Natural mortality of bluefish

Abigail Tyrell, Sam Truesdell

1 Introduction

The purpose of this working paper is to evaluate the methods of calculating natural mortality for the Northwest Atlantic bluefish stock, and to determine the most appropriate value of natural mortality to use in the 2022 Research Track stock assessment.

2 Methods

1.1 Bluefish data

Bluefish life history parameters were determined as described in Working Paper 5 (Truesdell et al. 2022). The maximum age assumed here is 14, which is the value used in the 2015 benchmark assessment. The maximum age observed in the life history data was 13 (Working Paper 5 Truesdell et al. 2022), but since the maximum age used for natural mortality estimates should represent the maximum age attained in an unexploited population, the working group felt that a maximum age of 14 was justified.

1.2 Rule-of-thumb

The so-called "rule-of-thumb" method is an age-based natural mortality estimate. It assumes that a 5% of the population remains at the maximum age, and correspondingly calculates the annual mortality rate that would lead to such a fraction remaining.

The rule of thumb method is:

$$M_{ROT} = \frac{3}{a_{max}}$$

where M_{ROT} is age-invariant natural mortality and a_{max} is the maximum age of a fish in the population. Although the equation has been used historically, some authors recommend other methods as a substitute (e.g., Hewitt and Hoenig 2005).

1.3 Hoenig (1983), Hewitt and Hoenig (2005)

An updated version of the rule-of-thumb equation (Hewitt and Hoenig 2005) approximates the relationship between maximum age and natural mortality from a linear regression fit to maximum age and natural mortality data gathered by Hoenig (1983). This linear fit estimates that closer to 1.3% of the population remains at the maximum age. The simplified mortality equation is:

$$M_{HH} = \frac{4.22}{a_{max}}$$

The authors believe that their linear regression method, which was fit using observed data, is more appropriate than the “rule-of-thumb,” which assumes that an arbitrary 5% of the population reaches the maximum age. Subsequently, the authors “recommend that the use of the $\frac{3}{a_{max}}$ rule of thumb be abandoned.”

The authors also note that such maximum-age-based methods are only accurate for stocks with negligible fishing mortality. In heavily exploited stocks, the observed maximum age is likely not reflective of the natural mortality under unexploited conditions.

1.4 Gislason et al (2010)

Gislason et al. (2010) calculated a length-varying natural mortality equation by regressing length, von Bertalanffy parameters, and temperature against natural mortality. Their recommended model was

$$M_{G,L} = \exp(0.55 - 1.61\log(L) + 1.44\log(L_\infty) + \log(K))$$

where $M_{G,L}$ is the natural mortality at length L in cm and L_∞ and K are von Bertalanffy parameters. In the results presented here, we used the von Bertalanffy estimated length at age to calculate the Gislason natural mortality. The von Bertalanffy length estimate is unreliable for age 0, and empirical lengths would likely provide a more robust natural mortality estimate; however, since the working group ultimately rejected the Gislason natural mortality method, we did not perform these calculations.

1.5 Lorenzen (1996, 2000)

Lorenzen (1996) calculated weight-varying natural mortality by assuming an allometric relationship between natural mortality and weight.

$$M_W = M_u W^b$$

Where M_W is estimated mortality at weight W in g, M_u is unit natural mortality and b is an estimated scalar. They used observations to estimate the parameters under different conditions; based on a sample of 113 ocean observations, their estimated equation was:

$$M_W = 3.69W^{-0.305}$$

The weights used for each age were the mean empirical weights-at-age used in the ASAP model. The WG preferred the weight-at-age approach due to the concerns related to calculating population-level natural mortality from the raw life history data, which may not capture a representative distribution of fish; the stratification that occurs with the weight-at-age calculations accounts for uneven sampling.

1.6 Then et al. (2015)

Then et al. (2015) evaluated and compared natural mortality calculation methods using updated direct mortality measurements from the literature. They compared the performance of multiple natural mortality models to determine which method had the best performance. The top two models are described below.

1.6.1 Hoenig method

Then et al. (2015) fit a model suggested by Hoenig (1983) to data using nonlinear least squares; the model and estimated parameters were:

$$M_{TH} = 4.899 a_{max}^{-0.916}$$

where M_{TH} is estimated age-invariant natural mortality, and a_{max} is the maximum age.

