Reference #7

A. Gulf of Maine Cod
WP #1
December 2012

A. GULF OF MAINE ATLANTIC COD (*GADUS MORHUA*) STOCK ASSESSMENT FOR 2012, UPDATED THROUGH 2011

SAW/SARC 55

3 – 7 December 2012
NOAA Fisheries
Northeast Fisheries Science Center
Woods Hole, MA 02543

15%) although the 2011 spawning stock biomass is more precisely estimated when a BH relationship is assumed. Use of a Ricker relationship is consistent with evidence for cannibalism observed in other Cod stocks (Puvanendran et al., 2008) although there has been no evidence of post-larval cannibalism in either Gulf of Maine or Georges Bank Cod.

A number of features don't lend support to use of the long-term dataset. Models run with either the Ricker or BH relationship starting in 1970 provide relatively the same estimates of spawning biomass and recruitment, indicating that it is primarily the information in the 1960s which is providing the basis for differing stock – recruit relationships. This is a time period during which there is no age compositional data and fisheries statistics are most uncertain. Issues with the historical data quality are discussed in SAW 55 WG (2012a). Further, the survey aggregate numbers indices for the 1960s contains data on age 0 cod which cannot be removed from the analysis, although when aggregate biomass indices are used (in which age 0 cod would play a less prominent role), the assessment results are qualitatively similar.

Regarding model fits, there is little difference in the value of the objective function when using either a Ricker or BH relationship in a model starting in 1932 (about 3 points for M=0.2 or 8 points for the M-ramp). For both M scenarios, the difference in log likelihoods between Ricker and BH was due to stock - recruit residuals during 1963-1969, the period with no age composition data. A pattern of positive residuals exists for both relationships during 1977 – 87, a period with high catches.

Simulation studies have indicated a propensity to fit domed stock – recruit relationships (i.e. Ricker), even when a BH is true (De Valpine and Hastings, 2002). However, the results of these studies depend heavily on the scenario being simulated (e.g. length of time series) and may not apply to the current situation. F_{MSY} (0.53) estimated using a Ricker model is generally larger than F_{MAX}, although this is to be expected when the stock – recruitment relationships are domed. On the other hand, spawning biomass did decline after the 1970s when the resource experienced fishing mortalities consistent with the Ricker – based F_{MSY}.

There is an overall concern that if there have been long-term stock productivity changes, analytically – derived estimates of B_{MSY} and F_{MSY} based on 1932 – present stock dynamics, which can be considered a weighted average over the entire time series, may not reflect current conditions.

Short-term (1982 – present): recruitment productivity based on SPR

The main feature supporting use of the shorter-term time series is that this is the period which has the highest data density. Data are available on the quantity and size composition of the landings and discards, both commercial and recreational. A number of survey indices are available, each with aggregate indices of abundance and biomass, along with data on age/size composition. Biological information such as growth, maturity and length / weight relationships are also available.

Regarding model fits, the estimates of biomass and fishing mortality, as well as the reference points are robust to a wide range of model assumptions and uncertainties.

The main issue against using the short-term time series is that it does not provide sufficient contrast to estimate stock – recruit relationships, and thus requires the use of B_{MSY} and F_{MSY} proxies which in turn has associated uncertainties (i.e. selection of percentage spawner per recruit).

Consequence Analysis

The risks associated with management actions taken during 2013 – 2015 were examined by undertaking stock projections under the competing assumptions for the state of nature. For instance, if the true state of nature is that natural mortality has remained unchanged at 0.2 and that stock productivity is best reflected by the 1982 – present dataset (SPR, M = 0.2 model), then the consequences of management actions by setting projected catch according to 75% F_{MSY} based on the

three alternative states of nature were examined (short-term (SPR) with M ramp, long-term (SR) with M = 0.2 and long-term (SR) with M-ramp). In all cases, the 2012 catch was provided by the NEFMC Groundfish Plan Development Team. Projections were only conducted until 2015. There may be longer term consequences which might be revealed through a more extensive analysis. This is beyond the current terms of reference.

In these explorations, the assessments using the long-term dataset assumed a Ricker stock – recruitment relationship. Use of a BH relationship produced results for future catches under 50% F_{MSY} within the range of the other alternate states of nature, indicating that the analyses presented below bracket the risks to the stock of assuming one state of nature while another might be true. It should be pointed out that while these runs are not presented in detail here, the results of these BH runs are also plausible.

