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Influence of environmental and longline fishing operational variables on the presence of killer whales (*Orcinus orca*) in south-western Atlantic

CECILIA PASSADORE[1,2,4], ANDRÉS DOMINGO[2], MARÍA SZEPHEGYI[1] AND EDUARDO R. SECCHI[3]

[1]Proyecto ODAS/Cetáceos Uruguay, Iguá 4225, P.C. 11400, Sección Etología–Facultad de Ciencias, Universidad de la República, Montevideo, Uruguay, [2]Recursos Pelágicos, Dirección Nacional de Recursos Acuáticos, Montevideo, Uruguay, [3]Laboratório de Tartarugas e Mamíferos Marinhos, Instituto de Oceanografia, Universidade Federal do Rio Grande, Rio Grande do Sul, Brazil, [4]ONG CICMAR, (Centro de Investigación y Conservación Marina), El Pinar, Uruguay

*Killer whale (*Orcinus orca*) is frequently encountered in coastal and high productive pelagic waters, near the shelf break. In the south-western Atlantic Ocean, spatial and temporal occurrence patterns are poorly known. However, the monitoring of the interaction between killer whales and longline fishery suggests that the species is frequent in this region. We analysed the killer whale presence within the Uruguayan pelagic longline fishing zone. Data were collected from 1996 to 2007, during 2189 fishing events, by vessel skippers and on-board observers. We estimated the sighting rate (SR = sightings days/fishing days * 100) for different time scales and in 1 × 1 degree grids. Generalized linear models were used to evaluate the effect of spatial, temporal, environmental and operational variables on the species presence. Killer whales were sighted in 100 fishing days (SR = 4.5%), this occurrence being explained by distance from shore and sea surface temperature, varying among months and fishing boats. Although sightings occurred year round, they were more frequent in autumn and winter, at 150–400 nautical miles (nm) from shore (mean = 250 nm) and in waters with temperatures ranging from 19 to 24°C (mean = 22°C). Sets took place between 19°–40°S and 21°–54°W, while killer whales occurred mostly from 34°–37°S and 48°–53°W. In this region, the high productive Brazil—Malvinas Confluence Zone is located, and concentrates fishing effort and also killer whales.*

Keywords: killer whales, *Orcinus orca*, distribution, south-western Atlantic, longline fishery, fishing practices, environmental variables

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INTRODUCTION

The geographical distribution and the use that species make of different habitats depend, basically, on the combination of their requirements and tolerances (Grémillet *et al.*, 2004; Guisan & Thuiller, 2005). Killer whale, *Orcinus orca* (Linnaeus, 1758), is considered a cosmopolitan species. It is more frequently encountered in coastal areas and continental borders, especially in high latitudes (Heyning & Dahlheim, 1988). In pelagic waters, the species is more abundant in high productive areas, near the shelf break (Forney & Wade, 2007). The temporal pattern also varies regionally. In some places killer whales occur year round while in others they are seasonal (Heyning & Dahlheim, 1988). Particularly, on the south-western Atlantic Ocean coast, reports of killer whales increased towards the south (Heyning & Dahlheim, 1988; Bastida *et al.*, 2007; Dalla Rosa & Secchi, 2007). Previous studies in this coastal region, identified a seasonal population of less than 30 individuals in northern Patagonia (Argentina), and suggested the existence of two other populations, one inhabiting the vicinity of the Falkland/Malvinas Islands and the other along the northern Argentinean coast. The latter would be the same that occurs in Uruguay and southern Brazil, according to data based on the saddle patch pattern (Iñíguez *et al.*, 1994). Along the Uruguayan and Brazilian coast, up to the northernmost record of killer whales (0°55′N 29°20′W: Dalla Rosa *et al.*, 2007), reports of this species are based on strandings (e.g. Ott & Danilewicz, 1998; Dalla Rosa *et al.*, 2007; Iriarte, unpublished data) and occasional sightings, mainly during spring and summer (Lodi & Hetzel, 1998; Siciliano *et al.*, 1999; Pinedo *et al.*, 2002; Zerbini *et al.*, 2004; Iriarte, 2006; Dalla Rosa *et al.*, 2007). In the adjacent open ocean, records come from studies on the interaction between cetaceans and pelagic longline fisheries, which indicate the occurrence of the species in Uruguayan and Brazilian Exclusive Economic Zones (EEZs) and international waters, particularly over the shelf break and continental slope, during winter and spring (Secchi & Vaske Jr, 1998; Brum & Marín, 2000; Dalla Rosa & Secchi, 2007; Dantas, 2007; Passadore *et al.*, 2007; Monteiro, 2008; Hernandez-Milian *et al.*, 2008).

