APPROXIMATING NATURAL MORTALITY RATE FOR NEW ENGLAND YELLOWTAIL FLOUNDER STOCKS

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Yellowtail Flounder Research Track Stock Assessment

Summary

Life history parameters were estimated for each stock of yellowtail flounder off New England to derive approximations of natural mortality rate. Maximum age by stock was determined from fishery-independent survey data or fishery monitoring data. Spring survey data was used to derive maturity at age. Spring and fall survey data were used to estimate von Bertalanffy growth parameters. Several estimators of natural mortality derived from life history parameters produced a wide range of estimates for each stock. Estimates of instantaneous natural mortality rate derived from longevity were approximately 0.4 for Cape Cod-Gulf of Maine and Georges Bank stocks and 0.4 to 0.5 for the southern New England -Mid Atlantic stock. Longevity-based estimates were intermediate to those based on growth, maturity, gonadosomatic index, or regional temperature. These approximations can be used to inform natural mortality as long-term lifetime rates, rescaled by size at age relative to age at maturity, priors for estimation by a stock assessment model, or time-series average for estimation of annual process errors.

Introduction

Estimates or assumptions of natural mortality rate (M) have a large influence on stock assessment (Clark 1999, Punt et al. 2021). Some stock assessments have sufficient information to estimate M as a model parameter, but most assessments assume a value of M derived from on life history information (Vetter 1998, Cope and Hammel 2022). The general approach to approximating M relies on long-term life history strategies that are adapted by natural selection and involve tradeoffs in fitness between energetic investments for survival, growth, or reproduction (Roff 1984, Winemiller & Rose 1992). Estimates of lifetime M derived from life history attributes can be rescaled based on size at age so that younger ages have greater M to account for size-dependent predation (Lorenzen 1996, 2022).

Previous assessments of yellowtail flounder stocks off New England (Cape Cod Gulf of Maine: CCGOM; Georges Bank: GB; Southern New England-Mid Atlantic: SNEMA) assumed a range of M values. The earliest age-structured assessments assumed lifetime M=0.2 based on tag returns (Lux 1969), relationships of total mortality to fishing effort (Brown & Hennemuth 1971), and the oldest observed age (A_{max}=14 y, M=3/A_{max}; NEFSC 2003). The most recent benchmark assessment for SNEMA yellowtail flounder assumed lifetime M=0.3 derived from longevity and gonadosomatic index, scaled to an age-specific mean length for all years (M=0.41 at age-1 to M=0.23 at age 6+; NEFSC 2012). The most recent benchmark assessment of GB yellowtail flounder assumed lifetime M=0.4 derived from several life history and tagging estimators (TRAC 2014).

The objectives of the current analyses are to update estimates of life history parameters for each stock of yellowtail flounder off New England, derive M for each stock from these parameters using several methods, and consider options for modeling M in the 2024 research track stock assessment.

Methods

NEFSC spring and fall trawl survey observations of length and maturity at age were the primary data used to update life history analyses. Stock areas were defined by the survey strata used for stock indices:

- CCGOM was offshore strata 25-27,39,40; inshore 56-66 (NEFSC 2003);
- GB was offshore strata 13-21 (NEFSC 2012); and
- SNEMA was offshore strata 1, 2, 5, 6, 9, 10, 69, 73, 74 (Legault et al. 2014).

Maximum observed age for each stock was from survey or fishery monitoring data. Bottom temperature for each stock area was derived from spatial aggregation of assimilated field observations (du Pontavice et al. 2023). Estimates of gonadosomatic index were from previous benchmark assessments for SNEMA (NEFSC 2012) and GB yellowtail flounder (Alade et al. 2014).

Von Bertalanffy growth parameters in length (L_∞, k_{length}, $t_{0,length}$) and weight (W_∞, k_{weight}, $t_{0,weighth}$, b) were estimated from length (cm) or weight (g) at ages 1+ from NEFSC spring and fall surveys. Biological age was derived as the observed integer age from spring surveys or integer age plus 0.5 y from fall surveys to reflect spring spawning. Although female yellowtail flounder grow to larger maximum size than males, male and female observations were combined in a single analysis to meet the objective of estimating a composite M for both sexes. The Research Track Working Group explored temporal patterns in size at age and decided to estimate growth parameters using data from all years for GB and SNEMA yellowtail flounder stocks, and to restrict growth analyses of CCGOM yellowtail flounder to 1963-2005 data to exclude recent years with smaller size at older ages (NEFSC 2022) for estimates of growth parameters that are related to M through long-term life history strategy rather than short-term environmental changes.

Age at 50% maturity (A_{50}) was derived from NEFSC spring survey data, in which A_{50} was linearly interpolated from proportion mature at age. Male and female observations were combined for a single analysis to meet the objective of estimating a composite M for both species. Previous estimates of A_{50} by sex were similar, with inconsistent variation between sexes (NEFSC 2012). The Research Track Working Group explored temporal patterns in maturity at age and decided to estimate maturity at age using data from all years for GB and SNEMA yellowtail flounder stocks, and to restrict maturity analyses of CCGOM yellowtail flounder to 1969-1992 to exclude recent years with greater maturity at age-2 (Alade & Hansell 2023) for estimates of A_{50} that are related to M through long-term life history strategy rather than short-term environmental changes.

