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MULTI-SPECIES ASSESSMENT OF TUNAS CAUGHT IN THE TROPICAL ATLANTIC PURSE SEINE FISHERY: SENSITIVITY OF PRODUCTION MODELS TO BIASES IN REPORTED CATCHES

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SUMMARY

In this document, different scenarios of uncertainties in a multispecies fishery are presented. Uncertainties have been considered in the estimation of the species composition of the tropical tuna catch as well as in the total catch. Although three species (yellofin, skipjack and bigeye) are involved in the tropical tuna fishery, only uncertainties in the bigeye vs skipjack have been taken into account, in order to simplify the analysis. Regarding the total catch, bigeye has been considered as the species with higher uncertainty due to the IUU catch component. Analyses have been focused in evaluating the sensitivity of the current assessment methods to these uncertainties. Taking into account that the two sources of uncertainty affect the age structure of the catch as well as the total catch, surplus production methods have been applied in the assessment.

RÉSUMÉ

Le présent document décrit différents scénarios d'incertitudes dans une pêcherie plurispécifique. Les incertitudes ont été prises en compte dans l'estimation de la composition spécifique des prises de thonidés tropicaux ainsi que dans la prise totale. Bien que trois espèces (albacore, listao et thon obèse) fassent l'objet de la pêcherie de thonidés tropicaux, seules les incertitudes entourant le thon obèse par opposition au listao ont été prises en compte afin de simplifier l'analyse. En ce qui concerne la prise totale, le thon obèse a été considéré comme l'espèce caractérisée par la plus grande incertitude en raison de la composante IUU dans la capture. Les analyses se sont concentrées sur l'évaluation de la sensibilité des méthodes d'évaluation actuelles à ces incertitudes. Etant donné que les deux sources d'incertitude affectent la structure démographique de la prise ainsi que la prise totale, des méthodes de production excédentaire ont été appliquées dans l'évaluation.

RESUMEN

En este documento se presentan diferentes escenarios de incertidumbres en una pesquería multiespecífica. Se han considerado las incertidumbres en la estimación de la composición por especies en la captura de túnidos tropicales, así como en la captura total. Aunque las tres especies (rabil, listado y patudo) están implicadas en la pesquería de túnidos tropicales, sólo se han tenido en cuenta las incertidumbres en el patudo versus *listado con el fin de simplificar el análisis. En cuanto a la captura total, el patudo se ha considerado la especie con mayor nivel de incertidumbre debida al componente de captura IUU. Los análisis se han centrado en evaluar la sensibilidad de los actuales métodos de evaluación a estas incertidumbres. Teniendo en cuenta que las dos fuentes de incertidumbre afectan a la estructura de edad de la captura así como a la captura total, se han aplicado métodos de producción excedente en la evaluación.*

KEYWORDS

Stock assessment, stochastic simulation, multispecies fishery, bigeye tuna, management scenarios

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1 Introduction

Since the early 1970s a fleet of purse seine vessels mainly targets yellowfin and skipjack tunas in the tropical Atlantic. Typically, skipjack forms mixed-species schools with small bigeye and yellowfin tuna around FADs. Since the beginning of the nineties the development of a fishery based on FADs dramatically increased the catch from this type of schools. Fishermen do not separate the entire catch by species and small tunas form a single market category. The catch by species for this fleet is calculated, from the amount of unsorted catch and from samples of species composition obtained from on-shore sampling of landings. Yet, there is considerable uncertainty associated with this procedure because species composition estimates are rather variable between samples and only about half of the sample variance is explained by the stratification used in the survey (Pallares and Hallier 1997). Errors in the estimated proportion of any given species will alter the calculated catches from all three species, e.g. if the catch of skipjack was underestimated, the catch for either yellowfin or bigeye tuna would be overestimated. Errors in this proportion can potentially affect the estimated catches for all three species and thus also influence the results of assessments for the three species. This paper attempts to establish how this uncertainty alters the perception of stock status for the three species of tropical tunas. The perception of stock status is evaluated with performance measures obtained from simulation experiments.

Two regional fishery organizations (ICCAT, IOTC) have recommended the development of an operational model to support simulation experiments that would test the sensitivity of current assessment to the different sources of uncertainty. Such an operational model could also form the basis for simulation testing of the robustness of management strategies to the uncertainties in the different inputs to an assessment.

