Received: 30 August & 22 September 2013

AN UPDATED OVERVIEW OF THE SWORDFISH CATCHES BY THE PORTUGUESE PELAGIC LONGLINE FISHERY IN THE INDIAN OCEAN BETWEEN 1998-2012: CATCH, EFFORT, CPUE AND CATCH-AT-SIZE

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SUMMARY

The Portuguese longline fishery targeting swordfish in the Indian Ocean started in the late 1990's, targeting mainly swordfish. A recent effort by Portuguese Marine and Atmosphere Institute (IPMA) has been made aiming the collection of historical catch data on this fishery since the late 1990's to the present date. This working document reports an updated overview of the Portuguese swordfish fishery, including analyses on the catches, effort, catch-at-size and CPUE trends for the period 1998-2012. The trends in the swordfish catch-at-size were analyzed annually, and compared between months and regions of operation of the fishery. Nominal annual CPUEs were calculated as kg/1000 hooks, and were standardized with Generalized Linear Models (GLMs) using year, quarter, location and swordfish/blue shark ratio as explanatory variables. Three different modeling approaches were used and compared, including tweedie, gamma and lognormal models, and model validation was carried out with a residual analysis. A sensitivity analysis to the influence of the ratio factor in the models was carried out. The results presented in this paper update a previous analysis on the trends of swordfish catches available from the Portuguese longline fishery operating in the Indian Ocean.

KEYWORDS: CPUE standardization, generalized linear models, pelagic longline fisheries, Xiphias gladius.

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1. Introduction

The Portuguese pelagic longline fishery in the Indian Ocean started in the late 1990's and has traditionally targeted swordfish (*Xiphias gladius*, SWO) even though, in certain areas and seasons, it also catches relatively high quantities of sharks as bycatch (particularly the blue shark *Prionace glauca*, BSH). The Portuguese fishing vessels operating in the IOTC area of competence consist only of pelagic longliners targeting swordfish, traditionally ranging in size from 35 to about 50m. On recent years the mean vessel size was 40 m of total length. The number of vessels licensed increased from the beginning of the fishery in 1998 (five vessels) until 2009 (24 vessels). The number of active vessels followed a similar trend, with a peak in 2006 (17 vessels). However, during the last 5 years, the active vessels in the convention area decreased to as low as three (in 2009, 2012). The reasons beyond such decrease of active fishing units in the IOTC convention area were related with the increase of exploitation costs (particularly oil in late 2000's), but also due to recent piracy related problems in the SW Indian Ocean, which has been traditionally the fishing area for the Portuguese fleet.

Following the paper presented in 2012 (Santos et al., 2012), this paper was prepared to provide an updated overview of the swordfish catches on the Portuguese pelagic longline fishery operating in the Indian Ocean between 1998 and 2012. Specific objectives are to present new information on the catch rates, catch-at-size, nominal and standardized CPUE trends to calculate a relative index of abundance for the swordfish captured in the region.

2. Material and methods

2.1. Catch and effort

In a recent effort by the *Portuguese Sea and Atmosphere Institute* (*IPMA*, former INRB I.P./IPIMAR), the historical catch data from the Portuguese longliners targeting swordfish in the Indian Ocean started to be compiled and analyzed. Information on effort (number of hooks used per set) is available for most of the fishing sets, with the exception of the first year in the time series (1998) for which information on effort is not available (**Table 1**). For this reason the time series analyzed in this paper refers to the years 1999-2012.

Table 1: Number of fishing sets with catch and effort information carried out by the Portuguese longline fleet in the Indian Ocean. The percentage of sets per year analyzed for this paper is indicated.

Year	Sets with catch information (N)	Sets with effort information (N)	% used for analysis
1998	113	0	0.0
1999	257	205	79.8
2000	340	333	97.9
2001	701	443	63.2
2002	877	578	65.9
2003	867	525	60.6
2004	756	495	65.5
2005	900	656	72.9
2006	2265	1931	85.3
2007	1739	1505	86.5
2008	360	360	100.0
2009	525	525	100.0
2010	630	623	98.9
2011	633	633	100.0
2012	516	516	100.0

2.2. Catch-at-size

The catch-at-size data (LJFL, lower-jaw-fork-length cm) came from the skippers logbooks, that voluntarily provided these to IPMA, as well as from information collected by the Fishery Observer program. However, most of the information used in this study comes from the first data source, as the Portuguese Fishery Observer program in the Indian Ocean only started collecting these data in 2011.

For the catch-at-size analysis, histograms with the yearly SWO catch-at-size distributions were created, and the mean sizes and boxplots were plotted by year, month and FAO subareas. The sizes were compared with Kruskal-Wallis non-parametric rank sum tests, that were chosen instead of the parametric approaches (e.g. ANOVA), because the data was not normally distributed (tested with Kolmogorov Smirnov tests with Lilliefors correction) and was heterogeneous between groups (tested with Levene tests). Generalized Additive Models (GAMs) were also run to analyze and plot the non-linear effects of latitude and longitude in the sizes of the captured SWO specimens. For these models the response variable considered was the fork length and the explanatory variables were the latitude, longitude, month and year. The error distribution was assumed to follow a gamma distribution, and the link function used was the log.

2.3. CPUE standardization

The CPUE analysis was carried out using the official fisheries statistics collected by the Portuguese Fisheries authorities, and the catch data refers to the total weight of swordfish captured per fishing set. The time series with the catch data started in 1998, but there is effort information available only since 1999. On this dataset, the general location using the FAO Areas (47, 51 and 57) is available for the entire time series, while starting in 2005, more detailed information (in terms of FAO Subareas) also started to be collected. Currently, IPMA is making an effort to collect VMS and skippers logbook data aiming to extend the analysis to the early years of the fishery.

