

**UPDATE OF STANDARDIZED CATCH RATES OF
LOGGERHEAD SEA TURTLES, *CARETTA CARETTA*, CAUGHT
BY URUGUAYAN AND BRAZILIAN LONGLINE FLEETS (1998-2012)**

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SUMMARY

This study presents an update of the standardized catch rate of the loggerhead sea turtles caught by the Uruguayan and Brazilian longline fleets between 1998 and 2012 based on information collected by the observer programs of both countries. Thirty three percent of the total sets had reported by-catch of loggerhead sea turtles. Thus, to deal with the excess of zeros, the CPUE was modeled by Generalized Linear Mixed Models using a Delta Lognormal approach. The variables used in the model took into account spatial and temporal variations as well as characteristics of the gear. The standardized and nominal loggerhead CPUE series showed similar trends as previous estimations although the time series were updated and some variations in the models were incorporated.

RÉSUMÉ

Cette étude présente une mise à jour du taux de capture standardisé des tortues caouannes capturées par les flottilles palangrières uruguayennes et brésiliennes entre 1998 et 2012 sur la base d'informations provenant de programmes d'observateurs de ces deux pays. Des prises accessoires de tortues caouannes ont été déclarées dans le cadre de 33% des opérations totales. Par conséquent, afin de tenir compte des prises nulles excédentaires, la CPUE a été modélisée par des modèles mixtes linéaires généralisés appliquant une approche delta lognormale. Les variables utilisées dans le modèle tenaient compte des variations spatio-temporelles ainsi que des caractéristiques de l'engin. Les séries standardisées et nominales de CPUE de la tortue caouanne affichaient des tendances analogues à celles des estimations antérieures, même si les séries temporelles ont été mises à jour et que quelques variations des modèles ont été intégrées.

RESUMEN

Este estudio presenta una actualización de la tasa de captura estandarizada de la tortuga boba capturada por las flotas de palangre de Uruguay y Brasil entre 1998 y 2012, basándose en información procedente de los programas de observadores de ambos países. Se comunicaron capturas fortuitas de tortuga boba en el 33% de las operaciones de pesca totales. Por ello, para solucionar el exceso de ceros, se modeló la CPUE mediante modelos lineales generalizados utilizando un enfoque delta lognormal. Las variables utilizadas en el modelo tuvieron en cuenta las variaciones espaciales y temporales, así como las características del arte. La serie de CPUE estandarizada y nominal de la tortuga boba presentaba tendencias similares a las de estimaciones previas aunque se actualizó la serie temporal y se incorporaron algunas variaciones en los modelos.

KEYWORDS

Pelagic longline, Southwestern Atlantic Ocean, GLMM, Observer program

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1. Introduction

This study presents an update of the standardized catch rate of the loggerhead sea turtles - presented in Pons *et al.*, 2013 - caught by the Uruguayan and Brazilian longline fleets based on information collected between 1998 and 2012 by the observer programs of both countries.

2. Material and methods

2.1 Data

The data analyzed were collected by observers of the *Programa Nacional de Observadores a Bordo de la Flota Atunera Uruguaya* (PNOFA) from Uruguay since 1998, and the *Programa Nacional de Observadores de Bordo da Frota Pesqueira do Brasil* (PROBORDO), Fundação Pró-TAMAR, Instituto ALBATROZ and Núcleo de Educação e Monitoramento Ambiental (NEMA) from Brazil since 1999. We analyzed a total of 5,761 fishing sets deployed between 1998 and 2012 in the area located between parallels 19°S and 45°S, representing a total effort of 8,487,981 hooks. We chose to use data corresponding to fishing effort deployed south of 19°S because at lower latitudes the occurrence of loggerheads sea turtles in the by-catch is extremely low (Domingo *et al.*, 2006, Giffoni *et al.*, 2008) and to follow the same criteria used in Pons *et al.*, 2010 and 2013. We also considered the sets west of 20°W due to the fact that there was only a small amount of fishing effort to the east (**Figure 1**).

2.2 Standardized methods

From the total, 1,896 sets (33%) reported by-catch of loggerhead sea turtles. To deal with the excess of zeros, the CPUE was standardized by Generalized Linear Models (GLMs) using a Delta Lognormal approach (Lo *et al.*, 1992). The Delta method treated the positive observations (Lognormal) separately from the probability that a positive observation occurs (Binomial). We used an identity link function and a logit link function for the Lognormal and Binomial models respectively.

Deviance tables (for both components of the delta model) were used to select the fixed explanatory factors and interactions that explained most of the variability in the data (Ortiz and Arocha 2004). The effect of each factor/interaction was evaluated according to the percent of deviance explained by the addition of each factor/interaction to the model. Only those factors/interactions whose deviation exceeds 5% of the total deviation were selected as explanatory variables.

