Estimating Natural Mortality for Gulf of Mexico Scamp Grouper

Gulf Fisheries Branch; NOAA Fisheries - SEFSC

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Estimating Natural Mortality for Gulf of Mexico Scamp Grouper

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Keywords

Natural Mortality, Age-specific, Scamp, Gulf of Mexico

Abstract

Point estimates and age-specific estimates of natural mortality are provided for use in the stock assessment for Gulf of Mexico Scamp.

Introduction

The natural mortality rate (M) of a fish species is often estimated indirectly using life history covariates due to the difficulty in estimating M directly (e.g. from population demographics or tagging data). While many equations are available to calculate a point estimate of M based on life history traits, regressions using maximum age (t_{max}) in the population are preferred (Hoenig, 1983; Then et al., 2015). In addition, it is generally recognized that M is highest during the early life stages of a fish and declines as the fish grow and mature. For that reason, equations that scale M as a function of size (Lorenzen, 1996, 2000, 2005; Charnov et al., 2012) are favored in stock assessment applications.

Materials and Methods

Natural Mortality Point Estimate

During the SEDAR 68 Research Track Assessment for Gulf of Mexico Scamp, the Life History Working Group (LHWG) recommended a maximum age (t_{max}) of 34 years (**Table 1**; additional details provided in SEDAR 2021). This estimate was recommended by the LHWG because it was found in multiple data sets and across many years. To account for uncertainty in maximum age (i.e., ageing error, limited sample size), the LHWG proposed a range of 32 to 36 years be used as the t_{max}, which directly translated into uncertainty about M.

The non-linear least squares methodology of Then et al. (2015) was recommended for use by the LHWG pending a few modifications. Following the guidance of Then et al. (2015), the LHWG first reviewed and evaluated the utility of the Then et al. (2015) data set (Then and Hoenig 2015, available at *https://www.vims.edu/research/departments/fisheries/programs/mort_db/index.php*) and then reran the regression on a subset of species with more similar life history strategies to Scamp. Criteria considered by the LHWG for sub-setting the data included having similar habitats (e.g., tropical/sub-tropical reef fish or demersal species rather than pelagic or coldwater species), a sufficient range in maximum ages, and enough data points for the regression to be robust. The non-linear least squares methodology of Then et al. (2015) was used to estimate M (M_{target}) using three different subsets of data:

1. All data (N = 226) excluding pygmy goby (*Eviota sigillata*) which is an outlier (M = 49.57 per year).

2. Reef Fish only (N = 67), which included Serranidae (groupers), Sparidae (porgies), Pomacanthidae (angelfishes), Pomacentridae (damselfishes), Scaridae (parrotfishes), Malacanthidae (tilefishes), Labridae (wrasses), Lutjanidae (snappers), Haemulidae (grunts), Carangidae (jacks), and Acanthuridae (surgeonfishes). The families for Balistidae (triggerfishes) and Polyprionidae (wreckfishes) were excluded due to concerns over the ageing methodology used within their respective studies.

3. Serranidae only (N = 12; **Table 2**).

Age-specific Natural Mortality

Natural mortality scaled as a function of size-at-age is often considered a more appropriate data input for stock assessment than age-invariant M because smaller fish are more susceptible to predation than older, larger fish. After discussions regarding both the Lorenzen (1996, 2000, 2005) and Charnov et al. (2012) approaches to scaling M, combined with input from Lorenzen on an updated analysis, the SEDAR 68 LHWG supported the Lorenzen approach for estimating age-specific M. Their justifications were that Lorenzen's (1996) data set and estimation procedure better address the population level natural mortality, whereas Charnov et al. (2012)'s estimator works better at a community level. In a new manuscript under review, Lorenzen made a strong argument that the new analyses resulted in an equation more similar to his original equation. Lorenzen advised that the natural mortality vector be scaled for the focal species (Scamp) using the Then et al. (2015) point estimate based on t_{max}. His reasoning was that, depending on the species, the mortality vector from his equation may not allow for the fish to survive to t_{max}.

