Preliminary application of a Bayesian surplus production model to striped marlin (*Tetrapturus audax*) in the North Pacific

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Abstract

A Bayesian surplus production model was applied to striped marlin (*Tetrapturus audax*) in the North Pacific and used to estimate current and future values of stock assessment reference points. This model's main strengths lie in the simplicity of its data requirements (catch data and at least one annual catch rate series) and its ability to incorporate existing information in the form of prior probability distributions for estimated parameters. This function facilitates fitting to times series that are less informative or have incomplete catch histories. The model incorporated a catch series in number (1952-2003), and was successfully fitted to an abundance index based on GLM standardized catch per unit effort (CPUE) in number provided in a database prepared by the Marlin Working Group of the International Scientific Committee (ISC). Alternative scenarios, including one based on catch in biomass, were tested to determine the sensitivity of the results to various assumptions. Results based on the available data suggest that the current stock is between 30-40% the stock at maximum sustainable yield (MSY stock) and the fishing mortality rate, estimated at 0.13 yr^{-1}, slightly exceeds F_{MSY}.

Introduction

Biomass dynamic models describe a fish stock's behavior over time as a function of its biomass, production and mortality. Although such models are highly simplified representations of complex population dynamics, they are commonly relied upon because of their minimal data requirements, and ease of use and interpretation (Hilborn and Walters, 1992). A Bayesian implementation of the classic Schaefer surplus production model (McAllister and Babcock, 2002) combines the simplicity of the biomass dynamic approach with the ability to specify prior probability distributions for all estimated parameters. The usual model outputs and reference points, namely the intrinsic rate of increase (r), carrying capacity (K), current biomass relative to carrying capacity (B_{cur}/K) and maximum sustainable yield (MSY), are produced as posterior probability distributions allowing a formal, quantitative interpretation of uncertainty. Applying the techniques of decision analysis, the model can also be used to project stock conditions into the future given various management strategies (McAllister *et al*. 2001).

The ISC Marlin Working Group held two meetings in 2005 designed to work toward a stock assessment for striped marlin in the North Pacific. These meetings resulted in agreements on data and various model parameters which are detailed in individual reports (Humphreys and DiNardo 2005; DiNardo 2006) and papers submitted to these meetings. This paper describes the application of the Bayesian Surplus Production (BSP) model in the ICCAT assessment software catalog (ICCAT, 2003) to the North Pacific striped marlin stock. This model has been previously applied in the North Pacific to blue shark (Clarke and McAllister 2005) and in the Atlantic to swordfish (McAllister *et al*. 2000), large coastal sharks (McAllister *et al*. 2001; Cortés and Babcock 2006), pelagic blue and mako sharks (ICCAT, 2005), and white marlin (Babcock and McAllister, 2003).

A number of studies relating to abundance indices and stock assessment of striped marlin have been conducted since 1966 and are concisely summarized in Hinton and Maunder (2004). Hinton and Bayliff (2002) which focused on the status of the stock, or stocks, in the Eastern Pacific Ocean (EPO), estimated that stock levels of striped marlin in the EPO were at or near the level expected to provide landings at the MSY level of 4,300 to 4,700 mt (B/B_{MSY} ratio = 1.01). An update to this study (Hinton and Maunder, 2004) concluded that the current production of striped marlin was substantially higher than the catch at that time, and that the EPO stocks are in good condition, with current and near-term anticipated fishing effort less than F_{MSY}. The current study aims to estimate similar stock assessment reference points for the same species in the North Pacific.

Materials and Methods

Description of the Model

The Bayesian surplus production (BSP) application software (ICCAT, 2003) is based on the Schaefer model with either a discrete catch removal or continuous fishing mortality parameterization. For example, the discrete version is parameterized as:

$$B_{t+1} = rB_t - \frac{r}{K}B_t^2 - C_t \tag{1}$$

where B is the biomass at each time step t, r is the intrinsic rate of increase, K is the carrying capacity and C is the catch at time t. The required inputs are a continuous catch series and at least one catch rate series with coefficients of variation, if available. The model allows specification of priors for K, r, the biomass in the first modeled time step as a ratio of K ($B_{t=1}/K$), and the average catch (C_0) for missing catch data (if any) at the beginning of the time series. The constant of proportionality between each abundance index and the biomass trend (i.e. catchability, or q) was treated as having a non-informative prior and calculated using the numerical shortcut of Walters and Ludwig (1994). Under this method, in each draw from the importance function of the model-estimated parameters (e.g. r and K) the maximum likelihood estimate for q is computed and this in turn is used to compute the likelihood of the data given r, K and the other parameters. This is equivalent to specifying an uninformative prior for q and drawing samples of q from the importance function.

