Consequence Analysis for Gulf of Maine Cod

The Assessment Models

The 2012 assessment models of the Gulf of Maine Cod stock differ both in use of pre-1982 information and natural mortality (M) assumptions. Four main assessment model options (herein referred to as 'states of nature') were configured:

- Stock-recruit dynamics based on model (SR) using long-term (1932 – present) dataset with either M constant (0.2) for the entire time series or M ramping up from 0.2 during 1932 – 1988 to 0.4 during 2003 – 2011 (these are two SCAA models)

- Stock-recruit dynamics based on spawner per analysis (SPR) of short – term (1982 – present) dataset with either M constant (0.2) for the entire time series or M ramping up from 0.2 during 1982 – 1988 to 0.4 during 2003 – 2011 (these are two ASAP models)

The model which uses the 1982 – present dataset with M constant (0.2) for the entire time was preferred by one lead scientist, while the model which uses the 1932 – present dataset with M ramping up from 0.2 to 0.4 was preferred by another lead scientist. There was not general consensus in the assessment process on these preferences and thus a consequence analysis was conducted.

Consequence Analysis

The risks associated with management actions taken during 2013 – 2015 were examined by undertaking stock projections under the competing assumptions of 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 (short-term (SPR) with M ramp, long-term (SR) with M = 0.2 and long-term (SR) with M ramp) were examined. Projections were only conducted until 2015. There may be long-termer consequences which may be revealed through a more extensive analysis.

The column headers in Table 1 and Figure 1 represent the 'true' states of nature, these being

- SPR & M = 0.2: stock dynamics and assessment based on 1982 – present dataset with M = 0.2 for the time series
- SPR & M ramp: stock dynamics and assessment based on 1982 – present dataset with M ramped from 0.2 to 0.4 during 1989 – 2002
- SR/M = 0.2: stock dynamics and assessment based on 1932 – present dataset with M = 0.2 for the time series
- SR/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 1 indicate the basis of the management action during the projected period (2013 – 2015). Thus, the row header 'SR & 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, which establishes the catch in each cell. This is the 'planned' catch. The cells of the table indicate the SSB and F_{full} which are a consequence of applying the 'planned' 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.

The consequence analysis is summarized in Figure 1. As with Table 1, 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 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 2.

When management actions are correctly based upon a particular state of nature (the diagonals of Table 1), a modest increase in SSB is projected until 2015 for the two SPR and one of the SR (with M=0.2) options. Only in the case of the SR & M ramp option is SSB projected to decline. The 2011 SSB estimates range 9,903 - 10,221 t and 13,735 - 14,509 t for the two SPR and SR options respectively. Fully recruited fishing mortality declines for the two SPR options (from 0.86 – 0.9 to 0.14 – 0.22), remains stable (at about 0.5) for the SR & M = 0.2 option, and increases modestly (from 0.61 to 0.66) for the SR & M ramp option. Catch for the two SPR options declines from 6830 t in 2011 to 1,929 – 2,030 t in 2015. For the SR & M = 0.2 option, catch increases from 6830 t in 2011 to 8,135 t in 2015 while it declines to 4878 t over the same period for the SR & M ramp option. If the management actions are correctly based upon the 'true' state of nature, the two SPR models indicate that, in 2013, the stock is in an overfished state (Table 3). In contrast, the two SR models indicate that the stock would not be in an overfished state in 2013. In all cases, overfishing is not occurring.

It is useful to consider the consequences of mis-specifying natural mortality separately from stock – recruit dynamics (based on either the SPR or SR model). For the two 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 (Table 1 and Fig. 1). Consequently, the 2013 stock status would remain as overfished but that overfishing is not occurring (Table 3.). The natural mortality assumption is slightly more of an issue when stock dynamics are based on the long-term derived stock – recruitment relationship. 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 (third columns of Table 1 and Fig. y1). When M assumed to be 0.2 but an M ramp is correct, fishing mortality and thus catch would be considerably higher than planned (columns four of Table 1 and Fig. 1) with the result that the stock would be considered overfished in 2013 (Table 3).

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 when those based on SR dynamics should have been used (columns 3 and 4 of Table 1 and Fig. 1), 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 status (Table 3: not overfished and no overfishing).