The column headers in Table A.97 and Figure A.210 represent the 'true' states of nature considered, these being:

- ASAP, 1982 start, M = 0.2: stock dynamics and assessment based on 1982 – present dataset with M = 0.2 for the time series
- ASAP, 1982, M-ramp: stock dynamics and assessment based on 1982 – present dataset with M ramped from 0.2 to 0.4 during 1989 – 2002
- SCAA, 1932 start, Ricker, M = 0.2: stock dynamics and assessment based on 1932 – present dataset with M = 0.2 for the time series
- SCAA, 1932, Ricker, M-ramp: stock dynamics and assessment based on 1932 – present dataset with M ramped from 0.2 to 0.4 during 1989 – 2002

The row headers in Table A.97 indicate the basis of the management action during the projected period (2013 – 2015). Thus, the row header 'SCAA, 1932, Ricker, M-ramp' indicates that catch was projected assuming that the stock conditions and reference points were as per these dynamics. All projections were conducted at 75% F_{MSY}, based on the assumed state of nature and thus which establishes the catch in each cell. This is the 'planned' catch. The cells of the table indicate the SSB and fully recruited fishing mortality (F_{full}) which are a consequence of applying the catch based on the assumed state of nature to the SSB of the 'true' state of nature. The diagonal rows represent the situation in which the management actions based upon the assumed state of nature are in fact correct. In these stochastic projections (see TOR 8a), there were cases in which the projection attempted to harvest more fish than exist in the population's exploitable biomass. The fraction of feasible projections for the eight combinations of states of nature and basis of management action are provided in Table A.100.

The consequence analysis is summarized in Figure A.210. As with Table A.97, the column headers indicate one of the 'true' states of nature. The row headers indicate whether or not catch, SSB or F_{full} is being displayed along the row. The content of each cell summarizes the consequences (reflected by the medians of the distributions in question) of assuming one state of nature when another is true. The black line in each cell indicates the catch, SSB and F_{full} for the 'true' state of nature. The coloured lines (for the projected period only) indicate the catch, SSB and F_{full} which result when the 75% F_{MSY} estimated catch is incorrectly based upon an alternate state of nature. The dashed lines in each figure are the B_{MSY}, F_{MSY} and MSY for the 'true' states of nature. The reference points associated with the 'true' states of nature are indicated in Table A.98.

When management actions are correctly based upon a particular state of nature (the diagonals of Table A.97), a modest increase in SSB is projected until 2015 for the two ASAP and one of the SCAA (with M=0.2) options. Only in the case of the SCAA, 1932, Ricker, M-ramp option is SSB projected to decline, though this is a consequence, at least in part, of the harvest strategy being applied where the resource is estimated to be above B_{MSY}. The 2011 SSB estimates range 9,903 - 10,221 t and 13,735 - 14,509 t for the two ASAP and SCAA options respectively. Fully recruited fishing mortality

declines for the two ASAP options (from 0.86 – 0.9 to 0.14 – 0.22), increases slightly (from 0.52 to 0.56) for the SCAA, 1932, Ricker, M = 0.2 option, and increases (from 0.61 to 0.71) for the SCAA, 1932, Ricker, M ramp option. Catch for the two ASAP options declines from 6830 t in 2011 to 1,929 – 2,030 t in 2015. For the SCAA, 1932, Ricker, M = 0.2 option, catch increases from 6830 t in 2011 to 8,424 t in 2015 while it declines to 5,020 t over the same period for the SCAA, 1932, Ricker, M-ramp option. If the management actions are correctly based upon the 'true' state of nature, the two ASAP models indicate that, in 2013, the stock is in an overfished state (Table A.99). In contrast, the two SCAA models indicate that the stock would not be in an overfished state in 2013. In all cases, overfishing is not occurring in 2013.

