ICES Journal of
Marine Science

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

ICES Journal of Marine Science (2015), 72(5), 1637–1652. doi:10.1093/icesjms/fsu250

Contribution to the Themed Section: '*Marine Mammal Bycatch and Depredation*'

Original Articles

Analysis of marine mammal bycatch in the Uruguayan pelagic longline fishery operating in the Southwestern Atlantic Ocean

Cecilia Passadore[1,2,3*†], Andrés Domingo[1,3], and Eduardo R. Secchi[4]

[1]*Laboratorio de Recursos Pelágicos, Dirección Nacional de Recursos Acuáticos, Constituyente 1497, CP 11200 Montevideo, Uruguay*
[2]*Proyecto ODAS/Cetáceos Uruguay, Sección Etología—Facultad de Ciencias, Universidad de la República, Iguá 4225, CP 11400 Montevideo, Uruguay*
[3]*CICMAR, Centro de Investigación y Conservación Marina, Giannattasio km 30.5, El Pinar, CP 15008, Canelones, Uruguay*
[4]*Laboratório de Ecologia e Conservação da Megafauna Marinha, Instituto de Oceanografia, Universidade Federal do Rio Grande, CP 474, Rio Grande, RS 96201-900, Brazil*

**Corresponding author: tel: +61 8 8201 3865; fax: +61 8 8201 3015; e-mail: cecipass8@gmail.com*
[†]*Present address: Cetacean Ecology, Behaviour and Evolution Lab (CEBEL), School of Biological Sciences, Flinders University, Sturt Road, Bedford Park, SA 5042, Australia.*

Passadore, C., Domingo, A., and Secchi, E. R. Analysis of marine mammal bycatch in the Uruguayan pelagic longline fishery operating in the Southwestern Atlantic Ocean. – ICES Journal of Marine Science, 72: 1637–1652.

Received 26 February 2014; revised 3 December 2014; accepted 23 December 2014; advance access publication 22 January 2015.

Bycatch is one of the main causes of human-caused mortality and population decline of many marine mammals. Monitoring bycatch is the first step to understand the impact of the fisheries on the species affected. Understanding how the interaction between marine mammals and fishing operations varies in space and time, and how it is influenced by environmental variables, is essential for designing mitigation strategies to reduce bycatch mortality. In this paper, we use data gathered by scientific observers and a fishing skipper to analyse marine mammals bycatch by the Uruguayan pelagic longline fishery operating in the Southwestern Atlantic Ocean from 1996 to 2007. The total bycatch per unit effort (Bcpue) was 0.0150 marine mammals/1000 hooks and the highest values (∼0.2) were recorded between 37°–38°S and 49°–51°W. Total cetacean Bcpue during the study period was low (0.0051 cetacean/1000 hooks) and occurred between 32°–37°S and 46°–54°W. Generalized additive models showed that cetaceans' bycatch was mainly affected by the depth, sea surface temperature, and season. Although cetaceans were captured year-round, the highest values were registered in spring months, most bycatch events occurred over the continental slope (median = 619 m) and in waters with a median temperature of 19.7°C. The bycatch of pinnipeds was influenced by depth, location, and season. Pinniped bycatch occurred mainly in winter, in waters ranging from 80 to 5000 m of depth (median = 2366 m) between 34°–37°S (median = 35.9°S) and 54°–49°W (median = 51.8°W). The spatial analysis showed that most bycatch events occurred within the Brazil–Malvinas Confluence zone, an area of high productivity where the pelagic longline fleet concentrates its fishing effort and where marine mammals probably concentrate to feed.

Keywords: cetaceans, fishery interaction, longlining, pelagic fisheries, pinnipeds, western South Atlantic.

Introduction

Bycatch occurs when "an animal not targeted by the fishery is caught and discarded at sea" (Alverson *et al.*, 1994) whether alive or dead. Mortality due to fisheries bycatch has resulted in population declines of several marine species, mainly of long-lived and low fecundity species such as sharks, marine birds, turtles, and mammals (e.g. Robertson and Gales, 1998; Northridge and Hofman, 1999; Hall *et al.*, 2000; Spotila *et al.*, 2000; Tuck *et al.*, 2001; Lewison *et al.*, 2004; Fowler *et al.*, 2005; Read *et al.*, 2006; Dulvy *et al.*, 2008; Žydelis *et al.*, 2009). Species with such characteristics are extremely vulnerable and even a selective fishery that captures a few individuals may cause serious effects on their populations' viability

(Lewison *et al.*, 2004). Bycatch is considered one of the main causes of human-caused mortality of marine mammals, and probably all coastal and most pelagic and open ocean species have suffered some level of bycatch (Read *et al.*, 2006). Particularly, mortalities due to bycatch in coastal gillnets are the main reason why several cetacean populations are currently under high risk of extinction (e.g. Northridge and Hofman, 1999; Read, 2005; Secchi, 2010). In several fisheries, bycatch is hardly monitored or regulated, thus its effects on populations may not be noticeable until the species disappear (Read, 2005). Specifically, the Plan of Action 2002–2010 for the World's Cetaceans identified a drastic reduction in bycatch as a necessary measure to prevent the collapse or even extinction of some species (Reeves *et al.*, 2003).

The monitoring of target species and bycatch is the first step to understanding the impact of the fisheries on the species affected. The interactions are given by the co-occurrence of two components: the presence of the species and of fishing gear. Environmental conditions may or may not favour the presence of both components and the fishing operation may or may not result in a bycatch event. The intensity of interactions and their impacts on the populations vary according to the fishing gear used, the species involved, the environmental conditions, and fishing area, among other things (Donoghue *et al.*, 2003; Lewison *et al.*, 2004; Read, 2005; Read *et al.*, 2006). For example, direct interactions with marine mammals occur more frequently in passive (e.g. gillnets, longlines) than in active fishing gear such as trawling (Read, 2005). Studies focusing on spatial patterns of bycatch over long periods (e.g. Gardner *et al.*, 2008; Sims *et al.*, 2008; Lewison *et al.*, 2009) are important to identify persistent areas of high bycatch. Besides the knowledge of how this interaction varies in space and time, understanding the processes that determine the interaction and how it is influenced by environmental and operational variables is essential for designing mitigation strategies to reduce bycatch mortality. Therefore, the effects of bycatch should be evaluated on a case-by-case basis (Alverson *et al.*, 1994) and the monitoring process should consider all the variables potentially involved.

The pelagic longline fishery is known to catch a wide variety of non-target large vertebrates. Studies on bycatch in the longline fishery in the Southwestern Atlantic Ocean (SWAO) have focused mainly on bony fish, elasmobranchs, seabirds, and turtles (e.g. Neves and Olmos, 1998; Domingo *et al.*, 2002, 2005, 2012; Forselledo *et al.*, 2008; Sales *et al.*, 2008; Jimenez *et al.*, 2009, 2010, 2012; Pons *et al.*, 2010; Domingo and Pons, 2011). Particularly in the Uruguayan and adjacent international waters over the continental shelf and slope, the bycatch is high and affects threatened albatrosses and petrels (Jiménez *et al.*, 2009, 2010, 2012), rays (Domingo *et al.*, 2005; Forselledo *et al.*, 2008), and especially loggerhead turtles (*Caretta caretta*) with the highest bycatch values worldwide (e.g. Sales *et al.*, 2008; Pons *et al.*, 2010). However, data on marine mammals bycatch in the longline fishery operating in the SWAO is limited to: a few records of individuals hooked or entangled in the lines (e.g. Marín *et al.*, 1998; Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007); some estimations of bycatch rates but with no temporally or spatially stratified analysis (Brum and Marín, 2000; Passadore *et al.*, 2008); and a bycatch study that only considered one marine mammal species (Ramos-Cartelle and Mejuto, 2008).

Several strategies have been used worldwide to monitor bycatch including on-board observer programmes, fishing logbooks, and interviews with fishers, among other methods. These strategies vary with respect to the type and quality of information provided, the percentage of coverage, the temporal extent of the monitoring, and in implementation costs. The Uruguayan fleet began pelagic longlining in 1981, and the National Observer Program for the Tuna Fleet (PNOFA) coordinated by the fishery agency "Dirección Nacional de Recursos Acuáticos" (DINARA) began monitoring it in 1998 (Mora and Domingo, 2006). Since then, all specimens caught are recorded in those fishing trips with observers onboard, including information on bycatch of marine mammals (Passadore *et al.*, 2008). Besides, fishers are required to submit official logbooks to the DINARA with data on catch, although most of the times they do not include data on marine mammals. However, since 1996, data on fishing effort and bycatch of marine mammals have been collected by one skipper in his personal logbook (which includes detailed data on fishing operations and on each specimen caught in every set) and it was provided to the authors of this work. In order to make a proper assessment of this interaction, it must be emphasized to consider all types of information available; in our case, we have the unique opportunity to utilize skipper's data in a bycatch study of protected species. Therefore, in this study, we use PNOFA data and skipper's personal logbook to perform the first comprehensive analysis of incidental capture of marine mammals by the Uruguayan pelagic longline fishery in the SWAO. The specific objectives are to determine spatio-temporal variations in marine mammal Bcpue, to estimate total bycatch for the fleet between 1996 and 2007, and to assess the potential effect of environmental and fishing operational variables on this interaction.

Material and methods

Uruguayan pelagic longline fishery

The Uruguayan fleet uses both monofilament and multifilament longlines, with mainline reaching up to 80 km in length (Chocca *et al.*, 2000; Domingo *et al.*, 2002). The spatial distribution of fishing effort is variable. Vessels using monofilament operate in Uruguayan EEZ and international waters deploying 600–1200 hooks per set at depths ranging between 25 and 60 m. Vessels using multifilament, on the other hand, concentrate in international waters of the SWAO, especially in lower latitudes, deploying 1000–3000 hooks per set at depths between 20 and 30 m or so (see Jiménez *et al.*, 2009; Domingo *et al.*, 2012). The baits used are the Argentine short-finned squid (*Illex argentinus*), mackerels (*Scomber* spp., *Trachurus* spp.), or shark guts (Mora and Domingo, 2006; Jiménez *et al.*, 2009), which may vary according to the target species. The target species for both longlines generally switch between fishing trips and include tunas (*Thunnus obesus*, *Thunnus albacores*, and *Thunnus alalunga*), swordfish (*Xiphias gladius*), and pelagic sharks such as blue shark (*Prionace glauca*; Domingo *et al.*, 2002; Mora and Domingo, 2006).

