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Natural mortality of Georges Bank yellowtail flounder derived from an instantaneous rates tagging model

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ABSTRACT

The primary objective of this working paper was to evaluate the mortality of Yellowtail Flounder tag releases in the Georges Bank stock area. A total of 27,685 releases and 2261 recaptures were used to estimate fishing and natural mortality from instantaneous rates formulation of Brownie tag-recovery models. Models were examined with group (releases inside versus outside closed area 2 and females versus males), and time-dependent parameters. The estimates from this work confirmed the general magnitude of total mortality estimated from age-based stock assessments.

Introduction

The purpose of this working paper was to expand upon previous analyses of the cooperative Yellowtail Flounder tagging study (Wood and Cadrin, 2013). This previous study estimated mortality from the cooperative yellowtail flounder data in its entirety, without consideration given to stock delineation. The analyses in this paper focused on deriving estimates of fishing and natural mortality from tags released within the boundary of the Georges Bank yellowtail flounder stock area. The results provide mortality estimates independent of estimates from current yellowtail flounder stock assessments, and provide a means of comparison.

Methods/Results

A total of 27,390 Yellowtail Flounder were tagged with conventional disc tags and releases in the Georges Bank stock area. Of these releases, 2,238 were recovered from the commercial fishery, an 8.2% recapture rate. Release matrices were constructed for tags released inside of closed area 2 (CA2) versus outside, as well for female and male releases, so that group effects could be explored in the modeling (Table 1). Inside CA2, 20,362 tags were released with 1,725 recaptures. Outside of the closed area, 7,028 tags were released with 513 recaptures. Overall the recapture percentages for CA2 and outside releases were 8.5 and 7.3, respectively. For females there were 21,692 releases and 1,952 recaptures, and for males there were 5,698 releases with 286 recaptures. Sex based recapture percentages were 9.0 and 5.0 for females and males, respectively.

Eight percent of all lottery tags and 14% of $100 reward tags were returned. The relative return rate of lottery tags to high-value tags indicated a 59% reporting rate, assuming that 100% of the high-value lottery tags were reported.

Releases occurred in monthly batches over a 39 month period from June 2003 to August 2006, between June and August each year (Figure 1). Encounter history periods used in this study were based on the release schedules of tags. Annual mortality estimates were derived for 12 month periods starting in July and ending in June of the next year (Figure 1). The recovery matrices were built this way to cater to the assumption that releases are instantaneous relative to the sampling occasion, and that all tags have the same probability of survival for the entire year.

Brownie et al. (1985) models use survival (*S*) and recovery rate (*f*) parameters to model tag returns. The instantaneous rates tagging model specifies the survival (*S*) and recovery rate (*f*) parameters in terms of fishing (*F*) and natural (*M*) mortality (Hoenig et al. 1998). Survival becomes:

$$S = e^{-(F+M)}$$

And recovery rate is:

$$f = \lambda \phi u$$

Where λ is the reporting rate (assumed 1.0 for all models) and ϕ is tag loss (assumed no tag loss in all models). Exploitation rate (*u*) is also specified in terms of *F* and *M*:

$$u = \frac{F}{F+M}\left(1 - e^{-(F+M)}\right)$$

Five models exploring group (CA2 versus Outside or Females versus Males) and time-dependent parameter estimates were fit to the data. Model complexity was increased and 7 additional models including both groups (CA2 versus Outside releases and

Females versus Males) and time dependent parameters were fit to the data (Table 2). Matrices of expected values for each model structure were developed. Recoveries were modeled as multinomial random variables and parameters were estimated via maximum likelihood estimation. Akaike's information criterion (AIC) was used to rank and select the model with the best fit:

$$\mathrm{AIC} = -2\ln(L) + 2K$$

Where *L* is the model likelihood and K is the number of parameters.