1.6.2 Pauly method

Then et al. (2015) also fit a model suggested by Pauly (1980), which was fit using nonlinear least squares and excluding temperature. The full equation was:

$$M_{THP} = 4.118 K^{0.73} L_{\infty}^{-0.33}.$$

1.6.3 Scaled approaches

Static approaches (i.e., rule-of-thumb, Hoenig (1983) and Hewitt and Hoenig (2005), and the methods presented in Then et al. 2015) were also used to provide age-varying schedules where the rate of decline in M matched Gislason et al. 2010 or Lorenzen (1996, 2000) but the absolute values were scaled to the static method. This was accomplished according to the following equation

$$\mathbf{M_{Rescld}} = \frac{\mathbf{M_{Scld}} M_{Stat}}{\bar{\mathbf{M}}_{\mathbf{Scld}}}$$

where $\mathbf{M_{Rescld}}$ is a rescaled vector of natural mortality-at-age, $\mathbf{M_{Scld}}$ is a vector of scaled estimates (i.e., Gislason et al. 2010 or Lorenzen (1996, 2000)), M_{Stat} is an age-invariant method and $\bar{\mathbf{M}}_{\mathbf{Scld}}$ is the mean of the scaled natural mortality vector.

1.6.4 Recommendation

The authors found that the maximum age-based (Hoenig) method had the lowest prediction error and therefore recommended to use this method when possible. In the case that maximum age data is not available, the authors recommended using the growth-based (Pauly) method. Notably, the authors did not evaluate any age-, weight-, or length-varying natural mortality methods.

3 Results

Age-invariant natural mortality estimates ranged from 0.21 to 0.44 (mean = 0.35). The Lorenzen natural mortality estimates ranged from 0.85 (age 0) to 0.27 (age 6+) (Table

2). The Gislason natural mortality estimates ranged from 4.92 (age 0) to 0.22 (age 12+) (Table 3); however, please note that if empirical lengths were used instead of the von Bertalanffy estimated length, the Gislason natural mortality estimate would not be as high for age 0.

4 Conclusion

The working group agreed with Then et al. (2015) that using von Bertalanffy parameters in the calculation of natural mortality estimates introduces additional sources of error. Therefore, we rejected using natural mortality methods based on von Bertalanffy parameters, namely, the Then et al. (Pauly) method and the Gislason et al. method.

Based on the updated analyses of Hewitt and Hoenig (2005) and Then et al. (2015), the working group agreed that the "rule of thumb" estimate of 0.2 used in the 2015 benchmark assessment was too low.

The working group decided to proceed with using the Lorenzen age-varying natural mortality method because these estimates were in line with both the Hewitt-Hoenig and Then et al. estimates, and furthermore retained biological realism.

5 Tables

Table 1: Natural mortality as estimated by the age-invariant models described in this working paper. Maximum age was assumed to be 14 years.

Age-invariant natural mortality estimates

Method	Estimate
"Rule of thumb"	0.21
Hewitt-Hoenig	0.30
Then et al. (Hewitt-Hoenig method)	0.44
Then et al. (Pauly method)	0.35

Table 2: Natural mortality at age as estimated by the Lorenzen (1996, 2000) weight-varying model. The weights used for each age were the mean empirical weights-at-age used in the ASAP model. The WG preferred the weight-at-age approach due to the concerns related to calculating population-level natural mortality from the raw life history data, which may not capture a representative distribution of fish; the stratification that occurs with the weight-at-age calculations accounts for uneven sampling. The additional estimates are the age-varying Lorenzen approach scaled to the mean of the non-age-varying approaches.

Age	Lorenzen estimate	Lorenzen estimate scaled to rule of thumb	Lorenzen estimate scaled to Hewitt-Hoenig	Lorenzen estimate scaled to Then et al. (Hewitt-Hoenig)	Lorenzen estimate scaled to Then et al. (Pauly)
0	0.85	0.52	0.73	1.05	0.84
1	0.58	0.35	0.49	0.71	0.57
2	0.45	0.28	0.39	0.56	0.45
3	0.37	0.23	0.32	0.46	0.37
4	0.32	0.20	0.28	0.40	0.32
5	0.29	0.18	0.25	0.36	0.29
6	0.27	0.16	0.23	0.33	0.27
7	0.27	0.16	0.23	0.33	0.27
8	0.27	0.16	0.23	0.33	0.27
9	0.27	0.16	0.23	0.33	0.27
10	0.27	0.16	0.23	0.33	0.27
11	0.27	0.16	0.23	0.33	0.27
12	0.27	0.16	0.23	0.33	0.27
13	0.27	0.16	0.23	0.33	0.27
14	0.27	0.16	0.23	0.33	0.27

Table 3: Natural mortality at age as estimated by the Gislason et al. (2000) length-varying model. The length used for each age was estimated from the von Bertalanffy growth parameters (Working Paper 5 Truesdell et al. 2022); note that these estimates are unrealistic for age-0 fish. The additional estimates are the age-varying Gislason et al. (2000) approach scaled to the mean of the non-age-varying approaches.