1.2 Current knowledge on tropical tuna stocks

Tropical tunas are highly migratory species widely distributed through the oceans. According to ICCAT (ref) there are four stocks of tropical tunas in the Atlantic, one stock of bigeye tuna, one of yellowfin tuna and two stocks of skipjack: an eastern and a western stock. The most recent assessments of yellowfin and bigeye carried out in ICCAT (ANON, 2004 and ANON, 2005) suggest that the current biomass of tuna for each of these stocks is between 0.7-1.1 and between 0.85-1.07 of the estimated biomass at BMSY respectively (ANON, 2005). Although these assessments were done independently and did not incorporate any possible correlations due to trophic or fishery interactions, both of them have identified a common set of uncertainty sources related to the values of specific biological parameters (M and others), fishery statistics (e.g. catch of IUU fleets, juvenile catch) and relative abundance indices for the different species.

In order to asses the effect that current uncertainties is having on the accuracy and variability of the assessments carried out by ICCAT Working Group on Tropical Tunas, a simulation procedure is presented here. Various sources of variability are stochastically incorporated at appropriate steps in the data processing protocol, and their effect is later assessed by applying the relevant assessment model to each of the simulated datasets.

2 Methods

2.1 Operational model: Base case

Operational models have been developed for yellowfin, bigeye and skipjack. In order to simplify the operational model for yellowfin and bigeye the number of fleets to consider has been reduced to three:

- Long line (LL): including the Asiatic and USA fleets
- Surface fleet fishing with FADs: including the European and associated fleets and the Ghanaian (PS+BB) fleet
- Other fleets

The average partial fishing mortality estimated from a forward VPA considering constant recruitment was used to define the selection pattern for these fleets The procedure used for the estimation of fishing mortality is the same as the one used to estimate the effects of the moratorium (ANON, 2001).

The operational model for skipjack is based on:

Total (annual) yields 1961-2001: ICCAT “Task I” data and fishing mortality. The fishing mortality for the period 1975-1997 was found using direct estimates of the fishing effort of European (French+Spanish+Other) purse-seine fleet operating in the eastern Atlantic. The annual catches for the period before 1975 (1961-1974) were used to estimate the F for that period because direct observations of the fishing effort did not exist.

2.2 Observation error model

Uncertainty in the collection of both fishery dependent and independent data can be simulated by assigning probability distributions that reflect the error, known or assumed, at each step of the sampling procedure.

A number of possible sources of uncertainty are being incorporated in the BET base case scenario. These were identified as the most likely relevant. Relatively simple formulations are being used at this stage, to easily understand the relative influence of each factor in the final uncertainty. In contrast with this approach, the data collection procedure could also be replicated by a series of submodels that attempt to mimic the different stages involved (recording of landings, estimation of discards...). Such extra level of complexity would only be justified if the initial simulation procedure had shown that data collection and transformation was an important component in the final uncertainty, or if the qualities of alternative sampling strategies needed to be evaluated.

Two scenarios have been considered to implement errors in the sampling procedure:

Scenario No. 1

- Error in species identification (BET vs. SKJ)

Scenario No. 2

- Error in total catches of BET

Management procedure

- Considering that the assessment of the Atlantic bigeye stock is mainly based in the Surplus Production models results, assessment have been conducted using this type of models.

Analysis of performance

Performance was measured around model parameters and MSY-related quantities, r, K, MSY, BMSY, FMSY, F2001/FMSY and B2001/BMSY.

2.3 Scenario 1: Species composition

The species composition is assumed to only have significant uncertainty in regards to the mixture of catches from purse seiners. Pallarés and Hallier (1997) showed that the proportion of bigeye in free schools is very low, but it approximates 20% for FAD associated schools. Because the operating model does not separate catches between free schools and schools associated with FADs we use a single value of proportion for both types of schools. The variance associated with this value depends on the sampling program used for the estimation of the proportion. Pallarés and Hallier (1997) estimated that 50% of the variance in the proportion is accounted by the stratification of the current program. Thus, in the simulation, the observed variance of the proportion is halved.

A simple way to express the initial uncertainty in a proportion of certain attribute in a population (*X*) is to assign to it a Beta distribution, which density function is

$$f(x) = kx^r (1-x)^{n-r} (0 \leq x \leq 1)$$

One interpretation of this distribution is to assume that the available *a priori* information is equivalent to obtaining *r* elements with a certain attribute in a sample of *n*. As *n* grows, the available information grows, and less is the dispersion of the distribution around its maximum. If $r = n = 0$, the function corresponds to the uniform distribution, that represents a situation without relevant initial information (Peña, 1998). Usually, statistical packages contains formulas to generate Beta distributions with a reparametrization of *n* and *r*. It was thus assumed that the proportion of small bigeye tuna (<10Kg) in the catch of purse-seiners follows a Beta distribution.