Generally, primary production is high in frontal areas, playing a key role in ecological processes, concentrating

Corresponding author:
C. Passadore
Email: cecipass8@gmail.com

marine biomass (Acha *et al.*, 2004; Palacios *et al.*, 2006; Alemany *et al.*, 2009), which leads to a significant food supply and/or possible suitable breeding habitats for many nektonic species, such as fish and squid, as well as their predators, including fisheries (Acha *et al.*, 2004; Sinclair *et al.*, 2005). Cetaceans are highly mobile and have high energy requirements, so their presence is often associated directly with environmental variables such as ocean fronts of high primary productivity, which tend to concentrate their prey (Tynan *et al.*, 2005; Kaschner *et al.*, 2006). As previously mentioned, killer whales are not randomly distributed in the ocean and its distribution may be related to several factors such as water temperature (Sinclair *et al.*, 2005) or the availability and distribution of their prey (López & López, 1985; Heyning & Dahlheim, 1988; Iñíguez, 2001; Pitman & Ensor, 2003; Ford *et al.*, 2010; Reisinger *et al.*, 2011). For example, the individuals of North Patagonia, make seasonal movements associated to increases in the availability of prey, hence, according to the calving periods of sea lions (*Otaria flavescens)* and elephant seals (*Mirounga leonina*) (Iñíguez, 2001). In addition, previous studies suggest that the presence of killer whales in the south-western Atlantic would be linked to areas of high productivity (Lodi & Hetzel, 1998; Siciliano *et al.*, 1999) and fronts (Passadore *et al.*, 2007). Therefore, marine fronts should be considered in ecological studies seeking to understand the feeding and reproductive strategies of populations, to integrate biological and physical processes (Acha *et al.*, 2004; Alemany *et al.*, 2009).

Killer whale forms small populations, which show substantial differences in feeding habits, behaviour, genetics, morphology, movement patterns and demography, including sympatric populations that do not interact between them (e.g. Baird *et al.*, 1992; Matkin & Sautilis, 1994; Hoelzel *et al.*, 1998; Baird, 2000; Ford, 2002). The understanding of spatial and temporal patterns of killer whale occurrence in the south-western Atlantic Ocean and the identification of high occurrence areas is needed. Such information is essential for estimating abundance and demographic parameters and, eventually, for evaluating the potential threats and the conservation status of the populations. Besides, the effect of environmental variables or fishing operations on the presence of this species remains unknown.

The identification of areas and periods of major occurrence can be achieved through fishermen data, especially because they cover a large open ocean area and, in many cases, also a large time scale (e.g. Irish *et al.*, 2002). As killer whales seem to recognize and follow longlining boats to eat their catch, adversely affecting the fishery (Donoghue *et al.*, 2002), many fishermen are recording the depredation events as well as the presence of killer whales within their fishing grounds.

Our hypothesis for the present work is that killer whale occurrence will be higher in areas of high primary production such as fronts and eddies, because these areas tend to concentrate prey. Our second hypothesis is that killer whales might detect fishing vessels and predate upon their capture, therefore, the presence of the species in the south-western Atlantic will also be related to operational characteristics of the fisheries. The main objectives of this study were to: (1) determine the spatial and temporal distribution of killer whales within the Uruguayan pelagic longline fishing ground; and (2) assess the potential effect of environmental and fishing operational variables on killer whale presence.

