Aquat. Living Resour. 23, 49–64 (2010)
© EDP Sciences, IFREMER, IRD 2010
DOI: 10.1051/alr/2010002
www.alr-journal.org

Aquatic Living Resources

ICCAT CICTA CICAA

# Assessing the impact of the pelagic longline fishery on albatrosses and petrels in the southwest Atlantic

Sebastián Jiménez[1,2,3], Martín Abreu[1,2], Maite Pons[2,3], Mauricio Ortiz[4] and Andrés Domingo[1,2,a]

[1] Proyecto Albatros y Petreles – Uruguay, Avenida Giannattasio Km. 30.500, El Pinar, Canelones, Uruguay
[2] Dirección Nacional de Recursos Acuáticos, Recursos Pelágicos, Constituyente 1497, CP 11.200, Montevideo, Uruguay
[3] Sección Ecología, Facultad de Ciencias, Universidad de la República, Iguá, 4225 Montevideo, Uruguay
[4] National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, 75 Virginia Beach Drive, Miami FL 33149, USA

Received 27 February 2009, Accepted 9 November 2009

**Abstract –** The black-browed (*Thalassarche melanophrys*) and Atlantic yellow-nosed (*Thalassarche chlororhynchos*) albatrosses and the white-chinned petrel (*Procellaria aequinoctialis*) are the seabird species most frequently captured by pelagic longline fisheries in the southwest Atlantic. This study estimates this type of bycatch and describes the spatial-temporal patterns of the incidental capture of these species by the Uruguayan pelagic longline fleet, based on data collected by scientific observers on 47 fishing trips from 2004 to 2007. Three generalized linear models (GLM) models were employed to predict bycatch for each species based on the observed data. We also developed a spatio-temporal species-specific analysis. Captures were recorded in Uruguayan waters, mainly over the slope and depth waters, and in international waters adjacent to Uruguay, the north of Argentina, and the south of Brazil. The highest catch rates for black-browed albatrosses and white-chinned petrels were recorded on the Uruguayan slope from fall to spring, while the highest values for Atlantic yellow-nosed albatrosses were recorded further to the north, in the international waters off Brazil in late winter. The average estimated number of black-browed and Atlantic yellow-nosed albatrosses and white-chinned petrels caught during the study period was 1683, 257 and 239 birds, respectively. Taking into account the total effort of the fleet, these values represent an estimated catch rate of 0.276, 0.042, and 0.039 birds/1000 hooks for these species, respectively. The results of the present study suggest that the annual impact of this fishery is medium to high on the black-browed albatross, low on the Atlantic yellow-nosed albatross and low on the white-chinned petrel. However, the situation of these species in the southwest Atlantic should be viewed with considerable concern, as our understanding of the impact of the bycatch on their populations requires more research. Any effort to reduce seabird mortality in the southern hemisphere should target this geographic region.

**Key words:** Seabird bycatch estimation / Albatrosses / Petrels / Pelagic longline / South Atlantic Ocean

**Résumé –** L'albatros à sourcils noirs (*Thalassarche melanophrys*), l'albatros à nez jaune (*Thalassarche chlororhynchos*) et le puffin à menton blanc (*Procellaria aequinoctialis*) sont des oiseaux de mer les plus souvent capturés lors des pêches à la palangre en Atlantique sud-ouest. Cette étude estime ce type de captures accessoires et décrit l'évolution spatio-temporelle des captures accidentelles de ces espèces par la flotte hauturière de palangriers de l'Uruguay, basée sur les données d'observateurs scientifiques de 47 sorties de 2004 à 2007. Trois modèles linéaires généralisés (GLM) ont été utilisés pour estimer les captures accessoires de chaque espèce d'après les données observées. Nous développons une analyse spatio-temporelle spécifique à chaque espèce. Les captures enregistrées dans les eaux uruguayennes sont effectuées principalement au-delà la pente continentale, au large et dans les eaux internationales adjacentes à l'Uruguay, au nord de l'Argentine, et au sud du Brésil. Les taux les plus élevés d'albatros à sourcils noirs et de puffin à menton blanc sont enregistrés au niveau de la pente continentale de l'automne au printemps australs, tandis que l'albatros à nez jaune est plus fréquent dans les eaux internationales au nord, au large du Brésil et en fin d'hiver austral. Le nombre moyen estimé d'albatros à sourcils noirs, d'albatros à nez jaune et de puffin à menton blanc, capturés durant cette période d'étude, est respectivement de 1683, 257 et 239 individus (soit 0,276 ; 0,042 et 0,039 oiseaux/1000 hameçons)

[a] Corresponding author:
adomingo@dinara.gub.uy; dimanchester@gmail.com

Nos résultats montrent que l'impact annuel de cette pêche serait moyen à élevé pour l'albatros à sourcils noirs, faible pour l'albatros à nez jaune, et faible pour le puffin à menton blanc. Cependant, la situation de ces espèces en Atlantique sud-ouest devrait être considérée avec précaution, notre connaissance de l'impact sur ces populations demandant davantage de recherches. Tout effort de réduction des mortalités d'oiseaux de mer en hémisphère sud devrait cibler cette région.

## 1 Introduction

Fisheries bycatch has been identified as an important cause of population decline in many species, including sharks, marine mammals, turtles, and birds (Robertson and Gales 1998; Spotila et al. 2000; Hall et al. 2000; Lewison et al. 2004; Dulvy et al. 2008). Bycatch of longline fisheries, in particular, represents one of the main causes of the global decline of albatross populations (Gales 1998), and poses a serious threat for several species of petrels (Brothers et al. 1999).

In the southwest Atlantic (SWA) longline fisheries targeting large pelagic fish [such as tuna (*Thunnus* spp.), swordfish (*Xiphias gladius*) and sharks (e.g. *Prionace glauca, Isurus oxyrinchus*)] record the highest seabird bycatch rates (Alexander et al. 1997; Brothers et al. 1999; Robertson and Gales 1998; Jiménez et al. 2009). Bugoni et al. (2008) reviewed the seabird catch rates of these fisheries in this region, and found that catch rates varied from zero to 5.03 birds per 1000 hooks. In the Uruguayan fishery in the early 1990s, the seabird bycatch rates reached values close to five birds per 1000 hooks (Stagi et al. 1998). In the period 1998-2004, Jiménez et al. (2009) recorded an overall catch rate of 0.42 birds/1000 hooks in the Uruguayan pelagic longline fleet, and found there was significant spatial and temporal variation, with higher captures on the Uruguayan slope (2.5 birds/1000 hooks).

Although our understanding of the bycatch rates of seabirds in pelagic longline fisheries operating in the SWA has increased over the last decade (Vaske 1991; Stagi et al. 1998; Neves and Olmos 1998; Bugoni et 2008; Jiménez et al. 2009), there have been no estimations of the magnitude of this bycatch so far. Prince et al. (1998) noted that there is considerable difficulty in obtaining reliable information regarding the number of captured seabirds, specifically in fisheries lacking comprehensive observer programs, as well as in relating this information with to populations that are being studied demographically. Alexander et al. (1997) recommended that data collection in fisheries consider all seabird species, so that the species, sex, age and, when possible, the provenance of captured individuals should be determined. To gather this information, dead seabirds need to be collected and later analyzed in the laboratory. This information is extremely useful for estimating the bycatch at species level, and ultimately for evaluating the effect of the fishery-related mortality in seabird populations (Alexander et al. 1997). In Uruguay, the Uruguayan National Observers Program of the Tuna Fleet ("*Programa Nacional de Observadores a bordo de la flota atunera uruguaya*", PNOFA) has been collecting information on seabird bycatch by pelagic longline vessels since 1998 (Jimenez et al. 2009). Captured seabird specimens have been collected since mid 2003, substantially improving the information obtained from captured individuals and, in turn, permitting a detailed assessment of seabird bycatch at the species level.

In this study, we focus on one of the key aspects in evaluating the impact of a pelagic longline fishery in the SWA: predicting the total number of seabirds captured by species. Also, since an understanding of when and where bycatch is most likely to occur can be very valuable in the development of mitigation strategies, we developed a spatio-temporal species-specific analysis. In the SWA, the black-browed albatross (*Thalassarche melanophrys*), Atlantic yellow-nosed albatross (*T. chlororhynchos*) and white-chinned petrel (*Procellaria aequinoctialis*) are the seabird species most frequently captured by the Uruguayan and Brazilian pelagic longline fleets (Neves and Olmos 1998; Bugoni et al. 2008; Jiménez et al. 2009). These seabirds are listed as globally threatened on the IUCN Red List of Threatened Species, and bycatch in pelagic longline is apparently one of the main causes of observed declines in their populations. Therefore, this study estimates the bycatch of black-browed and Atlantic yellow-nosed albatrosses and white-chinned petrels by the Uruguayan pelagic longline fishery and describes the spatial-temporal patterns of the incidental capture of these three species in the SWA Ocean.

## 2 Materials and methods

### 2.1 Fishery and observer data

Data were collected through the PNOFA by observers trained in the identification and collection of seabirds, in 47 fishing trips between January 2004 and December 2007 (Table 1). The vessels operated between 19°S and 40°S, and between 20°W and 53°W. This area encompasses the Uruguayan shelf, slope and deep waters (depths between 200 and 4000 m.), and international waters adjacent to Uruguay, northern Argentina and southern Brazil (depths between 3000 and 4000 m.), waters over the Rio Grande Rise, and deep waters northeast of this Rise (Fig. 1).