For the CPUE standardization, the response variable considered for this study was Catch per Unit of Effort (CPUE), measured as biomass of live fish (kg) per 1,000 hooks deployed. The standardized CPUEs were estimated with Generalized Linear Models (GLM). There were some fishing sets with zero catches of SWO that result in a response variable of CPUE=0. As these zeros can cause mathematical problems for fitting the models, three different methodologies were used and compared, specifically tweedie, gamma and lognormal models. For the tweedie models the nominal CPUE was used directly for the response variable, given that this distribution can handle a certain proportion of zeros. For the gamma and lognormal models, the response variable was defined as the nominal CPUE + constant (δ), with δ set to 10% of the overall mean catch rate. This value was recommended by Campbell (2004) as it seems to minimize the bias for this type of adjustments. Further, and in a comparative study, Shono (2008) showed that when the percentage of zeros in the dataset is low (10%), the method of adding a constant to the response variable performs relatively well.

The covariates considered for the models were:

- Year (analyzed between 1999 and 2012);
- Quarter of the year (4 categories: 1 = January to March, 2 = April to June, 3 = July to September, 4 = October to December);
- Region (FAO Regions);
- Ratio (Based on the SWO/SWO+BSH ratio of captures).

The significance of the explanatory variables was assessed with likelihood ratio tests comparing each univariate model to the null model (considering a significance level of 5%), and by analyzing the deviance explained by each covariate. Goodness of fit and model validation was carried out with a residual analysis. The final estimated indexes of abundance were calculated by scaling the annual standardized CPUE values by the mean standardized CPUE in the time series.

The "ratio" was defined as the percentage of swordfish catches related to combined swordfish and blue shark catches. This ratio is in general considered as a good proxy indicator of target criteria more clearly directed at swordfish *vs.* a more diffuse fishing strategy aimed at the two main species (SWO and BSH). Moreover, it has consistently applied to other fleets that have a similar method of operation, such as the Spanish fleet, with applications both to the Atlantic and the Indian Ocean (Ramos-Cartelle et al., 2011; Mejuto et al., 2012; Santos et al., 2013). The ratio was calculated for each fishing set and then divided into ten categories using the 10% percentiles. With the final models selected, a sensitivity analysis was carried out relative to the factor ratio. Specifically, the final models were compared with alternative models using: 1) a different ratio categorization, specifically 25% instead of 10% percentiles; and, 2) by removing the ratio variable from the models.

Statistical analysis for this paper was carried out with the R Project for Statistical Computing version 2.14.1 (R Development Core Team, 2011; Fox and Weisberg, 2011; Dunn, 2011; Warnes, 2011; Højsgaard and Halekoh, 2012).

3. Results and Discussion

3.1. Catch and effort

The total effort of the Portuguese longline fleet in the Indian Ocean remained relatively constant between 1999 and 2004, followed by an increase during 2006-2007. For the more recent years of (2008 to 2012) the effort was again similar to that of the early 2000's (**Figure 1**).

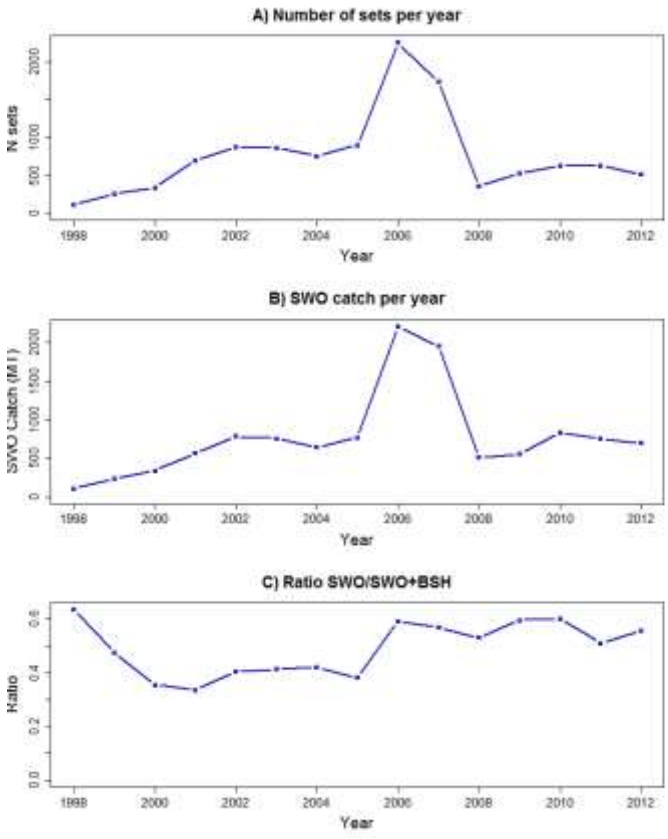

Figure 1: Descriptive plots of the total effort in sets (A), the total catch of swordfish (B), and the ratio of swordfish compared to the swordfish and blue shark catches (C), for the Portuguese longline fleet operating in the Indian Ocean.

The total SWO catches also tended to increase initially, with a peak during 2006-2007, followed by a sharp decrease in 2008. During recent years, a slight increase has been observed, with the total catch amounting to 696 MT in 2012. In terms of ratios of SWO compared to the SWO + BSH catches, a general increasing trend was observed during the time period. However, it has been relatively stable since 2006 (mean value of 0.57, **Figure 1**).

3.2. Catch-at-size

The size distribution of the SWO captured in the Indian Ocean by the Portuguese fleet remained relatively stable throughout the time series analyzed (**Figure 2**, **Figure 3**). In general, there was a slight decrease in the mean sizes between 2002 and 2009, followed by a slight increase in the more recent years, until 2012 (**Figure 2**). However, and even thought the observed differences were small, there were still significant differences in the yearly sizes (Kruskal-Wallis: chi-square = 2196, df = 10, p-value < 0.01).