An over-dispersion estimate was derived for the general model (two-group full parameterization) by dividing the model deviance by the degrees of freedom. To account for over-dispersion ($\hat{c}$) and for differences in effective sample size (*N*), a quasi likelihood adjusted AIC was used to adjust fit of the top selected models (Burnham and Anderson, 2002):

$$\mathrm{QAIC_c} = \frac{-2\ln(L)}{\hat{c}} + 2K + \frac{2K(K+1)}{N-K-1}$$

To quantify the differences in support between models an index using normalized Akaike weights (*w*) was also calculated for each model (*i*) (Buckland et al., 1997):

$$w_i = \frac{e^{\frac{-\Delta QAIC_i}{2}}}{\sum e^{\frac{-\Delta QAIC_i}{2}}}$$

Single-group models were fit to the data and ranked and selected based on the above model fit criterion. Full descriptions of the models fit to the data can be found in Table 2. The model with the best fit estimated a CA2 and Outside natural mortality, and CA2 and Outside time-dependent fishing mortalities with non-mixing estimates in the release year (Table 3). This model accounted for 70% of the QAIC weight. The next ranked model estimated a stock based natural mortality and Female and Male dependent fishing mortalities with non-mixing estimates in the release year. This model accounted for 17% of the QAIC weight. The last three models accounted for the rest of the QAIC weight (13%) and were not considered further (Table 3).

Next, model complexity was increased by modeling with both groups concurrently. For these two-group models, the model with the best fit estimated sex based natural mortality for CA2 releases, and a single M for outside releases (no sex dependence). This model included time, and sex dependent estimates of fishing mortality with non-mixing estimates in the release year for both CA2 and Outside releases (Table 3). The top model accounted for 44% of the weight with the next rank model very close, accounting for 42% of the weight. This second ranked model differed in the lack of sex dependence for the CA2 estimate of M (Table 3). While all of the models that included sex-dependent parameter estimates fit the data better the single group models, fishing mortalities were poorly estimated. In all cases, boundary estimates of F were returned from the model in multiple years. The estimates of M returned from the models with sex dependence were very similar to the single group model. Unfortunately, the sex based recapture matrices are sparse, particularly the male release-recapture matrices (Table 1), and do not seem to provide enough information for the model to estimate all parameters.

Natural mortality estimates from the top single-group models were high. From the top model, M for closed area releases was estimated to be 1.23, with a profile likelihood 95% confidence interval of 1.02 to 1.44. For outside releases, M was estimated to be significantly lower at 0.69, with confidence interval from 0.35 to 1.01 (Figure 2). Pearson residuals from this model did not show any noticeable trends (Figure 3). To examine the effect of an assumed reporting rate of 59%, natural mortality estimates from the top model were profiled over assumed reporting rates from 0-1 (Figure 4). If reporting rates are lower than assumed, estimates of natural mortality would decrease in both groups. Examining the second ranked single-group model indicates there is no sex based differences in natural mortality, however, females and males do seem to experience different levels of fishing mortality (Table 3).

Natural mortality estimates from the top ranked two-group model were not considered because of the sparseness of the male release-recapture matrix for closed area 2 releases (Table 1). The model returned a very high (1.87) and unrealistic estimate of M for males in CA2 and numerous boundary estimates for fishing mortality. The estimates of M from the second ranked two-group model were almost identical to the single-group models (Figure 5). Natural mortality for closed area releases was estimated to be 1.19, with a profile likelihood 95% confidence interval of 1.02 to 1.36. For outside releases, M was estimated to be significantly lower at 0.72, with confidence interval from 0.37 to 1.11. This second ranked model also had issues with estimating fishing mortality in certain years, returning multiple boundary estimates.

Summary

The results from this work are consistent with the perception that the Georges Bank Yellowtail Flounder resource is experiencing an intense rate of mortality. While these mortality estimates corroborate stock assessment estimates, they could be inflated due to model assumption violation. The models assumed that all marked animals had the same probability of recapture and survival, and that reporting rate remained constant throughout the study. It is probable that tags released well inside the closed area did not have the same recapture probability as those released near the border. In addition, it is likely that reporting rate for tags declined over time. Additional information on effort would have to be included as a covariate into the model to determine any temporal changes in reporting rate.

There does seem to be significant difference in mortality when comparing fish released inside versus outside the closed area. This is probably due to differences in fishing effort, as well as reporting rate differences between groups. There does not appear to be sex based differences in natural mortality but females and males do have differing recapture percentages and appear to experience different levels of fishing mortality. The data used in this work were dominated by female releases. Unfortunately, the low recapture percentage for males coupled with sparse release-recapture matrices caused problems for sex dependent parameter estimates in the two-group models.

While there is a large amount of uncertainty around the estimates derived from these models, even the lower bounds indicate the stock may be experiencing high levels of natural mortality. These results provide information on the Georges Bank yellowtail flounder stock from data that is not used in the assessment. As point estimates the

information is valuable to the empirical approach and the results could additionally be used to complement the stock assessment. Estimates of M from these tagging models could be used as a prior, or to set parameter bounds, or to provide a range over which to run sensitivity analyses.