Once selected the fixed factors and interactions, all interactions involving the factor *Year* were evaluated as random effects to obtain the estimated index per year, transforming the GLMs into GLMMs (Generalized Linear Mixed Models) (Cooke 1997). The significance of the random interactions was evaluated using the Akaike Information Criterion (AIC), Schwarz's Bayesian Criterion (BIC) and the likelihood ratio test (Pinheiro and Bates 2000). The models with smaller AIC and BIC values were selected. The indices of abundance were estimated then as the product of the least squares means (LSMeans) of the factor *Year* for the selected Lognormal and Binomial models (Lo *et al.*, 1992; Stefánsson 1996). Also, variance estimation for the standardized index was calculated following Walter and Ortiz (2012) for two-stage CPUE estimators.

The independent variables considered in the standardization model, as main factors and also as first-order interactions, are summarized in **Table 1**. The details about the categories of each variable can be found in Pons *et al.*, 2010 and 2013. All the analyses were conducted using the R software (R Development Core Team 2012) with the packages MASS (Venables *et al.*, 2002), lme4 (Bates 2012), lsmeans (Lenth 2014) and pbrktest (Højsgaard and Halekoh 2012).

3. Results and discussion

Deviance table analysis, one for the Lognormal and other for the Binomial model, are shown in **Tables 2a** and **2b** respectively. For the positive sets, the factors *Year*, *Quarter*, *Area* and *Gear*, and the interactions *Year:Quarter* and *Year:Area* were statistically significant (**Table 2a**). Also, for the proportion of positives/total sets the factors *Year*, *Area*, *SST* and *Gear* and the interactions *Year:Area*, *Year:Quarter*, *Quarter:Area* and *Area:Gear* were significant (**Table 2b**).

Thus, after fixed factors were selected, the interactions with the factor *Year* were included as random effects. According to the three criteria evaluated (the likelihood ratio tests and reductions in AIC and BIC values, **Table 3**) the final models selected for the Lognormal and Binomial components of the model were:

Lognormal Model: $\log(\text{CPUE}) = \text{Year} + \text{Area} + \text{Quarter} + \text{Gear} + \text{Random}(\text{Year}:\text{Area}) + \text{Random}(\text{Year}:\text{Quarter})$

Binomial Model: $\text{positive}/\text{total} = \text{Year} + \text{Area} + \text{Quarter} + \text{SST} + \text{Quarter}:\text{Area} + \text{Area}:\text{Gear} + \text{Random}(\text{Year}:\text{Area}) + \text{Random}(\text{Year}:\text{Quarter})$

Diagnostic plots for the final Lognormal and Binomial GLMMs confirmed model assumptions of homogeneity of variance and error distributions of the CPUE. However, some deviation could be observed towards the upper side of the distribution for the Binomial model in the qqplot (**Figure 3**).

The standardized CPUE index with their confidence intervals is shown in **Figure 4**. The differences observed to the last series presented in 2013 are related to an update of the database and slightly changes in the standardized methodology.

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Table 1. Summary of independent variables used in the GLMMs.

<i>Variable</i>	<i>Type</i>	<i>Observations</i>
<i>Year</i>	Categorical (15)	Period: 1998-2012
<i>Quarter</i>	Categorical (4)	Quarter 1: January-March Quarter 2: April-June Quarter 3: July-September Quarter 4: October-December
Sea surface temperature (<i>SST</i>)	Categorical (3)	In Celsius degrees (° C), range: 8°-32° C SST 1: < 15° C SST 2: between 15° and 20° C SST 3: > 20° C
<i>Area</i>	Categorical (3)	See Figure 1
<i>Gear</i>	Categorical (2)	1: Monofilament mainline 2: Multifilament mainline

Table 2. Deviance analysis table of positive by-catch rates (Lognormal) and proportion of positive sets (Binomial) models. ‘d.f.’ refers to degree of freedom of the added factor; ‘% of total deviance’ to the reduction in percentage of model deviance by adding the factor to the model.

