Preliminary stock assessment of black marlin (*Makaira indica*) caught in the Indian Ocean using a Bayesian state-space production model

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Abstract

Black marlin (*Makaira indica*) is often caught by tuna longline and gillnet fleets operating in the Indian Ocean. Unitary stock in Indian Ocean has been assumed as working hypothesis during recent years. In 2014 an Stock Reduction Analysis based only on catch data was used to assess the status of the the stock assessment which was then classified as “subject to overfishing”. Catch time series was updated and revised and new relative abundance indices for Indonesia, Japan and Taiwan were calculated. In this paper this new information was analyzed in an attempt to fit an Bayesian state-space production model. Informative and non-informative priors were used. Likelihood function was based on log-normal density distributions. Posterior samples were calculated using Monte Carlo Markov Chains. Three chains starting on different locations of the space of parameters were calculated. The first 30000 samples of each chain were discarded (burnin), and the next 90000 samples were sliced (thin of 30) in order to gather a final sample with 3000 for each of the three chains. All the models converged. Overall the production models fitted well the data as the time trends of predicted expectations and of catch rate data were similar. Results of Schaefer and Fox type calculations were similar. Both estimations indicate that black marlin stock has been overfished during the last 10-15 years.

Key words: black marlin, stock assessment, production model, Bayesian model, MCMC, biomass.

1. Introduction

Black marlin has been an important bycatch component in longline and gillnet pelagic fisheries in the Indian Ocean (Anon., 2013 a). There are estimations of the total catch, but only standardized catch rates of longline fleets are available. Black marlin is a highly migratory species, but unique stock has been assumed as the main hypothesis. In the 12th Working Party on Billfishes (WPB) held in 2012 Stock Reduction Analysis (SRA) was used to assess black marlin stock of Indian Ocean for the first time. In spite of the uncertain the results indicated that the stock “subject to overfishing”. Data is still limited. Quality of information concerning total catch is not the ideal. However, new standardized catch rates have been provided based on data of Indonesia (Setyadji and Andrade, 2016), Japan (Yokoi et al., 2016) and Taiwan (Wang, 2016) fleets. If the available standardized are considered as valid estimations of relative abundance, production models can be used fitted the data and to assess the status of the stock. Schaefer and Fox types of production models have been often used to fit catch and catch rates data. In this paper Bayesian state-space versions of Schaefer and Fox models were used in the stock assessment. Both observational and process errors were considered when fitting the models to the available datasets. In this paper Monte Carlo Markov Chain (MCMC) algorithm was used to calculate the samples of the posterior distributions.

2. Materials and Methods

2.1 Database

Updated estimation of total catch of black marlin provided by the IOTC secretariat this year (Anon, 2016) and the previous estimation of catch used in last stock assessment held in 2014 (Anon, 2014) are in Figure 1. Catch time series calculated in 2014 ends in 2013 while nowadays there are also estimations for 2014 and 2015. The two time series are similar from 1950 to 2013. However the catches of 1990's of the updated time series are higher than in the former dataset. Notice also that the catches have increased in 1950's but they did not change much throughout 1960's and 1970's. However, the estimations indicate that the total catch has increased slowly in 1980's, but quickly from 1990 until mid 2000's. Caches have decreased from 2004 to 2010, but they have increased in the recent year. The estimation for the 2015 (~18,500 t) is the highest value of the time series.

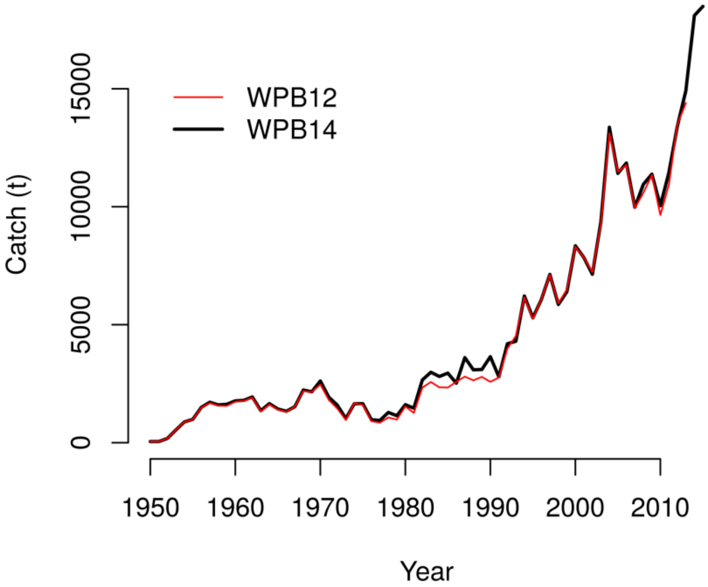

Figure 1 – Estimations of total catch of black marlin as calculated in the 12th Working Party on Billfish (WPB12-2014) and in WPB14 – 2016.

Standardized catch rates as calculated based on the Indonesian, Japanese and Taiwanese longline datasets were provided as input data for stock assessment models (Figure 2). Details on the calculations of the standardized catch rate of Indonesia, Japan and of Taiwan can be found in Setyadji and Andrade (2016), Yokoi et al. (2016) and Wang (2016), respectively. Time series of Japan (JPN) and of Taiwan (TWN) are long, while standardized catch rates of Indonesia (IDN1 and IDN2) are available for a shorter period (2005-2014). In order to make comparisons easier, standardized catch rates were divided by their means calculated for years ≥ 2005 (Figure 2).

There are two alternative time series for Indonesia (IDN1 and IDN2) due to uncertain concerning the structure of the model used to standardize the catch rate. In order to assess the sensitivity of the estimations to the alternative input datasets, in this preliminary analysis production models were fitted to two groups of time series: a) IDN1, Japan (JPN) and Taiwan (TWN); and b) IDN2, JPN and TWN. Overall standardized catch rates of Japan and Taiwan decreased from 1970's to 2005, but they are conflictive in some periods (Figure 2 – left panel). Standardized catch rates of Japan did not change much from 1970 to 1993, while catches rates of TWN decreased quickly in the mid 1980’s. In general, catch rates of Japan decreased from the beginning of 1990’s until mid 2000’s. Standardized catch rates of Taiwan showed an oscillatory pattern in 1990,s, but a clear decreasing trend appears only after 2000.

Time series were also conflictive from 2005 onwards (Figure 2 – right panel). Standardized catch rates IDN1 and TWN increased all over the recent years. However catch rates of Japan decreased from 2006 to 2013. The alternative time series of Indonesia (IDN2) increased from 2005 to 2011, but the estimations decreased in the recent years.