Life history parameters were used to estimate lifetime M for each stock of yellowtail flounder using several methods in which M was derived from maximum observed age, growth parameters, age at maturity, or combinations of maximum age and growth, growth and temperature, and growth and maturity (Cope and Hammel 2022, http://barefootecologist.com.au/shiny_m). Precision was approximated as a lognormal standard deviation of 0.31 from meta-analysis of longevity estimators (Cope and Hammel 2022). Based on guidance from Cope & Hammel (2022) and Then et al. (2015) age-based M was rescaled from estimates of lifetime M from the Then_nls method. Estimates of lifetime M were rescaled to age-specific M (M_a) based on the predicted length at age (e.g., L_a) and length at maturity (L_{50}) using the simplified form of the Lorenzen (1996) as a pragmatic approach recommended by Brodziak et al. (2011):

$$\widehat{M_a} = \widehat{M}\frac{\widehat{L_{50}}}{\widehat{L_a}}$$

Results

Maximum observed age of yellowtail flounder was 14.3y in the 2022 CCGOM fishery, 16.2y in the 2020 GB fishery, and 11y in SNEMA 1979 and 1980 spring surveys. Mean bottom temperature was 6.8°C in CCGOM, 8.6°C on GB, and 9.6°C in SNEMA (Table 1).

Von Bertalanffy growth models generally fit observations of length at age well, with normally distributed residuals (Figure 1). Lengths were mostly overestimated for ages older than 8 y, but most of those observations were female, which generally grow to larger maximum size than males. For the derivation of M, growth models indicate that L_∞ had been attained at the maximum observed age.

Von Bertalanffy growth models also fit observations of weight at age well, except for two positive residual outliers for CCGOM weight at age. However, there were fewer observations of weight for old ages, because surveys started sampling individual weight in 1992, and some parameter estimates for predicted weight may not be reliable. For example., the estimate of W_∞ for CCGOM is greater than the maximum observed value in the region or any reported for yellowtail (maximum reported body mass of 1.5 kg, Frimodt & Dore 1995, https://www.fishbase.se/summary/SpeciesSummary.php?ID=521&AT=yellowtail+flounder).

Estimates of growth parameters (Table 1) were similar to previous estimates for yellowtail flounder (e.g., Moseley 1986, NEFSC 2012, Alade et al. 2014), with slowest growth rates and largest asymptotic sizes for CCGOM, fastest growth and smallest asymptotic size for SNEMA, and intermediate values for GB. Estimates of A_{50} for yellowtail flounder (Table 1) were also similar to previous studies (O'Brien et al. 1993, Begg et al. 1999), with similar maturity in GB and SNEMA and older onset of maturity in CCGOM (Figure 3).

Estimates of M varied widely among estimators for each stock (Table 2, Figures 4-6). Estimates of M derived from longevity were approximately 0.4 for CCGOM, 0.3 to 0.4 for GB, and 0.5 for the SNEMA stock. Longevity-based estimates were intermediate to those from growth, maturity, gonadosomatic indices, or temperature. However, many estimates were outside the implied confidence limits of longevity-based estimates, so composite estimates may not be reliable (Cope & Hammel 2022).

Assuming lifetime M=0.4 for CCGOM and GB and M=0.5 for SNEMA (from Then_nls), rescaled vales of age-specific M were greatest for SNEMA yellowtail flounder (M=1.0 at age-1, decreasing to M=0.3 at age-7; Table 3, Figure 7), and lower for CCGOM and GB yellowtail flounder (M=0.6 at age-1, decreasing to M=0.2 at age-7). Estimates of M at age from growth-based estimates (Chen & Watanabe 1989, Gislason et al. 2010, Charnov et al. 2013) were much greater (e.g., M at age 1 was >1.3 for CCGOM, >1.6 for GB, >4.4 for SNEMA) and may not be realistic.

Discussion

Estimates of M were highly sensitive to the estimator and assumed relationship with life history traits. Maunder et al. (2023) concluded that estimators derived from maximum observed age should be preferred among life-history estimators. Cope & Hammel (2022) recommend to "*consider the longevity (if available) estimators of M as most informative (Then et al., 2015)*". Then et al. (2015) recommend

Then_nls (a.k.a. Hoenig_nls) because it performed the best among the longevity estimators. Although age distributions have been truncated by fishing, there were nearly 60,000 observed ages in the survey database and about the same or more from fishery monitoring, so maximum observed age may be an accurate indicator of longevity for New England stocks of yellowtail flounder. Length at age data also suggest that asymptotic sizes had been attained at the maximum observed ages.

