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Modeling species composition and mortality rates of sea turtles in the Portuguese pelagic longline fishery targeting swordfish in the Atlantic Ocean: preliminary results using statistical models

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SUMMARY

Sea turtles occasionally interact and are captured as bycatch in pelagic longline fisheries. In this work we used statistical models to estimate the species composition and fate of sea turtles captured in the Portuguese pelagic longline fishery operating in the equatorial and tropical north Atlantic. Specifically, multinomial models were used to predict the species composition and binomial models to predict the fate of the captured specimens. Both models showed good goodness-of-fit. In the multinomial models the estimated R^2 was 0.562 and the 10-fold cross-validation procedure resulted in a classification error rate of 46.8 %. In the binomial models the estimated R^2 was 0.293, the Area Under the Curve (AUC) was estimated to be 0.805 with a sensitivity of 74.5% and a specificity of 75.5%, and the 10-fold cross validation procedure resulted in a prediction error rate of 21.1%. The models produced are still preliminary, but can now be used to better estimate the species composition and fate of sea turtles that interact with the Portuguese pelagic longline fishery operating in the equatorial and tropical north Atlantic.

KEYWORDS: Catch composition, catch reconstruction, mortality rates, sea turtles, statistical models, longline fisheries.

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1. Introduction

Among the marine megafauna occasionally caught incidentally in oceanic fisheries, sea turtles are of special concern. Five of the seven species of sea turtles living in the world's oceans have been listed as either endangered or critically endangered in the IUCN red list (IUCN 2015), and their international trade is prohibited according to CITES, the Convention on International Trade in Endangered Species (CITES, 2015). Due to concerns on the status of sea turtles worldwide and the possible negative effects of fishing on these populations, all tuna Regional Fishery Management Organizations (tRFMOs) have taken conservation measures to address sea turtle interactions with marine fisheries (see Coelho *et al*., 2013 for a revision on this issue). The retention of sea turtles is forbidden in fishing vessels, and in the case of ICCAT there are specific requests for data collection and research, as well as guidelines for best practices for releasing accidentally captured specimens (ICCAT, 2010).

The Portuguese pelagic longline fishery targeting swordfish begun in the 1970s and the fishing method has remained almost unchanged since then, even though a few changes have been incorporated in the last decade, specifically shifting from the traditional to the "modern gear" using mainlines and branch lines of monofilament and using lightsticks or flashlights (see Watson and Kerstetter 2006 for gear descriptions). J-style hooks baited with squid have been traditionally used by this fleet, even though in particular areas and seasons pelagic sharks may be targeted, and sometimes the branch line material is switched to multifilament steel and mackerel is used as bait. Several studies have been carried out for this fleet comparing different hook style and bait type combinations on the sea turtle catches and mortality rates, as well as for target and bycatch species, for the major areas of operation of this fleet in the Atlantic, specifically the equatorial region (Santos *et al*., 2012; Coelho *et al*., 2012), the south Atlantic (Santos *et al.*, 2013; Amorim *et al*., *in press*) and the tropical NE area (Coelho *et al*., 2015; Fernandez-Carvalho *et al.*, 2015).

In the Portuguese longline fishery several data sources are available and used, including fishery observer and logbook data. With regards to sea turtles, the data from fishery observers is usually detailed and includes information on the species and fate of the specimen, while data from logbooks in less detailed and often does not include sea turtle species-specific *taxa* and fate information. Given the characteristics of these datasets and the interest in estimating overall catch composition and mortality rates for sea turtles, the objectives of this work were to create statistical models to predict the species composition and fate of sea turtles captured in the Portuguese pelagic longline fishery operating in the equatorial and tropical north Atlantic.

2. Material and methods

2.1. Data collection and descriptive statistics

The data used for this study was collected by fishery observers onboard Portuguese pelagic longline vessels and from skippers logbooks (self reporting program) voluntarily provided to IPMA, for the period 2003 to 2013. Data from 79 trips were used, accounting for a total 1899 sea turtle interactions.

The fishery observers record, whenever possible, the species-specific identification and the fate of the specimen after release (i.e., released alive or dead). Additional information recorded for each fishing set includes the date, location and effort. For the self reporting data usually only the generic sea turtle identification name is used, there is usually no information on fate, but there is set-specific information with date, location and effort.

For the sea turtles species identification, the 3 letter FAO codes were used, as follow:

- TTX – Sea turtle nei;
- TTL - *Caretta caretta*, loggerhead turtle;
- DKK - *Dermochelys coriacea*, leatherback turtle;
- LKV - *Lepidochelys olivacea*, olive ridley turtle;
- TUG - *Chelonia mydas*, green turtle.

The sea turtle incidental bycatches were plotted with barplots by range of latitude, longitude and season of the year. This allowed describing the patterns of the interactions between the sea turtle bycatches and the location and seasonal characteristics of the fleet. The relationship between species and proportions of alive *versus* dead specimens when released was assessed graphically with bar plots and tested statistically with contingency tables and chi-square proportion tests.

2.2. Multinomial models for predicting sea turtle species composition

For reconstructing the sea turtle bycatch when no species-specific information is available (mostly data from self-sampling logbooks), multinomial models was run for the data where such information is available (mostly data from fishery observers). Given the data characteristics and availability, these models were run only for the equatorial and tropical north region of the Atlantic Ocean. Multinomial models are extensions of binomial models that generalize the logistic regression to multiclass problems. This means that while binominal models are fit to categorical variables with a binary response, multinomial models can be fit to categorical variables with 3 or more possible discrete outcomes.

The model fitting process was tested using the following independent variables:

- Coordinates (latitude and longitude - continuous variables);
- Quarter of the year (categorical variable): 1=Jan to March; 2=Apr to Jun; 3 = Jul to Sep; 4 = Oct to Dec.
- Interactions between pairs of variables.

Model building and 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 comparison was carried out with the Akaike Information Criteria (AIC) and the McFadden coefficient of determination (McFadden, 1978).

A cross validation procedure was also carried out with *k*-fold cross validation (*k*=10) to estimate the expected level of fit (i.e., prediction error rate) of the model to new data. The original dataset was randomly partitioned into 10 subsamples: one subsample was retained as the validation dataset and the remaining *k*-1 subsamples were used as training datasets to build the models. The cross-validation procedure was repeated *k* times, with each of the *k* subsamples used one time as the validation dataset. The use of *k*=10 was chosen as this seems to be an adequate value for models using large datasets (Fushiki, 2011).

