International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

Preliminary Analysis of Stock Status for Blue Marlin (*Makaira nigricans*) in the Pacific Ocean by Bayesian Production Model[1]

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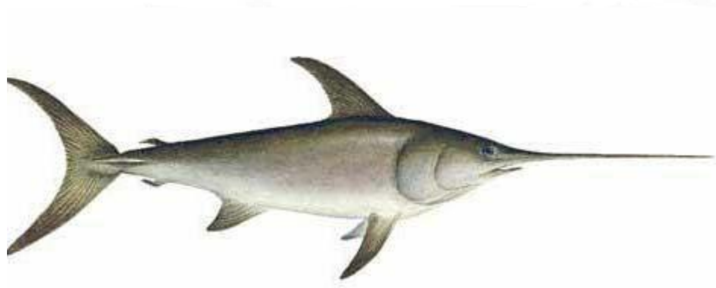

[1]Working document submitted to the ISC Billfish Working Group Workshop, 20-28 May 2013, Shimizu, Shizuoka, Japan. Document not to be cited without author's written permission.

Summary

Non-equilibrium, age-aggregated Bayesian surplus production (BSP) model was applied for Pacific blue marlin. The single stock in whole Pacific Ocean is assumed. An annual time-series of fishery data for 1950 – 2011 was used for the assessment. Catch and six stock indices, i.e. Japanese early and late distance and offshore longline, Hawaiian longline, Taiwanese early, middle and late longline, are used. The median estimates for the historical stock dynamics decline from 250,000 t to 170,000 t between the late 1980'2 and mid 2000's and increase after that. The stock biomass of Pacific blue marlin was well above the biomass at the maximum sustainable yield, MSY (Bmsy) and was exploited with the fishing rate well below that at MSY (Fmsy) during all years.

Introduction

Blue marlin are an incidental catch of longline fisheries. They are also taken in harpoon fisheries off Japan and Taiwan, and one of most important resources for recreational fishing. Fishery and biological data suggest that there is a single stock of blue marlin in the Pacific Ocean.

Several stock assessments are conducted in this three decades but the stock status of blue marlin in the Pacific Ocean is still uncertain. Kleiber et al (2003) shows the stock status of this species Ocean by MULTIFAN-CL and it was around 50,000t and the population was close to fully exploited. Su et al. mentioned that the estimated stock status are sensitive to the values assumed for natural mortality and stock-recruitment steepness. Although they concluded that the stock assessment method considering seasonal migration and sex structure is required, there is poor information. Bayesian surplus production model (BSP) allows for different inflection points and incorporates demographic data to improve parameter estimation. It also allow to estimate the distribution of estimated parameters with uncertainties of observed and process error so this method has advantage to evaluate the stock status with various uncertainty especially for the species with poor data components. In this paper, the estimated stock status of Blue marlin in the Pacific by using this components will be provided.

Data

1. Spatial and temporal stratification

The base case (also sometimes called the ‘reference’ case) analyses of this assessment is based on a single Pacific stock.

2. Temporal stratification

An annual (Jan. 1 – Dec. 31) time-series of fishery data for 1950 – 2011 was used for the assessment.

3. Definition of fisheries

The ISC Billfish Working Group estimated catches of many fisheries from different nations and member sources in an effort to understand the nature of fishing mortality (Figure 1). However, all catch estimates were aggregated into a single time-series for the base case and related sensitivity analyses of this study.

4. Catch data

Fishery data from ISC member nations and observers were compiled, shared, and reviewed through a series of working papers which were presented and discussed at ISC Billfish Working Group held in the USA and Japan. Catches were extracted from databases of landings, vessel logbooks, and observer records.

5. Abundance indices

Indices of abundance (CPUE) were developed from seven different longline fisheries presented by Japanese, Taiwanese, and USA delegations. In this paper, Japanese “early” (1976-1993), Japanese “late” (1994-2011) indices, Hawaiian longline (1995-2011), Taiwanese "early" (1967-1978), Taiwanese "middle" (1979-1999) and Taiwanese "late (2000-2011) are applied as input data (Figure 2).

