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Stock assessment of the Indian Ocean swordfish using a Bayesian production model with process and observational errors

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Abstract

Swordfish is often caught as by catch of fleets targeting tunas, but the species is the target of some fleets. Unique stock in the Indian Ocean is assumed to the most probable hypothesis, though there is some concern about a possible local depletion in the southwest area. In this work Bayesian production models (Schaefer and Fox types) are used in the stock assessment of swordfish caught in the entire Indian Ocean. Models were fitted to total catch and to standardized catch per unit effort (CPUE) time series calculated based on Japan and on Taiwan datasets. Informative and non-informative priors were used. Likelihood function was based on log-normal density distributions. Monte Carlo Markov Chains algorithm was used to calculate the posterior samples. Most of the models have converged. Standardized CPUE time series of Japan are informative about the parameters of the production models. However Taiwan data are not informative about carrying capacity. All the calculations indicate the stock is not overexploited if we rely on Ymsy, Fmsy and Bmsy benchmarks.

Key words: *Xiphias gladius*, biomass dynamic model, Bayesian model, MCMC.

1. Introduction

In the Indian Ocean the majority of the tuna and tuna-like species are caught by longline and gillnet fleets. Most of the available information concerns longline fleet of Japan and Taiwan. Fishermen aim at species of genera *Thunnus* and at swordfish (*Xiphias gladius*). Catches of swordfish increased quickly in mid 1990's but decreased in the last years. In spite mosaic composition (NE, NW, SE and SW swordfish groups) has been discussed, in last stock assessments the Indian Ocean Tuna Commission Working Group (IOTC WG) have assumed that unique stock in the Indian Ocean is the most probable hypothesis.

Available data include total catch, length frequencies and standardized catch rates for some of the fleets. Length data are probably biased hence the analyses might be based mainly in catch rate (Sharma and Herrera, 2014). Standardized catch rates concerning Japanese and Taiwanese longline fleets are the more informative in the sense the time series are long.

During the 9th Working Party on Billfish the IOTC WG have used simple (e.g. production model) and complex (e.g. stock synthesis) models in the swordfish stock assessment. Production models calculations were based on ASPIC software (Prager, in order to gather in order to assess the stock (IOTC, 2014). ASPIC (Prager, 1994) was used to run production models based on observational error. In this paper swordfish stock is assessed by using Bayesian state-space versions of both, Schaefer and Fox production models. Both observational and process errors are considered when fitting the models to total catch and standardized catch rates. Composite indices and models are an alternative but in this work models were fitted to the Japanese and Taiwanese standardized catch rate separated.

2. Materials and Methods

2.1 Database

The catch data of the aggregated Indian Ocean was extracted from the IOTC site (IOTC, 2014). Estimations of catch are available for year between 1950 and 2012. The whole catch time series was used in the analysis. Standardized catch rate as calculated based on the Japanese (Nishida and Wang, 2014) and Tawainese (Wang and Nishida, 2014) databases were the analyzed relative abundance indices. Details on the calculations of the catch rates can be found in two paper cited above.

2.2 Bayesian Approach

In the Bayesian approach all the relevant and available information on the parameters as described in a *prior* distribution, which is combined with the likelihood function to calculate the posterior distribution that conveys all the knowledge on the parameters estimations. The model used in this paper is in Meyer and Millar (1999). Both observational and process errors were considered assuming lognormal distributions.

Informative or non-informative priors can be used here, depending on the availability of information and knowledge on the species and the stock being analyzed, or even on similar species or stocks (McAllister and Kirkwood,1998, McAllister et al.,1994, Punt and Hilborn, 1997). Jeffrey's non-informative reference prior for q is independent of r and k, and is equivalent to a uniform prior on a logarithmic scale (Millar, 2002). Therefore, the uniform prior $U(-20,-1)$ on the logarithmic scale was used in the present study for q. For r and k, wide uniform priors that convey little information on the parameters were used. The uniform prior for k with lower and upper limits defined in tons was $U(45000,1000000)$. The lower limit is just a little higher than the maximum annual yield recorded for the species in the study area. The prior for r was $U(0,2)$, and those for σ^2 and τ^2 were both the inverse gamma $IG(0.1,0.01)$. The above set of priors is hereafter denominated "non-informative". The priors of the informative set are similar to the above prior. The exception is the lognormal prior of r with mean 0.4 and coefficient of variations 0.4. This prior is similar to that used in last stock assessment of Atlantic swordfish stocks (McAllister, 2014).

2.3 Calculations

Analytical solutions may be cumbersome or even impossible in some of the Bayesian analyses, hence numerical solutions are the alternative. In this paper Monte Carlo Markov Chains (MCMC) numerical approach was used to calculate the posterior estimations of the parameters. Gibbs sampler was implemented using the JAGS program (Plummer, 2005) and the R program (R Core Team 2012) package *runjags* (Denwood, 2009). Three chains were initiated with different initial values for the parameters. The first 100,000 values of each chain were eliminated as burnin, and values were retrieved at every 40 steps (slice sampling) of the subsequent 40000 steps of the chain, providing a set of 1000 values of the posterior distribution for each chain.

