} proxy (47,184 mt or 69,621 mt) in the M=0.2 or M-ramp models, respectively. The 2013 fully selected fishing mortality is estimated to be greater than 1.2 under both models.

Fishing mortality is near an all-time high, despite fishery catches being among the lowest in the time series. Survey indices are at time series lows. Recent recruitment has also declined to the time series low. Declining SSB and the truncated age-structure could compromise the future recruitment success of this stock. The potential for a regime shift (i.e., increased natural mortality in recent years), as previously considered in SARC 55, and its impact on the stock was also discussed by the peer review panel. The GOM cod stock is in poor condition.

The GOM cod ABC for FY 2014 (1,550 mt) exceeds the overfishing threshold of F=0.18. To avoid exceeding the projected OFL (harvest at $F_{MSY\text{-}proxy}$=0.18), catches would need to be substantially decreased. To meet rebuilding targets (rebuild to SSB_{MSY} by 2024), 2015 catches would need to be reduced considerably lower than the current ABC of 1,550 mt.

Short Term Catch Projections

Short term projections assumed a geometric mean recruitment of the 2009-2013 period for estimating 2014 age-1 recruitment. For age-1 recruitment in 2015 and beyond, the projections assume 1982-2011 median recruitment (M=0.2~ 4.6 million fish, M-ramp~ 9.1 million fish). For age-1 recruitment in 2015 and beyond, the projections assume 1982-2011 median recruitment (M=0.2~ 4.6 million fish, M-ramp~ 9.1 million fish) when spawning stock biomass is above 6,300 mt in the M=0.2 model and 7,900 mt in the M-ramp model (Figure 1). At spawning stock levels below these thresholds, recruitment declines linearly to zero. At SARC 55, the decision was made to set the threshold values to the lowest observed SSB. Rather than revise the biomass thresholds for the 2014 assessment update, the decision was made to retain the SARC 55 threshold values in recognition of the lower recruitments observed in recent years. Furthermore, the time period used to estimate age-1 recruitment in year t+1 was modified from using the geometric mean of the previous 10 years to using the geometric mean of only the last 5 years in an effort to better characterize recent lower recruitment patterns.

The peer review panel recommended conducting three different types of projections (M = 0.2 model, M-ramp model assuming M=0.2 in the projections, M-ramp model assuming M=0.4 in the projections). The projections provided by the PDT use $F_{rebuild}$ for ABC estimation as opposed to 75% F_{MSY} because of the rebuilding plan requirements for GOM cod (adopted in Framework Adjustment 51, FW 51) and the SSC control rule calls for fishing at the lower value of $F_{rebuild}$ or 75% F_{MSY}. $F_{rebuild}$ was calculated by determining the F needed to get the SSB_{MSY} in 2024. FW 51 specified a new rebuilding plan for GOM cod to rebuild by 2024 with a 50% probability of success. The M=0.2 model assumed that F_{MSY}=0.18, SSB_{MSY}=47,184. The two M-ramp projections (M=0.2 and M=0.4) differed in their assumptions about future natural mortality rates. Both used reference points based on M=0.2: F_{MSY} = 0.18 and SSB_{MSY} =69,621.

In considering catch projections for future fishing years, the PDT noted that recent GOM cod catches from recent projections have not resulted in the desired fishing mortality, and that stock growth has not occurred as expected. The PDT has documented this poor performance of projections in several reports to the SSC, and the issue was raised during the 2012 Groundfish Assessment Updates meeting. In addition, retrospective patterns remain a source of uncertainty in the 2014 assessment update (Figure 2). The peer review panel did not recommend using a retrospective adjustment. However, continuation of retrospective issues suggests the projections may be overly optimistic.

Projections:

- *the M=0.2 model;*
- *the M-ramp model, assuming natural mortality will return to 0.2 in 2014 ;and*
- *the M-ramp model, assuming natural mortality will remain at 0.4 through the 10 year rebuilding period.*

PDT Analysis, Results, and Discussion

Analysis: Projection Assumptions

For each projection, the PDT assumed the 2014 GOM cod ACL of 1,470mt would be fully utilized and calculated corresponding OFLs.

Results: Candidate GOM cod ABCs/OFLs

Table 1 summarizes candidate ABCs assuming a catch of 1470 mt in 2014 (the ACL). Table 2 provides the corresponding OFLs after imputing the candidate ABCs (i.e., OFLs were calculated by assuming the ABC in the previous year and re-running the projections). As noted above, and consistent with the rebuilding plan outlined in FW51, only projections derived under a $F_{rebuild}$ harvest strategy are presented as candidate ABCs/OFLs (Table 3, Table 4, and Figure 3).

The M-ramp model assuming M=0.4 was considered for ABC determination at SARC 55. However, with the 2014 assessment update, $F_{rebuild}$ is now lower than 75%FMSY. The PDT felt that a $F_{rebuild}$ estimate from the M-ramp model assuming M=0.4 for 10 years is not a credible estimate for ABC determination, since it is impossible to rebuild the stock if M remains at 0.4. M would need to change to 0.2 in 2016 to rebuild the stock by 2024 with an F=0. The SSB_{MSY} accepted by the peer review assumes natural mortality will return to 0.2. Therefore, estimating $F_{rebuild}$ assuming natural mortality does not revert back to 0.2 is inconsistent with the SSB_{MSY} reference point. However, concerns with the low spawning stock resulting in possible continued lower than observed recruitment will likely prevent the stock from rebuilding by the specified end date of 2024. Concerns that the stock could have entered into a depensatory state were also expressed at the 2014 assessment update peer review. For these reasons, ABCs as close to zero as practicable may be justified.

To better understand how catch assumptions impact ABC estimates, the PDT ran sensitivity projections assuming a catch of 1,000 mt for FY 2014 to see how sensitive the M=0.2 model is to a change in bridge year catch assumptions. Results of the sensitivity run increased $F_{rebuild}$ catch projections by 57 mt in 2015 to 237 mt (Table 5). These projections are not provided for catch advice, and are only included for discussion purposes. The PDT did not have time to examine if this number was the best estimate of catches in calendar year (CY) 2014. However, the PDT felt that the catch in CY 2014 will likely be within the range of the sensitivity projection and the projections that assume the ACL (1470 mt) in 2014.

Table 1: Summary of candidate ABCs.