MATERIALS AND METHODS

Study area

Data collected by Uruguayan pelagic longline fishing vessels included the Uruguayan EEZ and international waters, from 19° to 40°S and 21° to 54°W, including shelf brake, continental slope and deep waters of the south-western Atlantic Ocean (Figure 1). This region is characterized mainly by a northern subtropical zone, dominated by warm waters from the Brazil Current (average temperatures of 22–23°C) and a southern zone, dominated by sub-Antarctic waters from the Falkland/Malvinas Current (average temperatures of 6°C) (Brandini *et al.*, 2000). Where these two currents converge, a mixture zone occurs, the Brazil–Malvinas Confluence, which moves seasonally between 30°–50°S and 40°–60°W. Temperature in the confluence decreases southward, ranging from 19–20°C in the north to 8–9°C in the south (Olson *et al.*, 1988; Brandini *et al.*, 2000; Acha *et al.*, 2004; Barré *et al.*, 2006). In addition, in the south-western margin of the Atlantic Ocean between 30° and 41°S, there are several nutrient inputs, mainly from the Rio de la Plata (35°–36°S) and Patos Lagoon (30°–32°S) estuaries (Acha *et al.*, 2004; Braga *et al.*, 2008).

Data collection

Data were collected by skippers in their logbooks, between 1996 and 2006, and by scientific observers from the National Observer Programme of the Tuna Fleet (*Programa de Observadores a bordo de la flota atunera*, PNOFA), between 1998 and 2007. This fleet uses American monofilament or Spanish multifilament longline and targets mainly tuna (*Thunnus obesus*, *T. albacares* and *T. alalunga*), swordfish (*Xiphias gladius*) and pelagic sharks such as blue shark (*Prionace glauca*) (Domingo *et al.*, 2002; Mora & Domingo, 2006).

For each fishing day the following were recorded: killer whale presence/absence and number of individuals whenever possible, date, start and end time of setting and hauling of the longline, geographical position (latitude and longitude) at the beginning of the set and sea surface temperature (SST; minimum and maximum), measured *in situ* with boat

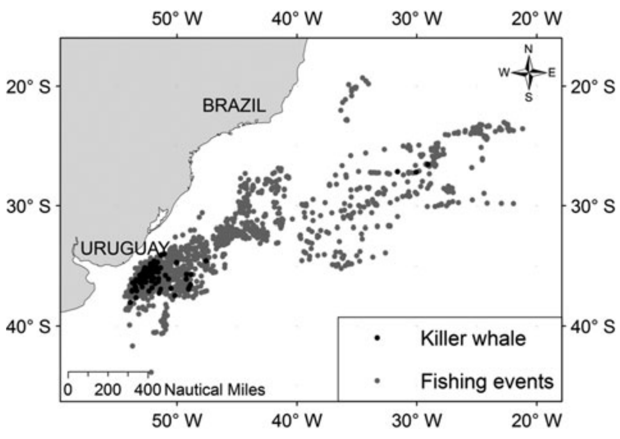

Fig. 1. Location of the fishing days with killer whale sightings (black dots) and without sightings (grey dots) of the Uruguayan surface longline fleet monitored by skippers and observers during the period 1996–2007.

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thermometer every time a radio-buoy was set or hauled. The SST variation was calculated from the maximum and minimum temperature recorded *in situ*, and could be used as an indicator of the presence of a SST front along the fishing haul. We determined the duration of the set as the time between the end of the set and the end of the haul. Each season was established according to the day of start of the set as: winter (from 22 June to 21 September); spring (from 22 September to 21 December); summer (from December 22 to 21 March); and autumn (from 22 March to 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). The slope of each set was then calculated as the difference between the deepest and the shallowest points of the start/end of the setting.

Data analysis

We selected only those surveys for which skippers or observers were trained in the identification of killer whales, and when they performed a complete record of the species presence/absence and the variables considered relevant for the analysis. When the hauling manoeuvre was carried out during daylight involving an observer on the deck, or a skipper on the bridge, it was considered as a day of sighting effort. Among these, a sighting was considered as a day of sighting effort when one or more killer whales were observed directly at least once. For the modelling analysis it was not considered the number of individuals recorded per day of effort, mainly because this information was not always recorded.

