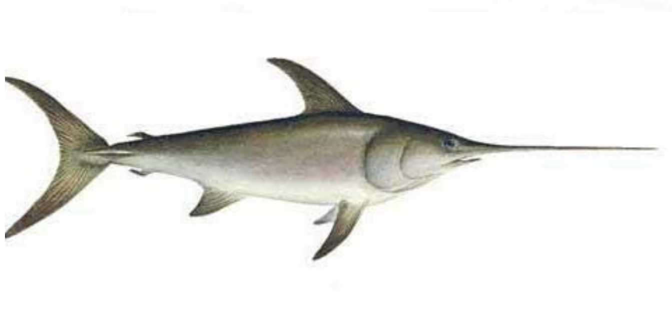
Meta-analysis of striped marlin natural mortality

Kevin Piner
NOAA NMFS PIFSC
2570 Dole St., Honolulu, Hawaii, USA 96822

Hui-Hua Lee
Joint Institute for Marine and Atmospheric Research
University of Hawaii
2570 Dole St., Honolulu, Hawaii, USA 96822



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Meta-analysis of striped marlin natural mortality[1]

Kevin Piner and Hui-Hua Lee
NOAA Fisheries, PIFSC
2570 Dole Street, Honolulu HI USA 96822

Abstract

Natural mortality estimates for North Pacific Ocean striped marlin were derived from a meta-analysis of 9 different M estimators. The M estimators relied on a range of factors (e.g. maximum age, maximum size, growth rate) and a broad range of levels within each factor was used to estimate within-method uncertainty. The overall M estimate was based on a random effects inverse variance weighting of each method (0.38 $^{-yr}$ 95% CI ± 0.038). An un-weighted mean (0.43 $^{-yr}$ 95% CI ± 0.029) was also calculated for comparison. The magnitude of the new estimates of M were higher than assumed in the previous assessment and somewhat higher than assumed for most other billfish stocks (0.3 $^{-yr}$ 95% CI ± 0.09).

Introduction

The magnitude of natural mortality (M) is one measure of the productivity of the stock. It is important in the calculation of population dynamics and biological reference points (e.g. MSY). Assumptions about M are often taken from assessments of similar stocks or based on 'expert' opinion. When M is estimated it comes from catch data, empirical relationships, and life history relationships (Vetter 1988). Catch data refers to either mark recapture (Chapman 1961, Seber 1982) or catch curve type analysis (Chapman and Robson 1960 and Robson and Chapman 1961). Life history theory (Roff 1984; Charnov 1993; Jensen 1996; Alverson and Carney 1975) estimates of M are based on the tradeoffs among biological properties such as growth, maturation and mortality to maximize lifetime reproductive success. Empirical relationships (Pauly 1980; Gunderson 1997; Hoenig 1983) are those based on regressions of natural mortality against explanatory factors over a wide range of stocks. There is no universal acceptance of any one method as optimal.

The assumed magnitude of natural morality for billfish stocks world-wide has varied considerably. Values of M ranged from levels indicating a relatively unproductive stock (Porch 2003) to levels of productivity more often assumed for tuna stocks (Hinton et al. 2010; Hinton and Bayliff 2002). Assumptions for M of striped marlin in the North Pacific Ocean (NPO) have ranged nearly as much (Hinton and Baylif 2002; Piner et al. 2007: Hinton et al. 2010). The level assumed can have significant effects on the outcome of the stock assessment.

In this paper we apply a range of M estimators for striped marlin in the NPO. Estimates of uncertainty are also generated using a range of plausible biological and environmental factors. A random effects meta-analysis of M is used to synthesize a single M estimate. We assume this estimate represents adult M, and M at younger ages is based on a size-mortality relationship

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(Lorenzen 1996 and Lorenzen 2000). The estimates of striped marlin M are then discussed in relation to M values assumed in other stocks.

Methods

We compiled 9 potential methods (Table 1) to estimate M based on empirical and life history methods from on a recent review paper (Maunders et al. submitted). These methods relied on a range of life history and environmental factors (Table 2). We used plausible ranges of factor levels (Table 2) to estimate within method uncertainty in the magnitude of M. The final estimate of M was random effects inverse variance weighted mean (an un-weighted estimated of mean M is given for comparison). The methods of estimation of the weighted mean are taken from (Borenstein et al. 2009):

Total variance (Q) is:

$$Q = \sum w_i\,(X_i - \overline{X})^2$$

Where w_i is the 1/ within method variance and X_i is the method mean and $\bar{X}$ is the weighted mean across methods.