In recent SEDAR stock assessments for Gulf of Mexico groupers, age-specific natural mortality (M) has typically been calculated using the Lorenzen (2000) function, assuming a size-dependent mortality schedule in which the instantaneous mortality rate-at-age is inversely proportional to length-at-age (see **Appendix A**). Parameters required for this approach include the age at full recruitment to the fishery ($minage$), an M_{target} point estimate (e.g. from the Then et al. 2015 estimator) for the species representing the cumulative mortality rate over the range of exploited ages, and growth curve parameter estimates (**Table 1**). Mortality rate for each individual age *a* can be calculated as:

$$M_a = -log(\frac{L_a}{L_a + L_\infty(e^{k(a+1-a)} - 1)})\frac{M_1}{L_\infty k}$$

where L_a is the length-at-age a, L_∞ and k are von Bertalanffy growth parameters and M_1 is the mortality rate at unit length. A detailed description of the derivation is provided in **Appendix A**.

Natural Mortality Parameterization in Stock Synthesis

Stock assessments in the Gulf of Mexico are conducted using the Stock Synthesis (SS) modeling platform (Methot and Wetzel, 2013), which is an integrated statistical catch-at-age model that can accommodate a wide range of fish populations and dynamics (Methot et al. 2022). While numerous options for modeling natural mortality (M) exist in Stock Synthesis, the most commonly applied approach for reef fish in the Gulf of Mexico has been to calculate the Lorenzen curve (described above) externally to SS and fix the age-specific M vector in the assessment model (referred to as Options 3 and 4 in SS; Methot et al. 2022). This approach has traditionally been applied in the absence of direct estimates of natural mortality for the species under assessment, or for a specific reference age group (required if the SS formulation of the Lorenzen function (Option 2) is selected).

In SS, fish are assigned a "real age" (relative to the birth date) and a "calendar age" (relative to January 1 of the spawn year - i.e., SS advances the age of fish on January 1 of each year regardless of when settlement occurs). Fish recruit at the real age 0.0 and growth is based on real age, so if settlement is January 1st, length mid-calendar-year is the length of a $x + 0.5$ year old (real age) fish. In contrast, if settlement is March 1st, length mid-calendar-year is the length of a $x + 0.5 - \frac{31+28.25}{365.25}$ year old (real age) fish. With Option 3, the input M vector expected by Stock Synthesis is the mortality that corresponds to the length of a fish mid-calendar-year so annual M must be adjusted *a priori* based on an assumed birth date. If Option 4 is selected, SS will expect a vector of M-at-age corresponding to the length of a fish mid-real-age and adjust the annual M internally based on the settlement definition provided.

The growth equation available for Scamp was estimated using decimal ages (i.e. the input ages were already adjusted for birth date), therefore using the von Bertalanffy parameter estimates to determine length-at-age 0.0 provides the length on the spawning day or birth date. Given that SS Option 3 was used for Scamp, L_a was adjusted to account for birth date:

$$L_a = L_\infty(1 - e^{k(a+shift-t0)})$$

where shift = $0.5 - \frac{d}{365.25}$ and d is the number of days elapsed between January 1st and the birth date, assumed to be April 15.

L_0 (used in the calculation of M_1, see **Appendix A**) is the length at full recruitment to the fishery and represents the length of a fish of real age = minimum age of 6 years:

$$L_0 = L_\infty(1 - e^{k(minage-t0)})$$

.

Results

Natural Mortality Point Estimate

Using all the data (excluding pygmy goby) in the Then et al. (2015) dataset, the point estimate of M based on a t_{max} of 34 years resulted in M = 0.1937 per year for Scamp (**Figure 1**). This equated to an estimate of survivorship of 0.004 based on the fully selected age range (6-34 years). The non-linear regression equation including only reef fish families resulted in M = 0.1935 per year and survivorship of 0.004 (**Figure 1**). The non-linear regression using the 12 Serranidae species (**Table 2**) led to an M of 0.1552 per year and an estimate of survivorship of 0.013 (**Figure 1**). Serranids ranged from 7 to 85 years in maximum age and estimates of M ranged from 0.078 to 0.68 (**Table 2**).

