Probable Values of Stock-Recruitment Steepness for North Pacific Albacore Tuna

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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 North Pacific albacore (*Thunnus alalunga*). Information on albacore life history parameters from the proposed stock assessment model for North Pacific albacore was gathered. This included information on growth, maturity at age, average weight at length, natural mortality rate and reproductive ecology of albacore tuna (Table 1).

Materials and Methods

There were three growth scenarios considered for North Pacific albacore: these were the Suda growth curve, the Wells growth curve, and the model-based estimate of a growth curve for albacore (Table 1). The parameters of these alternative growth hypotheses were used to construct alternative estimates of prior distributions for albacore steepness.

There was limited information available on the reproductive ecology of albacore. We rescaled the estimated batch fecundity at length curve of North Pacific bluefin tuna (Chen et al. 2006) to approximate the batch fecundity at length of albacore tuna. In particular, the length of bluefin tuna at which batch fecundity was expected to be zero was L_0 = 160.7 cm (Mangel et al. 2010). This parameter describing the maximum expected length at zero fecundity was a fraction $c = L_0/Linf = 0.5014$ of the asymptotic length of bluefin tuna, where Linf = 320.5 cm. We assumed that the asymptotic length at zero fecundity for albacore tuna had the same scaling constant c with Linf as for bluefin tuna. As a result, we estimated $L_0 = c \cdot Linf$ under the three alternative growth curves for albacore (Table 1). Estimates of L_0 were: L_0 = 73.4 cm for Suda growth, L_0 = 60.2 cm for Wells growth, and L_0 = 61.2 cm for model-based growth.

There was also limited information on the average mass of developed albacore eggs, an input parameter that was needed for the steepness simulations. We approximated the average mass of albacore eggs by assuming that the expected egg diameter was approximately 1.0 mm as suggested by the size of advanced stage albacore eggs measured by Otsu and Uchida (1959, see Figure 12) off Hawaii 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).

A total of 500 simulations were run for each 500 populations comprised of 500 individual fish to estimate the empirical distribution of stock-recruitment steepness values of a Beverton-Holt stock-recruitment curve for North Pacific albacore tuna under the alternative growth curves. Under the Wells growth curve, we found that the reported value of $t0 \approx -2$ did not match the expected egg and larval duration in the steepness calculation algorithm and as a result, we set the value of this parameter to be t0 = -0.9, which was very similar to the values of t0 under the Suda and model-based growth curves.

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

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

The fitted parameters can be used to set up a prior distribution for stock-recruitment steepness using the beta density (see Figures 1.1-1.3).

Results

Results under the Suda growth curve indicated that the mean steepness was μ_h=0.84 with a standard deviation of σ=0.04 (Figure 1.1). Similar results were obtained under the Wells growth curve which had a mean steepness of μ_h=0.85 with σ=0.03 (Figure 1.2). The model-based growth curve had a higher mean steepness of μ_h=0.95 with σ=0.01 (Figure 1.3). Thus, the results suggested that the North Pacific albacore tuna stock had a resilient to highly resilient stock-recruitment relationship depending upon the choice of growth curve. The results also conformed to the expectation that faster somatic growth, as indicated by higher values of the von Bertalanffy k parameter, was associated with higher resilience in the stock-recruitment relationship. Overall, the results indicated that the mean steepness of North Pacific albacore was less than unity (i.e., μ_h=1). In this context, assuming that mean steepness was unity was a biologically implausible assumption because setting μ_h=1 implies that there is an infinite amount of compensation in the stock-recruitment relationship at the origin (Brodziak et al. 2002, Mangel et al. 2010).

A sensitivity analysis to the assumed value of age-0 natural mortality rate M(0)=0.30 was also conducted. In this analysis, we doubled the value of age-0 natural mortality to be M(0)=0.60 and reran the steepness simulation algorithms for each of the growth curves. As expected (Mangel et al. 2010, see equation 29), increasing the natural mortality rate schedule reduced the estimates of mean steepness under each of the growth curves (Figure 2). Results of the sensitivity analysis indicated that doubling the age-0 natural mortality rate would reduce the mean steepness estimates under the Suda, Wells, and model-based growth curves to: μ_h=0.79 (-6%), μ_h=0.81 (-5%), and μ_h=0.93 (-2%), respectively.