Study area

The fishing zone of the Uruguayan pelagic longline fleet includes the shelf brake, continental slope, and deep waters of the country's economic exclusive zone (EEZ) and adjacent international waters (Figure 1). This area is characterized by a northern subtropical zone, dominated by warm waters of the Brazil Current (average temperatures of 22–23°C), and by a southern zone of Subantarctic waters from the Falkland/Malvinas Current (average temperatures of 6°C; Brandini *et al.*, 2000). These two currents meet between latitude 30° and 50°S and longitude 40° and 60°W generating the Brazil–Malvinas Confluence (Barré *et al.*, 2006), where a series of

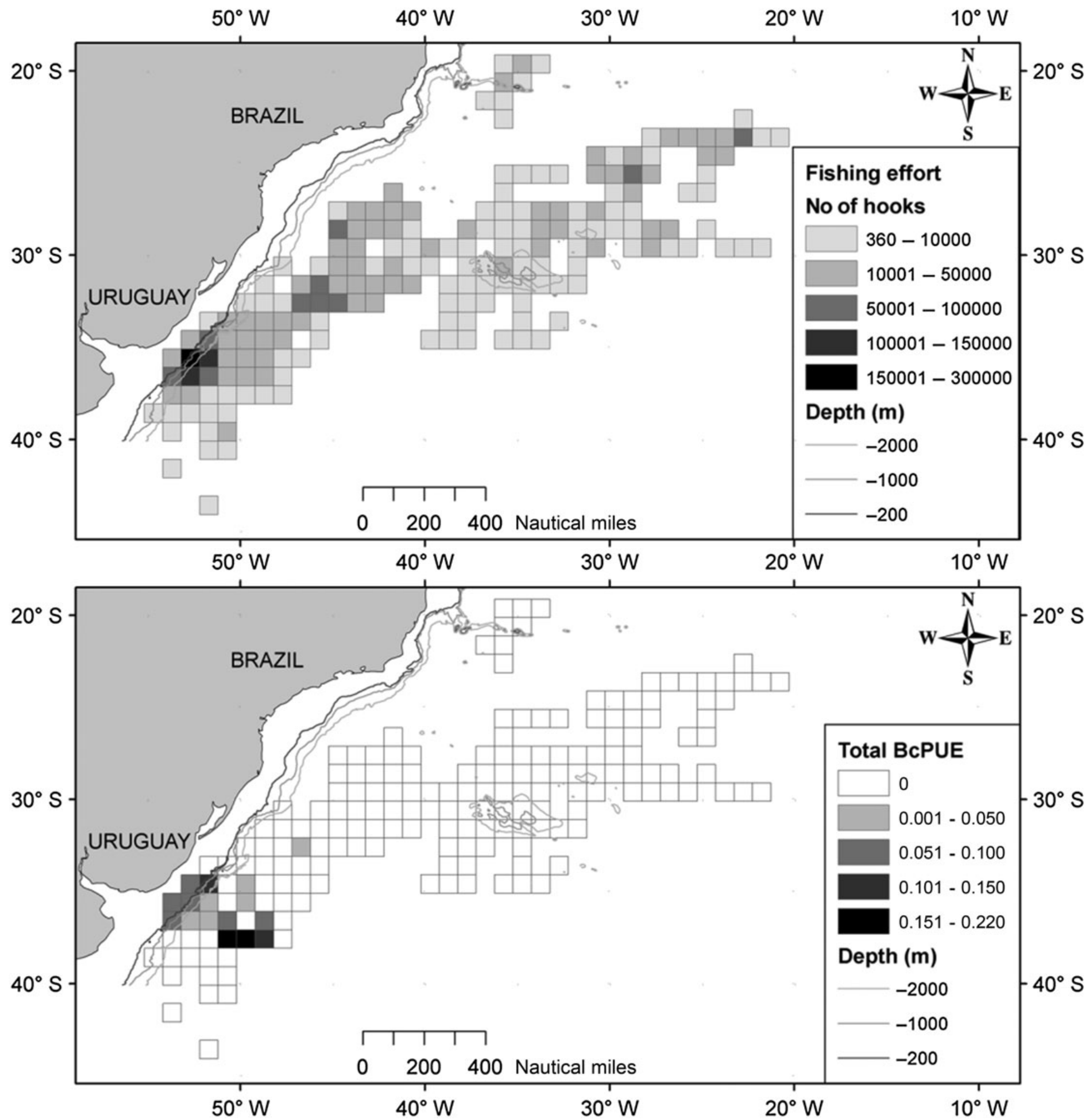

Figure 1. Cumulative data observed by skipper and PNOFA of the Uruguayan longline fishery presented in areas of $1 \times 1^{\circ}$ for the period 1996–2007: (a) fishing effort (no. of hooks); (b) marine mammal bycatch per unit effort (Bcpue = no. of marine mammals/1000 hooks).

large-scale meanders triggers strong upwelling of deep waters and eddies (Brandini *et al.*, 2000; Acha *et al.*, 2004; Ortega and Martinez, 2007) and a maximum concentration of chlorophyll-*a* occurs (Barré *et al.*, 2006). Sea surface temperature (SST) ranges from 8°C in the southern part of the confluence up to 20°C in the north (Brandini *et al.*, 2000; Acha *et al.*, 2004; Barré *et al.*, 2006). This constitutes one of the most productive areas of the ocean (Acha *et al.*, 2004), sustaining an important fishing industry and high abundance of marine top predators, such as seabirds, sea turtles, tuna, and sharks (e.g. Neves and Olmos, 1998; Domingo *et al.*, 2007, 2008, 2009; Sales *et al.*, 2008; Jimenez *et al.*, 2009, 2012; Cortés *et al.*, 2010; Pons *et al.*, 2010; Fossette *et al.*, 2014).

Data collection

Data were recorded by one skipper on his personal logbook between 1996 and 2006, and by scientific observers from the National Observer Program of the Tuna Fleet (PNOFA) between 1998 and 2007. This skipper was particularly concerned about fisheries interaction with marine mammals and started recording bycatch 2 years before the beginning of PNOFA. Thus, the captain's data were included in our analysis in order to add information to the records made by PNOFA and to make a better assessment of marine mammal bycatch by the Uruguayan longline fishery. Information on fishing effort employed by the entire fleet was obtained from official logbooks provided to the fishery agency

(DINARA). These official logbooks, however, did not include data on marine mammals bycatch and, for many trips, they only provided a rough position of the fishing events (i.e. rounded to the nearest degree), from which no precise depth or other position-dependent variable could be derived.

For each fishing set observed by PNOFA or by the skipper, the following data were recorded: time and geographic position (latitude and longitude) of the radio-buoys located at the start and end of the set and of the hauling, sea surface temperature (SST; minimum and maximum) measured *in situ* with thermometer at ~2–3 m of depth every time a radio-buoy was set or hauled, fishing gear used (mono or multifilament) and effort (number of hooks), and number of marine mammals captured by species. Individuals were classified as pinnipeds or cetaceans by observers, and in some cases to gender level. In order to avoid misidentification of marine mammal, photographic records of the individuals caught were provided by some observers to the authors to confirm the identification at species level.

For the analysis, we also determined other variables as follow. The "mean SST" per set was determined by averaging the maximum and minimum SST values recorded along the set. The "ΔSST" per set was calculated from the difference between the maximum and minimum SST recorded *in situ*, this variation could be used as an indicator of the presence of an SST front along the fishing haul. The "duration of the set" was determined as the elapsed time between the end of the set and the end of the haul. Each season was established according to the day of the setting as follows: winter (22 June–21 September); spring (22 September–21 December); summer (22 December–21 March); and autumn (22 March–21 June). For each set, the distance from shore and depth were determined using coastline maps and global bathymetry databases, respectively (ETOPO-20; http://monsoondata.org). As the longline extends several kilometres and the bottom depth can vary considerably along the set, we determine depth variation of seabed (DVS) as the difference between the deepest and the shallowest points of the set.

Data analysis

Only those fishing trips on which the skipper or trained observers performed a complete record of all marine mammals caught and most of the explanatory variables were included in the analysis. In order to determine if there were any systematic differences attributable to the data collector or if the skipper's reporting was potentially biased or subject to error, we included the data type as a categorical variable in the generalized additive model GAM analysis (see details below).

Spatial and temporal analysis of marine mammal bycatch

The software ArcGis 10.0 was used to calculate the effort and marine mammal Bcpue within grid cells of $1 \times 1^\circ$ during the whole period and per season. Because precise information of fishing position is lacking for most official logbooks provided to the fishery agency by vessels without on-board observers, only data from PNOFA and the skipper's personal logbook were used to produce geo-referenced maps. Likewise, lack of precise information on position-related variables hindered the use of the GAM to predict the bycatch for the entire fleet. Instead, the magnitude of bycatch was determined using nominal unstratified Bcpue, defined as the number of marine mammals caught (C) per number of hooks set times 1000. To analyse temporal variations of bycatch, we accounted for the accumulated number of sets and hooks observed annually and seasonally, as well as the total Bcpue and treated cetaceans and pinnipeds separately. The total number of sets reported in official logbooks was used to determine the proportion of sets observed per season and year. To determine the total bycatch (Tc) of the fleet, for the period 1996–2007, the uncertainty in (pinniped and cetacean) Bcpue estimates per vessel was calculated by non-parametric bootstrap (Manly, 1997). The data provided by each vessel i ($i = 1, \ldots, b$) included: (i) number of animals bycaught (C_i); (ii) number of sets during the period (S_i); and (iii) average number of hooks deployed during the period (H_i; see Supplementary Table S1). For each estimate of Bcpue, bootstrap sampling of b vessels taken randomly with replacement was performed 10 000 times. These vessels are those for which the settings were observed and are assumed to be representative of the entire fleet. For each sample, Tc was then estimated as Bcpue times the mean total effort among surveyed boats (b) times total effort (F) as the number of sets declared by the Uruguayan fleet [see Equations (1) and (2)].

$$Tc = \text{Bcpue} \times \frac{\sum Si \times Hi}{b} \times F. \tag{1}$$

$$Tc = \text{Bcpue} \times \left(\frac{\sum Si}{b} \times \frac{\sum Hi}{b}\right) \times F. \tag{2}$$

The difference between the two equations is related to the degree of covariance between the number of sets S and the number of hooks H observed. The covariance is:

$$\text{Cov.}(S, H) = E\{S \times H\} - E\{S\} \times E\{H\}, \tag{3}$$

where $E\{\ \}$ represents the expected value. The method of moments estimator of $E\{S \times H\}$ and $E\{S\} \times E\{H\}$ corresponds to the term within brackets in Equations (1) and (2), respectively. So, if: (i) $\text{Cov.}(S, H) = 0$ then, Equations (1) and (2) provide the same results; (ii) $\text{Cov.}(S, H) > 0$, the mean effort estimated from Equation (1) is higher, resulting in higher Tc; or (iii) $\text{Cov.}(S, H) < 0$, the mean effort estimated from Equation (1) is lower, resulting in lower Tc (Secchi *et al.*, 2004). The confidence interval for Tc was estimated as the 2.5 and 97.5 percentiles of the bootstrap replicates (Manly, 1997). This estimation approach assumes that marine mammals are equally vulnerable to any boat in the fleet. Considering the seasonal variations in Bcpue of pinnipeds (see the Results section), Tc was also determined for the vessels operating during winter when the bycatch was higher. Due to the small number of individuals caught in the remaining seasons and lack of information reported on the official logbooks (e.g. not accurate position, SST), it was not possible to perform further stratification of the data to estimate Tc.

Influence of spatial, temporal, environmental, and operational variables on bycatch

GAMs (Hastie and Tibshirani, 1990) were used to explore the relationships of spatial, temporal, environmental, and operational variables with marine mammal bycatch. GAMs relate a response variable that can be non-normally distributed with explanatory variables by non-linear smooth functions without imposing parametric constraints (Hastie and Tibshirani, 1990). Because 89% of sets with bycatch had only one individual captured, we considered a binomial distribution (Yi) family with a logit link function (Hastie and Tibshirani, 1990) to model the occurrence of cetaceans and pinnipeds bycatch (presence/absence) per fishing event. We modelled bycatch of the two taxa separately as a function of the explanatory variables considered as relevant *priors* based on previous studies that show that they potentially affect the distribution of marine mammals (e.g. Cañadas *et al.*, 2002; Tynan *et al.*, 2005) or their interaction with longline gear (e.g. Garrison, 2007; Forney *et al.*, 2011). The selected dataset for the models included 15 and 25 events with cetacean and pinniped bycatch, respectively. The following categorical explanatory variables were considered: data type (DATA: code assigned to each observer or skipper), YEAR, season (SEAS), MONTH, type of gear used (GEAR: mono or multifilament). The continuous variables were: distance to coast (COAST), average depth of the set (DEPTH), depth variation of seabed along the set (DVS), number of hooks per set (EFFORT), duration of the set (SET), duration of the fishing trip (DAYS), and mean and variation of sea surface temperature along the set (SSTmean and ΔSST, respectively). In addition, the dependence on spatial location was modelled using an isotropic bivariate function of longitude (LONG) and latitude (LAT; Wood and Augustin, 2002). Collinearity between variables was previously checked using multipanel scatterplots (Zuur *et al.*, 2010) and the Pearson and Spearman correlation coefficients (threshold of 0.6). After exploratory analyses, initial statistical models containing only uncorrelated explanatory variables were generated for cetaceans and pinnipeds separately. Models were fitted using the *gam* function of the library *mgcv*, which chooses simultaneously the degrees of freedom for each smooth term as part of model fitting by minimizing the unbiased risk estimator (UBRE) score of the full model (Wood, 2006). The UBRE score is the binomial GAM equivalent of the Akaike information criteria value and balances fit with the number of parameters used to describe the model (Wood, 2006). We used a thin plate regression spline (TPRS) for smoothing terms. TPRS is the default function of *mgcv* and allows the estimation of a smooth function using multiple predictors without previous knowledge of the knot locations (Wood, 2006). The *ad hoc* approach of general backward simplification described by Wood and Augustin (2002) was used. Each term was dropped from the model at a time and, terms were kept out of the model if their removal produced a reduction in UBRE score compared with the previous model. The best model was the one that presented the lowest UBRE score. Diagnostic plots were made to determine the fit effectiveness of the models (Wood, 2006). The explained deviance [$D^2 = $ (null deviance − residual deviance)/null deviance × 100], which corresponds to the percentage of data deviance explained by each model in relation to the null model, was also determined. All statistical analyses were performed using the free software R (R Development Core Team, 2008).