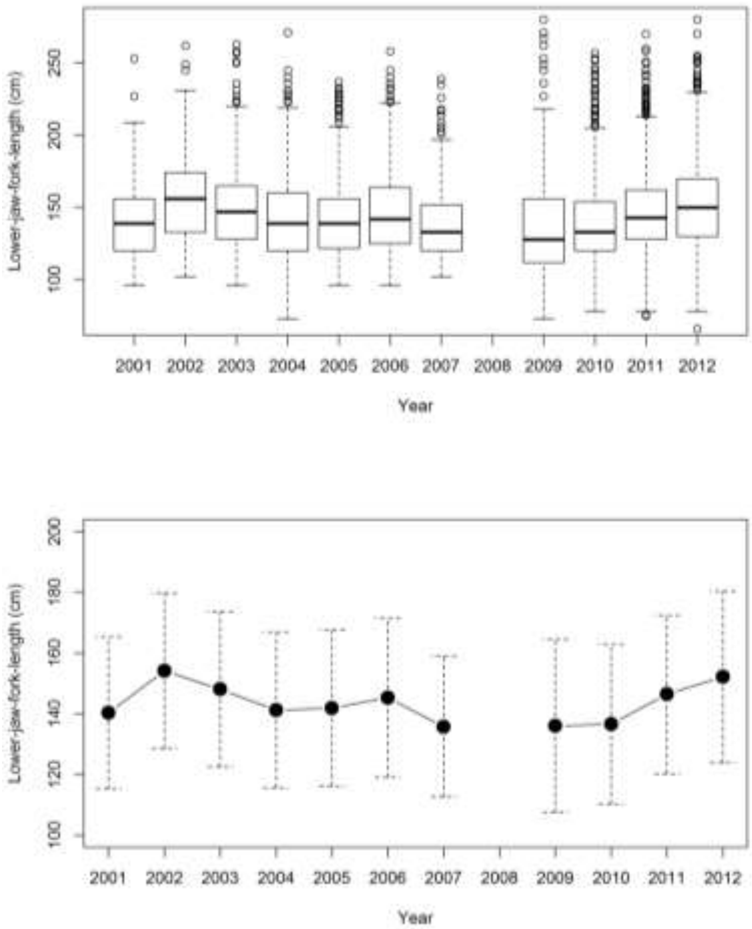

Figure 2. Yearly catch-at-size (LJFL, lower-jaw-fork-length) for the swordfish captured by the Portuguese pelagic longline fleet operating in the Indian Ocean. The graphic on the top represents the boxplots and the graphic on the bottom the mean annual sizes with the respective standard deviations.

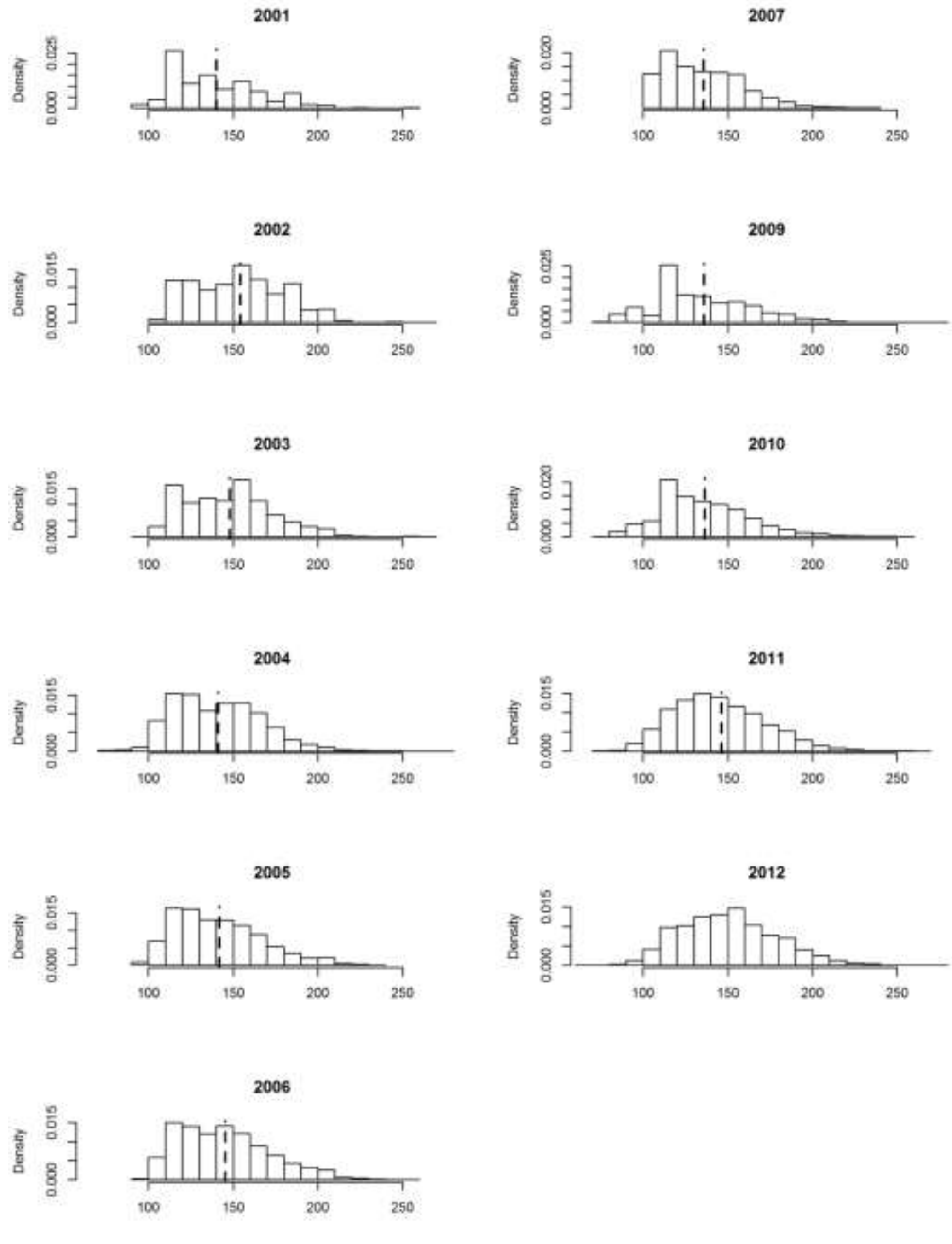

Figure 3. Frequency distribution of swordfish captured by the Portuguese longline fleet in the Indian Ocean between 2001 and 2012. The dotted vertical lines represent the yearly mean swordfish catch-at-size (LJFL, lower-jaw-fork-length).