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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 albacore 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_albacore_tuna_base_case_suda_growth
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 albacore: 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)-at-age (units are years) function, i.e., $L\ a\ = L\mathrm{inf}\ 1-\exp\ -k\ a-a0$ Suda growth: Linf = 146.46 Wells growth: Linf = 120.00 Model-based growth: Linf = 121.99
8	k_vb	double	The k parameter for Von Bertalanffy length-at-age function Suda growth: k = 0.1492 Wells growth: k = 0.1840 Model-based growth: k = 0.2240
9	A0	double	The a_0 parameter for Von Bertalanffy length-at-age function Suda growth: a0 = -0.8986 Wells growth: a0 = -0.9 Model-based growth: a0 = -0.86
10	A_lw	double	The A parameter of the length (units are cm)-weight (units are kg) equation $W = A \cdot L^B$, A = 0.00022
11	B_lw	double	The B parameter of the length (units are cm)-weight (units are kg) equation $W = A \cdot L^B$, B = 2.48

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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 $a_{50.}$ For albacore a_{50} = 5.0
13	sig50	double	The σ_M parameter for logistic probability of maturity-at-age function. For albacore $\sigma_{M.}$ = 0.05
14	nu	double	<u>Not applicable for albacore analysis.</u> The ν parameter in the gamma density for natural mortality rate for production model (eqn 31 in Mangel et al. (2010)).
15	Mbar	double	<u>Not applicable for albacore analysis.</u> 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 albacore 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 albacore r = 0.5
18	Spawn_season	double	The fraction of the year when spawning occurs, e.g., if the spawning season lasts 6 weeks, then Spawn_season is 6/52. For albacore, Spawn_season = 12/52.
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 albacore, Spawn_interval = 3.33
20	B0_fl	double	The parameter $B0_{fl}$ in the fecundity (units are numbers of eggs) at length (units are cm) relationship $$F\left(L\right)=\left(B0_{fl}+B1_{fl}\cdot L\right)\cdot 10^5$$ Suda growth: B0= -237.89 Wells growth: B0 = -194.91 Model-based growth: B0 = -198.15

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Table 1. Continued.

21	B1_fl	double	The parameter $B1_{fl}$ in the fecundity (units are numbers of eggs) at length (units are cm) relationship $F \; L \; = \; B0_{fl} + B1_{fl} \cdot L \; \cdot 10^5$ For albacore, B1 = 3.2393
22	sig_mcgurk_el	double	Standard deviation of log-log regression for daily natural mortality rate. Estimated to be 0.9177698 in Mangel et al. (2010).
23	sig_mcgurk_j	double	Standard deviation of log-log regression for daily natural mortality rate. Estimated to be 0.963802 in Mangel et al. (2010).
24	lhstructure	integer	Indicator for life history structure where lhstructure=1 is the production model and lhstructure=2 is the age-structured model. For albacore, lhstructure = 2
25	W_el[1]	double	Initial wet egg mass (units are g). For albacore W = 0.000522
26	M_el[1]	double	<u>Not applicable for albacore analysis.</u> Initial accumulated daily instantaneous mortality.
27	Mbar_a	double [Amax]	Natural mortality rate at age vector for ages 0,1,…, Amax. For albacore, M(j) = 0.30 for all ages j $\leq$ Amax

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Figure 1.1 Estimate of Prior Probability Density of Stock-Recruitment Steepness for North Pacific Albacore Tuna Under the Suda Growth Curve