ACKNOWLEDGMENTS

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Table 1. Georges Bank yellowtail flounder tag-recapture data from the cooperative yellowtail tagging program, 2003-2010.

All releases		Encounter Occasion							
Release Occasion	Releases	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	Never Seen
2003-2004	4106	346	121	21	3	0	2	1	3612
2004-2005	14148		717	218	26	4	1	0	13182
2005-2006	4346			405	28	3	2	1	3907
2006-2007	4790				291	28	12	8	4451

CA2 Females		Encounter Occasion							
Release Occasion	Releases	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	Never Seen
2003-2004	2856	202	99	13	1	0	1	0	2540
2004-2005	6811		433	107	17	2	1	0	6251
2005-2006	3283			350	24	1	2	1	2905
2006-2007	3346				236	23	7	8	3072

CA2 Males		Encounter Occasion							
Release Occasion	Releases	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	Never Seen
2003-2004	18	3	0	0	0	0	0	0	15
2004-2005	3784		140	39	2	1	0	0	3602
2005-2006	105			5	1	0	0	0	99
2006-2007	159				4	2	0	0	153

Outside Females		Encounter Occasion							
Release Occasion	Releases	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	Never Seen
2003-2004	861	108	19	8	1	0	1	0	724
2004-2005	2907		123	61	5	1	0	0	2717
2005-2006	797			44	2	2	0	0	749
2006-2007	831				41	3	5	0	782

Outside Males		Encounter Occasion							
Release Occasion	Releases	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	Never Seen
2003-2004	371	33	3	0	1	0	0	1	333
2004-2005	646		21	11	2	0	0	0	612
2005-2006	161			6	1	0	0	0	154
2006-2007	454				10	0	0	0	444

Table 2. Model descriptions for 12 instantaneous rates tagging models fit to Georges Bank yellowtail flounder data from 2003-2009

Model		Model Description
	Single group models: CA2 and outside releases	
M(CA2, OUT)	**F**(CA2(t,*), OUT(t,*))	Estimate of M for CA2 and outside releases. Time dependent estimates of F for CA2 and outside releases with non-mixing F in release year.
M(.)	**F**(Female(t,*), Male(t,*))	Stock based estimate of M. Time dependent estimates of F for female and male releases with non-mixing mixing F in release year.
M(.)	**F**(CA2(t,*), OUT(t,*)	Stock based estimate of M. Time dependent estimates of F for CA2 and outside releases with non-mixing mixing F in release year.
M(Female, Male)	**F**(Female(t,*), Male(t,*))	Estimate of M for female and male releases. Time dependent estimates of F for female and male releases with non-mixing F in release year.
M(Female, Male)	**F**(t,*)	Estimate of M for female and male releases. Time-dependent, stock based estimates of F.
	Two group models: CA2 and outside releases, Male and Female releases	
M(CA2(m,f), OUT(.))	**F**(CA2(m,f,t,*), OUT(m,f,t,*))	Group and sex based M for CA2 releases. Group based estimate of M for outside releases. Time, group, and sex dependent estimates of F for CA2 and outside releases with non-mixing F in release year.
M(CA2(.), OUT(.))	**F**(CA2(m,f,t,*), OUT(m,f,t,*))	Group based M for CA2 and outside releases. Time, group, and sex dependent estimates of F for CA2 and outside releases with non-mixing F in release year.
M(.)	**F**(CA2(m,f,t,*), OUT(m,f,t,*)	Stock based estimate of M. Time, group, and sex dependent estimates of F for CA2 and outside releases with non-mixing F in release year.
M(CA2(m,f), OUT(.))	**F**(CA2(m,f,t,*), OUT(t,*))	Group and sex based M for CA2 releases. Group based estimate of M for outside releases. Time, group, and sex dependent estimates of F for CA2 with non-mixing F in release year. Time dependent estimate of F for outside releases with non-mixing F in release year.
M(CA2(m,f), OUT(m,f))	**F**(CA2(t,*), OUT(t,*))	Group and sex based M for CA2 releases. Group and sex based M for outside releases. Time dependent estimates of F for CA2 with non-mixing F in release year. Time dependent estimate of F for outside releases with non-mixing F in release year.
M(CA2(m,f), OUT(m,f))	**F**(CA2(m,f,t,*), OUT(m,f,t,*)	Group and sex based M for CA2 releases. Group and sex based M for outside releases. Time, group, and sex dependent estimates of F for CA2 and outside releases with non-mixing F in release year.
M(CA2(m,f), OUT(.))	**F**(CA2(t,*), OUT(t,*))	Group and sex based M for CA2 releases. Group based estimate of M for outside releases. Time dependent estimates of F for CA2 with non-mixing F in release year. Time dependent estimate of F for outside releases with non-mixing F in release year.

