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STANDARDIZED CATCH RATES OF WHITE MARLIN (*TETRAPTURUS ALBIDUS*) CAUGHT BY BRAZILIAN TUNA LONGLINE FLEET (1978-2011)

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SUMMARY

*Standardized catch rates of white marlin (*Tetrapturus albidus*) were calculated for the Brazilian fleet using a zero inflated mixture model based on poisson distribution. The dataset contains information about longline sets carried out by national and leased vessels from 1978 to 2010. Vessels leased from Honduras, Japan, Panama, Portugal, Saint Vincent, Spain, Taiwan, Uruguay and USA were considered in the analyses but calculations were feasible only for all data pooled and for the dataset of Brazilian national vessels and vessels leased from Taiwan. The number of fish caught was the response variable. Effort was considered as offset. Sensitive analysis was carried out concerning levels of factor "area". Nevertheless, standardized catch rates proved to be insensitive to the definition of levels of area. Year and number of hooks per basket were the more important explanatory variables in the models fitted to the pooled dataset and to the dataset of Brazilian national vessels. Standardized catch rates calculated in this paper are similar to those calculated at the last white marlin preparatory meeting.*

RÉSUMÉ

*Les taux de capture standardisés du makaire blanc (*Tetrapturus albidus*) ont été calculés pour la flottille brésilienne à l'aide d'un modèle mixte avec inflation de zéros basé sur la distribution de Poisson. Le jeu de données contient des informations sur les opérations palangrières réalisées par des navires nationaux et affrétés de 1978 à 2010. Les analyses ont pris en compte les navires affrétés en provenance du Honduras, Japon, Panama, Portugal, Saint-Vincent, Espagne, Taipei chinois, Uruguay et des États-Unis, mais les calculs n'ont été possibles que pour toutes les données regroupées et pour le jeu de données des navires nationaux brésiliens et des navires affrétés du Taipei chinois. Le nombre de poissons capturés était la variable réponse. L'effort a été considéré comme compensation. Une analyse de sensibilité a été réalisée concernant les niveaux de facteur* "area"*. Néanmoins, les taux de capture standardisés se sont avérés insensibles à la définition des niveaux de zone. L'année et le nombre d'hameçons par panier étaient les variables explicatives les plus importantes dans les modèles ajustés au jeu de données regroupées et au jeu de données des navires nationaux brésiliens. Les taux de capture standardisés calculés dans ce document sont similaires à ceux calculés lors de la dernière réunion de préparation des données sur le makaire blanc.*

RESUMEN

*Se calcularon las tasas de capturas estandarizadas de aguja blanca (*Tetrapturus albidus*) utilizando un modelo mixto de ceros aumentados basado en la distribución Poisson para la flota brasileña. El conjunto de datos contiene información sobre los lances de palangre llevados a cabo por buques nacionales y fletados entre 1978 y 2010. Se consideraron en el análisis los buques fletados de Honduras, Japón, Panamá, Portugal, San Vicente, España, Taipei Chino, Uruguay y Estados Unidos, pero los cálculos fueron factibles sólo para todos los datos agrupados y para el conjunto de datos de los buques nacionales brasileños y los buques fletados de Taipei Chino. El número de peces capturados fue la variable de respuesta. El esfuerzo se consideró como compensación. Se realizó un análisis de sensibilidad para los niveles de factor* "area"*. Sin embargo, las tasas de captura estandarizadas fueron insensibles a la definición de niveles de área. El año y el número de anzuelos por cesta fueron las variables explicativas más importantes en los modelos ajustados al conjunto de datos agrupados y al conjunto de datos de los buques nacionales brasileños. Las tasas de captura estandarizadas calculadas en este documento son similares a las calculadas en la última reunión de preparación de datos de aguja blanca.*

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KEYWORDS

Long lining, catch/effort, catchability, abundance

1. Introduction

In fishery literature the relationship between abundance (N) and a potential relative abundance indices (I) in t^{th} year is often assumed to be $I_t = q_t N_t$. Hence I_t is an unbiased relative abundance indice if catchability coefficient q_t does not change in a monotonous fashion over the years. However catchability coefficient can change due to several factors related to environment, fishermen behavior, fishing strategy and fishing gears (Cooke and Beddington, 1984; Hilborn and Walters, 1992). Usually q of those species fishermen aim at tend to increase over the years due to fishermen learning and due to development of more efficient fishing techniques.

Commercial catch rate, often denominated catch-per-unit-effort (CPUE), is expected to result in biased relative abundance indices because they reflect changes in abundance (N) as well as changes of fishing strategies, techniques and gears. Although catch rates of fishing fleets are not ideal they are often used because many exploited species are not monitored or not monitored comprehensively. High cost associated with a large scale pelagic survey has prevented the development of comprehensive scientific monitoring programs for highly migratory species (Bishop, 2006) like tuna (Lynch *et al*., 2012). Indeed, there is not fishery-independent data for the area where the Brazilian longline tuna fleet operates. Hence estimations of relative abundance are usually based on CPUE data.