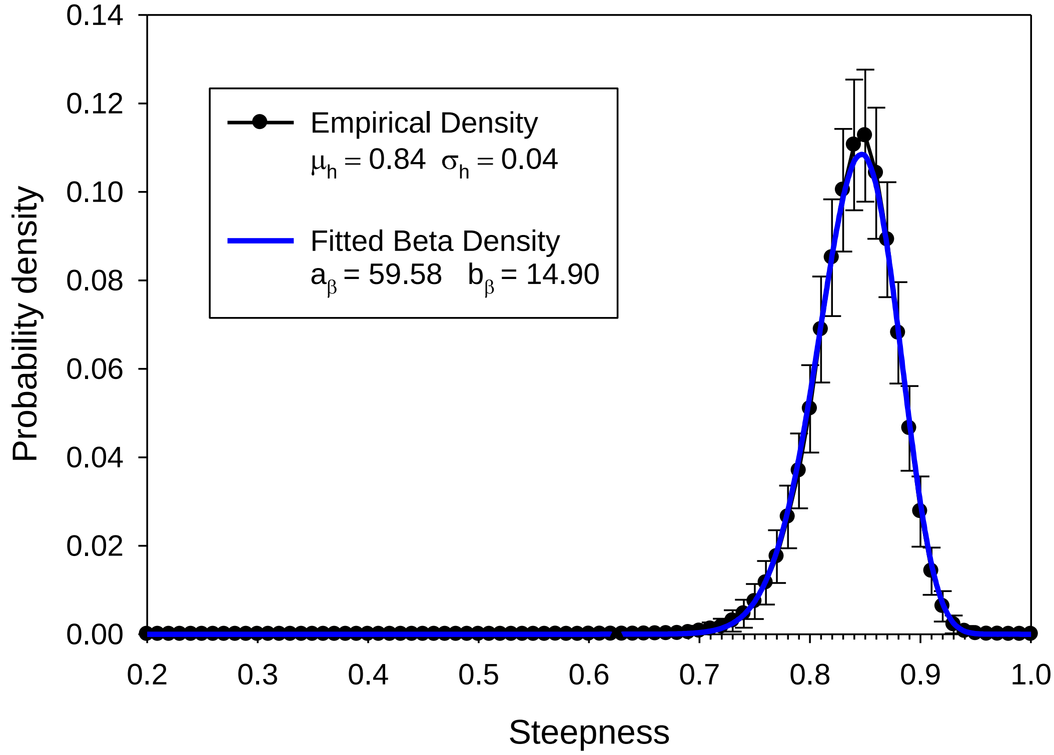

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Figure 1.2. Estimate of Prior Probability Density of Stock-Recruitment Steepness for North Pacific Albacore Tuna Under the Wells Growth Curve

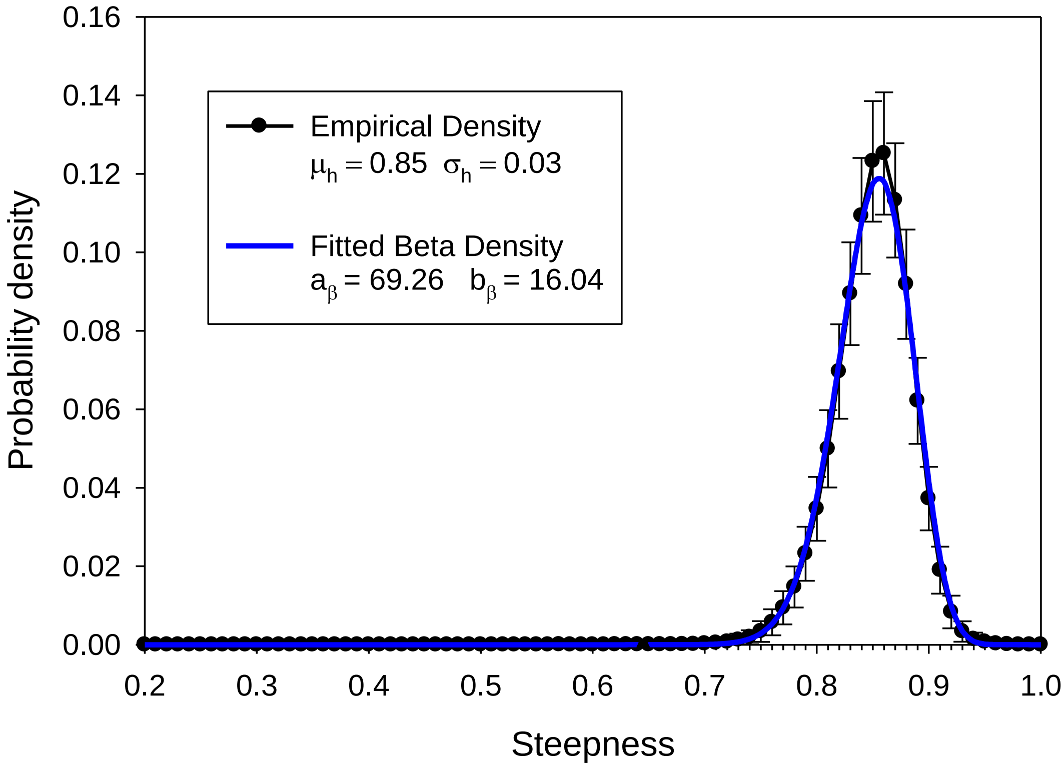

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Figure 1.3. Estimate of Prior Probability Density of Stock-Recruitment Steepness for North Pacific Albacore Tuna Under the Model-Based Growth Curve

