Probable Values of Steepness for North Pacific Striped Marlin

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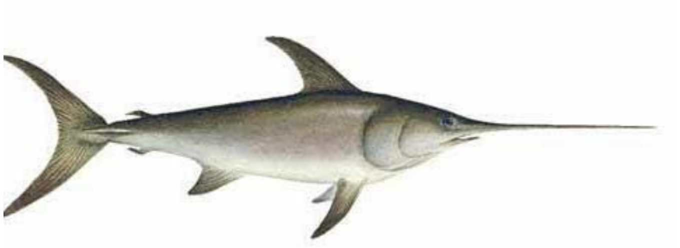

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Probable Values of Stock-Recruitment Steepness for North Pacific Striped Marlin

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Abstract

We applied the simulation method of Mangel et al. (2010) to estimate probable values of stock-recruitment steepness for a Beverton-Holt stock-recruitment curve for Western and Central North Pacific striped marlin (*Kajikia audax*). In this application, new information on the mean batch fecundity per body mass, spawning frequency, and spawning season of striped marlin along with existing information on striped marlin life history parameters consistent with the proposed stock assessment model for Western and Central North Pacific striped marlin was gathered. Results of the baseline steepness model indicated that the mean steepness estimate was $\mu_h = 0.87$ with a standard deviation of $\sigma = 0.05$. This steepness estimate was roughly equal to the average of the two values of steepness that were assumed in separate assessment scenarios (μ_h=0.75 and μ_h=1) for the 2007 North Pacific striped marlin assessment in the absence of any empirical information on the probable value of stock-recruitment steepness. Overall, the results of our analyses suggested that the stock-recruitment dynamics of North Pacific striped marlin were probably highly resilient. Our results also indicated that the estimated mean steepness of North Pacific striped marlin was significantly lower than unity (i.e., μ_h=1) based on the best information currently available for stock assessment. Further, sensitivity analyses indicated that the new life history parameters to be used in the current stock assessment implied a higher steepness than those used in the previous assessment.

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Introduction

We applied the simulation method of Mangel et al. (2010) to estimate probable values of stock-recruitment steepness for a Beverton-Holt stock-recruitment curve for Western and Central North Pacific striped marlin (*Kajikia audax*). In this application, new information on the mean batch fecundity per body mass, spawning frequency, and spawning season of striped marlin was provided by Sun et al. (2011a). Other information on striped marlin life history parameters that was consistent with the proposed stock assessment model for Western and Central North Pacific striped marlin was gathered (K. Piner, PIFSC, personal communication). This included information on growth, maturity at age, average weight at length, and natural mortality rate of striped marlin (Table 1).

Materials and Methods

The baseline steepness model for North Pacific striped marlin included new information on growth, maturity, and reproductive ecology relative to the 2007 stock assessment. We applied a new von Bertalanffy growth curve estimated by Sun et al. (2011b) with Linf = 234.9 (cm, lower jaw-fork length) and K=0.34. The Linf value was converted to units of eye-fork length (EFL) using the relationship estimated by Sun et al. (2011b). This led to an Linf value of 202.9 (cm, EFL). The value of t0 estimated by Sun et al. (2011b) was t0 = -1.9 years. This value of t0 was not consistent with the expected egg-larval and early juvenile life history duration of striped marlin which was expected to be less than one year. In order to apply the steepness algorithm, we imputed a value of t0 = -0.7 that was used for North Pacific bluefin tuna in Mangel et al. (2010) on the basis that the egg-larval and early juvenile duration of striped marlin and bluefin tuna were likely similar. We also conducted a sensitivity analysis to show the effect of using alternative values of t0 = { -0.5, -0.6, -0.8, -0.9 } on estimates of stock-recruitment steepness.