There are several approaches to analyze catch rate of fishery-dependent data in order to calculate indices affected mainly by changes of the biomass instead of changes of other factors. Those indices are usually denominated "standardized catch rates". Generalized linear models (GLM) have been often used to "standardize" commercial catch rates (or CPUE). In the GLM framework catch or catch rate is the response variable assumed to follow a probability distribution of the exponential family. One monotonous and differentiable function (*link function*) links the response variable to explanatory variables in an additive linear structure. Explanatory variables may be qualitative (factors) or quantitative (covariates) (McCullagh and Nelder, 1989 and Dobson, 2002). Variations of q due to changes in fishing grounds, technology and other factors are hopefully represented by coefficients calculated for factors like "area", "type of gear", and so on. Coefficients calculated for the factor "year" are then expected to represent the effect of annual variation of abundance (Maunder and Punt, 2004). That is true if all important factors affecting q are appropriately included in the model. Usually those issues mentioned above are not assessed in the papers concerning standardized catch rates. For example, the choice about the levels of factors like "area" is subjective but validation or, at least, sensitive analyses have not been carried out elsewhere (e.g. Ortiz and Arocha, 2004; Andrade, 2012).

Catches of valuable and abundant species that fishermen aim at are rarely equal to zero. However if the species is not the target or, if the abundance is not high or, if the catchability is low, a large amount of null catches arise. That is the white marlin case in Brazilian fisheries. Most of Brazilian national and leased vessels captains have been fishing swordfish, yellowfin, blue shark and bigeye tuna (Hsu and Chang, 1993; Arfelli, 1996; Meneses de Lima *et al.*, 2000), hence the numbers white marlins caught are often low or equal to zero.

If the amount of zeros is large, the data is overdispersed and it is not easy to find out an appropriate probability distribution that fits the data. However mixed or hurdle models may be used to model overdispersed counting data (*e.g.* Mullahy, 1986; Ridout *et al.*, 1998). The approach used to cope with zeros in hurdle models is to use Bernoulli or binomial distributions to model the proportion of positive catches, while some probability distribution truncated at zero (*e.g.* truncated Poisson) is used to model positive catches. In the mixed models zero catch may arise from two distributions. One of them is used to model part of the zero catches and the positive catches (*e.g.* Poisson). The other distribution is the Bernoulli used to model the excess of zero values. Models used to cope with overdispersed data due to excess of zeros are often called zero-inflated models, specially the mixed ones.

In this paper data concerning Brazilian tuna longline fishing fleet are analyzed to estimate standardized catch rates for white marlin using a zero inflated generalized linear model. Brazilian fleet is composed of national vessels as well as vessels leased from several countries. Models were fitted to data split by flag as well as to all data pooled. Sensitive analysis concerning the subjective choice of levels of factor "area" was also carried out.

2. Data and Analysis

2.1 Database

Dataset analyzed in this paper is similar to that described by Andrade (2012). Details can be found in that paper but a summary of the dataset is warranted. Variables available in database are flag of the vessel, date, location, number of hooks, number of hooks per basket, time when the longline was set into the water and time when longline was retrieved. Soak time was calculated based on the difference between the time at the end of longline setting and the time at the end of longline retrieval. Time expended while setting the longline in the water was calculated as the difference between time at start and at end of longline setting operation.

Some of the leased vessels have been fishing for few years. In this paper only data of national and leased fleets that fished during a large number of years were considered. Most of the information available for years before 1990 is about brazilian national fleet and vessels leased from Japan that left Brazil in the beginning of 2000's. After 1990 vessels were leased from other countries but only those leased from Spain remained from 2008 to 2010. Finally, in 2011 vessels leased from Japan have been fishing again off Brazilian coast.

Most of the national and leased boats have been fishing over equatorial, tropical and subtropical areas of the South Atlantic off Brazilian coast (**Figure 1**). Most of the fleets have fished mainly in the equatorial area, except the ones composed by vessels leased from Honduras and Japan that fished mainly in south area (**Table 1**).

2.2 Models and Variables

The response variable (Y) (number of fish caught in each of the fishing sets) is assumed to follow the zero-inflated Poisson (ZIP) distribution:

(1) $$\Pr(Y = y) = \begin{cases} \omega + (1-\omega)\exp(-\lambda) & y = 0 \\ (1-\omega)\exp(-\lambda)\,\lambda^y/y! & y > 0 \end{cases}$$

Catches equal to zero are assumed to arise with probability ω plus probability $(1-\omega)\exp(-\lambda)$. The parameter λ is the mean of Poisson distribution. Lambert (1992) has used the logarithm and de logit as link functions:

(4) $$\log(\lambda) = X\beta \qquad log\left(\frac{\omega}{1-\omega}\right) = Z\gamma$$

where X and Z are design matrices for explanatory variables while β and γ are vectors of parameters. Those link functions were also used in this paper and, the two sets of covariates X and Z are equal. Welsh *et al.* (1996) provided analytic solutions to calculate the exceptions and variance for the expectations based on information matrices of Poisson and Bernoulli models. Another alternative is to assume that the parameters estimations follows multivariate normal sample distribution, hence hessian matrix and Monte Carlo approach can be used to calculate variance and confidence intervals for the expectations. That numerical approach was the one used in this paper.