Model Description

1. Bayesian Surplus Production Model

In this paper, a non-equilibrium, age-aggregated Bayesian surplus production (BSP) model was applied (Stanley, McAllister and Starr 2012) and the BSP2 implementation developed for ICCAT (McAllister and Babcock 2006[1]) was chose as this model's

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[1] The current software manual of the BSP model (McAllister and Babcock 2006) does not fully explain input parameters, model options and outputs for a state-space version of the BSP model, although it is still useful to learn how to run the software. The ISC Shark Working Group held a three-day workshop in Yokohama, Japan in November 2012 during which Dr. Murdoch McAllister demonstrated how to run the state-space BSP model.

platform. It is a state-space version of BSP model which incorporates stochastic process error in the stock dynamics and thereby allows a more thorough accounting of uncertainty in estimates of stock biomass, future projections, and deviations as compared to a deterministic BSP model. A Bayesian approach was adopted to fit the model to data, permitting the use of informed priors which can incorporate information and expert judgments. BSP2 fits either a Schaefer or Fletcher/Schaefer production model to time-series of catch and indices of abundance (CPUE), with CV's if available. The parameters that can be fit include carrying capacity (*K*), intrinsic rate of increase (*r*), biomass in the first modeled year defined as a proportion of *K* (alpha.b0), the shape parameter for the surplus production function for the Schaefer or Fletcher/Schaefer fit (*n*), the average annual catch for years prior to recorded catch data (cat0), and catchability for each CPUE series (*q*). Priors can be used for all parameters. The biomass trajectory can be projected under any catch or harvest policy by the fitted model, with confidence bounds. Decision tables with policy performance at given time horizons, such as stock rebuilding are included in the outputs.

The Schafer surplus production model is expressed as (Prager 1994):

$$\text{(1)} \qquad \frac{dB_t}{dt} = rB_t - \frac{r}{K} B_t^2 - F_t B_t$$

where *r* is intrinsic rate of increase, *K* is carrying capacity, B_t is biomass at time *t*, and F_t is fishing mortality rate at time *t*. In the Schaefer model, the biomass that produces maximum sustainable yield (B_{msy}) is one half of *K*.

A generalized version of the model which allows B_{msy}/K to vary includes a shape parameter, *n*, as well as the parameters *K* and *m* (maximum sustainable yield) (Fletcher 1978):

$$\text{(2)} \qquad \frac{dB_t}{dt} = gm \frac{B_t}{K} - gm \left(\frac{B_t}{K}\right)^n - F_t B_t$$

where;

$$\text{(3)} \qquad g = \frac{n^{n/n-1}}{n-1}$$

and the inflection point is;

$$\emptyset = \frac{B_{msy}}{K} = \left(\frac{1}{n}\right)^{1/n-1} \quad (4)$$

At n=2, the inflection point occurs at 0.5K and this model is identical with the Schaefer model (Prager 2002). This model predicts near-infinite rates of surplus production per capita as abundance decreases to low levels when n ≤ 1 (i.e. $B_{msy}/K \leq 1/e$) (Quinn & Deriso 1999, Prager 2002). BSP2 software has been adapted to provide a more realistic production model by fitting a synthesis of the Fletcher and Schaefer models that can take on reasonable values of r at all inflection points (called the Fletcher-Schaefer model) (McAllister & Babcock 2006). For n > 2 the original Fletcher model as in equation 2 applies. For n < 2 and B_t/B_{msy} > 1 the Fletcher model also applies. For n < 2 and $B_t/B_{msy} \leq 1$ the functional Schaefer model as in equation 1 applies, where h=2$\emptyset K$, and $\emptyset$ is from equation 4.

A state-space version of the BSP model that incorporates lognormal deviates from total annual stock biomass predictions as described in (Stanley et al. 2012):

$$B_t = \left(B_{t-1} + rB_{t-1} - \frac{r}{K} B_{t-1}^2 - F_{t-1}B_{t-1}\right) exp\left(\varepsilon_t - \frac{\sigma_p^2}{2}\right) \quad (5)$$

where the prior probability distribution for the process error term is given by $\varepsilon_t \sim Normal(0, \sigma_p^2)$.

2. Biological and demographic assumptions

BSP2 fits a single catch time-series to one or more abundance index. This means that all catch data from all fleets in all areas are aggregated into a single catch time series. Assumptions implied by this include a single well-mixed stock, uniform distribution of sex and age structure, and comparable gear selectivities.