We gathered new information on striped marlin spawning and reproductive ecology from Sun et al. (2011a). Spawning frequency of striped marlin during the spawning season was reported to average 3.4 days by Sun et al. (2011a) and this average value of spawning frequency was used in the baseline steepness model. Sun et al. (2011a) also reported that the average relative fecundity of striped marlin was 53.61 oocytes per gram of body weight with a range of 30.28-78.34 eggs per gram. We used the average relative fecundity of 53.61 eggs per gram of female biomass in the baseline steepness model. To simulate probable variation in female fecundity, we assumed that individual relative fecundity was normally-distributed with a mean of 53.61 and standard deviation of 12.02 (one-fourth of the range); individual realizations of relative fecundity were also restricted to lie within the interval [1.0, 200.0] eggs per gram. The spawning season of striped marlin was reported to be April-August in Sun et al. (2011a) and in the baseline steepness model, we set the length of the spawning season to be 5 months. The length of spawning season of striped marlin in various areas of the North Pacific had previously been reported to be May-June by Kume and Joseph (1969), June-July by Eldridge and Wares (1974), and July-August by Armas et al. (2006). Given these various estimates of spawning season length, we conducted two sensitivity analyses; one with a spawning season of 2 months (e.g., May-June) and one with a spawning season of 4 months (e.g., May-August) to show the effect of using alternative spawning season lengths on estimates of steepness.

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We also gathered new information on striped marlin maturity at length from Sun et al. (2011a). The median length at maturity of female striped marlin from Sun et al. (2011a) was reported to be L50 = 179.0 cm EFL. We translated this estimate of L50 into a median age of female maturity (A50) using the von Bertalanffy growth parameter estimates from Sun et al. (2011b). This led to an estimate of A50 = 4.4 years. There was substantial variability in the estimated length of maturity in Sun et al. (2011b) and we assumed that a coefficient of variation of 25% was a reasonable proxy estimate for the variance of the logistic probability function for maturity at age. This led to a standard deviation of median age of maturity of $\sigma_A = 1.1$ years.

We also conducted sensitivity analyses to show the effect of using alternative values of A50 on estimates of steepness. A lower estimated value of A50 = 2.3 years was reported by Sun et al. (2011a) and we used this value in a sensitivity analysis to show the effects of assuming a lower A50 on estimated steepness. Similarly, a higher A50 value of A50 = 5.6 years was derived from von Bertalanffy Linf and K parameters from Sun et al. (2011b) along with the imputed value from Mangel et al. (2010) of t0 = -0.7 years and we used this A50 in a sensitivity analysis to show the effects of assuming a higher median age of maturity.

There was limited information on the average mass of developed striped marlin eggs, an input parameter that was needed for the steepness simulations. We imputed the average mass of striped marlin eggs by assuming that the expected egg diameter was equal to that of bluefin tuna as used in Mangel et al. (2010) and by calculating the spherical egg volume $V=4\pi r^3/3$ and associated water mass expected at a temperature of 25 ˚C (Table 1).

We also conducted a sensitivity analysis to show the effect of using the striped marlin life history parameters that were used in the previous 2007 stock assessment (Piner et al. 2007) on estimates of steepness. In this case, the growth curve, maturity at age ogive, and natural mortality at age parameters were gathered from the previous assessment (Table 1). For all analyses, the length-weight relationship used for North Pacific striped marlin was the same as in the 2007 assessment (Ponce and Ramirez 1991) which was $W = 0.00009727 \cdot L^{2.5682}$ for predicted weight W (kg) at length L (cm, EFL).

For all analyses, we ran a total of 200 simulations for each of 200 populations comprised of 200 individual fish to estimate the empirical distribution of stock-recruitment steepness values of a Beverton-Holt stock-recruitment curve. We also estimated parameters of a beta density for steepness f(h) that provided the maximum likelihood fit to the empirical steepness distribution from the population simulations, where the form of the fitted density with beta density parameters a_β and b_β was

$$f(h) = \frac{\Gamma(a_\beta + b_\beta)}{\Gamma(a_\beta)\Gamma(b_\beta)} h^{a_\beta - 1} (1-h)^{b_\beta - 1}$$

The fitted parameters can be used to set up a prior distribution for stock-recruitment steepness using the beta density.