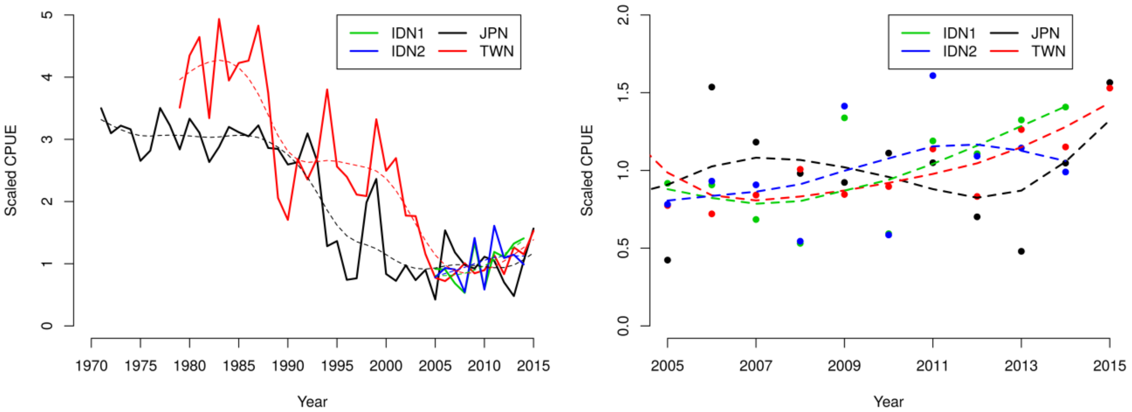

Figure 2 – Standardized catch rates of Indonesia (IDN1 and IDN2), Japan (JPN) and Taiwan (TWN). Solid lines and points stand for the observed values, while dashed lines stand for smooth calculations. Right panel is a zoom of the end of the time series showed in the left panel.

2.2 Model

The model used here is the same of Meyer and Millar (1999), and it is summarized in Andrade (2016). In order to simplify the model is not described again in this working paper. The two papers mentioned above are recommended for those interested in the formulae. Markov Chain Monte Carlo (MCMC) algorithm was used in this paper to calculate the posterior samples. Gibbs sampler was implemented in the JAGS program (Plummer, 2005) available in the R program (R Core Team 2016) with the *runjags* package (Denwood, 2009). Three chains were initiated with different initial values for the parameters. The first 30,000 values of each chain were eliminated as burnin, and values were retrieved at every 50 steps (slice sampling) of the subsequent 50000 steps of the chain, providing a set of 1000 values of the posterior distribution for each chain.

2.3 Priors

If it is available information concerning the parameters of the models, informative prior may be used in the Bayesian approach. Otherwise, non-informative prior is the only alternative. 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, in this work the uniform prior $U(-45, -1)$ on the logarithmic scale was used for q of both fleets (JPN and TWN). For r and k, wide uniform priors that convey little information on the parameters were used. The uniform prior for k in tons was $U(18{,}500; 20 \times 18{,}500)$. Lower and upper limits of the prior of k are based on the value $18{,}000$ which higher but close to maximum estimation of catch that was 18,490 in 2015 (Anon, 2016). The non-informative prior for r was $U(0; 2)$. Priors of $\sigma^2$and τ^2 were inverse gamma $IG(0.8; 0.01)$and $IG(0.8,0.01)$, respectively. These priors for the errors were selected because they convey little information and because those density distributions and the posterior distributions were not conflictive.

Overall the priors described above convey little information about the parameters hence they are denominated as the non-informative priors hereafter.

Information about black marlin is limited, but experts consulted suggested that if we rely in biological and ecological characteristics the black marlins would be not more productive than most of the other marlins. Maybe black marlin is even less productive than the blue marlin. Hence in this preliminary run I have used non-informative prior but also an informative prior for r which gives more weight to values lower than 0.2, because this was approximately the mode of the posteriors calculated for the blue marlin of the Indian Ocean (Andrade, 2016). However, I have used an “open-minded” informative prior in the sense the standard deviation was higher than the expectation. The informative prior used in this paper was lognormal with mean $\log(0.15)$ and standard deviation equal to 0.4, which gives weight to values lower than the prior used for blue marlin (see Andrade, 2016).

2.4 Diagnostics and Convergence

Graphs (e.g. traceplots) and diagnostic tests were used to determine whether a stationary distribution had been reached. These analyses 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 calculated to evaluate the mixing degree of the samples of the posterior distribution. Estimations of the some parameters are usually correlated hence coefficients of correlations were calculated and the joint posterior were examined. Residuals were also investigated to assess the quality of the fittings to each time series.

3. Results

3.1 Relationships among Catch and Standardize Catch Rates

Histograms of distributions, scatterplots of relationships and coefficients of correlations of available estimations of catch and standardized catch rates are showed in Figure 3. In spite of the oscillatory pattern of the time series, overall catches have been increasing during the last decades. Hence the correlation between catches and years was positive and high.

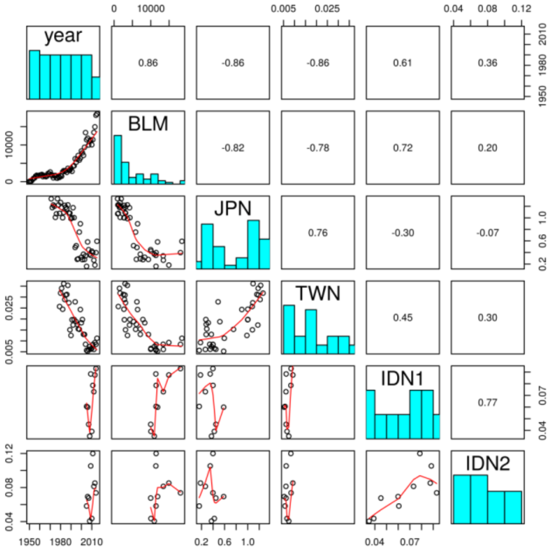

Figure 3 – Estimations of catch (t) of black marlin (*Makaira indica*) (BLM), and standardized catch rates of Japan (JPN), Taiwan (TWN) and Indonesia (IDN1 and IDN2) considered in the analyses.

Coefficient of correlation between year and catch rates of Japan (JPN) and between year and catch rates of Taiwan (TWN) were strong but negative. However the correlation between year and catch rates of Indonesia (IDN1 or IDN2) were positive but not high. These results that catch rates of JPN and TWN, in general, have decreased over the decades, while the catch rates of Indonesia have increased over the last years. Remind that estimations of Indonesia are available only from 2004 onwards.

Correlation between catches and catch rates of Japan and also of TWN were negative and strong. However, in the recent years catches and catch rates of Indonesia have increased, hence the correlations were positive. Correlation between the standardized catch rates of Japan and Taiwan was positive. This result indicates that both time series showed grossly the same time trends. However notice that the correlations between catch rates of Japan and of Indonesia were negative, while the correlations between catch rates of Taiwan and Indonesia were negative. Remind again that time series of Indonesia covers only recent years. In this later period TWN, IDN1 and IDN2 are in agreement in the sense all of them have increased in general. However, those three indices and the Japan catch rates are conflictive, the later time series has decreased in the last years.

3.2 Convergence and autocorrelations

Because the estimations of parameters were not sensitive to the choice concerning the Indonesia time series used in the analysis (IDN1 or IDN2), only the results calculated with IDN1 are shown hereafter. All the calculations of 97.5% quantile of PSRF (Gelman and Rubin, 1992) were below 1.01 hence all the models (Fox or Schaefer types with non-informative or informative priors) have converged if we rely in that criterion. In addition the autocorrelation analyzes indicates a fairly acceptable mixing degree of the samples of the posterior distribution for the Schaefer type with non-informative (Figure 3), Schaefer type with informative (Figure 4), Fox type with non-informative (Figure 5) and Fox type with informative (Figure 6) models. Performance of MCMC algorithm with informative prior was superior especially when calculating the sample of r, as indicated by the quick decrease of correlation along with the increase of the lag.