Year	ABC (M=0.2)	ABC (M-ramp M=0.2)	ABC (constant)
2015	180	207	200
2016	270	329	200
2017	379	491	200

Table 2: Summary of candidate OFLs.

Year	OFL (M=0.2)	OFL (M-ramp M=0.2)	OFL M=0.2 (constant ABC)	OFL M-ramp M=0.2 (constant ABC)	OFL M-ramp M=0.4 (constant ABC)
2015	517	595	517	595	430
2016	774	942	771	943	557
2017	1086	1406	1093	1428	698

<u>Discussion: Assessment Findings and Comparison of ABCs</u>

There are several sources of uncertainty in the 2014 assessment. With SSB at a time series low and poor recruitment in recent years, it is difficult to predict how the stock may respond under these conditions. If the stock is experiencing depensation, even slower recovery than currently assumed in both models should be expected. Additionally, the M=0.4 assumption in the M-ramp model represents a fundamental change in thinking about the life history and productivity of GOM cod.

The PDT discussed the need to keep the F's as low as practicable given that rebuilding by 2024 can only be achieved under a very low F, which may be unattainable. The PDT noted that target F for GOM cod has yet to be attained under any rebuilding or management program. For example, the lowest F achieved in the time series was 0.5 in the 1990's, and currently F would need to be reduced to 0.06 to enable rebuilding. An Operational Assessment for GOM cod is scheduled for September of 2015. This may provide an opportunity to update 2016 and 2017 ABCs.

PDT Recommendation

The PDT recommends that GOM cod catch be set very low and additional protections be provided to further protect the spawning stock. The PDT finds merit in a constant catch approach that is within the range of outputs from short-term catch projections for catch advice (Table 3 and Table 4). Specifically, the PDT recommends a 200 mt constant ABC for setting FY 2015-FY2017 ABCs. Under this harvest strategy, long-term projections indicate that the stock will rebuild by 2024 (Table 4).

The M-ramp model assuming M changes back to 0.2 produced slightly higher estimates for 2015 ABCs, but the PDT questioned the reasons why one would expect M to change back to 0.2 in year T+1 (2014). Slightly higher catches from the M-ramp M=0.2 model are likely a result of increases in recruitment with the assumed increase in natural mortality along with a sudden step reduction in M at the beginning of the projection in 2014 (Figure 2). At SARC 55, this scenario was thought to be unlikely. The PDT highlights that large reductions in catch are necessary to rebuild the stock by 2024 and past projections have over-estimated rebuilding. If stock size is lower than currently estimated, the stock may not rebuild by 2024. As such, the PDT recommends that a constant catch approach is adopted for FY2015-FY2017, until there is evidence that predicted stock growth has occurred. The stock is currently at 3-4% of SSB_{MSY}. The PDT also recognized that the stock assessment will be updated in 2015.

It is not clear which of the three projections (M=0.2 model, M-ramp M=0.2 projection, M-ramp M=0.4 projection) should be used for OFL estimation with the 200 mt ABCs estimate. From SARC 55, the SSC based OFL estimates on the M=0.2 model. OFLs based on the M=0.2 model are between the estimates from the M-ramp model assuming M=0.2 and 0.4 in the projections (Table 2).

The PDT also considered that achieving the rebuilding target of SSB_{MSY} would require a 37% (M=0.2 model) or a 40% (M-ramp model) annual growth for 10 years (See Appendix). This analysis assumes constant proportional growth and further suggests that the $F_{rebuild}$ projections could be overly optimistic.

All indications are that the stock is in very poor condition and catches/ABCs should be based on an $F_{rebuild}$ as required by the FMP's control rule. However, predicting future recruitment for a stock in such poor condition becomes much more difficult. Protecting as much spawning stock biomass as possible and the act of spawning itself is needed to promote improvements in recruitment. Low ABCs are needed to increase the possibility of rebuilding this stock. The PDT also acknowledges that along with the low ABC recommendations additional management measures that reduce access to the stock will likely be needed to ensure that the catch limits are truly met.

Tables

Table 3: Model runs for FY2015-FY2017.

Fmsy (F40%=Fmsy=0.18-->75%=0.14), recruitment modelled from CDF of 1982-2011 (model 21: hinge SSBused SARC55 hinge values, M=0.2: 6.3 kmt, M-ramp: 7.9 kmt); MCMC used geomean of 2009-2013 for t+1 recruitment
2024 = rebuilding horizon, Frebuild based on 50% probability

Harvest strategy	Year	Input	M=0.2 model			M-ramp model					
			No retro adjustment			M=0.2			M=0.4		
			Catch (mt)	Spawning stock biomass (mt)	F_{full}	Catch (mt)	Spawning stock biomass (mt)	F_{full}	Catch (mt)	Spawning stock biomass (mt)	F_{full}
F_{MSY}	2013	Model result	1,715	2,063	1.33	1,715	2,432	1.24	1,715	2,432	1.24
	2014	Assumed catch	1,470	2,690	0.80	1,470	3,009	0.76	1,470	2,832	0.85
	2015	Projection	517	3,363	0.18	595	4,039	0.18	430	3,064	0.18
	2016	Projection	721	4,632	0.18	880	5,999	0.18	527	3,792	0.18
	2017	Projection	953	6,265	0.18	1,251	8,579	0.18	629	4,596	0.18
75% F_{MSY}	2013	Model result	1,715	2,063	1.33	1,715	2,432	1.24	1,715	2,432	1.24
	2014	Assumed catch	1,470	2,690	0.80	1,470	3,009	0.76	1,470	2,832	0.85
	2015	Projection	408	3,385	0.14	469	4,064	0.14	339	3,083	0.14
	2016	Projection	583	4,764	0.14	711	6,154	0.14	425	3,887	0.14
	2017	Projection	786	6,550	0.14	1,026	8,914	0.14	515	4,772	0.14
$F_{rebuild}$	2013	Model result	1,715	2,063	1.33	1,715	2,432	1.24	1,715	2,432	1.24
	2014	Assumed catch	1,470	2,690	0.80	1,470	3,009	0.76	1,470	2,832	0.85
	2015	Projection	180	3,429	0.06	207	4,115	0.06	***0***	***3,150***	***0.00***
	2016	Projection	270	5,046	0.06	329	6,478	0.06	***0***	***4,247***	***0.00***
	2017	Projection	379	7,168	0.06	491	9,669	0.06	***0***	***5,475***	***0.00***

Table 4: Rebuilding trajectory using 200 mt constant catch scenario for FY2015-FY2017.