Although based on the principles of biomass dynamics, this model can also operate using fish number instead of weight as the unit of interest. The model time step is fixed as years. There is no explicit spatial component, but if the existence of separate stocks is suspected, the model may be run with separate catch and CPUE series within delineated boundaries.

It is preferable to run the uncompiled version of the source code as it provides greater flexibility in modifying the model and tracing the source of parameter specification and other errors. However, the uncompiled code must be loaded within the Visual Basic 5.0 or 6.0 platforms and will not run within more recent versions of Visual Basic. For most scenarios, the number of iterations was set to one million which on a Pentium(R) 4, 3.20 GHz CPU required approximately 10 minutes to compute.

Catch and Catch per Unit Effort (CPUE) Data

Of the abundance indices presented at the striped marlin stock assessment workshop, the CPUE series obtained by standardizing logbook catch and effort data from the Japanese offshore and distant water longline fleet from 1952-2004 was agreed to provide the best spatial and temporal coverage of the study area. The standardization utilized a generalized linear model (GLM) with a log normal distribution and factors for year, quarter, area and gear. Five areas were delineated and seven depth intervals were applied as factors for the gear effect (Yokawa and Clarke 2005). The other available standardized abundance indices would not provide the necessary coverage for a model of the entire North Pacific (e.g. the Japanese coastal longline and Hawaii longline indices) or were presented but not selected for use in the model (e.g. habitat model indices of Japanese offshore and distant water longline fleet) (DiNardo 2006).

The database produced by the striped marlin working group contains quarterly CPUE values, which for the purposes of the BSP model, needed to be converted to annual values. This was accomplished by weighting each quarterly value in each of the five areas by its proportional effort in each quarter for that area to produce annual values by area. Annual values for each area were then weighted by the areal extent of each area as a proportion of the North Pacific area of interest to produce a single annual value. CPUE values for Area 5 were lacking for 1952-1961 as fishing activities by the Japanese longline fleet did not extend into the Eastern Pacific Ocean until after that time. In order to avoid biasing the abundance index and the model, data from 1962 onward only were used. Although it was not provided in the official database, the year coefficients from the same GLM which produced the quarterly values were made available and used in this modeling for comparative purposes. Both the annual and quarterly-composited CPUE values provided by the GLM were further standardized by dividing by the mean of each 1962-2003 series to produce the abundance index used in the model (Figure. 1).

The catch data contained in the striped marlin database are described in detail in DiNardo (2006). Since some key data series lacked data for 2004 (e.g. Hawaii longline, Japan coastal fisheries) 2003 was selected as the final year for the model. Total catches in number of striped marlin are shown in Figure 2. The upper panel in this figure represents the catches as documented in the workshop database; the lower panel shows the data after correction based on a revised submission of catch data from Japan (K. Yokawa, pers. comm.). Although the differences are not large, both series were applied in separate model runs for comparative purposes. Annual catch in weight was also calculated using either submitted catch weight data from the database, or where missing, applying the most appropriate available average weight values (Table 1).

Model Initialization

Parameter specification for the base case of the model is described in Table 2. Based on data availability, the initial year in the model is 1952 and the current year is assumed to be 2003. As described above, the CPUE index begins in 1962; prior years were input and indicated as missing. Units of 1,000 fish were used for K (carrying capacity) and $B_{t=1}/K$ (biomass in the first year of the model as a proportion of K). A non-informative prior was specified for K using a uniform distribution on log(K) which allowed the value to range between the specified minimum and maximum values while weakly favoring smaller values. The population was assumed to be slightly below carrying capacity at the beginning of the model ($B_{t=1}/K$=0.8) since the fishery had been in existence for some time. This parameter ($B_{t=1}/K$) was assigned a normal distribution with a standard deviation of 0.2 which allowed it to range between 41 and 120% over the 95% prior probability of K. The prior for the intrinsic rate of increase (r) was assigned a log normal distribution with reference to a previous analysis (Clarke 2005) indicating that the mean of r for striped marlin is 0.32 with a standard deviation equal to 0.2 (corresponding to a 95% probability interval of 0.215-0.474).

The method of estimating σ (the standard deviation in the natural logarithm of the difference between observed and model predicted values) for each time step in the series (i.e. the weighting method) was equal weighting of each data point using a default coefficient of variation (CV). This was implemented through specification of weighting method #6 (McAllister and Babcock, 2002). Based on a simple spreadsheet implementing standard surplus production calculations (Hilborn and Walters 1992) the overall value of σ was estimated at 0.32. In order facilitate model fitting within the BSP the input variances (CVs) were set at 0.35 for each year except for the first 7 years of the time series which were set at the higher value of 0.45 based on observed lack of fit in spreadsheet for the early years of the time series. The marginal posterior distributions for model parameters were calculated using the sampling-importance resampling algorithm (SIR), with the importance function defined as a multivariate t distribution (McAllister *et al*., 2001).