3. Intrinsic rate of increase (r)

There is little information about direct estimation value of the intrinsic rate of increase for Pacific blue marlin. On fishbase (http://www.fishbase.org), this estimated value is 0.46. In the 2011 blue marlin stock assessment of Atlantic Ocean by ICCAT, there are two scenario of r, i.e. 0.11 and 0.65, and the average value is 0.38 (ICCAT 2011). Carruthers and McAllister (2011) estimated it as 0.125 with 0.253 CV for Atlantic bluemarlin.

4. Shape parameter

A key characteristic of the Schaefer model formulation is the relationship of Bmsy to K (carrying capacity) with Bmsy defined as K/2 (Hilborn & Walters 1992).

5. Weighting of model components

The CV of each normalized (to the mean) abundance index was rescaled by interative reweighting, starting with a CV of 0.15 and repeating until the ratio of inputed CV to outputted CV fell within the range of 1.1-1.5. BSP2 treats total CV as sqrt(obs CV^2 + process CV^2).

Within the model, inverse variance weighting of each yearly CPUE value was used to estimate variance σ^2 according to the following equations;

$$\mathrm{Ln}L = -\sum_{j}\sum_{y}\left[\frac{\left(\ln\left(I_{j,y}\right) - \ln\left(\hat{q}_j \widehat{B_y}\right)\right)^2}{2\sigma_{j,k}^2} + \ln\left(\sigma_{j,y}\right)\right]$$

where,

$$\hat{q}_j = \left(\frac{\sum_y \left(\ln\left(I_{j,k}\right) - \ln\left(\hat{B}_y\right)\right) / \left(\sigma_{j,k}^2\right)}{\sum_y 1/\left(\sigma_{j,k}^2\right)}\right)$$

This approach was recommended when weighting uniform variance estimates across different index years (McAllister pers, comm,).

6. Base case specifications and input parameter choices

As a prior for r in this paper, 0.38 with 0.5 CV is used as base case because of average value for r which is used for the stock assessment of Atlantic blue marlin. Other detail of setting is on Table 1

7. Evaluation of model convergence

Whether model runs had properly converged was checked by using available diagnostic statistics from the BSP2 model software (McAllister & Babcock 2006). In general, the joint posterior distribution is sufficiently well estimated when the maximum weight of any draw is less than about 0.5~1% (McAllister & Babcock 2006, McAllister pers. comm.). This is a measure of the relative influence of the draw with highest weight. At least 20,000 samples should be saved (simulations are discarded if any of the parameters' values exceed the specified minimum or maximum). The CV of the weights should be low. Most importantly, the CV of the weights of the importance draws should be less than the CV of the likelihood times priors for the same draws (McAllister et al. 2002).

Results

Available diagnostic statistics for model convergence from the BSP2 model software were checked to verify low posterior correlations (r and K); an adequate number of saved draws in importance sampling; and that the CV of the weights of the importance draws was less than the CV of the likelihood times priors for the same draws().

The model fits to the input indices and relevant residual plots are shown in Figure 3. Although there were slight systematic trends (positive to negative or vice versa) in residuals especially for Hawaiian indices, the residuals values are small for all indices especially for all Taiwanese indices. Thus, overall model fits to the data was considered sufficient.

Stock assessment statistics are shown in Table 2. The marginal posterior distributions for r and K are plotted in Figure 4. Both posterior mean and median for the maximum intrinsic rate of natural increase, r, were estimated as about 0.33, which is smaller than the input r prior mean of 0.38.

The posterior mean and median estimates for the current (2011) stock biomass were 435,000 t and 305,000 t (CV=1.04), respectively. The posterior mean and median estimates for the maximum sustainable yield (MSY) were 38,000 t and 23,000 t (CV=0.89), respectively. The ratio of the current biomass to that at MSY (Bcur/Bmsy) was about 1.4 (CV=0.22). The 90% confidence limits (5% and 95% percentiles) of the median for Bcur/Bmsy ranged between 0.90 and 1.89 The posterior median of the current abundance relative to the unfished stock size (Bcur/K) was about 0.68 (CV=0.22). The posterior median for the ratio of fishing mortality rate in 2011 to that at MSY (Fcur/Fmsy) was about 0.5 (CV=0.54) and the 90% confidence limits of the median was 0.08 and 0.97. The posterior median ratio of the total catch in 2011 relative to the replacement yield (Catch/REPY) was 0.79 (CV=0.40).