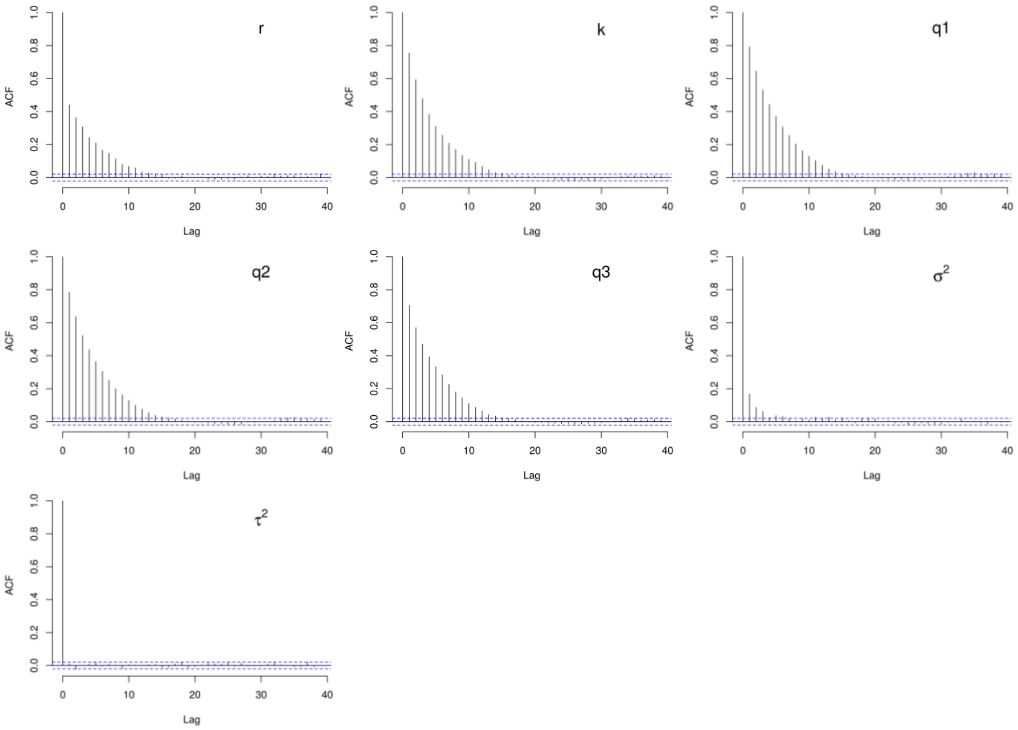

Figure 3 – Autocorrelation of samples of posteriors as calculated using Fox type and non-informative prior. r – intrinsic growth rate; k – carrying capacity; q1 – catchability coefficient of Japan; q2 – catchability coefficient of Taiwan; σ^2 variance of the process error; τ^2 variance of the observational error.

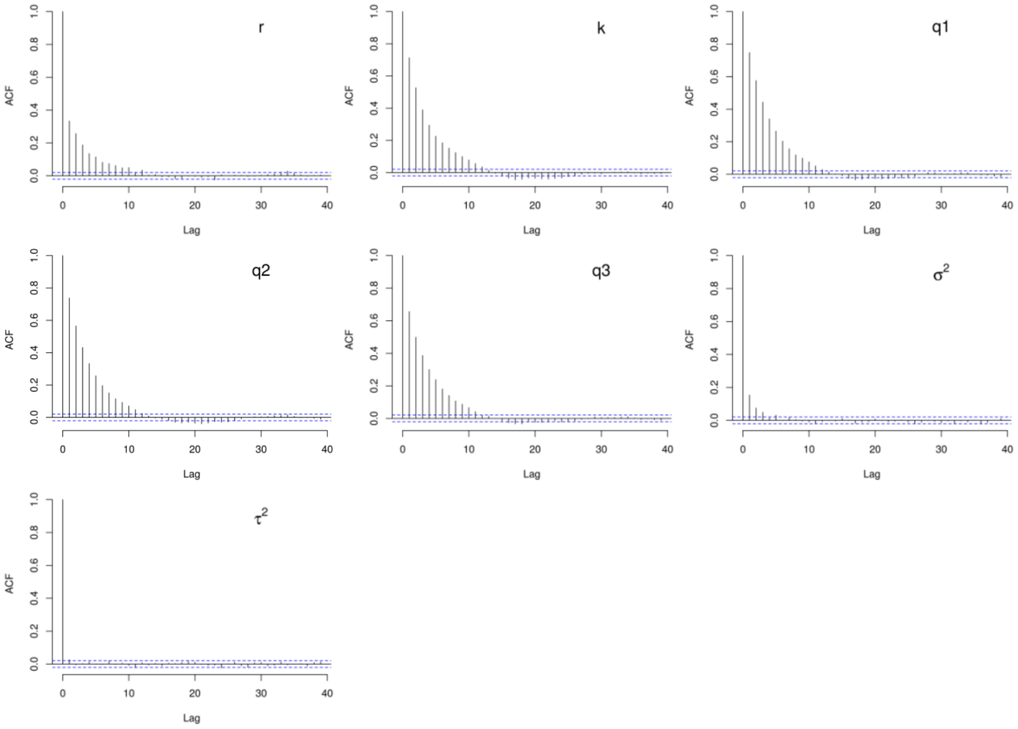

Figure 4 – Autocorrelation of samples of posteriors as calculated using Fox type and informative prior. r – intrinsic growth rate; k – carrying capacity; q1 – catchability coefficient of Japan; q2 – catchability coefficient of Taiwan; σ^2 variance of the process error; τ^2 variance of the observational error.

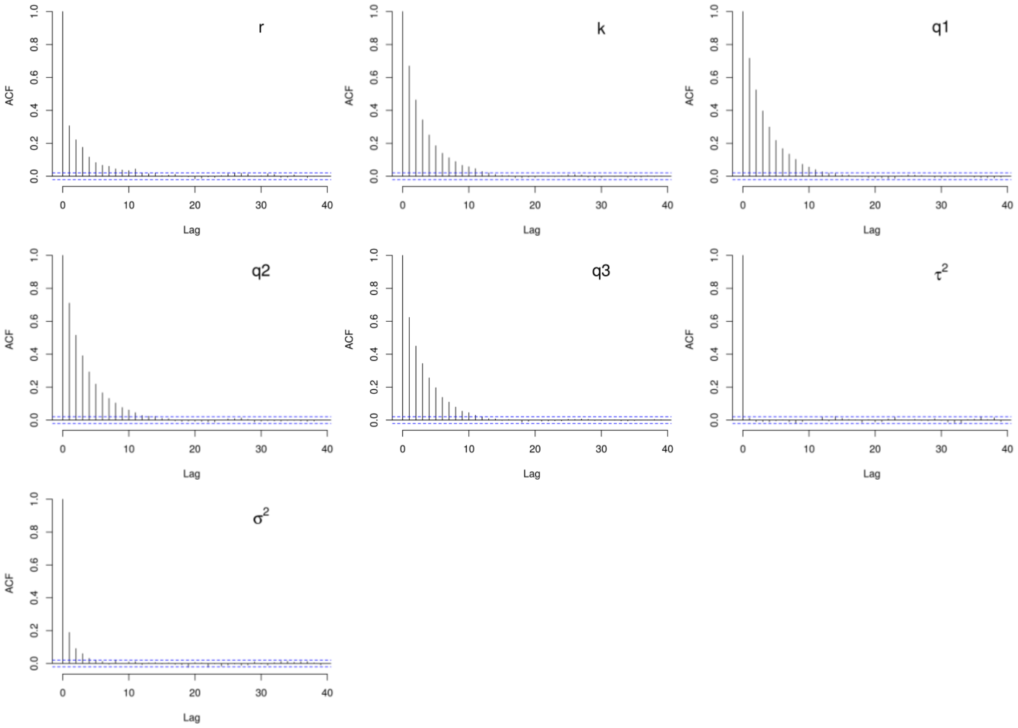

Figure 5 – Autocorrelation of samples of posteriors as calculated using Schaefer type and non-informative prior. r – intrinsic growth rate; k – carrying capacity; q1 – catchability coefficient of Japan; q2 – catchability coefficient of Taiwan; σ^2 variance of the process error; τ^2 variance of the observational error.