Sensitivity analyses were conducted to examine the impact of the priors on the results and selection of the weighting method. These tests included:

- Specifying the prior for K as uniform on K rather than uniform on log(K);
- Specifying a less informative prior for r;
- Assuming the starting biomass ($B_{t=1}/K$) is well below K and slightly above K;

- Specifying an alternative method for weighting the CPUE data points using the maximum likelihood estimate (MLE) of σ for each series (i.e. weighting method #2) (McAllister and Babcock, 2002).

Available diagnostic statistics for model runs were checked to determine whether there were significant posterior correlations. Values in the Hessian matrix were very small, or negative in some initial runs, indicating that the model had difficulty locating the mode due to it being either very sharp or very poorly defined. In such cases, to allow importance sampling to run, values in the Hessian matrix were adjusted to positive (e.g. 0.4) or merely larger (1.0E-2) values, and the model proceeded using the estimated mode as its starting point. In the importance sampling step the following diagnostics were verified: a low number of discarded simulations (i.e. simulations were discarded on the basis of any of the parameters' values exceeding the specified minimum or maximum); a low percentage value for the weight of the maximally weighted draw (i.e. a measure of the relative influence of the draw with the highest weight); and the CV of the weights of the importance draws less than the CV of the likelihood times the priors for the same draws (McAllister *et al*., 2004)

The decision analysis component of the model was used to project population parameters into the future based on a number of policy scenarios. Since there are currently no quotas or other management measures implemented for striped marlin in the North Pacific, policies based on fishing mortality (F) were selected. Six F levels (0.05 to 0.30) were modeled over a 15-year time horizon.

Results

Simple spreadsheet surplus production models were executed for the base scenario to derive reasonable starting values for the Bayesian parameter estimation. The spreadsheet-based estimate of K was approximately 3,500 (or 3.5 M fish), and the model was able to find an optimal solution with using the informative prior on r set at 0.32. The variance between the observed and estimated biomass (σ) suggests some problems with the estimation ($\sigma = 0.318$) and autocorrelation was present in the residuals of the deviates through 8 lags.

Based on these preliminary results, base and sensitivity trials of the BSP model were conducted. With the exception of two sensitivity runs (Table 3, runs 4 and 5), the evaluation of diagnostics for each run indicated convergence and reliable estimation, i.e. maximum fractional weight of any one draw was less than 0.002, and the CV of the weights (52) was reasonably close to the CV of the prior times the likelihood (20). No high correlation between K and r was observed in the Hessian matrices. The fit of the base case estimates of the parameters to the data by the BSP model is shown in Figure 3. The deviates of the BSP model fit showed statistically significant autocorrelation through three lags only.

The numeric results for the base scenario are presented in Table 3 and Figure 3. Estimates of K are approximately 4.1 million fish and MSY catch is ≈270,000 fish. The current biomass is estimated as being approximately 36% of *K* and the value of *r* is 0.27, slightly lower than anticipated by the informative prior.

Results for variations on the base scenario involving alternative catch and abundance indices show little difference (Table 3, runs 2 and 3). When the prior on *K* was not log transformed the model failed to converge (Table 3, run 4). Application of a less informative prior on *r* indicated that if not constrained the model tended toward a lower *r* value than indicated by the informative prior and the base scenario (Table 3, run 5). Initially under this scenario, the variance on *r* was increased to 0.64, allowing *r* to vary between 0.063 and 1.506, but the model failed to converge. The model ran successfully with the variance specified at 0.16, (95% probability interval for *r* of 0.145-0.723) and resulting posterior mean of *r* was 0.19. The model appeared relatively insensitive to assumptions regarding the starting biomass as a proportion of *K* and use of an alternative weighting method (Table 3, runs 6 -8).

To facilitate comparison with results from the ASPIC model (Yokawa and Clarke, 2006) a model run was performed using catch in biomass. Since the abundance index was only available based on catch in number, this scenario incorporates a potential mismatch in data types which could bias the results if the number to weight relationship is not constant over time. This assumption would need to be formally explored for the North Pacific striped marlin stock before the results of such a run could be considered credible. Under these caveats, in units of biomass, the model indicated *K* is approximately 180,000 mt, the MSY catch is approximately 105,000 mt, *r* is 0.24 and the current biomass is roughly 30% of *K*. The latter two values are roughly similar to, but slightly lower than, the base scenario results using catch in number.