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Results

Results of the baseline steepness model indicated that the mean steepness was $\mu_h = 0.87$ with a standard deviation of $\sigma = 0.05$ (Figure 1.1) and fitted beta density parameters of $a_\beta = 24.44$ and $b_\beta = 4.68$. This mean steepness value was roughly equal to the average of the two values of steepness assumed in separate assessment scenarios (μ_h=0.75 and μ_h=1) for the 2007 North Pacific striped marlin assessment. Overall, the results suggested that the stock-recruitment dynamics of North Pacific striped marlin were probably highly resilient. Our results also indicated that the estimated mean steepness of North Pacific striped marlin was significantly lower than unity (i.e., μ_h=1) based on the best information currently available for stock assessment. In this context, assuming that mean steepness was unity was not a plausible biological assumption because setting μ_h=1 would imply that there was an infinite amount of compensation in the stock-recruitment relationship at the origin (Brodziak et al. 2002, Mangel et al. 2010).

The sensitivity analyses on the effect of the length of spawning season on estimates of steepness showed that steepness estimates decreased with the length of spawning season (Figure 1.2). Changing from a five-month to a two-month spawning season would reduce the mean steepness estimate by 16% to $\mu_h = 0.73$ (Figure 1.2) with fitted beta density parameters of $a_\beta = 19.86$ and $b_\beta = 4.76$. Similarly, changing to a four-month spawning season would reduce mean steepness by 2% to $\mu_h = 0.85$ (Figure 1.2) with fitted beta density parameters of $a_\beta = 9.68$ and $b_\beta = 5.06$. Overall, the results indicated that a shorter spawning season would produce a lower stock-recruitment steepness for North Pacific striped marlin.

Sensitivity analyses for the effect of female age at 50% maturity on estimates of steepness showed that a higher median age of maturity would produce a lower value of steepness, all else being equal (Figure 1.3). Increasing the estimated age of median maturity to 5.6 years would reduce the mean steepness estimate by 5% to $\mu_h = 0.83$ (Figure 1.3) with fitted beta density parameters of $a_\beta = 12.65$ and $b_\beta = 3.47$. In contrast, decreasing the estimated age of median maturity to 2.3 years would increase the mean steepness estimate by 6% to $\mu_h = 0.92$ (Figure 1.3) with fitted beta density parameters of $a_\beta = 69.17$ and $b_\beta = 7.63$. Overall, the results indicated that a lower median age of female maturity would produce a higher estimate of stock-recruitment steepness for North Pacific striped marlin.

The sensitivity analyses on the effects of changing the von Bertalanffy t0 parameter showed that the estimates of steepness were sensitive to this parameter (Figure 1.4). Larger absolute values of t0 produced lower values of mean steepness (Figure 1.4) while smaller absolute values of t0 produced higher values of steepness. In this context, there was an upper bound to the feasible range of absolute values of t0 and using a t0 with an absolute value of $|t0| \geq 1$ would produce an infeasible steepness distribution. One interpretation of this empirical result is that higher absolute values of steepness represented longer egg-larval and early juvenile stage durations, which in turn, implied a longer time period for cumulative mortality to occur for early life history stages and lower production of new individuals and biomass in the population. Overall, the results showed that higher absolute values of t0 were associated with lower steepness and decreased population resilience.

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The sensitivity analysis comparing the baseline results with those obtained using the striped marlin life history parameters from the previous assessment showed that using the previous life history parameters would lead to a lower estimate of stock-recruitment steepness (Figure 1.5). In particular, using the life history parameters from the previous stock assessment would reduce the mean steepness estimate by 13% to $\mu_h = 0.76$ (Figure 1.5) with beta density parameters of $a_\beta = 10.98$ and $b_\beta = 4.82$. Thus, the new life history parameters to be used in the current North Pacific striped marlin assessment implied a higher steepness than those used in the 2007 assessment.

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Table 1. List of input simulation and life history parameters for the application of the steepness simulation program of Mangel et el. (2010) to North Pacific striped marlin tuna.