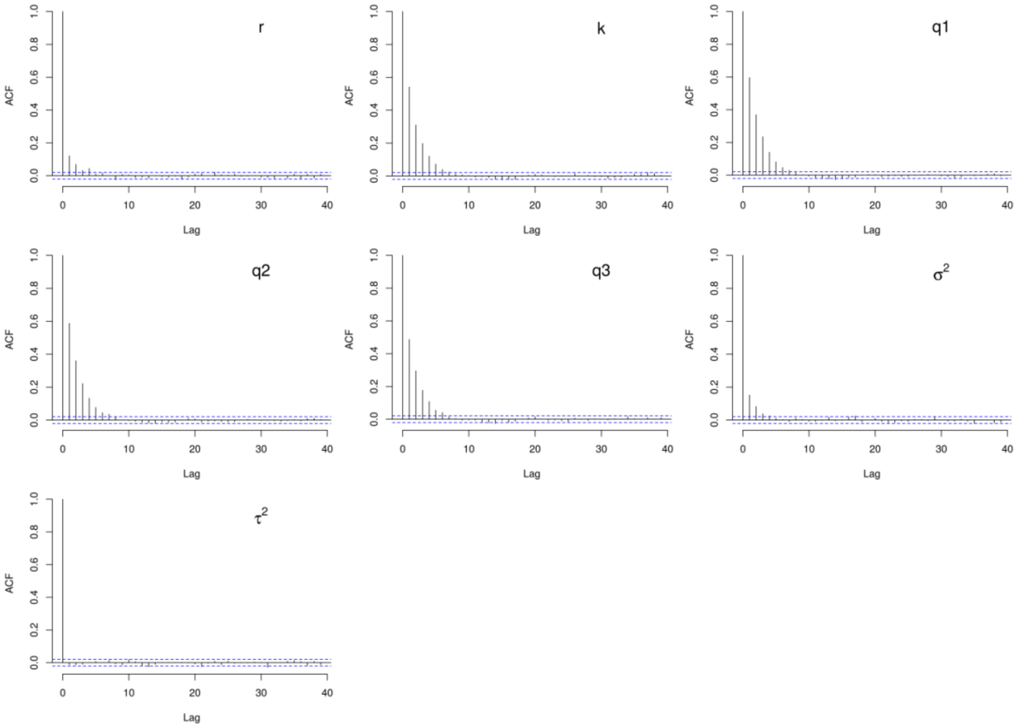

Figure 6 – Autocorrelation of samples of posteriors as calculated using Schaefer type and informative prior. r – intrinsic growth rate; k – carrying capacity; q1 – catchability coefficient of Japan; q2 – catchability coefficient of Taiwan; σ^2 variance of the process error; τ^2 variance of the observational error.

3.3 Model fittings and Residuals

Fox type models fitted to data using non-informative and informative priors are shown in Figure 7. Credibility intervals in the beginning of the time series were wide, which was expected due to the limited data. Model fittings as calculated using and non-informative and informative priors were very similar. Expectations and medians of the posteriors did not change much until the end of 1980's, but they have decreased from 1988 to mid 2000's. In the end of the time series the expectations increased slightly. Models fittings as calculated using Schaefer formulae (Figure 8) were very similar to those calculated using Fox type (Figure 7).

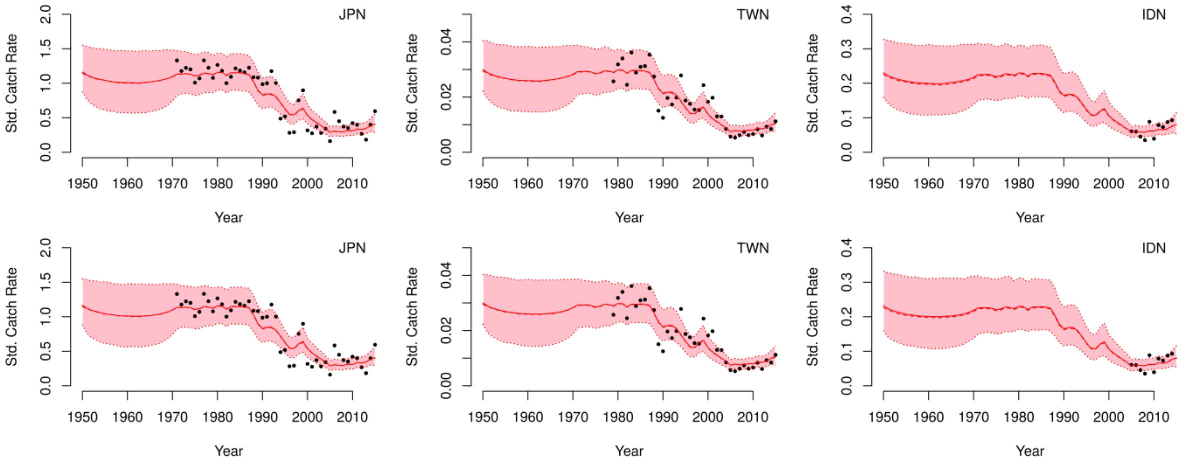

Figure 7 – Fox type models fitted to available catch rate series as calculated using non-informative (top panels) and informative priors (bottom panels). Standardized catch rate time series: Japan (JPN) and Taiwan (TWN).

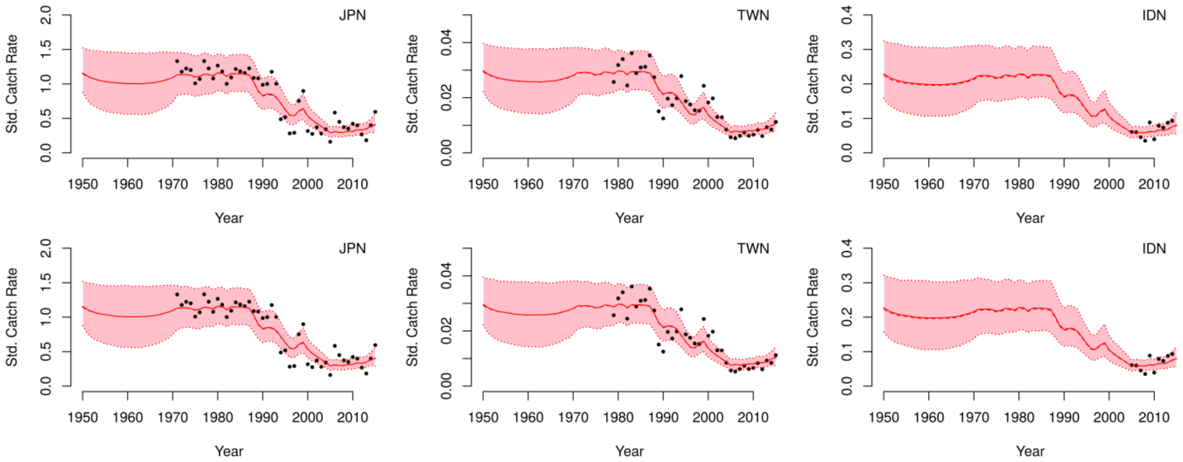

Figure 8 – Schaefer type models fitted to available catch rate series as calculated using non-informative (top panels) and informative priors (bottom panels). Standardized catch rate time series: Japan (JPN) and Taiwan (TWN).