The estimates of *M*=0.4 or *M*=0.5 are substantially greater than the *M*=0.2 assumed by early yellowtail flounder stock assessments (NEFSC 2003) and all assessments of CCGOM yellowtail (NEFSC 2022), but those may be overestimates (TRAC 2014). The initial approximation of *M*=0.2 was from three methods:

1) probability of observed time at liberty for seven tagged yellowtail flounder (Lux 1969);
2) changes in total mortality from the 1940s (estimated by catch ratios, Royce et al. 1959) to the 1960s (estimated from catch curves, Lux 1969; and cohort analysis) and the corresponding change in fishing effort (Brown & Hennemuth 1971), and
3) oldest observed age and guidance for setting the maximum age for yield-per-recruit analysis as the age when 5% survive from the assumed value of *M* (Anthony 1982), which was commonly rearranged to approximate *M* from the oldest observed age: $e^{-(M \cdot Amax)}=0.05$; $A_{max}=Ln(0.05)/M$; $M=3/A_{max}$).

The estimates of *M*=0.4 and *M*=0.5 are within the range of estimates from the most recent benchmark assessments of SNEMA and GB yellowtail flounder (NEFSC 2012, TRAC 2014). The most recent benchmark assessment of SNEMA yellowtail flounder considered estimates of *M*=0.32 derived from a gonadosomatic Index, *M*=0.34 from Hoenig's (1983) method and *M*=0.47 from Hewitt and Hoenig (2005) with a maximum length of 54 cm and a predicted mean age of 8.9 y (NEFSC 2012). The most recent benchmark assessment of GB yellowtail flounder concluded that *M*=0.2 is likely an underestimate and that *M*=0.4 is more consistent with equilibrium age compositions and the range of *M* values estimated from life history attributes. Then & Brooks (2014) estimated sex-specific *M*=0.3 to 0.5, and Alade et al. (2014) estimated *M*=0.27 to 0.75 based on life history parameters. Wood (2014) estimated *M*=0.7 to 1.2 from tag-recovery analysis.

These approximations of *M*=0.4 for CCGOM and GB and *M*=0.5 for SNEMA can be used in research track stock assessments as assumed values of *M*, rescaled to age-specific *M*, priors for estimation by a stock assessment model, or the time-series average for estimation of annual process errors. The range of plausible estimates could also be used for sensitivity analyses. Inter-annual variation in size or maturity at age may not be reliable for estimating time-varying *M* for yellowtail flounder, because size at age was not well sampled for some years and ages, particularly for older ages and recent years. Substantial changes in size at age have been for older ages, which should not influence interannual variation in predation as much as for younger ages, which have had more constant size at age. Therefore, annual process errors may be the most appropriate approach to exploring inter-annual variation in *M* for New England stocks of yellowtail flounder.

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Table 1. Life history parameters used to estimate natural mortality of yellowtail flounder by stock.

Attribute	CC-GOM	Source	GB	Source	SNE-MA	Source
A_{max} (y)	14.3	2022 fishery	16.2	2020 fishery	11.0	1979 and 1980 spring surveys
L_{∞} (cm)	46.1	surveys 1963-2005	43.1	all surveys	36.6	all surveys
k_{length}	0.41	surveys 1963-2005	0.6	all surveys	0.88	all surveys
$t_{0,length}$	0.11	surveys 1963-2005	0.22	all surveys	0.53	all surveys
W_{∞} (g)	3872	surveys 1992-2005	1363	surveys 1992-2022	974	surveys 1992-2022
k_{weight}	0.02	surveys 1992-2005	0.18	surveys 1992-2005	0.29	surveys 1992-2022
A_{50} (y)	2.5	spring survey 1969-1992	1.7	all spring surveys	1.7	all spring surveys
L_{50} (cm)	21	spring survey 1969-1992	23	all spring surveys	24	all spring surveys
Temperature (^{o}C)	6.8	duPontavice et al. 2023	8.6	duPontavice et al. 2023	9.6	duPontavice et al. 2023
GSI			0.52	TRAC 2014	0.178	NEFSC 2012

Table 2. Estimates of natural mortality for New England yellowtail flounder stocks.

Method	CCGOM	GB	SNEMA	Basis	Reference
Then_nls	0.43	0.38	0.54	MaxAge	Then et al. 2015
Then_lm	0.38	0.33	0.49	MaxAge	Then et al. 2015
Hamel_Amax	0.38	0.33	0.49	MaxAge	Hamel 2015
Chen-Wat	0.42	-	-	MaxAge&Growth	Chen & Watanabe 1989
ZM_Ca_Pel	0.28	0.12	0.25	MaxAge&Growth	Zhang & Megrey 2006
ZM_Ca_Dem	0.11	0.03	0.06	MaxAge&Growth	Zhang & Megrey 2006
Then_VBgf	0.58	0.82	1.14	Growth	Then et al. 2015
Hamel_k	0.68	1.05	1.54	Growth	Hamel 2015
Jensen_k 1	0.59	0.90	1.32	Growth	Jensen 1997
Jensen_k 2	0.62	0.96	1.41	Growth	Jensen 1997
Gislason	0.35	0.55	0.83	Growth	Gislason et al. 2010
Charnov	0.39	0.60	0.88	Growth&Maturity	Charnov et al. 2013
Pauly_Lt	0.44	0.67	0.95	Growth	Pauly 1980
Roff	0.71	1.02	0.76	Maturity	Roff 1984
Jensen_Amat	0.66	0.97	0.97	Maturity	Jensen 1997
Ri_Ef_Amat	0.63	0.88	0.88	Growth&Maturity	Rikhter & Efanov 1976
Pauly_Wt	0.15	0.30	0.43	Growth	Pauly 1980
GSI	NA	0.94	0.32	GSI	Gunderson & Dygert 1988

Table 3. Estimates of natural mortality at age for New England yellowtail flounder stocks, rescaled from lifetime *M*=0.4.