Table 3. Model results and diagnostics for 12 instantaneous rates tagging models fit to Georges Bank yellowtail flounder data from 2003-2009.

Model		Parameters	-LL	AIC	QAIC	QAIC Weight	Deviance
Single-group models: CA2 and outside releases or Females and Males							
M(CA2, OUT)	**F**(CA2(t,*), OUT(t,*))	22	9023	18089.8	16056.3	0.70	137
M(.)	**F**(Female(t,*), Male(t,*))	21	9026	18093.3	16059.1	0.17	142
M(.)	**F**(CA2(t,*), OUT(t,*)	21	9027	18095.3	16060.9	0.07	143
M(Female, Male)	**F**(Female(t,*), Male(t,*))	22	9026	18095.3	16061.1	0.06	142
M(Female, Male)	**F**(t,*)	12	9047	18118	16079.0	0.00	183
Two-group models: CA2 and outside releases and Male and Female Releases							
Model		Parameters	-LL	AIC	QAIC	QAIC Weight	Deviance
M(CA2(m,f), OUT(.))	**F**(CA2(m,f,t,*), OUT(m,f,t,*))	43	8973.9	18033.9	16011.4	0.44	39
M(CA2(.), OUT(.))	**F**(CA2(m,f,t,*), OUT(m,f,t,*))	42	8975.1	18034.3	16011.5	0.42	41
M(.)	**F**(CA2(m,f,t,*), OUT(m,f,t,*)	41	8978	18038.2	16014.8	0.08	47
M(CA2(m,f), OUT(.))	**F**(CA2(m,f,t,*), OUT(t,*))	33	8988	18042.4	16016.7	0.03	67
M(CA2(m,f), OUT(m,f))	**F**(CA2(t,*), OUT(t,*))	24	8999	18046	16017.8	0.02	89
M(CA2(m,f), OUT(m,f))	**F**(CA2(m,f,t,*), OUT(m,f,t,*)	44	8974	18035.9	16019.0	0.01	39
M(CA2(m,f), OUT(.))	**F**(CA2(t,*), OUT(t,*))	23	9003	18051.9	16022.8	0.00	97

Table 4. Fishing mortality estimates from the top ranked single-group model. *indicates non-mixing F.

CA2		
2004-2005	F_2	0.520584
2005-2006	F_3	0.182022
2006-2007	F_4	0.101981
2007-2008	F_5	0.073993
2008-2009	F_6	0.10462
2009-2010	F_7	0.404921
2003-2004*	$F1$*	0.228561
2004-2005*	$F2$*	0.170619
2005-2006*	$F3$*	0.354421
2006-2007*	$F4$*	0.219345
OUTSIDE		
2004-2005	F_2	0.122246
2005-2006	F_3	0.106685
2006-2007	F_4	0.022631
2007-2008	F_5	0.011698
2008-2009	F_6	0.02362
2009-2010	F_7	0.007946
2003-2004*	$F1$*	0.304501
2004-2005*	$F2$*	0.099703
2005-2006*	$F3$*	0.129635
2006-2007*	$F4$*	0.096646