Graphs and diagnostic tests were used to assess the mixing degree of the chains and to determine whether a stationary distribution (convergence) had been reached. The analyses regarding convergence were run in the CODA library (Plummer et al., 2006). Gelman and Rubin's (1992) statistic was used for diagnosis. Convergence was assumed when the 97.5% quantile of the Potential Scale Reduction Factor (PSRF) was equal to or lower than 1.01. Autocorrelations were also used to evaluate the mixing degree of the samples of the posterior distribution.

3. Results

3.1 Catch and Standardize Catch Rates

Catches increased fast in mid 1950's but did not show time trends in 1960's and 1970's (Figure 1). There was an increasing from the beginning of 1980's until the end of 1990's, which was followed by a plunge and a peak. In the very end of the time series the catches were all close to 10000 t.

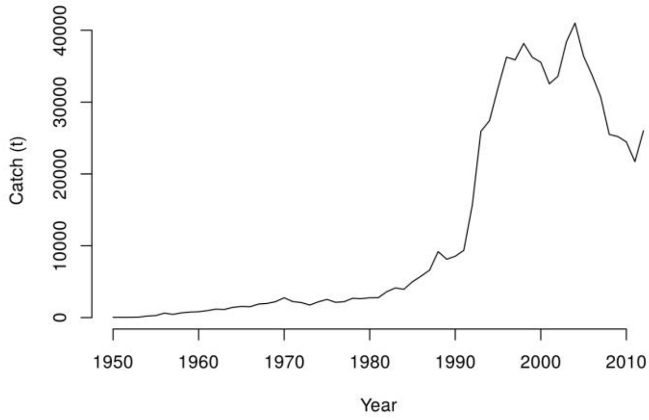

Figura1 – Catch of blue marlin (*Xiphias gladius*) in the Indian Ocean.

Relationship between standardized catch rates and the indices of effort (total catch / standardized catch rates) are in Figure 2. Effort and catch rate calculated based on Japan database are inversely related in the sense catch decrease as effort increase, which is an expected pattern. In opposition, effort and standardized catch rate calculated are positively correlated. Notice also that the relationships among catch, effort and standardized catch rate for Japan are characteristic "one way trip" until mid 2000's. However, catch has decreased and catch rate has increased in the recent years. Overall the results suggest that the standardized catch rates based on Japan database are probably more informative about the parameters of the production models.

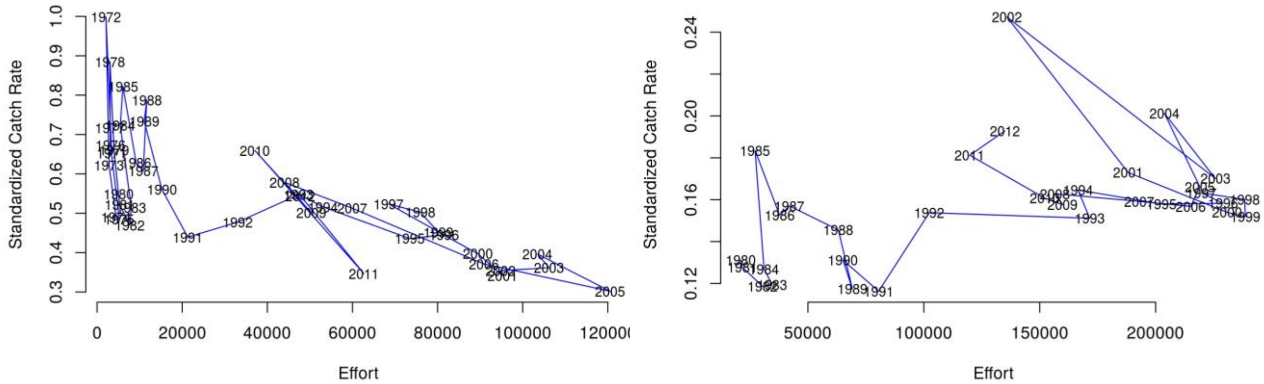

Figure 2 – Relationship between effort (catch/standardized catch rates) and standardized catch rate for Japan (left panel) and Taiwan (right panel).

3.2 Convergence

All the 97% quantiles of Potential Scale Reduction Factor (PSRF) calculated when fitting the models were low (< 1.05), hence convergence is not a problematic issue. PSRF calculated using Schaeffer model were especially satisfactory (≤ 1.01) when analyzing catch rates of Japan. However PSRF of some parameter estimations were close to 1.02 when fitting Fox type model to Japan dataset. In opposition PSRF calculations were acceptable when fitting Fox type model to Taiwan dataset. However, PSRF calculations were not lower than 1.02 when using Schaefer model. Therefore Schaefer model performed better for Japan, and Fox model performed better for Taiwan. However all the PSRF were low.

Autocorrelations were calculated to assess the degree of mixing of the chains. All the calculations show the correlations decrease quick with small lags, hence the results suggest there not bad mixing of the chains.

3.3 Model fits and Residuals Diagnostics

Schaeffer and Fox type models fittings using informative and non informative priors are very similar. Only Schaefer type fittings with non informative prior are shown to no clutter. State-space models with process plus observational errors have several parameters hence they are flexible enough consequently the fittings are usually satisfactory (Figure 3). Credibility intervals of models fitted to Japan database are wide before 1970 and before 1980 for Taiwan, because there are not catch rate data for those periods. Catch rates calculated based on Japan dataset show peaks and plunges from 1970 to mid 1980’s, but decreases from 1988 to 2005. In the very recent years catches rates have increased until 2010. Catch rates of Taiwan show plunges and peaks until early 1990’s, but an increasing trend appears since then. Notice also the peak in 2002.