Fmsy (F40%=Fmsy=0.18-->75%=0.14), recruitment modelled from CDF of 1982-2011 (model 21: hinge SSBused SARC55 hinge values, M=0.2: 6.3 kmt, M-ramp: 7.9 kmt); MCMC used geomean of 2009-2013 for t+1 recruitment
2024 = rebuilding horizon, Frebuild based on 50% probability

Harvest strategy	Year	Input	M=0.2 model			M-ramp model					
			No retro adjustment			M=0.2			M=0.4		
			Catch (mt)	Spawning stock biomass (mt)	F_{full}	Catch (mt)	Spawning stock biomass (mt)	F_{full}	Catch (mt)	Spawning stock biomass (mt)	F_{full}
constant catch 200mt	2013	Model result	1,715	2,063	1.33	1,715	2,432	1.24	1,715	2,432	1.24
	2014	Assumed catch	1,470	2,690	0.80	1,470	3,009	0.76	1,470	2,832	0.85
	2015	catch	200	3,425	0.07	200	4,115	0.06	200	3,111	0.08
	2016	catch	200	5,039	0.04	200	6,513	0.04	200	4,047	0.06
	2017	catch	200	7,260	0.03	200	9,851	0.02	200	5,128	0.05
	2018	Frebuild	559	10,597	0.06	761	14,784	0.06	***0***	***6,548***	***0.00***
	2019	Frebuild	799	15,242	0.06	1,105	21,663	0.06	***0***	***8,491***	***0.00***
	2020	Frebuild	1164	21,799	0.06	1,644	31,347	0.06	***0***	***11,115***	***0.00***
	2021	Frebuild	1523	27,763	0.06	2,191	40,474	0.06	***0***	***13,716***	***0.00***
	2022	Frebuild	1918	34,314	0.06	2,820	50,862	0.06	***0***	***16,948***	***0.00***
	2023	Frebuild	2333	41,337	0.06	3,418	60,662	0.06	***0***	***20,252***	***0.00***
	2024	Frebuild	2728	48,059	0.06	3,992	70,543	0.06	***0***	***23,292***	***0.00***

Table 5: Sensitivity run at 2014 assumed catch of 1,000 mt.

Fmsy (F40%=Fmsy=0.18-->75%=0.14), recruitment modelled from CDF of 1982-2011 (model 21: hinge SSBused SARC55 hinge values, M=0.2: 6.3 kmt, M-ramp: 7.9 kmt); MCMC used geomean of 2009-2013 for t+1 recruitment
2024 = rebuilding horizon, Frebuild based on 50% probability

Harvest strategy	Year	Input	M=0.2 model			M-ramp model					
			No retro adjustment			M=0.2			M=0.4		
			Catch (mt)	Spawning stock biomass (mt)	F_{full}	Catch (mt)	Spawning stock biomass (mt)	F_{full}	Catch (mt)	Spawning stock biomass (mt)	F_{full}
75% F_{MSY}	2013	Model result	1,715	2,063	1.33	1,715	2,432	1.24	1,715	2,432	1.24
	2014	Assumed catch	1,000	2,796	0.51	1,000	3,111	0.48	1,000	2,941	0.53
	2015	Projection	462	3,782	0.14	523	4,459	0.14	382	3,416	0.14
	2016	Projection	641	5,183	0.14	769	6,573	0.14	464	4,180	0.14
	2017	Projection	845	7,024	0.14	1,086	9,418	0.14	548	5,063	0.14
$F_{rebuild}$	2013	Model result	1,715	2,063	1.33	1,715	2,432	1.24	1,715	2,432	1.24
	2014	Assumed catch	1,000	2,796	0.51	1,000	3,111	0.48	1,000	2,941	0.53
	2015	Projection	237	3,828	0.07	268	4,510	0.07	***0***	***3,493***	***0.00***
	2016	Projection	344	5,458	0.07	411	6,888	0.07	***0***	***4,586***	***0.00***
	2017	Projection	470	7,625	0.07	599	10,122	0.07	***0***	***5,843***	***0.00***

Figures

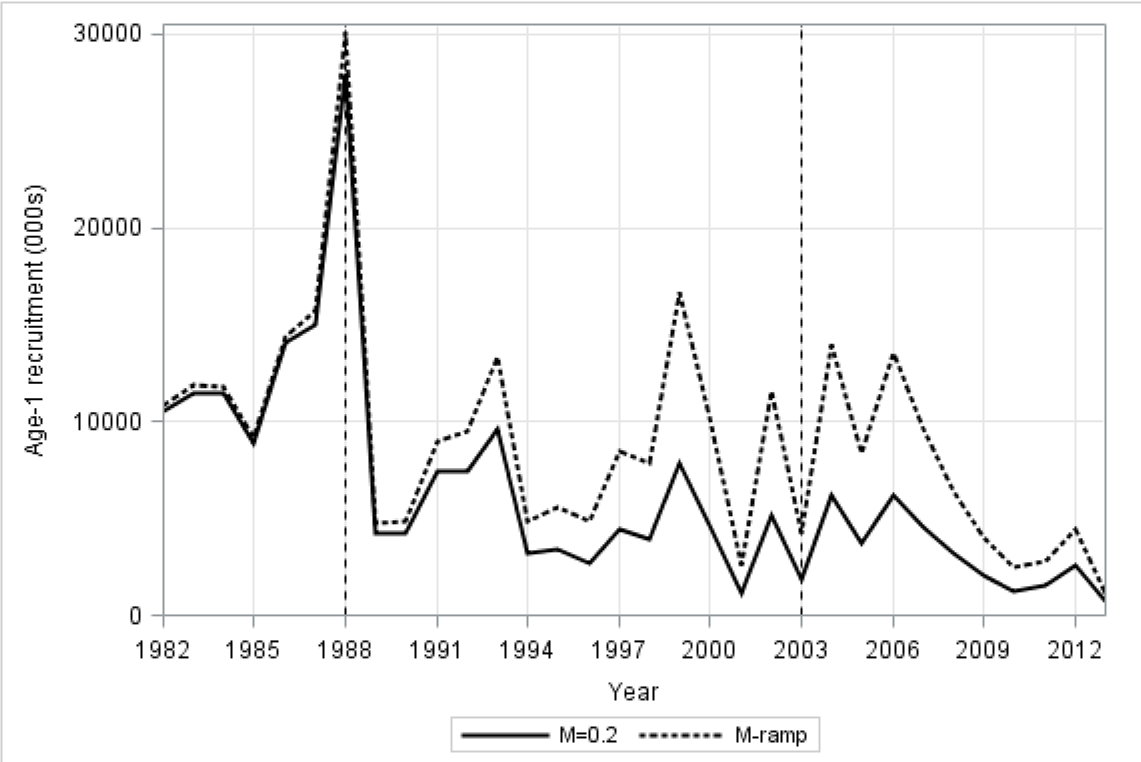

Figure 1: Comparison of estimated age-1 recruitment between the M=0.2 and the M-ramp models from the 2014 assessment update.