In terms of seasonal variations, the size distribution along the months of the year were also stable, with a slight increase in sizes during the February-March period, followed by a decrease in sizes during April, and then a slight continuous increase throughout the rest of the year (**Figure 4**. These differences in the monthly size distributions were significant (Kruskal-Wallis: chi-square = 248, df = 11, p-value < 0.01).

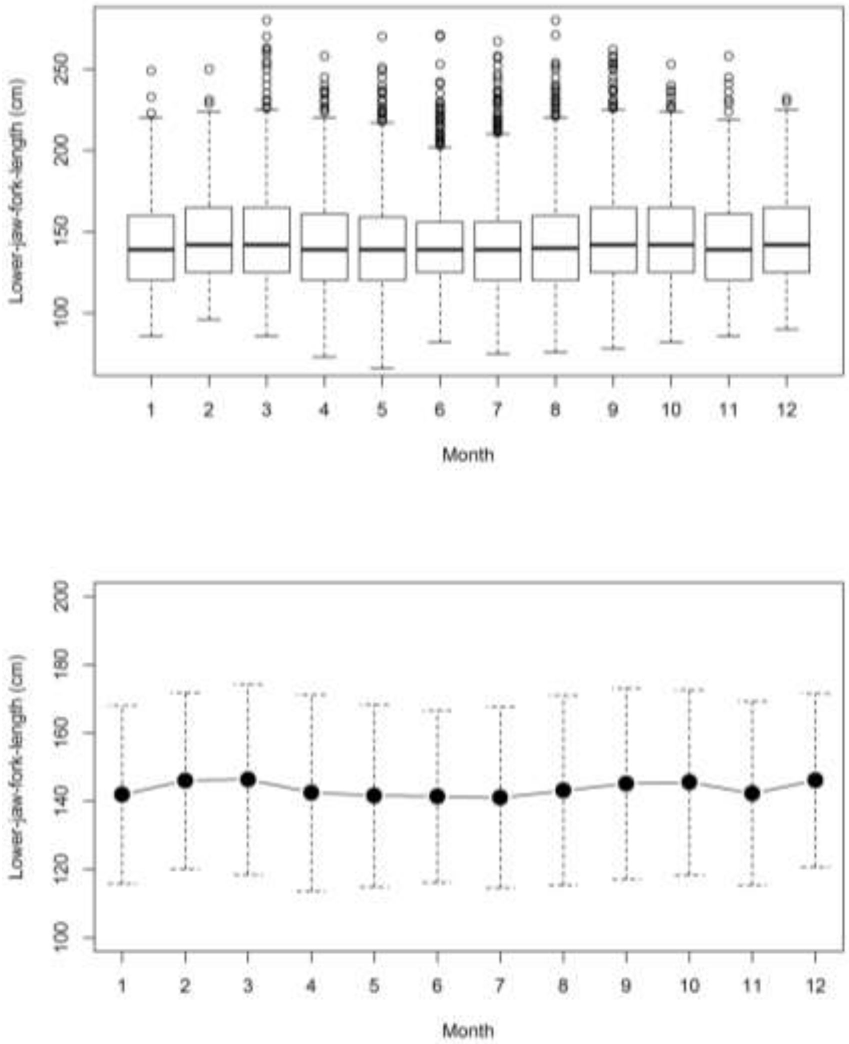

Figure 4: Monthly catch-at-size (LJFL, lower-jaw-fork-length) variations for swordfish captured by the Portuguese pelagic longline fleet in the Indian Ocean. The graphic on the top represents the boxplots and the graphic on the bottom the monthly sizes (all year combined) with the respective standard deviations.

In terms of regional variations, there were significant differences in terms of the catch-at-sizes recorded in each of the FAO Subareas (51.4, 51.6, 51.7, 51.8) for the Major FAO Area 51 (**Figure 5**) (Kruskal-Wallis: chi-square = 582, df = 3, p-value < 0.01). These spatial effects were also observed by plotting the non-linear effects of the latitude and longitude (after removing the effects of year and month) on the SWO catch rates, where there was a tendency for larger specimens to be captured towards southern latitudes and eastern longitudes (**Figure 6**).