Although the marginal posterior distribution has short range to recognize high precision in the estimates for most key parameters, the range of posterior distribution of K has long tail.

The median estimate and 90% confidence limits for the historical stock dynamics are plotted in Figure 5. The results of this analysis indicated that the stock biomass level of Pacific blue marlin decline from 250,000 t to 170,000 t between the late 1980's and mid 2000's. The stock biomass increased after the mid 2000s. The blue marlin biomass has been mostly stable during the target years of this assessment.

Degree of stock depletion and over-fishing for this anlysis are illustrated using the "KOBE plot" '(Figure 6). The stock biomass of Pacific blue marlin was well above the biomass at the maximum sustainable yield, MSY (Bmsy) and was exploited with the fishing rate well below that at MSY (Fmsy) during all years.

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Table 1 Specifications and key parameters settings for this analysis

Specifications/Parameters	**Value**	**Description/comments**
K	Uniform distribution for log(K)	Range: [50, 2000] x 1000 MT
r prior mean	0.38, SD=0.19	Based on ICCAT's Atrantic information
B0/K (alpha.b0) prior mean	0.9, SD=0.5	Assuming started form almost virgin stock
Surplus production function	Bmsy/K=0.5	Fletcher-Schaefer model, corresponded to shape parameter of n=2.0
Catch		Total dead removals summarised by WG members
Abundance index	JP LL: early (75-93) & late (94-11) HI LL: 95-11 TW LL: early (67-78), mid (79-99) & late(00-11)	See ISC BILLWG 13-01 WP & Reports
Process error CV	Iterative method was used	Considering that total CV is treated as the square root of ((observation CV)^2+(process CV)^2) in the BSP2 software and the observation CV for CPUE index is quite small, the total CV is dominated by the process CV. To set the process CV properly, inputted CV for index was repeatedly adjusted (iterative reweighting) with an initial value of 0.20 until the ratio of inputted CV to outputted CV got roughly equal to 1.1-1.5 assuming that CV for index is constant across years (M. McAllister, pers. comm.)

Table 2 Stock assessment statistics

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.344	0.064	0.186	0.2482	0.3287	0.4645
K	435	345	0.792	200	305	1212
MSY	38	33	0.893	19	23	111
Bmsy	218	172	0.792	100	153	606
Binit	289	229	0.793	114	260	866
Bcur	333	347	1.042	101	209	1120
Bcur/Bmsy	1.367	0.302	0.221	0.902	1.372	1.885
Bcur/Binit	0.99	0.416	0.42	0.493	0.86	1.738
Bcur/K	0.683	0.151	0.221	0.4508	0.686	0.9423
FMSY	0.172	0.0321	0.186	0.1241	0.1643	0.2323
Fcur	0.0863	0.0472	0.548	0.015	0.0803	0.1648
Fcur/FMSY	0.5129	0.2803	0.546	0.0821	0.5239	0.9652
REPY	23.5	8.9	0.38	16.7	21.4	39
Catch/REPY	0.6887	0.2718	0.395	0	0.7851	0.9594

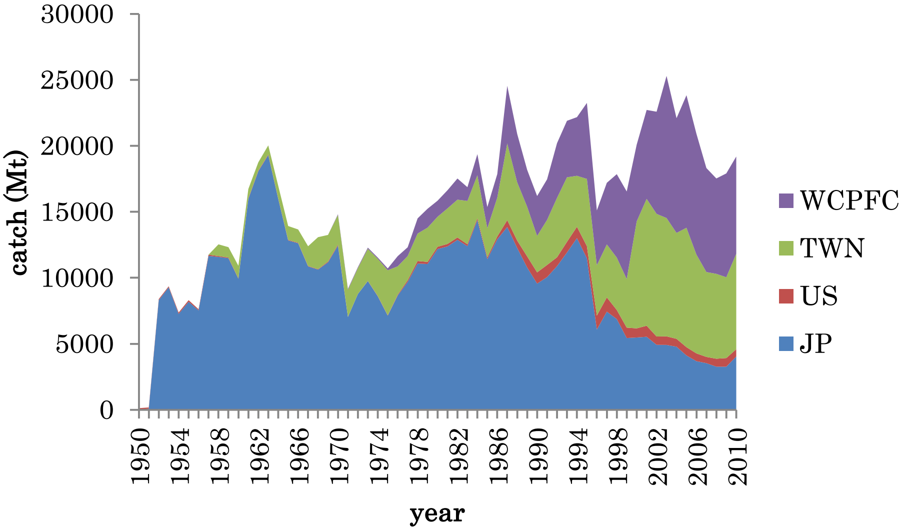


Figure 1. Total catch of blue marlin in Pacific Ocean from 1951 – 2011 across all data sources.