The Uruguayan pelagic longline fleet targets swordfish (*X. gladius*), yellow-fin tuna (*Thunnus albacares*), bigeye tuna (*T. obesus*), albacore (*T. alalunga*), and pelagic sharks (mainly *P. glauca*). A mean of 11 vessels (range 9-13) per year, with lengths ranging from 15 m to 37 m, were active in the period 2004-2007. Most of these vessels employed an American-type longline (monofilament mainline), while some freezer vessels used Spanish longline (multifilament mainline). Both types of fishing gear are described in Domingo et al. (2005) and Jiménez et al. (2009). Typically, the longline is set over the vessel's stern, usually after sunset. Setting is generally completed before midnight. Daily effort varies between 600 and 1600 hooks in the American longline, and between 1000 and 3360 in the Spanish longline. Early in the morning the gear

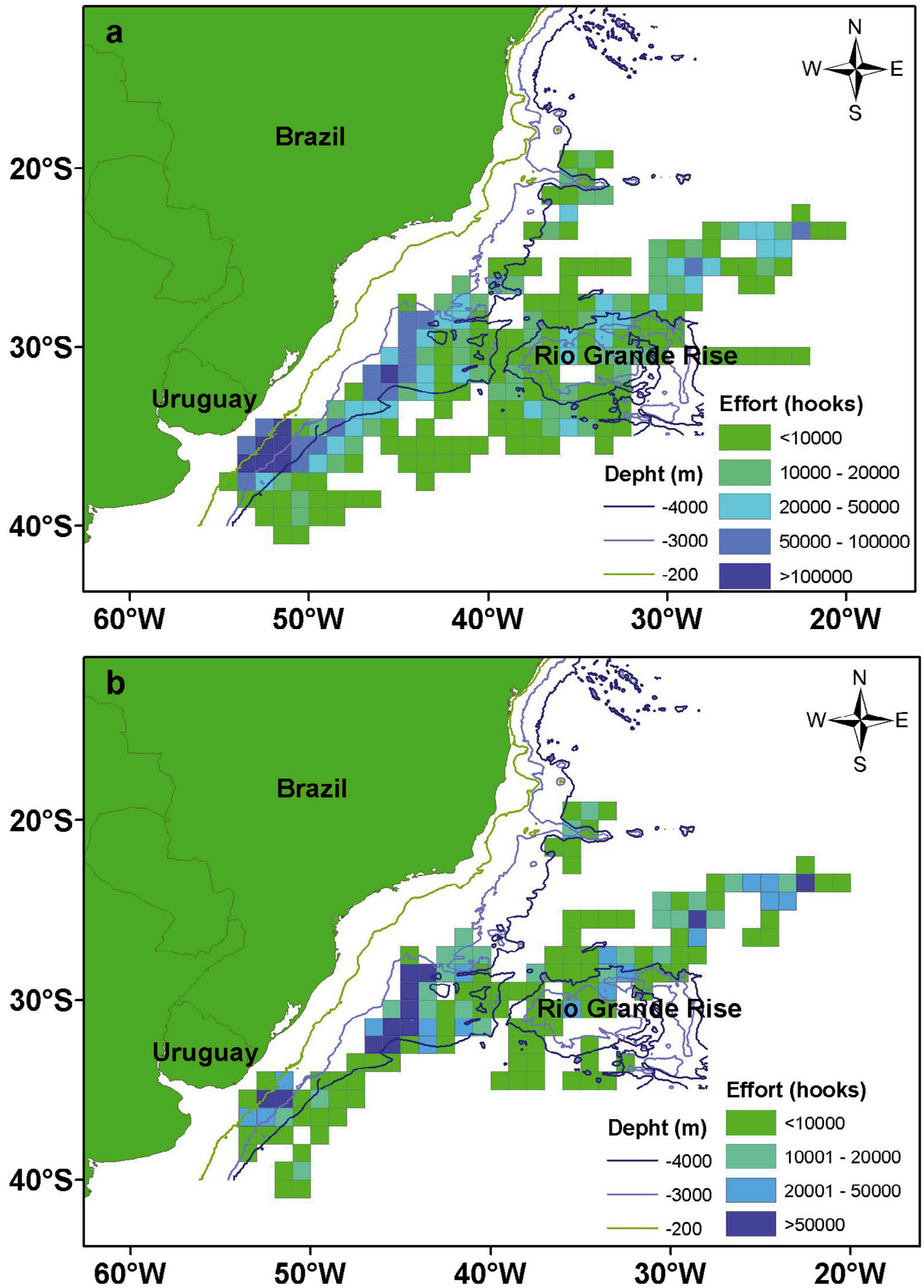


**Fig. 1.** Spatial distribution of the fishing effort (number of hooks) realized by the Uruguayan pelagic longline fishery from 2004 to 2007 in squares of 1 × 1°. a) Total fishing effort. b) Observed fishing effort.

is hauled onboard at the starboard side of the vessel. Hauling takes approximately seven hours, although this varies according to the number of hooks set, the volume of the capture, and the meteorological conditions. The baits used are squid (*Illex argentinus*), mackerel (*Scomber* spp., *Trachurus* spp.) and shark belly, thawed a few hours before line setting. Night setting is practiced mainly as a fishing strategy, and it has a mitigating effect on seabird bycatch. However, between late spring and early fall, sets beginning in the daylight hours before nightfall are more frequent. During the observed trips, blue-dyed baits and tori lines were used as mitigation measures in only a very small proportion of the observed hooks (< 1%), with no effects on seabird bycatch rates.

Data for the unobserved fishing trips were obtained from logbooks provided by the Depart. *Recursos Pelágicos*, *Directión Nacional de Recursos Acuáticos* (DINARA). The logbooks include a sworn statement filled out by the ship captains, who recorded the geographical position, effort, catch of target species, and other variables. We used six variables recorded for each set: date (year and month), latitude and longitude (both at

**Table 1.** Details of the observed effort in each fishing trip realized during the period 2004-2007 aboard the Uruguayan pelagic longline fleet. The lengths of the observed vessels ranged from 22 m to 37 m. Monofilament gear was used except where indicated with an asterisk.

| Year | Date of the trip | Number of sets | Number of hooks |
|---|---|---|---|
| 2004 | 14-23 Jan. | 10 | 9 200 |
| | 18 Jan.-28 Mar. | 68 * | 219 218 |
| | 9 Apr.-10 Jun. | 45 * | 76 238 |
| | 9-22 May | 12 | 12 850 |
| | 16 May-3 Jun. | 15 | 15 120 |
| | 1 May-10 Jul. | 69 * | 210 528 |
| | 9 Aug-13 Oct. | 66 * | 196 124 |
| | 7-25 Sep. | 16 | 14 060 |
| | 20 Sep.-2 Oct. | 11 | 11 580 |
| Total | | 312 | 764 918 |
| 2005 | 29 Jan.-10 Feb. | 9 * | 15 884 |
| | 14-20 Feb. | 7 | 7 629 |
| | 25-27 Feb. | 3 | 4 800 |
| | 28 Feb.-17 May | 72 * | 206 844 |
| | 21 Apr.-4 May | 12 | 14 150 |
| | 27 Apr.-5 May | 9 | 9 750 |
| | 13-28 May | 14 | 15 840 |
| | 31 May-11 Jun. | 10 | 10 010 |
| | 12 Jun.-23 Aug. | 63 * | 177 394 |
| | 22-30 Jul. | 9 | 10 300 |
| | 6-14 Aug. | 9 | 10 200 |
| | 22-30 Sep. | 8 | 7 240 |
| | 15 Oct. | 1 | 900 |
| | 18-21 Oct. | 4 | 4 500 |
| | 1-20 Dec. | 14 | 15 965 |
| Total | | 244 | 511 406 |
| 2006 | 4 Jan.-14 Mar. | 68 * | 224 832 |
| | 5-14 Mar. | 11 | 9 900 |
| | 29 Apr.-12 May | 10 | 10 350 |
| | 7-12 Jun. | 6 | 5 700 |
| | 13 Jul.-21 Sep. | 68 * | 191 040 |
| | 12-21 Oct. | 8 | 8 000 |
| | 30 Oct.-4 Nov. | 6 | 6 800 |
| | 3-8 Dec. | 6 | 5 450 |
| | 10-22 Nov. | 13 | 11 160 |
| Total | | 196 | 473 232 |
| 2007 | 12 Jan.-20 Mar. | 66 * | 220 896 |
| | 21 Feb.-2 Mar. | 9 | 9 700 |
| | 19-27 Apr. | 8 | 6 660 |
| | 20-31 May | 10 | 11 065 |
| | 7-29 Jun. | 16 | 19 680 |
| | 9-17 Jul. | 7 | 7 890 |
| | 24 Jul.-7 Aug. | 12 | 11 340 |
| | 29 Jul.-13 Aug. | 11 | 14 625 |
| | 13-27 Aug. | 13 | 13 750 |
| | 3-14 Sep. | 9 | 10 389 |
| | 2-12 Oct. | 9 | 9 344 |
| | 26 Oct.-9 Nov. | 13 | 13 713 |
| | 3-21 Nov. | 16 | 21 965 |
| | 13-15 Dec. | 3 | 2 880 |
| Total | | 202 | 373 897 |
| All years | | 954 | 2 123 453 |

the beginning of each set), number of hooks deployed, and type of gear (monofilament and multifilament). Sets from logbooks with missing latitude/longitude data were excluded from the analysis. The total unobserved data comprised 3 351 sets with 3 968 450 hooks deployed.

The observer program monitored 35% of the total fishing effort (i.e. number of hooks) realized by the fleet during the study period. The average percentage of the annual observed effort with respect to the total realized effort by the fleet during this period was 37%, with a minimum of 26% in 2005 and a maximum of 49% in 2007. The observer program monitored 65% of the geographic area covered by the fleet during the study period (Fig. 1). On average about 20% of the 1 degree latitude-longitude cells where the fleet operated were monitored by the observer program, with a maximum of 25% in 2004 and a minimum of 13% in 2006. However, the observer program did consistently monitor those cells where most of the fishing operations took place each year (Fig. 1). During the study period, the observed fishing trips covered all months of the year, with the exception of November and December 2004 (Table 1). At least one trip was made on each of the vessels of the fleet (with the exception of two vessels of 15 m length that operated during the first half of the study period and did not have sufficient capacity to carry an observer). On each fishing trip, an observer recorded (during the setting of the gear) for all sets: the date, position, type of gear utilized, and the fishing effort (in number of hooks). During each hauling, the observer performed a sampling of the capture; there was 100% coverage for the duration of the fishing operation. The observer identified the species, classified the capture (catch, discard - bycatch and released – lost catch), and then recorded biological information. With regard to the incidental capture of seabirds, the observer's specific tasks were to record the total number of birds caught per set, to identify the species, and to collect samples (i.e. head and tarsus or entire specimens) and bird tag rings (if available).

## 2.2 Data analysis

The bird capture per unit of effort (BCPUE) was defined as the number of birds captured per thousand hooks (birds/1000 hooks). Birds entangled in buoy lines were not counted in the estimate. To analyze the spatial distribution of the fishing effort and the location of bird captures, we used the geographical position of the vessel at the beginning of each set.