2.3. Binomial models for predicting sea turtle mortality rates

For modeling the sea turtle mortality rates, generalized linear models with a binomial error distribution and a *logit* link function were run. The response variable was transformed into a binomial variable code as: 1=dead and 0=released alive. Like in the multinomial models for the species composition, these binomial models were also run only for the equatorial and tropical north region of the Atlantic Ocean. Additionally, the green turtle was excluded from these models due to the very low sample size and limited information on the specimen fate.

The model fitting process was tested using the following independent variables:

- Species (categorical variable): DKK, TTL and LKV;
- Coordinates (latitude and longitude - continuous variables);
- Quarter of the year (categorical variable): 1=Jan to March; 2=Apr to Jun; 3 = Jul to Sep; 4 = Oct to Dec;
- Interactions between pairs of variables.

Model building and 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 comparison was carried out with the Akaike Information Criteria (AIC) and the Nagelkerke coefficient of determination (Nagelkerke, 1991). The discriminative capacity of the models was determined by the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) curves (Fawcett, 2006), and with the calculation of the model sensitivity (i.e., capacity to correctly detect the event = sea turtle mortality), and model specificity (i.e., capacity to correctly exclude sea turtles that do not die during the fishing operations). A *k*-fold cross-validation procedure similar to the one applied to the multinomial models was also applied to the binomial models, also using *k*=10, to estimate the expected prediction error rate of the model to new datasets (Fushiki, 2011).

The odds-ratios of the parameters with their respective 95% confidence intervals were calculated and used for interpretation. Additionally, the species-specific probabilities of mortality were calculated for each quarter and along varying latitude and longitude gradients.

Statistical analysis for this paper was carried out with the R Project for Statistical Computing version 3.0.1 (R Core Team, 2013) using several additional libraries (Venables and Ripley, 2002; Wickham, 2007, 2009; Fox and Weisberg, 2011; Carstensen *et al*., 2013; Kahle and Wickham, 2013; Warnes *et al*., 2013).

3. Results and Discussion

3.1. Exploratory data analysis

A total of 1899 sea turtle interaction were recorded during this study, specifically 496 leatherbacks, 402 olive ridleys, 373 loggerheads, 6 green turtles and 622 as non identified species. A total of 121 specimens were recorded in the tropical NE Atlantic region (>25N), 1316 in the tropical NE and equatorial regions (between 25N and 10S), and 462 in the South Atlantic (<10S). When considering only the tropical NE and equatorial regions, the species-specific records were 412 leatherbacks, 310 olive ridleys, 212 loggerheads, 5 green turtles and 377 not identified (**Figure 1**).

In terms of species composition, it was possible to see patterns in the sea turtle data both in the locations (latitude and longitude) and in the seasons of the year (**Figure 2**). In terms of latitude, olive ridleys are more captured in southern latitudes, leatherbacks in the middle of the latitude range, and loggerheads in higher latitudes of tropical waters (**Figure 2A**). In terms of longitude there was more overlap between the species, but it was possible to see a pattern of more leatherbacks in western longitudes, more olive ridleys in the middle of the longitude range, and more loggerheads in eastern longitudes (**Figure 2B**). For all the quarters of the year there is a high overlap between leatherbacks and olive ridleys, while loggerheads tend to be captured mainly in the last quarter of the year (**Figure 2C**).

Most of the sea turtles observed in this study were captured and released alive, with an overall mortality rate of 19.3% in the equatorial and tropical NE region. The species specific mortalities were 3.7% for leatherbacks, 38.2% for olive ridley and 25.9% for loggerheads (**Figure 3**), with those differences statistically significant (proportion test: chi-square = 111.93, df = 2, p-value < 0.001).

3.2. Modeling sea turtle species composition

When selecting covariates and building the multinomial models, the goodness-of-fit improved as more simple effects were added (quarter, latitude and longitude) and also by adding the interaction between the coordinates (**Table 1**). Therefore, the final selected model considered all simple effects (quarter, latitude and longitude) and the interaction between latitude and longitude (**Table 2**).

For this final model, the coefficient of determination (McFadden R^2) was estimated to be 0.562 which is considered an excellent fit for multinomial models (McFadden, 1978). The *10*-fold cross-validation procedure resulted in a classification error rate of 46.8 %; given that there are 4 possible outputs in the response variable, i.e., 4 possible sea turtle species, a random choice of outcomes would produce a mean error rate of 75%. Therefore, the prediction ability of the model with an error rate of 46.8% is also considered good.

In terms of predictions from this final multinomial model, when considering the areas closer to the equatorial waters there is the expectation of capturing mostly olive ridleys in western longitudes and either leatherbacks or green turtles in eastern longitudes, depending on the season of the year (**Figure 4**). By the contrary, for the northern region of the study area, in tropical waters, there is the expectation to catch more leatherbacks in western longitudes and more loggerheads in eastern longitudes, with the catches of olive ridley decreasing towards higher latitudes (**Figures 5 and 6**).

For the data from the Portuguese pelagic longline fishery operating in the equatorial and north tropical Atlantic ocean that currently has 377 unidentified sea turtles captured in that region, by applying this model to the data and taking into account their location and capture date, it was possible to predict that 172 specimens are most likely to be leatherbacks and 205 are most likely to be olive ridleys.

3.2. Modeling sea turtle mortality rates

The variables that were significant and improved the goodness-of-fit of the binomial model were the simple effects of species, quarter, latitude and longitude, and the interaction between latitude and longitude (**Table 3**). The longitude variable by itself was not significant, but was significant in the interaction with latitude. Therefore, the final selected binomial model to predict sea-turtle mortalities considered all simple effects (species, quarter, latitude and longitude) and the interaction between latitude and longitude (**Table 4**).

In terms of goodness-of-fit values, the coefficient of determination (Nagelkerke R^2) for this final model was estimated to be 0.293 which is considered an excellent fit for binomial models (Nagelkerke, 1991). The discriminative capacity of the model estimated with the ROC curve was also considered excellent (Hosmer and Lemeshow, 2000), with an AUC of 0.805, a sensitivity of 74.5% and a specificity of 75.5% (**Figure 7**). The *10*-fold cross validation procedure resulted in an estimated prediction error of 21.1%, which is also considered good given that in binomial models 2 possible outcomes are possible for the response variable, and therefore a random choice of outcomes would produce a mean error rate of 50%.