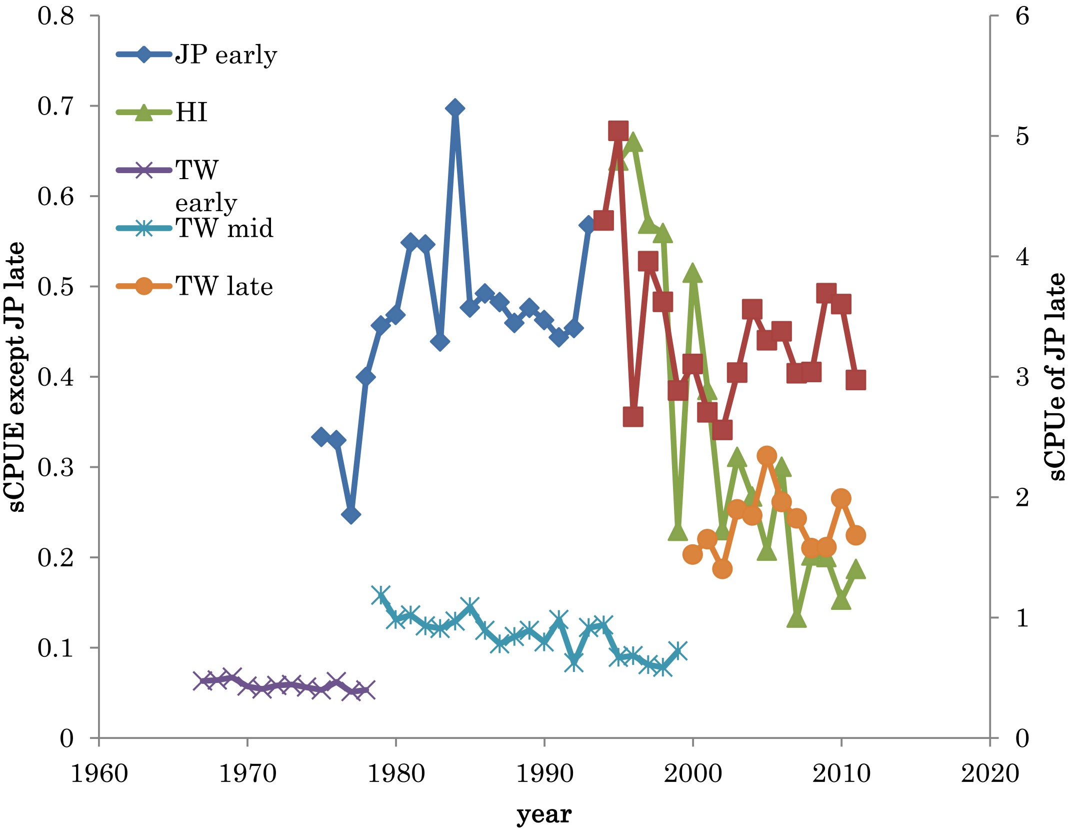


Figure 2. Abundance indices used in stock assessment.