Age-specific Natural Mortality

The age-specific M vector scaled to the Then et al. (2015) point estimate based on Serranidae family is shown in **Table 3** and **Figure 2**. A Low and High M-at-age vector reflecting uncertainty around maximum age are also presented.

Discussion

Some of the relevant literature cited by Then et al. (2015) was reviewed by various members of the SEDAR 68 LHWG. Many of the studies drew concern over ageing methodology or how M was calculated. For example, many of the M values were based on catch-curve analysis of unfished or lightly fished stocks. The SEDAR 68 LHWG noted that a more thorough review of the literature cited in Then et al. (2015) is needed, as well as investigation in the most appropriate way to subset the data for other SEDAR species. Further, additional research aimed at obtaining direct estimates of natural mortality are warranted, such as mark-recapture approaches (conventional, telemetry, or close-kin).

Pending a more detailed assessment of the Then et al. (2015) database, the LHWG decided to obtain the base M (M_{target}) from the Serranidae family subset with Lorenzen scaling for the SEDAR 68 stock assessment for Gulf of Mexico Scamp.

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Tables

Table 1: Parameters required to estimate natural mortality for Gulf of Mexico Scamp.

Parameter	Value	Units
Point Estimate		
Maximum age (tmax)	34	years
Maximum age lower bound	32	years
Maximum age upper bound	36	years
Family	Serranidae	
Age-specific Vector		
von Bertalanffy asymptotic length (Linf)	702.22	mm Fork Length
von Bertalanffy growth rate (K)	0.134	per year
von Bertalanffy age at length 0 (t0)	-1.762	years
First age fully vulnerable to fishery (min age)	6	years
Peak spawning date (i.e., birth date)	April 15	

Table 2: Family-specific data used to estimate natural mortality (M) from maximum age (t_{max}). Data obtained from Then and Hoenig (2015).

Scientific Name	Common Name	M (reference)	tmax (reference
Serranus cabrilla	comber	0.68 (Macpherson et al., 2000)	7 (Macpherson et al., 2000)
Plectropomus maculatus	inshore coral trout	0.39 (Ferreira & Russ, 1992)	12 (Ferreira & Russ, 1992)
Plectropomus areolatus	passionfruit trout	0.3995 (Williams et al., 2008)	14 (Williams et al., 2008)
Plectropomus leopardus	coral trout	0.147 (Russ et al., 1998)	18 (Russ et al., 1998)
Epinephelus guttatus	red hind	0.2 (Lopez-Rivera & Sabat, 2009)	18 (Sadovy et al.,1992)
Cromileptes altivelis	humpback grouper	0.26 (Williams et al., 2009)	19 (Williams et al., 2009)
Epinephelus coioides	estuary rockcod	0.29 (Pember et al., 2005)	22 (Pember et al., 2005)
Epinephelus niveatus	snowy grouper	0.18 (Moore & Labisky, 1984)	27 (Moore & Labisky, 1984)
Epinephelus malabaricus	Malabar grouper	0.17 (Pember et al., 2005)	31 (Pember et al., 2005)
Paralabrax clathratus	kelp bass	0.287 (Young, 1963)	33 (Love et al., 1996)
Mycteroperca bonaci	black grouper	0.16 (Muller, 2009)	33 (Muller, 2009)
Epinephelus flavolimbatus	yellowedge grouper	0.078 (*Walter, J.F., unpublished data)	85 (Cook et al., 2009)

Table 3: Age-specific vector of natural mortality (M) estimated based on Lorenzen (2000). Female and male natural mortality are assumed equivalent due to the lack of sex-specific information.