Input Number	Input Variable Name	Data Type	Comments
1	runname	character[128]	Description of the model run up to 128 characters (with no spaces), e.g., "NP_WCP_striped_marlin_steepness_Sun_growth_May_August_spawn"
2	Amax	integer	Maximum age, Amax = 12
3	N_fish	integer	Number of fish per simulated population, N_fish = 200
4	Pop_num	integer	Number of simulated populations, Pop_num = 200
5	Imax	integer	Number of grid points in the interval [0.2, 1.0] for evaluating the prior density of steepness including h=0.2. Set Imax=(0.8/h_inc)+1 where h_inc is the mesh of the grid, e.g., if Imax=81, then h_inc=0.01 and the prior is evaluated for h=0.2, 0.21, 0.22, …, 1.0. For striped marlin: Imax = 81
6	Case_max	integer	Number of simulations per population, Case_max = 200
7	Linf	double	The Linf parameter for Von Bertalanffy length (units are cm, eye-fork length converted from lower jaw-fork length)-at-age (units are years) function, $L(t) = L\inf\left(1-\exp\left(-k\left(t-t0\right)\right)\right)$ Sun growth: Linf = 203.2 Previous assessment: Linf = 190.5
8	k_vb	double	The k parameter for Von Bertalanffy length-at-age function Sun growth: k = 0.34 Previous assessment: k = 0.23
9	t0	double	Value of t_0 parameter for Von Bertalanffy length-at-age function Imputed t0 from Mangel et al. (2010): t0 = -0.7034
10	A_lw	double	The A parameter of the length (units are cm)-weight (units are kg) equation $W = A \cdot L^B$, A = 0.00009727
11	B_lw	double	The B parameter of the length (units are cm)-weight (units are kg) equation $W = A \cdot L^B$, B = 2.5682

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Table 1. Continued.

12	A50	double	The a_{50} parameter for logistic probability of maturity-at-age (units are years) function. $\Pr\left(mature\,at\,age\,a\right) = \frac{\exp\left(\frac{a-a_{50}}{\sigma_M}\right)}{1+\exp\left(\frac{a-a_{50}}{\sigma_M}\right)}$ Note that 50% of a cohort is mature at age $a_{50.}$ Sun growth: $a_{50} = 4.36$ Previous assessment: $a_{50} = 6.0$
13	sigma_a50	double	The σ_M parameter for logistic probability of maturity-at-age function. For striped marlin $\sigma_{M.} = 1.09$
14	nu	double	Not applicable for striped marlin analysis. The ν parameter in the gamma density for natural mortality rate for production model (eqn 31 in Mangel et al. (2010)).
15	Mbar	double	Not applicable for striped marlin analysis. Expected value of natural mortality rate in gamma density for production model (eqn 31 in Mangel et al. (2010. Fish and Fisheries 11:89-104.)).
16	h_inc	double	Mesh of the grid to evaluate steepness. This value of h_inc is linked to Imax above via Imax=(0.8/h_inc)+1, e.g., if h_inc=0.005, then Imax=161. For striped marlin h_inc = 0.01
17	r_sex	double	The sex ratio or fraction (r) of males at birth where (1-r) is the fraction of females at birth. For striped marlin r = 0.5
18	Spawn_season	double	The fraction of the year when spawning occurs, e.g., if the spawning season lasts 4 months, then Spawn_season is 4/12. For striped marlin from Sun maturity, Spawn_season = 5/12.
19	Spawn_interval	double	The average number of days between individual spawning events during spawning season, e.g., if Spawn_interval is 3 days and spawning season last 3 weeks, then the expected number of spawning events would be 21/3=7 events. For striped marlin, from Sun maturity Spawn_interval = 3.4
20	Eggs_per_gram	double	The parameter Eggs_per_gram is the mean number of oocytes per gram of body weight (units are numbers of eggs per gram of wet body weight) For striped marlin, from Sun maturity: Eggs_per_gram= 53.61

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Table 1. Continued.