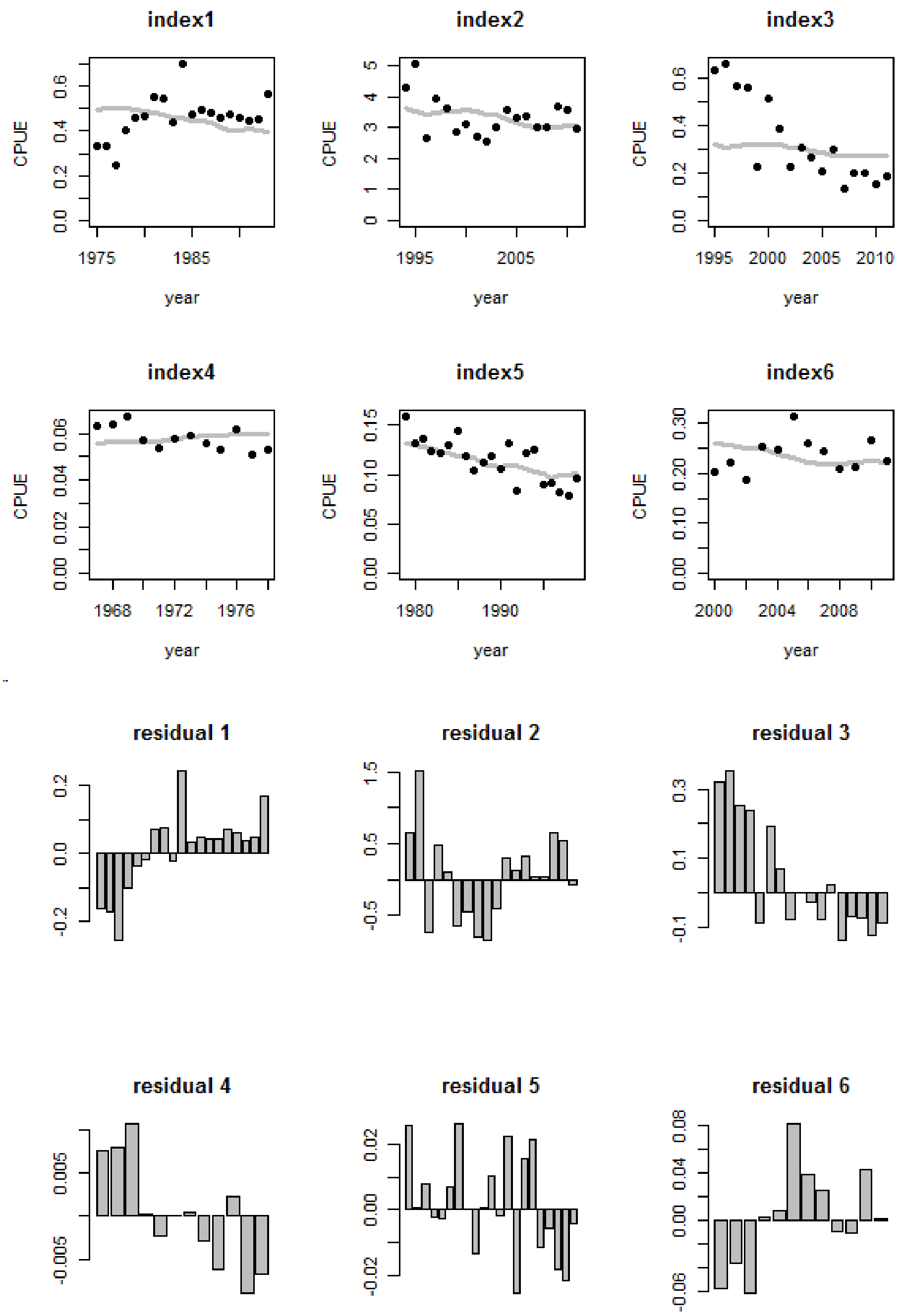


Figure 3. Model fits to the standardized CPUE indices used for Base case in the blue shark stock assessment (top panels) and the residual plots (bottom panels). The gray solid lines are the model predicted values and the black circles are observed (data) values. Indices 1-6 described JP early, JP late, HI, TW early, TW mid, TW late, respectively.