The most common notation to represent the Beta distribution is the following:

$$\begin{aligned} & X \approx Beta(\alpha, \beta), \\ & 0 \leq X \leq 1 \\ & \alpha > 0 \\ & \beta > 0 \end{aligned}$$

The probability density function is:

$$f(x) = \frac{x^{\alpha-1}(1-x)^{\beta-1}}{B(\alpha, \beta)},$$

where

$$B(\alpha, \beta) = \int_0^1 x^{\alpha-1}(1-x)^{\beta-1}\, dx$$

The mean and variance are:

$$E(X) = \frac{\alpha}{\alpha+\beta}$$

$$V(X) = \frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)}$$

The parameters α and β can be estimated from the sample mean and variance of observed proportions as:

$$\hat{\alpha} = \bar{x}\left[\left[\frac{\bar{x}(1-\bar{x})}{s^2}\right]-1\right]$$

$$\hat{\beta} = (1-\bar{x})\left[\left[\frac{\bar{x}(1-\bar{x})}{s^2}\right]-1\right]$$

where $\bar{x}$ stands for the sample mean

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

and s^2 represents the biased sample variance

$$s^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2$$

each proportion of catches of small bigeye tuna (<10 kg) each year is assumed to follow a Beta distribution $B(\alpha, \beta)$,with mean equals to the proportion itself, and variance equals to a percentage of error in the distribution of catches between skipjack and small bigeye.

Simulation procedure

The combined catches of small bigeye (<10 kg), $C_{bet01,\,y}$, and skipjack, $C_{skj,\,y}$, are assumed to be known for the purposes of this analysis. As described above, the historical estimates of the proportion of small bigeye , $p_{bet,\,y}$ are randomly taken from Beta distribution $B(\alpha, \beta)$.,

For each simulation a vector of proportions, $p^*_{bet,\,y} = (p_{1961}, \ldots, p_{2001})$ is computed and then used to calculate the simulated catch per species:

Catch small bigeye, $C^*_{bet01,\,y} = p^*_{bet,\,y} \cdot C_{(bet01+skj),\,y}$,
Catch skipjack, $C^*_{skj,\,y} = (1-p^*_{bet,\,y}) \cdot C_{(bet01+skj),\,y}$,

Then, new simulated total catches of bigeye are calculated as the sum of the fix component of catches for ages 2 to 7+, and the simulated component of catches for ages 0 and 1.

Catch bigeye, $C^*_{bet,\,y} = C^*_{bet01,\,y} + C_{bet2\text{-}7+,\,y}$

These catches $C^*_{bet,\,y}$, $C^*_{skj,\,y}$, are then used together with relative abundance indices to estimate the status of the stock by using a biomass dynamic model for each of the species. The Fox formulation was used to fit the model to data .The status of the stock "as evaluated" with the original catches can then be compared to the status of the stock when the simulated catches were used. Initially both stocks are evaluated with biomass dynamic models based on catch and relative abundance indices obtained using the biomass of the operating model (equals to an assumption that cpue is an index of relative abundance with no error). For bigeye the biomass used is that of the adult fish (as it is in the real fishery) and for skipjack the biomass used is the total biomass.

2.4 Scenario 1: Uncertainties in the proportion of bigeye on juvenile catch

Simulations were conducted considering three values of error in the proportion of small bigeye corresponding to CV of 10%, 20% and 30%. For each level of error, 400 runs were conducted using catch proportions drawn randomly. For each iteration estimates of K, r, BMSY, FMSY have been obtained. Also, the performance statistics related to MSY (F2001/FMSY and B2001/BMSY) were obtained.

Because the surplus production model used for assessment purposes was different to the age structured model used in the operational model it was necessary to define a reference case for comparison of results. The biomass dynamic model was fitted under two assumptions for the virgin biomass: a) the parameter K is equal to the biomass generated by the operating model in 1961, and, b) the value of K it is an estimated parameter. Under the first assumption the model supported values for some of the parameters which were unrealistic. Thus the second assumption was selected as a base case.