Other model parameters estimated from the base scenario in numbers (but not graphically presented) indicate that the current catch is 70% of the MSY catch level (CV=0.032), the current biomass is 43% of the biomass at the beginning of the time series (1952; CV=0.238), and the current fishing mortality is 103% of the fishing mortality at MSY (CV=0.165). Since under the Schaefer model the harvest rate at MSY closely approximates the fishing mortality at MSY and can be calculated as *r*/2 (Hilborn and Walters, 1992), the harvest rate at MSY is approximately 0.269/2=0.134.

Results from the biomass base case can be contrasted with the results of Hinton and Maunder (2004) for the EPO. Whereas the previous study estimated biomass at MSY as 4,300 to 4,700 mt, the current study's MSY estimate for the entire North Pacific is only 930 mt (CV=0.124). Furthermore, the EPO study found that current biomass was near the MSY biomass (1.01), but in the present study the ratio of current biomass to MSY biomass is estimated at 0.66. Finally, the EPO study concluded that production is much higher than current catch, and near-term anticipated fishing effort is less than $F_{MSY.}$ The present study somewhat agreed in estimating that current catch is 63% of MSY catch, but also indicated that the current fishing mortality is nearly equal to the fishing mortality at MSY. Differences between these two studies would most obviously derive from the fact that the EPO is known to be highly productive for striped marlin. Other factors, such as use of alternative methodologies, differing data sources and varying time scales, may also contribute.

In addition to these key parameters, a variety of stock assessment reference points were produced by decision analysis for various levels of fishing mortality (Table 4; Figure 5). These results indicate the North Pacific striped marlin population will not attain *MSY* levels (i.e. $B_{fin}/B_{MSY}<1.0$) unless fishing mortality (F) is reduced to levels close to 0.1. If fishing mortality remains near current levels, approximated by the modeled scenario of F=0.15, the population will remain at levels near 40% of carrying capacity biomass and 75-85% of MSY biomass over a 15-year horizon. However, reduction of fishing mortality to F=0.10 will allow the stock to recover to above its MSY biomass and to more than half of its carrying capacity within 10 years.

Discussion

The findings of this assessment, while based on preliminary data and a limited range of sensitivity tests, suggest that the striped marlin population in the North Pacific is being fished at harvest rates above MSY levels and that the current population levels are less than half of those in the early 1950s. As for all stock assessments, there are a number of data and model shortcomings which should be highlighted as directions for future research. For these species, as for many in the North Pacific, a long time series of catch rates is lacking for most fleets, therefore a heavy reliance is placed on data from the Japanese offshore longline fleet. Any biases in these data, arising either from compilation, raising or standardization will strongly affect the assessment results. Inaccuracies in historical catches for most fleets are also inevitable given the past lack of attention to recording non-target species.

The BSP model proved adequate in this application to fit parameters for at least one of the available time series, and the unit-free parameter estimates (e.g. B_{cur}/B_{MSY}, F_{MSY}) were similar to those estimated by the ASPIC model (Yokawa and Clarke 2006) and slightly more pessimistic than previous assessments in the EPO. The estimated intrinsic rate of increase (r=0.27) was slightly lower than anticipated based on demographic methods (0.32; see Clarke 2005). Further work to refine the catch and catch rate indices is anticipated and recommended. In particular, the model appeared to be quite sensitive to changes in the catch rate index at the end of the time series, and alternate methods of standardization, e.g. use of different forms of a habitat model (Bigelow et al. 2004) may elucidate other trends and provide for interesting, comparative scenarios.

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Table 1. Average weight data applied to catch in numbers data in the striped marlin database to produce annual estimates of catch biomass. Note that data for Taiwan's and Korea's distant water longline fleets' catches were provided in weight.