21	sigma_eggs	double	The parameter sigma_eggs is the standard deviation of oocytes per gram of body weight (units are numbers of eggs per gram of wet body weight) For striped marlin, from Sun maturity, sigma_eggs=12.02
22	LB_eggs	double	Lower bound for simulated eggs per gram
23	UB_eggs	double	Upper bound for simulated eggs per gram
24	sigma_mcgurk_el	double	Standard deviation of log-log regression for daily natural mortality rate. Estimated to be 0.9177698 in Mangel et al. (2010).
25	sigma_mcgurk_j	double	Standard deviation of log-log regression for daily natural mortality rate. Estimated to be 0.963802 in Mangel et al. (2010).
26	lhstructure	integer	Indicator for life history structure where lhstructure=1 is the production model and lhstructure=2 is the age-structured model. For striped marlin, lhstructure = 2
27	W_el[1]	double	Initial wet egg mass (units are g). For striped marlin from Mangel et al. (2010), W = 0.00035
28	M_el[1]	double	Not applicable for striped marlin analysis. Initial accumulated daily instantaneous mortality.
29	Mbar_a	double [Amax]	Natural mortality rate at age vector for ages 0,1,…, Amax. For striped marlin in the current assessment: M(0) = 0.49 M(1) = 0.45 M(j) = 0.40 for all ages $2 \le j \le$ Amax Previous assessment: M(j) = 0.30 for all ages j.

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Figure 1.1. Estimate of Prior Probability Density of Stock-Recruitment Steepness for Western and Central North Pacific Striped Marlin Under the Sun et al. Growth Curve

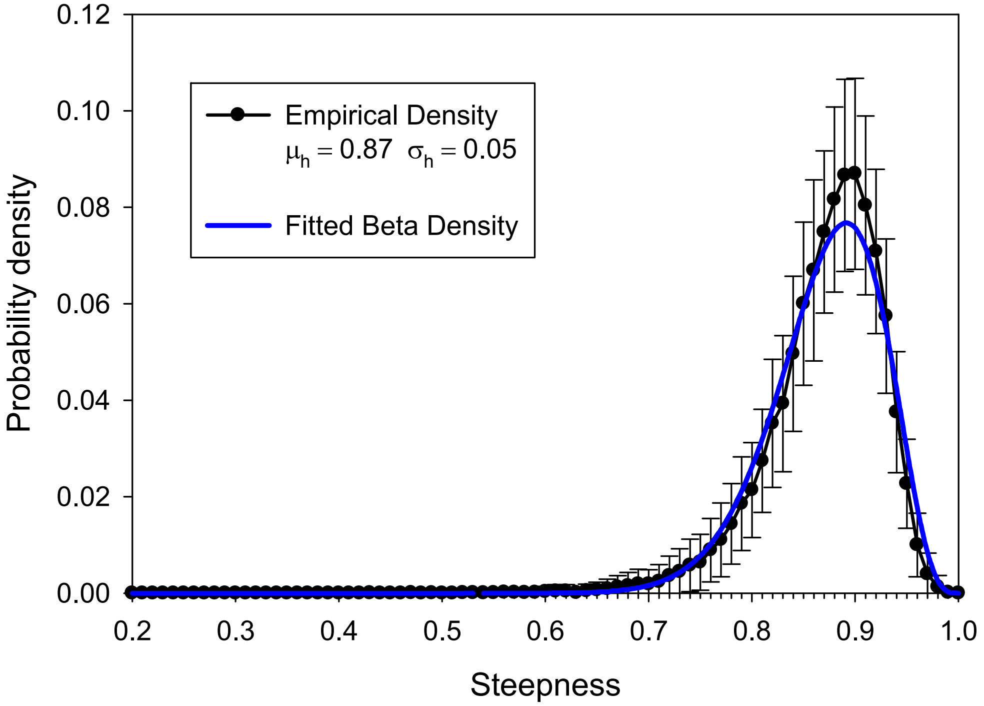

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Figure 1.2. Sensitivity Analysis for the Effect of Spawning Season Assumed to be May-June or May-August on the Prior Probability Density of Stock-Recruitment Steepness for Western and Central North Pacific Striped Marlin