2.5 Scenario 2: Uncertainties in total catches of Bigeye

For this scenario, only carrying capacity, K, was estimated in the surplus production model. The value of r was fixed at 0.7, considered to be a reasonable value for Atlantic bigeye. This was necessary due to difficulties encountered by the searching algorithm when estimating both parameters that were highly correlated.

Regarding total catch, the uncertainties related to the catches of the IUU (Illegal, Unreported and Unregulated) fleets, starting in the early 1990s, were investigated. Underestimation of the total catch has been investigated assuming equal probability of underestimation in the catches from 1992 between three different intervals (0-15% 15-30% and 0-30%).

Simulation procedure

Total catches of bigeye in the period 1961-1991, $C_{y=61\text{-}91}$, are assumed to be known without error obtained from the operating model. Uncertainty is considered in total catches for the years 1992-2001, $C_{92\text{-}01}$. This is implemented assuming that real catches can have any level of underestimation, during the period considered, with the same probability between three different intervals: 0-15%, 15-30% and 0-30%. Simulated catches, $C^*_{92\text{-}01}$, are obtained as a random proportion of the real catches. Considering that bias in total catch is unlikely independent from one year to the next, the percentage of bias has been kept constant during the period. As an example, for each run simulated catches are:

$$C^*_{92-01} = C_{92-01} \cdot (1 - ps)$$

where *ps* is the percentage of underestimation in total catches obtained randomly from a uniform distribution which limits are the maximum and minimum levels of underestimation considered.

So, the simulated catches of bigeye for the complete period are in 1992-2001

$$C^*_y = \begin{cases} C_y \text{ for } y = 1961, \ldots, 1991 \\ C^*_y \text{ for } y = 1992, \ldots, 2001 \end{cases}$$

These catches together with relative abundance index of bigeye defined as the adult fish as in the Scenario 1, are used to fit a biomass dynamic model.

Simulations for three levels of underestimation in total catches have been run with values: *pu = 0-15%, 15%-30%* and *0-30%.* These ranges have been selected in order to evaluate both bias and variance in the estimates.

The same performance measures as in the scenario 1 have been calculated from the stock production model.

3 Results

3.1 Surplus Production model

In order to evaluate simultaneously the precision and bias of the results of the simulations, we have considered, in a first step, the operational model parameters and estimates as the base case to fit the biomass dynamic model. After that we have calculated the distributions of the estimates relatives to the base case results.

Boxplots of the various parameter values obtained, expressed as the ratio over the base case values, are shown in **Figures 1 and 2-3** for scenarios 1 and 2 respectively. Only the parameters for bigeye tuna, the species most affected by the problems explored in this study, are presented.

Increasing the proportion of bigeye in the catch of small tuna (juvenile bigeye plus skipjack) has a corresponding effect on the uncertainty at estimating the model parameters. Interestingly, the variability appears to be almost equivalent for the first two values of bigeye catch, 10% and 20%. However, when bigeye catch increases to 30%, the effect on the uncertainty of the estimated parameters is much larger (more that double). No simple explanation could be found for this marked non-linear relationship.

The effect of an increase on the maximum possible value of bigeye misreporting, from 15% to 30%, appears to be mostly a proportional increase in the variability on the estimates obtained (**Figure 2**). The minor differences in bias do not appear to be significant. Similarly, sifting upwards the range from which random values of misreporting were drawn, from 0-15 to 15-30, increases almost linearly the negative bias of the estimates with no increase in variability.

A somewhat surprising result is the relative sensitivity of the assessment model applied, a standard MLE Fox model, to various levels of catch uncertainty. Model values and derived management quantities appear to change from being underestimated to overestimated only by increasing the level of uncertainty in catch levels. For example, mean carrying capacity, K, changes from 1.05 to 0.98 of the base case value when missreporting of bigeye catch is allowed to oscillate between 0 and 15% or between 0 and 30% respectively.

It is also of interest the presence of a limited number of outliers among the estimates of fishing pressure and biomass for the last year on the series, 2001. The precise origin of these results has not been determined.

When the error in the proportion of bigeye in the catch of small tuna (Scenario 1 – **Table 1**) is considered, MSY is the quantity estimated with less bias, and that remains closer to the true value as the coefficient of variation in the beta distribution increases from 10 to 20 and 30%.

For Scenario 2 (**Table 2**), quantities related to the present status of the stock (F2001/FMSY, B2001/BMSY) are less influenced by increases in the uncertainty around total catches. For example, when the maximum proportion of unreported catches goes from 15 to 30%, F2001/FMSY relative estimates only vary by 2%.