Age	Base M	High M	Low M
0	0.4995	0.5241	0.4771
1	0.3764	0.3949	0.3595
2	0.3099	0.3251	0.2960
3	0.2685	0.2817	0.2565
4	0.2405	0.2523	0.2297
5	0.2204	0.2312	0.2105
6	0.2054	0.2155	0.1962
7	0.1939	0.2034	0.1852
8	0.1848	0.1939	0.1765
9	0.1775	0.1862	0.1696
10	0.1716	0.1800	0.1639
11	0.1668	0.1750	0.1593
12	0.1627	0.1707	0.1554
13	0.1594	0.1672	0.1522
14	0.1565	0.1642	0.1495
15	0.1542	0.1617	0.1473
16	0.1521	0.1596	0.1453
17	0.1504	0.1578	0.1437
18	0.1489	0.1562	0.1422
19	0.1476	0.1549	0.1410
20	0.1465	0.1537	0.1400
21	0.1456	0.1527	0.1391
22	0.1448	0.1519	0.1383
23	0.1441	0.1511	0.1376
24	0.1435	0.1505	0.1370

Table 3 Continued: Age-specific vector of natural mortality (M) estimated based on Lorenzen (2000). Female and male natural mortality are assumed equivalent due to the lack of sex-specific information.

Age	Base M	High M	Low M
25	0.1429	0.1499	0.1365
26	0.1425	0.1495	0.1361
27	0.1421	0.1490	0.1357
28	0.1417	0.1487	0.1354
29	0.1414	0.1484	0.1351
30	0.1411	0.1481	0.1348
31	0.1409	0.1478	0.1346
32	0.1407	0.1478	0.1344
33	0.1405		0.1342
34	0.1405		0.1341
35			0.1340
36			0.1340