The explanatory variables I have considered are similar to those described in Andrade (2012), namely:

- $year$ (factor);
- $flag$ (factor);
- hpb (covariate) ⇒ Number of hooks per basket;
- $quarter$ (factor);
- $area$ (factor) ⇒ Levels as showed in **Figure 1**;
- $soak$ (covariate) ⇒ Soak time as calculated by the difference between time at the end of longline setting and at the end of longline retrieval;
- $dset$ (covariate) ⇒ Time expended when setting the longline as calculated by the difference between time at start and time at end of longline setting operation; and
- $pset$ (factor) ⇒ Period of the day when the longline set started. There are two levels: N (night) – before 9:00 or after 17:00 and D (day).

Three different structures concerning levels of factor $area$ were defined by adaptations of the subareas showed in **Figure 1**. Four levels just like those showed in **Figure 1** were considered in the first approach. In the second approach three levels, namely subarea A, subareas B and C pooled together (BC), and subarea D were considered. In the third approach only two levels, subareas A and B pooled together (AB) and, subareas C and D pooled together (CD) were considered. Hence the levels of the factor $area$ as defined in the second and third approach are composite of the levels defined in the first approach. The motivations underlying the selection of those levels were the distribution of effort and also in papers on standardization of white marlin catch rates published elsewhere. More specifically, the areas defined in the third approach are similar to those considered by Hazin *et al*. (2007), while the areas defined in the second approach are similar to three of the areas considered by Yeh (2007). Both papers were presented during the last ICCAT white marlin stock assessment meeting carried out in 2006 (ANON, 2007).

Logarithm of number of hooks was the offset in the models. Main effects and all possible first order interactions between two of the explanatory variables were considered. I have used two approaches to cope with the multiple fleets. In the first I have fitted models to complete dataset including flag of vessels as explanatory variable. In the second approach the dataset was split by flag.

The function $zeroinfl(\,)$ of the package *pscl* developed by Zeileis $et\ al$ (2008) to run using R software (R Development Core Team, 2011) was used to estimate the parameters of the models. Estimations were calculated by maximizing likelihood using $optim(\,)$ (function of R). Hessian matrices returned by $optim(\,)$ were used to calculate variance-covariance matrices and standard errors.

2.3 Selection of Variables and Models

One alternative to select variables and models is to start with a simple model and, to increase the complexity by adding one term (an explanatory variable or an interaction). Thus some criterion like Bayesian Information Criterion (BIC) (Schwarz, 1978) can be used to assess if the inclusion of the new term has improved the model. Usually fishery data is not balanced and the design matrix is not orthogonal, hence the estimations of the parameters may be strongly correlated. Consequently the order the parameters enter the model is important. Several approaches can be used to cope with that issue. I have used the one described in Andrade (2012).

3. Results

3.1 Catch, Effort and Catch Rate

Total effort, catch and average catch rate weighted by effort were calculated for aggregated data (all years and flags) by 1^o x 1^o (latitude x longitude) squares (**Figure 1**). Effort was concentrated mainly in equatorial and tropical waters northward of 15^{o}S but fishing effort was also high in the oceanic areas between 15^{o}S and 25^{o}S and, in south close to Brazilian coast (**Figure 1**). Spatial distribution of catch is similar to that of effort. High CPUE values of white marlin were spread out all over the areas were the fishermen have been working. Although there is not a clear pattern I shall mention that apparently the CPUEs were higher close to coast in equatorial waters, in the oceanic subtropical waters and that the CPUE values were not that high southward of 25^{o}S close to coast where the effort was high.

3.2 Models

Calculations using the algorithm BFGS of package *pscl* were not feasible for several fleets (BRA-ESP, BRA-HND, BRA-JPN, BRA-PAN, BRA-PRT, BRA-URY, BRA-USA, BRA-VCT) when $year$ was included in the models. The order the main exploratory variables were included in each of the selected models for pooled, BRA and BRA-TAI datasets are in **Table 2**. Explanatory variables $year$ and hpb ranked first and second in models for all data pooled and for national boats (BRA) while $year$ and $quarter$ were the more important factor in the models for leased boats from Taiwan (BRA-TAI).

Interactions dropped off of the models as well as the number of parameters estimated and the BIC calculations are in **Table 3**. Most of the interactions were dropped because the algorithm calculations were not feasible when they were included in the models. Notice that all interactions involving $year$ were discarded.