4 Discussion

As a rule, large uncertainties in “whole stock” catch statistics limit our ability to assess the status of the stocks. This is especially true when the dynamics of the stock are assessed through a production model that strongly depends on the assumption that catch is known without error. The precise relationship between the error in catch data and the uncertainty in the estimated values of production models parameters is complex. It is likely to be related to the characteristics of the estimation algorithm and the information content of the data series. This paper has shown that simulation modeling is a useful procedure to quantify the effects of uncertainty in catch estimates on the parameters of production models.

The relative insensitivity of the production model to uncertainty in the species composition of juveniles is not surprising, as common production models have no age structure and thus this uncertainty can only be reflected as changes in the total catch (the catch derived from the “whole stock”). Age-structured models may be better candidates to detect the impacts of such uncertainty. We applied production models, however, because these have been the most common method used by ICCAT in the assessment of tropical tunas. This paper suggests that even relative severe uncertainty in the catch composition of juveniles is unlikely to affect much production model results, reflecting the insensitivity of production models to uncertainty in the age structure of the catch. This suggest that productivity estimates for bigeye tuna derived from production models are unlikely to be biased due to the existing uncertainty in catch composition of juveniles. Investigation of the effects of this uncertainty on the productivity estimates derived from age-structured models deserve future analysis.

The Atlantic bigeye data series for catch and catch per unit of fishing effort are not very informative, thus the production model fits require making strong assumptions about the values of some parameters, such as r and B_o . It is therefore not surprising that slight changes in the catch series, as those simulated in scenario 1 and especially in 2, lead to changes in the values estimated for production model parameters. In other words, small biases in catch create enough of a signal in the data to influence the model fit. This is a well known phenomenon of model fitting: biases that create trends impact more those data/fit combinations where the signal to noise ratio is small.

This result suggests that biases on catch reports are likely to be more important for stocks that are assessed through methods were the total catch contains much of the signal used to explain the dynamic of the stock. Ensuring the accuracy of catch records is therefore an essential part of the process of using production models for stock assessment.

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Table 1. Scenario 1 mean and standard error of the different statistics.

		mean			*std. dev*	
	10	20	30	10	20	30
r	0.9988	1.0011	1.0016	0.027	0.0278	0.0824
K	1.0015	0.9997	1.0037	0.0233	0.0239	0.0716
MSY	0.9996	1.0001	0.9995	0.0051	0.0052	0.0153
Bmsy	1.0015	0.9997	1.0037	0.0233	0.0239	0.0716
Fmsy	0.9988	1.0011	1.0016	0.027	0.0278	0.0824
F2001	0.9996	1.0006	1.0032	0.024	0.0248	0.0745
F2001/Fmsy	1.001	0.9997	1.0027	0.0094	0.0099	0.03
B2001/Bmsy	0.9995	1.0003	0.9986	0.0063	0.0065	0.02

Table 2. Scenario 2 mean and standard error of the different statistics.

Mean	0-15	15-30
k	1.0466	0.9333
MSY	0.8971	0.8000
BMSY	1.0466	0.9333
B2001/BMSY	0.9343	0.8827
F2001	1.0901	1.0298
F2001/Fmsy	0.9452	0.9428

Std. Dev	0-15	0-30
k	0.0339	0.0656
MSY	0.0291	0.0562
BMSY	0.0339	0.0656
B2001/BMSY	0.0080	0.0560
F2001	0.0093	0.0654
F2001/Fmsy	0.0047	0.0494