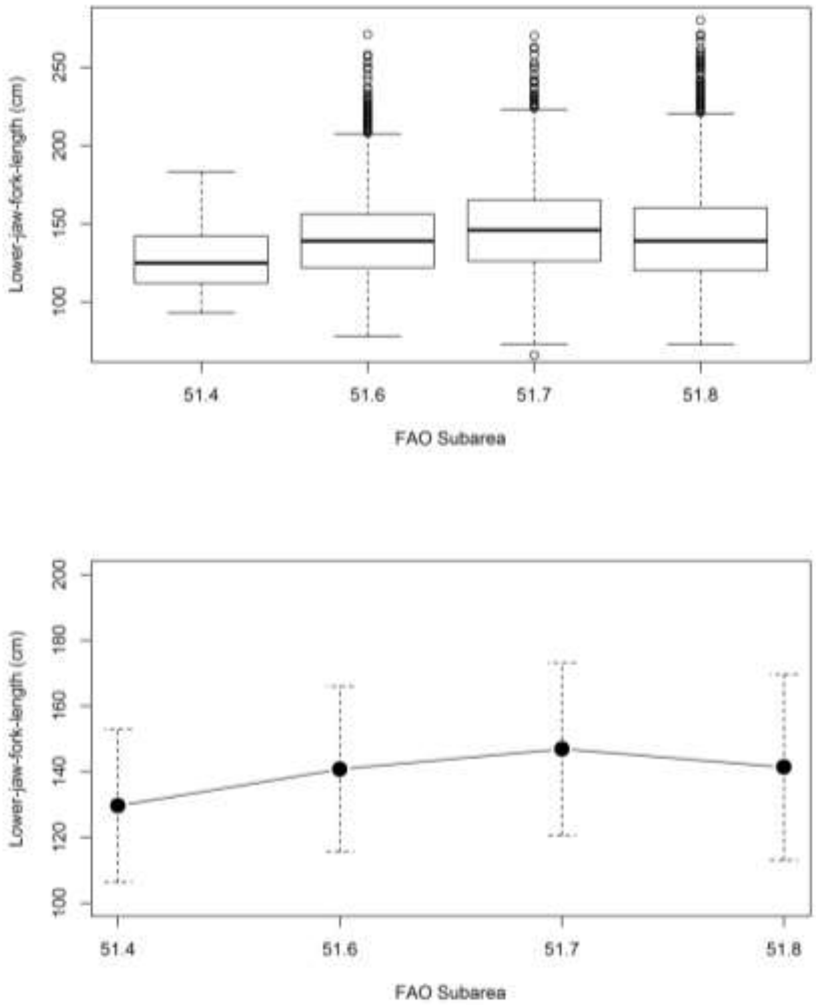

Figure 5. Catch-at-size (LJFL, lower-jaw-fork-length) of swordfish caught by the Portuguese pelagic longline fleet in various FAO Sub-areas of the FAO fishing area 51 (Western Indian Ocean). The graphic on the top represents the boxplots and the graphic on the bottom the region average sizes (all years combined) with the respective standard deviations.

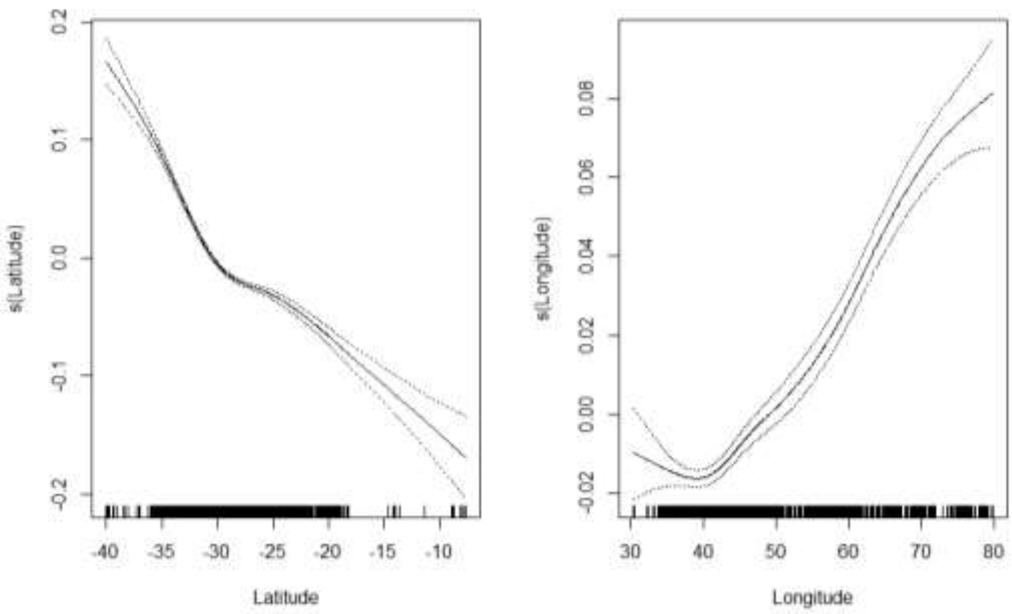

Figure 6. GAM plots with the effects of latitude and longitude on the swordfish catch-at- sizes, after removing the effects of factors month and year, and in a model using a Gamma distribution with a log link function. The dashed lines represent the standard errors and the vertical bars in the bottom represent numbers of observations.

3.3. CPUE standardization

In terms of nominal CPUEs, a general increasing trend was observed in the time series, which ranged between values of approximately 400kg/1000 hooks early in the time series to values of approximately 1000kg/1000 hooks in the more recent years (**Figure 7**).

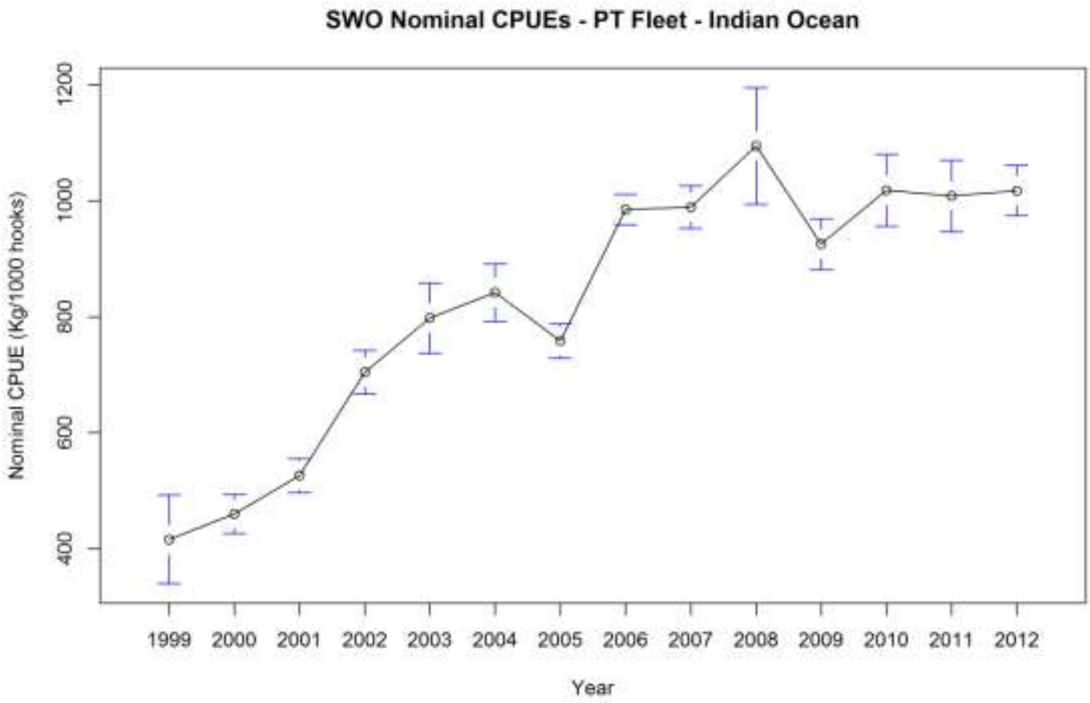

Figure 7. Nominal CPUEs (kg/1000 hooks) for swordfish caught by the Portuguese pelagic longline fishery operating in the Indian Ocean, between 1999 and 2012. The error bars refer to the 95% confidence intervals of the means.