Standard diagnostic plots of residuals are in **Figure 2**. Smoothed lines in the dispersion diagrams of fitted versus standardized residuals oscillates around zero in most of the cases. Nevertheless there is some concern about biases when the model predictions (fitted values) are larger than 2 fish per 1000 hooks.

3.3 Standardized and Nominal Catch Rates

Nominal catch rates (number of fish per 1000 hooks) for pooled data, Brazilian national vessels and vessels leased from Taiwan are in **Figure 3**. Catch rate of all flags pooled and of national vessels are similar in the sense both time series show a peak in 1996 and in the end of 2000's. Nevertheless the remarkable peak of catch rate in 1993 appears only in the time series calculated for national vessels. Overall catch rates of vessels leased from Taiwan are smaller than the others.

Standardized catch rates as calculated for all data pooled, for national vessels and for vessels leased from Taiwan are showed in **Figure 4**. Estimations calculated for the three different approaches concerning the levels of factor $area$ are very similar hence the lines overlap in **Figure 4**. Overall catch rates of all fleets pooled showed a decreasing trend until the mid 1980's, a peak in mid 1990's and a couple of peaks in the end of 2000's (**Figure 4 A**). The main difference between the nominal and the standardized catch rates for all fleets pooled appears in the end of 1970's. The nominal catch rates are very low back 1980 while the standardized ones are high. Catch rates of national Brazilian vessels are higher in 1990's than in other periods (**Figure 4 B**). It is remarkable the peak in 1993 that also appears in the nominal catch rate time series. Nevertheless the peak in 1996 noticeable in the nominal catch rate series is not that high in the standardized time series. The standardized catch rate series for vessels leased from Taiwan (**Figure 4 C**) are similar to the nominal time series (**Figure 3**).

Because estimations as calculated with the three approaches concerning the factor $area$ are very similar, 95% confidence intervals (**Figure 5**) are shown only for one of the approaches for simplicity. Confidence intervals are wide for most of the years. Furthermore most of the confidence intervals overlap each other. Hence consistent increasing (or decreasing) time trends are not apparent in the standardized time series.

Standardized time series as calculated in this paper for pooled data are showed together with Brazilian time series used in the last white marlin assessment meeting (Anon., 2007) and with the time series presented in the last preparatory meeting carried out in 2011 (Anon., 2012) (**Figure 6**). Estimations calculated in this paper and presented in the 2011 preparatory meeting are very similar. The exception is the peak in 2007 that appears only in the estimations calculated in this paper. Time series of calculations used in the last stock assessment meeting are very different than the others.

4. Discussion

Calculations were not feasible for several datasets split by flag (BRA-ESP, BRA-HND, BRA-JPN, BRA-PAN, BRA-PRT, BRA-URY, BRA-USA, BRA-VCT) due to convergence failure. Worth to carry out investigations based on other algorithms than BFGS of the package *pscl*. Despite other algorithm may eventually be successful where the BFGS has failed it is evident that those datasets mentioned above are not informative about the relationship between catch rate of white marlin and the explanatory variables I have considered in the models. That is a hint that the fishery dependent dataset is not satisfactory.

Convergences were reached for three datasets: all flags pooled, Brazilian national vessels (BRA) and vessels leased from Taiwan (BRA-TAI). Ideally changes in abundance are represented by the coefficients calculated for levels of factor $year$. If $year$ is in interactions with other factors and covariates, the task of extracting those separated $year$ effects may be cumbersome and/or may require some subjective weighting of the coefficients (Maunder and Punt, 2004). Nevertheless that difficult did not arise in this paper because iterative algorithm did not converge when considering $year$ in interactions. That convergence failure was probably due to the large number of parameters to be estimated because $year$ has many levels. Calculations are easier when interactions concerning $year$ are not included in the models but standardized catch rates as calculated using such simple models may be biased. That issue worth investigation because the difficulties to include interactions will probably increase in the future once the available time series becomes longer year after year. As a matter of fact biases has arisen especially when the model's fitted values were high.

Calculations of standardized catch rates were not sensitive to the three different sets of levels of the factor $area$. There are at least two possible explanations: a) the selected levels of factor $area$ considered in the models do not reflect stratifications of catch rate distribution at least when all fish caught is pooled whatever the maturation stage and sex; and b) levels of the factor $area$ would be important in interactions (ex: $year{:}\,area$) that were not calculated due to iterative algorithm failure. Those issues remain to be further investigated in the future but, at first glance, exhaustive discussions on which are the appropriate levels of factor $area$ do not worth the effort when analyzing white marlin catch rates in the South Atlantic Ocean.