Compared to the baseline combination, i.e., mortality rates of leatherbacks captured in quarter 1 at the minimum values of latitude and longitude of the study area, the odds of dying during the fishing process were higher for the remaining species and increased in higher latitudes and in quarter 4. By the contrary, the odds of dying were not significantly different from the baseline combination in quarters 2 and 3 and slightly decreased with increasing longitude (**Figure 8**).

In terms of predicting mortality rates from this final binomial model, there is the expectation of very low mortality rates for leatherbacks and slightly higher for olive ridleys and loggerheads (**Figure 9**). For all species the mortality rates tended to decrease with increasing latitudes, with the relative proportions between species maintained along the quarters of the year (**Figure 9**).

4. Conclusions

This work presents statistical models that can be used for predicting sea turtle species composition and mortality rates when species-specific data is not recorded. This is the first time that such types of models are used and applied to Portuguese pelagic longline data.

All models created were relatively simple and used only seasonal and location effects for the explanatory variables. It would be possible to further add covariates that could eventually increase the predictive capabilities of the models (e.g. specimen size, bait type, hook style, etc), but those variables are not always recorded in logbook data. As the main objective of this work was to estimate species composition and mortality rates for data than can also come from logbooks (usually unidentified species and limited additional information), we preferred to use only data that is also usually available in logbooks. The fishing set date and locations are usually available in logbooks, and as such the advantage of the simple models created is that they can be easily applied to most logbook data.

Given the data characteristics, the multinomial models for predicting species composition and the binomial models for predicting mortality rates were run only for the equatorial and tropical northeastern region of the Atlantic Ocean. As such, the models presented should be considered only for that region and for the shallow water pelagic longlines that target mainly swordfish (night setting), such as the longlines used by the Portuguese pelagic longline fleet.

In this work the sample size of green turtles (TUG) was very low, and this reflects the very low level of interactions of that species with this fishery. It should therefore be noted that the results and predictions presented in this work for green turtles need to be considered carefully, as the very low sample size can be producing large bias in the results for that species.

Even though this analysis is still preliminary, the models created are useful and can now be used for a first estimation of the overall catch composition and mortality rates for the Portuguese pelagic longline fleet operating in the equatorial and tropical northeastern Atlantic, even when no detailed species-specific and specimen fate information is available. However, these results shall not be extrapolated to other regions or fisheries, as there are differences in terms of the species distributions and gear selectivity, which will bias the outputs.

5. Acknowledgments

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Tables

Table 1: Goodness-of-fit of the model building process for the sea turtle multinomial models to estimate species composition. The goodness-of-fit values shown are the Akaike Information Criteria (AIC), the McFadden R^2 and the error rate estimated with a *10*-fold cross-validation (CV) procedure.

Model	**AIC**	**McFadden R^2**	***10*-fold CV (error rate, %)**
Quarter	1815.3	0.127	76.0
Quarter + Lat	1300.8	0.387	55.8
Quarter + Lat + Long	1200.4	0.440	52.6
Quarter + Lat + Long + Lat:Long	964.8	0.562	46.8

Table 2: Deviance table (anova type II) of the parameters used for the final sea turtle multinomial model to estimate species composition. For each parameter it is indicated the degrees of freedom (Df), the chi-square statistic and the significance (*p-value*).

Variable	**Df**	**Chisq**	***p-value***
Quarter	9	51.85	< 0.001
Lat	3	543.04	< 0.001
Long	3	106.43	< 0.001
Lat : Long	3	241.59	< 0.001

Table 3: Goodness-of-fit of the model building process for the sea turtle binomial models to estimate mortality rates. The goodness-of-fit values shown are the Akaike Information Criteria (AIC), the Area Under the Curve (AUC) from the Receiver Operating Curve (ROC) analysis, the Nagelkerke R^2 and the error rate estimated with a *10*-fold cross-validation (CV) procedure.

Model	**AIC**	**AUC**	**Nagelkerke R^2**	***10*-fold CV (error rate, %)**
Species	758.3	0.737	0.221	23.8
Species + Quarter	744.2	0.769	0.252	21.9
Species + Quarter + Lat	741.0	0.782	0.260	21.1
Species + Quarter + Lat + Long	742.2	0.785	0.262	21.0
Species + Quarter + Lat + Long + Lat:Long	723.3	0.805	0.293	20.8

Table 4: Deviance table (anova type II) of the parameters used for the final sea turtle binomial model to estimate sea turtle mortality rates. For each parameter it is indicated the degrees of freedom (Df), the chi-square statistic and the significance (*p-value*).

Variable	**Df**	**Chisq**	***p-value***
Species	2	23.19	< 0.001
Quarter	3	22.74	< 0.001
Lat	1	4.18	0.041
Long	1	0.82	0.366
Lat:Long	1	20.87	< 0.001