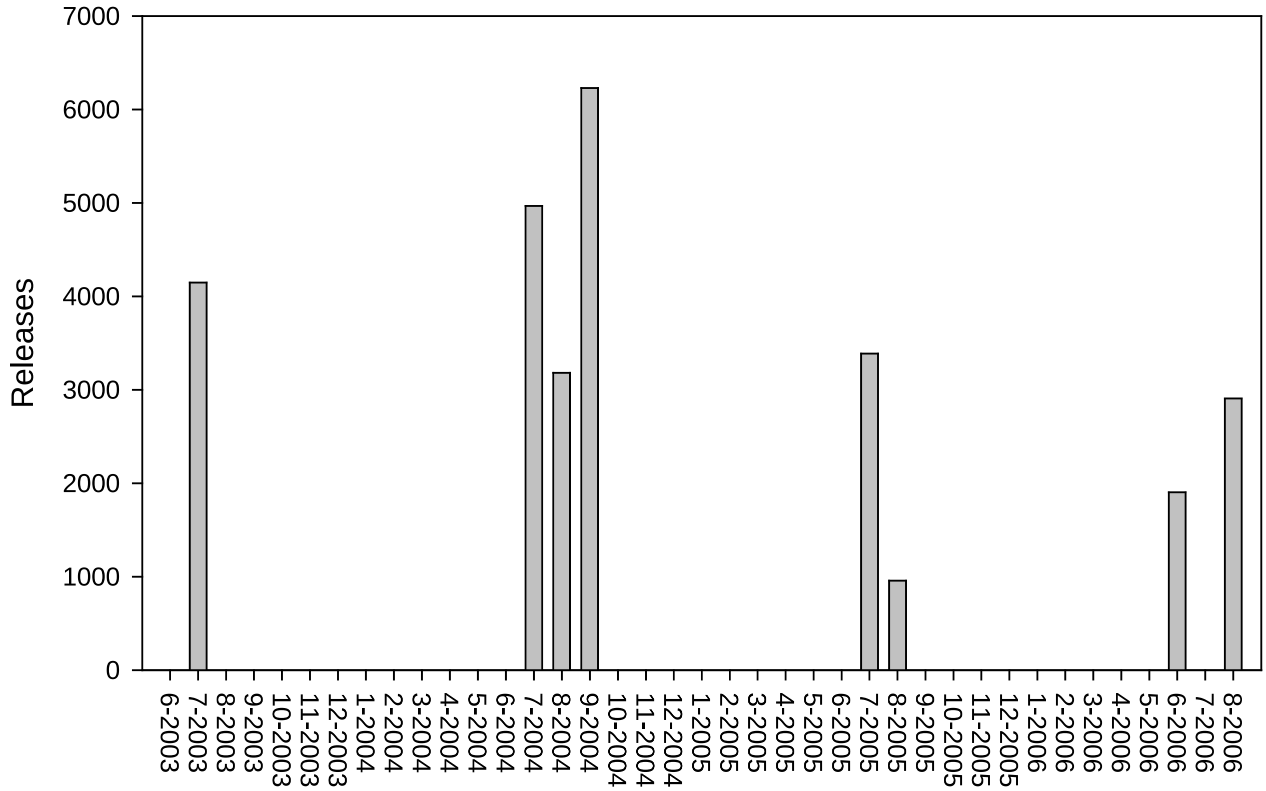

Figure 1. Tag releases for Georges Bank Yellowtail Flounder from July 2003 to August 2006.