### Bycatch estimation

The modeling of seabird bycatch in the Uruguayan pelagic longline fisheries falls under the category of modeling count data of rare events (Cunningham and Lindenmayer 2005). The excess of zero observations of seabird bycatch poses a statistical issue because traditional distribution assumptions of standard statistical analysis are not meet. Zero observations may arise because of random sampling (i.e. seabirds are present during the fishing operation, but no seabird bycatch is observed), or from structural conditions (i.e. absence of seabird(s) in the time/area of fishing operations). A problem is posed by the fact that it is rarely possible to distinguish between these two types of "zeros," and, more importantly, the ratio between these type of "zeros" is often not constant over the years. Changes in this ratio may indicate changes in bird population dynamics; for example, the increase in the number of zero proportions may be due to a decline in the overall bird population or changes in the area/time distribution of the fishing operations in relation to the seabird population. Cunningham and Lindemaryer (2005) and Ridout et al. (1998) have reviewed available models and algorithms for statistical modeling of data with excess zeros, a problem known as "zero inflation". Briefly, zero inflated data is usually modeled as the result of a mixture of two distributional processes. In some cases, the two processes are assumed to be partially independent (i.e. two-stage delta models), predicting the proportions of positive catches and the non-zero catch separately. In other approaches, the two processes are part of the same distribution that model the zero inflation as a probabilistic additional component of a one-parameter exponential family distribution (i.e. zero-inflated Poisson and zero-inflated negative binomial models) (Liu and Chan 2008).

One of the main objectives of this study was to present estimates of annual seabird bycatch, thus several models were evaluated to predict bycatch for each species based on the observed data. In the case of statistical modeling, generalized linear models (GLMs) (McCullagh and Nelder 1989) were used to evaluate a set of explanatory variables that potentially influence seabird bycatch rates [including year, month, gear type (American or Spanish type longline), latitude and longitude of the fishing set operation]. Preliminary analysis explored the relationship between the nominal bycatch rates of seabirds (number of birds per thousand hooks) and the continuous variables of month, latitude and longitude using Generalized Additive Models (GAMs) through non-parametric smoother spline-functions. Based on these results, the longitude and latitude variables were modeled as continuous covariates, while months were categorized into seasonal quarters (Jan-Mar, Apr.-Jun., Jul-Sep., and Oct.-Dec.) and modeled as a factor in addition to the gear and year factors. We evaluated three GLM models: delta lognormal, delta Poisson (Lo et al. 1992), and zero-inflated Poisson (ZIP) (Lambert 1992). In the case of the delta lognormal model, the dependent variable was the nominal bycatch rates (number of seabirds per 1000 hooks); while in the Poisson models, the dependent variable was the number of seabirds with the log-transformed variable (hooks/1000) set as an offset in the model formulations. A deviance analysis table was used to determine the statistical significant of each factor/covariate in the model. In the delta-type models, the proportion of zero observations were assumed to follow a binomial error distribution with a logit-link function. While the positive observations were assumed to follow either: a) a normal error on the log-transformed bycatch rates with a identity link function (delta lognormal), or b) a Poisson error distribution on the number of birds and the log(hooks/1000) as offset covariate, with a log link function (delta Poisson). The third model evaluated was a zero-inflated Poisson model (ZIP) where the observed number of seabirds was a mixture of a Bernoulli and Poisson distributions (Lambert 1992). Year, gear and quarter were treated as discrete factors, while latitude (Lat) and longitude (Lon) were included as continuous covariates in all models.

We estimated the BCPUE (estimated BCPUE) as the predicted number of birds captured every 1000 hooks using the annual effort and the total effort of the fleet for the entire period. Analyses were carried out with SAS statistical computer software (Littell et al. 1996) and with R software (R Development Core Team 2009), VGAM library (Yee 2008).

### Spatial and temporal patterns

To visualize the spatial (latitude and longitude) and monthly variation of the BCPUE for each species, we employed a classification and regression tree (CART) (Breiman et al. 1984). CART is a modern statistical technique ideally suited for both exploring and modeling data, and used in ecology to explain and predict species distribution patterns (De'ath and Fabricius 2000, Vayssiéres et al. 200; Benito Garzón et al. 2006). CART is a non parametric analysis that does not assume a previous data distribution of the response variable. This approach is able to capture some relationships that make sense ecologically, but are difficult to recognize with conventional linear models (McCune and Grace 2002). Another advantage is their presentation in the form of a binary tree, which is easy to interpret even when working with high dimension variables ranking (Nerini and Ghattas 2007).

CART is a binary splitting method that partitions the sample space recursively into distinct regions defined by the predictors that may be categorical and/or numerical. CART explains the variation of a response variable by repeatedly splitting the data into more homogeneous sub-samples, using combinations of explanatory variables. The two sub-samples obtained are then partitioned recursively in the same way until there are too few observations (usually five) in the samples obtained; other stopping rules are also available. The homogeneity of nodes is defined by impurity, and many measures of impurity (i.e. splitting criteria) exist. We used the sum of squares about the means to identify impurity in our analyses (Breiman et al. 1984; De'ath and Fabricius 2000).

The latitude and longitude at the beginning of each observed set were used as continuous independent variables, while months were used as categorical variables. The BCPUE of each set was the response variable ($n = 954$), and because this is a continuous variable, we performed regression procedures. For regression trees, the mean value of the output variable is assigned to each leaf, and computed over the observations within the corresponding region. This analysis was carried out in R software (R Development Core Team 2009) using the packages tree (Ripley 2007).

## 3 Results

The dataset concerned 598 seabirds, representing an observed BCPUE of 0.281 birds/1000 hooks. Black-browed albatrosses were the most numerous [$n = 341$ (57.0%)], followed by Atlantic yellow-nosed albatrosses [$n = 153$ (25.6%)] and white-chinned petrels [$n = 54$ (9.0%)]. The observed BCPUE for each species were 0.161, 0.072 and 0.025 birds

**Table 2.** Annual variation of the observed BCPUE (birds/1000 hooks) of black-browed albatross (*Thalassarche melanophrys*), Atlantic yellow-nosed albatross (*Thalassarche chlororhynchos*) and white-chinned petrel (*Procellaria aequinoctialis*) observed onboard the Uruguayan pelagic longline fishery from 2004 to 2007 (number of sets observed each year).

| Species | | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|
| | | Number of sets observed | | | |
| | | 312 | 244 | 196 | 202 |
| *Thalassarche melanophrys* | birds | 125 | 40 | 89 | 87 |
| BCPUE, mean (± SE) | | 0.21 (0.06) | 0.11 (0.07) | 0.20 (0.05) | 0.41 (0.11) |
| | min.-max. | 0–10.00 | 0–16.80 | 0–5.10 | 0–12.50 |
| *Thalassarche chlororhynchos* | birds | 19 | 42 | 90 | 2 |
| BCPUE, mean (± SE) | | 0.01 (0.00) | 0.07 (0.02) | 0.18 (0.06) | 0.01 (0.01) |
| | min.-max. | 0 –0.74 | 0–1.74 | 0–8.10 | 0–1.40 |
| *Procellaria aequinoctialis* | birds | 13 | 3 | 19 | 19 |
| BCPUE, mean (± SE) | | 0.02 (0.01) | 0.01 (0.00) | 0.04 (0.01) | 0.09 (0.03) |
| | min.-max. | 0–2.86 | 0–1.11 | 0–1.04 | 0–3.13 |

**Table 3.** Summary of the main criteria and dispersion parameters for each species and model. The Akaike information criteria (AIC) or log likelihood are not comparable between the delta models and the ZIP model.

| Model | *T. chlororhynchos* | *T. melanophrys* | *P. aequinoctialis* |
|---|---|---|---|
| Delta binomial | | | |
| AIC | 6456.3 | 3359.3 | 4423.7 |
| Deviance | 326.1 | 568.8 | 253.7 |
| Dispersion | 0.92 | 1.02 | 1.29 |
| Delta lognormal | | | |
| AIC | 139.0 | 275.5 | 48.3 |
| Deviance | 30.2 | 67.4 | 5.5 |
| Delta Poisson | | | |
| AIC | 183.1 | 334.2 | 57.7 |
| Deviance | 131.0 | 241.8 | 8.7 |
| Dispersion | 3.72 | 3.06 | 0.31 |
| ZIP | | | |
| AIC | 647.4 | 1110.4 | 327.9 |
| log-likelihood | –303.7 | –537.2 | –146.0 |
| Dispersion | 0.31 | 1.24 | 0.30 |

per 1000 hooks, respectively. Annual observed BCPUE trends for these three species are presented in Table 2. The other hooked birds recorded included: the wandering (*Diomedea exulans*), Tristan (*Diomedea dabbenena*), southern royal (*Diomedea epomophora*), northern royal (*Diomedea sanfordi*), shy-type (*Thalassarche* spp.) and sooty (*Phoebetria fusca*) albatrosses; northern giant (*Macronectes halli* and spectacled (*Procellaria conspicillata*) petrels; great shearwater (*Puffinus gravis*), and unidentified species (PNOFA unpublished data), representing the 8% of the total bycatch.

### 3.1 Estimated bycatch

From the observed data, it is clear that the bycatch of seabirds in the pelagic longline fisheries is a rare event. On average, the percent of sets where any of the three chosen bird species was caught was 7.5%, with the highest incidence for black-browed albatross (11.7%) and the lowest for white-chinned petrel (4.5%). The distribution of the number of sea birds by species caught is highly skewed, with a typical high proportion of zero catch observations, few observations with catches between 1 and 5 birds per set, and rare extremely large catches (>15 birds per set) in the case of black-browed albatross and Atlantic yellow-nosed albatross.