Figures

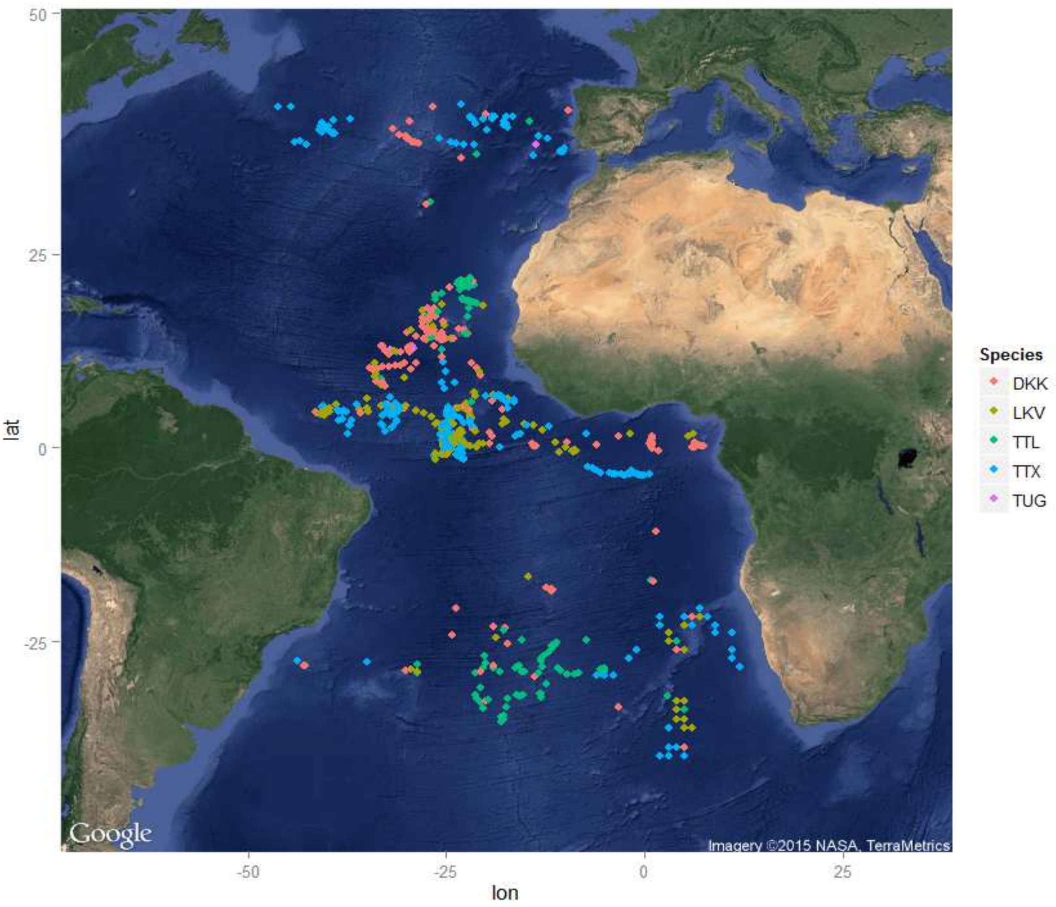

Figure 1: Distribution map of the sea turtle interactions recorded by the Portuguese pelagic longline fleet operating in the Atlantic Ocean. Data is from the fishery observer and the self reporting programs for the years 2003 to 2013.DKK is *Dermochelys coriacea* (leatherback turtle); LKV is *Lepidochelys olivacea* (olive ridley turtle); TTL is *Caretta caretta* (loggerhead turtle); TTX is sea turtle nei (non identified turtle) and TUG is *Chelonia mydas* (green turtle).

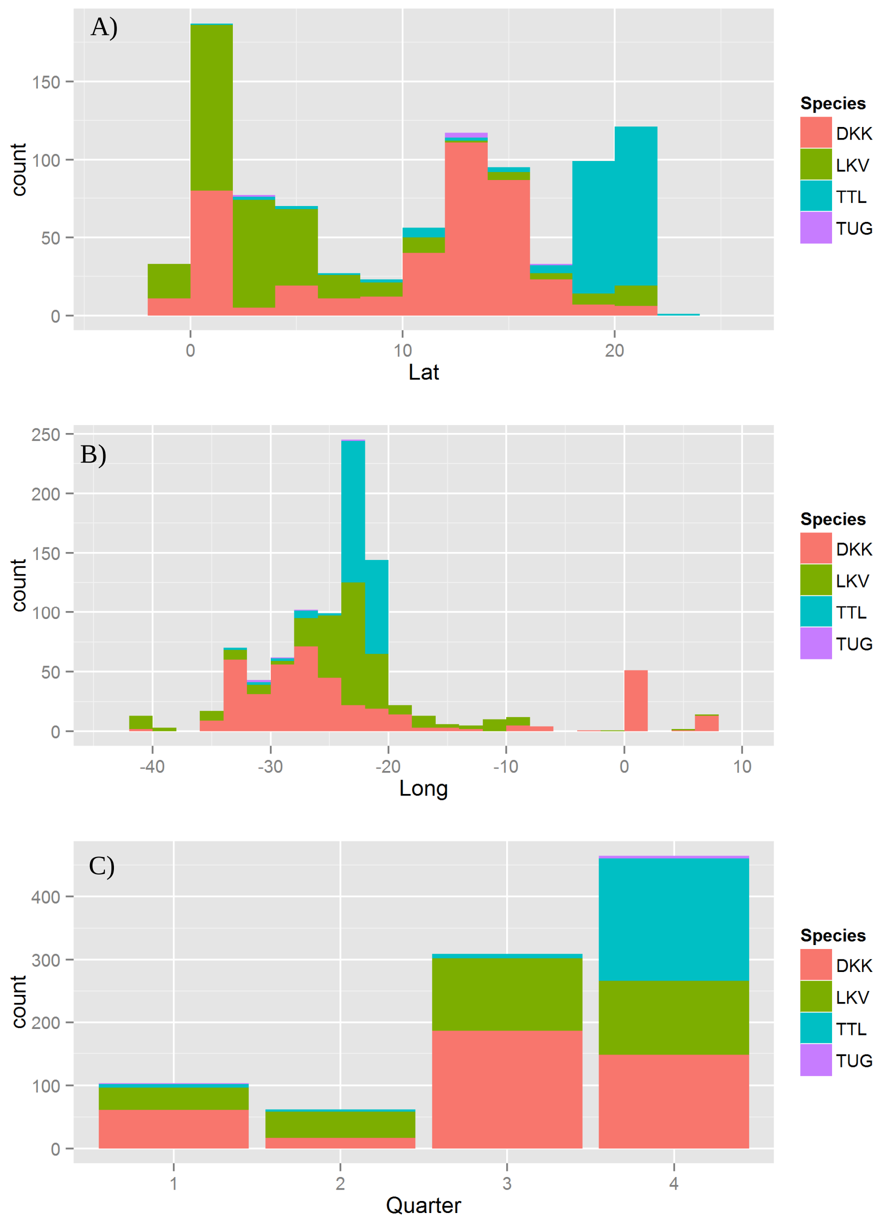

Figure 2: Species composition of sea turtles bycatch by latitude range (A), longitude range (B) and quarter of the year (C), for the Portuguese pelagic longline fishery operating in the equatorial and NE tropical regions. DKK is *Dermochelys coriacea* (leatherback turtle); LKV is *Lepidochelys olivacea* (olive ridley turtle); TTL is *Caretta caretta* (loggerhead turtle) and TUG is *Chelonia mydas* (green turtle).