Overall the fittings were good in the sense the expectations are close to most of the observed standardized catch rates. However, in the beginning of 1990's, the estimations of standardized catch rates of Japan were higher than the expectations estimated using the model. Notice also that catch rates of Taiwan were also higher than the expectation from 1994 to 2001.

Time series of residuals are shown in Figures 9 and 10. Confidence intervals were wide for Indonesia time series. In opposition, confidence intervals calculated for Japan and Taiwan residuals were relatively narrow. In fact, Japan and Taiwan time series are more influential than the Indonesia time series which is short. Overall the confidence intervals of residuals of the three time series include the zero, which indicate that models were unbiased for most of the decades since 1970.

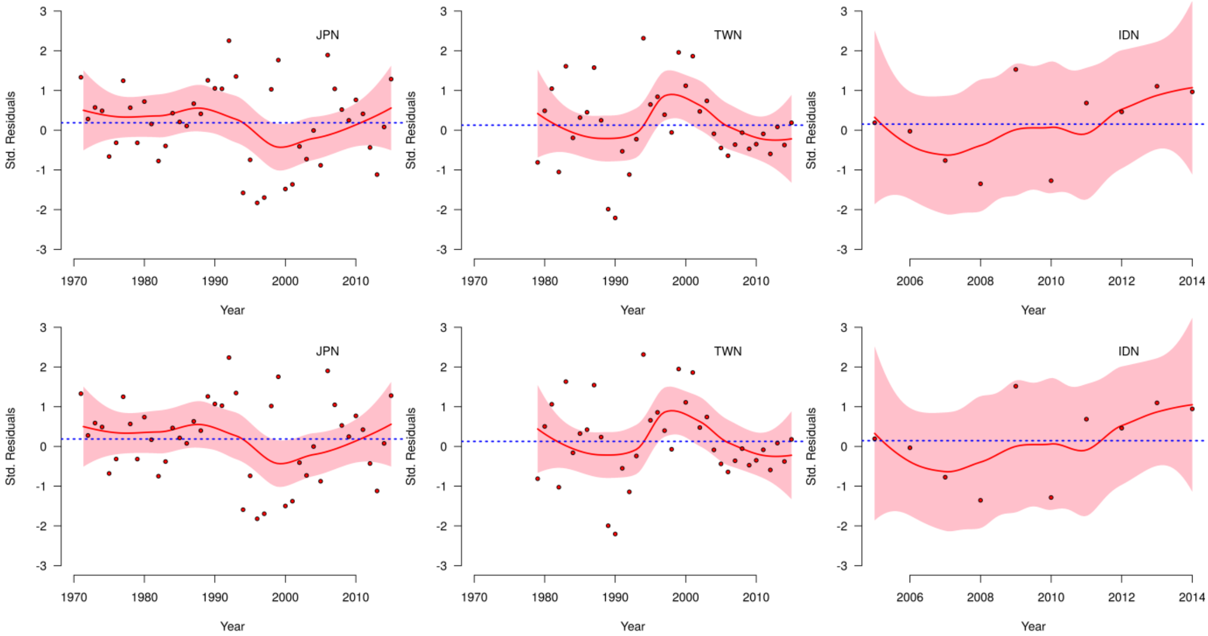

Figure 9 – Residuals of Fox type models fitted to available catch rate time series using non-informative (top panels) and informative priors (bottom panel). Catch rates: Japan (JPN) and Taiwan (TWN).

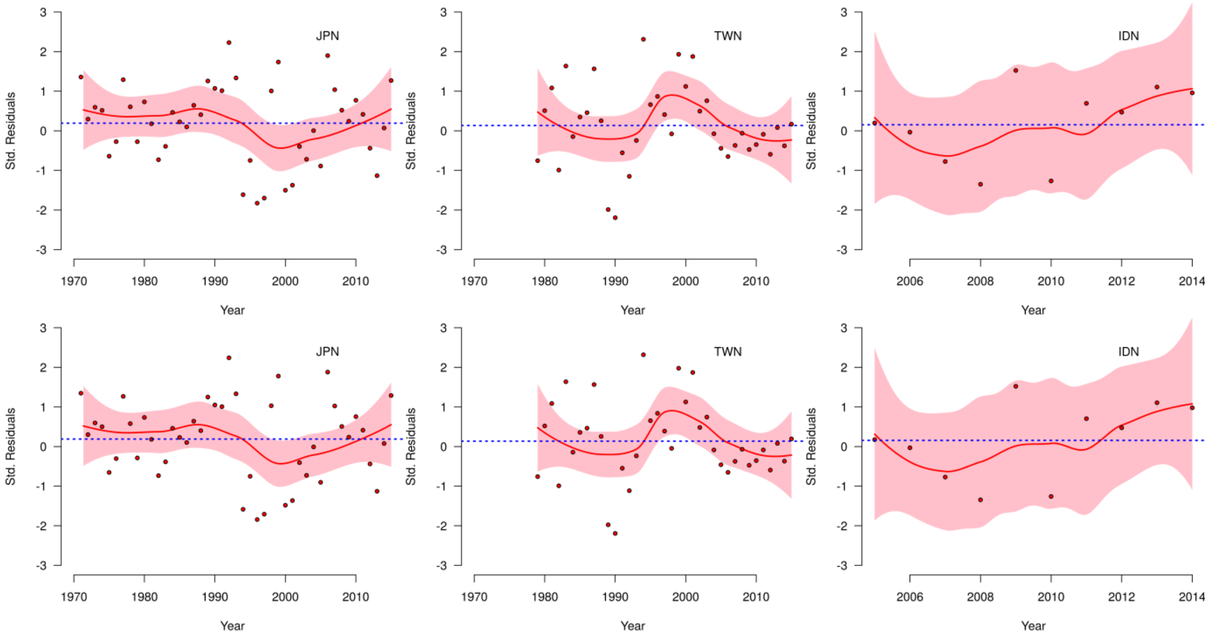

Figure 10 – Residuals of Schaefer type models fitted to available catch rate time series using non-informative (top panels) and informative priors (bottom panel). Catch rates: Japan (JPN) and Taiwan (TWN).