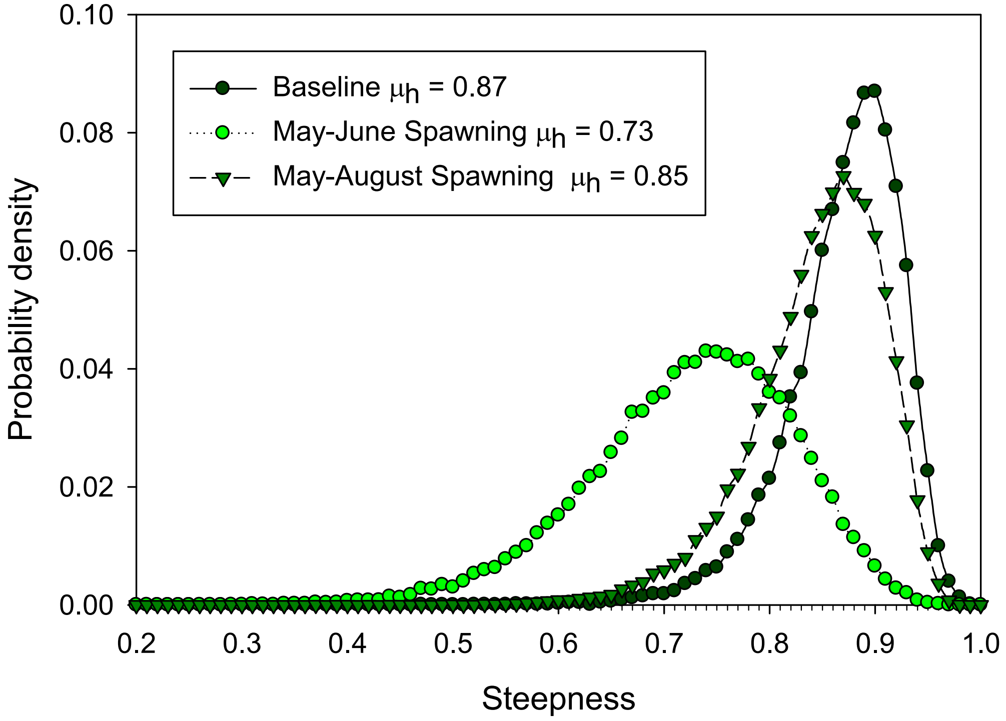

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Figure 1.3. Sensitivity Analysis for the Effect of Female Age at 50% Maturity on the Prior Probability Density of Stock-Recruitment Steepness for Western and Central North Pacific Striped Marlin