Fishery providing catch in numbers of fish only	**Fishery from which average weight per fish was calculated**	**Methods**
Area 5 Recreational, Mexico fleet	Area 5 Recreational, California fleet	Annual mean weights from California applied to Mexican catch in number, 1990-2003
Hawaii longline fleet (Areas 3 and 4)	Hawaii longline and Japan offshore & distant water longline fleet (Jdwll) (Areas 3 and 4)	For each area, recorded length frequencies were converted to individual fish weights using conversion factors agreed in the database (i.e. $W=a \bullet L^b$ where a=0.0000972, b=2.5682). Each bin in each year was multiplied by the proportion of fish observed in that bin and all products were summed to produce an annual average weight. Such annual average weights were calculated for the Hawaii longline fleet for 1994-2003 (2003 average applied to 2004). Since no data were available for1990-1993, annual average weights, calculated in a similar manner for the Jdwll fleets in Areas 3 and 4, were applied for 1990-1993.
Japan offshore & distant water longline fleet (all 5 areas)	Jdwll fleet (all 5 areas)	The methodology described above for Hawaii was applied to data from the Jdwll fleet for each of the five areas in each year. Length frequencies were not available prior to 1970, thus for 1952-1969 an average weight from 1970-1974 was applied. Length frequencies were also not available for 2003 and 2004, thus the 2002 average weight was applied.
Area 5 Costa Rica fleet	Area 5 Korea longline fleet	Catch data for the Korea longline fleet in Area 5 were used to produce annual average weights by dividing catch biomass by catch number. Area 5 Korea fleet annual average weights were applied to Area 5 Costa Rica fleet catches in numbers for 1991-2002. Since Korea data for 2003-2004 were not available, the 2002 annual average weight from Korea was applied to the Costa Rica catch numbers for 2003-2004.
Japan coastal longline fleet (Areas 1 and 2).	Jdwll fleet (Areas 1 and 2)	The area-specific annual average weights for the Jdwll fleet for Areas 1 and 2 were applied to the Japan coastal longline fleet catch data in number for 1970-2002. Since data were not available for 1969, 1970 average weight was applied. Since data for 2003-2004 were also not available, 2002 average weight was applied.
Japan drift net fishery (Areas 1 and 3),	Jdwll fleet (Areas 1 and 3)	The area-specific annual average weights for the Jdwll fleet for Areas 1 and 3 were applied to the Japan large and small mesh drift net fleet catch data in number for 1964-2002. Since data were not available for 1964-1969, the average of annual weights from 1970-1974 was applied.
Other fisheries in Area 1 (Japan, Taiwan and Costa Rica)	Jdwll fleet (Area 1)	The annual average weights for the Jdwll fleet for Area 1 were applied to catch data in number from other Area 1 fisheries for 1970-2002. Since data were not available for 1952-1969, the average of annual weights from 1970-1974 was applied. Since data for 2003-2004 were also not available, the 2002 average was applied.
Other fisheries in Area 2 (Taiwan)	Jdwll fleet (Area 2)	The area-specific annual average weights for the Jdwll fleet for Area 2 were applied to catch data in number from other Area 2 fisheries for 1970-2002. Since data were not available for 1952-1969, the average of annual weights from 1970-1974 was applied. Since data for 2003-2004 were also not available, 2002 average weight was applied.

Table 2. Parameter specification for the base case (catch in number) of the BSP model.

Parameter	**Distribution**	**Mean**	**Standard Deviation**	**Range (Input Minimum and Maximum)**
K	Uniform	-	-	1,000 to 10,000
$B_{t=1}/K$	Normal	0.8	0.2 (gives a 95% P.I. of 0.41 to 1.2)	0.2 to 3.5
r	Log normal	0.322	0.2 (input to model as variance = 0.04; gives a 95% P.I. of 0.22 to 0.47)	0.001 to 2
Catch series: 1952-2003; annual sum of data in numbers for North Pacific from workshop database				
Abundance Index: 1962-2003; based on quarterly and area weighted GLM-standardized CPUE values in the workshop database				

Table 3. BSP model results for various scenarios. The results are presented as the expected value from posterior probability distributions for each parameter. Figures in parentheses, where shown, represent standard deviations.

	Scenario	K	r	*MSY*	B_{cur}/K	*σ (MLE)*	*q*
Number-based scenarios (units: ‘000 fish)							
1	Base	4,111 (592)	0.27 (0.04)	269 (8.44)	0.36 (5.49)	0.262	6.09E-04
2	Base with abundance index based on year coefficients direct from GLM	4,269(564)	0.26 (0.04)	270 (7.69)	0.45 (6.17)	0.222	5.74E-04
3	Base with corrected catch data	4086 (561)	0.25 (0.04)	250 (9.21)	0.32 (4.97)	0.264	6.58E-04
4	K prior not log normal	Did not converge					
5	Less informative r (relatively poor convergence diagnostics)	5,638 (1168)	0.19 (4.89)	250 (14.37)	0.35 (5.62)	0.260	4.84E-04
6	Starting biomass well below K	4,144 (545)	0.27 (4.24)	273 (8.17)	0.34 (0.05)	0.261	6.36E-04
7	Starting biomass slightly above K	4,314 (569)	0.25 (4.21)	263 (9.38)	0.36 (5.60)	0.263	5.98E-04
8	Alternative weighting method (MLE estimate of variance)	4,200 (556)	0.26 (4.19)	268 (8.47)	0.35 (5.88)	0.262	6.11E-04
Biomass-based scenarios (units: ’00 mt)							
9	Base	1,860 (230)	0.24 (3.79)	110 (4.09)	0.33 (5.21)	0.262	1.49E-03
10	Base with corrected data)	1,753 (222)	0.24 (4.00)	104 (4.37)	0.29 (4.65)	0.395	2.04E-04

Table 4. Expected values of biomass as a proportion of carrying capacity (B_{fin}/K) and biomass as a proportion of MSY (B_{fin}/B_{msy}) as estimated by decision analysis for the base scenario over a 15-year time frame.