Results

A total of 2008 sets performed by the Uruguayan pelagic longline fishery were monitored (767 by the skipper and 1241 by PNOFA observers) between 1996 and 2007 (Figure 1), which correspond to 20.4% of all sets of the fleet. A large number of hooks was monitored (618 357 by the skipper and 2 518 922 by observers), representing 28.9% of the hooks deployed by the entire fleet during that period. The interannual variation in the number of observed sets and hooks was wide and reflects changes in observer coverage as well as changes in the amount of annual fishing effort (Table 1). Mammals bycatch was recorded in 42 fishing sets (17 sets observed by the skipper and 25 by PNOFA). Forty-seven marine mammals (16 cetaceans and 31 pinnipeds) were captured. The capture of a single individual per fishing event was the most frequent (89%). The respective Bcpues for the period 1996–2007 were 0.0051 cetacean/1000 hooks and 0.0099 pinniped/1000 hooks (Table 1).

Table 1. Annually, seasonally, and total cumulated information on fishing effort and marine mammals bycatch in the Uruguayan longline fishery observed by PNOFA (PNO) and skipper (Sk) during the period 1996–2007.

	No. of sets					No. of hooks				Cetaceans		Pinnipeds		Bcpue (ind./1000 hooks)		
YEAR/SEASON	Tot.	PNO	Sk	% obs.	w/byc.	Tot.	PNO	Sk	% obs.	PNO	Sk	PNO	Sk	Cet.	Pin.	Mm.
1996	721	0	82	11.4	0	496 912	0	47 568	9.6	0	0	0	0	0	0	0
1997	551	0	71	12.9	1	502 880	0	45 040	9	0	1	0	0	0.0222	0	0.0222
1998	684	59	110	24.7	5	626 995	57 905	93 897	24.2	0	0	2	3	0	0.0329	0.0329
1999	582	0	11	1.9	0	549 642	0	12 350	2.2	0	0	0	0	0	0	0
2000	466	0	70	15	1	394 462	0	64 645	16.4	0	0	0	1	0	0.0155	0.0155
2001	553	33	129	29.3	5	497 083	33 290	129 573	32.8	0	2	1	2	0.0123	0.0184	0.0307
2002	695	69	176	35.3	14	551 682	54 380	100 686	28.1	4	4	7	4	0.0516	0.0709	0.1225
2003	1254	187	38	17.9	4	1 356 861	413 939	28 844	32.6	1	1	2	0	0.0045	0.0045	0.0090
2004	1348	244	0	18.1	2	1 824 428	556 310	0	30.5	1	0	1	0	0.0018	0.0018	0.0036
2005	1470	219	70	19.7	5	1 960 220	484 214	84 224	29	2	0	3	0	0.0035	0.0053	0.0088
2006	933	179	10	20.3	0	1 283 245	456 382	11 530	36.5	0	0	0	0	0	0	0
2007	586	251	0	42.8	5	812 249	462 502	0	56.9	0	0	5	0	0	0.0108	0.0108
Autumn	2833	594	6	21.0	6	2 042 751	608 542	207 149	39.9	0	4	0	2	0.0049	0.0025	0.0074
Winter	3167	581	23	18.3	23	3 202 379	750 327	155 435	28.3	2	0	18	7	0.0022	0.0276	0.0298
Spring	2449	445	10	18.2	10	3 343 965	400 550	178 544	17.3	5	2	3	1	0.0121	0.0069	0.0190
Summer	1394	388	3	27.8	3	2 267 564	759 503	77 229	36.9	1	2	0	0	0.0036	0.0000	0.0036
Total	9843	1241	767	20.4	42	10 856 659	2 518 922	618 357	28.9	8	8	21	10	0.0051	0.0099	0.015

Total number of sets and hooks declared by the longline Uruguayan fleet (Tot.), observed by PNOFA and skipper, percentage of total observed (% obs.), and the number of sets (binary count) observed with marine mammals' bycatch (w/byc.). Total number of cetaceans and pinnipeds recorded incidentally caught by PNOFA and skipper. Nominal bycatch per unit effort (Bcpue = no. of individuals/ no. of hooks × 1000) of cetaceans (Cet.), pinnipeds (Pin.), and total of marine mammals (Mm.).

Table 2. Daily records of marine mammals' bycaught by the Uruguayan pelagic longline fleet between 1996 and 2007.

Date	*n*	Species[a]	Latitude	Longitude	Depth (m)	DVS (m)	Coast dist. (nm)	SST max (°C)	SST min (°C)	SST range (°C)	Type	Comments
9 December 2005	1	*Arctocephalus* sp.	−36.100	−53.200	−490	0	172.6	17.2	14.7	2.5	PNOFA	Entangled, released alive
23 August 2007	1	*Arctocephalus tropicalis*	−35.500	−49.707	−4149	104	394.6	16.4	15.6	0.8	PNOFA	Broke line and was released alive with hook
7 March 2002	1	*Delphinus* sp.	−35.370	−52.730	−219	0	146.6	20.4	20.1	0.3	PNOFA	
25 October 2002	2	*Delphinus delphis*	−35.820	−52.220	−819	736	164.0	20.1	19.2	1.0	PNOFA	One entangled in buoy line and released alive; other hooked and released with hook
15 December 2005	1	*Delphinus* sp.	−35.017	−52.250	−957	0	190.4	19.7	19.1	0.6	PNOFA	Entangled in main line, released alive
17 December 2005	1	*Delphinus* sp.	−35.050	−52.550	−520	437	152.3	19.4	19.0	0.4	PNOFA	Hooked, released alive
14 May 1997	1	DNI	−35.362	−52.370	−788	169	171.3	22.1	17.2	4.8	Skipper	Entangled in buoy line
4 December 2001	1	DNI	−35.718	−52.837	−619	0	169.0	20.0	18.8	1.2	Skipper	
12 January 2002	1	DNI	−35.772	−52.658	−619	0	180.9	23.8	22.9	0.8	Skipper	
22 February 2002	1	DNI	−35.493	−52.522	−788	169	157.5	23.7	22.4	1.3	Skipper	
25 March 2002	1	DNI	−35.890	−53.087	−337	282	153.0	21.6	20.4	1.1	Skipper	
29 September 2002	1	DNI	−35.692	−52.802	−419	200	162.1	16.9	13.4	3.6	Skipper	
20 May 2003	1	DNI	−35.707	−52.795	−619	0	178.8	15.2	14.7	0.5	Skipper	
14 August 2003	1	DNI	−36.183	−53.333	−490	0	171.5	17.0	12.0	5.0	PNOFA	
11 August 2004	1	DNI	−32.800	−46.400	−3885	0	453.2	18.7	18.2	0.5	PNOFA	Released alive
25 May 2001	1	*Orcinus orca*	−37.377	−49.960	−4853	64	483.7	20.9	19.7	1.2	Skipper	Entangled by the tail
30 October 2002	1	*Orcinus orca*	−36.180	−52.380	−3115	457	293.4	21.3	19.8	1.5	PNOFA	Entangled in the main line, released alive by itself
15 September 2002	1	*Otaria flavescens*	−34.570	−52.120	−83	0	152.1	16.7	14.1	2.6	PNOFA	Released alive, female pregnant
18 September 2004	1	*Otaria flavescens*	−35.433	−52.417	−957	0	173.2	16.7	11.8	4.9	PNOFA	
1 December 2005	1	*Otaria flavescens*	−34.917	−52.550	−83	0	159.3	20.7	19.9	0.7	PNOFA	Entangled, released alive
11 June 1998	1	PNI	−37.190	−50.633	−4646	0	397.0	19.4	18.5	0.9	Skipper	
17 August 1998	1	PNI	−36.148	−51.915	−2958	334	232.9	18.6	16.7	1.9	Skipper	
20 September 1998	1	PNI	−36.630	−52.552	−3205	186	286.9	18.7	17.8	0.8	Skipper	
4 June 2000	1	PNI	−37.282	−48.893	−4995	28	553.8	18.7	17.8	0.9	Skipper	
17 July 2001	1	PNI	−34.252	−49.287	−3225	0	368.3	20.2	19.8	0.4	Skipper	
23 August 2001	1	PNI	−37.222	−50.062	−4788	0	454.6	18.3	17.2	1.1	Skipper	
7 July 2002	1	PNI	−35.008	−52.147	−520	437	157.0	19.6	18.4	1.2	Skipper	
6 August 2002	2	PNI	−35.942	−52.880	−554	65	183.8	19.2	13.7	5.6	Skipper	
28 September 2002	1	PNI	−36.157	−53.183	−490	0	189.4	11.4	9.4	2.1	Skipper	
19 July 1998	1	PNI	−36.880	−48.770	−4860	0	537.6	20.6	17.4	3.2	PNOFA	Released alive
21 October 1998	1	PNI	−36.500	−53.030	−490	0	214.2	20.2	19.3	0.9	PNOFA	Hooked on the back, released alive
1 August 2001	1	PNI	−36.370	−50.780	−4237	219	389.8	20.0	19.8	0.2	PNOFA	Hooked on the flipper, released alive
13 July 2002	3	PNI	−34.920	−51.480	−2064	117	221.1	19.6	18.5	1.1	PNOFA	Line cut before hauling onboard, one was female; one was dead
14 July 2002	2	PNI	−35.000	−51.380	−2366	186	235.6	21.9	19.0	2.9	PNOFA	Released alive, one was a male
19 July 2002	1	PNI	−35.480	−51.450	−2357	195	238.1	21.2	20.1	1.1	PNOFA	Line cut before hauling onboard
15 August 2003	1	PNI	−35.833	−52.917	−619	0	168.4	15.0	14.0	1.0	PNOFA	
16 August 2003	1	PNI	−35.550	−52.667	−219	0	162.8	16.0	14.0	2.0	PNOFA	
24 July 2005	1	PNI	−36.850	−53.770	−1088	484	283.2	20.2	18.3	1.8	PNOFA	Released alive
17 August 2007	1	PNI	−34.977	−51.632	−1291	0	178.0	15.4	14.5	0.9	PNOFA	Released alive

28 July 2007	1	PNI	−36.850	−51.800	−3590	17	306.0	17.3	17.1	0.2	PNOFA	Hooked, released alive with hook
31 July 2007	1	PNI	−36.583	−50.717	−4145	127	343.8	16.3	15.1	1.2	PNOFA	Released alive with hook and branch line
12 August 2007	1	PNI	−36.700	−51.867	−3115	457.3	275.8	17.1	16.7	0.4	PNOFA	Released alive with hook and branch line

[a]Dolphin and pinniped not identified at gender level are presented as "DNI" and "PNI", respectively.
The number of individuals caught per set, the species, location (latitude and longitude), average depth, depth variation of seabed (DVS) along the set, distance to coast (Coast dist.), and maximum, minimum, and range of sea surface temperature along the set (SST max, SST min, and SST range, respectively). Type of data (whether gathered by skipper or observers from PNOFA) and comments on the catch event.