The percentage of fishing sets with zero catches of SWO was low, specifically 0.98%, and the nominal SWO CPUE distribution was highly skewed to the right (**Figure 8**). This level of low percentages of fishing sets with zero catches are similar, for example, to what has been previously reported by the Spanish fleet targeting SWO in the Indian Ocean, where the values of fishing sets with zero catches were also generally lower than 1% (Ramos-Cartelle et al., 2011).

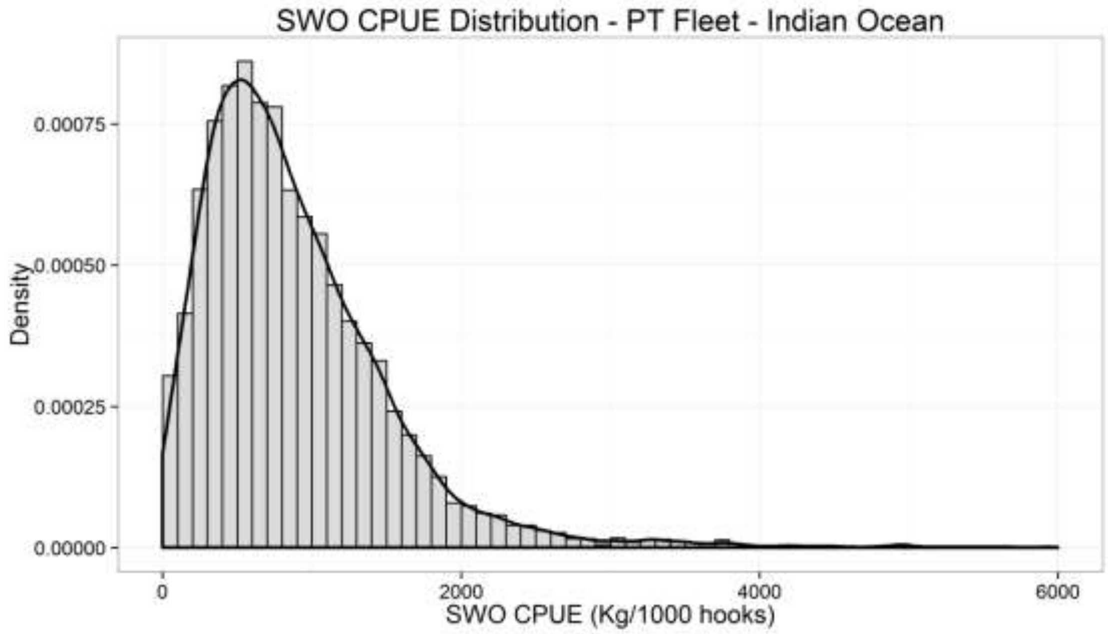

Figure 8: Distribution of the nominal CPUEs for swordfish captured by the by the Portuguese longline fleet operating in the Indian Ocean.

All the explanatory variables tested for the SWO CPUE standardization were significant and contributed significantly for explaining part of the deviance, including the interaction between quarter and area (**Table 2**). The factors that contributed most for the deviance explanation were the Ratio factor followed by the Year, and this was similar regardless of the model type used (**Table 2**).

Table 2. Deviance of the parameters used for the different CPUE standardization models (tweedie, gamma and lognormal). For each parameter it is indicated the degrees of freedom used, the deviance explained, the residual degrees of freedom and deviance after incorporating each parameter and the significance (p-value) of each parameter. For each model it is also indicated the coefficient of determination value (R^2).

Tweedie Model (R^2 = 42.1%)					
Parameter	Df	Deviance	Resid. Df.	Resid. deviance	Significance (p-value)
Null			9310	94681	
Year	13	8621	9297	86060	< 0.01
Quarter	3	891	9294	85169	< 0.01
Region	2	229	9292	84940	< 0.01
Ratio	9	30089	9283	54851	< 0.01
Quarter:Region	6	178	9277	54672	< 0.01
Gamma Model (R^2 = 44.5%)					
Parameter	Df	Deviance	Resid. Df.	Resid. deviance	Significance (p-value)
Null			9310	3822	
Year	13	364	9297	3458	< 0.01
Quarter	3	34	9294	3424	< 0.01
Region	2	10	9292	3414	< 0.01
Ratio	9	1291	9283	2123	< 0.01
Quarter:Region	6	8	9277	2115	< 0.01
Log-Normal Model (R^2 = 47.3%)					
Parameter	Df	Deviance	Resid. Df.	Resid. deviance	Significance (p-value)
Null			9310	4213	
Year	13	467	9297	3746	< 0.01
Quarter	3	33	9294	3714	< 0.01
Region	2	35	9292	3679	< 0.01
Ratio	9	1456	9283	2223	< 0.01
Quarter:Region	6	8.32	9277	2214.3	< 0.01

In terms of model validation, the three tested models seemed adequate for this particular situation with a low quantity of zeros. The residual analysis for the models tested, including the residuals distribution along the fitted values, the QQ plots and the residuals histograms did not identified any major problems in the models (**Figure 9**).