a) Model factors positive by-catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance
NULL	1	1629		
Year	14	1391	238	43.5
Year Quarter	3	1363	28	5.1
Year Quarter Area	2	1225	138	25.2
Year Quarter Area SST	2	1219	6	1.2
Year Quarter Area SST Gear	1	1081	137	25.1
Year Quarter Area SST Gear Year* Quarter	36	991	91	14.2
Year Quarter Area SST Gear Year* Area	25	1019	63	10.3
Year Quarter Area SST Gear Quarter* SST	4	1074	7	1.3
Year Quarter Area SST Gear Quarter* Area	6	1071	10	1.9
Year Quarter Area SST Gear Area*Gear	2	1067	15	2.6
b) Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance
NULL	1	2681		
Year	14	2379	302	23.8
Year Area	2	1688	691	54.4
Year Area Quarter	3	1648	41	3.2
Year Quarter Area SST	2	1506	141	11.1
Year Quarter Area SST Gear	1	1411	95	7.5
Year Quarter Area SST Gear Year* Area	26	1189	222	14.9
Year Quarter Area SST Gear Year* Quarter	38	1196	215	14.5
Year Quarter Area SST Gear Quarter* Area	6	1325	86	6.4
Year Quarter Area SST Gear Quarter* SST	6	1378	34	2.6
Year Quarter Area SST Gear Area*Gear	2	1253	158	11.1

Table 3. Analyses of the delta lognormal mixed model formulations for swordfish catch rates from the Uruguayan pelagic longline fishery (1998-2012).

GLMM	Akaik e's Information Criterion	Bayesian Information Criterion	Log Likelihood	Likelihood Ratio Test
Positives catch rates				
Year Area Quarter Gear	4366	4494	-2160	
Year Area Quarter Gear Year:Area	4344	4472	-2149	<0.0001
Year Area Quarter Gear Year:Area Year:Quarter	4301	4434	-2126	<0.0001
Proportion of positives				
Year Area Quarter SST Area:Gear Quarter:Area	1795	1915	-865	
Year Area Quarter SST Area:Gear Quarter:Area Year:Area	1736	1857	-836	<0.0001
Year Area Quarter SST Area:Gear Quarter:Area Year:Area Year:Quarter	1689	1813	-811	<0.0001

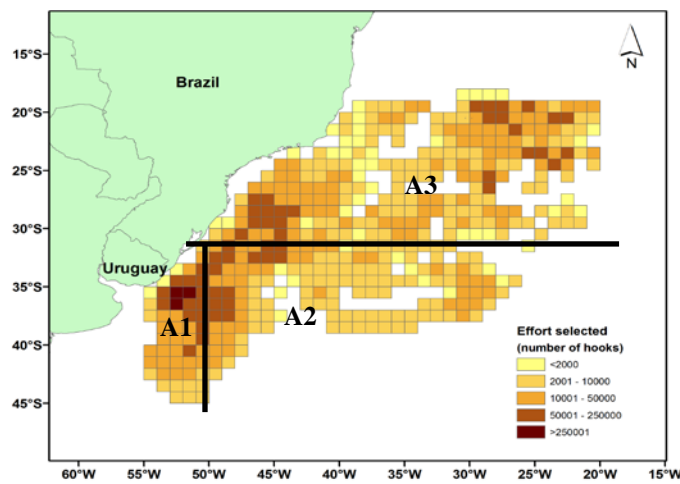


Figure 1. Distribution of the total effort (number of hooks) deployed by the Observer Programs from Uruguay and Brazil and areas selected for the analysis (A1, A2 and A3).

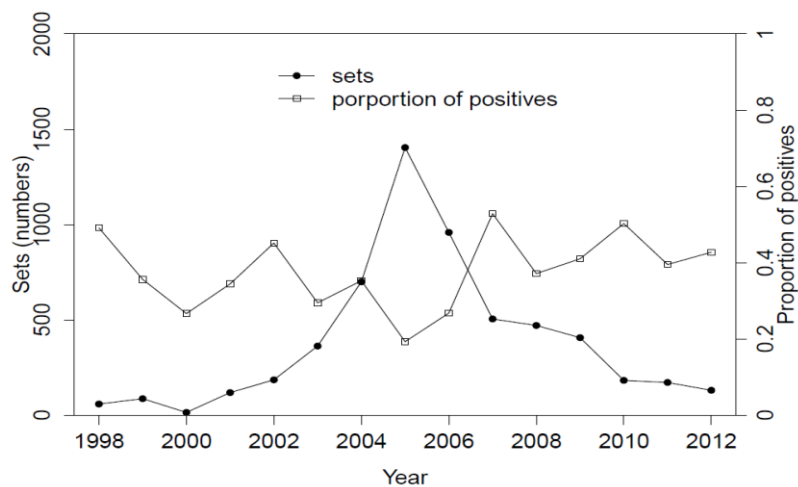


Figure 2. Number of total sets and proportion of positive sets by year (1998-2012) observed by the Observer Programs of Brazil and Uruguay.