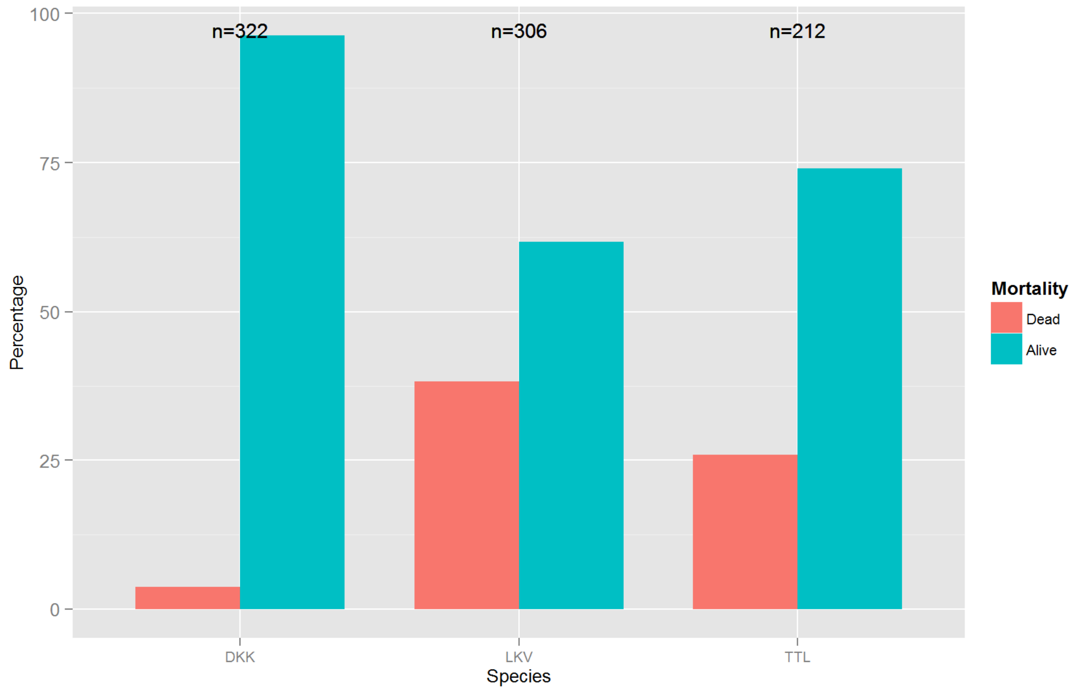

Figure 3: Species-specific sea turtle mortality rates in the Portuguese pelagic longline fishery operating in the equatorial and tropical NE Atlantic. The bars refer to the percentage of mortality and the numbers above each bar refers to the sample size (N) for each species. DKK is *Dermochelys coriacea* (leatherback turtle); LKV is *Lepidochelys olivacea* (olive ridley turtle) and TTL is *Caretta caretta* (loggerhead turtle).

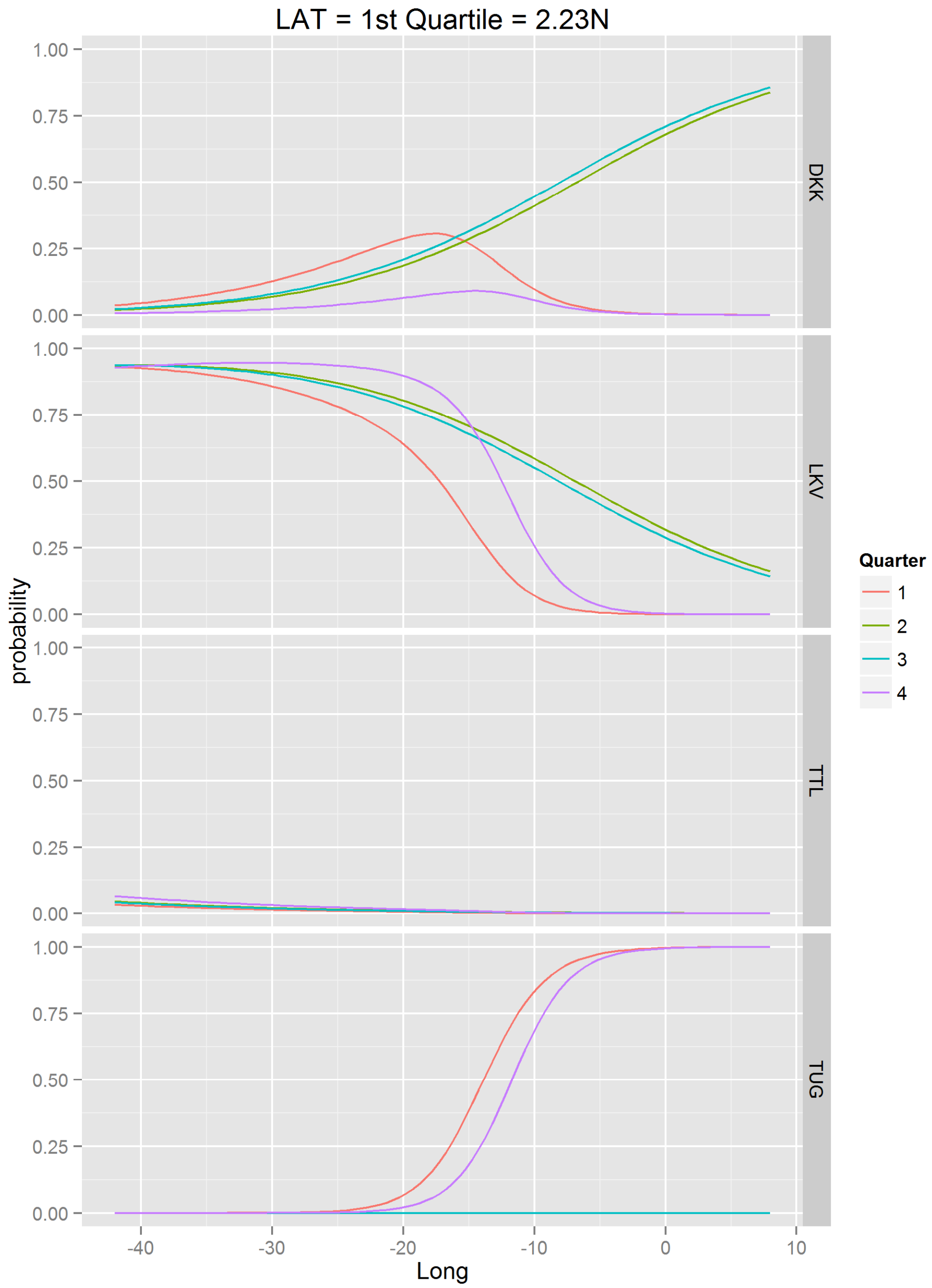

Figure 4: Predictions of sea turtle species composition interacting with the Portuguese pelagic longline fishery operating in the equatorial and tropical NE Atlantic. The predictions are calculated for each quarter of the year and along the longitudinal gradient of the study area, with the latitude fixed at the southern region (1st quartile of latitudes) in equatorial waters. DKK is *Dermochelys coriacea* (leatherback turtle); LKV is *Lepidochelys olivacea* (olive ridley turtle); TTL is *Caretta caretta* (loggerhead turtle) and TUG is *Chelonia mydas* (green turtle). The predictions shown for TUG should be considered with care given the low sample size in that species.