There are important differences between the nominal time series and standardized catch rates as calculated for all data pooled and only for the national Brazilian vessels. Those differences are a good sign that the standardizing procedure was, at least in part, successful. One interpretation of those differences is that they indicate that some of the biases of the nominal catch rates were eliminated or at least attenuated. Nevertheless there are also other symptoms that suggest the standardizing procedure was not that successful. Calculations should result in numbers that reflect only the changes of abundance across the years. Hence, time trend of standardized indices should be similar whatever the dataset used, unless, some important factors were not included in the models. Moreover, time trend of standardized catch rates should be meaningful on biological grounds. For example, peaks or sharp increasing trends in a small amount of time are very unlike for white marlin populations. Nevertheless both bad signs have showed up in this paper. The standardized time series of the several fleets are not that similar and, those not biologically meaningful peaks have also arisen in the results. Hence standardized catch rates as calculated in this work should be carefully considered as relative abundance indices.

Finally, the Brazilian standardized time series used in the 2006 white marlin stock assessment meeting (ANON, 2007) is quite different from that presented in the 2011 preparatory meeting and that showed in this paper. I was not able to find out in the 2006 detailed report how that standardized catch rate series was calculated. Nevertheless the series showed in the report is similar to that showed in Andrade (2007) that was calculated based on aggregated ICCAT task II dataset. That is probably the explanation for the differences found between the time series because in 2011 and in this paper the dataset is not aggregated, instead, it contains information about each longline fishing set. Details on the calculations presented in the 2011 preparatory meeting are in the paper of Hazin *et al*. (2012) that is not published yet. I do not know the model they have used but, I know they have used the same dataset. That is an explanation for the similarity between the results they have got and the ones showed in this paper.

References

Andrade, H. 2007, Estimation of the relative abundance of Atlantic billfish: Effects of three approaches to cope with catches equal to zero. Col. Vol. Sci. Pap. ICCAT, 60(5):1707-1719.

Andrade, H. 2011, Standardized catch rates of albacore (*Thunnus alalunga*) caught by Brazilian fleet (1978-2010). Collect. Vol. Sci. Pap. ICCAT. 68(2): 615-631.

Anon. 2007, Report of the 2006 ICCAT Billfish Stock Assessment. Collect. Vol. Sci. Pap. ICCAT, 60(5): 1431-1546.

Anon. 2012. Report of the 2011 Blue Marlin Stock Assessment and White Marlin Data Preparatory Meeting. Collect. Vol. Sci. Pap. ICCAT, 68(4): 1273-1386.

Arfelli, C.A. 1996, Estudo da Pesca e Aspectos da Dinâmica Populacional de Espadarte, Xiphias Gladius L. 1758, no Atlântico Sul. Rio Claro (SP). Ph. D. Thesis - Instituto de Biociências, Universidade Estadual Paulista.

Bishop, J., 2006, Standardizing fishery-dependent catch and effort data in complex fisheries with technology change. Rev. Fish Biol. Fish. 16, 21–38.

Cooke, J.G. and Beddington, J.R. 1984, The relationship between catch rates and abundance in fisheries. IMA J. Math. Appl. Med. Biol. 1: 291-405.

Dobson, A. J. 2002, An introduction to Generalized Linear Models. Chapman and Hall/CRC, London. 225 p.

Hazin, F.H.V.; Hazin, H.G.; Travassos, P. and Oliveira, I. M. 2007, Standardized catch per unit effort of white marlin, Tetrapturus albidus, and blue marlin, Makaira nigricans, caught by Brazilian tuna longline fleet. Collect. Vol. Sci. Pap. ICCAT, 60(5): 1652-1662.

Hazin, H.G., Mourato, B., Hazin, F., Carvalho, F., Frédou, T., Travassos, P. and Pacheco, J.C. 2012, Standardized CPUE series of blue and white marlins caught by Brazilian tuna longline fisheries in the southwestern Atlantic ocean (1980-2010). Collect. Vol. Sci. Pap. ICCAT, 68(4): 1531-1542.

Hilborn, R. and Walters, C.J. 1992. Quantitative Fisheries Stock Assessment. Chapman and Hall, New York. 570p.

Hsu, C.C. and Chang, S.K. 1993, The adjusted longline CPUE of North and South Atlantic albacore stocks by three methods. Collect. Vol. Sci. Pap. ICCAT, 40(2): 333-342.

Lynch, P. D.; Shertzer, K.W. and Latour, R. J. 2012, Performance of methods used to estimate indices of abundance for highly migratory species. Fis. Res. 125–126: 27–39.

Maunder, M.N. and Punt, A.E. 2004, Standardizing catch and effort data: a review of recent approaches. Fish. Res. 70: 141-159.

McCulagh, P. and Nelder, J. A. 1989, Generalized Linear Models. Chapman and Hall, London. 513 p.

Meneses de Lima, J.H.; Kotas, J.E. and Lin, C.F. 2000, A historical review of the brazilian long-line fishery and catch of swordfish. Collect. Vol. Sci. Pap. ICCAT, 51(36): 1329-1358.

Mullahy, J. 1986, Specification and testing of some modified count data models. J. Econometrics, 33: 341–365.

Ortiz, M. and Arocha, F. 2004, Alternative error distribution models for standardization of catch rates of non-target species from a pelagic longline fishery: billfish species in the Venezuelan tuna longline fishery. Fish. Res. 70: 275-297.