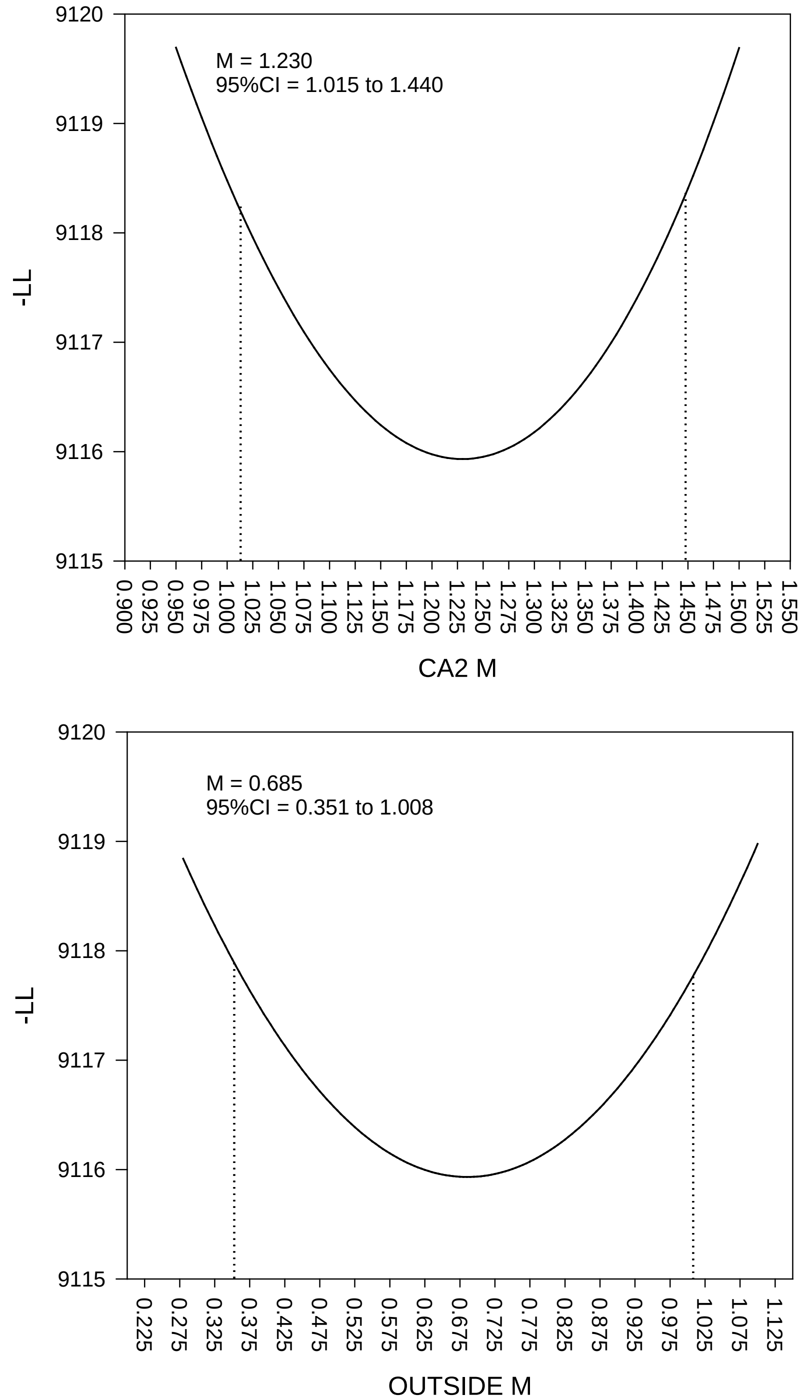

Figure 2. Group based estimates of natural mortality for Georges Bank Yellowtail Flounder from the top ranked single-group model with 95% profile likelihood confidence intervals.