Nine dolphins and 26 pinnipeds could not be identified to species or genus levels (Table 2). Among the identified species using photographic records of bycatch, three were South American sea lions (*Otaria flavescens*), one was the Subantarctic fur seal (*Arctocephalus tropicalis*), two were killer whales (*Orcinus orca*), and two were short-beaked common dolphin (*Delphinus delphis*). In most cases, the individuals were released in unknown conditions. One common dolphin was released with serious injuries (i.e. hooked on the head) and only one unidentified pinniped was dead (Table 2).

Spatial and temporal distribution of fishing effort and bycatch

No marine mammal bycatch was recorded in 1996, 1999, and 2006. The highest Bcpue and estimated number of individuals caught occurred in 2002 (Table 1).

The fishing ground spread between latitudes 19° and 44°S and longitudes 20° and 55°W, though the observed effort (Figure 1a), marine mammal bycatch, and Bcpue (Figure 1b) were highly concentrated. The highest Bcpues were recorded between 37° and 38°S and 49° and 51°W (Bcpue ranging from 0.151 to 0.220; Figure 1b). Most cetaceans were captured over the continental shelf break and slope, except for an unidentified dolphin and a killer whale that were caught in waters over 4000 m deep (Table 2; Figure 2a). The area of pinniped bycatch was more restricted but also included waters over the continental shelf and slope. The South American sea lions were generally caught closer to the coast (Table 2; Figure 2b).

The fishing effort was highest in spring and lowest in autumn, with the lowest percentage of coverage occurring in spring (Table 1; Figure 3). The highest Bcpues for cetaceans and pinnipeds were recorded in spring and winter, respectively. No captures of pinnipeds were observed in summer (Table 1). Totals of 79 (CI: 25–147) cetaceans and 152 (CI: 69–260) pinnipeds were estimated to have being caught by the entire Uruguayan fleet along the 12 years of monitoring [according to Equation (1); Table 3]. Most of the captures of pinnipeds correspond to winter (137.2; CI: 71.5–220). Estimates are slightly lower when Equation (2) is used instead (Table 3). The distribution of the bootstrap estimates of cetacean and pinniped total bycatch for the 12 years of study is shown in Supplementary Figure S1.

In summer, the highest fishing effort observed occurred in open waters at the northern part of the study area, while in winter, the effort was concentrated in a relatively narrow stretch parallel with the coast. The effort was widespread in autumn and patchy, with large numbers of hooks set both close and far from the coast, in spring (Figure 3). Cetacean bycatch was low and occurred in all seasons off the Uruguayan coast and during autumn and winter in international waters (Figure 4). Pinniped bycatch, on the other hand, was high and occurred near the Uruguayan coast in winter and spring. During autumn, it was lower and occurred further away from coast (Figure 5).

Influence of environmental and operational variables on the bycatch

After exploratory analysis, the uncorrelated explanatory variables (correlation coefficients presented in Supplementary Table S2) included in the modelling process were: DATA, year, season, GEAR, DEPTH, DVS, SET, DAYS, SSTmean, and ΔSST, as well as the interaction between LAT and LONG. Information about some of these variables was missing in 143 fishing events. Therefore, only 1864 events were used to model the occurrence of cetaceans and pinnipeds bycatch separately. Our analysis combined the two

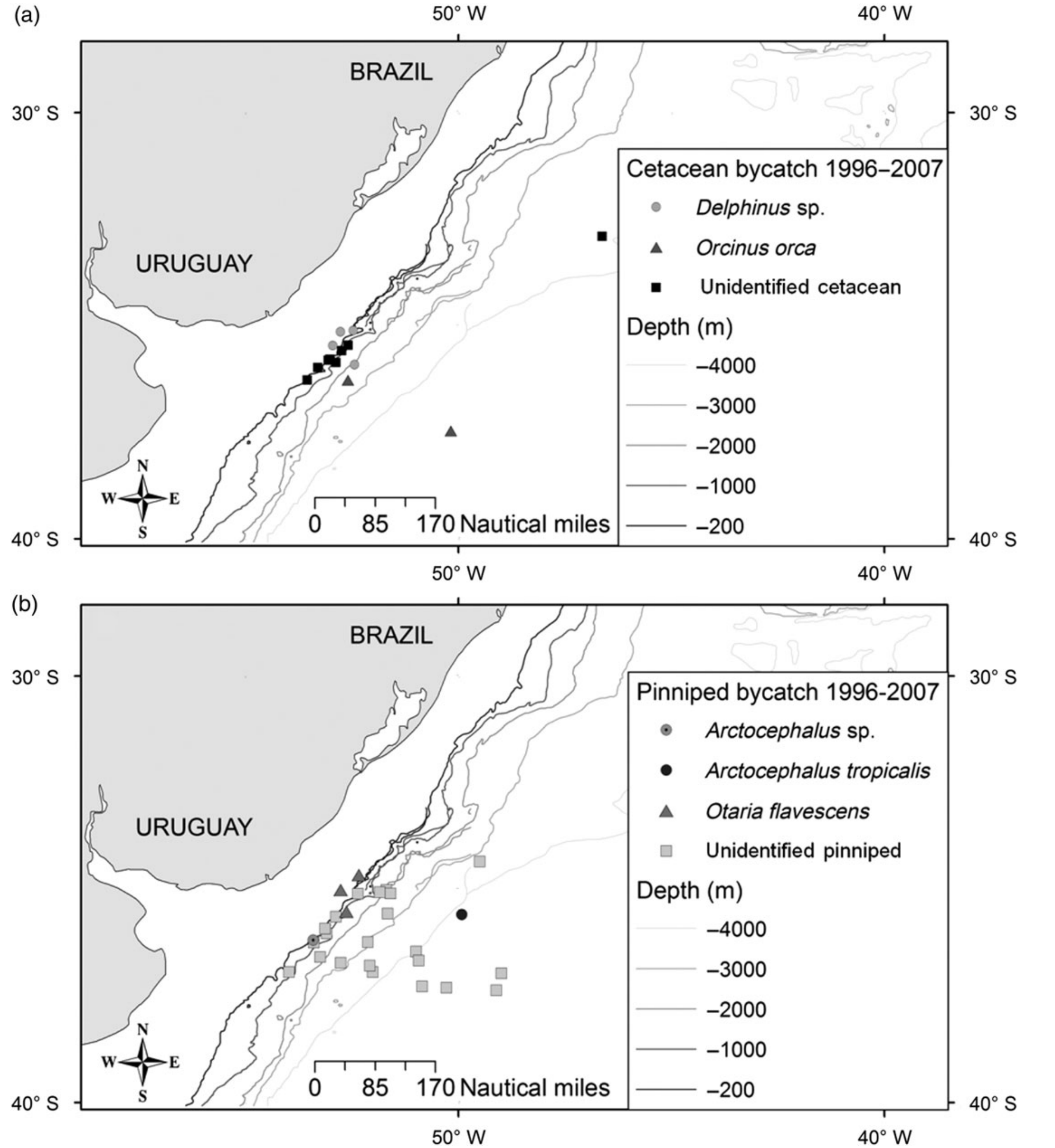

Figure 2. Spatial distribution of bycatch of marine mammals (a: cetaceans, b: pinnipeds) in Uruguayan longline fishery. Data correspond to records provided by the PNOFA and one skipper's personal logbook between 1996 and 2007.

data sources (skipper and PNOFA) to increase sample size and broaden the spatio-temporal range of available information.

The final GAM, with lowest UBRE, included season as a factor, a smoothed term of depth of seabed, and of sea surface temperature as variables to explain cetacean bycatch (Table 4; Figure 6a and b). This model explained 26.3% of the deviance of the data (Table 4). Cetaceans were captured year-round, though the highest values were registered in spring. While the fishing fleet operated in a wide area, with depths ranging from 50 to 5700 m, cetaceans were captured in relatively shallow areas with a median depth of 619 m, which correspond to the upper continental slope. The median sea surface temperature of the bycatch events was 19.7°C.

The final GAM that best explained pinniped bycatch included season as a factor, a smoothed function of depth, and the isotropic bivariate function of longitude and latitude as explanatory variables (Table 4; Figure 6c and d). This GAM explained 23.6% of the deviance of the data (Table 4). Pinniped bycatch occurred mainly in winter, in waters with depths ranging between 80 and 5000 m depth (median = 2366 m), and located between 34° and 37°S (median = 35.9°S) and 54° and 49°W (median = 51.8°W).

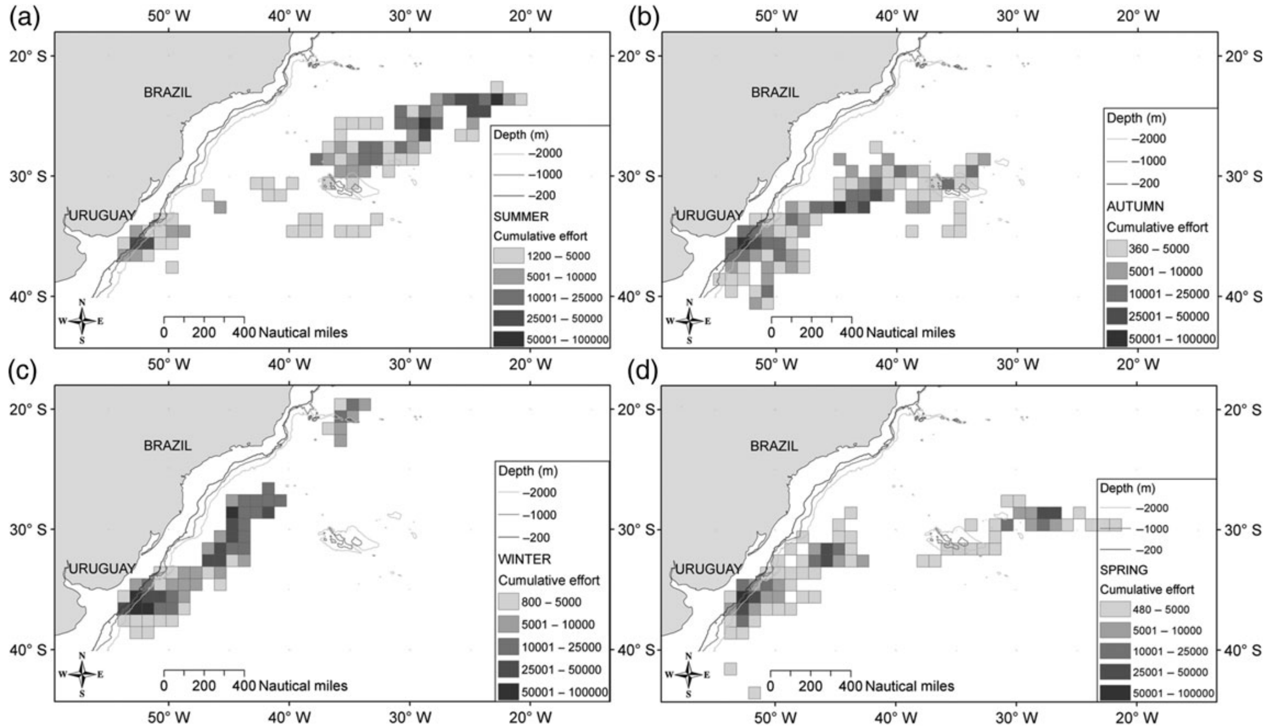

Figure 3. Observed fishing effort (no. of hooks) of the Uruguayan longline fishery accumulated seasonally in areas of $1 \times 1^{\circ}$ for the period 1996–2007: (a) autumn, (b) winter, (c) spring, and (d) summer.

Table 3. Total estimated number of cetaceans and pinnipeds bycaught by the Uruguayan longline fleet during the period 1996–2007.

	Equation	*Tc* mean	*Tc* s.d.	CI (0.025)	CI (0.975)
Cetaceans					
Total (1996–2007)	(1)	78.7	31.4	24.5	147
	(2)	64.1	32.4	18.3	143.7
Pinnipeds					
Total (1996–2007)	(1)	151.5	49.5	68.6	259.7
	(2)	122.8	51.2	46.8	243.7
Winter (1996–2007)	(1)	137.2	38.1	71.5	220
	(2)	111.8	38.8	56.2	206

Estimates with Equations (1) and (2) of the mean number of individuals (*Tc* mean), standard deviation (*Tc* s.d.), and the confidence interval (CI) for the 0.025 and 0.975 percentile are presented. Estimates of pinnipeds' captures occurring exclusively in winter during the 12 years of study are also presented.

