On the Implications of Tagging Analyses for the Shape of Selectivity at Age for Gulf of Maine Cod

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INTRODUCTION

This paper provides some comments in response to Hart and Miller's (2008) interpretation of the implications of their analyses of tagging data regarding the dome shape estimated for selectivity for Gulf of Maine cod in the ASPM Reference Case assessment of Butterworth and Rademeyer (2008a).

It is first informative to consider the sensitivity of the 2007 Reference Case ASPM assessment of Butterworth and Rademeyer (2008a) to alternative values of age-independent natural mortality *M*. The results are shown in Table 1 and Fig. 1 below.

From Fig. 1 it is clear that the inference or otherwise of a dome in selectivity depends strongly on the value assumed for *M*. If M=0.2 yr^{-1} as assumed for the Butterworth and Rademeyer (2008a) Reference Case, then selectivity for the NEFSC surveys is appreciably dome shaped with a rapid decline with age above age 7. However for $M \sim 0.4 – 0.5$, the selectivity for these ages becomes effectively flat.

Interestingly, the tagging analyses of Hart and Miller (2008), from which they infer such flat selectivity, estimate (approximately) M=0.5 for length<60 cm and M=1.0 for length>60 cm.

SELECTIVITY AND EMIGRATION

A decrease in selectivity that is estimated for large ages can be a surrogate for emigration. Butterworth and Rademeyer (2008b) show that an annual emigration rate *E* will appear as a decrease in selectivity at age (S_a) of magnitude:

$$S_{a+1} / S_a \sim e^{-E} \tag{1}$$

Given the results of Hart and Miller (2008) that at larger ages the return rate of tags is independent of age for Gulf of Maine cod for larger ages at release, it would follow that in the emigration in equation (1) must be *permanent*, i.e. once cod in this population become older, it is not merely that they become less likely to be captured by trawl gear, but rather that some of these cod behave in a way (see later section) that renders them unavailable to such gear. Strictly such behaviour is more accurately modelled by a two-box framework with permanent movement from one box to the other, as it implies that the complete population is not fully mixed, but treating this as decreasing selectivity at age within a single box framework is common practice as it is virtually identical mathematically and simplifies the modelling.

ESTIMATES FROM TAG-RECAPTURE DATA

In the situation of a population with parameters independent of age, the tag-return information can be summarised by two statistics:

$$R = \phi F/Z \quad (2)$$

$$T = 1/Z \quad (3)$$

$$Z = F + M + M^* + E + \lambda \quad (4)$$

where:

R	is the fraction of tags that are eventually recovered,
T	is the average time elapsed before a tag is recovered,
F	is the fishing mortality rate,
Φ	is some combination of immediate mortality of a tagged fish and a proportion less than 1 of tagged fish recaptured (in the Hart and Miller (2008) analyses high-reward tagged fish) that are reported,
M	is the natural mortality rate,
M^*	is an additional tag-induced continuous mortality rate,
E	is the emigration rate, and
λ	is the tag shedding rate.

The Hart and Miller (2008) analyses model a more complex situation including length-specific differences and movements between three areas, but in essence are governed by equations (2) to (4) above. Specifically they amount to making the assumptions E=0 and Φ=1, which leads to:

$$R = F/(F + M + M^* + \lambda) \quad (5)$$

$$T = 1/(F + M + M^* + \lambda) \quad (6)$$

Taking λ ~ 0.15 from the Hart and Miller (2008) analyses, and given values for *R* and *T* from the data, these amount to two equations for two unknowns, *F* and ($M + M^*$). The smallish value of *R* essentially drives the estimate of *F* to be relatively low, so that equation (6) coupled also to a lowish value of *T* leads to the high values of ($M + M^*$) reported in Hart and Miller (2008). If M=0.2, these imply M^*= 0.3 for younger and 0.8 for larger cod, with the latter value in particular seeming much too high to be realistic for a continuous tag-induced additional natural mortality rate.

However, there are two alternative interpretations of the tag data which equations (2) to (4) also suggest:

i) E>0: (permanent) emigration of cod from availability to trawl gear, as the analyses are able to estimate only the parameter combination ($M + M^* + E$), so that the values of *M*, M^* and *E* are confounded – for example a positive value for *E* as suggested by estimates of dome shaped selectivity, while maintaining a conventional value for M ~ 0.2 would see M^* reduced to seemingly more realistic levels; and

ii) Φ<1: some combination of immediate mortality of tagged cod and non-reporting of recovery of high-reward tagged cod; equation (2) then suggests a compensating increase of *F* necessary to maintain the value of its numerator, which could then lead to a decrease in the estimate of ($M + M^* + E$) sufficient to allow a realistic estimate of M^* consistent with an E=0 assumption; what then would have to be checked though, is whether or not a decrease in Φ sufficient to achieve such a reduction of ($M + M^* + E$) required an increase in *F* beyond what is compatible with assessment computations (note that the present estimates of *F* for Gulf of Maine cod of length>60 cm in Hart and Miller (2008) (~ 0.18 - 0.19) would seem perfectly compatible with those for F_{2006} for the ASPM Reference Case assessment of Butterworth and Rademeyer (2008a) (~ 0.17)).