Age	Gislason estimate	Gislason estimate scaled to rule of thumb	Gislason estimate scaled to Hewitt-Hoenig	Gislason estimate scaled to Then et al. (Hewitt-Hoenig)	Gislason estimate scaled to Then et al. (Pauly)
0	4.92	1.56	2.20	3.18	2.54
1	1.22	0.39	0.54	0.79	0.63
2	0.67	0.21	0.30	0.43	0.34
3	0.47	0.15	0.21	0.31	0.24
4	0.38	0.12	0.17	0.24	0.19
5	0.32	0.10	0.14	0.21	0.17
6	0.29	0.09	0.13	0.19	0.15
7	0.27	0.08	0.12	0.17	0.14
8	0.25	0.08	0.11	0.16	0.13
9	0.24	0.08	0.11	0.15	0.12
10	0.23	0.07	0.10	0.15	0.12
11	0.23	0.07	0.10	0.15	0.12
12	0.22	0.07	0.10	0.14	0.11
13	0.22	0.07	0.10	0.14	0.11
14	0.22	0.07	0.10	0.14	0.11

6 Figures

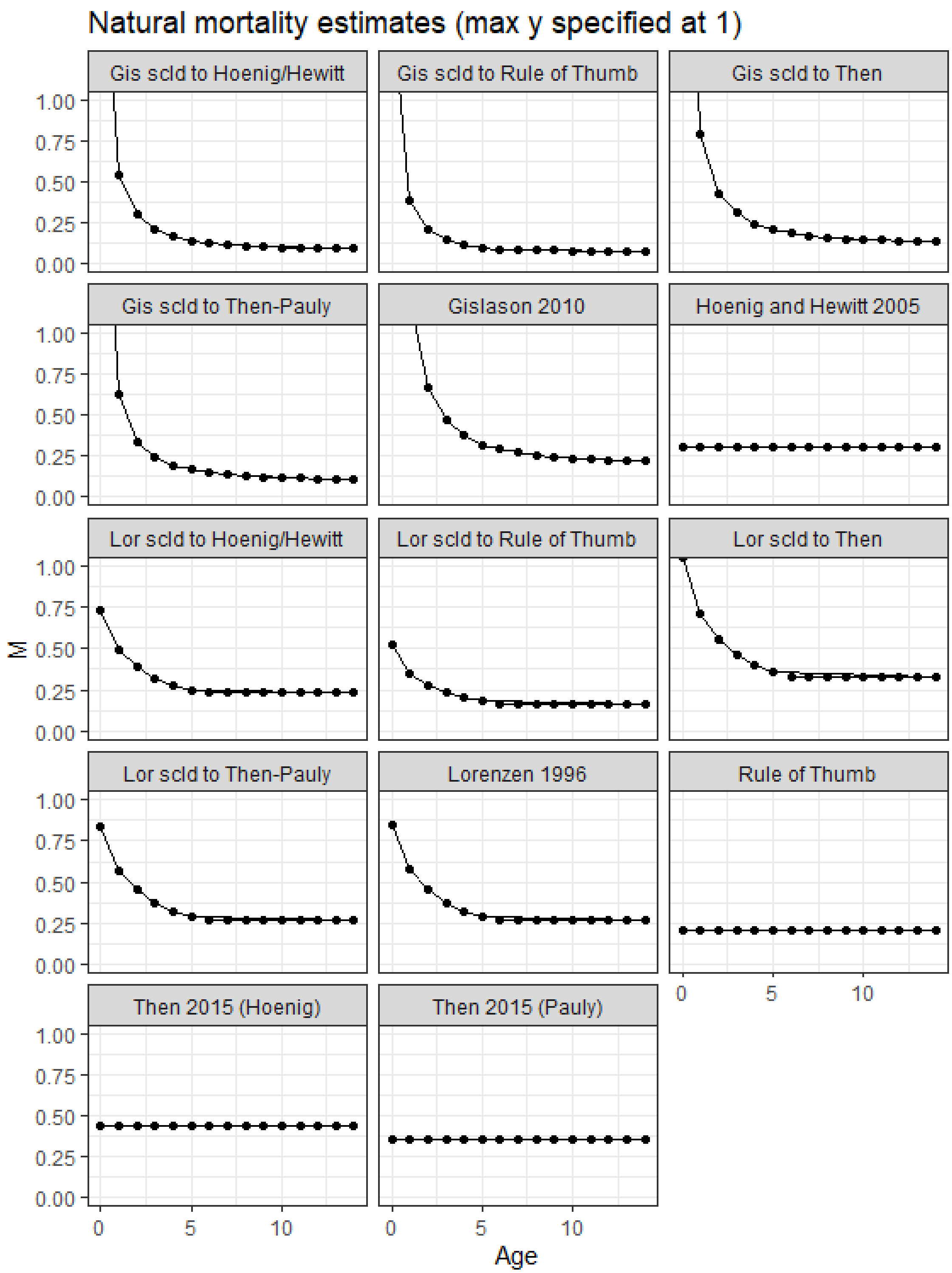

Figure 1: Natural mortality-at-age estimated by the various methods. The Y axis has been censored at 1.0 to better show the variability at ages older than age-0. See the table above for the estimated values, including those for all age-0.

References

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