Discussion

Prior knowledge about marine mammal bycatch in pelagic longline fisheries in the SWAO was constrained to anecdotal records of captures and to rough estimates of catch per unit effort, which were reported in studies of depredation (Marín *et al.*, 1998; Secchi and Vaske, 1998; Brum and Marín, 2000; Dalla Rosa and Secchi, 2007; Ramos-Cartelle and Mejuto, 2008). Although in a previous paper, Passadore *et al.* (2008) used data from the PNOFA to present general information on bycatch of marine mammals by Uruguayan longline fleet, no analysis on the spatio-temporal variations nor exploration on the effects of several variables in the interaction were performed. Thus, the integration of the data used by Passadore *et al.* (2008) together with new data collected by the PNOFA and a database generated with a skipper's personal logbook allowed us to perform a spatially explicit analysis of the bycatch of marine mammals by pelagic longline fisheries in the SWAO and to model separately bycatch of cetaceans and pinnipeds. Although this study is based only on the Uruguayan fleet, the two sources of information used (i.e. skipper and observers' data) allowed us to assess this interaction during a 12-year period (1996–2007) and covering a wide area of the Southwestern Atlantic Ocean (between latitudes 19° and 44°S and longitudes 20° and 55°W). However, spatial and temporal variables were only significant for explaining bycatch of pinnipeds. An analysis integrating the data from several pelagic longline fleets (e.g. Uruguayan and Brazilian) should result in a better assessment of the interaction with marine mammals in this region of the Atlantic.

Self-reporting data from vessel's skippers could be argued to be unreliable, particularly with respect to under-reporting of bycatch and species misidentification. Although the number of unidentified species was higher by the skipper than by the observers, the frequency of marine mammals caught reported by the skipper (2.21%, with 17 out of 767 sets with captures) was similar to the reported by PNOFA observers (2.01%, 25 out 1241 sets with captures). Thus, we considered that the data provided by this skipper were unbiased with respect to the number of reported bycatch.

The values of marine mammal bycatch reported here by the Uruguayan fleet (0.0149 marine mammals/1000 hooks) are far below those previously reported in the SWAO by the US fleet (0.045 marine mammals/1000 hooks; Brum and Marín, 2000) and above the ones reported for the Spanish fleet (0.001464 false killer whales/1000 hooks; Ramos-Cartelle and Mejuto, 2008). The difference in catch per unit effort by these fleets could be attributed to methodological differences to estimate catch rates but also due to spatial variation on their fishing dynamics with some fleets

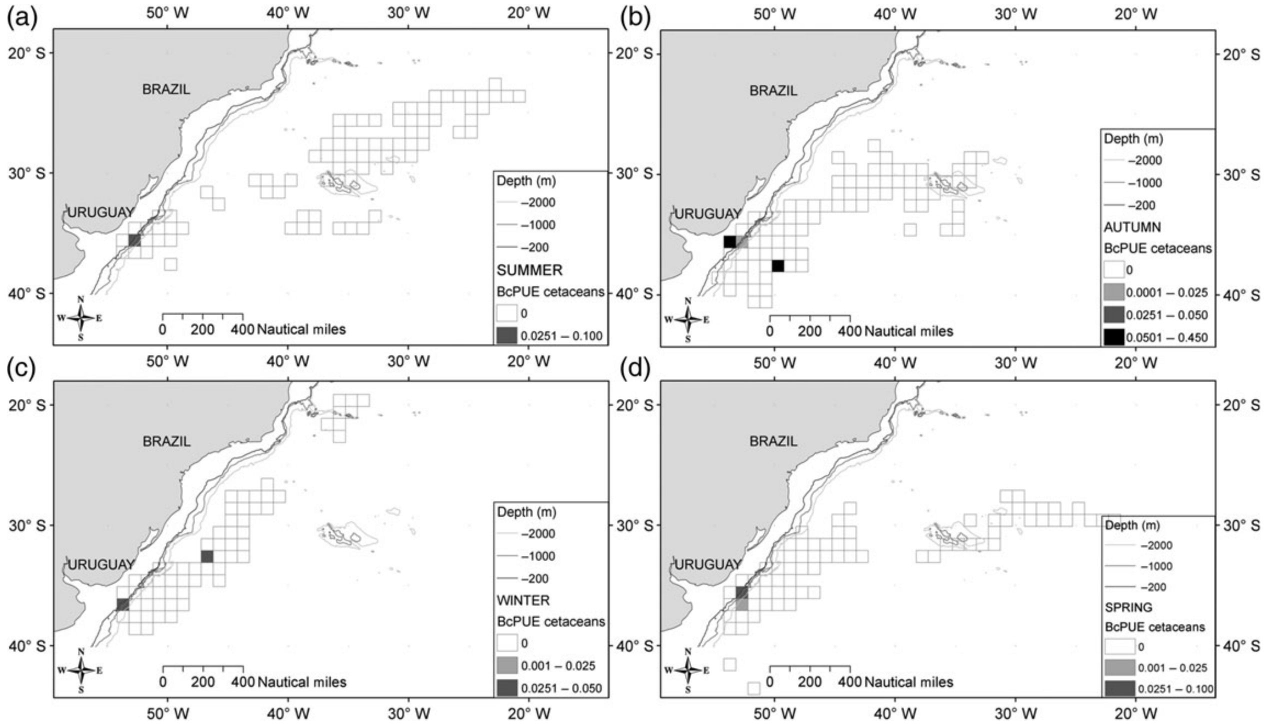

Figure 4. Cetacean bycatch per unit effort (Bcpue = no. of cetaceans/1000 hooks) of the Uruguayan longline fishery, data are presented accumulated seasonally in areas of 1 × 1° for the period 1996–2007: (a) autumn, (b) winter, (c) spring, and (d) summer.

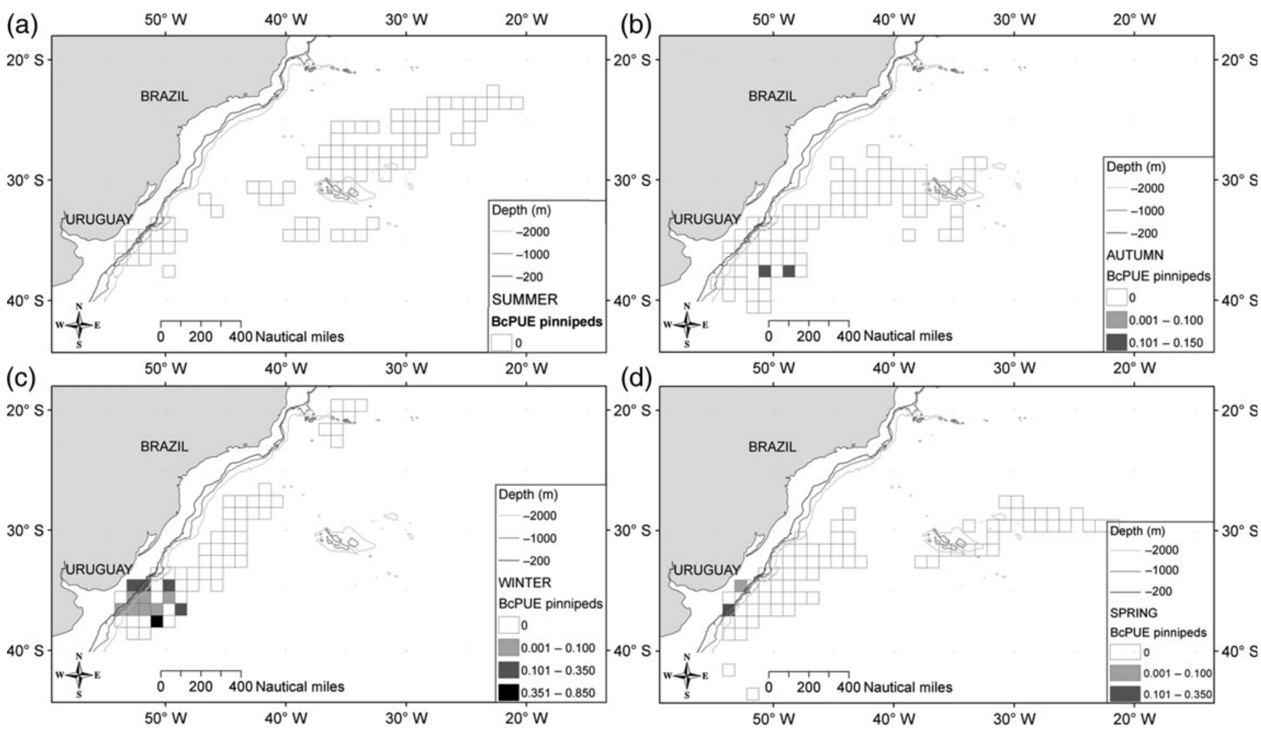

Figure 5. Pinniped bycatch per unit effort (Bcpue = no. of cetaceans/1000 hooks) of the Uruguayan longline fishery, data are presented accumulated seasonally in areas of 1 × 1° for the period 1996–2007: (a) autumn, (b) winter, (c) spring, and (d) summer.

operating in areas yielding high catch rate and others concentrating their effort in areas with low catch rates. While approximately half of the sets observed in our study and by Brum and Marín (2000) took place in the Uruguayan EEZ, the study by Ramos-Cartelle and Mejuto (2008) covered the entire Atlantic Ocean except the Uruguayan EEZ. Besides the variation related to fishing ground

Table 4. Results of GAMs for cetaceans' and pinnipeds' bycatch observed in the Uruguayan longline fishery, including the covariates selected by the models.

Taxon	Parameter	Estimate	e.d.f.	Std. error	*z*-value	χ^2	*p*-value	Explained deviance (%)	r^2	UBRE score	*n*
Cetacean											
	(Intercept)	−9.173		4.00	−2.29		0.022				
Linear terms											
	S-Spring	0.613		0.74	0.83		0.405				
	S-Summer	1.448		0.97	1.50		0.135				
	S-Winter	−0.691		1.03	−0.67		0.504				
Smooth terms											
	s(DEPTH)		4.56			9.24	0.132				
	s(SSTmean)		6.15			10.67	0.133				
Best final model: Cetacean bycatch ~ *s*(DEPTH) + SEASON + *s*(SSTmean)								26.3	0.056	−0.9152	1864
Pinnipeds											
	(Intercept)	−7.200		1.50	−4.79		0.000				
Linear terms											
	S-Spring	0.666		1.03	0.65		0.517				
	S-Summer	−127.700		3 508 000.00	0.00		1.000				
	S-Winter	2.892		0.79	3.65		0.000				
Smooth terms											
	s(DEPTH)		2.06			5.37	0.112				
	s(LONG,LAT)		3.75			4.16	0.525				
Best final model: pinniped bycatch ~ *s*(DEPTH) + *s*(LONG, LAT) + SEASON								23.6	0.045	−0.8808	1864

and catch rates, other factors could be determining the observed differences in Bcpue; for instance, differences in reporting procedure, the fishing strategy (e.g. configuration of the longline, bait used, and duration of the set), or the species involved (e.g. abundance, catchability). The study of Ramos-Cartelle and Mejuto (2008) dealt with one species only, while the other studies mentioned determined the catch considering several marine mammal species, which can have different vulnerability to bycatch.