Age (y)	**CCGOM**	**GB**	**SNEMA**
1	0.60	0.57	0.97
2	0.34	0.33	0.45
3	0.26	0.26	0.37
4	0.23	0.24	0.34
5	0.21	0.23	0.33
6	0.20	0.22	0.33
7	0.19	0.22	0.33

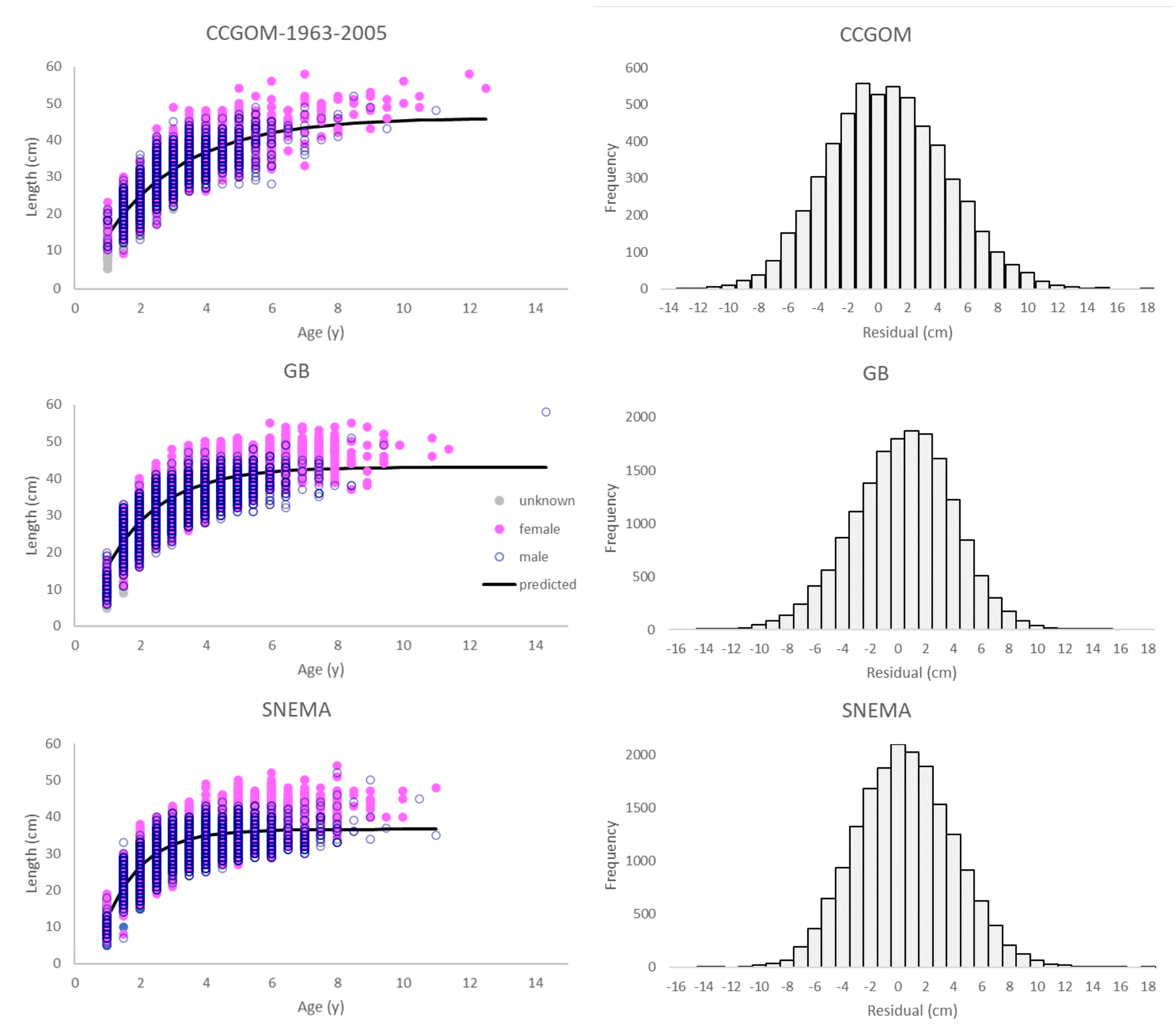

Figure 1. Observations of length at age by sex, growth model predictions and model residuals for yellowtail flounder by stock.