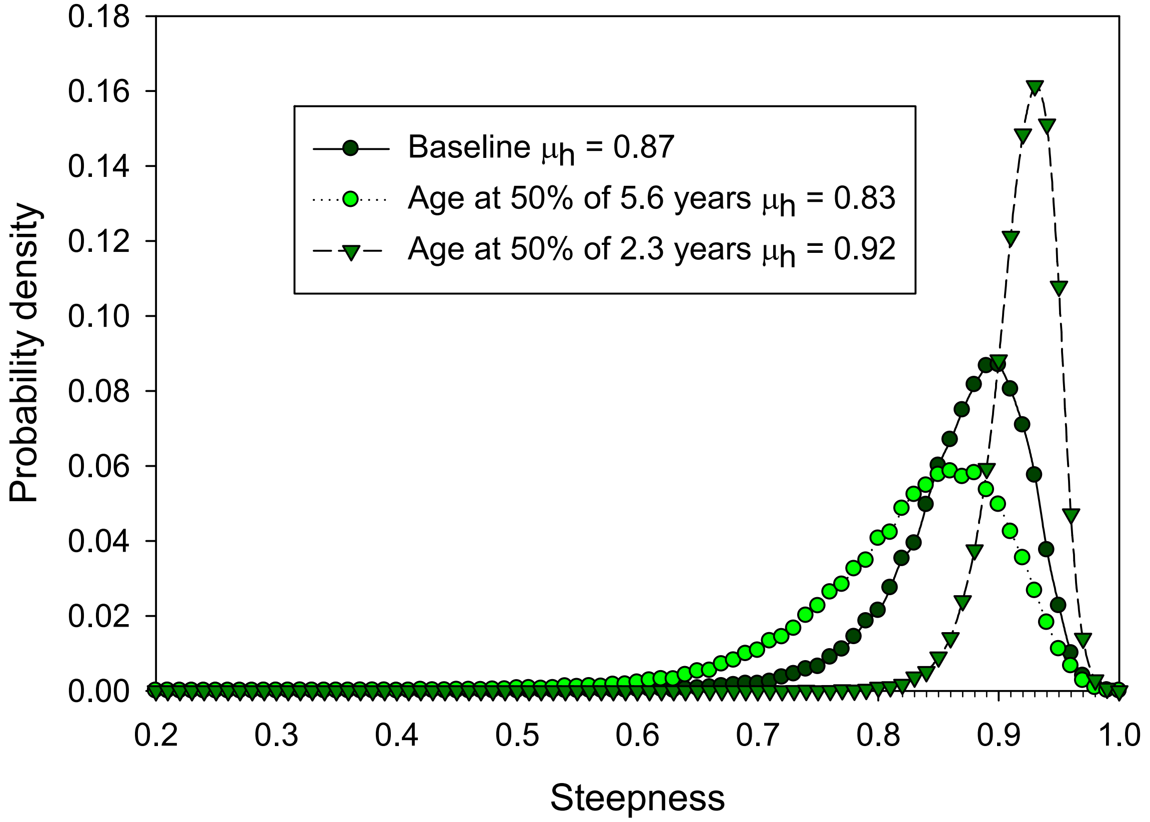

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Figure 1.4. Sensitivity Analysis for the Effect of von Bertalanffy Growth Curve T0 Parameter on the Prior Probability Density of Stock-Recruitment Steepness for Western and Central North Pacific Striped Marlin