Horizon	**Policy**	**E(B_{fin}/K)**	**E(B_{fin}/B_{msy})**
5-year	F=0.05	.538	1.076
	F=0.10	.453	.905
	F=0.15	.376	.752
	F=0.20	.308	.616
	F=0.25	.249	.497
	F=0.30	.197	.394
10-year	F=0.05	.679	1.358
	F=0.10	.524	1.047
	F=0.15	.389	.779
	F=0.20	.278	.556
	F=0.25	.190	.379
	F=0.30	.123	.247
15-year	F=0.05	.748	1.496
	F=0.10	.561	1.122
	F=0.15	.396	.791
	F=0.20	.259	.518
	F=0.25	.156	.313
	F=0.30	.086	.172

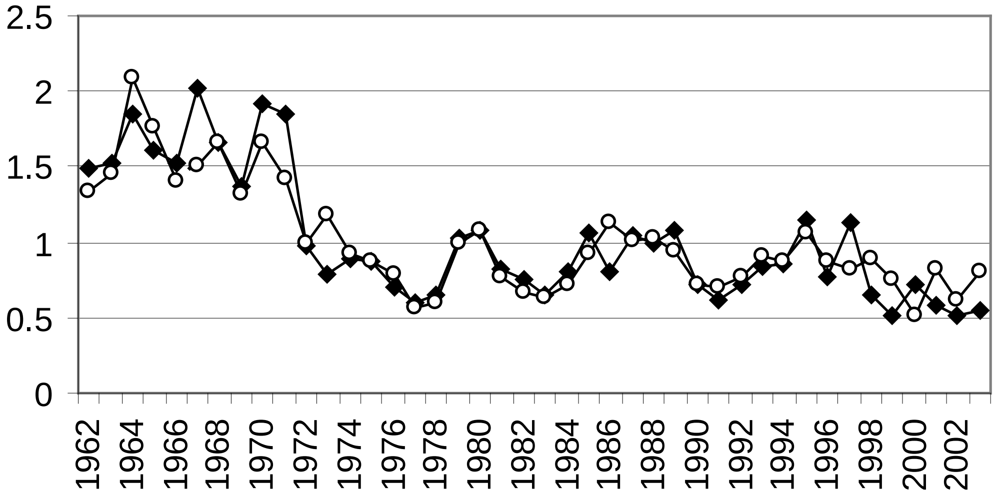

Figure 1. CPUE of striped marlin caught by the Japanese longline fleet 1962-2003 standardized using a generalized linear model. Annual values calculated from quarterly values in the ISC striped marlin database using effort and area weighting represent the base scenario (-♦-). Annual values drawn directly from year coefficients in the standardized model (-○-) are shown for reference. Actual CPUE values from each source were divided by the mean of the respective series to produce an index, i.e. centered on 1.