R Development Core Team. 2011, R: A Language and Environment for Statistical Computing. http://www. R-project.org.

Ridout, M., Demétrio, C. G. B. and Hinde, J. 1998, Models for count data with many zeros. In: Proceedings of the XIX International Bio- metric Conference, Cape Town, South Africa, 14–18 December 1998. International Biometric Society, pp. 179–192.

Schwarz, G. 1978, Estimating the dimension of a model. Ann. Stat. 6: 461-464.

Welsh, A.H.; Cunningham, R.B.; Donnely, C.F. and Lindenmayer, D.B. 1996, Modelling the abundance of rare species: statistical models for counts with extra zeros. Ecol. Model. 88: 297–308.

Yeh, Y.M. 2007. Updated white marlin and blue marlin catch rates from the Taiwanese longline fishery in the Atlantic. Col. Vol. Sci. Pap. ICCAT, 60(5): 1696-1706.

Zeileis, A.; Kleiber, C. and Jackman, S. 2008, Regression Models for Count Data in R. J. Stat. Softw. 27(8). http://www.jstatsoft.org/v27/i08/.

Table 1. Number of longline sets by area and fleet as reported in database "Banco Nacional de Dados de Atuns e Afins" (BNDA). Areas: (A) northward of 5°S; (B) between 5°S and 15°S; (C) between 15°S and 25°S; (D) southward of 25°S. BRA stands for national vessels while other columns contain information about vessels leased from Spain (BRA-ESP), Honduras (BRA-HND), Japan (BRA-JPN), Panama (BRA-PAN), Portugal (BRA-PRT), China-Taipei (BRA-TAI), Uruguay (BRA-URY), USA (BRA-USA) and Saint Vincent (BRA-VCT).

Fleet	*Area*				
	A	*B*	*C*	*D*	*Total*
BRA	12505	1635	1554	5431	21125
BRA-ESP	7690	3388	7352	1690	20120
BRA-HND	1168	72	446	1480	3166
BRA-JPN	1052	929	148	6110	8239
BRA-PAN	6855	466	370	83	7774
BRA-PRT	363	322	448	157	1290
BRA-TAI	2599	1482	590	1624	6295
BRA-URY	608	49	5	142	804
BRA-USA	283	45	101	31	460
BRA-VCT	2916	3046	805	1070	7837
Total	36039	11434	11819	17818	77110

Table 2. Main effects of the selected models. Dots at right of equations stand for interactions.

Database	*Levels of area*	*Model*
Pooled	A, B, C, D	$catch \sim hpb + year + flag + quarter + area + dset + soak + pset + \cdots$
BRA	A, B, C, D	$catch \sim hpb + year + area + soak + quarter + dset + pset + \cdots$
BRA-TAI	A, B, C, D	$catch \sim year + quarter + area + hpb + soak + pset + dset + \cdots$
Pooled	A, BC, D	$catch \sim hpb + year + flag + quarter + area + dset + soak + pset + \cdots$
BRA	A, BC, D	$catch \sim hpb + year + area + soak + quarter + dset + pset + \cdots$
BRA-TAI	A, BC, D	$catch \sim year + quarter + area + hpb + soak + pset + dset + \cdots$
Pooled	AB, CD	$catch \sim hpb + year + flag + quarter + dset + soak + area + pset + \cdots$
BRA	AB, CD	$catch \sim hpb + year + soak + quarter + dset + pset + area + \cdots$
BRA-TAI	AB, CD	$catch \sim year + quarter + hpb + soak + area + pset + dset + \cdots$

Table 3. Selected zero inflated mixed poisson models when analyzing the pooled data and datasets split base on flag: national vessels (BRA) and vessels leased from Taiwan (BRA-TAI). Sample size (n), number of parameter estimations (k) and Bayesian Information Criterion (BIC) are in the three columns at right. Explanatory variables are: *year*, *f lag*, *hpb* – Number of hooks per basket, *quarter*, *area*, *soak* – soak time, *dset* – Time expended when setting the longline and *pset* – Period of the day (day or night) when the longline was set.