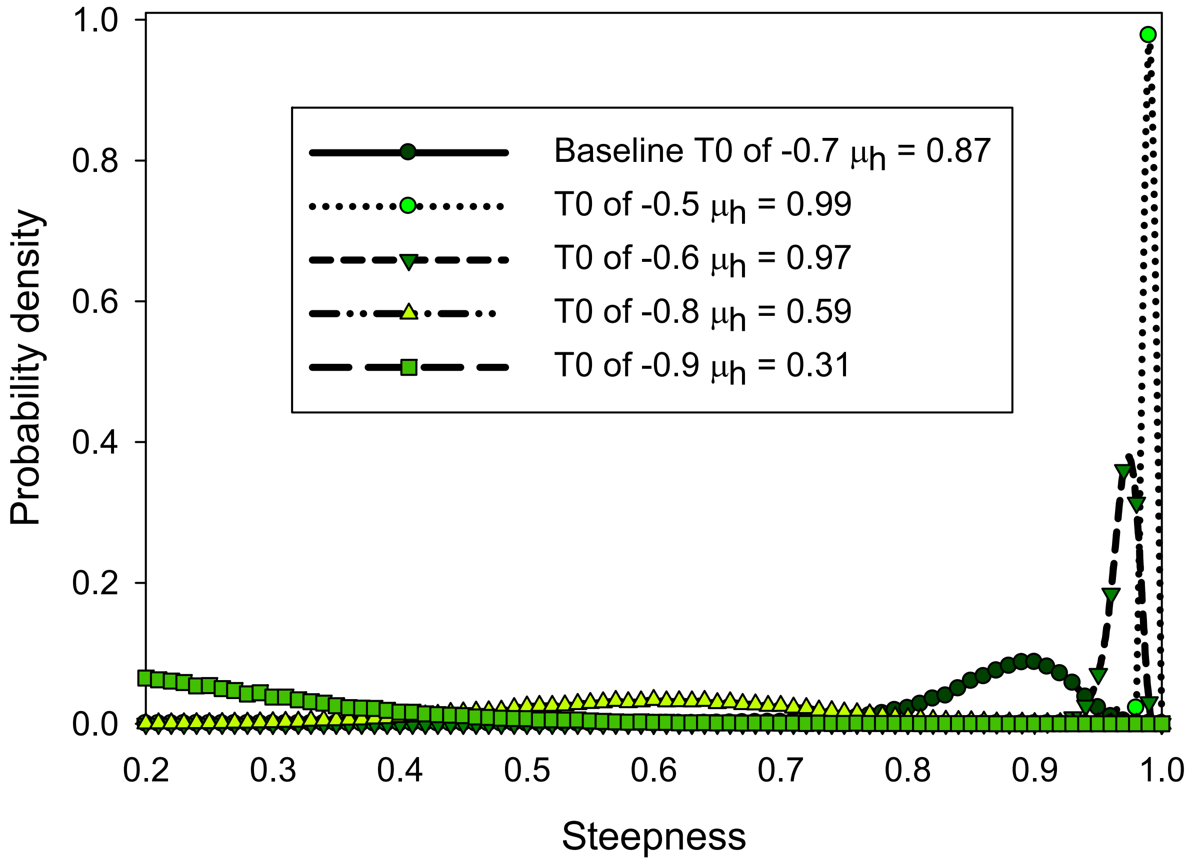

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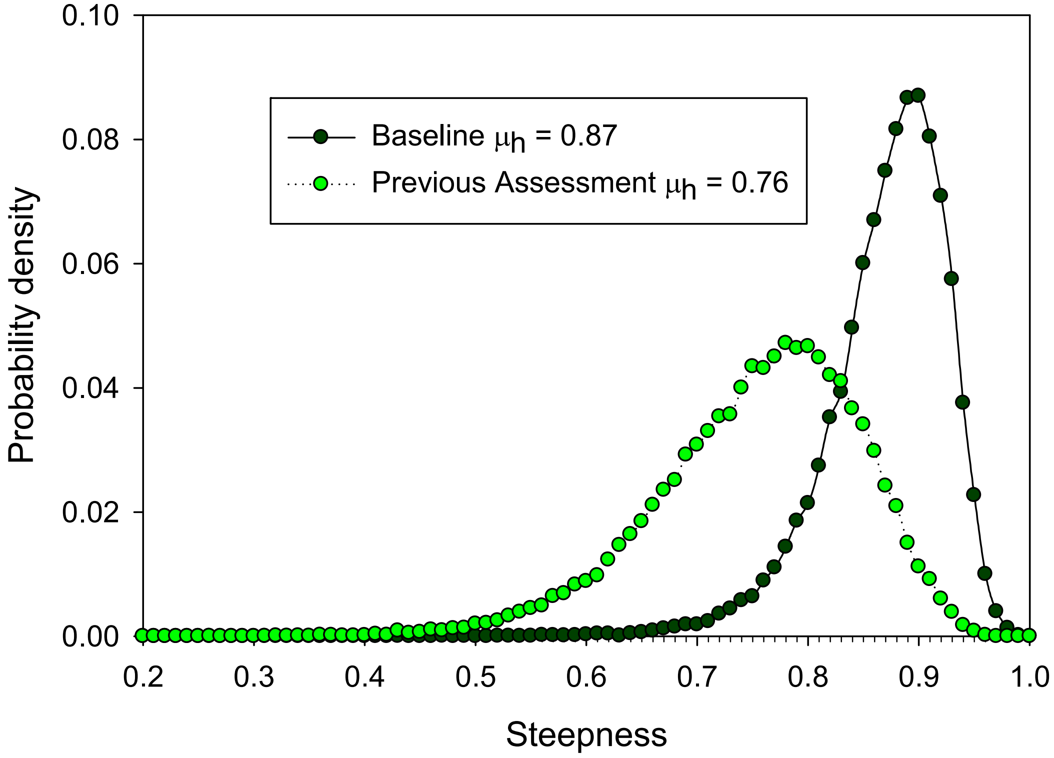
Figure 1.5. Sensitivity Analysis for the Effect of Using Life History Parameters from Previous Assessment on the Prior Probability Density of Stock-Recruitment Steepness for Western and Central North Pacific Striped Marlin



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