If management actions during 2012 – 2015 were based on stock – recruit dynamics assuming an SR function, when those based on SPR should have been used (columns 1 and 2 and rows 3 and 4 of Table 1), 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 regardless of the natural mortality (Table 3.).

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).

Table 1. 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

			State of Nature											
Basis of Management Action		Year	SPR & M = 0.2			SPR & M ramp			SR & M = 0.2			SR & M ramp		
			Catch (mt)	SSB (mt)	F_{full}	Catch (mt)	SSB (mt)	F_{full}	Catch (mt)	SSB (mt)	F_{full}	Catch (mt)	SSB (mt)	F_{full}
	SPR & M = 0.2	2011	6,830	9,903	0.86	6,830	10,221	0.90	6830	14509	0.52	6830	13735	0.61
		2012	3,767	8,995	0.46	3,767	7,711	0.58	3771	16427	0.25	3771	12582	0.37
		2013	1,249	9,406	0.14	1,249	6,833	0.21	1,249	17661	0.07	1,249	10921	0.12
		2014	1,503	12,143	0.14	1,503	8,436	0.24	1,503	24375	0.06	1,503	13527	0.13
		2015	2,030	16,802	0.14	2,030	11,432	0.23	2,030	33073	0.06	2,030	16709	0.15
	SPR & M ramp	2011	6,830	9,903	0.86	6,830	10,221	0.90	6830	14509	0.52	6830	13735	0.61
		2012	3,767	8,995	0.46	3,767	7,711	0.58	3771	16427	0.25	3772	12582	0.37
		2013	1,289	9,389	0.14	1,289	6,825	0.22	1,289	17661	0.07	1,289	10921	0.13
		2014	1,396	12,145	0.13	1,396	8,426	0.22	1,396	24328	0.06	1,396	13488	0.12
		2015	1,929	16,937	0.13	1,929	11,456	0.22	1,929	33161	0.06	1,929	16791	0.14
	SR & M = 0.2	2011	6,830	9,903	0.86	6,830	10,221	0.90	6830	14509	0.52	6830	13735	0.61
		2012	3,767	8,995	0.46	3,767	7,711	0.58	3771	16427	0.25	3771	12582	0.37
		2013	8,423	7,215	1.41	8,423	4,942	2.63	7911	17661	0.52	8,423	10921	1.10
		2014	7,621	4,719	2.77	7,621	3,231	5.00	7320	17003	0.51	7,621	7706	1.91
		2015	8,424	5,134	3.09	8,424	4,043	4.89	8135	19691	0.50	8,424	7032	2.42
	SR & M ramp	2011	6,830	9,903	0.86	6,830	10,221	0.90	6830	14509	0.52	6830	13735	0.61
		2012	3,767	8,995	0.46	3,767	7,711	0.58	3771	16427	0.25	3772	12582	0.37
		2013	5,803	8,214	0.81	5,803	7,711	1.46	5,803	17661	0.34	5614	10921	0.68
		2014	4,507	7,354	0.81	4,507	5,450	1.84	4,507	19447	0.25	4396	9529	0.67
		2015	5,020	9,159	0.76	5,020	4,636	1.46	5,020	25272	0.22	4878	10935	0.66

Table 2. Reference points associated with states of nature of Gulf of Maine cod

Reference Point	SPR		SR (Ricker)	
	M=0.2	M ramp	M=0.2	M ramp
SSB_{MSY} (B_{target}), t	54,743	19,605	20,910	11,180
1/2 SSB_{MSY} ($B_{threshold}$), t	27,372	9,803	10,455	5,590
MSY, t	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 3. 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 (columns)

			State of Nature			
			SPR		SR (Ricker)	
			M=0.2	M ramp	M=0.2	M ramp
Basis of Management Action	SPR	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
	SPR (Ricker)	M=0.2	Overfished, overfishing is occuring	Overfished, overfishing is occuring	Not overfished, overfishing is not occuring	Overfished, overfishing is not occuring
		M-ramp	Overfished, overfishing is occuring	Overfished, overfishing is occuring	Not overfished, overfishing is not occuring	Not overfished, overfishing is not occuring