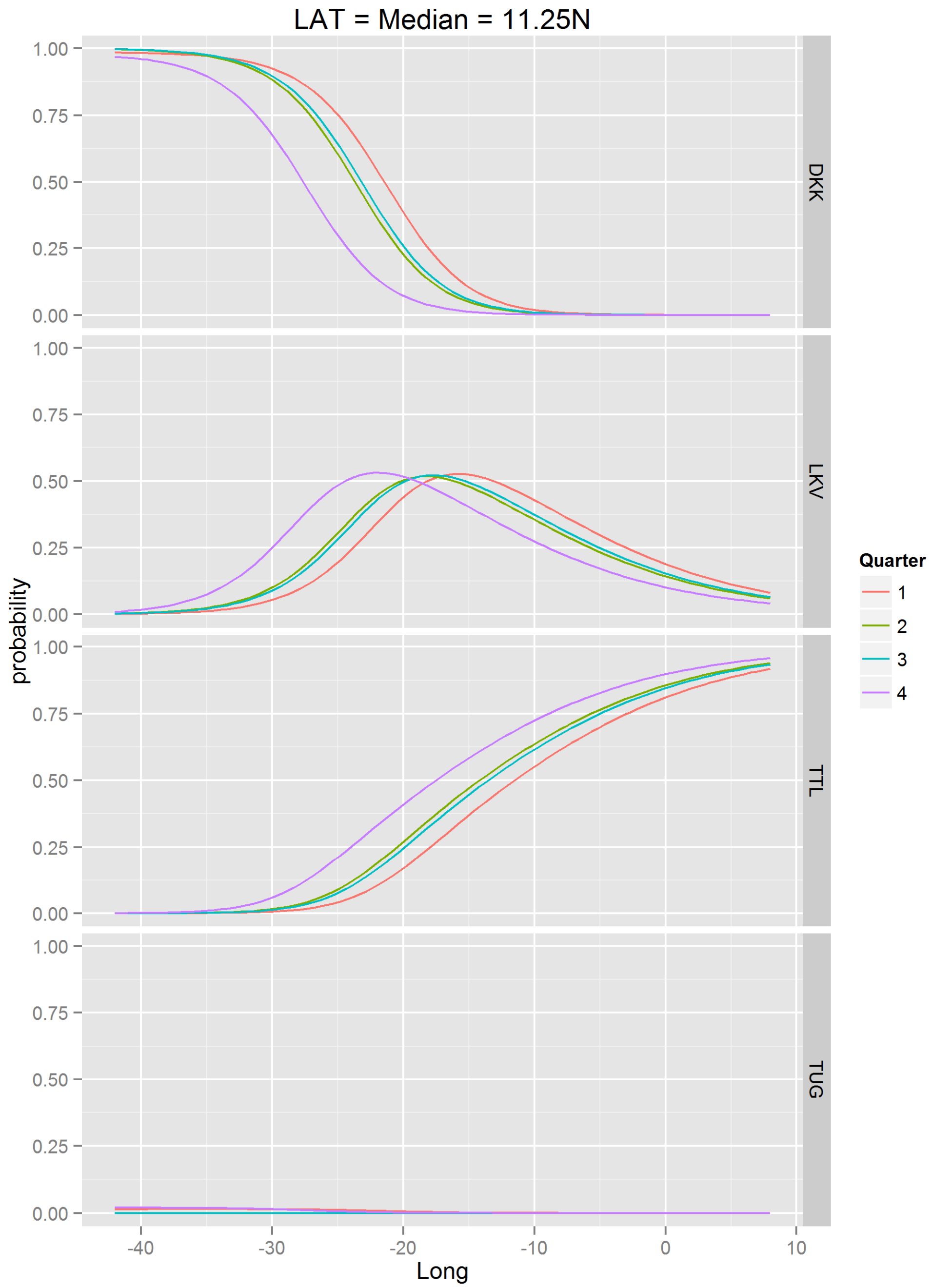

Figure 5: Predictions of sea turtle species composition interacting with the Portuguese pelagic longline fishery operating in the equatorial and tropical NE Atlantic. The predictions are calculated for each quarter of the year and along the longitudinal gradient of the study area, with the latitude fixed at the median region (median of latitudes) in waters between the equatorial and tropical regions. DKK is *Dermochelys coriacea* (leatherback turtle); LKV is *Lepidochelys olivacea* (olive ridley turtle); TTL is *Caretta caretta* (loggerhead turtle) and TUG is *Chelonia mydas* (green turtle). The predictions shown for TUG should be considered with care given the low sample size in that species.