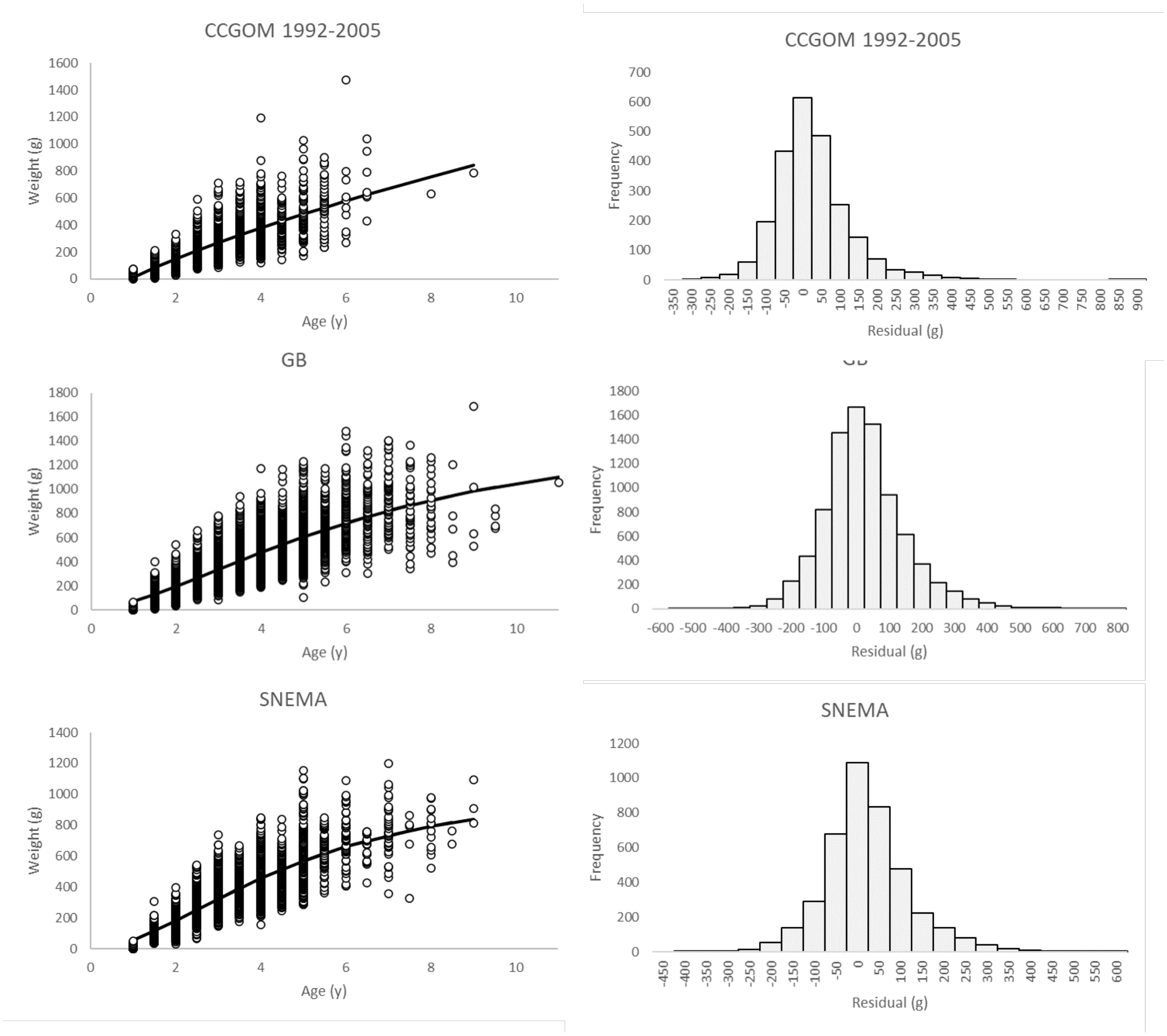

Figure 2. Observations of weight at age, growth model predictions and model residuals for yellowtail flounder by stock.