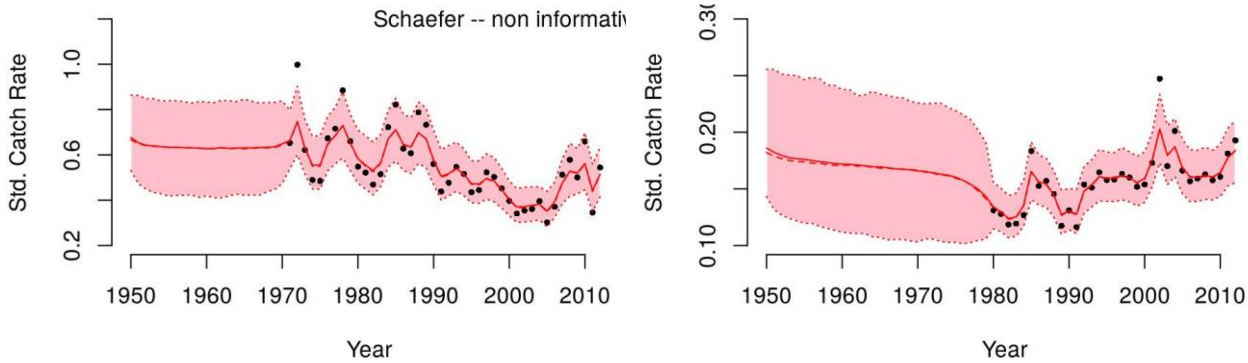

Figure 3 - Fittings of the schaeffer model with non-informative prior to Japan (left panel) and Taiwan (right panel) databases. Dotted lines stand for the 95% credibility intervals, while solid and dashed lines stand for mean and median respectively.

Residuals and fitted values as calculate using Schaefer type model are shown in Figure 4. Residuals were relatively high for the years showing peaks in the very beginning of the Japan time series. These relatively high residuals corresponds to high fitted values (> 0.7) in the left panel of Figure 4. However, overall the models are not strongly biased. Notice also that the fittings to the cath rates of the very last years (circles filled gray) are not of concern. Similarly the residuals of models fitted to Taiwan database are also not of concern (right panel – Figure 4). It is important to highlight that the residuals analyses showed in this working paper is descriptive, exploratory and superficial. Inferential analyses like calculations of Bayes posterior predictive tests concerning some quantity of interest are requested in order to fully assess models.

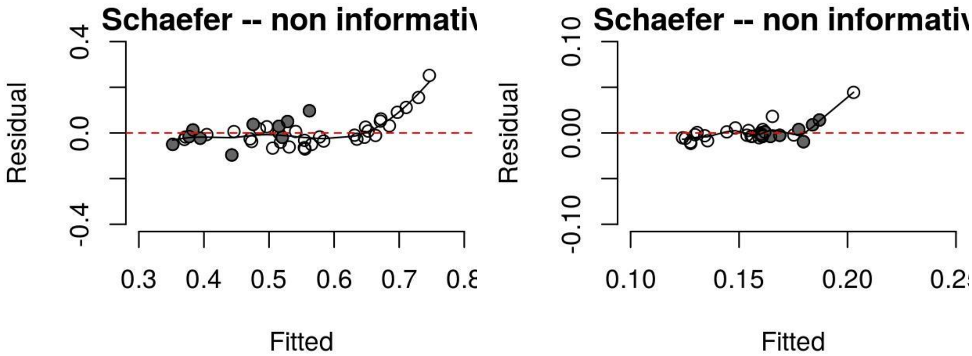

Figure 4 – Relationship between fitted values and residuals of Schaefer model fitted to Japan (left panel) and Taiwan (right panel) databases using non-informative priors. Circle filled gray stand for the estimations for the last ten years to show up in database.

3.4 Marginal Posterior Distributions

Marginal posteriors of parameters r , k and q of models fitted to Japan dataset are in the three top panels of Figure 5, while the bottom panels stand for calculations based on Taiwan dataset. Posteriors of r calculated based on Japan dataset give high weight to values close to 0.3-0.4 (upper left panel – Figure 5). Modes of posteriors calculated with informative and non informative priors are similar, but the precision of posteriors calculated with informative prior is high. Posteriors of k calculated with non informative prior are precise and give weight to values close to 200000 (upper mid panel – Figure 5). However precisions of posteriors of k calculated based on informative priors set are low. Notice also that the posterior calculated using Schaefer and informative prior was bounded by the upper limit (1000000). All posteriors of q calculated using informative and non informative priors give weight to values close 1E-6.

The prior and the posteriors of r as calculated based on Taiwan database are conflictive (left bottom panel – Figure 5). The mode of the prior is close to 0.4 but the posteriors give weight to low values (< 0.2) which are not supported by the prior. Posteriors of k are all bounded by the upper limit of the prior (mid bottom panel – Figure 5). Posteriors of q are narrow and give high weight to values close to 2.2E-7.