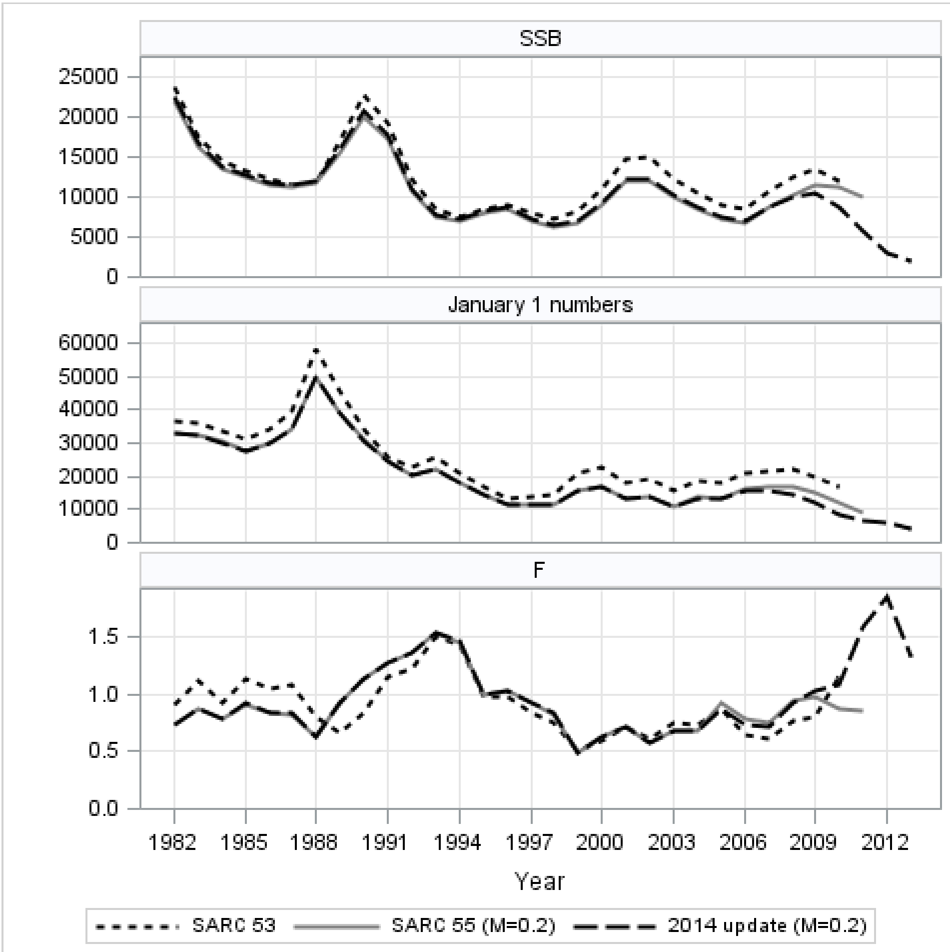

Figure 2. Historical model retrospective analysis comparing the model results (spawning stock biomass, January 1 population numbers and fishing mortality) of the SARC 53 (2011), SARC 55 (2012) and 2014 update assessments of the Gulf of Maine Atlantic cod. ***Note that for the SARC 55 and 2014 update, only results for the M=0.2 model are shown to provide a direct comparison to the SARC 53 model results.*** **Figure 7, pp. 14 from the 2014 Assessment Update Report, dated September 3, 2014.**