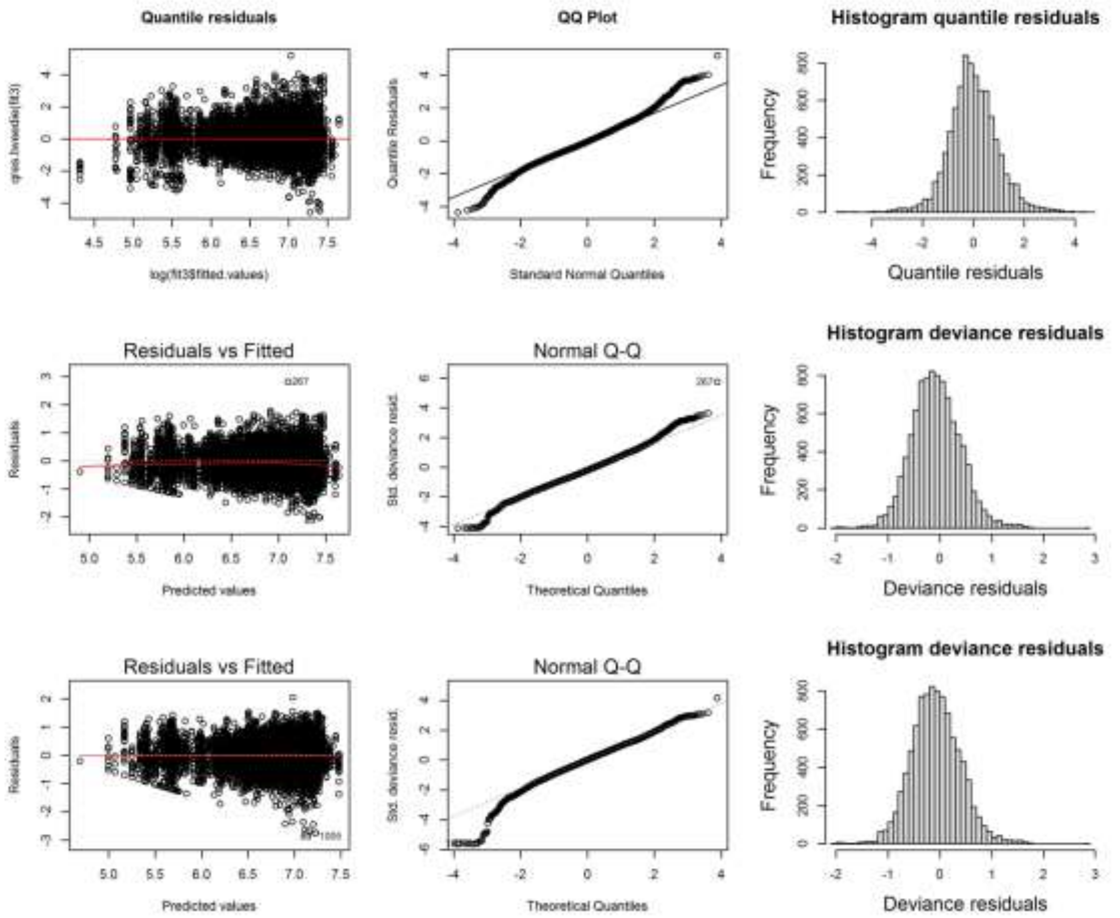

Figure 9. Residual analysis for the models tested for the CPUE standardization, namely the tweedie model on the top, the gamma model in the middle, and the lognormal model on the bottom. For each model, it is presented the residuals along the fitted values on the log scale (graphics on the left), the QQPlot (graphics on the middle), and the histogram of the distribution of the residuals (graphics on the right).

In general there has been an increase in the standardized CPUEs obtained by the Portuguese longline fleet between 1999 and 2012. The relative index of abundance showed an increase in the initial years between 1999 and 2000, followed by a relatively stable period between 2000 and 2009, and then another increase in the more recent years, between 2009 and 2012 (**Figure 10**). In terms of model comparisons, the results of the three tested models (tweedie, gamma and lognormal) produced on all cases very similar results and trends, with highly overlapping 95% confidence intervals (**Figure 10**).

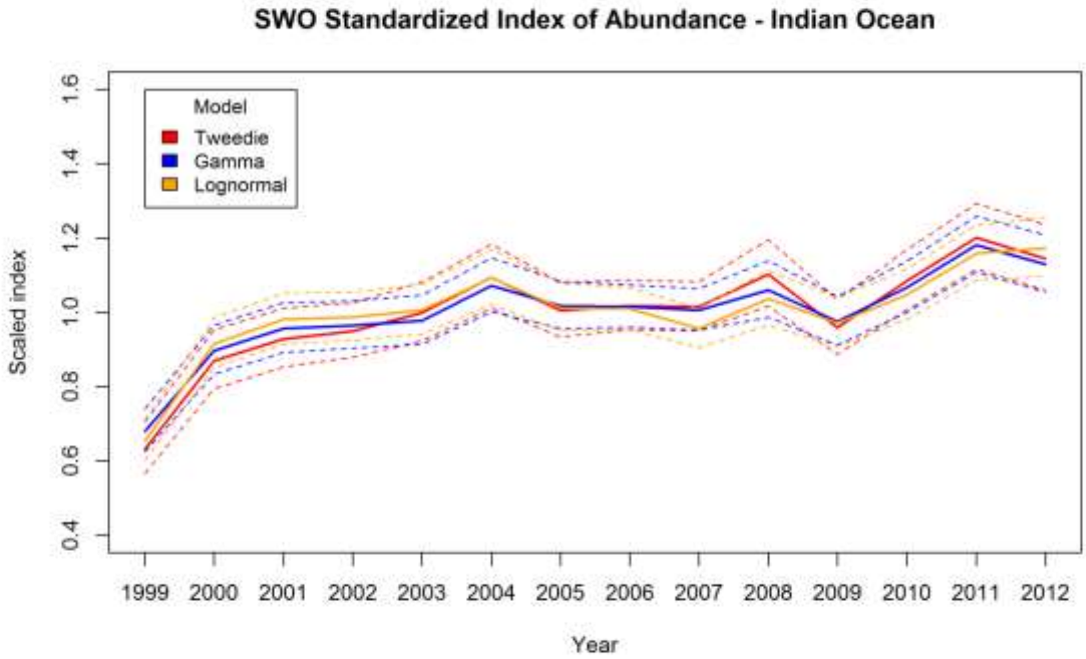

Figure 10. Scaled annual index of abundance for swordfish captured by the Portuguese pelagic longline fleet operating in the Indian Ocean. The solid lines refer to the standardized series calculated with the different alternative models, and the dotted lines refer to the respective 95% confidence intervals.