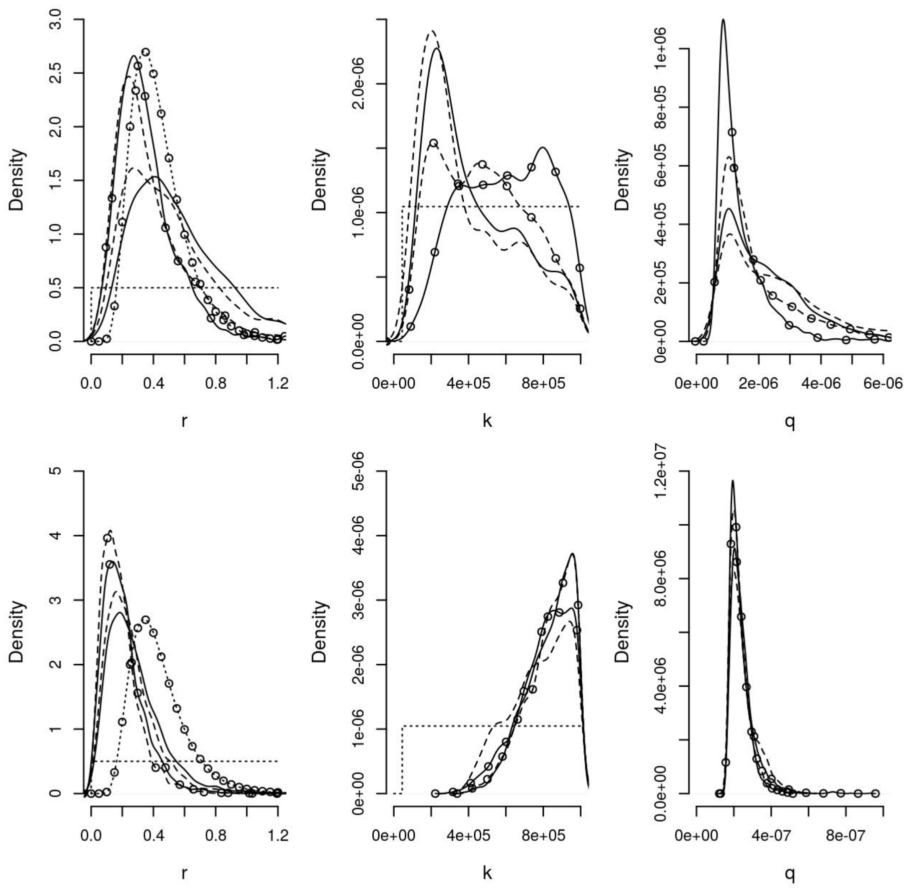

Figure 5 – Marginal posterior distributions calculated for the Schaeffer model with observational error only and with the non-informative priors. Dotted lines stand for priors. Solid and dashed lines stand for calculation using Schaefer and Fox models respectively. Calculations with informative prior are indicated by empty circles, while symbols are not used for non informative prior.

Posteriors of Y_{msy} are shown in Figure 6. Modes of Schaefer model posteriors calculated based on Japan database are close to 39,000 t, while modes of Fox posteriors give more weight to values close to 45,000 t (left panel – Figure 6). Precisions of posteriors calculated using Taiwan dataset are low (high variance) (right panel – Figure 6). Modes are close to 30,000-35,000 t but the posteriors are asymmetric and wide, hence they give weights to values higher than 50,000 t.

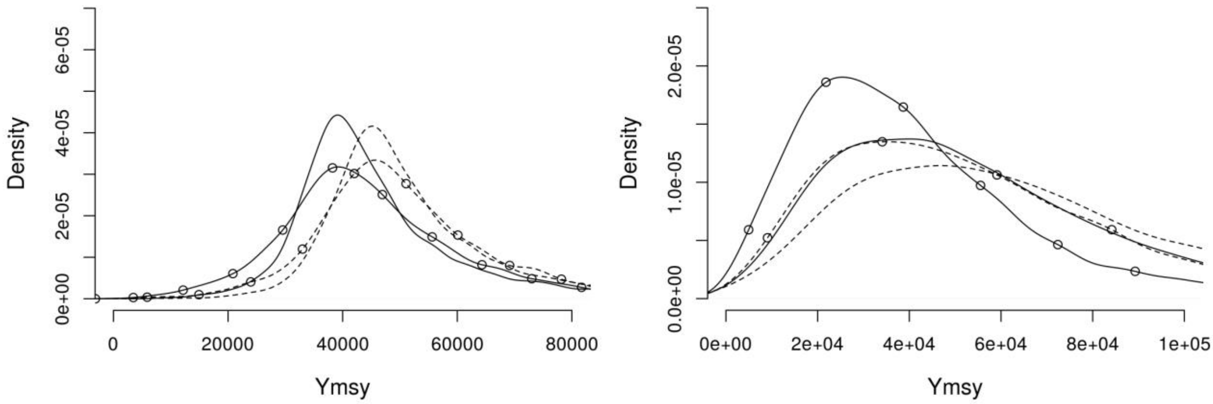

Figure 6 – Marginal posterior distributions of Y_{msy} as calculated for Japan (left panel) and Taiwan (right panel) dataset. Solid lines and dashed lines stand for Schaefer and Fox models respectively. Empty circles indicate results gathered with informative prior, while no symbols are used for non informative prior.