The species incidentally captured in our study are similar to those reported in other studies (Marín *et al.*, 1998; Brum and Marín, 2000; Dalla Rosa and Secchi, 2007; Hernandez-Milian *et al.*, 2008), except for the South American sea lion for which the bycatch has been recorded only by Uruguayan pelagic longline fleet operating in the SWAO (this study; Passadore *et al.*, 2008). This might have happened because the fishing sets were relatively close to the coast (34.57°–35.43°S and 52.12°–52.55°W) in the area which constitutes the oceanward limit of this species distribution (Bastida *et al.*, 2007). Although the two individuals captured were released alive and the registered and estimated total numbers of marine mammals bycaught by the Uruguayan longline fleet were very low, the potential impact of this fishery on sea lion populations should not be overlooked. The South American sea lion population that breeds in Uruguay is declining (Páez, 2006), and fisheries bycatch could be one of the reasons. This species is also incidentally caught in artisanal gillnet (Corcuera *et al.*, 1994; Crespo *et al.*, 1994; Franco-Trecu *et al.*, 2009) and the coastal trawl fisheries in SWAO (Crespo *et al.*, 1997; Dimitriadis *et al.*, 2006; Szephegyi *et al.*, 2010). Therefore, special attention should be taken to reduce the bycatch and post-release mortality of this species in all fisheries operating in coastal waters of the SWAO.

Spatial and temporal distribution of bycatch

Oceanographic processes occurring on the shelf brake and slope constitute important areas for bycatch of several species of marine megafauna. In our study, the highest Bcpue values of cetaceans (except for two events) were recorded between 35° and 36°S and 52° and 53°W, over the continental shelf break and slope. This coincides with the area of highest Bcpue for albatrosses, petrels, and loggerhead turtles (López-Mendilaharsu *et al.*, 2007; Jiménez *et al.*, 2009; Fossette *et al.*, 2014). In this area, the confluence of the Brazil and Malvinas/Falkland currents and the fronts generated at the shelf break play an important role in the ecological processes. There, high primary production offers adequate feeding habitats for nektonic species, such as fish and squids, and thus attracts fisheries' target species and other predators (Acha *et al.*, 2004). Patterns of high values of bycatch were also observed along the US coast (Garrison, 2007).

The highest pinniped Bcpues were observed during winter, in a relatively narrow area (34°–37°S and 48°–53°W), to the south of the fishing zone, which coincided with previous records of marine mammals captured by the US fleet (Brum and Marín, 2000). While many pinnipeds incidentally caught by the Uruguayan fleet could not be identified to species level, it is considered that most could have been Subantarctic fur seals, as was reported by Brum and Marín (2000). This would be supported by the fact that this species occurs mainly off the Buenos Aires Province from June to December in waters under the influence of the Brazil Current between 30° and 40°S (Bastida *et al.*, 2007). The seasonality of pinniped bycatch could be explained by their seasonal movements and changes in fishing effort. The colonies of South American sea lion are located on islands and on the Atlantic coast of South America, while the Subantarctic fur seal rookeries are on islands off South America north of the Antarctic Convergence (Bastida *et al.*, 2007). During summer, pinnipeds are less likely to be caught as they stay close to breeding colonies, while fisheries' effort moves northward away from the coast (Figure 3a). In winter, the fishing effort is greater close to the coast (Figure 3a) in the Confluence area.

Marine mammal bycatch also showed marked interannual variability, with the highest value (Bcpue = 0.1225/1000 hooks) observed in 2002. This was also the year with highest seabird bycatch (Bcpue = 2.48 birds/1000 hooks) for the same fleet (Jiménez *et al.*, 2009). These high levels of bycatch in 2002 could have been due to the fact that the monitored vessels concentrated their fishing activities between 34° and 36°S and 52° and 53°W, where the highest Bcpue was usually observed.

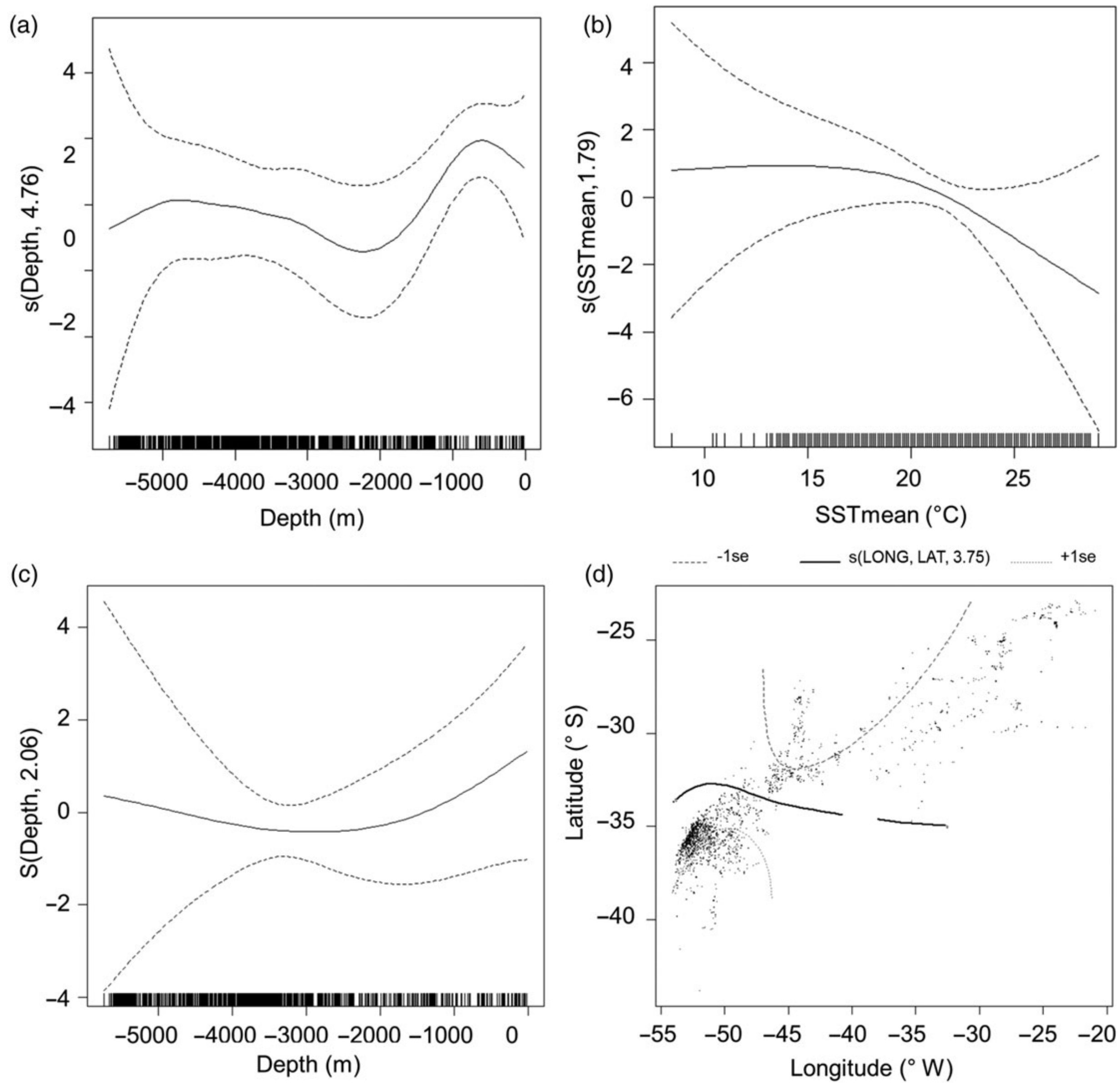

Figure 6. GAM-predicted smooth splines of the response variable presence/absence of bycatch as a function of the explanatory variables. In (a) and (b), the response is cetacean bycatch and the explanatory variables are depth of seabed and mean sea surface temperature, respectively. In (c) and (d), the response is pinnped bycatch and the explanatory variables are depth of seabed and the isotropic bivariate factor of longitude and latitude, respectively. The degrees of freedom for non-linear fits are in parentheses on the *y*-axis. Tick marks above the *x*-axis indicate the distribution of fishing events (with and without bycatch). Dotted lines represent the 95% confidence intervals of the smooth spline functions.

Influence of environmental and operational variables on bycatch

Due to the low frequency of occurrence of bycatch in the longline fleet and the failure to identify many of the captured individuals to species level, the occurrence of bycatch was modelled as a function of several explanatory variables considering all cetacean or all pinniped species together. According to the final GAMs, the bycatch of both groups was influenced by season and by position-related variables. Cetacean bycatch seems to be more frequent in the upper continental slope. Similarly, bycatch of pilot whales (*Globicephala* spp.) and Risso's dolphin (*Grampus griseus*) in the pelagic longline fishery in the US Atlantic Ocean was more frequent in sets close to the shelf brake (Garrison, 2007). Several species of pelagic cetaceans tend to concentrate over the continental slope of the SWAO (e.g. Zerbini *et al.*, 2004) probably to take advantage of the relatively higher local productivity associated with the shelf break compared with deeper oceanic water (Madureira and Rossi-Wongrshowski, 2005). Bycatch was higher in waters with sea surface temperature around 19.7°C (median), which corresponds to the northern boundary of the Brazil–Malvinas Confluence (Brandini *et al.*, 2000). This is similar to the temperature sought by skippers targeting swordfish (Mora, 1988). Although most pinnipeds' bycatch occurred in the lower continental slope, location (as a smoothed bivariate function of longitude and latitude) was an important factor for bycatch. The area of highest pinniped bycatch also coincides with the Brazil–Malvinas Confluence zone. This suggests that both the pinnipeds and the pelagic longline fishery are targeting the same dynamic oceanic areas, thus bycatch could be reduced if overlap with fishing vessels is minimized.

Since the bycatch of each species is likely determined by particular variables, a species-specific analysis would probably reveal the importance of other variables in explaining the occurrence of bycatch. The small proportion of bycatch occurrence explained by our models is probably because the influence of some potentially relevant variables could not be evaluated. For example, no data on bait type, depth of the hook, moon phase/cloud cover, and sea state (i.e. windspeed) were available for most of the sets. Bait type included Argentine squid, mackerels, and shark guts. According to the literature, fur seals, sea lions, and small dolphins would most likely eat squid or mackerel (e.g. Santos and Haimovici, 2000; Franco-Trecu *et al.*, 2012, 2013) instead of shark guts. The depth of the hook varies depending on its position on the longline, i.e. the closer to the buoy the shallower it will be. It is possible that air-breathing mammals would attempt to remove bait from hooks that are closer to the surface, thus increasing their chance of getting hooked (Donoghue *et al.*, 2003). The same rationale applies for the moon phases. During nights of full half-phase of the moon, the bait would be more easily detected than during the new moon half-phase, especially if hooks are in deeper waters. The latter is probably less relevant for echolocating cetaceans. Both moon phase and depth of the hook are variables that affect seabird and marine mammals interaction rates (e.g. Ashford and Croxall, 1998; Gilman *et al.*, 2005; Hernandez-Milian *et al.*, 2008). Sea state conditions may also affect the probability of marine mammals' bycatch, though no proper assessment has been made so far. Lastly, because some longline vessels have reported significantly higher frequency of interactions with marine mammals, it has been argued (e.g. Donoghue *et al.*, 2003) that the characteristics of the noise produced by such vessels might attract marine mammals. Although we acknowledge the potential role that these variables may play on the interaction probability, before a proper evaluation is made, their actual influence will remain hypothetical. Despite the necessary caution, the results presented here can be used as a starting point for evaluating and implementing certain marine mammal bycatch mitigation measures related to the observed spatio-temporal patterns of the bycatch.

The impact of longline on marine mammals

Our results suggest that the impact of longline fishery on marine mammals' populations is low compared with other Uruguayan fisheries. The estimated total bycatch of both cetaceans and pinnipeds by the entire longline fleet during this 12-year study was much lower than the annual mortality of marine mammals caused by Uruguayan artisanal gillnet fishery (mainly of Franciscana dolphin, *Pontoporia blainvillei*; Franco-Trecu *et al.*, 2009) or by the coastal trawl fleet (of Franciscana dolphin, South American sea lions, and South American fur seals; Szephegyi *et al.*, 2010). Only one unidentified pinniped died due to bycatch during the present study in Uruguayan longlines. All other incidentally caught marine mammals were released alive. The health condition of most animals was unknown, while others were injured. Although the fate of post-released animals is unknown, the mortality rate is presumably low, given that most animals, for which information was available, did not present evidence of serious injuries (i.e. line entanglement or superficial hooking). For olive Ridley sea turtle (*Lepidochelys olivacea*), survival of post-release individuals incidentally hooked in pelagic longline was not reduced (Swimmer *et al.*, 2006). Given the lack of empirical data on post-release survival of marine mammals incidentally caught in longline fisheries, the possibility that the impact is underestimated cannot be overlooked. Thus, a detailed record of the condition of the released animals (e.g. Andersen *et al.*, 2008) by the Uruguayan pelagic longline fleet is recommended for a better assessment of the potential impact of this fishery on marine mammals.