3.4. Sensitivity analysis

The sensitivity analysis of the factor Ratio in the annual indexes of abundance tended to show that there were some differences, particularly when the ratio variable was removed (**Figure 11**), even though on all cases there was an ascending trend in the standardized indexes. In terms of goodness-of-fit, the removal of the ratio factor produced models with worse fits, with a decrease in the R^2 value form 47.3% in the original model to 13.3% in the model without the variable ratio. Using a different categorization of the ratio factor (25% instead of 10% percentiles) also decreased the R^2 to a value of 42.1%.

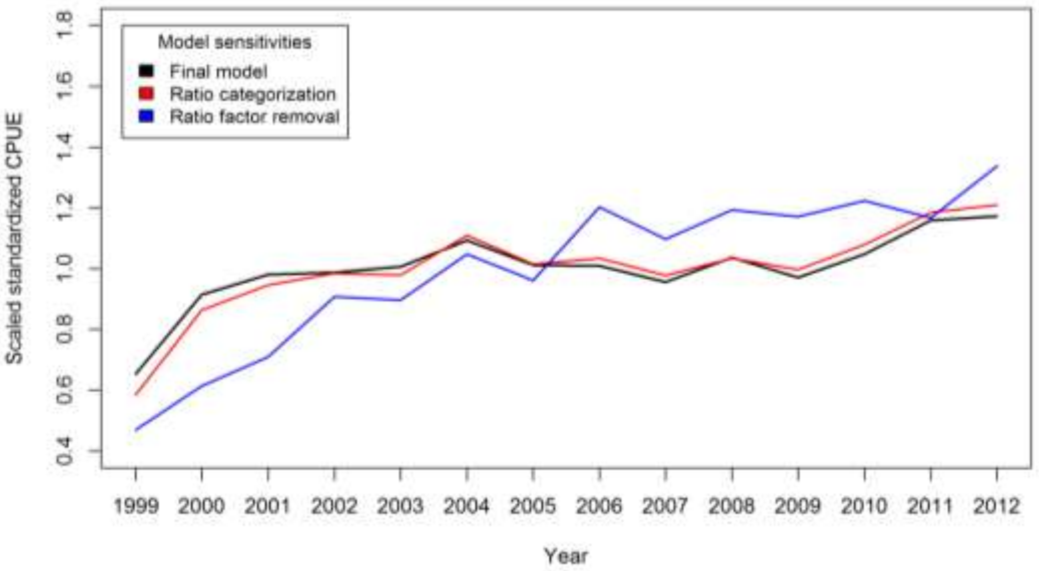

Figure 11. Model sensitivities of the factor ratio to the annual index of abundance of swordfish captured by the Portuguese pelagic longline fleet operating in the Indian Ocean. The scaled annual indexes of abundance of the final model selected (lognormal) are represented in black and the alternative models in red (using a different categorization of the ratios) and blue (removing the ratio factor).

4. Acknowledgments

All the data used was collected for within the EU Data Collection Framework. Rui Coelho was supported with a grant from FCT (Ref: BPD 40523 / 2007) co-funded by "POCI-2010 - Programa Operacional Ciência e Inovação 2010" and "FSE - Fundo Social Europeu". Special thanks are due to all skippers that voluntarily provided data from their fishing activities in the IOTC convention area.

5. References

Campbell, R.A., 2004. CPUE standardisation and the construction of indices of stock abundance in a spatially varying fishery using general linear models. *Fisheries Research*, 70: 209–227.

Dunn, P.K. 2011). tweedie: Tweedie exponential family models. R package version 2.1.1.

Fox, J., Weisberg, S., 2011. An R Companion to Applied Regression, 2nd Edition. Sage, Thousand Oaks CA.

Højsgaard, S. and Halekoh, U., 2012. doBy: Groupwise summary statistics, general linear contrasts, population means (least-squares-means), and other utilities. R package version 4.5.0. http://CRAN.R-project.org/package=doBy.

Mejuto, J., García-Cortés, B., Ramos-Cartelle, A., De la Serna, J.M., González-González, I., 2012. Standardized catch rates of shortfin mako (*Isurus oxyrinchus*) caught by the Spanish surface longline fishery targeting swordfish in the Atlantic Ocean during the period 1990-2010. *ICCAT SCRS/2012/046*. 12pp.

Ramos-Cartelle, A., García-Cortés, B., Fernández-Costa, J., Mejuto, J., 2011. Standardized catch rates for the swordfish (*Xiphias gladius*) caught by the Spanish longline in the Indian Ocean during the period 2011-2012. *IOTC Working Document*. IOTC-2011-WPB09-23. 19pp.

R Development Core Team., 2011. R: A language and environment for statistical computing. Version 2.14.1. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Santos, M.N., Coelho, R., Lino, P.G., 2012. A brief overview of the swordfish catches by the Portuguese pelagic longline fishery in the Indian Ocean: catch, effort, CPUE and catch-at-size. *IOTC–2012–WPB10–11*: 14 p.

Santos, M.N., Coelho, R., Lino, P.G., 2013. Standardized CPUE for swordfish (*Xiphias gladius*) caught by the Portuguese pelagic longline fishery in the North Atlantic Ocean. *ICCAT SCRS/2013/104*: 11p.

Shono, H., 2008. Application of the Tweedie distribution to zero-catch data in CPUE analysis. *Fisheries Research*, 93: 154–162.

Warnes, G.R., 2011. gplots: various R programming tools for plotting data. R package version 2.10.1. http://CRAN.R-project.org/package=gplots.