3.4 Marginal Posteriors of Parameters

Posteriors of parameters r, k, q, σ^2 and τ^2 as calculated using Fox type model are showed in Figure 11. Posteriors of proportions ($P_t = B_t/k$) (one for each year) were not showed to not clutter. Posterior of r calculated with Fox type model and the non-informative is not symmetric and it conveys information about the parameter (Figure 11). The posterior gives more weight to values between 0.05 and 0.2. Notice that the precision of the posteriors of r calculated with informative prior is greater than that calculate with non-informative prior. Informative prior and the posterior overlaps as both give weight to small values of r. Posteriors of r calculated with non-informative and informative priors and the informative prior were all similar. Hence the available information (previous knowledge and the data analyzed) are not conflictive. Posteriors of k calculated with non-informative and informative priors were similar (Figure 11 – top panel at right). Both posteriors were bounded by the upper limit of the prior. Data does not convey much information about the parameter as estimations of k much higher than $20 \times$ maximum catch seem unreliable.

Expectations of posteriors of q calculated for Indonesia, Japan and Taiwan using Fox model and the two sets of priors (non-informative and informative) were all similar (Figure 11). The scales of posteriors of q calculated for the three fleets were different which reflect the differences of the scales of the available standardized catch rate time series. Posteriors of variances of observational (σ^2) error calculated using non-informative and informative priors were similar (Figure 11). Similar pattern were also found in the calculations of process error parameter (τ^2). However, the modes of posteriors of σ^2 and of τ^2 were different. If we rely in the posteriors calculations most of data noise are related to the observational model, while the variance of the process error is relatively low ($\sigma^2 \sim 0.4\tau^2$).

Posteriors calculated using the Schaefer type model (Figure 12) were in general similar to those calculated using the Fox type model (Figure 11). However the precision of posteriors of r as calculated using Fox type model was higher than that calculated with Schaefer type model.

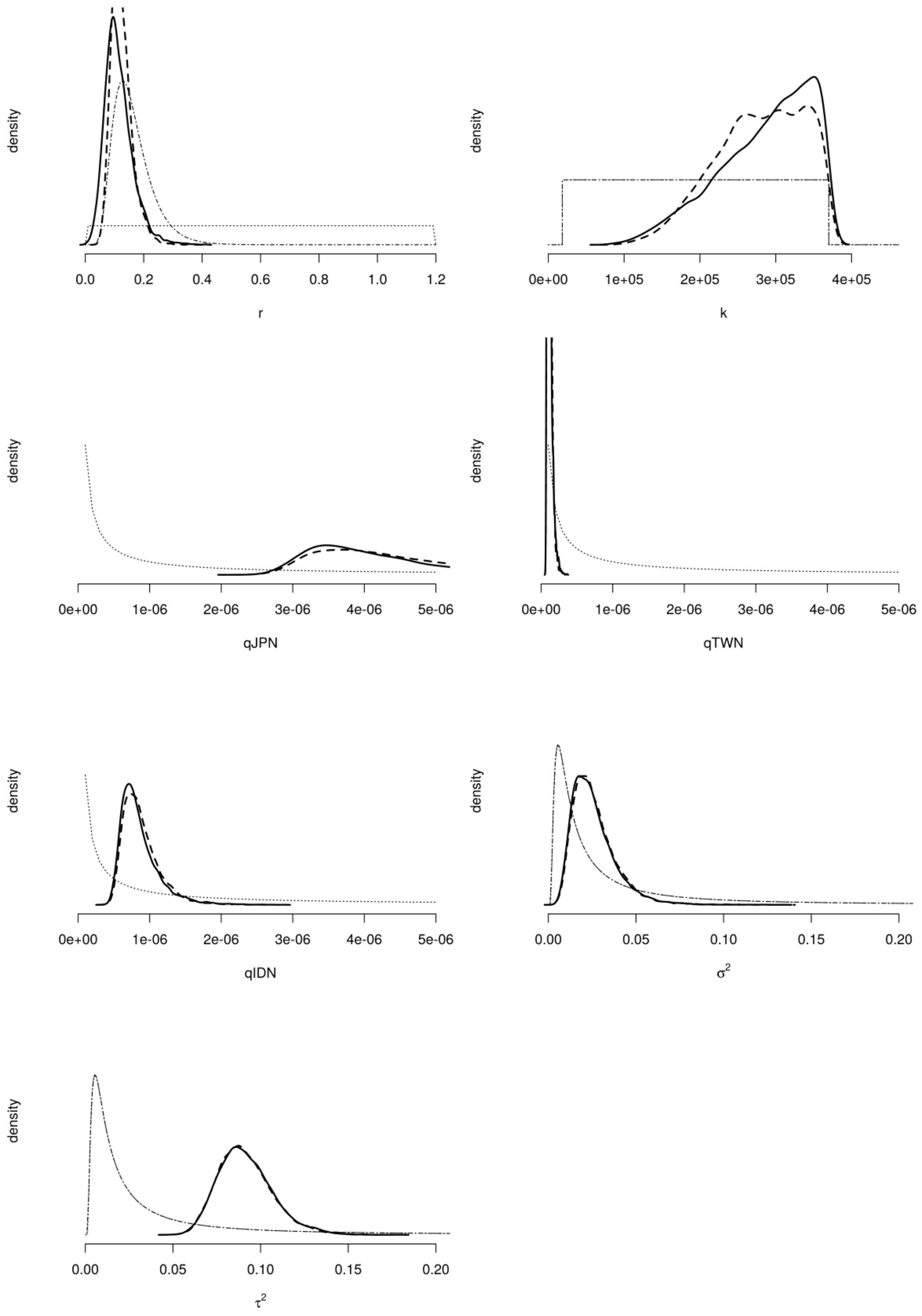

Figure 11 – Priors and posteriors of parameters of Fox type models fitted to catch rates of Japan (JPN), Taiwan (TWN) and Indonesia (IDN). Non-informative prior is indicated by thin dotted line, while the informative was represented by the dotted and dashed thin line. Thick lines stand for the posteriors calculated using the non-informative (solid line) and the informative (dashed line) priors.