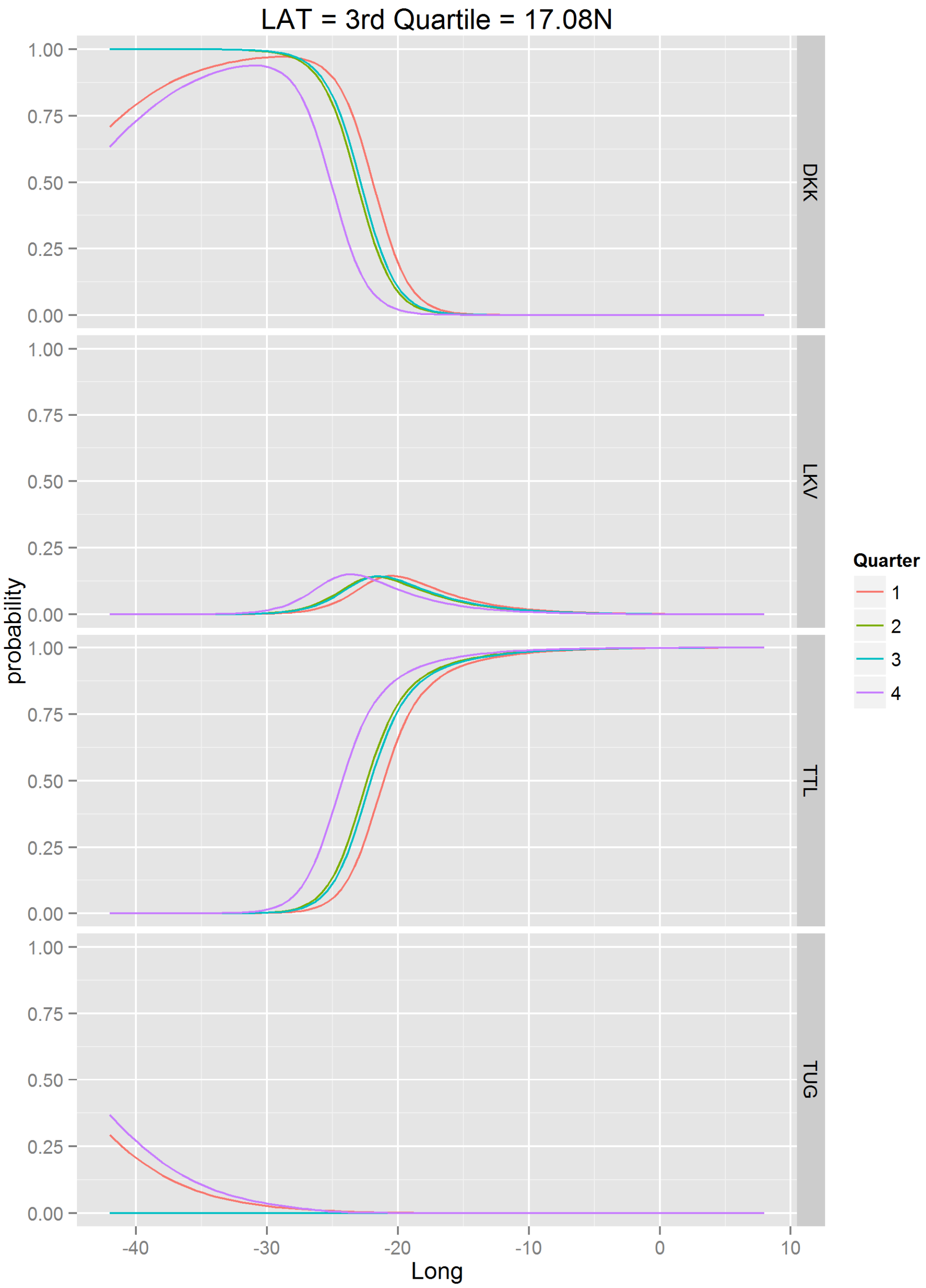

Figure 6: Predictions of sea turtle species composition interacting with the Portuguese pelagic longline fishery operating in the equatorial and tropical NE Atlantic. The predictions are calculated for each quarter of the year and along the longitudinal gradient of the study area, with the latitude fixed at the northern region (3^{rd} quartile of latitudes) in tropical waters. DKK is *Dermochelys coriacea* (leatherback turtle); LKV is *Lepidochelys olivacea* (olive ridley turtle); TTL is *Caretta caretta* (loggerhead turtle) and TUG is *Chelonia mydas* (green turtle). The predictions shown for TUG should be considered with care given the low sample size in that species.

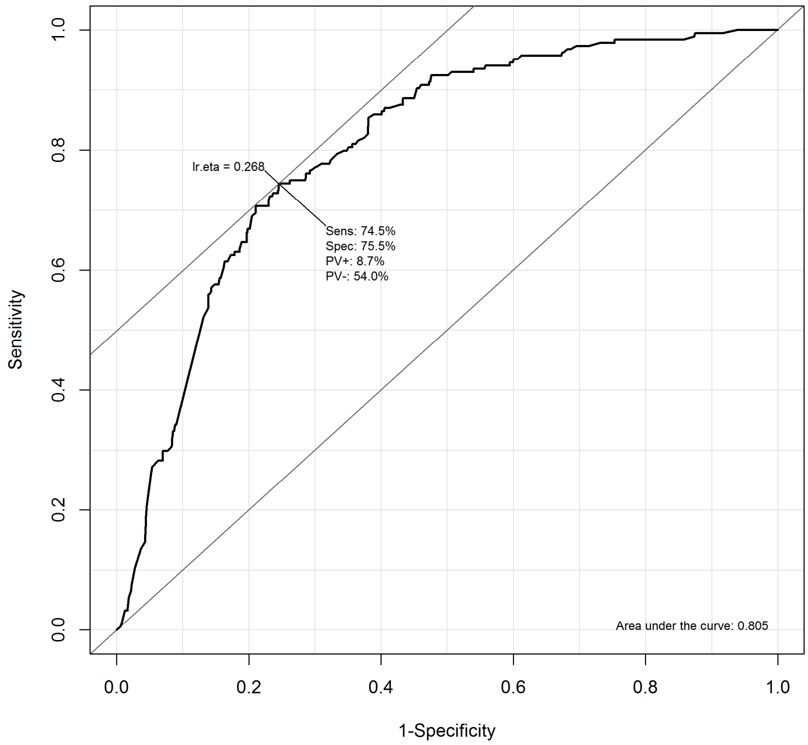

Figure 7: Receiver Operating Characteristic (ROC) curve for the binomial model for predicting sea turtle mortality rates. The Area Under the Curve (AUC) values is given, as well as the sensitivity (Sens), specificity (Spec) and predictive values (PV) at the optimal response cut-points (Ir.eta).