It is useful to consider the consequences of mis-specifying natural mortality separately from stock – recruit dynamics (based on either the ASAP or SCAA models). For the two ASAP models which base stock – recruit dynamics on spawner per recruit considerations, mis-specifying the natural mortality is inconsequential, with catch, SSB and F_{full} being very similar. Consequently, the 2013 stock status would remain as overfished but that overfishing is not occurring. The natural mortality assumption is slightly more of an issue when stock dynamics are based on the long-term derived stock – recruitment relationship (SCAA models). Assuming an M-ramp when M is actually equal to 0.2 results in a lower than 'planned' fishing mortality and catch and higher than 'planned' SSB. Status in 2013 would still be not overfished and overfishing not occurring. When M is assumed to be 0.2 but an M-ramp is correct, fishing mortality and thus catch would be considerably higher than 'planned' with the result that in 2013 the stock would be experiencing overfishing although it would not be overfished (Table A.99).

The consequences of mis-specifying the stock-recruit dynamics are overall more severe than mis-specifying natural mortality. If management actions during 2012 – 2015 are based on stock-recruit dynamics assuming SPR dynamics (the ASAP models) when those based on SR dynamics should have been used (the SCAA models), fishing mortality and thus catch would be lower than 'planned' while SSB would be higher than 'planned'. There would, nevertheless, be no change in the 2013 status.

If management actions during 2012 – 2015 were based on stock-recruit dynamics assuming an SR function (the SCAA models), when those based on SPR should have been used (the ASAP models), fishing mortality and thus catch would be much higher than 'planned' while SSB would decline more than 'planned', particularly if M had also been assumed to be 0.2. This would result in the stock being determined as overfished as well as overfishing occurring in 2013 regardless of the natural mortality.

To summarize, mis-specification of stock-recruit dynamics has greater implications for management actions during 2012 – 2015 than mis-specification of natural mortality. Mis-specification of natural mortality is inconsequential if stock-recruit dynamics conform to SPR considerations but are more of an issue when recruitment is based on an SR function (in this case a Ricker relationship).

TOR A.8.c. Describe this stock's vulnerability

The Gulf of Maine cod stock is currently undergoing processes that have not been incorporated into the analytical formulations. Nevertheless, they should be considered when setting the ABC.

Since the mid-1990s, as observed in the NEFSC bottom trawl surveys and consistent with the trends in the fishery, 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 stock has become particularly concentrated in a small region of the western Gulf, an area which appears to be a forage 'hotspot' due to the presence of sand lance, a prey of cod.

Natural mortality of cod may be increasing through consumption by other fishes and marine mammals as these populations increase; however, evidence of this is lacking in the food habits data. On the other hand, tagging studies suggest an elevated M during 2003 – 2006, which was the basis of the M

Table A.97. Results of consequence analysis of Gulf of Maine cod; column and row headers indicate 'true' state of nature and basis of management action (75% F_{MSY} for 2013 – 2015) under assumed states of nature; cells provide projections of SSB and fully recruited fishing mortality for 'true' states of nature for catch set according to assumed state of nature; diagonals (shaded) indicate that management actions were correctly specified for the state of nature.