We determined the killer whale occurrence in relation to the sighting effort and compared among different spatial and temporal scales. To do so, we defined the sighting rate (SR) as follows:

$$SR = SD/FD * 100$$

where SD is the number of days with at least one sighting and FD the number of days of sighting effort. This rate was calculated for the entire fishing ground, considering two different time scales (annual and monthly), and in 1×1 degree grids (total and accumulated seasonally).

Generalized Linear Models (GLM; McCullagh & Nelder, 1989) were used to evaluate the effect of spatial, temporal, environmental and fishing operational variables on the killer whale presence. In GLMs, the occurrence of killer whales (Yi: binomial distribution; 1 = presence and 0 = absence) was analysed as a function of the explanatory variables considered as relevant *a priori* for this species (see Table 1 for description). The models were constructed using stepwise process and following the selection criteria of the Akaike information criterion (AIC) as described in Marques & Buckland (2003). Model selection was based on $\Delta AICi$ values lower than 2, calculated as the difference between the AIC values for each model and the model with lowest AIC (Burnham & Anderson, 2002). For the final models with $\Delta AICi$ values lower than 2 the explained deviance was determined (D^2 = (Null Deviance-Residual Deviance)/Null Deviance * 100), which corresponds to the percentage of data deviance explained by the selected models in relation to the null model that do not contain explanatory variables. Finally, the model with the lowest AIC was selected to

Table 1. List of explanatory variables included in generalized linear models to model the occurrence of killer whales (binary response variable) in the south-western Atlantic detected by the Uruguayan longline fishery. The name of each variable entered into the models, description of each one, type and levels of the categorical variables are presented.

Name	Variable description	Type of variable	Levels of variables
Location			
COAST	Distance between the position of the beginning of the set and the coastline (nautical miles × 10^2)	Continuous	
DEPTH	Average depth between the beginning and the end of the set (metres)	Continuous	
SLOPE	Slope between the beginning and the end of the set (metres)	Continuous	
Time			
YEAR	Year of fishing day	Categorical	1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007
SEAS	Season of fishing day	Categorical	summer, autumn, winter, spring
MONTH	Month of fishing day	Categorical	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
Fishing operations			
BOAT	Code assigned to each fishing boat	Categorical	1, 3, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 21
GEAR	Fishing strategy related to gear type	Categorical	1: American monofilament, 2: Spanish multifilament
SET	Duration of the set, between the end of the set of the longline and the end of the haul (hours)	Continuous	
DUR	Duration of the survey, as the number of effective fishing days	Continuous	
Environment			
SSTMax	Maximum sea surface temperature of the set (°C)	Continuous	
SSTMin	Minimum sea surface temperature of the set (°C)	Continuous	
SSTd	Variation of the sea surface temperature along the set (°C) (SSTMax–SSTMin)	Continuous	
OBS	Code assigned to each observer/skipper	Categorical	1, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 20

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explain the occurrence of killer whales. Statistical analysis was performed using the free software R (R Development Core Team, 2008).

RESULTS

Spatial and temporal distribution of killer whales

In general, the 2189 fishing events monitored between 1996 and 2007 (875 by skippers and 1313 from PNOFA observers) were performed in the area comprised between 19° and 40°S and 21° and 54°W (Figure 1). This effort corresponds to the 22.2% of the total fishing events made by the fleet. Killer whales were sighted in 100 of these 2189 fishing days (SR = 4.5%) and occurred mainly between the latitudes 34°–37°S and the longitudes 48°–53°W, except for three sightings that occurred at 27°–28°S, between 28° and 31°W (Figure 1).

The highest sighting rates were recorded in the grids between 35°–36°S and 51°–53°W and the species was present in nearly 10% of the sets in the grids between 33°S–50°W and 34°S–47°W (Figure 2B).

The group size was recorded in only 38% of the sightings, which corresponds to 34 records by observers and only three by skippers. The group size of two individuals was the most frequently recorded (31%), followed by groups of three and one whale. Though groups composed of up to 15 individuals were also observed (Figure 3).