Figures

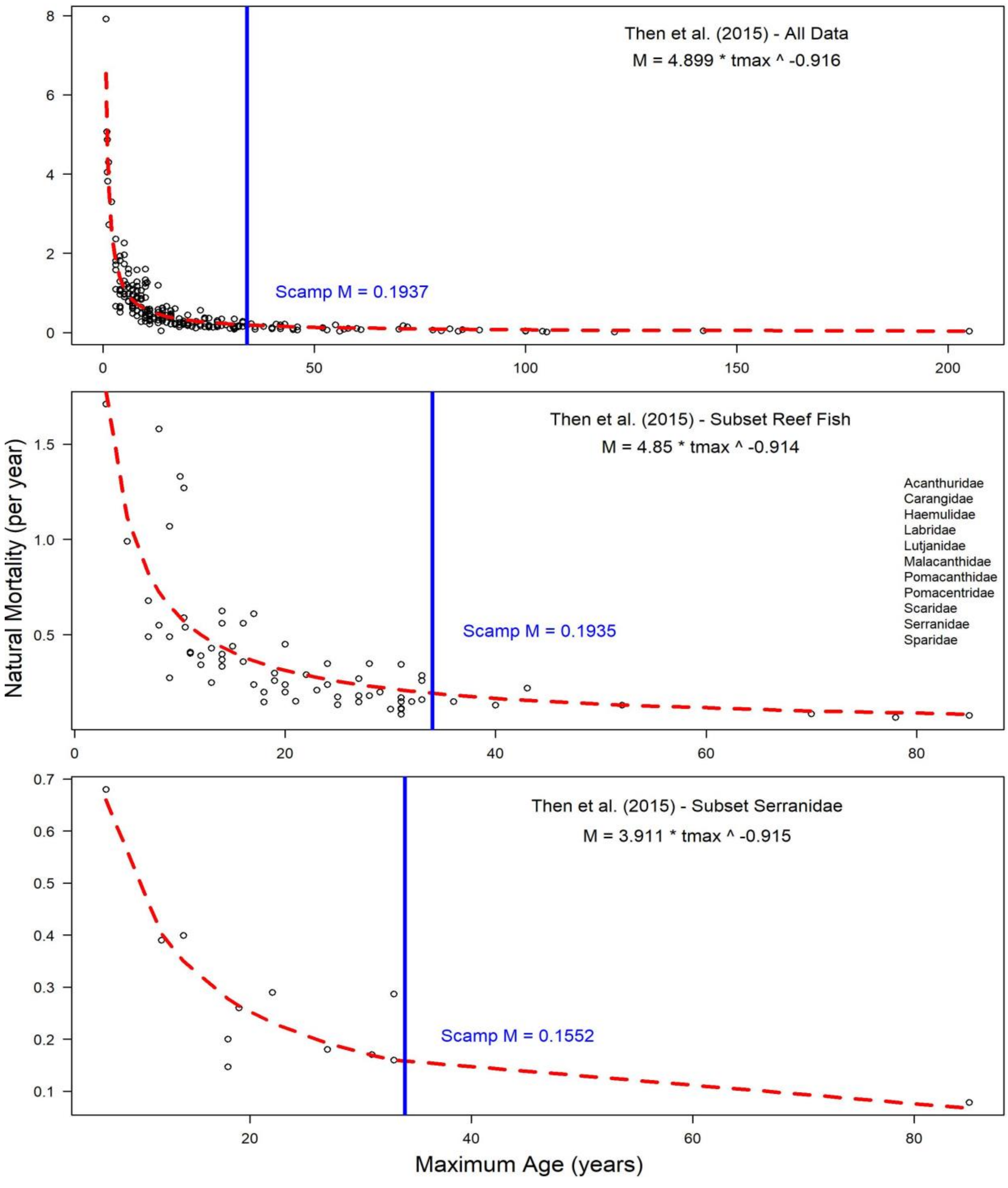

Figure 1: Comparison of point estimates of natural mortality for Gulf of Mexico Scamp based on the Then et al. (2015) non-linear regression using all data (top panel), Reef Fish only (middle panel; families included are shown at the right), and Serranidae only (bottom panel).