			States of Nature											
Management actions - catches in 2013-2015	Year	Input	ASAP, 1982 start, M=0.2			ASAP, 1982 start, M-ramp			SCAA, 1932 start, Ricker, M=0.2			SCAA, 1932 start, Ricker, M-ramp		
			SSBmsy = 54,743 mt	MSY = 9,399 mt	F_{msy} = 0.18	SSBmsy = 19,605 mt	MSY = 4,840 mt	F_{msy} = 0.29	SSBmsy = 20,910 mt	MSY = 12,840 mt	F_{msy} = 0.75	SSBmsy = 11,180 mt	MSY = 7,170 mt	F_{msy} = 0.95
			Catch (mt)	SSB (mt)	F_{full}	Catch (mt)	SSB (mt)	F_{full}	Catch (mt)	SSB (mt)	F_{full}	Catch (mt)	SSB (mt)	F_{full}
ASAP, 1982 start, M=0.2	2011	Result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	14,509	0.52	6,830	13,735	0.61
	2012	Assumed catch	3,767	8,995	0.46	3,767	7,711	0.58	3,771	16,427	0.25	3,771	12,582	0.37
	2013	Projection	1,249	9,406	0.14	1,249	6,833	0.21	1,249	17,661	0.07	1,249	10,921	0.12
	2014	Projection	1,503	12,143	0.14	1,503	8,436	0.24	1,503	24,375	0.06	1,503	13,527	0.13
	2015	Projection	2,030	16,802	0.14	2,030	11,432	0.23	2,030	33,073	0.06	2,030	16,709	0.15
ASAP, 1982 start, M-ramp	2011	Result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	14,509	0.52	6,830	13,735	0.61
	2012	Assumed catch	3,767	8,995	0.46	3,767	7,711	0.58	3,771	16,427	0.25	3,771	12,582	0.37
	2013	Projection	1,289	9,389	0.14	1,289	6,825	0.22	1,289	17,661	0.07	1,289	10,921	0.13
	2014	Projection	1,396	12,145	0.13	1,396	8,426	0.22	1,396	24,328	0.06	1,396	13,488	0.12
	2015	Projection	1,929	16,937	0.13	1,929	11,456	0.22	1,929	33,161	0.06	1,929	16,791	0.14
SCAA, 1932 start, Ricker, M=0.2	2011	Result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	14,509	0.52	6,830	13,735	0.61
	2012	Assumed catch	3,767	8,995	0.46	3,767	7,711	0.58	3,771	16,427	0.25	3,771	12,582	0.37
	2013	Projection	8,423	7,215	1.41	8,423	4,942	2.63	8,423	17,661	0.56	8,423	10,921	1.10
	2014	Projection	7,621	4,719	2.77	7,621	3,231	5.00	7,621	16,266	0.56	7,621	7,706	1.91
	2015	Projection	8,424	5,134	3.09	8,424	4,043	4.89	8,424	18,367	0.56	8,424	7,032	2.42
SCAA, 1932 start, Ricker, M-ramp	2011	Result	6,830	9,903	0.86	6,830	10,221	0.90	6,830	14,509	0.52	6,830	13,735	0.61
	2012	Assumed catch	3,767	8,995	0.46	3,767	7,711	0.58	3,771	16,427	0.25	3,771	12,582	0.37
	2013	Projection	5,803	8,214	0.81	5,803	7,711	1.46	5,803	17,661	0.34	5,803	10,921	0.71
	2014	Projection	4,507	7,354	0.81	4,507	5,450	1.84	4,507	19,447	0.25	4,507	9,252	0.71
	2015	Projection	5,020	9,159	0.76	5,020	4,636	1.46	5,020	25,272	0.22	5,020	10,385	0.71

Table A.98. Reference points associated with states of nature of Gulf of Maine cod.

Reference Point	ASAP, 1982 start		SCAA, 1932 start, Ricker	
	M=0.2	M-ramp	M=0.2	M-ramp
SSB_{MSY} (B_{target})	54,743	19,605	20,910	11,180
1/2 SSB_{MSY} ($B_{threshold}$)	27,372	9,803	10,455	5,590
MSY	9,399	4,840	12,840	7,170
F_{MSY}	0.18	0.29	0.75	0.95
75% F_{MSY}	0.14	0.22	0.56	0.71

Table A.99. Status of 2013 spawning stock biomass and fishing mortality of Gulf of Maine cod; column and row headings indicate 'true' state of nature and basis of management action respectively; cells indicate 2013 stock status resulting from application of management actions under assumed state of nature (rows) to 'true' state of nature.

			True state of nature			
			ASAP, 1982 start		SCAA, 1932 start, Ricker	
			M=0.2	M-ramp	M=0.2	M-ramp
Management action basis	ASAP, 1982 start, YPR	M=0.2	Overfished, overfishing is not occuring	Overfished, overfishing is not occuring	Not overfished, overfishing is not occuring	Not overfished, overfishing is not occuring
		M-ramp	Overfished, overfishing is not occuring	Overfished, overfishing is not occuring	Not overfished, overfishing is not occuring	Not overfished, overfishing is not occuring
	SCAA, 1932 start, Ricker	M=0.2	Overfished, overfishing is occuring	Overfished, overfishing is occuring	Not overfished, overfishing is not occuring	Not overfished, overfishing is occuring
		M-ramp	Overfished, overfishing is occuring	Overfished, overfishing is occuring	Not overfished, overfishing is not occuring	Not overfished, overfishing is not occuring