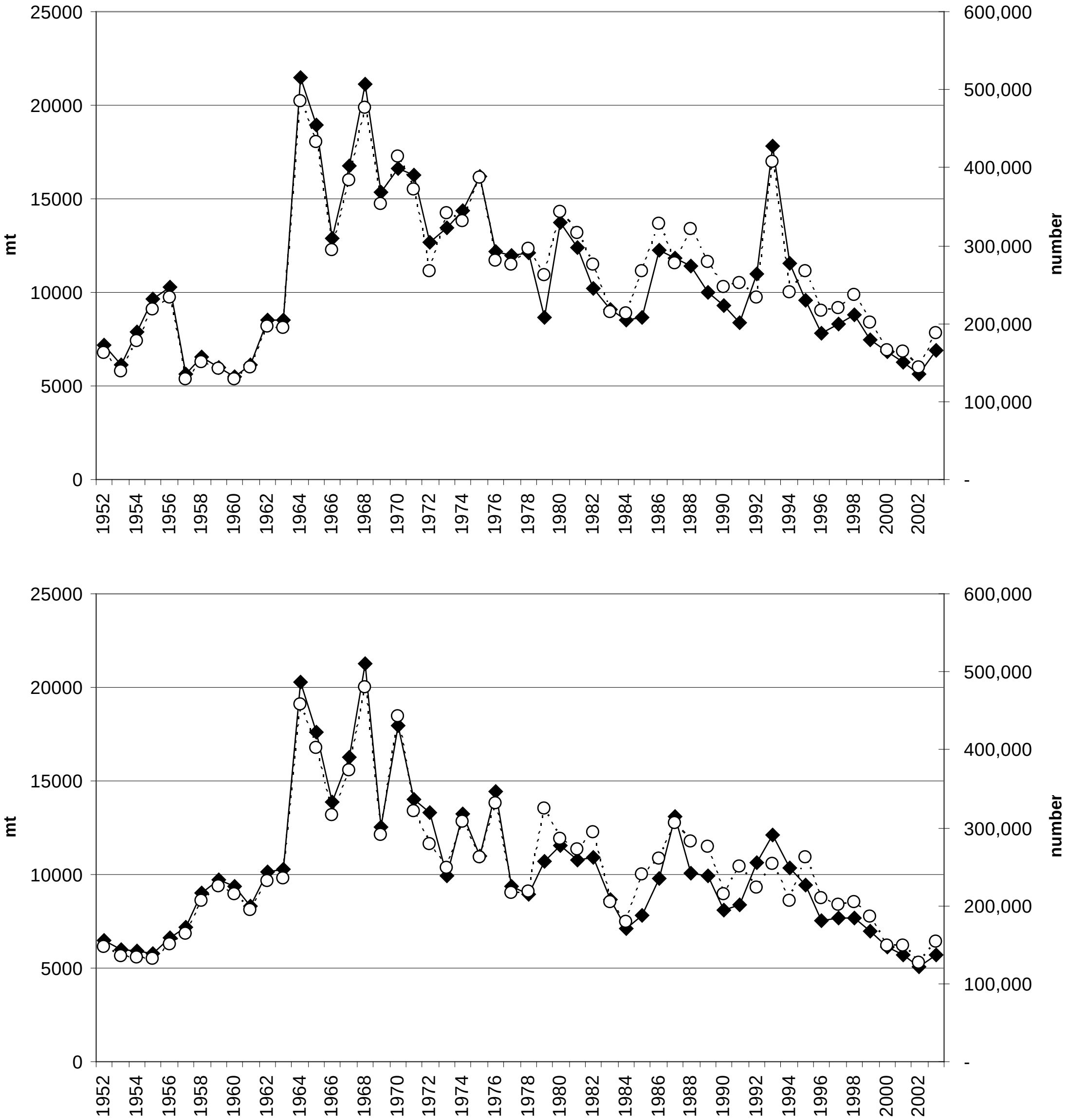

Figure 2. Estimate of total catches of striped marlin in the North Pacific by all fleets, 1952-2003. Catches in number (-○-) were obtained directly from the striped marlin database. Catches in weight (-♦-) were calculated using catch in number values (see Table 1). The upper panel shows the catch data as given in the database. The lower panel shows the catch data as corrected by a revised submission from Japan (K. Yokawa, pers. comm.).

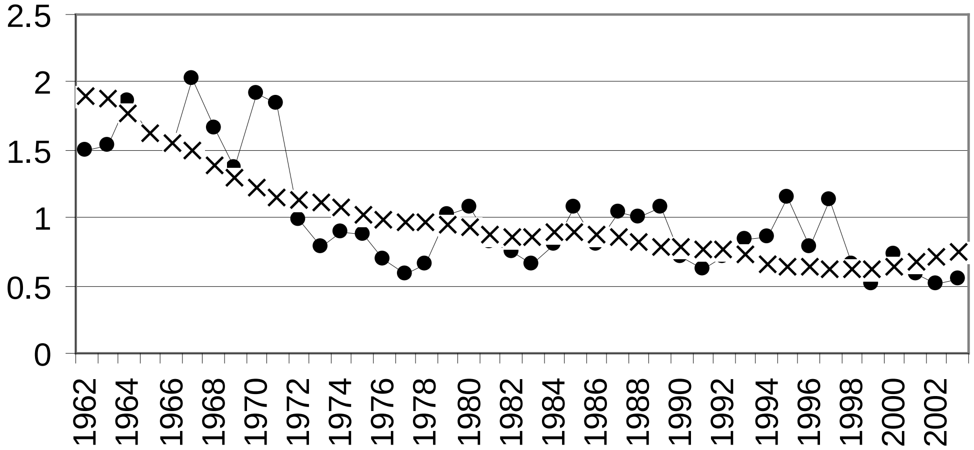

Figure 3. Fit of the BSP model predicted (×) CPUE to the observed (•)CPUE index for striped marlin based on a generalized linear model. The observed CPUE values have been standardized by dividing each value by the mean of the series.