As one of main objectives was to estimate the overall annual bycatch for each species, it was decided to select models in which all parameters were estimated, to be able to predict total annual seabird bycatch. Overall the three models (delta lognormal, delta Poisson and ZIP models) predicted seabird bycatch as the combined effects of *year*, *quarter*, and *gear* factors with the covariates *latitude* and *longitude*. Details of the deviance analysis for the delta models are given in Appendix (3 tables) where the main variables for predicting seabird bycatch are shown for each component of the models by species. It is important to note that the final model for each species was not necessarily the same. Also, in the case of the delta models, the factors that determine the probability of encounter (binomial subcomponent) are not always the same factors that determine the mean catch rate (lognormal subcomponent) or numbers caught (Poisson subcomponent). Overall, all three models did agree in the main set of explanatory factors; year, gear, and longitude. Season was an important factor in the bycatch

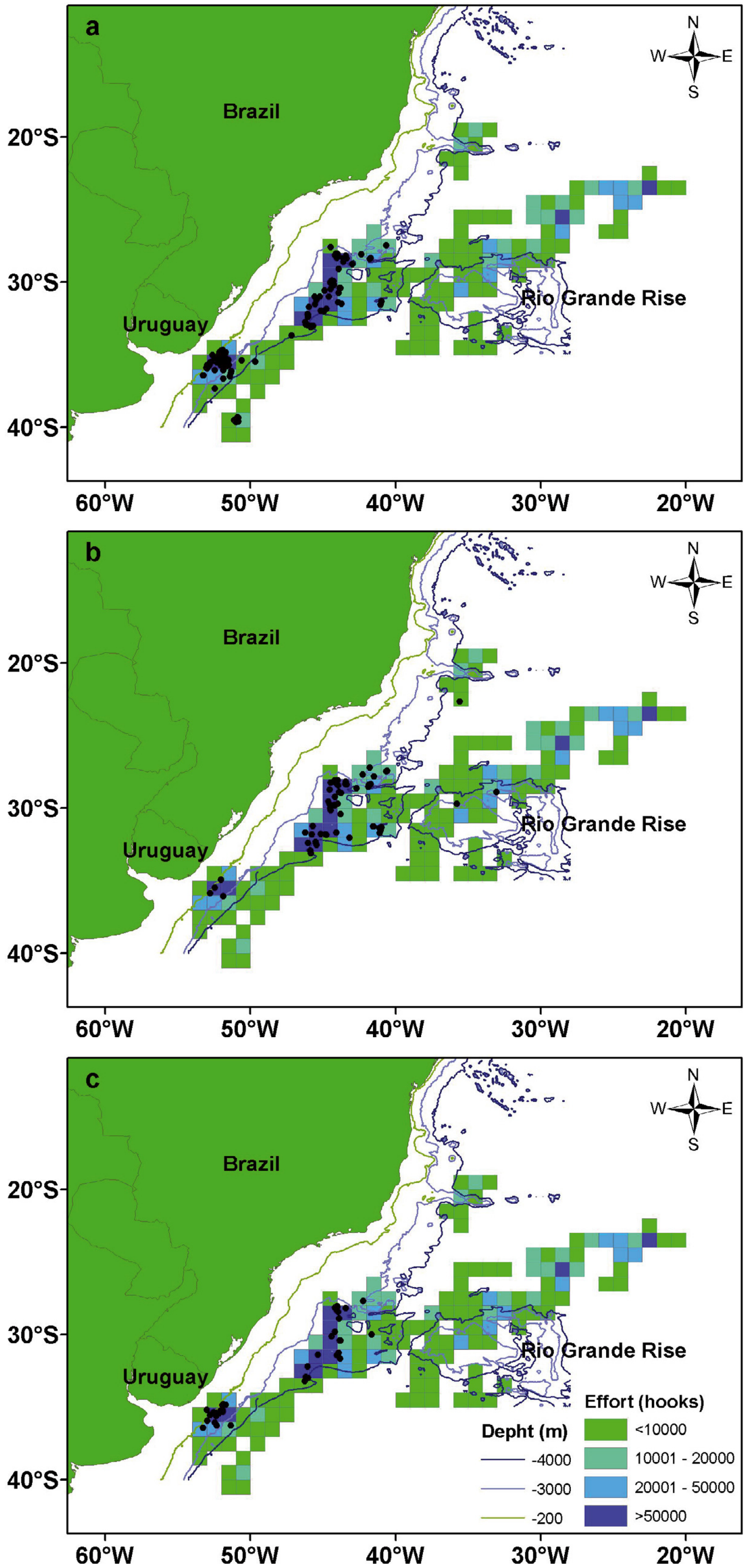


**Fig. 2.** Spatial distribution of the incidental captures of seabirds (black points) observed in the Uruguayan pelagic longline fishery. a) Distribution of the captures of black-browed albatross (*Thalassarche melanophrys*). b) Distribution of the captures of Atlantic yellow-nosed albatross (*Thalassarche chlororhynchos*). c) Distribution of the captures of white-chinned petrel (*Procellaria aequinoctialis*).

**Table 4.** Estimated bycatch for black-browed albatross (*Thalassarche melanophrys*), Atlantic yellow-nosed albatross (*T. chlororhynchos*) and white-chinned petrel (*Procellaria aequinoctialis*) by the Uruguayan pelagic longline fishery from 2004 to 2007. The table shows the observed (Obs.) capture and total predicted (Pred.) capture (with the 95% confidence interval) for each model (delta lognormal, delta Poisson and ZIP) and the average predicted capture by the three models.

| Model | Year | ***T. melanophrys*** | | | | ***T. chlororhynchos*** | | | | ***P. aequinoctialis*** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Obs | Pred. | low 95% | up 95% | Obs. | Pred. | low 95% | up 95% | Obs. | Pred. | low 95% | up 95% |
| Delta log- | 2004 | 125 | 420 | 161 | 1002 | 19 | 24 | 4 | 91 | 13 | 39 | 10 | 136 |
| -normal | 2005 | 40 | 191 | 62 | 606 | 42 | 88 | 23 | 343 | 3 | 19 | 5 | 81 |
| | 2006 | 89 | 499 | 277 | 949 | 90 | 68 | 21 | 229 | 19 | 97 | 37 | 266 |
| | 2007 | 87 | 194 | 90 | 433 | 2 | 54 | 19 | 165 | 19 | 61 | 25 | 160 |
| Delta | 2004 | 125 | 485 | 173 | 1212 | 19 | 27 | 6 | 78 | 13 | 48 | 12 | 186 |
| Poisson | 2005 | 40 | 409 | 131 | 1288 | 42 | 93 | 34 | 266 | 3 | 23 | 5 | 101 |
| | 2006 | 89 | 728 | 311 | 1716 | 90 | 126 | 47 | 361 | 19 | 123 | 39 | 387 |
| | 2007 | 87 | 310 | 129 | 748 | 2 | 38 | 14 | 108 | 19 | 75 | 25 | 224 |
| ZIP | 2004 | 125 | 464 | | | 19 | 25 | | | 13 | 56 | | |
| | 2005 | 40 | 430 | | | 42 | 77 | | | 3 | 10 | | |
| | 2006 | 89 | 499 | | | 90 | 135 | | | 19 | 118 | | |
| | 2007 | 87 | 420 | | | 2 | 14 | | | 19 | 44 | | |
| Average 3 | 2004 | 125 | 456 | 167 | 1107 | 19 | 26 | 5 | 85 | 13 | 48 | 11 | 161 |
| Models | 2005 | 40 | 344 | 96 | 947 | 42 | 86 | 29 | 305 | 3 | 18 | 5 | 91 |
| | 2006 | 89 | 575 | 294 | 1333 | 90 | 110 | 34 | 295 | 19 | 113 | 38 | 326 |
| | 2007 | 87 | 308 | 110 | 591 | 2 | 35 | 16 | 137 | 19 | 60 | 25 | 192 |
| Sum 2004-07 | | 341 | 1683 | 667 | 3977 | 153 | 257 | 84 | 821 | 54 | 239 | 80 | 770 |

**Table 5.** Annual variation of the estimated BCPUE (birds/1000 hooks) for black-browed albatross (*Thalassarche melanophrys*), Atlantic yellow-nosed albatross (*T. chlororhynchos*) and white-chinned petrel (*Procellaria aequinoctialis*) by the Uruguayan pelagic longline fishery from 2004 to 2007.

| Year | Total effort (number of hooks) | *T. melanophrys* | | *T. chlororhynchos* | | *P. aequinoctialis* | |
|---|---|---|---|---|---|---|---|
| | | Average predicted capture | Estimated BCPUE | Average predicted capture | Estimated BCPUE | Average predicted capture | Estimated BCPUE |
| 2004 | 2 022 106 | 456 | 0.226 | 26 | 0.013 | 48 | 0.024 |
| 2005 | 1 944 416 | 344 | 0.177 | 86 | 0.044 | 18 | 0.009 |
| 2006 | 1 363 587 | 575 | 0.422 | 110 | 0.081 | 113 | 0.083 |
| 2007 | 761 794 | 308 | 0.405 | 35 | 0.046 | 60 | 0.079 |

of Atlantic yellow-nosed and black-browed albatrosses. Although the deviance table indicated that some of the interactions may be important, the imbalance of the data prevented their inclusion in the final model, particularly if annual estimates of bycatch were made. Table 3 presents a summary of the main criteria and dispersion parameters for each species and model. Unfortunately, criteria like the Akaike information criteria (AIC) or log likelihood are not comparable between the delta models and the ZIP model. Within the delta models, the binomial subcomponent indicated a relatively good fit, with no indication of over-dispersion. The delta Poisson results indicated over-dispersion for Atlantic yellow-nosed and black-browed albatrosses (3.72 and 3.06, respectively), and under-dispersion in the case of white-chinned petrel. These results suggest that the variance in the numbers of birds caught in a positive set is much greater than that expected if they were following a Poisson distribution. The dispersion parameter for the ZIP model indicated under-dispersion for Atlantic yellow-nosed albatross and white-chinned petrel.

Table 4 presents the estimated annual seabird bycatch for the three models and the average of mean estimates with their 95% confidence intervals. The results from the three models agree in most cases, with the largest differences for the estimates of black-browed albatross bycatch between the delta lognormal model and the other models in 2006. The estimates of total bycatch were consistent between the models and, given that no particular model was clearly superior, it was decided to present the average of the three models as the best estimate of total bycatch, to similarly estimate the 95% confidence bounds as the average between the models for which these estimates were available. Using the average of mean estimates from the three models, Atlantic yellow-nosed albatross annual bycatch estimates ranged from 26 in 2004 to 110 in 2006; black-browed albatross bycatch ranged from 308 in 2007 to 575 in 2006; and white-chinned petrel bycatch ranged from 18 in 2005 to 113 in 2006 (Table 4).

The total estimated capture from 2004 to 2007 was 1683 (667-3977), 257 (84-821) and 239 (80-770) birds, for black-browed albatrosses, Atlantic yellow-nosed albatrosses and white-chinned petrels, respectively (Table 4). Considering the total effort of the fleet, these values represent an estimated BCPUE of 0.276, 0.042, and 0.039 birds/1000 hooks for these species, respectively. Taking into account the annual fishing effort of the fleet, for black-browed albatross the estimated BCPUE ranged from 0.177 in 2005 to 0.422 in 2006; for white-chinned petrel the estimated BCPUE ranged from 0.009 in 2005 to 0.083 in 2006; and for Atlantic yellow-nosed albatross the estimated BCPUE ranged from 0.013 in 2004 to 0.081 in 2006 (Table 5).

### 3.2 Spatial and monthly distribution of seabird bycatch

Captures were recorded throughout the study area, mainly at depths of 200 to 4000 m. In depths over 4000 m, captures were scarce, and no captures were recorded east of 33 °W (Fig. 2a-c). The spatial distributions of the captures of black-browed albatrosses and white-chinned petrels were similar (Fig. 2a and c), and these took place principally in Uruguayan waters and adjacent international waters near the limit with Brazilian jurisdictional waters. Most captures of Atlantic yellow-nosed albatrosses occurred in international waters adjacent to Brazilian waters; this species presented the easternmost captures recorded (Fig. 2b).