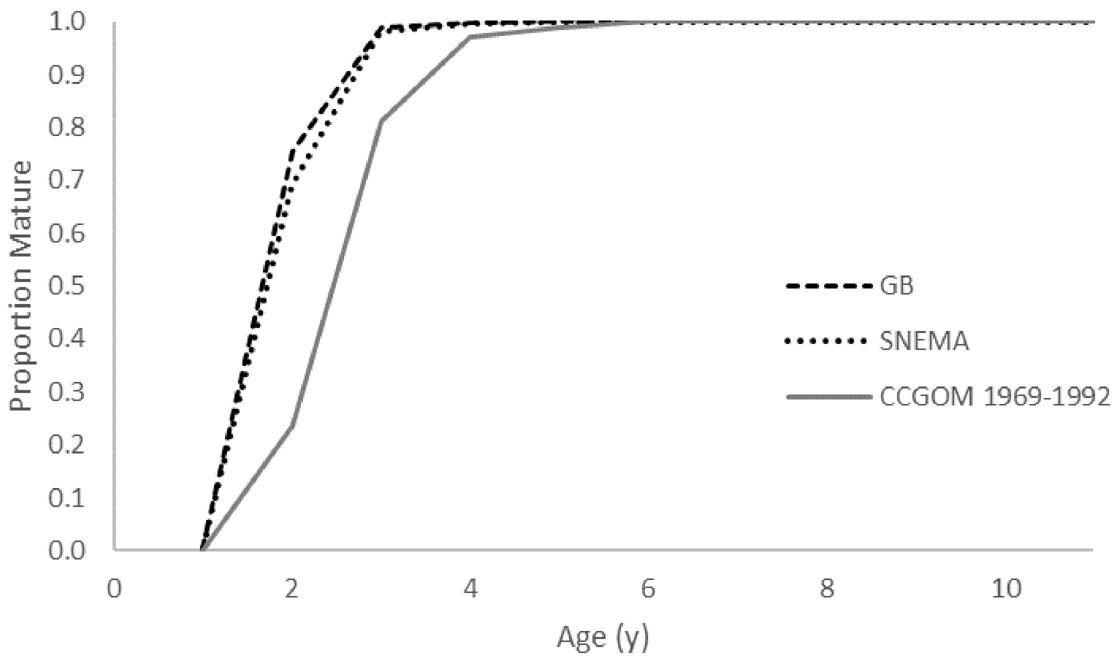

Figure 3. Yellowtail flounder maturity at age by stock.

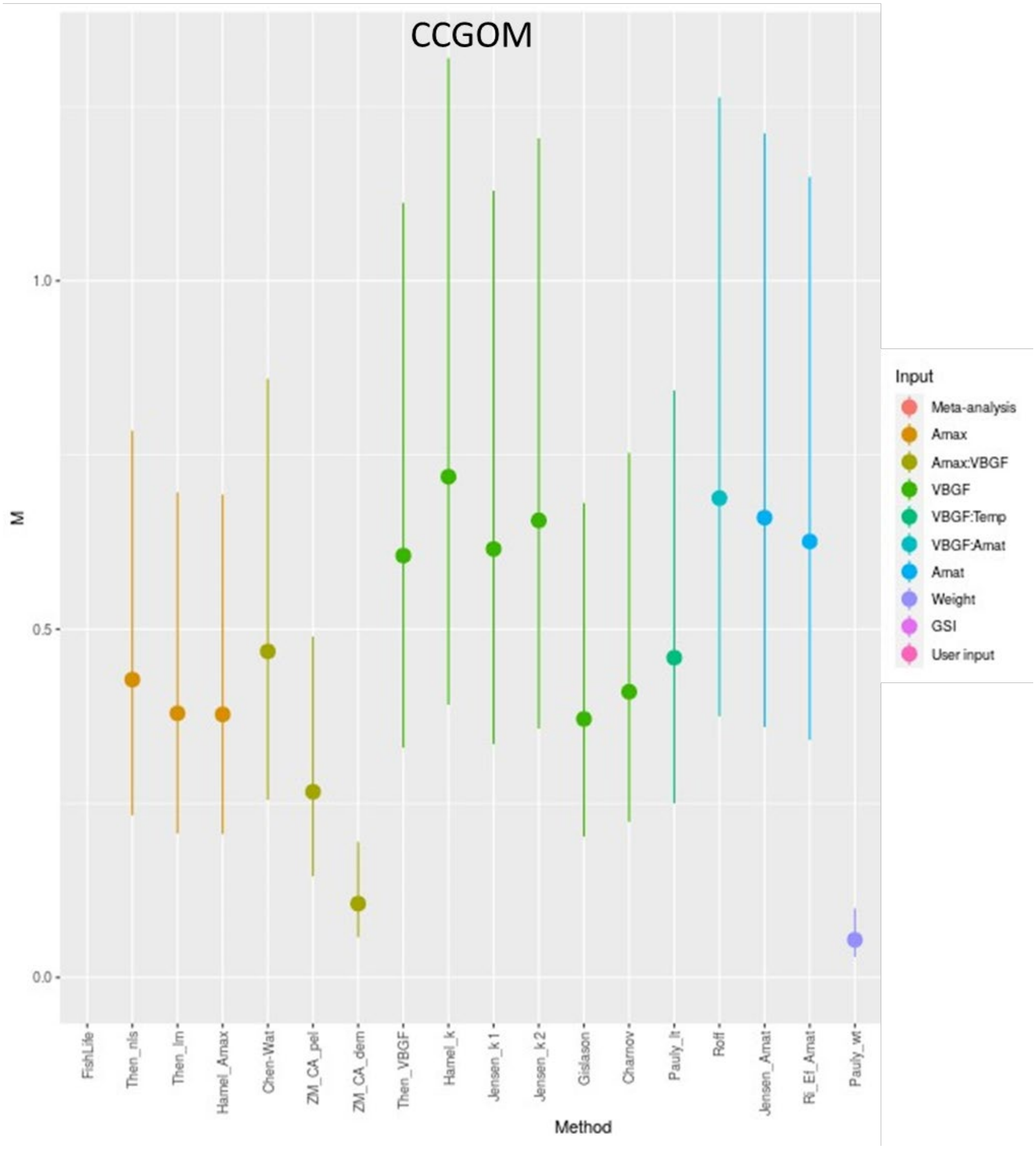

Figure 4. Estimates of natural mortality for Cape-Cod-Gulf of Maine yellowtail flounder.