3.5 Ratio Y/Y_{msy}

Time trends of ratios Y/Y_{msy} as calculated based on Japan dataset are shown in Figure 7. Credibility intervals are wide specially after 1990 when the informative prior is used. Ratio Y/Y_{msy} was low in the very beginning of the fishery but it has increased quickly in the early 1990's. Overall the results gathered with the Schaefer model are less optimistic in the sense the ratios Y/Y_{msy} are higher than those calculated with Fox models. However the maximum mean of the ratios found in mid 2000's did not reach 1. Ratios have decreased in the very end of the time series.

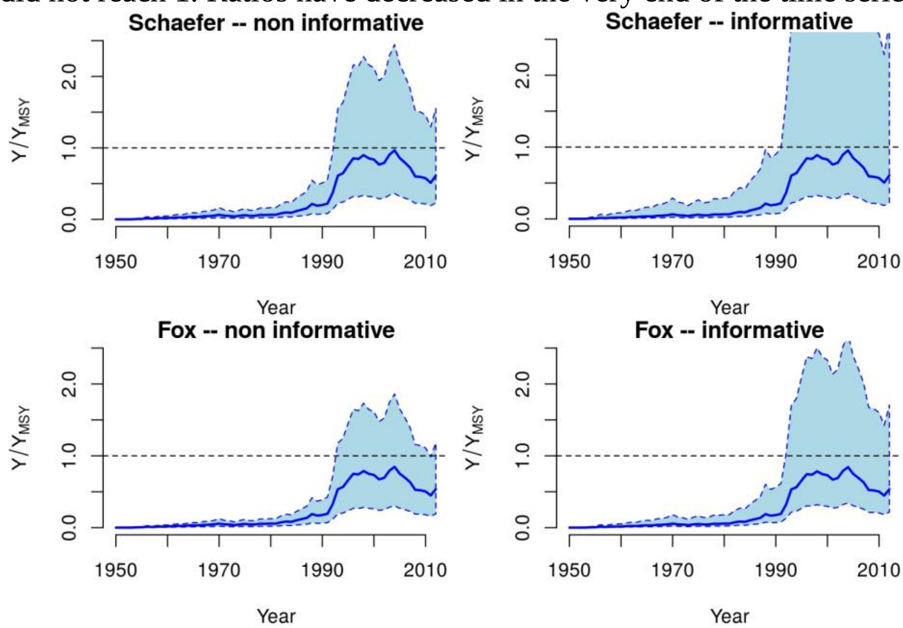

Figure 7 – Marginal posteriors of Y/Y_{msy} calculated based on Japan database. Dashed lines stand for the 95% credibility intervals, while the solid lines stand for the mean.

Credibility intervals of ratio Y/Y_{msy} calculated based on Taiwan database (Fugure – 8) are wider than those calculated for Japan database. However time trends of means of Y/Y_{msy} were similar.

They were low before 1990, but they have increased quickly in early 1990's. The ratio has overtaken 1 in mid 2000's only when using Schaefer model and informative prior. Overtake

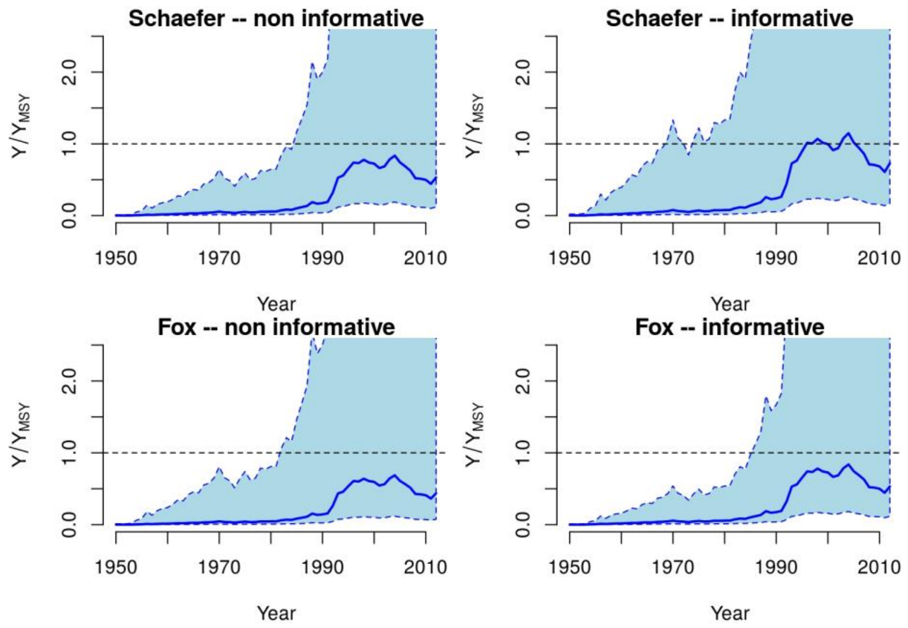

Figure 8 – Marginal posteriors of Y/Y_{msy} calculated based on Taiwan database. Dashed lines stand for the 95% credibility intervals, while the solid lines stand for the mean.