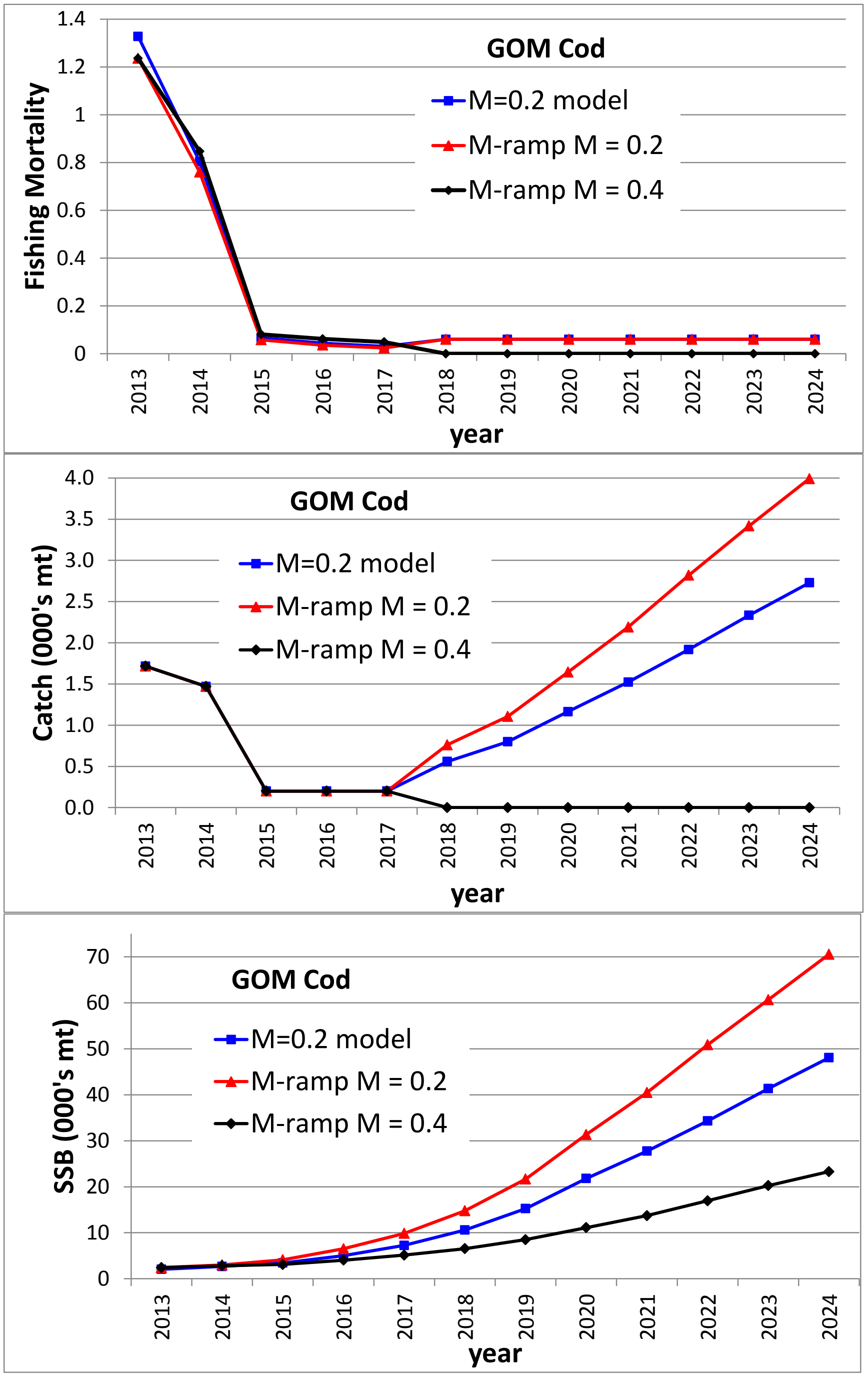

Figure 3: Projection comparison of M=0.2 model, M-ramp with M=0.2 and M-ramp with M=0.4 for fishing mortality, catch and SSB. Terminal year of the assessment is 2013. A 1,470 mt catch is assumed in 2014, 200 mt ABC catch from 2015-2017, and $F_{Rebuild}$ from 2018-2024. M-ramp with M=0.4 cannot rebuild.

Appendix 1: Evaluating projected rebuilding trajectories for Gulf of Maine cod

Steven J. Correia September 11, 2014

Overview

The Groundfish Plan Development Team spends much energy trying to define rebuilding timeframes for overfished stocks. We can qualitatively judge the rebuilding model by examining the estimates of average annual growth rate needed to achieve rebuilding for Gulf of Maine cod. We should be skeptical of projected growth rates that are much higher than previously observed in the assessment, tempered by the history of fishing mortality on the stock. For Gulf of Maine cod, fishing mortality has been well above overfishing threshold and F_{max} . We have little history to guide us on growth rates under low mortality rates. Projections that show doubling of SSB every couple of years (Table 4) are likely optimistic given the poor condition of the stock.

Annual Growth Rate

We can estimate the annual growth rate needed to grow a stock from the terminal year SSB to SSB_{msy} given a fixed number of years. I use the well-known relationship between present value and future value, time and interest rate, as modified for a fish stock.

$$G= (SSB_{msy}/ SSB_{t})^{1/n} -1$$

In Table 1 and Table 2, I start the growth rate with SSB in the terminal year (2013).

M=0.2 assessment			# years to rebuild from 2013	Annual growth rate
	end	ratio	10	0.37
SSBmsy	47,184	22.9	9	0.42
SSb2013	2,063		8	0.48
			7	0.56
			6	0.68
			5	0.87
			4	1.19
			3	1.84
			2	3.78
			1	21.87

Table 1. Estimated annual growth rates needed to achieve rebuilding under constant annual growth assumption within specified years from the terminal year 2013 SSB. M=0.2 model

Mramp assessment			# years to rebuild from 2013	Annual growth rate
	End	ratio	10	0.40
SSBmsy	69621	28.6	9	0.45
SSb2013	2432		8	0.52
			7	0.61
			6	0.75
			5	0.96
			4	1.31
			3	2.06
			2	4.35
			1	27.63

Table 2. Estimated annual growth rates needed to achieve rebuilding under constant annual growth assumption within specified years from the terminal year 2013 SSB. M=mramp model.

Results

For either the M=0.2 (Table 1) or the mramp assessment (Table 2), growth rates to rebuild in 10 years from 2013 requires a 20 to 30 fold increase in SSB (growth rates of which have rarely been observed, Table 3). This is approximately 37 to 40% per year for the entire 10 year period assuming constant growth. These are rates that only Thomas Malthus could appreciate.

Year	Ffull	SSB 000's tons	Ratio yr t+1/T	Annual mortality rate
1982	0.7	23		0.61
1983	0.9	17	0.74	0.66
1984	0.8	14	0.82	0.62
1985	0.9	13	0.92	0.67
1986	0.8	12	0.93	0.65
1987	0.8	11	0.97	0.64
1988	0.6	12	1.04	0.56
1989	0.9	16	1.34	0.67
1990	1.1	21	1.30	0.74
1991	1.3	18	0.85	0.77
1992	1.4	11	0.62	0.79
1993	1.5	8	0.71	0.82
1994	1.5	7	0.93	0.81
1995	1.0	8	1.14	0.70
1996	1.0	9	1.04	0.71
1997	0.9	7	0.84	0.68
1998	0.8	6	0.88	0.64
1999	0.5	7	1.09	0.50
2000	0.6	9	1.33	0.56
2001	0.7	12	1.32	0.60
2002	0.6	12	1.00	0.54
2003	0.7	10	0.83	0.58
2004	0.7	9	0.86	0.59
2005	0.9	7	0.84	0.66
2006	0.7	7	0.94	0.61
2007	0.7	9	1.27	0.60
2008	0.9	10	1.15	0.68
2009	1.0	11	1.04	0.71
2010	1.1	9	0.84	0.72
2011	1.6	6	0.66	0.83
2012	1.9	3	0.51	0.87
2013	1.3	2	0.69	0.78

Table 3. Spawning stock biomass for m=0.2 assessment and ratio SSB_{t+1}/SSB_t for 1982 to 2013. Highlighted cells have annual growth rates > 30%.

The median SSB from the projections for m=0.2 and mramp model for Frebuild are shown in Table 4. The projected growth rates are relatively high from 2016 through 2020 and are much higher than seen in the assessment time series (Table 3). Projections under either model result in about 52% of the simulations resulting in rebuilding. This amount of uncertainty for rebuilding is not comforting, and perhaps slightly better than a flip of a fair coin in 2024.