	Discarded Terms				
Dataset	*Levels of area*	*Interactions*	n	k	*BIC*
Pooled	A, B, C, D	$year{:}hpb, year{:}dset, year{:}quarter, year{:}pset, year{:}area, year{:}soak,$ $year{:}flag, flag{:}area, flag{:}hpb, area{:}pset$	53961	292	96478.1
BRA	A, B, C, D	$year{:}hpb, year{:}dset, year{:}quarter, year{:}pset, year{:}area, year{:}soak$	11015	162	18439.0
BRA-TAI	A, B, C, D	$year{:}hpb, year{:}dset, year{:}quarter, year{:}pset, year{:}area, year{:}soak$ $quarter{:}area$	6283	102	4264.7
Pooled	A, BC, D	$year{:}hpb, year{:}dset, year{:}quarter, year{:}pset, year{:}area, year{:}soak,$ $year{:}flag, flag{:}area, flag{:}hpb$	53961	276	97236.4
BRA	A, BC, D	$year{:}hpb, year{:}dset, year{:}quarter, year{:}pset, year{:}area, year{:}soak$	11015	146	18707.3
BRA-TAI	A, BC, D	$year{:}hpb, year{:}dset, year{:}quarter, year{:}pset, year{:}area, year{:}soak$ $quarter{:}area$	6283	92	4459.8
Pooled	AB, CD	$year{:}hpb, year{:}dset, year{:}quarter, year{:}pset, year{:}area, year{:}soak,$ $year{:}flag, flag{:}area, flag{:}hpb$	53961	260	98366.2
BRA	AB, CD	$year{:}hpb, year{:}dset, year{:}quarter, year{:}pset, year{:}area, year{:}soak$	11015	130	19131.0
BRA-TAI	AB, CD	$year{:}hpb, year{:}dset, year{:}quarter, year{:}pset, year{:}area, year{:}soak$	6283	88	4558.245

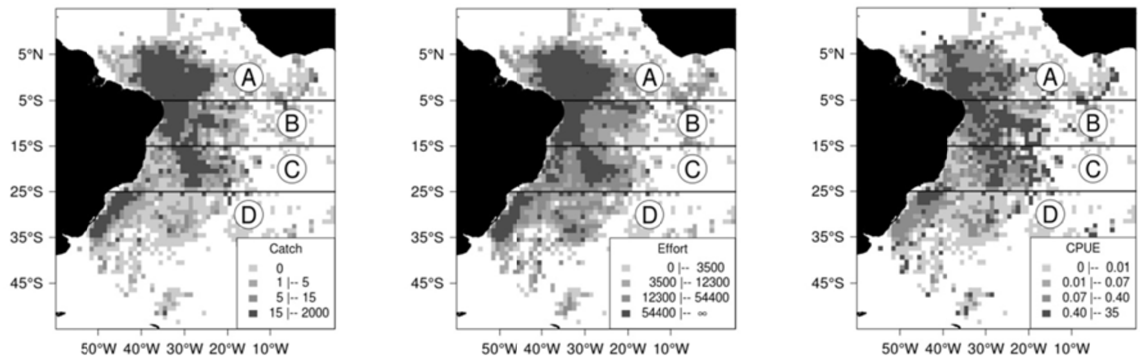

Figure 1. Effort (number of hooks), catch (number of fish) and average CPUE (number of fish/hooks) weighted by effort. Letters in the panels stand for areas considered in the models. Data from 1978 to 2011. Source: "Banco Nacional de Dados de Atuns e Afins" (BNDA).

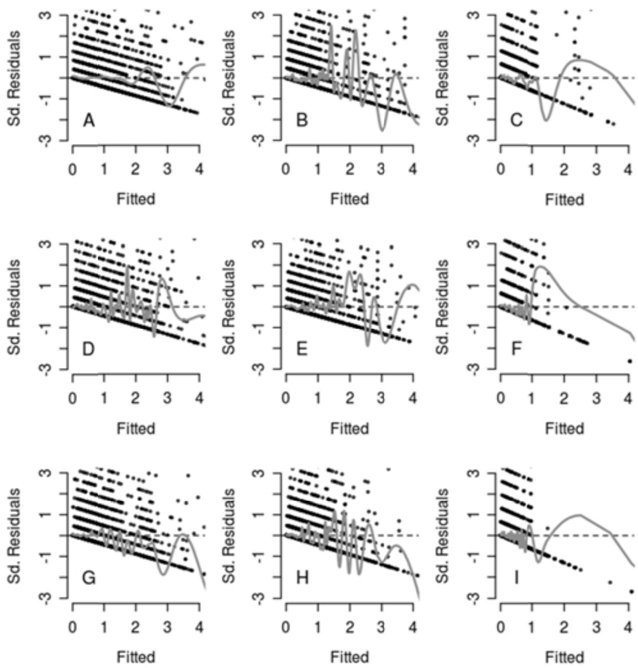

Figure 2. Fitted (number of fish per 1000 hooks) versus residuals (panels at left) and normal quantiles plots for standardized residuals. a) all flags pooled, b) Brazilian national vessels, c) vessels leased from Spain, d) vessels leased from Honduras, e) vessels leased from Japan, f) vessels leased from Panama and g) vessels leased from China Taipei.