3.6 Ratios F/F_{msy} and B/B_{msy}

Variations of ratios F/F_{msy} and B/B_{msy} across the years calculated based on Japan dataset are shown in Figure 9. Results gathered using Fox model are optimistic in the sense the probability that annual F have overtaken F_{msy}, or that annual B have overtaken B_{msy}, were very low all over the years. However, calculations using Schaefer model indicate that the stock may have been overfished in mid 2000's.

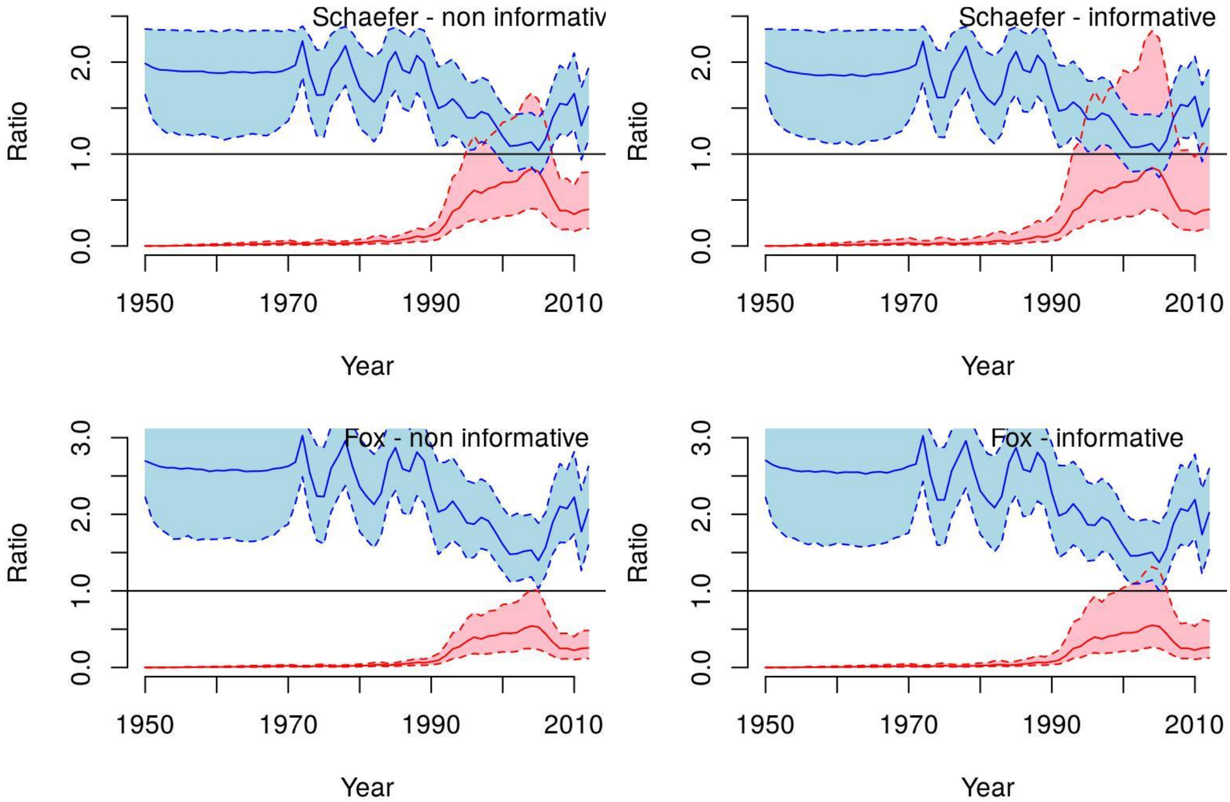

Figure 9 – Variations of marginal posterior distributions of F/F_{msy} and B/B_{msy} across the years as calculated based on Japan dataset. Dashed lines stand for credibility intervals, while solid lines stand for the mean. Pink is used to represent the ratio B/B_{msy}, while bluish colors stand for the ratio F/F_{msy}.

Calculations of B/B_{msy} based on Taiwan dataset were high all across the years (Figure 10). In opposition the mean ratio F/F_{msy} were well below 1. However the 95% credibility intervals are very wide, hence the posterior distributions of F/F_{msy} also give weight to values higher than 1, especially when using Schaefer model. Notice that the relationship between the ratios F/F_{msy} and B/B_{msy} are positive in 1990's in sense both time series show increasing trends, which is an unexpected pattern.