	M=0.2		mramp	
year	SSB	growth	SSB	Growth rate
2013	2.06		2.43	
2014	2.69	0.30	3.01	0.24
2015	3.43	0.27	4.12	0.37
2016	5.05	0.47	6.48	0.57
2017	7.17	0.42	9.67	0.49
2018	10.37	0.45	14.37	0.49
2019	15.00	0.45	21.19	0.47
2020	21.54	0.44	30.81	0.45
2021	27.56	0.28	39.97	0.30
2022	34.11	0.24	50.41	0.26
2023	41.22	0.21	60.27	0.20
2024	47.95	0.16	70.25	0.17

Table 4. SSB (000's tons) from Frebuild projections for m=0.2 and mramp model. Highlighted cells have growth rates greater than 30%.

Logistic growth as a common fishery model and prediction for rebuilding rates

The logistic growth model is a common model underlying simple dynamics of surplus production and assumes that the growth rate of the population is density dependent. The logistic curve is an S-shape curve that describes biomass growth as function of current biomass, carrying capacity (K), intrinsic rate of growth (r). This growth model assumes that under constraining resources, the rate of population growth is a function of population abundance. Under constant r and K conditions, the stock will grow slowly at low biomass (left asymptote) and at high biomass as B approaches K (right asymptote). The stock should have maximal growth rates at the inflection point (where surplus production can also be maximized). The catch that maintained the population near the inflection point (1/2 carrying capacity) could be taken as MSY. This would be the basis of a surplus production assessment model, but these models are not used for GOM cod. If GOM cod followed a logistic type surplus production, we would expect slow growth and low fishery yields if biomass were near the left lower asymptote. Given that the stock is now at record low spawning stock biomass, it is likely on the low end of the surplus production curve rather than anywhere else on the curve.

Median SSB from the projections indicate that annual growth rates slow in later years of the projections (Table 4), suggesting some deviation from exponential growth. Projected growth rates exceed 40% in some years.

I estimated the empirical surplus production using the 2014 GOM cod assessment (m=0.2) based on an approach outlined in Jacobson et al, 2002. I did not attempt to estimate production parameters, but rather to conduct an exploratory analysis of the trends in surplus production from the 2014 assessment model. A plot of surplus production against age 1^+ biomass is shown in Figure 3. In general, a relationship between total biomass and surplus production is evident in Figure 3. The figure indicates that recent production has been low (as might be expected from the assessment results) and that current biomass is near the lower left asymptote with low production capability.

Growth processes

Two mechanisms exist for growing the stock. The first mechanism is through somatic growth of recruiting fish through mediation of removal rates from fishing. If fishing mortality is set to zero, SSB would increase based on growth alone (assuming constant M). This growth mechanism is accounted for in the various yield per recruit and spawning stock biomass per recruit analyses. Under the previous SARC 55 yield per recruit analyses, the spawning stock biomass per recruit is 20.33 kg per recruit at F=0. Under current fishing mortality rates of 1.3, the SSB per recruit is about 1.6 kg per recruit. But this process takes time as the recruits have to survive long enough to obtain the growth gained through low F.

Recruitment

The other source of growth is through better recruitment. Recruitment is often seen as a function of SSB, with lower recruitment at lower SSB. A tree regression between log (age 1 recruits) and SSB for the recent GOM cod assessment update, suggests that a split point for SSB is around 10.8K mt (Figure 1).

The predicted geometric mean recruits for the splits are shown in Table 5. This suggests that we can expect recruitment that is nearly 37% lower when the SSB is below 11K tons. Table 6 shows summary statistics for recruitment in two bins of SSB. Note that the maximum recruitment in the < 10.8K mt bin is lower than the median for the higher SSB bin.

	SSB < 10,794 mt	SSB≥ 10,794 mt
Predicted age 1 recruits (millions)	3.0	8.1

Table 5. Predicted recruitment (millions) for two bins of SSB, split at 10.8 K mt SSB.

SSB mt	minimum	25th	median	mean	75th	maximum
≥ 10.8K	1.9	5.2	8.9	9.9	11.5	27.9
<10.8K	0.7	2.2	3.4	3.5	4.6	7.9

Table 6. Summary statistics for recruitment (millions age 1 cod) for two bins of SSB identified from the tree regression. The analysis does not include the 1981 yearclass as SSB that produced that yearclass is unknown.

An environmental component is likely to influence the survival mortality from eggs to age of recruitment and would interact with SSB. This component has been extensively discussed, but has yet to be identified. The trend in the ratio of recruits to SSB (Figure 2) provides some insight into the effects of current conditions on recruitment. The ratio of R/SSB has been below the 25^{th} quantile in four out of the past 5 yearclasses. If the average of the previous 5 year ratio continues (236 recruits per mt SSB), we might expect recruitments of near half million fish (236*2063) for a spawning stock biomass near 2000 tons.

This suggests that the most important tactic for rebuilding SSB is to reduce fishing mortality to increase SSB through growth and hope that recruitment increases in response to higher SSB or favorable environmental conditions. Reducing fishing mortality on this stock has been a long-term management goal since 1994. The objective has been unmet via input or output controls measures.

The Canadian experience

The Canadians experience with cod has been well documented. Low stock biomass have resulted in extended period of low productivity for many stocks and the conclusion that current exploitation rates for some stocks have little influence on stock dynamics. The majority of the Canadian coastal stocks have shown little recovery, with perhaps Southern Newfoundland (3PS) as an exception. Northern cod (2J 3KL) and Grand Banks (3NO) cod remain low. Biomass for Flemish Cap cod (3M) has increased. Most stocks remain below their limit biomass reference points. Some were classified as special concern (Maritimes stock 4TVnm 4VsW, 5ZEjm), threatened, or endangered (Northern and Labrador cod stocks (2GH, 2j, 3KL and 3NO). We have our own local experience with the disappearance of cod in the eastern GOM. There has been no evidence of a return of cod to former spawning areas in the eastern GOM.

Growth overfishing

Current fishing mortality under the m=0.2 model (F=1.3) suggests that fishing mortality rates are well above Fmax (approximately F=0.4 under SARC 55 conditions). Because of our current estimates of fishery selectivity in the m=0.2 model, the loss in yield per recruit at current F (1.33,ypr=1.47kg/r) compared to from Fmax (0.42, ypr=1.55kg/r) is about 6%. In terms of fishery yields, any marked gains will need to arise via increasing the number of recruits entering the fishery. This is a discouraging conclusion given the recent declines in recruitment as estimated in the assessment and seen in three fishery independent trawl surveys operating in the Gulf of Maine.