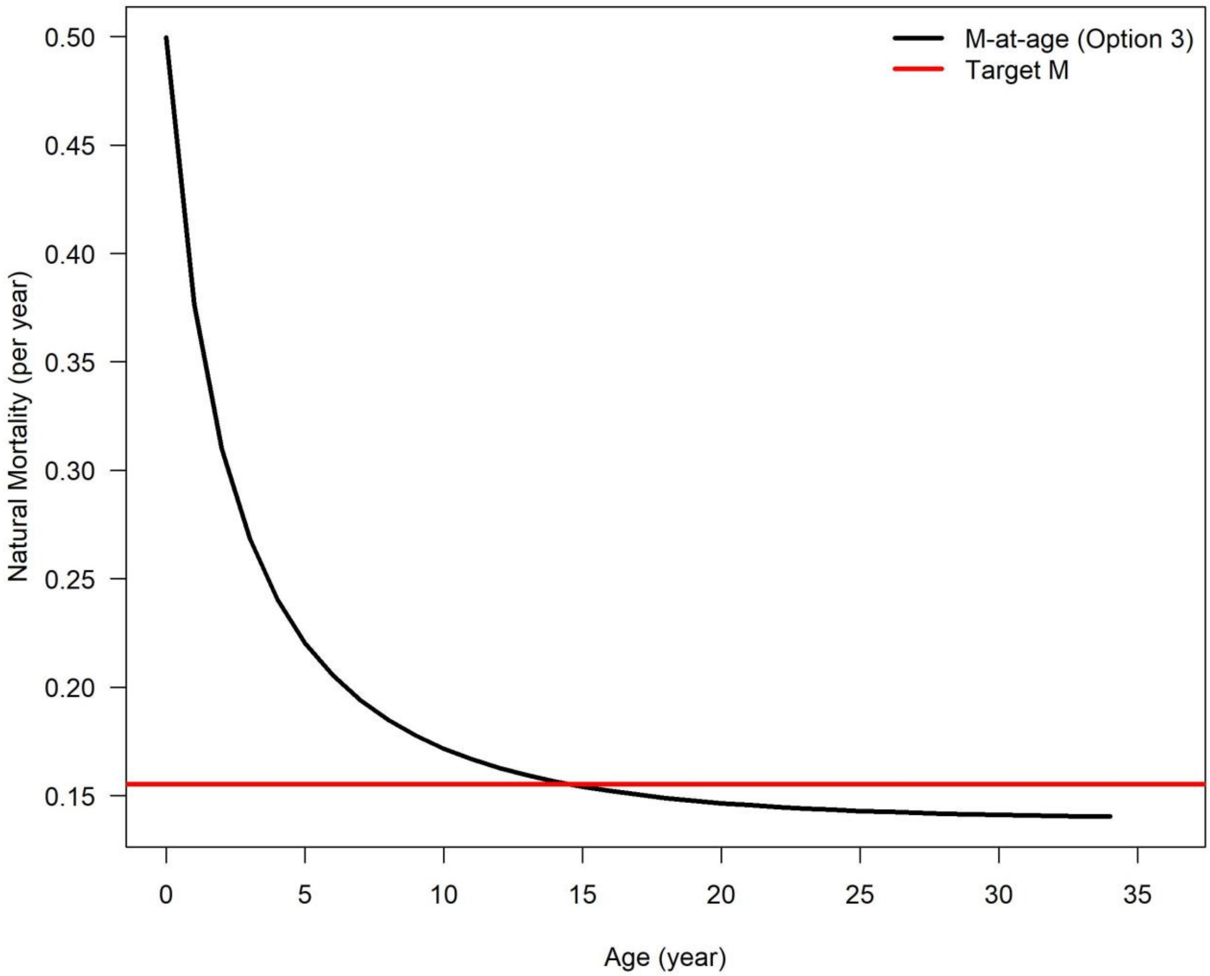

Figure 2: Age-specific natural mortality for Gulf of Mexico Scamp as estimated from Lorenzen (2000) while accounting for a shift in peak spawning.

Appendix A. Derivation of Lorenzen (2000) age-specific vector

Following Lorenzen (2000), if we assume that mortality is inversely proportional to length and that the growth of the species of interest is best described by a von Bertalanffy model, then S_t, the proportion of individuals surviving from recruitment to the fishery to time *t*, can be described by the equation:

$$S_t = \frac{L_0}{L_0 + L_\infty(e^{kt} - 1)}^{\frac{M_r L_r}{L_\infty k}} \quad (Equation1)$$

where:
L_0 = the length at full recruitment to the fishery;
L_∞ = the von Bertalanffy asymptotic length;
k = the von Bertalanffy growth rate; and
M_r = the mortality rate at reference length L_r.

Assuming instantaneous mortality rate-at-age *r* (M_r) is inversely proportional to length-at-age *r* (L_r) (Lorenzen 2000), we can convert mortality rate-at-length *r* into a mortality rate at unit length (M_1):

$$M_r = M_1 \frac{1}{L_r}$$

$$M_1 = M_r L_r (Equation2)$$

By substituting Equation 2 in Equation 1 we can solve for M_1:

$$S_{maxage-minage} = \frac{L_0}{L_0 + L_\infty(e^{k(maxage-minage)} - 1)}^{\frac{M_1}{L_\infty k}}$$

$$S_{maxage-minage} = e^{-M_{maxage-minage}} = \frac{L_0}{L_0 + L_\infty(e^{k(maxage-minage)} - 1)}^{\frac{M_1}{L_\infty k}}$$

$$M_{maxage-minage} = -log(\frac{L_0}{L_0 + L_\infty(e^{k(maxage-minage)} - 1)}) \frac{M_1}{L_\infty k}$$

$$M_1 = -\frac{M_{maxage-minage} L_\infty k}{log(\frac{L_0}{L_0 + L_\infty(e^{k(maxage-minage)} - 1)})}$$

M_{target}, for example obtained using the Then et al. (2015) estimator, represents the cumulative mortality rate from the age at full recruitment to the fishery ($minage$) to the maximum age in the population ($maxage$) and can be substituted here:

$$M_1 = -\frac{(\sum_{minage}^{maxage} M_{target}) L_\infty k}{log(\frac{L_0}{L_0 + L_\infty(e^{k(maxage-minage)} - 1)})}$$

$$M_1 = -\frac{(maxage - minage)M_{target}L_\infty k}{log(\frac{L_0}{L_0 + L_\infty(e^{k(maxage-minage)} - 1)})}$$

Using $M_t = -log(S_t)$ and changing the time step to go from one age (*a*) to the next (*a+1*), we can now calculate the mortality rate for each individual age (M_a) using:

$$M_a = -log(\frac{L_a}{L_a + L_\infty(e^{k(a+1-a)} - 1)})\frac{M_1}{L_\infty k}$$