Most incidental captures of the three species were recorded from fall to spring (Fig. 3a-c). Only a few captures of Atlantic yellow-nosed albatrosses were recorded in March (Fig. 3b). The highest mean BCPUE of black-browed albatross was recorded in July (0.66 birds/1000 hooks, SE ± 0.21); for Atlantic yellow-nosed albatross, the peak was in September (0.34 birds/1000 hooks, SE ± 0.13); and for white-chinned petrel, it was in August (0.12 birds/1000 hooks, SE ± 0.04) (Fig. 3a-c).

The results of the CART regression analysis are shown in Figure 4. For black-browed albatross, two areas were identified: east of 51ºW the mean BCPUE was lower (0.077 birds/1000 hooks), while to the West the values varied between months from 0.136 to 6.12 birds/1000 hooks. In the months of May, June, July, August and November the mean BCPUE was high (0.283 to 5.597 birds/1000 hooks), particularly around the slope, reaching its highest value (6.12 birds/1000 hooks) in July over the slope (Fig. 4a). The results for the white-chinned petrel were similar, with a low BCPUE (0.015 birds/1000 hooks) to the east of 51°W (Fig. 4b). On the Uruguayan slope the mean BCPUE was 0.057 birds/1000 hooks throughout the year, except for the month of August when the mean BCPUE reached 0.917 birds/1000 hooks (Fig. 4b). A different pattern was observed for Atlantic yellow-nosed albatross. The mean BCPUE throughout the year was 0.03 birds/1000 hooks, except in September, when the mean BCPUE reached 4 birds/1000 hooks north of 29 °S and 0.078 birds/1000 hooks, south of this latitude (Fig. 4c).

## 4 Discussion

From 1998 to 2004, the overall catch rate of seabirds recorded for the Uruguayan pelagic longline fleet was 0.42 birds/1000 hooks (Jiménez et al. 2009). The BCPUE observed in the present study for the period 2004-2007 was lower (0.28 birds/1000 hooks). However, the estimated joint BCPUE for the three species was 0.36 birds/1000 hooks. All these values are much lower than those recorded by Stagi et al. (1998) for the same fleet in 1993-1994 (4.7 birds/1000 hooks), which has been cited as the highest BCPUE value worldwide. This difference is possibly due to the fact that Stagi et al. (1998) analyzed a very small fishing effort during a brief period, as suggested by Bugoni et al. (2008).

The bycatch rates observed in this study for black-browed albatross (0.161 birds/1000 hooks), Atlantic yellow-nosed albatross (0.072 birds/1000 hooks) and white-chinned petrel (0.025 birds/1000 hooks) are similar to those reported for the Brazilian pelagic longline fleet (0.126, 0.011 and 0.059 birds/1000 hooks, respectively) (Bugoni et al. 2008). The operation areas of these fleets overlap in international waters off southern Brazil, Uruguay and over the Rio Grande Rise.

### 4.1 Estimated bycatch

In this study, we present the first estimation of seabird bycatch at species level for the Uruguayan pelagic longline fleet operating in the SWA. We used a large (more than 2 000 000 hooks observed) and representative (mean observed coverage of 37% of the annual effort) database obtained by trained observers. In addition, this estimation incorporated different factors influencing bycatch. Deviance analysis indicated that year, quarter (season) and gear are particularly important predictors of seabird bycatch (see Appendix). There is also a strong spatial effect on the seabird bycatch (see below). These results demonstrate the importance of all the above mentioned factors in seabird bycatch. In addition, there are other factors (e.g. moon phases, time of the set, gear configurations) that influence bycatch rates (Brothers et al. 1999; Bull et al. 2007; Jiménez et al. 2009), many of which are poorly known (Furness 2003). The consideration of other factors, such as environmental and oceanographic conditions, fishing practices, and gear configurations, will improve these estimations in the future; however, more complete information from logbooks will be required.

A previous estimate of seabird mortality for the Brazilian pelagic longline fishery suggests a mean annual mortality of 3084, 1623 and 690 white-chinned petrels and black-browed and Atlantic yellow-nosed albatrosses, respectively (Olmos et al. 2000). However this work was published as an abstract, and it was not possible to obtain detailed information about the study period or about the higher impact of this fleet on the white-chinned petrel. For Argentina, estimates of seabird mortality with longlines are available for bottom fisheries. Favero et al. (2003) estimated an annual average of 1160 seabirds caught during 1999-2001 in the demersal longline fishery targeting Patagonian toothfish (*Dissostichus eleginoides*) and kingclip (*Genypterus blacodes*). Black-browed albatross and white-chinned petrel represented about 80% of the total captures (Favero et al. 2003). Gandini and Frere (2006) estimated that 343 birds were caught between December 2000 and September 2001 for the kingclip demersal longline fishery. Of these birds, 55% would be black-browed albatross and 45% white-chinned petrels (Gandini and Frere 2006). Finally,

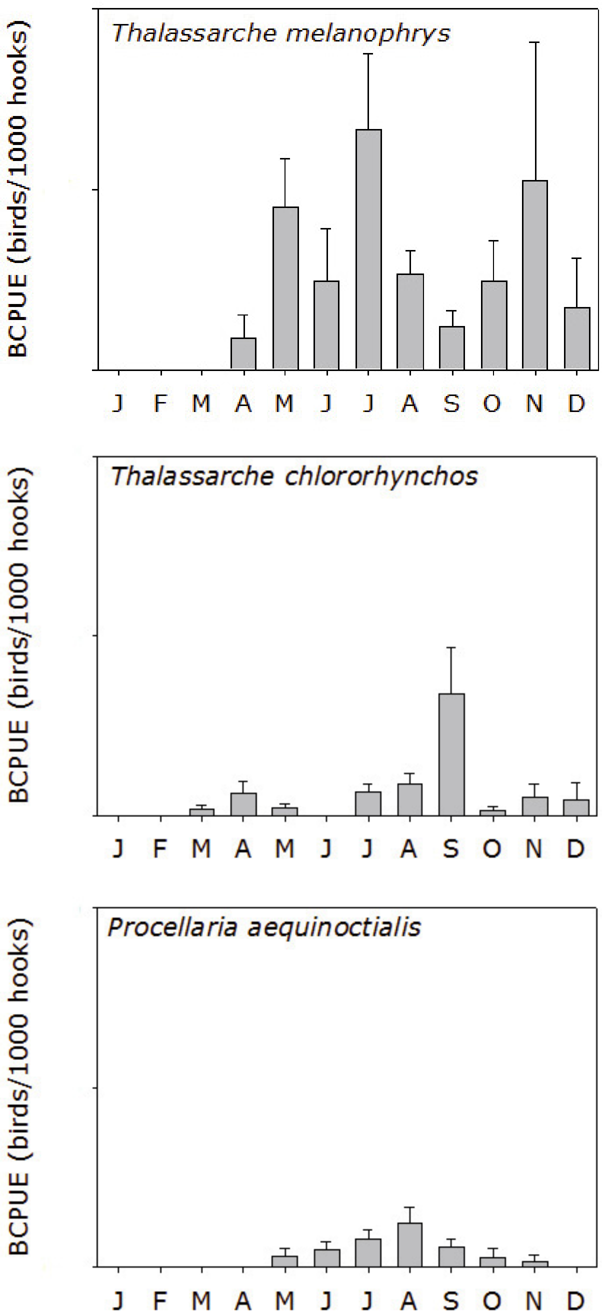


**Fig. 3.** Monthly variation of the incidental capture of black-browed (*Thalassarche melanophrys*) and Atlantic yellow-nosed (*Thalassarche chlororhynchos*) albatrosses and white-chinned petrel (*Procellaria aequinoctialis*). The mean BCPUE and standard error are shown for each species.

Goméz Laich et al. (2006) estimated that at least 900 black-browed albatrosses would be killed annually along the Patagonian shelf and shelf-break in demersal longline fisheries based on data obtained between 1999 and 2003. The estimations of seabird bycatch in longline fisheries by the coastal countries indicated that the magnitude of the problem in the SWA could be in the order of thousands of seabird killed annually. However, no published data about seabird mortality exists for foreign pelagic longline fleets operating in international waters.

### 4.2 Spatial and temporal patterns of seabird bycatch

The patterns found in this study are similar to those observed by Jiménez et al. (2009), with high capture rates in Uruguayan waters (mainly over the slope) and international waters off Uruguay and southern Brazil. The present study discriminates the bycatch by species. The spatial and temporal distributions of the captures of black-browed albatrosses and white-chinned petrels were very similar, with highest catch rates for both species recorded on the Uruguayan slope from fall to mid-spring. In contrast, the higher catch rates of Atlantic yellow-nosed albatrosses were recorded northwards in international waters off Brazil in late winter. The spatial distribution of the captures agrees with the reported distribution of these species in the southwest Atlantic. Black-browed albatrosses and white-chinned petrels are widely distributed in this region, while Atlantic yellow-nosed albatrosses present a northern distribution with the Subtropical Convergence as the southern limit of their foraging range within this area. These differences in distribution are reflected in bycatch composition: black-browed albatrosses and white-chinned petrels have been recorded as the most captured seabird species in all longline fisheries operating in the southwest Atlantic (Neves and Olmos 1998; Favero et al. 2003; Gandini and Frere 2006; Gómez Laich et al. 2006; Gómez Laich and Favero 2007; Seco Pon et al. 2007; Bugoni et al. 2008; Jiménez et al. 2009); whereas captures of Atlantic yellow-nosed albatrosses are more localized, occurring mainly in Brazilian and Uruguayan waters and international waters off these countries (Neves and Olmos 1998; Bugoni et al. 2008).

The time of the year when captures of black-browed albatrosses and white-chinned petrels were recorded in greatest numbers is the non-breeding season, although some black-browed albatross were also caught in late spring, which is the late pre-laying or early incubation period. However, most of the birds caught by the Uruguayan pelagic longline fishery are juveniles (>90%; S. Jiménez and M. Abreu unpublished data). In the case of the Atlantic yellow-nosed albatrosses, most captures occurred during the non-breeding season, although some captures in later summer and late spring overlap with the breeding season.