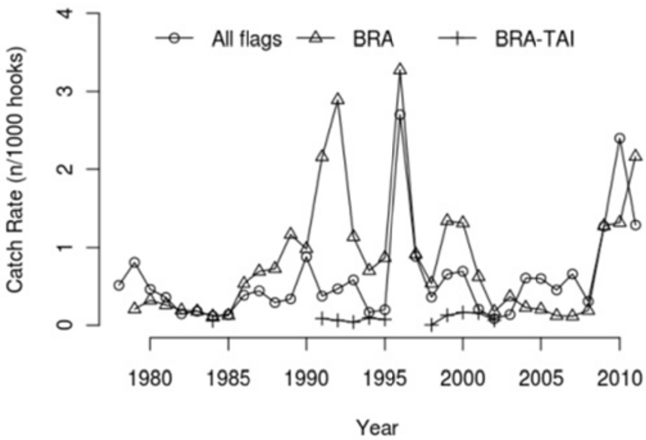

Figure 3. Average nominal catch rate (number of fish per 1000 hooks) as calculated for all data pooled and for datasets split by flag. BRA – Brazilian national vessels. BRA-TAI – vessels leased from Taiwan.

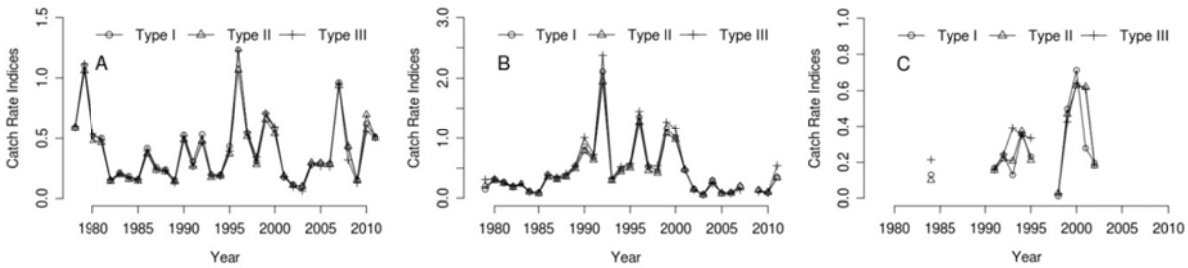

Figure 4. Standardized catch rate as calculated for all flags pooled (A), Brazilian national vessels (B) and vessels leased from Taiwan (C). Type I – estimations calculated with factor *area* with levels A, B, C and D. Type II – estimations calculated with factor *area* with levels A, BC and D. Type III – estimations calculated with factor *area* with levels AB and CD.

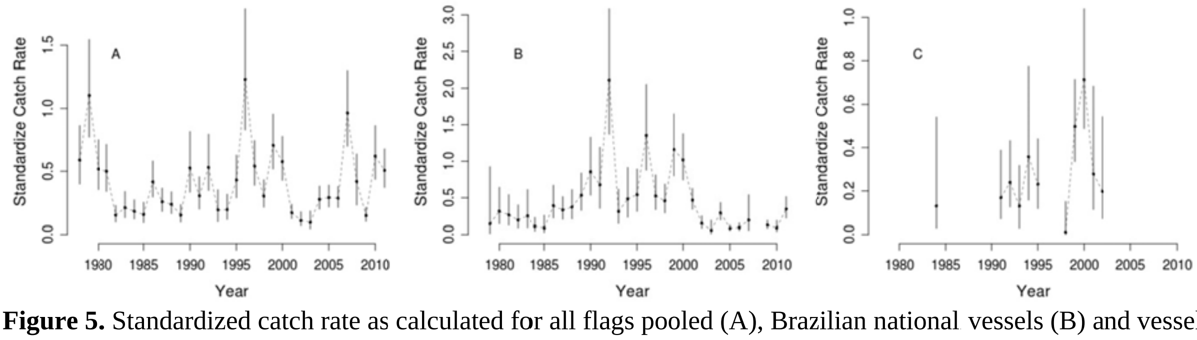

Figure 5. Standardized catch rate as calculated for all flags pooled (A), Brazilian national vessels (B) and vessels leased from Taiwan (C) with the 95% confidence intervals.

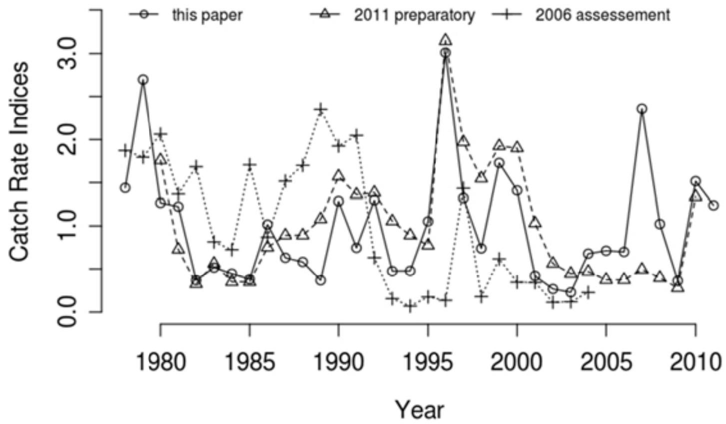

Figure 6. Standardized catch rate of Brazilian fleet as calculated in this paper, presented in the 2011 preparatory meeting and presented in the 2006 assessment meeting.