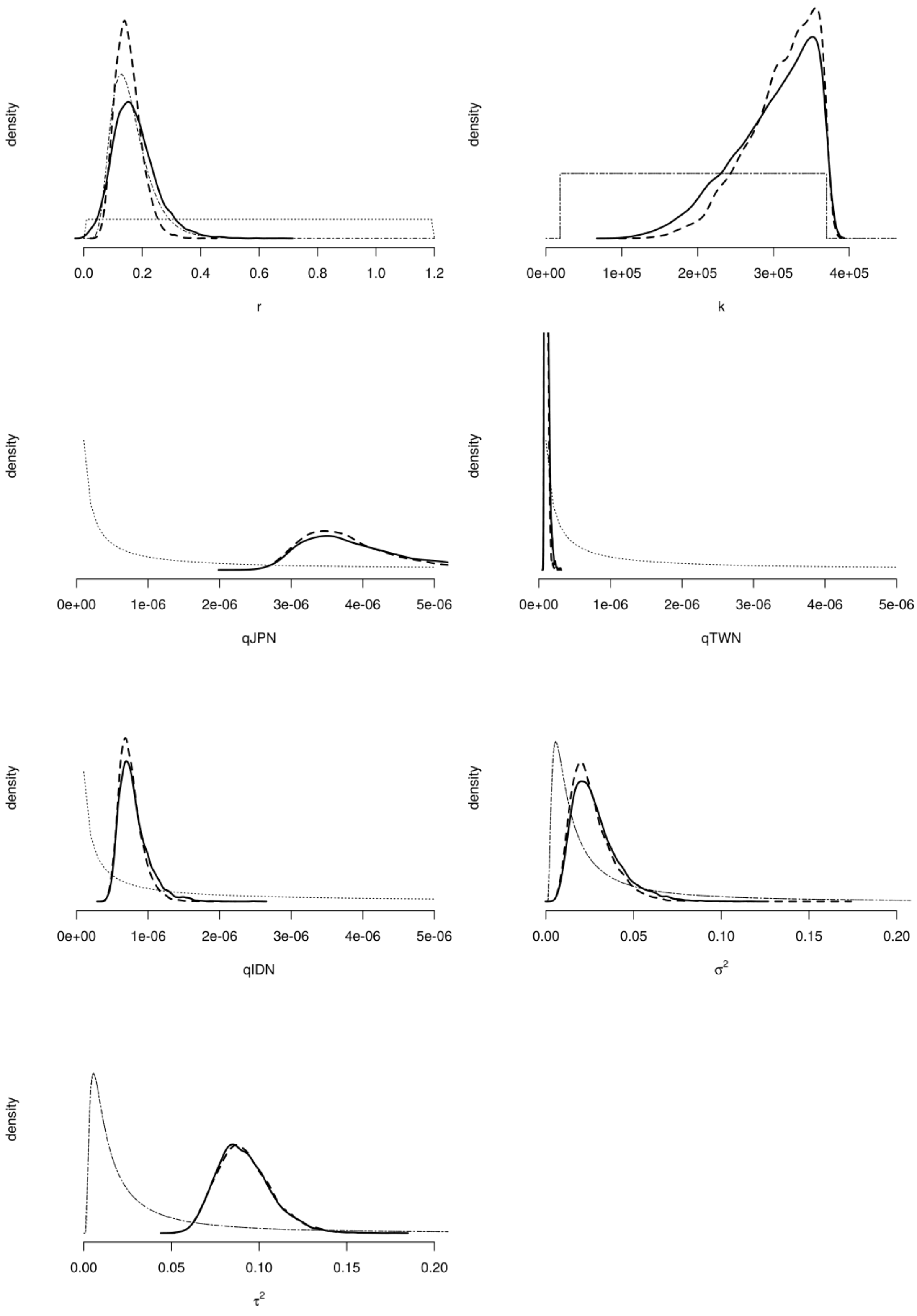

Figure 12 – Priors and posteriors of parameters of Schaefer type models fitted to catch rates of Japan (JPN) and of Taiwan (TWN). Non-informative prior is indicated by thin dotted line, while the informative was represented by the dotted and dashed thin line. Thick lines stand for the posteriors calculated using the non-informative (solid line) and the informative (dashed line) priors.

3.5 Posteriors of Ymsy

Posteriors of Y_{MSY} calculated using Fox and Schaefer type models are in Figure 13. Posteriors calculated with informative priors were more asymmetrical (positive skew) than those estimated with non-informative priors. However the modes of all four posterior samples are between 10,000-12,000 t. Variance of all posteriors were similar. Posteriors give more weight to values of Y_{MSY} between 5,000 and 20,000 t.

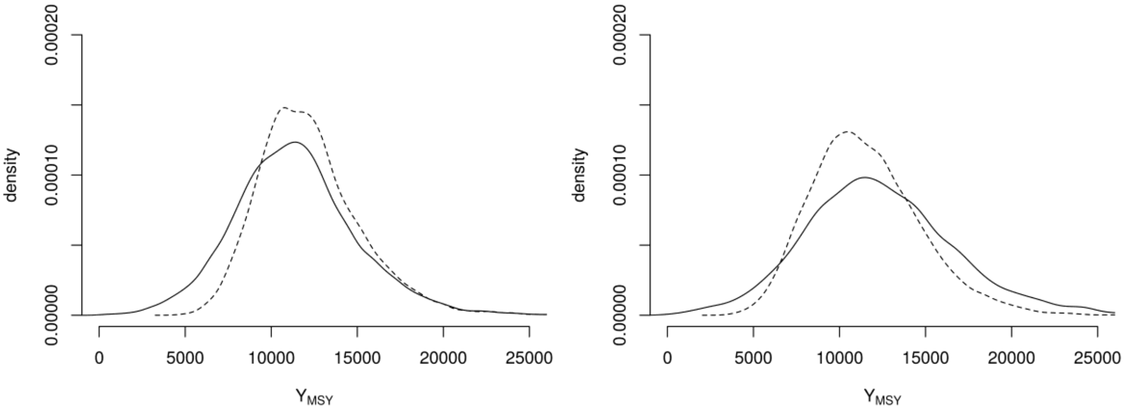

Figure 13 – Posteriors of yield at “maximum sustainable yield” as calculated using Fox (left panel) and Schaefer (right panel) type models. Priors: Non-informative (solid line) and Informative (dashed line).

3.6 Ratios H/HMSY and B/BMSY

Time series of ratios H/HMSY and B/BMSY calculated using Fox type model are in Figure 14. Credibility intervals of B/BMSY were wider in the beginning of time series due to limitation of catch rate data for that period. In opposition, credibility intervals of H/HMSY were wide in the end of time series, which is in part due to the variance of catches in the recent decades. Overall the posteriors calculated with the non-informative and informative priors were similar. The B/BMSY ratio did not change much before mid 1980’s, but it has decreased quickly between 1986 and 2004. Estimations indicate that B/BMSY ratio have been below 1 since mid 2000’s, though a slight recover trend showed up in the recent years.

Harvest ratio H/HMSY was low until the end of 1980’s, but the ratio increased from the beginning of 1990’s until mid 2000’s (Figure 14). Expectations of H/HMSY showed oscillations since then, but they were probably above 1 over the recent years. However, it is important to highly that the credibility interval of H/HMSY was wide and that it includes the reference value 1 since the beginning of 2000’s.

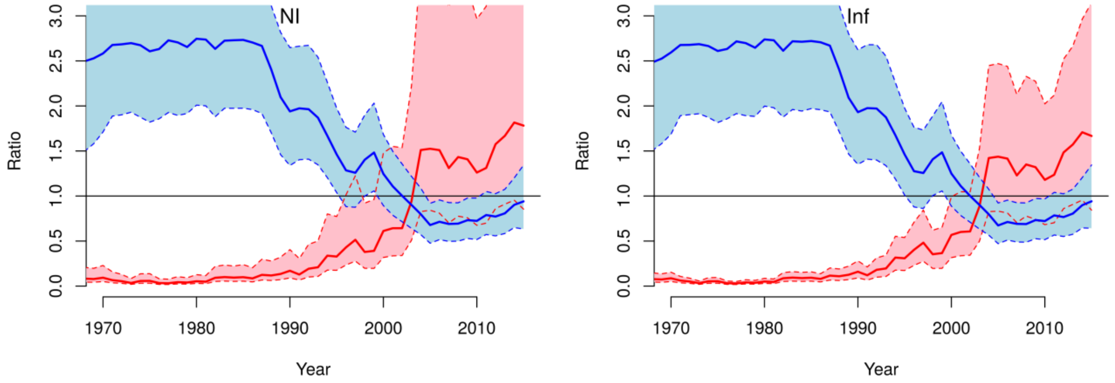

Figure 14 – Time trends of ratios between harvest rate and harvest rate at MSY (H/HMSY) (green/blue), and between biomass and biomass at MSY (B/BMSY) (pink/red), as calculated using Fox type model. Solid lines stand for the means. Calculations with non-informative (NI) prior are in the left, while the panel at right stand for calculations with informative (Inf) prior.