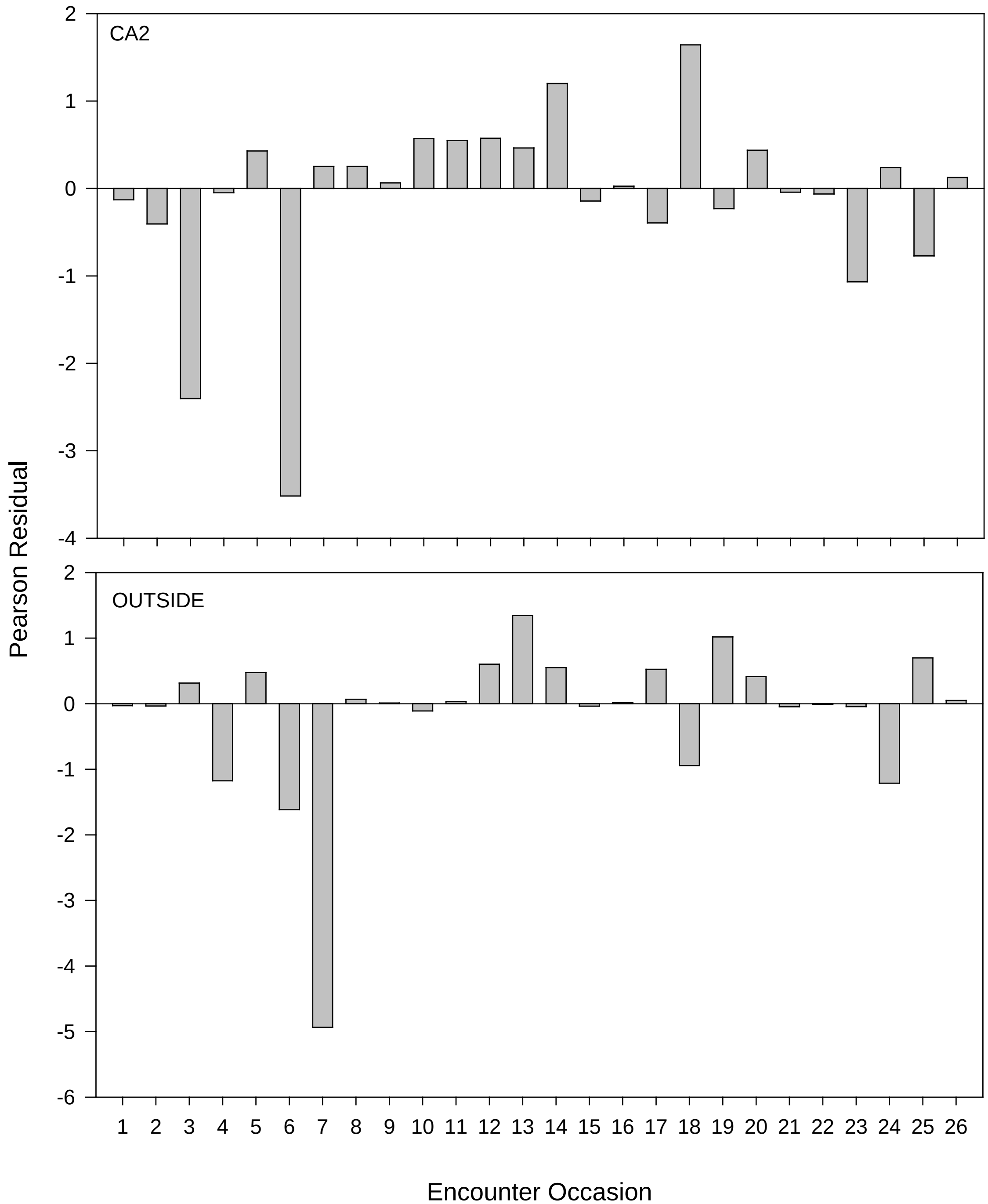

Figure 3. Pearson residuals from the top ranked single-group model fit to Georges Bank Yellowtail Flounder tag-recapture data.

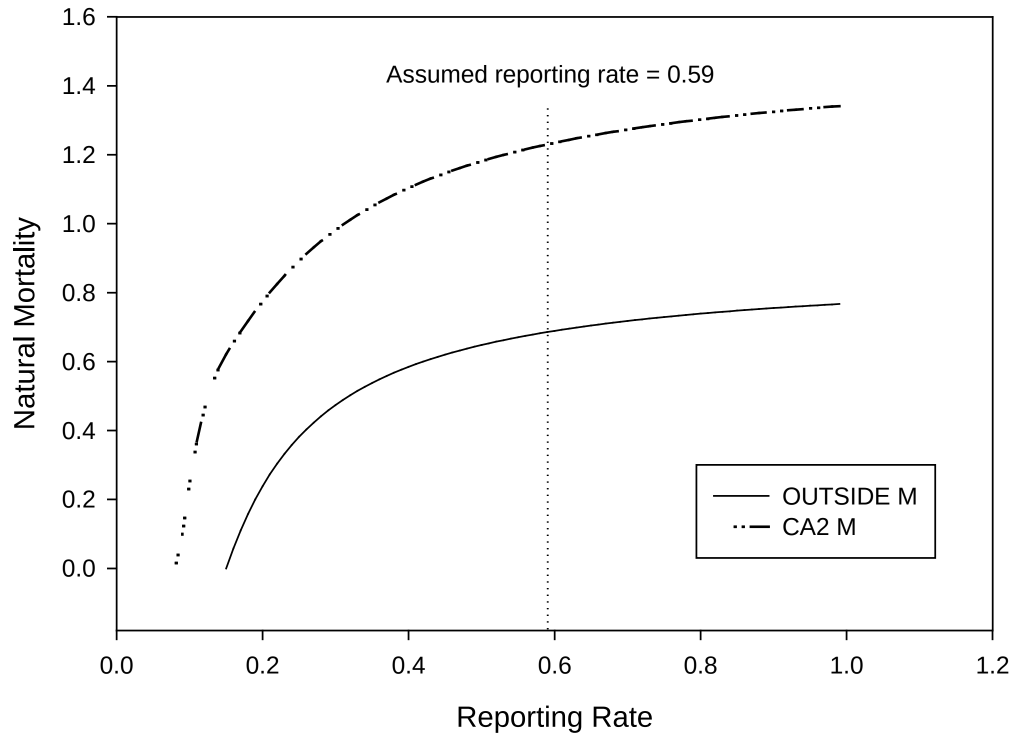

Figure 4. Group based estimates of Georges Bank Yellowtail Flounder natural mortality from the top ranked single-group model profiled over a range of reporting rates from 0-1 (reporting rate assumed to be 0.59 for modeling).