The between methods variance (*t*) is:

if $Q>df$

$$t = (Q - df)/C$$

if $Q<df$

$$t=0$$

Where *df* is the number of methods -1 (8) and C is a scaling factor and w_i is inverse variance of the method (1/variance).

$$C = \sum w_i - \frac{\sum w_i^2}{\sum w_i}$$

The weight given to a method (w^*_i) is given by:

$$w_i^* = 1/v_i^*$$

Where v^*_i is the within component of total variance:

$$v_i^* = v_i + t_i$$

Where v_i is the within method variance.

The weighted mean is calculated as:

$$weighted\ mean(M) = \sum w_i^*\,x_i / \sum w_i^*$$

The variance $(V)^*$ of the weighted *Mean (M)* is given by:

$$V^* = 1/\sum W_i^*$$

A Lorenzen (1996) relationship (Table 1) was used to estimate juvenile M based on the meta-analysis of adult M. Using the Lorenzen relationship, we calculated relative M for ages <5 (M estimate at age/M estimate at age 5). Juvenile M was the product of the relative M and adult M. Biological parameters (length-at age and weight at length) used in the Lorenzen rescaling were the same as used in the previous assessment (Eldgridge and Wares 1974: Melo-Barrerra 2003; Piner et al. 2007).

Results

The estimated M by method ranged from 0.32-0.56 $^{-yr}$ (Table 2). The inverse weighted average M across all methods was 0.38^{-yr} (95% CI 0.34-0.42^{-yr}) and without weighting 0.43^{-yr} (95% CI 0.37-0.48^{-yr}). Age-specific M, derived from the relative size-dependent relationship (Lorenzen 1996) is given in (Table 3).

A review of the literature (Table 4) indicated that billfish stock assessments generally assumed M between 0.2 -0.5^{-yr} with a mean of 0.3^{-yr} (95% CI 0.21-0.39^{-yr}), which is remarkably consistent with the previous assessment assumption of M (Piner et al. 2003). Our new weighted estimate of M is at the upper end of this CI and the un-weighted estimated is in the tails. Most published estimates previously used in population models were constant across age and only one was estimated by the assessment model.

Discussion

Given our approach and the choice of factor levels the estimates of M are most dependent on methods by Jensen (1996), Hoenig (1983) and Pauly (1980). Our method of averaging estimates of M across a range of methods and levels of factors is based on how sensitive the estimate is to a realistic range of levels within factors. An inverse weighting approach gives more weight to the method with less variation in M estimates. A random effects approach was used because it is unclear if M based on different approaches should give the same M value and to include the within and between components of variance. We also note that we are assuming that each method provides an independent measure of M.

All of our information comes from fishery data (exploited stocks) and thus the observed vital rates (e.g. maximum age) represents vital rates influenced by fishing. In this cases when a theoretical maximum age is needed (Hoenig and Revised Alverson and Carney), Tmax was taken from Melo-Barrera (2003). We assumed that uncertainty in maximum age (regarding unfished population) would be one directional (older). For other estimators that also could be influence through fishery dependent data selection (eg. growth rate) we assume uncertainty in both directions although in the presence of size selective gears the estimates of K are probably biased high. Similar arguments could be made for mean age at maturity (Tm). We also note that one estimator derived (Maximum age given a sample size) an estimate of total mortality (Z) and not M, and thus plausible ranges of F had to be taken from previous assessment work. These decisions are somewhat subjective and thus we included fairly broad ranges in those factors.

It is clear that there is considerable uncertainty with regards to growth and size of striped marlin in the WCPO. Our estimates of maximum age and growth are taken from Melo-Barrera (2003), which represents fish from outside the WCPO. However the estimates of maximum size in that study is more consistent with the size range of fish seen in the WCPO than are the growth curves from the Southwest Pacific Ocean. It is also not clear what is the appropriate description of length when discussing billfishes. Is the effective size inclusive of the bill? We note that the L_{inf} and temperature are applicable only to the Pauly estimator and we used a wider range of both temp and size to account for this uncertainty.

This paper derived age-specific estimates of M that account for size-dependent mortality. Although this is not the practice for most assessments of billfish, this is consistent with recommendations from a recent NOAA workshop on M. It is also consistent with the approach used in this Billfish WG (Brodziak 2009) and the Pacific Bluefin Tuna Working Group of the ISC. This paper does not explicitly consider increasing M at older ages due to senescence (Siler (1979) or with increasing maturation Lehodey et al. (2008). Although increasing M at the oldest ages is a possibility, we are assuming that the approaches to adult M used in this paper produce an average adult M that includes age-specific adult M. This is an area for future work.

This paper recommends increasing M in the next striped marlin stock assessment to be more productive than previously assumed. This change would move striped marlin towards the upper bound of assumed billfish M, but striped marlin may be more productive than the general billfish species. Although this analysis is still based on some subjective decisions, the resulting estimates are likely more appropriate than an equal weighting and the derived CI may provide guidance on appropriate bounds of assessment sensitivity analysis.