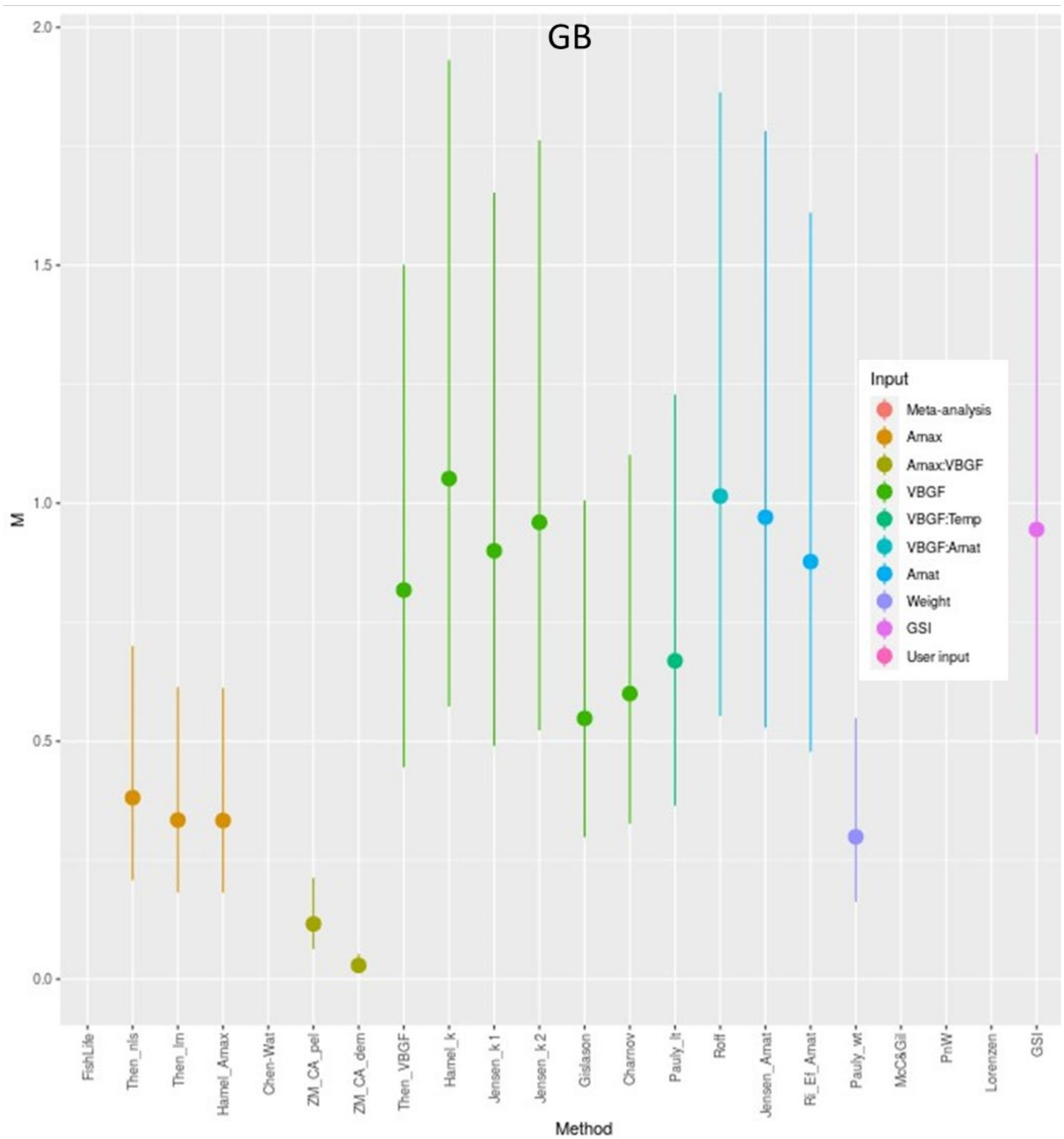

Figure 5. Estimates of natural mortality for Georges Bank yellowtail flounder.