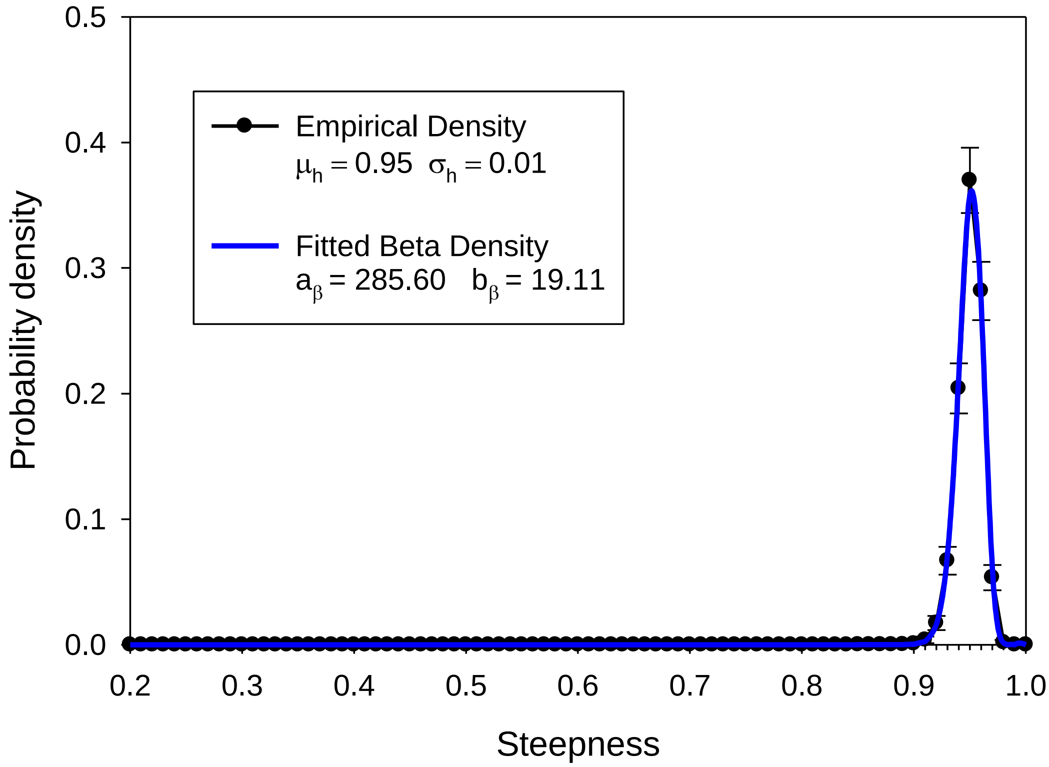

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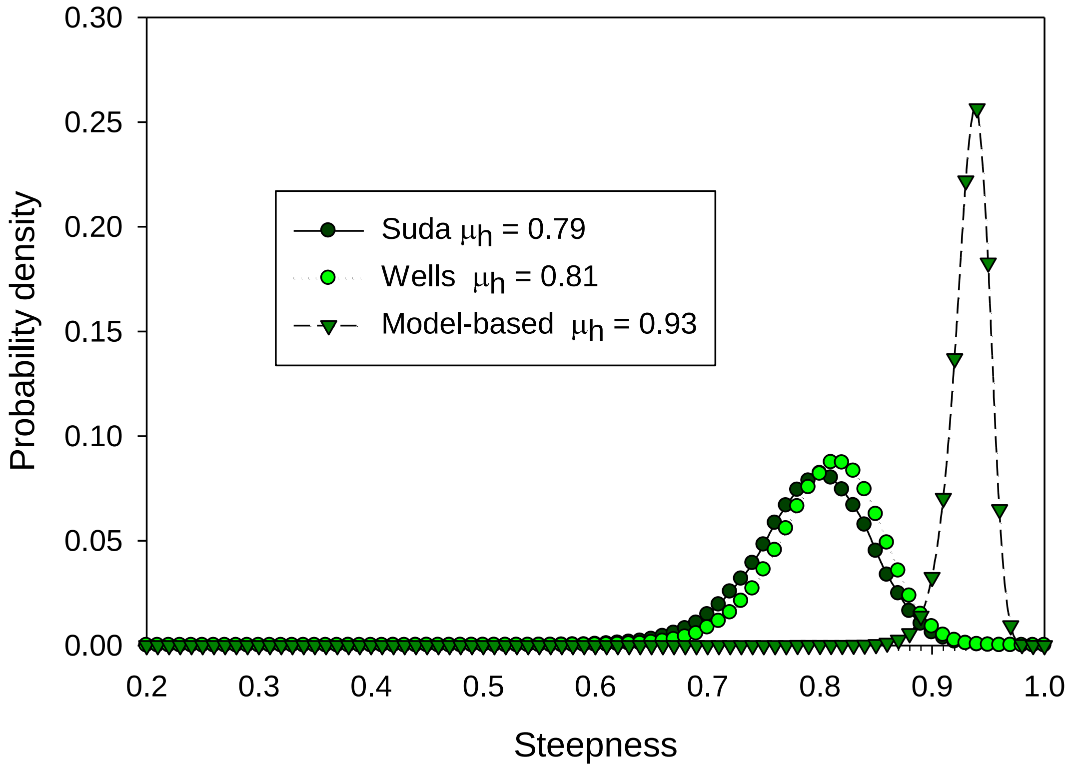
Figure 2. Sensitivity Analyses With the Age-0 Natural Mortality Rate Increased to M_0=0.6 of Prior Probability Density of Stock-Recruitment Steepness for North Pacific Albacore Tuna Under the Alternative Growth Curves



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