The spatio-temporal patterns obtained in this study have implications for the conservation of these three species. Determining areas and seasons where intense bycatch occurs is very important for the development of mitigation strategies. In the SWA, the majority of seabird captures in pelagic longline fisheries occur between May and November (Bugoni et al. 2008; Jimenez et al. 2009). Therefore, the implementation of mitigation measures during these months of the year would greatly benefit these three species. Additionally, the results from this study indicate specific areas and seasons that require strict control of these mitigation measures in the various fleets that operate in this region. The extreme case is for Atlantic yellow-nosed albatross, where most of the bycatch (>90%) in all years is restricted to a relatively small area (as mentioned in Appendix). In the SWA, strict night setting can

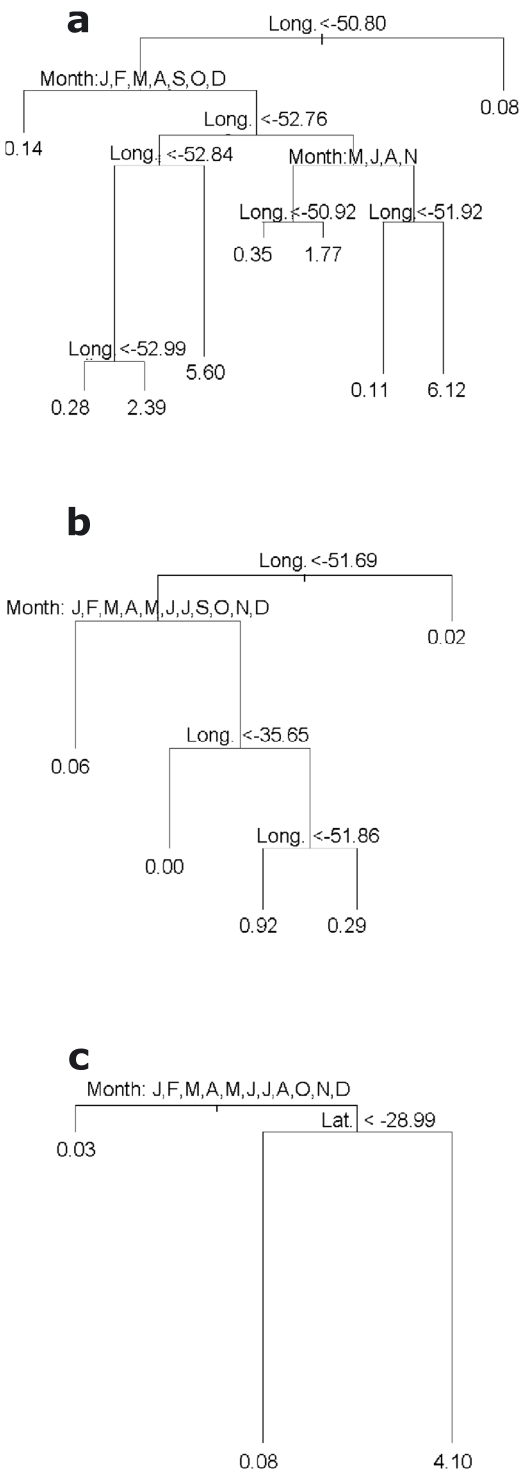


**Fig. 4.** Results of the regression analysis used to differentiate the monthly and spatial variation of incidental capture of a) black-browed albatross (*Thalassarche melanophrys*); b) white-chinned petrel (*Procellaria aequinoctialis*); c) Atlantic yellow-nosed albatross (*Thalassarche chlororhynchos*). In each terminal node the mean BCPUE (birds/1000 hooks). In each node the criteria for the decision are shown. Data with values of less than the splitting point go to the left daughter node. The (-) sign in the latitude (Lat) and longitude (Lon) values within the nodes corresponds to southern and western coordinates respectively, and are in a decimal scale [e.g. –28.99 = 28°59' S, –51.69 = 51°41' W].

significantly reduce the capture of seabirds; however, its efficiency decreases in nights with first quarter and full moon phases (Jimenez et al. 2009). In consequence, other complimentary measures (such as the use of the tori-line and other means to increase the gear sink rate) should be implemented. Such measures, however, still need urgently to be developed and tested in pelagic longline fisheries.

## 5 Bycatch significance

More white-chinned petrels are accidentally killed in fisheries than perhaps any other seabird in the world (Phillips et al. 2006). Most petrels of this species caught by the Uruguayan longline fishery are likely to be wintering birds originating from the south Georgia population, with only a low proportion from the small breeding population in the Falkland/Malvinas (Phillips et al. 2006; Reid et al. 2007; Jiménez et al. 2009). The south Georgia population has long been considered the largest breeding population in the world, with an estimated 2 millions pairs (Berrow et al. 2000). However, Martin et al. (2009) recently showed that the population size is 40–45% of this value, thus reducing the estimated world population by almost half. This population is probably declining due to fishery bycatch, with annual mortality of tens and possibly hundreds of thousands (Martin et al. 2009). Applying the arbitrary categorization of the impact presented by Baker et al. (2007) as "low", "medium", "high" or "very high" for an estimated annual bycatch of <100, 100–499, 500–999 or >1000 birds, respectively, the results presented here suggest a low impact of the Uruguayan longline fishery on white-chinned petrels in most years of the study period (Table 4), which would lead to the conclusion that this fishery is not contributing substantially to the observed decline of south Georgia population.

Nevertheless, attention should be paid to the interactions of white-chinned petrels with this fishery, as this species is one of the most difficult to deter from baited hooks. They are active both day and night, are avid ship followers, and agile flyers capable of diving several meters to retrieve baits (Robertson et al. 2006). Albatrosses compete with white-chinned petrels for the retrieved hooked baits at the surface (S. Jiménez unpublished data). Therefore, the ability of white-chinned petrels to access hooked baits should be taken into consideration in any attempt to reduce albatross bycatch. Additionally, it is important to emphasize that it is highly probable that the sum of generated impacts by all pelagic longline fleets operating in the SWA result in a high impact on the white-chinned petrel. Therefore, the potential impact of the Uruguayan fleet cannot be ignored, and should be considered as contributing to the larger issue.

The largest populations of black-browed albatrosses, located in the Falkland/Malvinas (Croxall and Gales 1998), have declined (Sullivan et al. 2004) and longline fishing appears to be the main cause. It is very likely that most black-browed albatrosses captured by the southwest Atlantic longline fishery breed on the Falkland/Malvinas Islands, with a small proportion of birds from south Georgia (Phillips et al. 2005; Jiménez et al. 2009). The results of the present study show a considerable mortality of this species, suggesting a medium to high impact. Most black-browed albatrosses caught are juveniles, and this age class appears to extend northwards of

Uruguayan waters. Moreover the sex composition of the capture remains poorly known, although an early paper on bycatch in Uruguayan waters suggests a female-biased mortality (Stagi et al. 1998). Age class and sex composition of the bycatch in the area should be taken into consideration in future studies to better understand the impact of the pelagic longline fishery on this population.

The Atlantic yellow-nosed albatross has a small breeding population, endemic to the Tristan da Cunha Archipelago and Gough Island (Cuthbert et al. 2003; Cuthbert and Sommer 2004). Population modeling has predicted annual rates of decrease of 1.5–2.8% on Gough Island, and 5.5% on Tristan da Cunha (Cuthbert et al. 2003). These declines are most likely caused by longline fisheries. If we consider the arbitrary categorization of Baker et al. (2007), the number of Atlantic yellow-nosed albatrosses captured by the Uruguayan longline fishery suggests a low impact on this species in most years of the study period (Table 4). However, this species has a population (tens of thousands of breeding pairs) one or two orders of magnitude lower than the black-browed albatross (hundreds of thousands breeding pairs in Falkland/Malvinas) and white-chinned petrel (hundreds of thousands to a million breeding pairs in south Georgia), respectively. Several other fleets operate in international waters where higher bycatch rates of this species were recorded. The combined efforts of all these fleets could be causing a stronger impact on this small population. In addition, although it is known that the adults and immature birds of this species occur in the SWA (Bugoni et al. 2008), little is known on the age and sex composition of their bycatch.

The situation of Black-browed and Atlantic yellow-nosed albatrosses and white-chinned petrels in the SWA should be viewed with considerable concern, since mortality in pelagic longline fishery has been widely reported (Vaske et al. 1991; Neves and Olmos 1998; Stagi et al. 1998; Bugoni et al. 2008; Jiménez et al. 2009). However, more research is needed to assess the impact of this fishery on their populations. In order to better understand the impacts of pelagic longline fishing in the SWA, there is a need to make estimations of the total number of seabirds captured by the different fleets that operate in the region. Also, future bycatch studies of seabirds should determine the age and sex composition, as well as the origin of incidentally captured individuals. The global conservation status of these species requires the urgent implementation of mitigation measures. This region of the world should receive particular attention in any effort to reduce seabird mortality in the southern hemisphere.

*Acknowledgements.* The authors would like to thank the boat owners of the Uruguayan fleet and their crews for their continued cooperation, as well as the PNOFA observers. We express our gratitude to our colleagues of the Pelagic Resources Department (DINARA) for their continued support. "Proyecto Albatros y Petreles – Uruguay" would like to thank the International Association of Antarctic Tour Operators (IAATO), Birds Australia, and Birdlife International's "Save the Albatross" campaign, for funding the program "Conservation of Albatrosses and Petrels in Uruguay". Special thanks go to Caren Barceló for the translation; Stella Weng and L.E. Fleming for the comments and translation review. We would also like to express our recognition towards the anonymous referees whose comments and recommendations helped us to improve this paper.

## References

Alexander K., Robertson G., Gales R., 1997, The incidental mortality of albatrosses in longline fisheries. Tasmania, Australian Antarctic Division.

Baker G.B., Double M.C., Gales R., Tuck G.N., Abbott C.L., Ryan P.G., Petersen S.L., Robertson C.J.R., Alderman R., 2007, A global assessment of the impact of fisheries-related mortality on shy and white-capped albatrosses: Conservation implications. Biol. Conserv. 137, 319–333.

Benito Garzón, M., Blazek R., Neteler M., Sánchez de Dios R., Sainz Ollero H., Furlanello C., 2006, Machine learning models for predicting species habitat suitability: an example with *Pinus sylvestris* L. for the Iberian peninsula. Ecol. Model. 197, 383–393.

Berrow S.D., Croxall J.P., Grant S.D., 2000, Status of white-chinned petrels *Procellaria aequinoctialis* Linnaeus 1758, at Bird Island, South Georgia. Antarct. Sci. 12, 399–405.

Breiman L., Friedman J.H., Olshen R.A., Stone C.J., 1984, Classification and regression trees. New York, Chapman and Hall.

Brothers N.P., Cooper J., Løkkeborg S., 1999, The incidental catch of seabirds by longline fisheries: worldwide review and technical guidelines for mitigation. Rome, FAO Fish. Circ. No. 937.