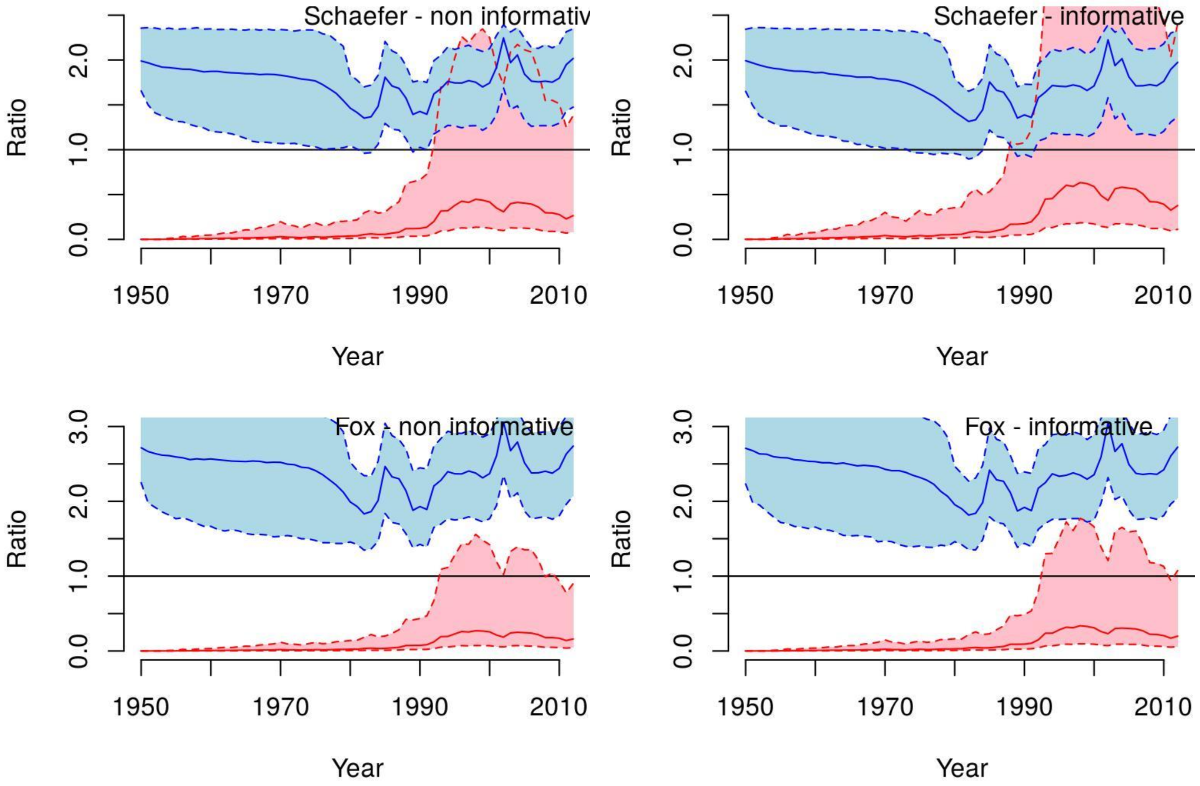

Figure 10 - Variations of marginal posterior distributions of F/F_{msy} and B/B_{msy} across the years as calculated based on Taiwan dataset. Dashed lines stand for credibility intervals, while solid lines stand for the mean. Pink is used to represent the ratio B/B_{msy}, while bluish colors stand for the ratio F/F_{msy}.

Kobe plots as calculated based on Japan and Taiwan are shown in figure 11. Calculations indicate that probably the stock have not been overexploited since the start of the fishery. Results also indicate that currently the stock is still not overfished. Posteriors calculated based on Taiwan database are more diffuse and asymmetric than those calculated based on Japan dataset.

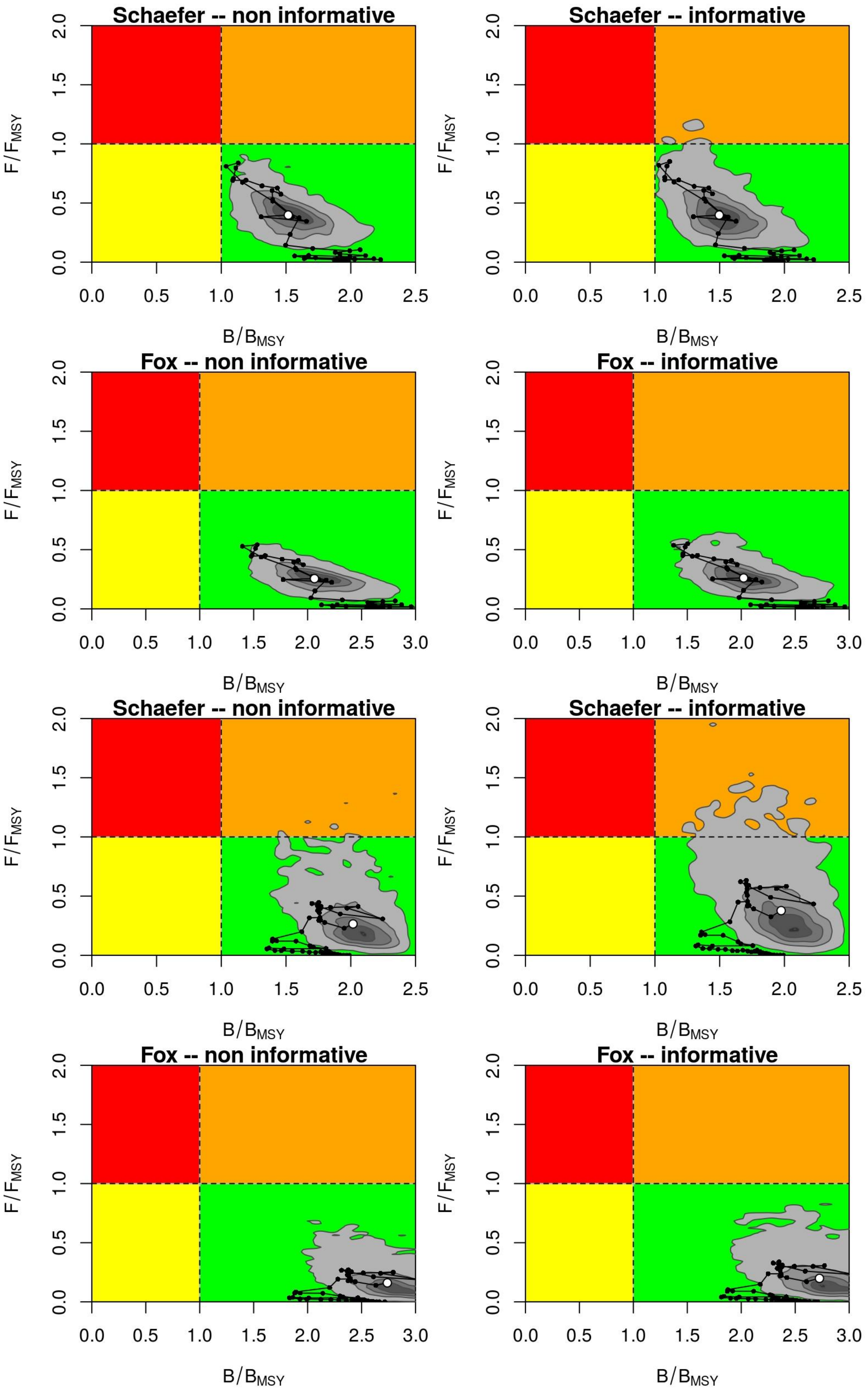
Schaefer -- non informative
Schaefer -- informative
Fox -- non informative
Fox -- informative
Schaefer -- non informative
Schaefer -- informative
Fox -- non informative
Fox -- informative
F/F_{MSY}
B/B_{MSY}
0.0
0.5
1.0
1.5
2.0
2.5
3.0