Overall time trends of H/HMSY and B/BMSY calculated using Schaefer model (Figure 15) were similar to those calculated with Fox model (Figure 14). However the posteriors gathered with Schaefer type formulae were more pessimistic in the sense the expectations of B/BMSY were lower that those calculated with Fox, and the ratio H/HMSY as calculated using Schaefer type model was far higher than over the past 15 years.

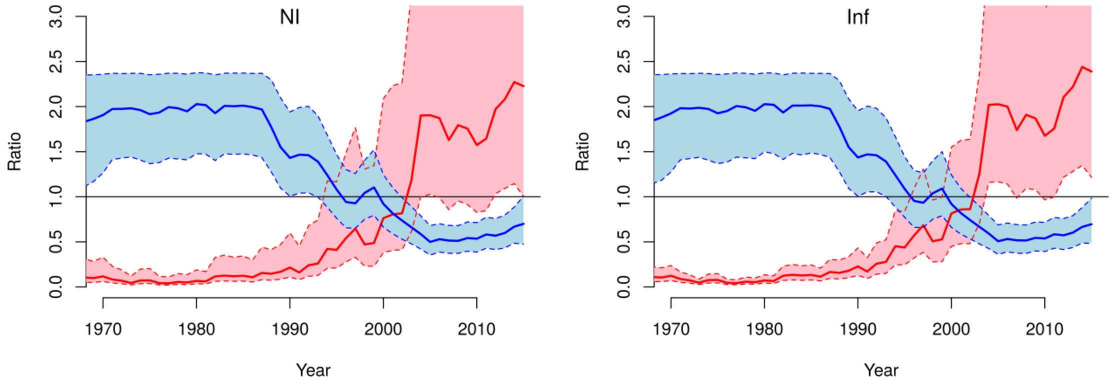

Figure 15 – Time trends of ratios between harvest rate and harvest rate at MSY (H/HMSY) (green/blue), and between biomass and biomass at MSY (B/BMSY) (pink/red), as calculated using Fox type model. Solid lines stand for the means. Calculations with non-informative (NI) prior are in the left, while the panel at right stand for calculations with informative (Inf) prior.

3.7 Kobe plots

Joint posterior distribution of H/HMSY and B/BMSY as calculated Fox and Schaefer models are asymmetrical (Figures 16 and 17). Calculations with Fox type model indicate that black marlin stock was not overfished during a couple of decades after the beginning of the fishery (Figure 16). However, marginal medians and expectations of posteriors indicate that the stock was overfished during the last years. Calculations with Schaefer type model were more pessimistic in the sense they indicate that the stock has been heavily overfished in the recent years (Figure 17). Expectation and median of H/HMSY ratio of 2015 was well above 2, while estimations of B/BMSY are probably close to 0.7.

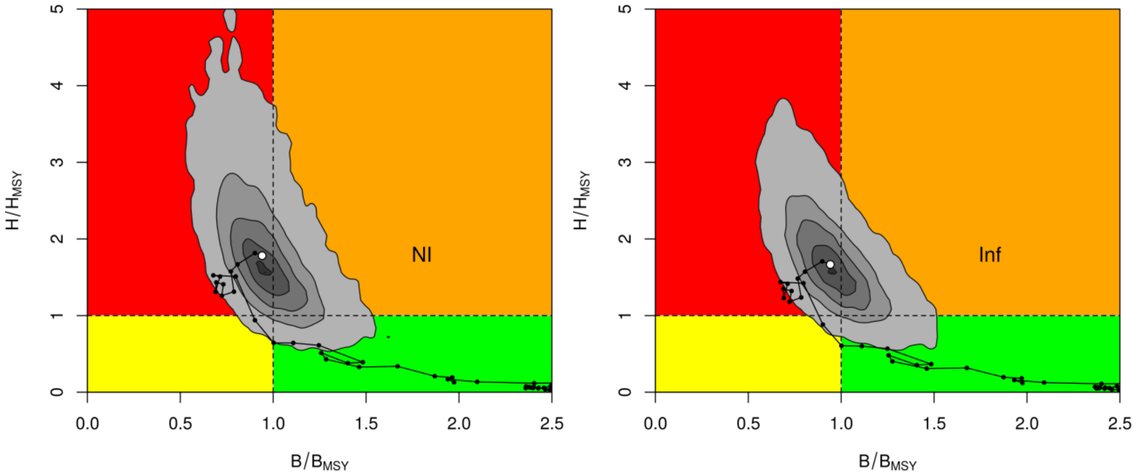

Figure 16 – Contour plots of posteriors of H/H_{MSY} and B/B_{MSY} calculated based on Fox type model. Solid lines and filled circles stand for the trajectories of marginal medians. NI – non-informative prior; Inf – Informative prior.

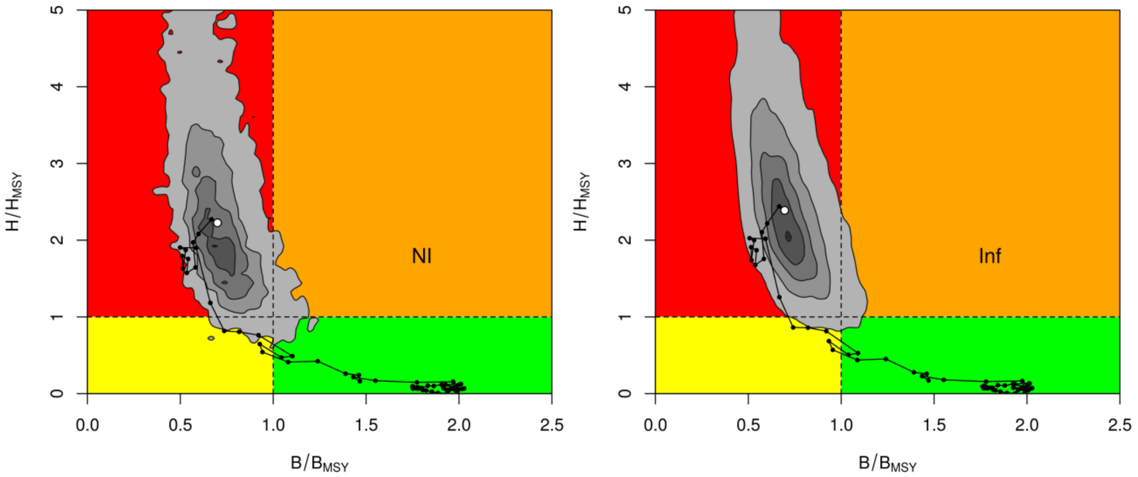

Figure 17 – Contour plots of posteriors of H/H_{MSY} and B/B_{MSY} calculated based on Schaefer type model. Solid lines and filled circles stand for the trajectories of marginal medians. NI – non-informative prior; Inf – Informative prior.

Remarks

All the models were satisfactory concerning criteria to assess convergence of MCMC algorithm. Models are not biased as indicated by the residuals distributions and expectations. Data convey information about r parameter, but estimations of k were not reliable. Posteriors calculated using non-informative and informative priors were not quite different. Current status of the stock is "overfished" if we rely on calculations using Fox and Schaefer type production models. Catches in the very recent years are well above the estimations of YMSY.

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