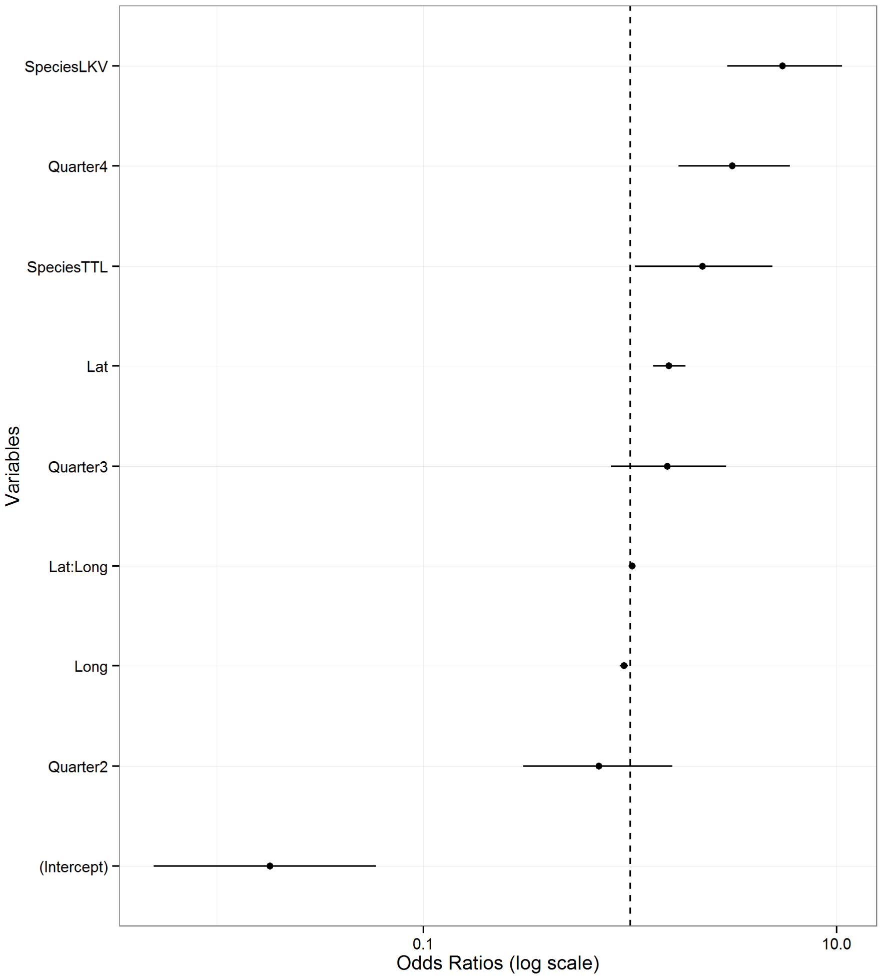

Figure 8: Odds ratios (with 90% confidence intervals) of sea turtle mortality rates in each of the variables considered in the binomial models, specifically species, quarter, latitude, longitude and interaction between latitude and longitude. The baseline combination (intercept) for comparison purposes refers to leatherbacks (DKK), quarter 1, and minimum values of latitude and longitude. The x-axis is represented in a base10 logarithm scale. LKV is *Lepidochelys olivacea* (olive ridley turtle) and TTL is *Caretta caretta* (loggerhead turtle).

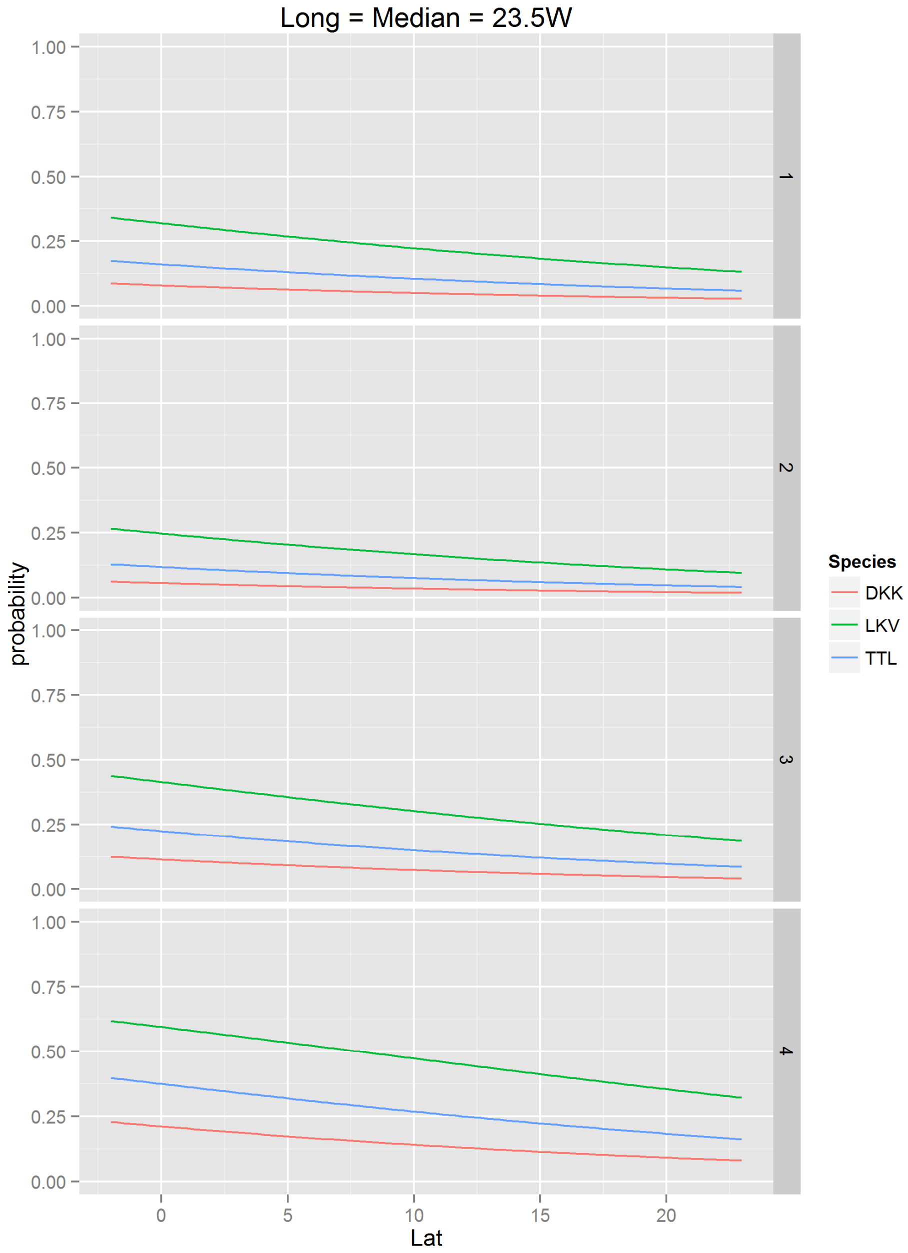

Figure 9: Predictions of sea turtle species-specific mortality rates when interacting with the Portuguese pelagic longline fishery operating in the Equatorial and Tropical North Atlantic. The predictions are calculated for each species in each quarter of the year and along the latitudinal gradient of the study area, with the longitude fixed at the median area (median quartile of latitudes). DKK is *Dermochelys coriacea* (leatherback turtle); LKV is *Lepidochelys olivacea* (olive ridley turtle) and TTL is *Caretta caretta* (loggerhead turtle).