Bugoni L., Mancini P.L., Monteiro D.S., Nascimento L., Neves T.S., 2008, Seabird bycatch in the Brazilian pelagic longline fishery and a review of capture rates in the southwestern Atlantic Ocean. Endang. Species Res. 5, 137–147.

Bull L.S., 2007, Reducing seabird bycatch in longline, trawl and gillnet fisheries. Fish Fish. 8, 31–56.

Croxall J.P., Gales R., 1998, An assessment of the conservation status of albatrosses. In: Robertson G., Gales R. (Eds.) Albatross Biology and Conservation, Chipping Norton, Surrey Beatty & Sons, pp. 46–65.

Cunningham R. B., Lindenmayer D.B., 2005, Modeling count data of rare species: some statistical issues. Ecology 86, 1135–1142.

Cuthbert R., Ryan P.G., Cooper J., Hilton G., 2003, Demography and population trends of the Atlantic yellow-nosed albatross. Condor 105, 439–452.

Cuthbert R., Sommer E., 2004, Population size and trends of four globally threatened seabirds at Gough Island, South Atlantic Ocean. Mar. Ornithol. 32, 97–103.

De'ath G., Fabricius K.E., 2000, Classification and regression trees: a powerful yet simple technique for ecological data analysis, Ecology 81, 3178–3192.

Domingo A., Menni R.C., Forselledo R., 2005, Bycatch of the pelagic ray *Dasyatis violacea* in Uruguayan longline fisheries and aspects of distribution in the southwestern Atlantic. Sci. Mar. 69, 161–166.

Dulvy N.K., Baum J.K., Clarke S., Compagno L.J.V., Cortés E., Domingo A., Fordham S., Fowler S., Francis M.P., Gibson C., Martinez J.,Musick J.A., Soldo A., Stevens J.D.,Valenti S., 2008, You can swim but you can't hide: the global status and conservation of oceanic pelagic sharks and rays. Aquat. Conserv. Mar. Freshw. Ecosyst. 18, 459–482.

Favero M., Khatchikian C.E., Arias A., Silva Rodríguez M.P., Cañete G., Mariano-Jelicich R., 2003, Estimates of seabirds by-catch along the Patagonian shelf by Argentine longline fishing vessels, 1999-2001. Bird Conserv. Int. 13, 273–281.

Furness R.W., 2003, Impacts of fisheries on seabirds communities. Sci. Mar. 67, 33–45.

Gales R. 1998, Albatross populations: status and threats. In: Robertson G., Gales R. (Eds.) Albatross biology and conservation, Chipping Norton, Surrey Beatty & Sons, pp. 20–45.

Gandini P.A., Frere E., 2006, Spatial and temporal patterns in the by-catch of seabirds in the Argentinean longline fishery. Fish. Bull. 104, 482–485.

Gómez Laich A., Favero M., 2007, Spatio-temporal variation in mortality rates of white-chinned petrels *Procellaria aequinoctialis* interacting with longliners in the south-west Atlantic. Bird. Conserv. Int. 17, 359–366.

Gómez Laich A., Favero M., Mariano-Jelicich R., Blanco G., Cañete G., Arias A., Silva Rodriguez P., Brachetta H., 2006, Environmental and operational variability affecting the mortality of black-browed albatrosses associated with long-liners in Argentina. Emu 106, 21–28.

Hall M., Alverson D.L., Metuzals K.I., 2000, By-Catch: Problems and solutions. Mar. Pollut. Bull. 41, 204–219.

Jiménez S., Domingo A., Brazeiro A., 2009, Seabird bycatch in the Southwest Atlantic: interaction with the Uruguayan pelagic longline fishery. Polar Biol. 32, 187–196.

Lambert D., 1992, Zero-inflated Poisson regression, with an application to defects in manufacturing. Technometrics 34, 1–14.

Lewison R.L., Crowder L.B., Read A.J., Freeman S.A., 2004, Understanding impacts of fisheries bycatch on marine megafauna. Trends Ecol. Evol. 19, 598–604.

Littell R.C., Milliken G.A., Stroup W.W., Wolfinger R.D., 1996, SAS® System for Mixed Models. SAS Institute Inc., Cary NC.

Liu H., Chan K.S., 2008, Constrained generalized additive model with zero-inflated data. Department of Statistics and Actuarial Science, The University of Iowa, Techn. Rep. 388.

Lo N.C., Jacobson L.D., Squire J.L., 1992, Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49, 2515–2526.

Martin A.R., Poncet S., Barbraud C., Foster E., Fretwell P., Rothery P., 2009, The white-chinned petrel (*Procellaria aequinoctialis*) on South Georgia: population size, distribution and global significance. Polar Biol. 32, 655–661.

McCullagh P, Nelder J.A., 1989, Generalized linear models. Monographs on statistics and applied probability 37. London, Chapman & Hall. 2nd edition.

McCune B., Grace J.B., 2002, Analysis of Ecological Communities. M j M Software Design. Gleneden Beach, Oregon, EEUU.

Nerini D., Ghattas B., 2007, Classifying densities using functional regression trees: Applications in Oceanology. Comput. Stat. Data Anal. 51, 4984–4993.

Neves T., Olmos F., 1998, Albatross mortality in fisheries off the coast of Brazil. In: Robertson G., Gales R. (Eds.) Albatross biology and conservation, Chipping Norton, Surrey Beatty & Sons, pp. 214–19.

Olmos F., Bastos G.C.C., da Silva Neves T., 2000, Estimating seabird bycatch in Brazil. In Flint E., Swift K. (Eds) Second International Conference on the Biology and Conservation of Albatrosses and other Petrels, Honolulu, Hawaii, 8–12 May 2000. Abstracts of oral and poster presentations. Mar. Ornithol. 28, 141.

Phillips R.A., Silk J.R.D., Croxall J.P., Afanasyev V., Benett V.J., 2005, Summer distribution and migration of non- breeding albatrosses: individual consistencies and implications for conservation. Ecology 81, 2386–2396.

Phillips R.A., Silk J.R. D, Croxall J.P., Afanasyev V., 2006, Year-round distribution of white-chinned petrels from South Georgia: Relationships with oceanography and fisheries. Biol. Conserv. 129, 336–347.

Prince P.A., Croxall J.P., Trathan P.N., Wood A.G., 1998, The pelagic distribution of South Georgia albatrosses and their relationships with fisheries. In: Robertson G., Gales R. (Eds.) Albatross biology and conservation, Chipping Norton, Surrey Beatty & Sons, pp. 137–167.

R Development Core Team, 2009, R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. Available at: http://www.r-project.org/.

Reid T.A., Lecoq M., Catry P., 2007, The white-chinned petrel *Procellaria aequinoctialis* population of the Falkland Island. Mar. Ornithol. 35, 57–60.

Ridout M., Demetrio C.G.B., Hinde J, 1998, Models for count data with many zeros. International Biometric Conference. Cape Town. December 1998.

Ripley B., 2007, Tree: classification and regression trees. [R package version 1.0-26]. Available at: http://cran.r-project.org/web/packages/tree/.

Robertson G., McNeill M., Smith N., Wienecke B., Candy S., Olivier F., 2006, Fast sinking (integrated weight) longlines reduce mortality of white-chinned petrels (*Procellaria aequinoctialis*) and sooty shearwaters (*Puffinus griseus*) in demersal longline fisheries. Biol. Conserv. 132, 458–471.

Robertson G., Gales R., 1998, Albatross biology and conservation. Chipping Norton, Surrey Beatty & Sons.

Seco Pon J.P., Gandini P.A., Favero M., 2007, Effect of longline configuration on seabird mortality in the Argentine semi-pelagic kingclip *Genypterus blacodes* fishery. Fish. Res. 85, 101–105.

Spotila J.R., Reina R.R., Steyermark A.C., Plotkin P.T., Paladino F.V., 2000, Pacific leatherback turtles face extinction. Nature 405, 529–530.

Stagi A., Vaz-Ferreira R., Marin Y., Joseph L., 1998, The conservation of albatrosses in Uruguayan waters. In: Robertson G, Gales R (Eds.) Albatross biology and conservation. Surrey Beatty, Chipping Norton, pp. 220–224.

Sullivan B.J., Reid T.A., Pompert J., Enticott J.W., Black A.D., 2004, Seabird mortality associated with Patagonian toothfish (*Dissostichus eleginoides*) longliners in Falkland Island waters. Emu 104, 317–325.

Vaske T. Jr., 1991. Seabirds mortality on longline fishing for tuna in Southern Brazil. Ciencia e Cultura 43, 388–390.

Vayssières M.P., Richard R.E., Allen-Diaz B.H., 2000, Classification trees: an alternative non-parametric approach for predicting species distribution. J. Veget. Sci. 11, 679–694.

Yee T.W. 2008, The VGAM package. R News 8, 28–39.

## APPENDIX

**(1) Atlantic yellow-nosed albatross**. A deviance factor analysis is shown for each of the components of the delta model (Table S1). Because the binomial model for the proportion of positive observations is the same in the delta lognormal and delta Poisson models, only one deviance table is presented in this case. The proportion of positives indicated that the *year*, *gear* and *quarter* factors were statistically significant, and explained the largest proportion of the deviance.

The deviance information for the positive observation delta type models; the lognormal and the Poisson distribution assumptions are provided. In the case of the lognormal model, none of the factors is statistically significant, although the model itself is considered better compared to the null model (overall average). In the case of the Poisson distribution, the *quarter* and *year* factors were statistically significant and explained most of the deviance observed. For the bycatch of this albatross, the covariates latitude and longitude showed low influence in predicting the probability of catch, or the mean catch rates. This was in part because the observed bycatch of Atlantic yellow-nosed albatross (> 90%) took place predominantly in the area between 41 and 46°W longitude and 27° and 32°S latitude.

**(2) Black-browed albatross and (3) white-chinned petrel.** Similar deviance tables are shown for the delta type models fitted to the black-browed albatross and white-chinned petrel, respectively. For both species, there were no bycatch observations during quarter 1 (January-March) in any year, thus the analyses were restricted to the months of April through December. For these species, the probability of bycatch was explained mainly by the *year* and *quarter* factors, and the *longitude* covariate. However, for the positive, the *gear* factor was important for both species in addition to *year* and *latitude longitude* covariates. Some of the interactions between factors, particularly *year*quarter*, were statistically significant in more than one species. However, for estimating the total annual bycatch, due to the unbalanced nature of the data, interactions were not included in the final models.