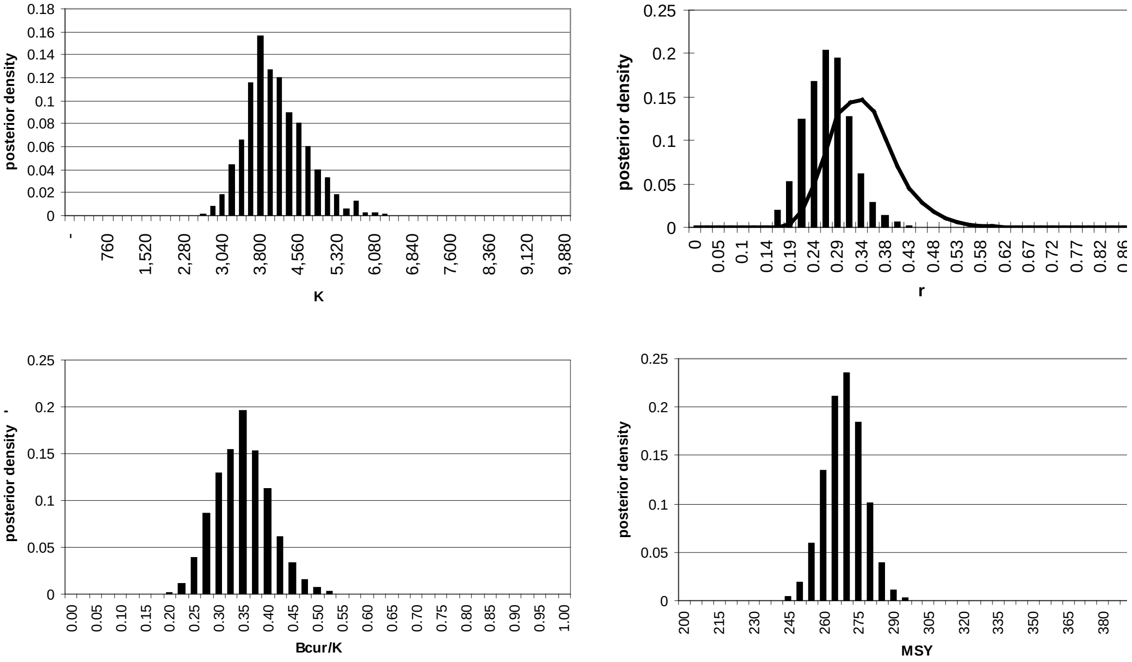

Figure 4. Posterior probability density functions estimated by the BSP striped marlin model for key parameters based on the base case. In the graph showing the intrinsic rate of increase (r), both the posterior probability density function (columns) and the prior probability density function (line) are shown.

F=0.20

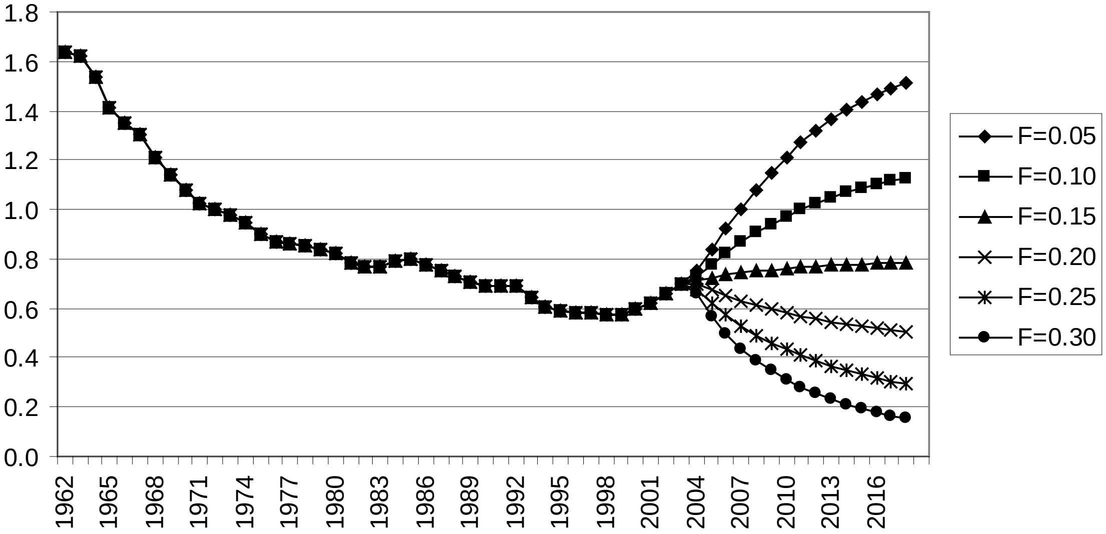

Figure 5. Median values (annotated thick lines) and 90% probability intervals (thin lines) for stock size as a proportion of maximum sustainable yield under various scenarios for *F*, fishing mortality, projected for 15 years.