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Table 1. Estimators of M and rescaling of juvenile M.

Name	Reference	type	Equation
Maximum age sample size	Derived from Hoenig (1983)	Maximum age - theory	$Z \cong \frac{\ln(2n+1)}{t_{\max} - t_c}$
Jensen K	Jensen (1996)	Life history theory	M=1.5K
Jensen t_m	Jensen (1996)	Life history theory	M=1.65/t_m
Roff	Roff's (1984)	Life history theory	$M = \frac{3K}{\exp(t_m K) - 1}$
Revised Alverson and Carney	Zhang and Megrey (2006)	Life history theory	M=bK/(e$^{K(.302Tmax-t0)-1}$
Pauly	Pauly (1980)	Empirical	$\ln[M] = -0.0152 - 0.279\ln[L_\infty] + 0.6543\ln[K] + 0.4634\ln[T]$
Empirical K	Jensen (1996)	Empirical	M=1.60K
Empirical t_m	Charnov and Berrigan (1990)	Empirical	M=2/t_m
Hoenig	Hoenig (1983)	Empirical	ln[Z] = 1.45-1.01ln[t_{max}]
Lorenzen	Lorenzen (1996)	Empirical	M=3$W^{-0.288}$

Table 2. Assumed levels of variability in key factors and resulting estimates of M, variance and weight by method. Weights have been normalized (0-1).

factor	range of level	source
Tmax	10 to 16 yr	Melo-Barerra (2003)
K	0.2 to 0.26	Melo-Barerra (2003)
L_{inf}	185 to 233 cm	Melo-Barerra (2003)
T_0	-0.75	Melo-Barerra (2003)
T_m	3 to 5 yr	Eldgridge and Wares (1974)
temperature	20 to 28 C	PO.DAAX[1]
T_c	2-4 yr	Piner et al. (2007)
F	0.25-0.55 $^{-yr}$	Piner et al. (2007); Hinton et al. 2010
method	mean M	Variance (weight)
Hoenig	0.33	0.0032 (0.10)
Jensen K	0.35	0.0011 (0.25)
Jensen Empirical	0.37	0.0012 (0.23)
Jensen Tm	0.43	0.0124 (0.03)
Revised Alverson and Carney	0.56	0.006 (0.06)
Charnov and Berrigan	0.52	0.0181 (0.02)
Roff	0.49	0.0254 (0.01)
Pauly	0.37	0.0009 (0.27)
Maximum age sample size	0.44	0.0219 (0.02)
		95% CI lower and upper bound
un-weighted mean	0.43	0.37 - 0.48
inverse wt mean	0.38	0.34 - 0.42

[1] Physical Oceanography DAAC. AVHRR Oceans Pathfinder Global Equal-angle Best SST (NOAA/NASA). NASA JPL Physical Oceanography DAAC, Pasadena, CA. 1985

Table 3. Vector of age-specific M taken from adult M analysis (this paper) and using Lorenzen method. M is constant at ages above 5+.

Age	Weighted	unweighted
0	0.87	0.99
1	0.61	0.69
2	0.50	0.56
3	0.44	0.50
4	0.40	0.46
5+	0.38	0.43

Table 4. Overview of the estimates of M used in other billfish stock assessment and modeling work. The category age specific refers to if a constant M or age-specific M was used in the model. The category assumption refers to if the M was estimated or fixed at a specific value in the model. The bottom of the table gives the mean of the values and associated 95% CI.

species	area	M	age specific	assumption	source
striped marlin	SW pacific	0.4	no	assumption	Langley et al. 2006
blue marlin	pacific	0.38	no	estimated	Kleiber et al. 2002
striped marlin	EPO Pacific	0.5	no	assumption	Hinton et al. 2010
white marlin	Atlantic	0.1	no	assumption	Porch 2003
striped marlin	EPO Pacific	0.2-0.8	no	assumption	Hinton and Bayliff 2002
swordfish	Western Pacific	0.25	no	assumption	Wang et al. 2005
swordfish	SW pacific	0.16,0.24,0.26,0.41	no	assumption	Kolody et al. 2008
swordfish	NPO	0.2-0.3	no	assumption	Sun et al. 2003
blue marlin	Atlantic	0.15	no	assumption	Prager and Goodyear 2001
blue marlin	Pacific	0.2	no	assumption	Cox et al. 2002
swordfish	Pacific	0.2	no	assumption	Cox et al. 2003
Swordfish	WC north Pacific	0.35	Yes	assumption	Brodziak (2009)
Mean		0.3			
S.E.		0.04		Upper bound	Lower bound
95%CI				0.39	0.21