**Table S1.** Deviance analysis table of explanatory variables for each species of seabird bycatch from the delta-type; delta lognormal and delta Poisson models. The sub-model for proportion of positive observations was the same for the two delta models (binomial error distribution assumption). The models are fitted sequentially (single factors), and each interaction model compared to the model without the interaction in question. The columns give: the degrees of freedom for each model (d.f.), the residual deviance, the resulting change in deviance, the percentage of total deviance change compared to the deviance of the maximum model (model with the lowest deviance overall), and the *p* value refers to the $\chi 2$ test between two consecutive models (single factors) or the model with and without interaction (1) Atlantic yellow-nosed albatross (*Thalassarche chlororhynchos*), (2) Black-browed albatross (*Thalassarche melanophrys*) and (3) White-chinned petrel (*Procellaria aequinoctialis*).

| **(1) Atlantic yellow-nosed albatross (*Thalassarche chlororhynchos*)** | | | | | |
|---|---|---|---|---|---|
| | **Residual d.f.** | **Change in deviance** | **% of total deviance** | **deviance** | ***p*** |
| **BINOMIAL MODEL FACTORS** | | | | | |
| NULL | 1 | 437.0 | | | |
| Year | 3 | 405.4 | 31.55 | 25% | < 0.001 |
| Year Gear | 1 | 381.5 | 23.89 | 19% | < 0.001 |
| Year Gear Quarter | 3 | 331.3 | 50.25 | 39% | < 0.001 |
| Year Gear Quarter Lat | 1 | 328.8 | 2.46 | 2% | 0.117 |
| Year Gear Quarter Lat Lon | 1 | 326.0 | 2.80 | 2% | 0.094 |
| Year Gear Quarter Lat Lon Year*Gear | 3 | 324.4 | 1.58 | 1% | 0.664 |
| Year Gear Quarter Lat Lon Year*Gear Gear*Quarter | 3 | 320.6 | 5.37 | 4% | 0.146 |
| Year Gear Quarter Lat Lon Year*Gear Gear*Quarter Year*Quarter | 9 | 309.7 | 16.37 | 13% | 0.060 |
| **LOGNORMAL MODEL FACTORS** | | | | | |
| NULL | 1 | 37.99 | | | |
| Year | 3 | 32.82 | 5.16 | 63.4% | 0.160 |
| Year Gear | 1 | 31.98 | 0.85 | 10.4% | 0.358 |
| Year Gear Quarter | 3 | 31.61 | 0.37 | 4.6% | 0.946 |
| Year Gear Quarter Lat | 1 | 31.28 | 0.33 | 4.0% | 0.566 |
| Year Gear Quarter Lat Lon | 1 | 30.17 | 1.10 | 13.5% | 0.294 |
| Year Gear Quarter Lat Lon Gear*Quarter | 1 | 30.13 | 0.05 | 0.6% | 0.832 |
| Year Gear Quarter Lat Lon Gear*Quarter Year*Gear | 1 | 29.88 | 0.29 | 3.6% | 0.589 |
| Year Gear Quarter Lat Lon Gear*Quarter Year*Gear Year*Quarter | 3 | 29.84 | 0.33 | 4.1% | 0.954 |
| **POISSON MODEL FACTORS** | | | | | |
| NULL | 1 | 306.9 | | | |
| Year | 3 | 278.9 | 28.06 | 28% | < 0.001 |
| Year Gear | 1 | 275.7 | 3.12 | 3% | 0.078 |
| Year Gear Quarter | 3 | 228.7 | 47.03 | 47% | < 0.001 |
| Year Gear Quarter Lat | 1 | 225.6 | 3.12 | 3% | 0.077 |
| Year Gear Quarter Lat Lon | 1 | 223.0 | 2.55 | 3% | 0.110 |
| Year Gear Quarter Lat Lon Year*Gear | 3 | 221.4 | 1.68 | 2% | 0.640 |
| Year Gear Quarter Lat Lon Year*Gear Gear*Quarter | 3 | 218.2 | 4.85 | 5% | 0.183 |
| Year Gear Quarter Lat Lon Year*Gear Gear*Quarter Year*Quarter | 9 | 207.3 | 15.78 | 16% | 0.072 |

**Table S1.** continued.

| (2) Black-browed albatross (*Thalassarche melanophrys*) | | | | | |
|---|---|---|---|---|---|
| | **Residual d.f.** | **Change in deviance** | **% of total deviance** | **deviance** | ***p*** |
| **BINOMIAL MODEL FACTORS** | | | | | |
| NULL | 1 | 602.3 | | | |
| Year | 3 | 579.5 | 22.79 | 36% | < 0.001 |
| Year Gear | 1 | 578.9 | 0.64 | 1% | 0.423 |
| Year Gear Quarter | 2 | 571.1 | 7.81 | 12% | 0.020 |
| Year Gear Quarter Lat | 1 | 570.4 | 0.66 | 1% | 0.416 |
| Year Gear Quarter Lat Lon | 1 | 558.5 | 11.92 | 19% | < 0.001 |
| Year Gear Quarter Lat Lon Year*Gear | 2 | 553.9 | 4.58 | 7% | 0.101 |
| Year Gear Quarter Lat Lon Year*Gear Gear*Quarter | 2 | 546.8 | 11.68 | 19% | 0.003 |
| Year Gear Quarter Lat Lon Year*Gear Gear*Quarter Year*Quarter | 6 | 539.4 | 19.05 | 30% | 0.004 |
| **LOGNORMAL MODEL FACTORS** | | | | | |
| NULL | 1 | 113.1 | | | |
| Year | 3 | 98.0 | 15.08 | 27.7% | 0.002 |
| Year Gear | 1 | 71.1 | 26.96 | 49.5% | < 0.001 |
| Year Gear Quarter | 2 | 68.2 | 2.84 | 5.2% | 0.242 |
| Year Gear Quarter Lat | 1 | 64.4 | 3.83 | 7.0% | 0.050 |
| Year Gear Quarter Lat Lon | 1 | 64.0 | 0.45 | 0.8% | 0.504 |
| Year Gear Quarter Lat Lon Year*Gear | 2 | 61.8 | 2.14 | 3.9% | 0.344 |
| Year Gear Quarter Lat Lon Year*Gear Gear*Quarter | 1 | 60.4 | 3.58 | 6.6% | 0.058 |
| Year Gear Quarter Lat Lon Year*Gear Gear*Quarter Year*Quarter | 5 | 58.7 | 5.29 | 9.7% | 0.382 |
| **POISSON MODEL FACTORS** | | | | | |
| NULL | 1 | 424.7 | | | |
| Year | 3 | 392.1 | 32.60 | 42% | < 0.001 |
| Year Gear | 1 | 381.6 | 10.49 | 14% | 0.001 |
| Year Gear Quarter | 2 | 376.4 | 5.23 | 7% | 0.073 |
| Year Gear Quarter Lat | 1 | 373.7 | 2.68 | 3% | 0.102 |
| Year Gear Quarter Lat Lon | 1 | 364.2 | 9.52 | 12% | 0.002 |
| Year Gear Quarter Lat Lon Year*Gear | 2 | 359.0 | 5.14 | 7% | 0.076 |
| Year Gear Quarter Lat Lon Year*Gear Gear*Quarter | 2 | 354.3 | 9.84 | 13% | 0.007 |
| Year Gear Quarter Lat Lon Year*Gear Gear*Quarter Year*Quarter | 6 | 347.5 | 16.61 | 22% | 0.011 |

**Table S1.** continued.

| (3) White-chinned petrel (*Procellaria aequinoctialis*) | | | | | |
|---|---|---|---|---|---|
| | **Residual d.f.** | **Change in deviance** | **% of total deviance** | **deviance** | ***p*** |
| **BINOMIAL MODEL FACTORS** | | | | | |
| NULL | 1 | 297.7 | | | |
| Year | 3 | 273.8 | 23.91 | 42% | < 0.001 |
| Year Gear | 1 | 269.6 | 4.20 | 7% | 0.040 |
| Year Gear Quarter | 2 | 254.9 | 14.69 | 26% | < 0.001 |
| Year Gear Quarter Lat | 1 | 254.9 | 0.06 | 0% | 0.814 |
| Year Gear Quarter Lat Lon | 1 | 250.6 | 4.30 | 8% | 0.038 |
| Year Gear Quarter Lat Lon Gear*Quarter | 2 | 250.1 | 0.51 | 1% | 0.776 |
| Year Gear Quarter Lat Lon Gear*Quarter Year*Gear | 2 | 249.9 | 0.63 | 1% | 0.728 |
| Year Gear Quarter Lat Lon Gear*Quarter Year*Gear Year*Quarter | 6 | 241.2 | 9.35 | 17% | 0.155 |
| **LOGNORMAL MODEL FACTORS** | | | | | |
| NULL | 1 | 18.1 | | | |
| Year | 3 | 10.9 | 7.17 | 54.3% | 0.067 |
| Year Gear | 1 | 6.1 | 4.76 | 36.1% | 0.029 |
| Year Gear Quarter | 2 | 6.0 | 0.17 | 1.3% | 0.916 |
| Year Gear Quarter Lat | 1 | 5.3 | 0.66 | 5.0% | 0.418 |
| Year Gear Quarter Lat Lon | 1 | 5.3 | 0.03 | 0.3% | 0.854 |
| Year Gear Quarter Lat Lon Gear*Quarter | 1 | 5.3 | 0.00 | 0.0% | 0.972 |
| Year Gear Quarter Lat Lon Gear*Quarter Year*Gear | 2 | 4.9 | 0.35 | 2.7% | 0.839 |
| Year Gear Quarter Lat Lon Gear*Quarter Year*Gear Year*Quarter | 4 | 4.9 | 0.40 | 3.0% | 0.982 |
| **POISSON MODEL FACTORS** | | | | | |
| NULL | 1 | 424.7 | | | |
| Year | 3 | 392.1 | 32.60 | 42% | < 0.001 |
| Year Gear | 1 | 381.6 | 10.49 | 14% | 0.001 |
| Year Gear Quarter | 2 | 376.4 | 5.23 | 7% | 0.073 |
| Year Gear Quarter Lat | 1 | 373.7 | 2.68 | 3% | 0.102 |
| Year Gear Quarter Lat Lon | 1 | 364.2 | 9.52 | 12% | 0.002 |
| Year Gear Quarter Lat Lon Year*Gear | 2 | 359.0 | 5.14 | 7% | 0.076 |
| Year Gear Quarter Lat Lon Year*Gear Gear*Quarter | 2 | 354.3 | 9.84 | 13% | 0.007 |
| Year Gear Quarter Lat Lon Year*Gear Gear*Quarter Year*Quarter | 6 | 347.5 | 16.61 | 22% | 0.011 |