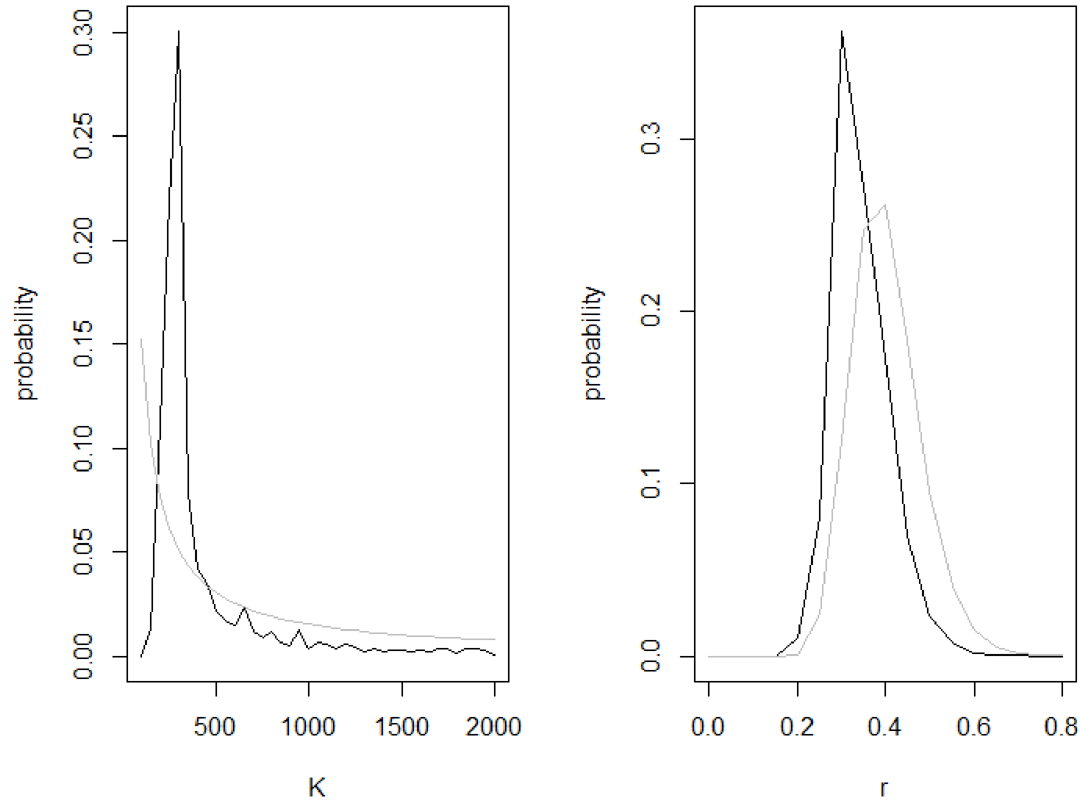
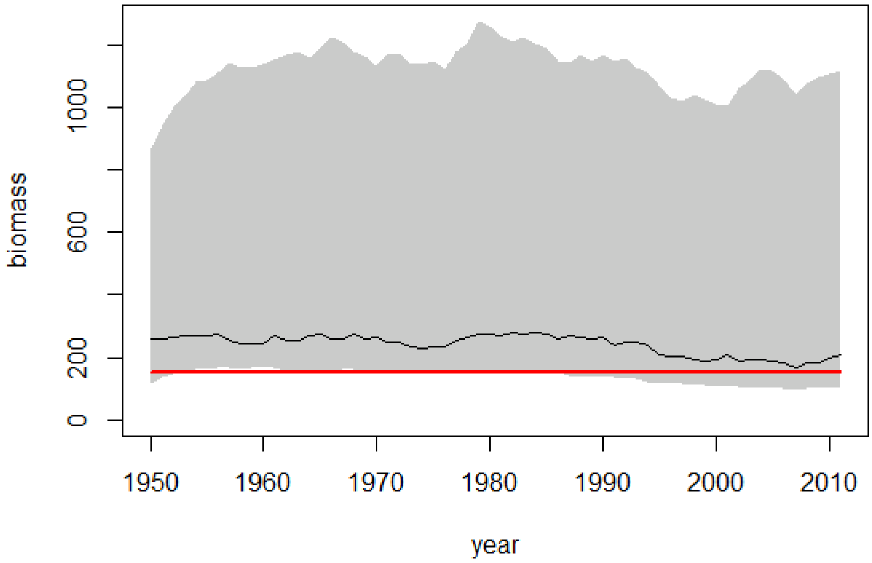


Figure 4. Marginal posterior distributions for carrying capacity (K), the maximum intrinsic rate of natural increase (r).