Furthermore, an essential issue still preventing an accurate assessment on the impact of human-caused threats such as fisheries (i.e. if mortality caused by fisheries exceeds sustainable removal levels; see Wade, 1998) and oil/gas exploration (which has recently begun within Uruguayan waters) is the lack of information on marine mammals' populations inhabiting the SWAO region. There are no estimates of the abundance of marine mammals inhabiting pelagic waters (except for South American sea lion; Páez, 2006); it is difficult to assess the potential impact of bycatch on the other species populations.

Final remarks

Several mitigation strategies to reduce the bycatch of marine mammals and other taxa in longlines have been already tested around the world (e.g. Donoghue *et al.*, 2003; Howell *et al.*, 2008; Forney *et al.*, 2011). Some of them could be adapted and tested in the Uruguayan fishery. Studies focusing on spatial patterns of bycatch of several taxa over long periods are useful to identify persistent areas of high bycatch where the application of mitigation strategies must be a priority. Particularly, in the SWAO, it is important to emphasize the importance of the continental shelf and slope for the pelagic longline fishery, which is also the area of the Brazil–Malvinas/Falkland Confluence. This area is a zone of high occurrence of bycatch of marine mammals, seabirds, sea turtles, and target species of the longline fleet (e.g. this study; Mora, 1988; Domingo *et al.*, 2007; López-Mendilaharsu *et al.*, 2007; Domingo *et al.*, 2009; Jiménez *et al.*, 2009; Fossette *et al.*, 2014). The bycatch analysis of all the taxa captured by longline fleet should be integrated to define the most effective mitigation strategies that could benefit several species at a time. In the case of cetaceans, the bycatch could be reduced by a decrease in the effort performed over the continental shelf break and slope. A mitigation measure like this could also benefit other species highly affected by this fishery such as albatrosses, petrels, and loggerhead turtles (see López-Mendilaharsu *et al.*, 2007; Jiménez *et al.*, 2009; Fossette *et al.*, 2014). A reduction on fishing effort in waters where the northern boundary of the Brazil–Malvinas Confluence occur could reduce the bycatch of pinnipeds, especially during winter. Nevertheless, it is crucial that the influence of other potentially relevant variables in determining the species-specific likelihood of bycatch, not evaluated in this study, is investigated prior to the implementation of mitigation strategies in a legal framework.

Supplementary data

Supplementary material is available at *ICESJMS* online.

Acknowledgements

Thanks to Gabriel Tomas for providing his fishing personal logbooks and to all PNOFA observers who collected the data used in this analysis. Fishing companies, skippers, and crews of the longline Uruguayan fleet that participated in the PNOFA. A. Segura helped in obtaining depth data, D. Monteiro collaborated with literature and scripts elaboration, and S. Weng helped with translation to English. Our fellows from Recursos Pelágicos (DINARA) shared their knowledge and experience, M. Pons assisted with statistical analysis. Anonymous reviewers made valuable comments to improve the manuscript. This is a contribution of Cetáceos Uruguay, CICMAR, Laboratorio de Recursos Pelágicos (DINARA), and the Research Group "Ecologia e Conservação da Megafauna Marinha-EcoMega/CNPq". CP received a scholarship from the Development Program of Basic Sciences (PEDECIBA) and the National Agency for Research and Innovation (ANII) to develop her master's thesis from which this work arises. ERS received a scholarship from CNPq (PQ 307843/2011–4 and PDE 229334/20113-0).

References

Acha, E. M., Mianzan, H. W., Guerrero, R. A., Favero, M., and Bava, J. 2004. Marine fronts at the continental shelves of austral South America physical and ecological processes. Journal of Marine Systems, 44: 83–105.

Alverson, D. L., Freeberg, M. H., Pope, J. G., and Murawski, S. A. 1994. A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper, 339. FAO, Rome. 233 pp. http://www.fao.org/docrep/003/t4890e/T4890E00.HTM.

Andersen, M. S., Forney, K. A., Cole, T. V. N., Eagle, T., Angliss, R., Long, K., and Barre, L., et al. 2008. Differentiating Serious and Non-Serious Injury of Marine Mammals: Report of the Serious Injury Technical Workshop, 10–13 September 2007, Seattle, Washington. US Dep. Commer., NOAA Technical Memo. NMFS-OPR-39. 94 pp.

Ashford, J. R., and Croxall, J. P. 1998. An assessment of CCAMLR measures employed to mitigate seabird mortality in longlining operations for *Dissostichus eleginoides* around South Georgia. CCAMLR Science, 5: 217–230.

Barré, N., Provost, C., and Saraceno, M. 2006. Spatial and temporal scales of the Brazil–Malvinas Current confluence documented by simultaneous MODIS Aqua 1.1-km resolution SST and color images. Advances in Space Research, 37: 770–786.

Bastida, R., Rodriguez, D., Secchi, E. R., and Da Silva, V. M. F., 2007. Mamíferos Acuáticos de Sudamérica y Antártida, 1st edn. Vazquez Mazzini Editores, Buenos Aires, 360 pp.

Brandini, F. P., Boltovskoy, D., Piola, A., Kocmur, S., Röttgers, R., Abreu, P. C., and Mendes Lopes, R. 2000. Multiannual trends in fronts and distribution of nutrients and chlorophyll in the southwestern Atlantic (30–62°S). Deep Sea Research I, 47: 1015–1033.

Brum, F. L., and Marín, Y. H. 2000. Interacciones entre mamíferos marinos y la pesquería de pez espada *Xiphias gladius* con palangres pelágicos en el Atlántico Sudoccidental. *In* Captura de grandes peces pelágicos (pez espada y atunes) en el Atlántico Sudoccidental y su interacción con otras poblaciones, pp. 89–96. Ed. by G. Arena, and M. Rey. INAPE, MGAP, PNUD, Montevideo.

Cañadas, A., Sagarminaga, R., and García-Tiscar, S. 2002. Cetacean distribution related with depth and slope in the Mediterranean waters off southern Spain. Deep Sea Research Part I: Oceanographic Research Papers, 49: 2053–2073.

Chocca, J. F., Marín, Y. H., and Barea, L. C. 2000. Evolución del palangre pelágico en la pesquería de pez espada y atunes en la flota uruguaya. *In* Captura de grandes peces pelágicos (pez espada y atunes) en el atlántico sudoccidental, y su interacción con otras poblaciones, pp. 7–17. Ed. by G. Arena, and M. Rey. Proyecto URU/92/003, ISBN 9974-563-15-1, 96 pp.

Corcuera, J., Monzón, F., Crespo, E. A., Aguilar, A., and Raga, J. A. 1994. Interactions between marine mammals and coastal fisheries of Necochea and Claromecó (Buenos Aires Province, Argentina). Reports of the International Whaling Commission Special Issue, 15: 283–290.

Cortés, E., Arocha, F., Beerkircher, L., Carvalho, F., Domingo, A., Heupel, M., Holtzhausen, H., *et al.* 2010. Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. Aquatic Living Resources, 23: 25–34.

Crespo, E. A., Corcuera, J., and López Cazorla, A. 1994. Interactions between marine mammals and fisheries in some fishing areas of the coast of Argentina. Gillnets and Cetaceans: Proceedings of the Symposium and Workshop on the Mortality of Cetaceans in Passive Fishing Nets and Traps. Reports of the International Whaling Commission Special Issue, 15: 283–290.

Crespo, E. A., Pedraza, S. N., Dans, S. L., Koen Alonso, M., Reyes, L. M., García, N. A., and Coscarella, M. 1997. Direct and indirect effects of the highseas fisheries on the marine mammal populations in the northern and central patagonian coast. Journal of Northwest Atlantic Fishery Science, 22: 189–207.

Dalla Rosa, L., and Secchi, E. R. 2007. Killer whale (*Orcinus orca*) interactions with the tuna and swordfish longline fishery off southern and southeastern Brazil: a comparison with shark interactions. Journal of the Marine Biological Association of the United Kingdom, 87: 135–140.

Dimitriadis, C., Abud, C., Costa, P., Franco, V., Laporta, P., and Piedra, M. 2006. Pesca de arrastre: un nuevo problema para la franciscana *Pontoporia blainvillei* en Uruguay. *In* Proceedings of the symposium: 1° Reunión Internacional sobre el Estudio de los Mamíferos Acuáticos; Merida-México, 5–9 November 2006. SOMEMMA-SOLAMAC.

Domingo, A., Forselledo, R., Miller, P., and Passadore, C. 2008. Plan de Acción Nacional para la Conservación de Condrictios en las pesquerías uruguayas, 1st edn. Dirección Nacional de Recursos Acuáticos, Montevideo, 88 pp.

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

Domingo, A., Mora, O., and Cornes, M. 2002. Evolución de las capturas de elasmobranquios pelágicos en la pesquería de atunes de Uruguay, con énfasis en los tiburones azul (*Prionace glauca*), moro (*Isurus oxyrinchus*) y porbeagle (*Lamna nasus*). Collective Volume of Scientific Papers ICCAT, 54: 1406–1420.

Domingo, A., Mora, O., Pons, M., Miller, P., and Pereyra, G. 2007. Análisis de la CPUE y la composición de tallas del SWO (*Xiphias gladius*), capturado por la Flota Uruguaya (2001–2005) en el Atlántico SW. Collective Volume of Scientific Papers ICCAT, 60: 1953–1963.

Domingo, A., and Pons, M. 2011. Análisis de la captura, distribución y composición de tallas de la aguja azul, *Makaira nigricans*, observada en la flota de palangre uruguaya (1998–2009). Collective Volume of Scientific Papers ICCAT, 66: 1715–1724.

Domingo, A., Pons, M., Jiménez, S., Miller, P., Barceló, C., and Swimmer, Y. 2012. Circle hook performance in the Uruguayan pelagic longline fishery. Bulletin of Marine Science, 88: 499–511.

Domingo, A., Rios, M., and Pons, M. 2009. Spatial and temporal distribution, size and sex composition of yellowfin tuna (*Thunnus albacares*) in the southwest Atlantic Ocean. Collective Volume of Scientific Papers ICCAT, 64: 999–1010.

Donoghue, M., Reeves, R. R., and Stone, G. 2003. Report of the workshop on interactions between cetaceans and longline fisheries held in Apia, Samoa, November 2002. New England Aquarium Aquatic Forum Series Report, 03-1: 1–44.

Dulvy, N. K., Baum, J. K., Clarke, S., Compagno, L. J. V., Cortés, E., Domingo, A., Fordham, S., *et al.* 2008. You can swim but you can't hide: the global status and conservation of oceanic pelagic sharks and rays. Aquatic Conservation: Marine and Freshwater Ecosystems, 18: 459–482.

Forney, K. A., Kobayashi, D. R., Johnston, D. W., Marchetti, J. A., and Marsik, M. G. 2011. What's the catch? Patterns of cetacean bycatch and depredation in Hawaii based pelagic longline fisheries. Marine Ecology, 32: 380–391.

Forselledo, R., Pons, M., Miller, P., and Domingo, A. 2008. Distribution and population structure of the pelagic stingray, *Pteroplatytrygon violacea* (Dasyatidae), in the south-western Atlantic. Aquatic Living Resources, 21: 357–363.

Fossette, S., Witt, M. J., Miller, P., Nalovic, M. A., Albareda, D., Almeida, A. P., Broderick, A. C., *et al.* 2014. Pan-Atlantic analysis of the overlap of a highly migratory species, the leatherback turtle, with pelagic longline fisheries. Proceedings of the Royal Society B: Biological Sciences, 281. doi: 10.1098/rspb.2013.3065

Fowler, S. L., Cavanagh, R. D., Camhi, M., Burguess, G. H., Cailliet, G. M., Fordham, S. V., and Simpfendorfer, C. A., et al. 2005. Sharks, Rays and Chimaeras: The Status of the Chondrichthyan Fishes. IUCN/SSC Shark Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. x + 461 pp.