Errors in the terminal year abundance estimates

The terminal year estimate of SSB is 2063 with 90% confidence interval of 1561 to 2774 for m=0.2. The assessment has a well-defined retrospective diagnostic that suggests that terminal year estimates are optimistic with respect to base years. The terminal year estimates may be high just from random variation, and if the retrospective pattern is true, we are likely to overestimate our starting point. Previous assessment models have a history of retrospective issues, although some of the historical differences are explained by changes to inputs and model formulations.

Errors in low catches

The PDT has suggested catches in the vicinity of 200 mt are needed to rebuild SSB. Given low catch there may be an incentive for discarding. Observer effects at a low quota could also be possible (i.e., fishing behavior differences between observer and unobserved trips). Most of the catch will come from estimations of recreation and discards and will be measured with error and potentially bias (e.g., due to an observer effect).

For purposes of argument, I will treat the 95% confidence interval around the catch estimates as a probability distribution of the parameter. Suppose that we achieve a CV of 30% on the catch estimates. For 200 tons, this implies a standard error around 60, and a 95% confidence limits (±2SE) 80 to 329 tons.

Small errors in catch (particular in the direction of underestimating catch) may prevent us from achieving the mortality objectives.

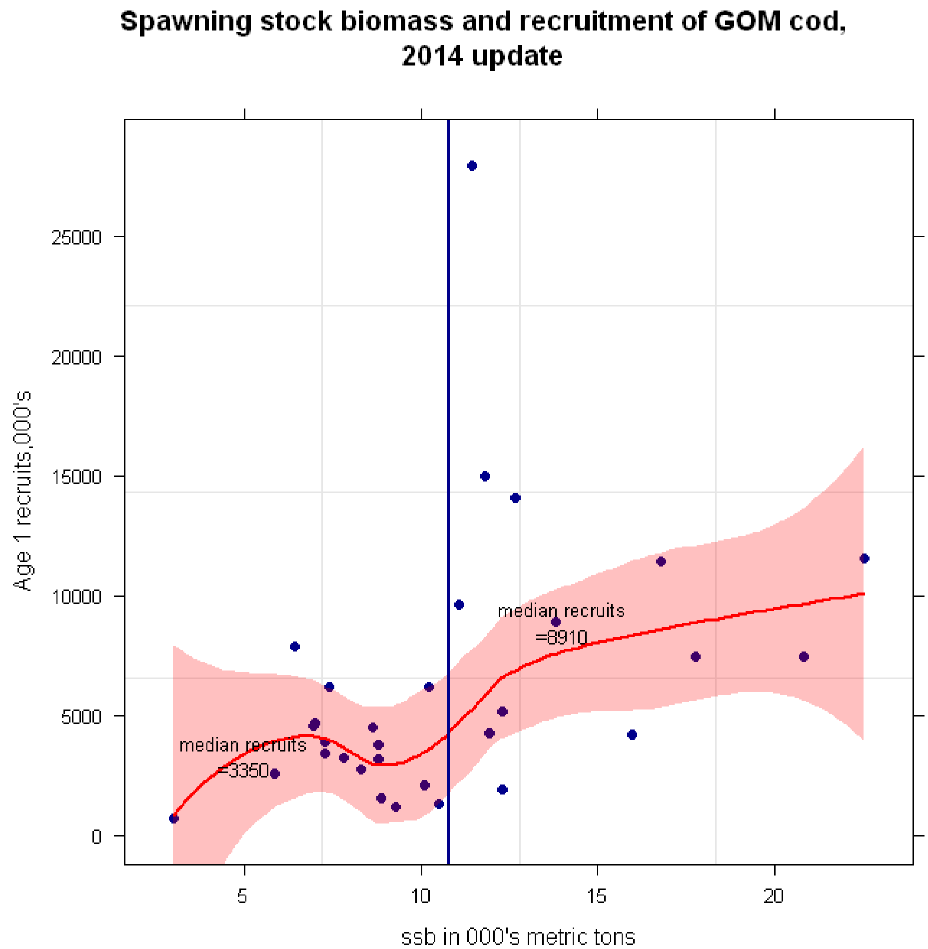

Figure 1. Recruits (000's) against SSB (000's mt) from the 2014 GOM cod assessment m=0.2 model. Red line is loess fit with span=0.66 and family=symmetric. Pink polygon is approximate 95% confidence limits on fitted line. Vertical blue line represents SSB split from tree regression 10.8 K SSB.

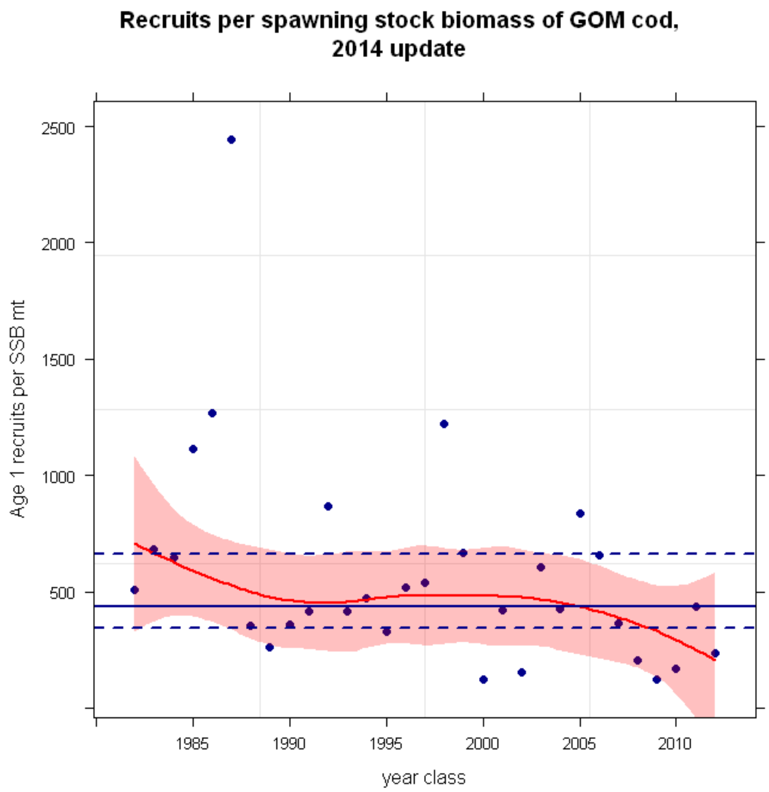

Figure 2. Trend in number of age 1 recruits per mt of SSB (M=0.2 model). Redline is a loess smoother with span=0.66 and family=symmetric. Pink solid polygon is approximately 95% confidence interval on smoothed trend. The solid blue line is the time series median and the dashed lines are 25th and 75th quantiles.