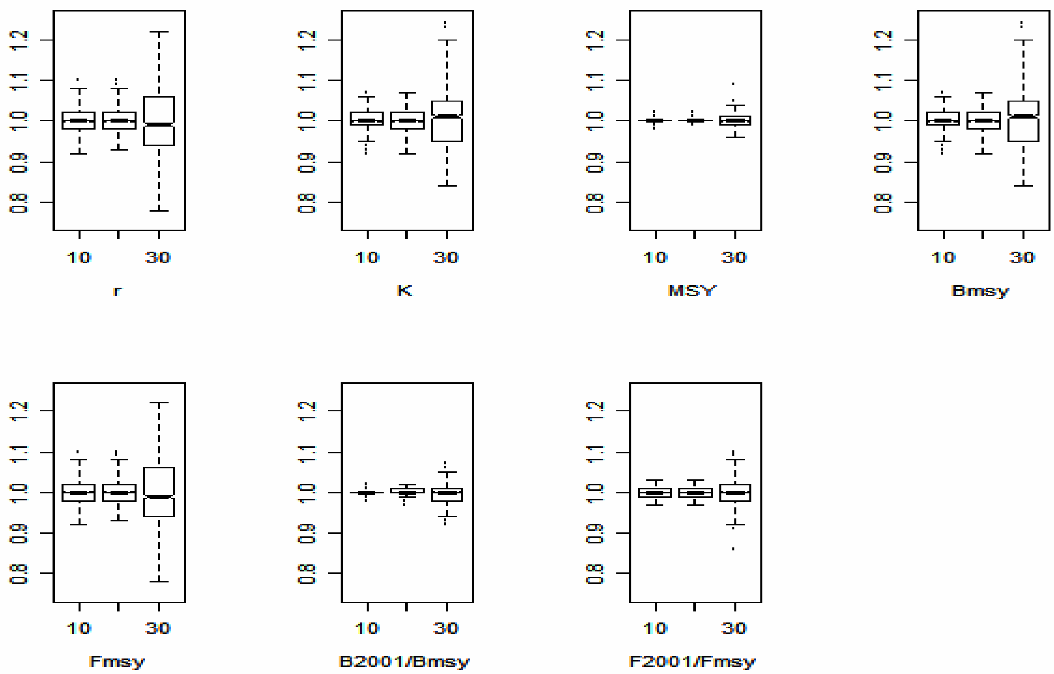

Figure 1. Scenario 1: Relative statistics from Fox production model.

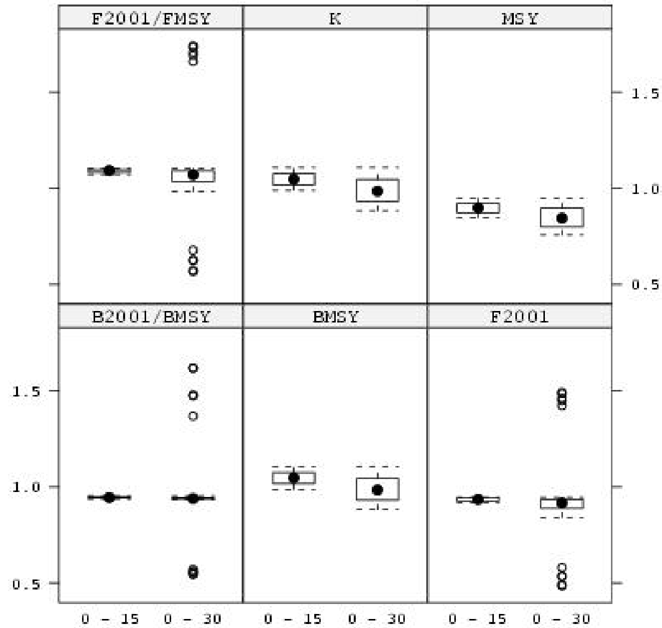

Figure 2. Scenario 2: Relative statistics from Fox production model.

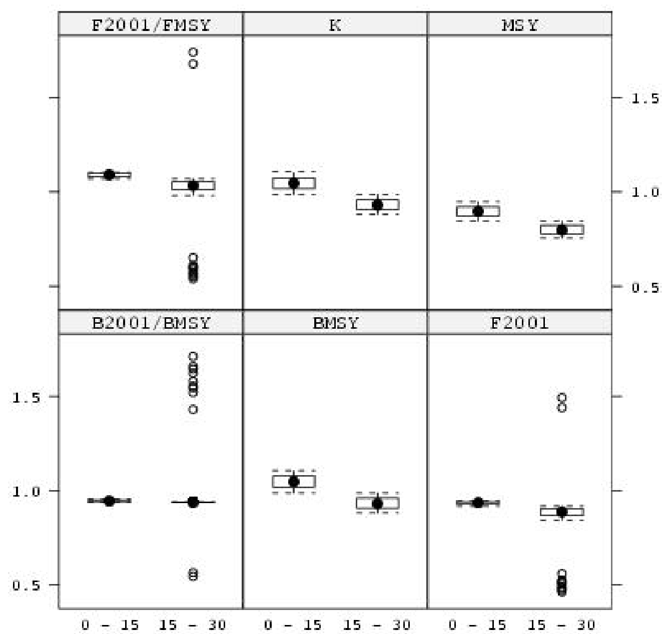

Figure 3. Scenario 2: Relative statistics from Fox production model considering different underestimation rates of catches.