Figure 11 – Kobe plots as calculated based on Japan databases (top four panels) and Taiwan databases (bottom four panels).

4. Remarks

The results suggest the model fittings are satisfactory, but it is important to remind that only superficial diagnostic analyses were carried out in this preliminary run.

Most of the models have converged.

Japan dataset is more informative about the parameters of the models, probably because the inconsistent relationship between total catch and standardized CPUE calculated based on Taiwan database.

All of the preliminary results indicate the stock is not overfished.

5. References

Denwood, M. J., 2009. runjags: Run Bayesian MCMC Models in the BUGS syntax from within R - manual. http://cran.r-project.org/web/packages/runjags/.

Fox, W. W., 1970. An exponential yield model for optimizing exploited fish populations.Trans. Amer. Fish. Soc. 99, 80-88.

Gelman, A. and D.B. Rubin. 1992. A single series from the Gibbs sampler provides a false sense of security. In: Bernardo, J. M., Berger, J. O., Dawid, A. P., Smith, A. F. M. (Eds.). In:Bayesian Statistics, Vol. 4. Oxford University Press, Oxford, pp. 625-631.

IOTC. 2014. www.iotc.org. accessed: September 19, 2014.
McAllister, M. K. 2014. A generalized Bayesian surplus production stock assessment software (BSP2). Collect. Vol. Sci. Pap. ICCAT. 70(4): 1725-1757.

McAllister, M.K., Kirkwood, G.P., 1998. Bayesian stock assessment: a review and example application using the logistic model. ICES J. Mar. Sci. 55: 1031-1060.

McAllister, M.K., Pikitch, E.K., Punt, A.E., Hilborn, R., 1994. A bayesian approach to stock assessmentand harvest decisions using the sampling/importance resampling algorithm. Can. J. Fish. Aquat. Sci. 51, 2673-2687.

Meyer, R., Millar, R. B., 1999. BUGS in bayesian stock assessment. Can. J. Fish. Aquat. Sci. 56, 1078-1086.

Millar, R. B., 2002. Reference priors for Bayesian fishery models. Can. J. Fish. Aquat. Sci. 59, 1492-1502.

Nishida, T. and Wang, S-P. 2014. CPUE standardization of swordfish (*Xiphias gladius*) exploited by Japanese tuna longline fisheries in the Indian Ocean using cluster analysis for targeting effect. IOTC-2014-WPB12-21 Rev.

Plummer, M., 2005. JAGS: Just Another Gibbs Sampler. Version 1.0.3 manual. http://www-ice.iarc.fr/˜martyn/software/jags/.

Plummer, M., Best, N., Cowles, K., Vines, K., 2006. CODA: Convergence diagnosis and output analysisfor MCMC. R News. 6(1), 7-11.

Prager, M. H. 1994. A suite extension to non-equilibrium surplus production model. Fishery Bulletin. 92: 374-389.

Punt, A.E., Hilborn, R., 1997, Fisheries stock assessment and decision analysis: the Bayesian approach. Rev. Fish Biol. Fish. 7, 35–63.

R Core Team., 2012. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Schaefer, M. B., 1954. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. Inter-Am. Trop. Tuna Comm. Bull. 1, 27-56.

Sharma, R. and Herrera, M. 2014. An Age-, Sex-, and Spacially-Structured Stock Assessment of the Indian Ocean Swordfish 1950-2012, Using Stock Synthesis. IOTC-2014-WP12-27.

Wang, S-P. and Nishida, T. 2014. CPUE standardization with targeting analysis for swordfish