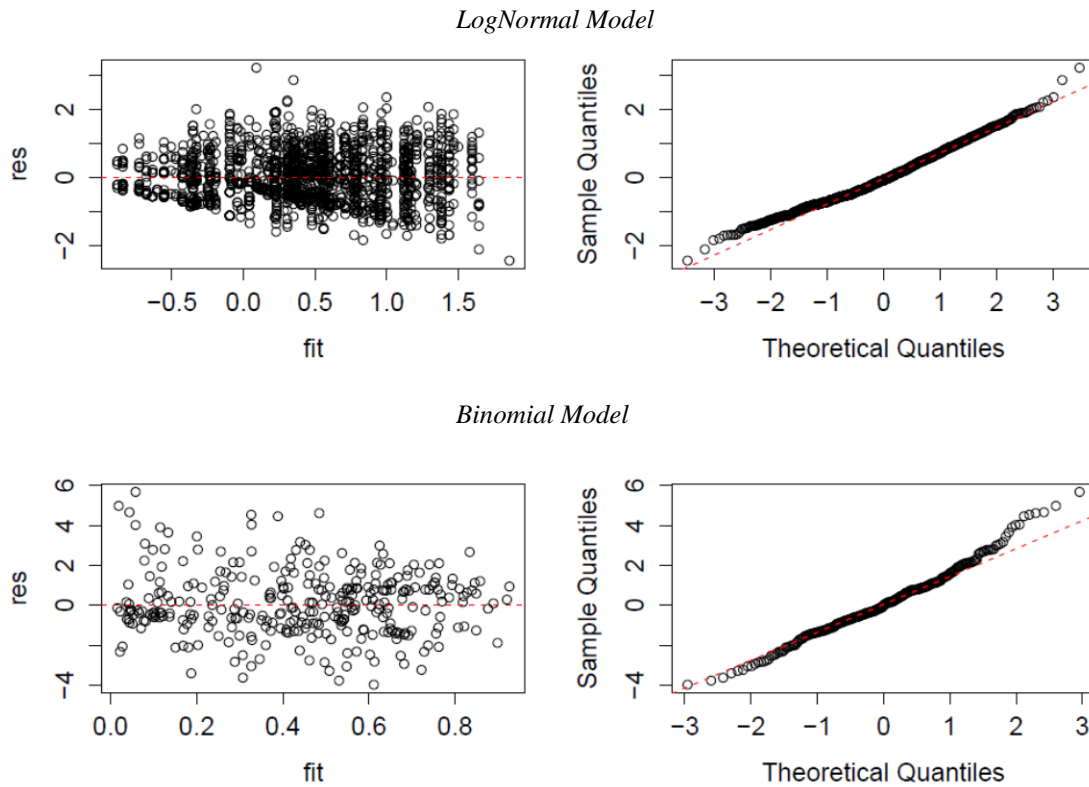


Figure 3. Diagnostic plots for positive catch rates (Lognormal model) and proportion of positives (Binomial). The red line represents the expected pattern of observations.

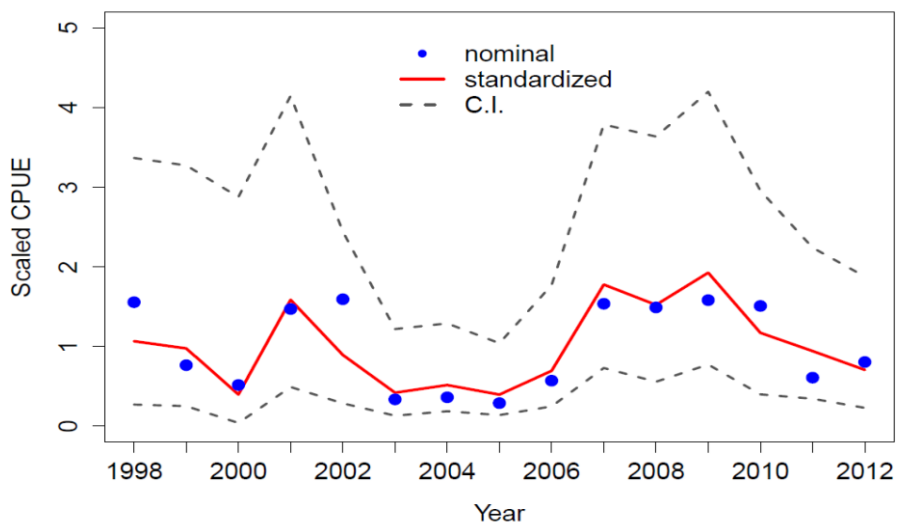


Figure 4. Nominal and standardized CPUE of loggerhead sea turtles caught by Uruguayan and Brazilian pelagic longline fleets. Dashed line corresponds to 95% Confidence Interval (C.I.) of the standardized index.