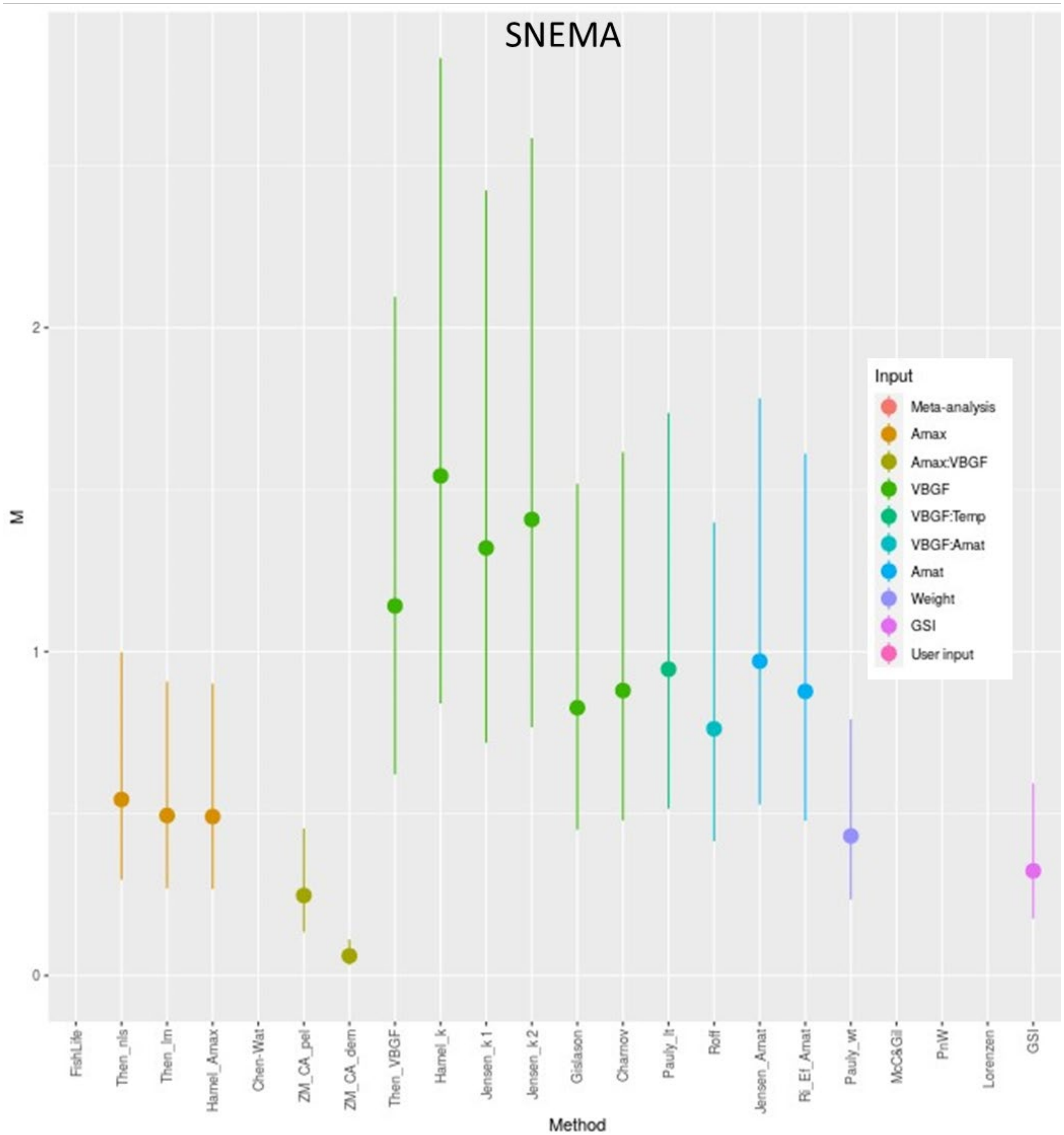

Figure 6. Estimates of natural mortality for Southern New England-Mid Atlantic yellowtail flounder.

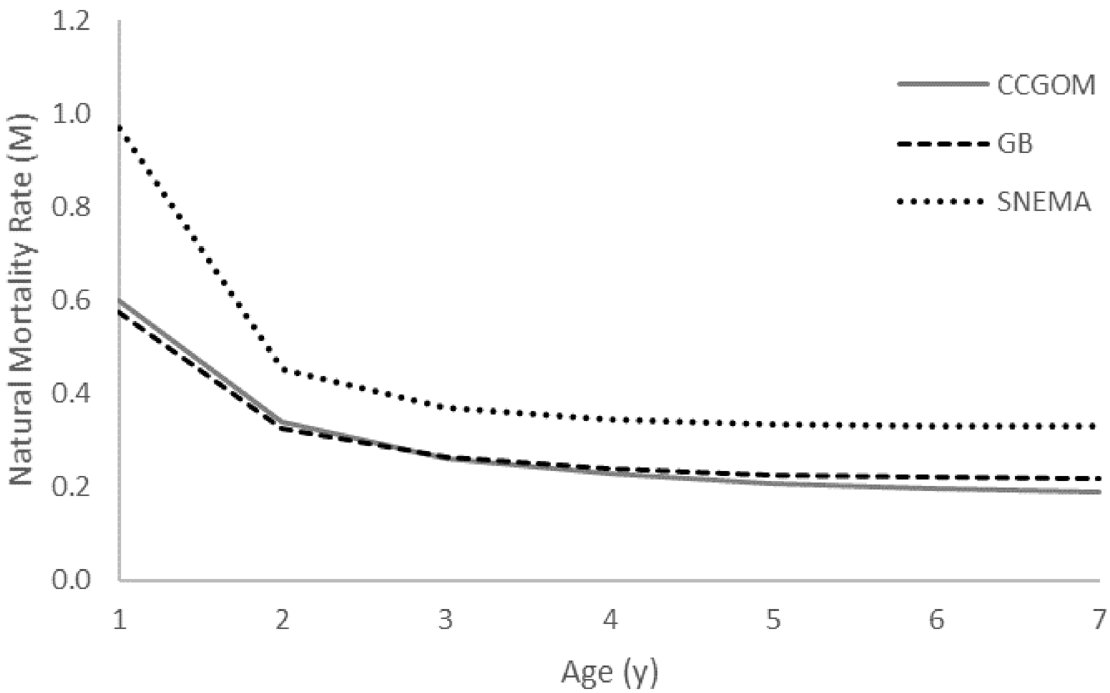

Figure 7. Estimates of natural mortality at age for New England yellowtail flounder stocks.