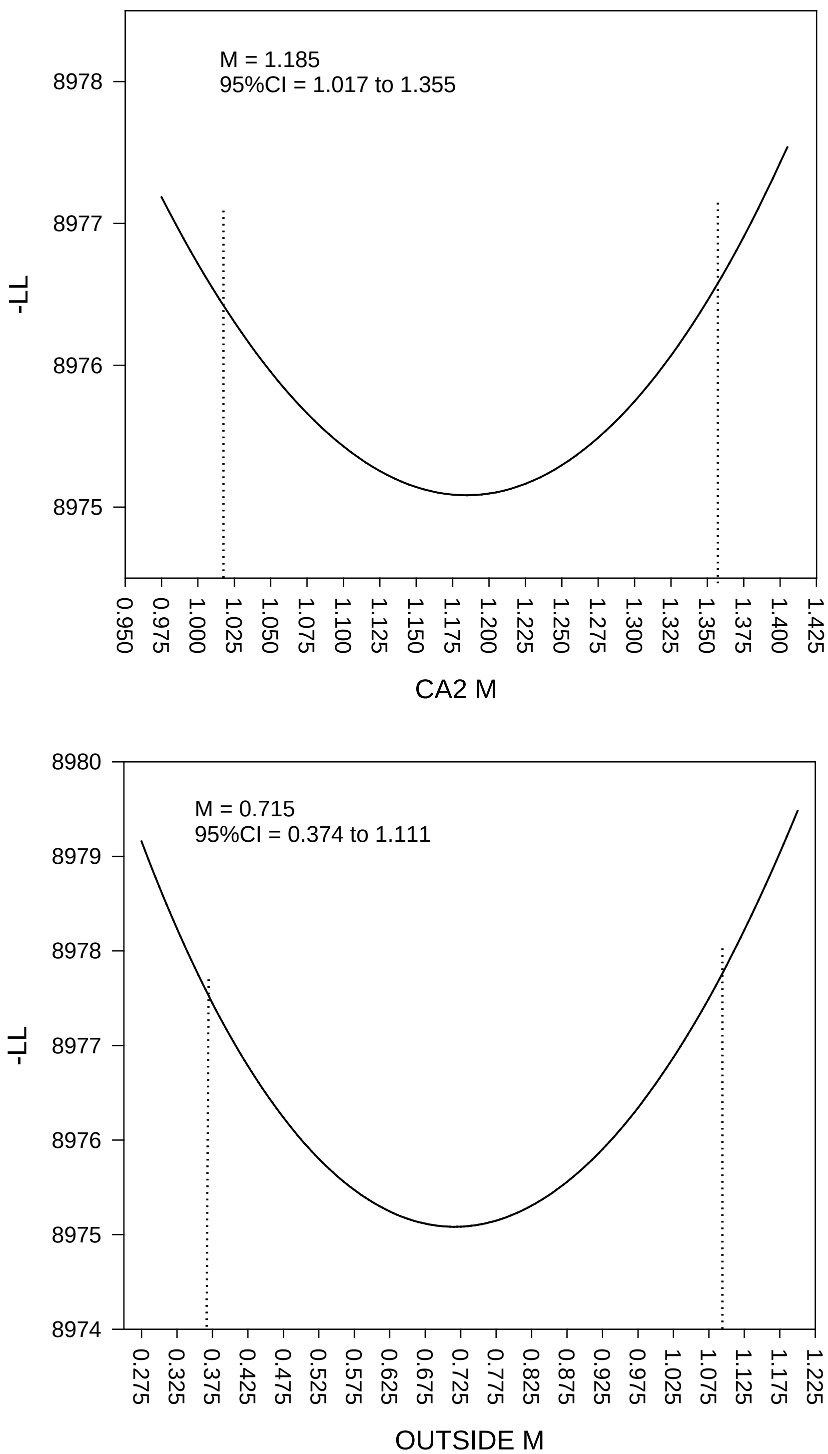

Figure 5. Group based estimates of natural mortality for Georges Bank Yellowtail Flounder from the second ranked two-group model with 95% profile likelihood confidence intervals.