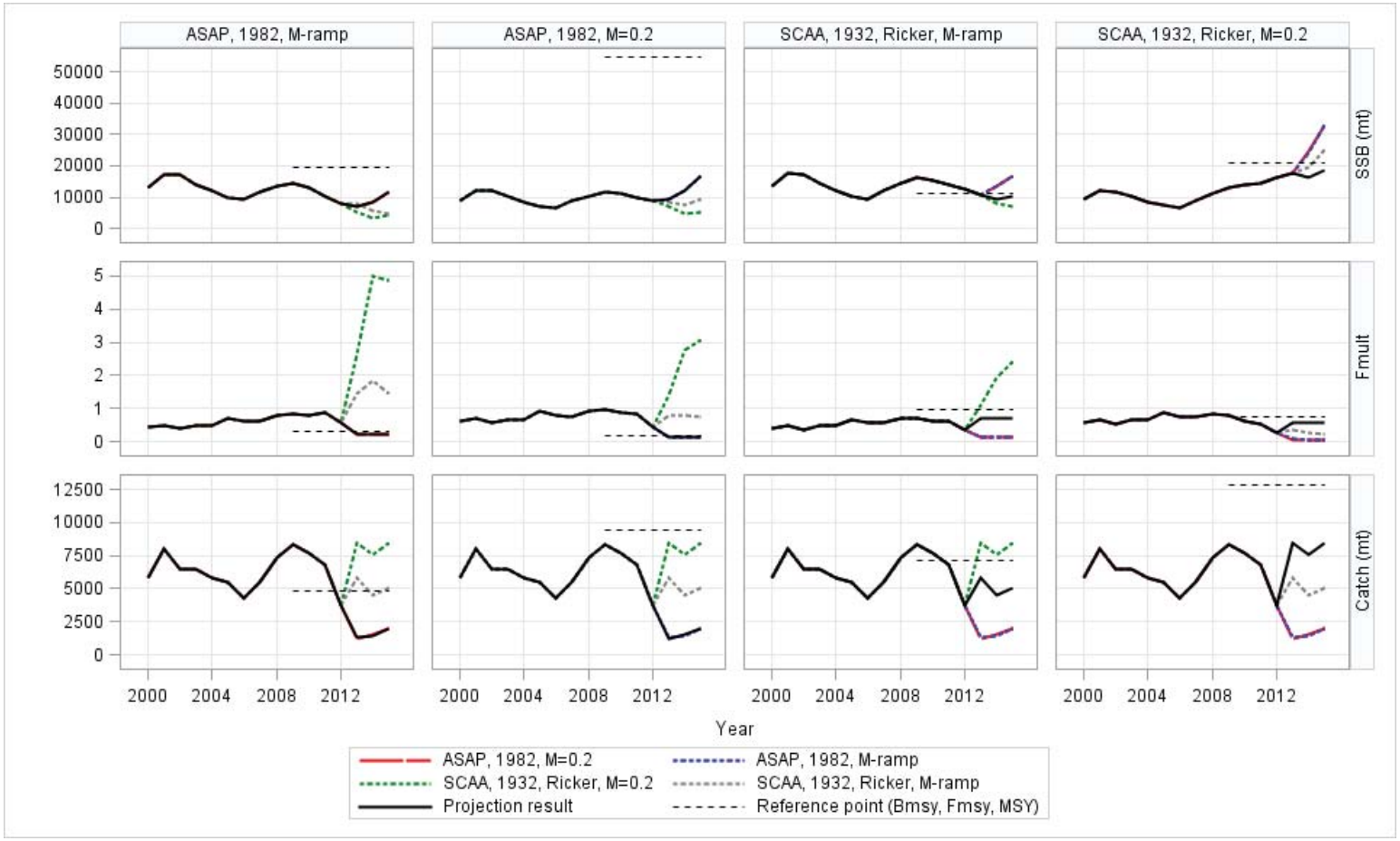

Figure A.210. Trends in Gulf of Maine cod SSB (top row), fully recruited fishing mortality (middle row) and catch (bottom row) during 2000 – 2015; column headers indicate 'true' state of nature; cells provide trend in indicator under 'true' state of nature when catch during projection period (based on 75% F_{MSY} is correctly specified (black) and mis-specified (red: ASAP, 1982, M = 0.2; blue: ASAP, 1982, M-ramp; green: SCAA, 1932, Ricker, M = 0.2; grey: SCAA, 1932, Ricker, M -ramp; MSY – based reference points indicated in dashed line on each plot