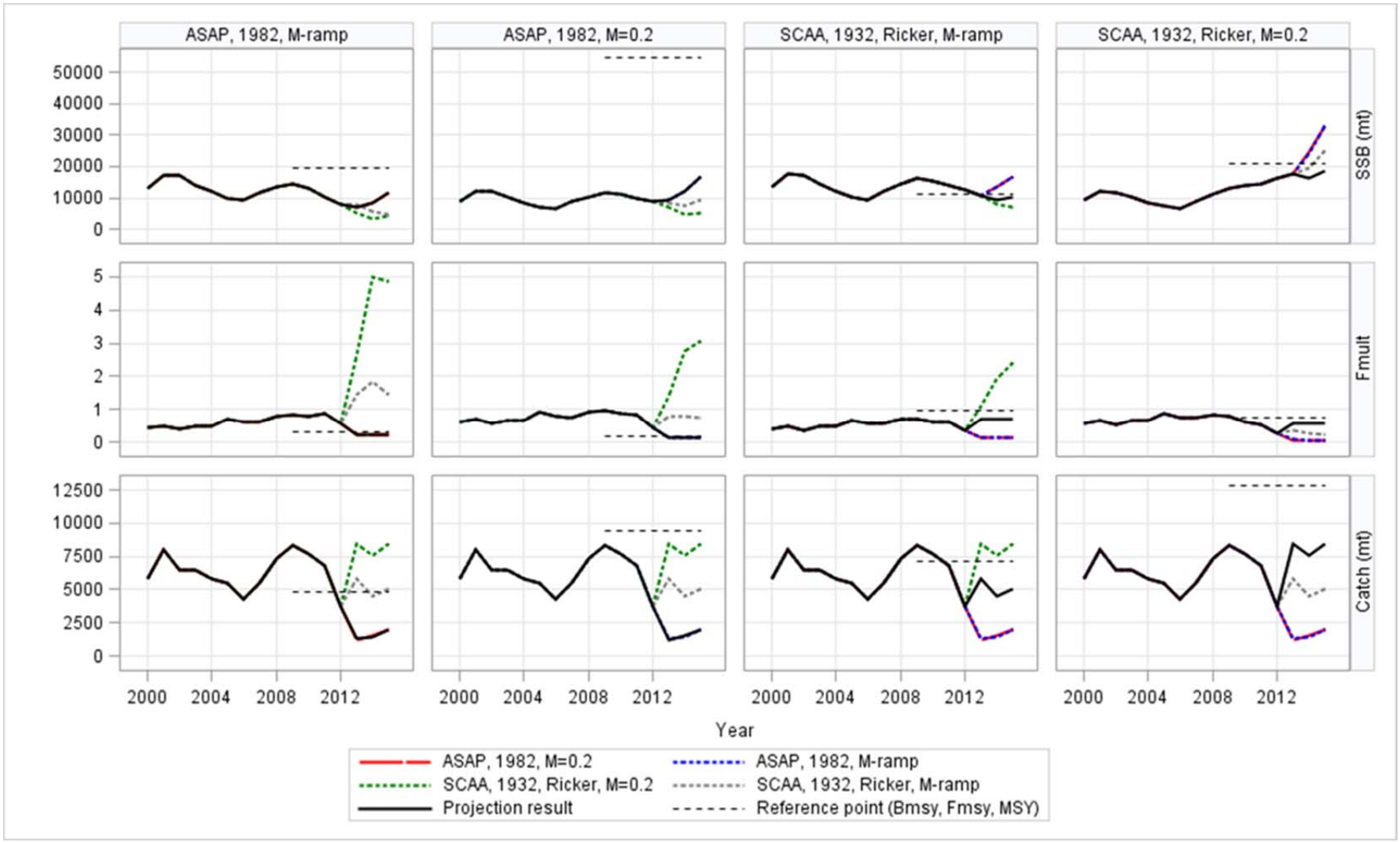

Figure 1. Trends in Gulf of Maine cod SSB (top row), fully recruited fishing mortality (middle row) and catch (bottom row) during 2000 – 2015; column headers indicate 'true' state of nature; cells provide trend in indicator under 'true' state of nature when catch during projection period (based on 75% F_{MSY} is correctly specified (black) and mis-specified (red: SPR & M = 0.2; blue: SPR & M ramp; green: SR & M = 0.2; grey: SR & M ramp; MSY – based reference points indicated in dashed line on each plot