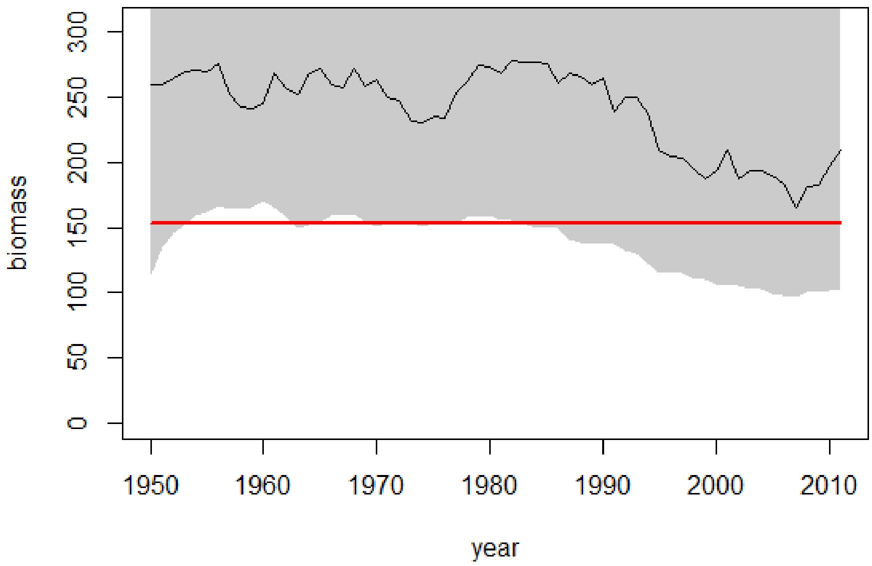


Figure 5. Median estimate and 90% confidence limits for the historical stock dynamics of Pacific blue marlin. The black solid and gray shade represent the median, 10th and 90th percentiles, respectively. The red solid line indicates the median estimate for the biomass at maximum sustainable yield (Bmsy).

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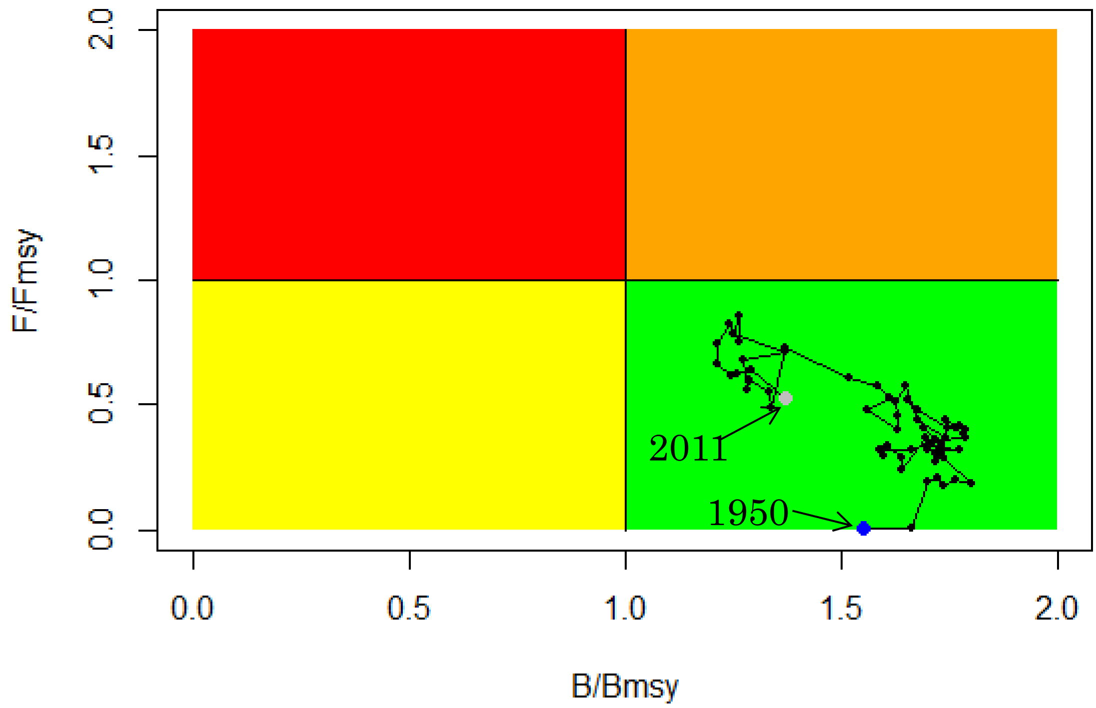

Figure 6. Kobe plot for this analysis. Kobe plot illustrates degrees of stock depletion (horizontal axis) and over-fishing (vertical axis). Colors represent the magnitude of risk of stock collapse green (safe) to red (high risk). The blue circle indicates the median estimate in 1950 (the start year of stock assessment calculation) for this analysis. The gray circle indicates that in 2011. The black circles are the medians in year between 1950 and 2011.