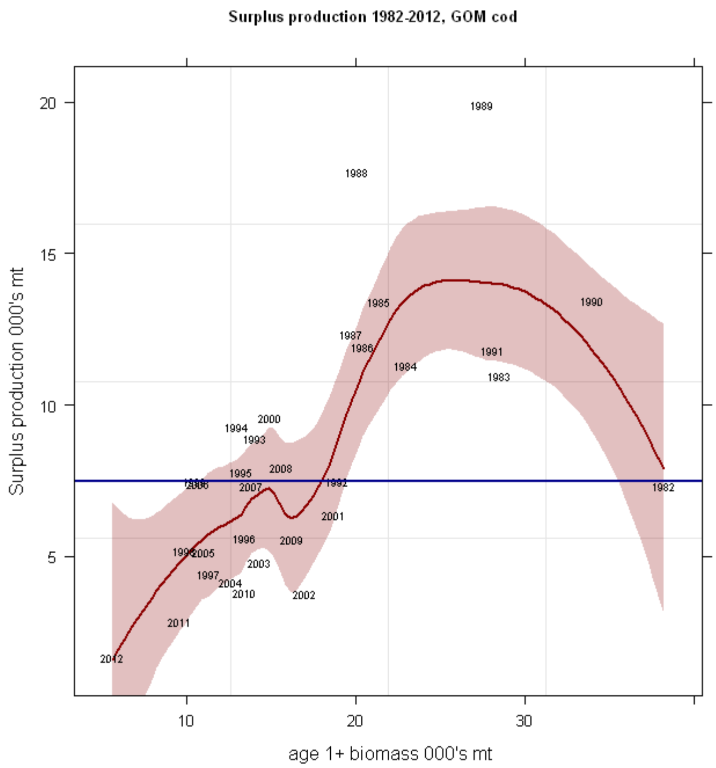

Figure 3. Surplus production against age 1$^+$ biomass using the 2014 GOM cod assessment for M=0.2. The red line is a loess fit with span=0.6 and family=symmetric. Blue line is time series median. Surplus production is labeled as year B_t.

Summary
The GOM cod stock is in an overfished condition and overfishing is occurring under reference points estimated under either model. Recruitment has been poor with declining trends in survival ratios (R/SSB). Since implementing Amendment 5 (1994), the management system has been unable to achieve targeted fishing mortality rates under input or output controls and has been unable to produce sustained biomass growth over that period (Table 7). This conclusion is robust to choice of assessment model.

	m=0.2		mramp	
period	Mean SSB 000's T	Median SSB 000's T	Mean SSB 000's T	Median SSB 000's T
1982-1994	14.0	12.7	14.2	12.5
1995-2013	8.1	8.6	10.8	10.6
2010-2013	4.9	4.4	5.9	5.2

Table 7. Average SSB for three time blocks: Pre-amendment 5 (1982-1994), post-Amendment 5 (1995-2013, and post-Amendment 16 (2010-2013).

Large sustained annual growth rates (near 40%) are needed to rebuild the stock in 10 years. This implies doubling the population biomass every two years. This rate of growth seems implausible.

Given a nearly 20 year history demonstrating our inability to control fishing mortality rates or to rebuild the stock, these implied growth rates seem unrealistic given the relatively poor recruitment. It is difficult to envision rebuilding with total mortality rates hovering near 80% per year on fully recruited animals. An 80% total mortality rate means that half of the fully recruited population alive on January 1 dies within 6 months. Clearly, the current total mortality rate is not conducive to stock rebuilding for a stock that is fully mature at age 5. Whether we can fish this stock to recovery remains an open question. The Canadian experience suggests that cod stocks are less resilient and rebuilding is difficult once biomass is low.

The projections that rebuild have low F (0.06) and previous projections have a history of optimistic rebuilding trajectories. We are likely to miss our target F (and rebuilding target) if small deviations in starting conditions or inability to constrain and measure low catches associated with the F. We will need unprecedented precision in the assessment and projections. Past history indicates that projections results have been optimistic and are fragile to starting conditions and assumptions. ABC's generated via projections will need to be robust to starting conditions and projection assumptions in order to end overfishing and rebuild biomass.

Rebuilding GOM cod will require a large reduction in fishing mortality and improved recruitment. A large reduction in fishing mortality is needed to end overfishing. This statement is true even if reference points for Mramp model were consistent with a natural mortality rate=0.4.

The PDT notes that, technically the GOM cod stock can rebuild to SSB_{MSY} based on the math in the projections. These projections have over time, as has been previously noted, been shown to be overly optimistic for GOM cod. The PDT has serious concerns whether rebuilding is possible in the specified time period for all the reasons listed above. Rebuilding projections from 2015-2024 assume recruitment will occur as it has over the past three decades. There are indications of recruitment failure with the present record low spawning stock biomass. The stock will not rebuild in time if future recruitment is compromised and is lower then what was observed in the past.

All indications are that the stock is in very poor condition and catches/ABCs should be based on an $F_{rebuild}$ as required by the FMP's control rule. However, predicting future recruitment for a stock in such a condition becomes much more difficult. Protecting as much spawning stock biomass as possible and the act of spawning itself is needed to promote improvements in recruitment. Low ABCs are needed to increase the possibility of rebuilding this stock.

The PDT acknowledges that along with the low ABC recommendations additional management measures that reduce access to the stock will likely be needed to ensure that the catch limits are truly met. The PDT is concerned that the low ABCs needed to protect the stock will lead to an unknown underestimate of the true catch. This could ultimately result in further reductions in stock productivity and compromise future stock assessment models (e.g., stronger retrospective patterns). Furthermore, the possibility of rebuilding GOM cod remains unlikely until such time that one or more successive strong year classes recruit to the stock.

References:

Jacobson, L.D., S.X. Cadrin and J.R. Weinberg. 2002. Tools for Estimating Surplus Production and FMSY in Any Stock Assessment Model. North American Journal of Fisheries Management 22:326–338.