WHERE NEXT?

The key question becomes: how might the alternative possible interpretations above of the implications of the tag-recapture data be distinguished?

A) Φ<1: A proposal would be to rerun the model in Hart and Miller (2008) with Φ=0.5 (say) to re-estimate F and ($M + M^* + E$) so as to check whether the resultant increase in the estimates of F for Gulf of Maine cod can result in a sufficient decrease in corresponding estimates of ($M + M^* + E$) to be reasonably compatible with an E=0 inference (i.e. achieve a realistic reduction in the associated M^* value) without increasing F to an extent incompatible with assessments.

B) E<0: There are a number of possible mechanisms which could lead to this, such as migration to outside the areas effectively considered by Hart and Miller, including to deeper water or to untrawlable rocky ground preferentially inhabited by older cod, or an ability of cod related (though with variance) to their age/length to achieve greater capability as they age to escape capture by trawls because of improved swimming ability. The first possibility might be tested through placement of alternative gear such as longlines both in areas covered and not covered by the current trawling surveys, while recordings from cameras placed on nets of fish behaviour with the approach of a net might shed light on the second.

REFERENCES

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Table 1: Results for the 2007 Reference Case ASPM assessment for Gulf of Maine cod for different (age-independent) input values for natural mortality *M*.

	1		6a		6d		6e	
	2007 Reference Case		M=0.3		M=0.4		M=0.5	
-lnL	8.34		7.92		10.95		21.00	
M	**0.20**	-	**0.30**	-	**0.40**	-	**0.50**	-
h	1.34	(0.15)	1.13	(0.16)	0.94	(0.17)	0.68	(0.16)
γ	**1.00**	-	**1.00**	-	**1.00**	-	**1.00**	-
K^{sp}	147.31	(0.10)	93.34	(0.11)	72.56	(0.12)	77.85	(0.11)
B^{sp}_{2004}	34.49	(0.14)	31.41	(0.12)	30.84	(0.11)	35.18	(0.11)
B^{sp}_{2006}	42.87	(0.15)	38.47	(0.13)	37.39	(0.13)	42.18	(0.13)
B^{sp}_{2004}/K	0.23	(0.13)	0.34	(0.14)	0.42	(0.13)	0.45	(0.13)
B^{sp}_{2006}/K	0.29	(0.15)	0.41	(0.16)	0.52	(0.15)	0.54	(0.15)
B^{sp}_{MSY}	53.05	(0.09)	35.41	(0.07)	29.10	(0.11)	32.63	(0.14)
$B^{sp}_{2004}/B^{sp}_{MSY}$	0.65	(0.15)	0.89	(0.14)	1.06	(0.14)	1.08	(0.15)
$B^{sp}_{2006}/B^{sp}_{MSY}$	0.81	(0.15)	1.09	(0.14)	1.28	(0.14)	1.29	(0.15)
B^{sp}_{MSY}/K	0.36	(0.13)	0.38	(0.15)	0.40	(0.17)	0.42	(0.19)
MSY	12.54	(0.06)	11.81	(0.06)	11.49	(0.11)	12.16	(0.13)
F_{MSY}	0.46	-	0.53	-	0.70	-	0.80	-
$F_{2004/2006}$	0.17	(0.15)	0.17	(0.14)	0.17	(0.14)	0.16	(0.14)
Comm *slope*	0.57	(0.18)	0.37	(0.31)	0.17	(0.71)	0.06	(1.97)
NEFSC *slope*	0.47	(0.10)	0.25	(0.20)	0.04	(1.28)	-0.01	(6.30)

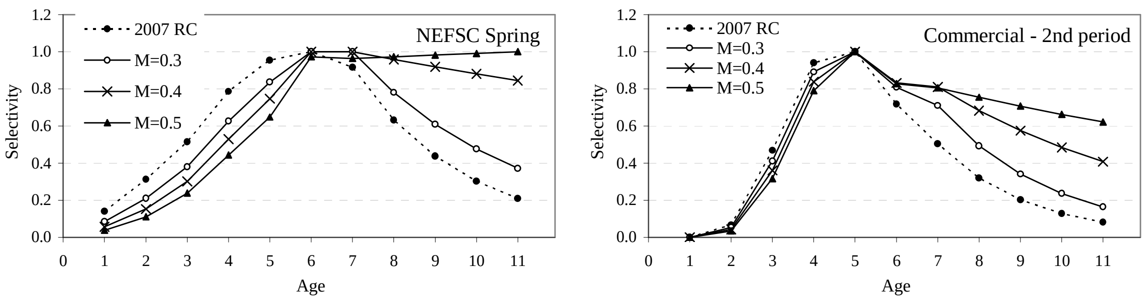

Fig. 1: NEFSC Spring and commercial selectivity at age functions estimated for the 2007 Reference Case ASPM assessment for the various values of age-independent *M* for which results are reported in Table 1.