Franco-Trecu, V., Aurioles-Gamboa, D., Arim, M., and Lima, M. 2012. Prepartum and postpartum trophic segregation between sympatrically breeding female *Arctocephalus australis* and *Otaria flavescens*. Journal of Mammalogy, 93: 514–521.

Franco-Trecu, V., Costa, P., Abud, C., Dimitriadis, C., Laporta, P., Passadore, C., and Szephegyi, M. 2009. By-catch of Franciscana *Pontoporia blainvillei* in Uruguay artisanal gillnet fisheries: an evaluation after a twelve-year gap in data collection. Latin American Journal of Aquatic Mammals, 71: 11–22.

Franco-Trecu, V., Drago, M., Riet-Sapriza, F. G., Parnell, A., Frau, R., and Inchausti, P. 2013. Bias in diet determination: incorporating traditional methods in Bayesian mixing models. PLoS ONE, 8: e80019. doi:10.1371/journal.pone.0080019

Gardner, B., Sullivan, P. J., Morreale, S. J., and Epperly, S. P. 2008. Spatial and temporal statistical analysis of bycatch data: patterns of sea turtle bycatch in the North Atlantic. Canadian Journal of Fisheries and Aquatic Sciences, 65: 2461–2470.

Garrison, L. P. 2007. Interactions between marine mammals and pelagic longline fishing gear in the U.S. Atlantic Ocean between 1992 and 2004. Fishery Bulletin, 1005: 408–417.

Gilman, E., Brothers, N., and Kobayashi, D. R. 2005. Principles and approaches to abate seabird by-catch in longline fisheries. Fish and Fisheries, 6: 35–49.

Hall, M. A., Alverson, D. L., and Metuzals, K. I. 2000. By-catch: problems and solutions. Marine Pollution Bulletin, 41: 204–219.

Hastie, T. J., and Tibshirani, R. J. 1990. Generalized Additive Models. Chapman and Hall, London, New York.

Hernandez-Milian, G., Goetz, S., Varela-Dopico, C., Rodriguez-Gutierrez, J., Romón-Olea, J., Fuertes-Gamundi, J. R., Ulloa-Alonso, E., *et al.* 2008. Results of a short study of interactions of cetaceans and longline fisheries in Atlantic waters: environmental correlates of catches and depredation events. Hidrobiología, 612: 251–268.

Howell, E. A., Kobayashi, D. R., Parker, D. M., Balazs, G. H., and Polovina, J. J. 2008. TurtleWatch: a tool to aid in the bycatch reduction of loggerhead turtles *Caretta caretta* in the Hawaii-based pelagic longline fishery. Endangered Species Research, 5: 267–278.

Jiménez, S., Abreu, M., Pons, M., Ortiz, M., and Domingo, A. 2010. Assessing the impact of the pelagic longline fishery on albatrosses and petrels in the southwest Atlantic. Aquatic Living Resources, 23: 49–64.

Jiménez, S., Domingo, A., Abreu, M., and Brazeiro, A. 2012. Risk assessment and relative impact of Uruguayan pelagic longliners on seabirds. Aquatic Living Resources, 25: 281–295.

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

Lewison, R. L., Crowder, L. B., Read, A. J., and Freeman, S. A. 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends in Ecology and Evolution, 19: 598–604.

Lewison, R. L., Soykan, C. U., and Franklin, J. 2009. Mapping the bycatch seascape: multispecies and multi-scale spatial patterns of fisheries bycatch. Ecological Applications, 19: 920–930.

López-Mendilaharsu, M., Sales, G., Giffoni, B., Miller, P., Maurutto, G., and Domingo, A. 2007. Distribución y composición de tallas de las tortugas marinas (*Caretta caretta* y *Dermochelys coriacea*) que interactúan con el palangre pelágico en el Atlántico Sur. Collective Volume of Scientific Papers ICCAT, 60: 2094–2109.

Madureira, L. S., and Rossi-Wongrshowski, C. L. D. B. 2005. Prospecção de recursos pesqueiros pelágicos na Zona Econômica Exclusiva da região sudeste-sul do Brasil: hidroacústica e biomassas. Série de Documentos Revizee-Score Sul. 144 pp.

Manly, B. F. J. 1997. Randomization, Bootstrap and Monte Carlo Methods in Biology, 2nd edn. Chapman and Hall, London, UK.

Marín, Y. H., Brum, F., Barea, L. C., and Chocca, J. F. 1998. Incidental catch associated with swordfish longline fisheries in the south-west Atlantic Ocean. Marine and Freshwater Research, 49: 633–639.

Mora, O. 1988. Descripción de pesquería de pez espada. Collective Volume of Scientific Papers ICCAT, 27: 283–286.

Mora, O., and Domingo, A. 2006. La Flota Atunera Uruguaya: Evolución y Tendencias (1981–2004). Collective Volume of Scientific Papers ICCAT, 59: 608–614.

Neves, T., and Olmos, F. 1998. Albatross mortality in fisheries off the coast of Brazil. *In* Albatross Biology and Conservation, pp. 214–219. Ed. by G. Robertson, and R. Gales. Surrey Beatty & Sons, Chipping Norton.

Northridge, S. P., and Hofman, R. J. 1999. Marine mammal interactions with fisheries. *In* Conservation and Management of Marine Mammals, pp. 99–119. Ed. by J. R. Twiss, Jr., and R. R. Reeves, Smithonian Institution Press, Washington, DC.

Ortega, L., and Martinez, A. 2007. Multiannual and seasonal variability of water masses and fronts over the Uruguayan shelf. Journal of Coastal Research, 23: 618–629.

Páez, E. 2006. Situación de la administración del recurso lobos y leones marinos en Uruguay. *In* Bases para la conservación y el manejo de la costa uruguaya, pp. 577–583. Ed. by R. Menafra, L. Rodríguez-Gallego, F. Scarabino, and D. Conde, Vida Silvestre, Sociedad Uruguaya para la Conservación de la Naturaleza, Montevideo.

Passadore, C., Szephegyi, M., and Domingo, A. 2008. Presencia de mamíferos marinos y captura incidental en la flota uruguaya de palangre pelágico (1998–2007). Collective Volume of Scientific Papers ICCAT, 62: 1851–1857.

Pons, M., Domingo, A., Sales, G., Niemeyer, F., Miller, P., Giffoni, B., and Ortiz, M. 2010. Standardization of CPUE of loggerhead sea turtle (*Caretta caretta*) caught by pelagic longliners in the Southwestern Atlantic Ocean. Aquatic Living Resources, 23: 65–75.

R Development Core Team. 2008. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org (last accessed February 2014).

Ramos-Cartelle, A., and Mejuto, J. 2008. Interaction of the false killer whale (*Pseudorca crassidens*) and depredation on the swordfish catches of the Spanish surface longline fleet in the Atlantic, Indian and Pacific Oceans. Collective Volume of Scientific Papers ICCAT, 62: 1721–1738.

Read, A. J. 2005. Bycatch and depredation. *In* Marine Mammal Research: Conservation Beyond Crisis, pp. 5–17. Ed. by J. E. Reynolds, W. F. Perrin, R. R. Reeves, S. Montgomery, and T. J. Ragen. Johns Hopkins University Press, Baltimore, MD.

Read, A. J., Drinker, P., and Northridge, S. 2006. Bycatch of marine mammals in U.S. and global fisheries. Conservation Biology, 20: 163–169.

Reeves, R. R., Smith, B. D., Crespo, E. A., and Notarbartolo di Sciara, G. (compilers). 2003. Dolphins, Whales and Porpoises: 2002–2010 Conservation Action Plan for the World's Cetaceans. IUCN/SSC Cetacean Specialist Group, 1st edn. IUCN, Gland, Switzerland and Cambridge, UK. 139 pp. http://app.iucn.org/dbtw-wpd/edocs/2003-009.pdf (last accessed September 2011).

Robertson, G., and Gales, R. 1998. Albatross Biology and Conservation, 1st edn. Surrey Beatty & Sons, Chipping Norton. 300 pp.

Sales, G., Giffoni, B., and Barata, P. 2008. Incidental catch of sea turtles by the Brazilian pelagic longline fishery. Journal of the Marine Biological Association of the United Kingdom, 88: 853–864.

Santos, R. A., and Haimovici, M. 2000. The Argentine short-finned squid *Illex argentinus* in the food webs of southern Brazil. Sarsia, 85: 49–60.

Secchi, E. R. 2010. Review on the threats and conservation status of franciscana, *Pontoporia Blainvillei* (Cetacea, Pontoporiidae). *In* Biology, Evolution and Conservation of River Dolphins within South America and Asia, pp. 323–339. Ed. by M. Ruiz-Garcia, and J. M. Shostell. Nova Science Publishers, Inc., Hauppange, New York.

Secchi, E. R., Kinas, P. G., and Muelbert, M. 2004. Incidental catches of franciscana in coastal gillnet fisheries in the Franciscana Management Area III: period 1999–2000. The Latin American Journal of Aquatic Mammals, 3: 61–68.

Secchi, E. R., and Vaske, T., Jr. 1998. Killer whale (*Orcinus orca*) sightings and depredation on tuna and swordfish longline catches in southern Brazil. Aquatic Mammals, 24: 117–122.

Sims, M., Cox, T., and Lewison, R. 2008. Modeling spatial patterns in fisheries bycatch: improving bycatch maps to aid fisheries management. Ecological Applications, 18: 649–661.

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

Swimmer, Y., Arauz, R., McCracken, M., McNaughton, L., Musyl, M., Ballestero, J., Bigelow, K., *et al.* 2006. Survivorship and dive behavior of olive Ridley (*Lepidochelys olivacea*) sea turtles after their release from longline fishing gear off Costa Rica. Marine Ecology Progress Series, 323: 253–261.

Szephegyi, M. N., Franco-Trecu, V., Doño, F., Reyes, F., Forselledo, R., and Crespo, E. A. 2010. Primer relevamiento sistemático de captura incidental de mamíferos marinos en la flota de arrastre de fondo costero de Uruguay. *In* Proceedings of the symposium: XIV Reunión de Trabajo de especialistas en mamíferos acuáticos de América del Sur; Florianópolis, Brazil, 24–28 October 2010. SOLAMAC.

Tuck, G. N., Polachek, T., Croxall, J. P., and Weimerskirch, H. 2001. Modelling the impact of fishery by-catches on albatross populations. Journal of Applied Ecology, 38: 1182–1196.

Tynan, C. T., Ainley, D. G., Barth, J. A., Cowles, T. J., Pierce, S. D., and Spear, L. B. 2005. Cetacean distribution relative to ocean processes in the northern California Current System. Deep Sea Research, 52(II): 145–167.

Wade, P. R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Marine Mammal Science, 14: 1–37.

Wood, S. N. 2006. Generalized Additive Models: an Introduction with R. Chapman and Hall/CRC, Boca Raton, Florida.

Wood, S. N., and Augustin, N. H. 2002. GAMs with integrated model selection using penalized regression splines and applications to environmental modeling. Ecological Modelling, 157: 157–177.

Zerbini, A. N., Secchi, E. R., Bassoi, M., Dalla Rosa, L., Higa, A., Sousa, L., Moreno, I. B., *et al.* 2004. Distribução e abundância relativa de cetáceos na Zona Econômica Exclusiva da região sudeste-sul do Brasil. Série de Documentos Revizee-Score Sul. 40 pp.

Zuur, A. F., Ieno, E. N., and Elphick, C. S. 2010. A protocol for data exploration to avoid common statistical problems. Methods in Ecology and Evolution, 1: 3–14.

Žydelis, R., Wallace, B. P., Gilman, E. L., and Werner, T. B. 2009. Conservation of marine megafauna through minimization of fisheries bycatch. Conservation Biology, 23: 608–616.

Handling editor: Simon Northridge