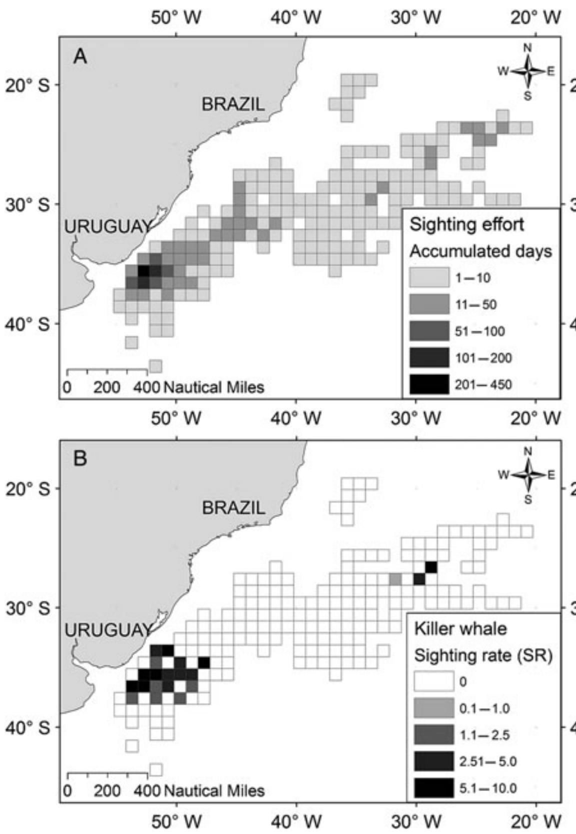

Fig. 2. Accumulated sighting effort (A) and sighting rate (SR = sightings days/fishing days * 100) for killer whales (B) in areas of 1 × 1 degree for the period 1996–2007.

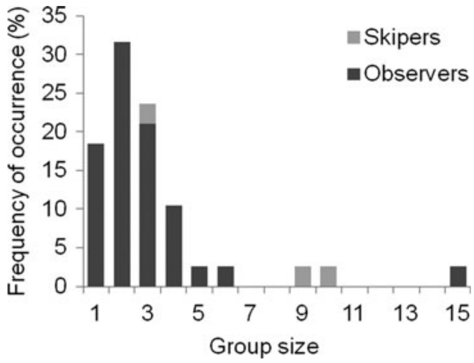

Fig. 3. Killer whale groups sighted by skippers and observers of the Uruguayan surface longline fleet in the south-western Atlantic (N = 38). The frequency of occurrence (%) of the number of individuals per group is shown.

Killer whale presence was reported for all surveyed years (1996–2007), except in 1999 coinciding with a low number of fishing days monitored (Table 2). The maximum sighting rate occurred in 1996 and has remained stable since 2004 (Table 2).

The highest sighting rate, for the whole study period accumulated, occurred during autumn (SR = 8.1), mainly in April (Table 3), and followed by winter (SR = 4.2), when it was about fourfold higher than spring and summer (2.3 and 2.6, respectively). Sightings were very low from December to February, with no records of killer whales in January, despite the large number of fishing events surveyed throughout the study period (Table 3).

Within the area comprising 35°–36°S and 51°–53°W, the SR remained relatively high along seasons (Figure 4). Furthermore, the species was also present in the vicinity of that area during autumn, winter and spring (Figure 4A, B, C), while in summer, only few sightings were made northward and very far from the coast (Figure 4D), but it is worthwhile noting that the total number of fishing days was very low in these quadrants (Figure 2A).

Environmental and operational variables explaining killer whale presence

After excluding fishing events with missing data on vessels identity (N = 158) and set duration (N = 136), a total of

Table 2. Total number of fishing days (FD) and days with presence of killer whales (SD) for the period 1996–2007, recorded by skippers and observers. The sighting rate (SR = SD/FD * 100) of killer whales per year is presented.

Year	FD	SD	SR (%)
1996	120	17	14.167
1997	73	1	1.370
1998	174	16	9.195
1999	11	0	0.000
2000	72	4	5.556
2001	162	6	3.704
2002	291	7	2.405
2003	240	6	2.500
2004	244	9	3.689
2005	290	12	4.138
2006	199	8	4.020
2007	312	14	4.487
TOTAL	2188	100	4.570

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Table 3. Monthly number of fishing days (FD) and days with presence of killer whales (SD) accumulated for the period 1996–2007, recorded by skippers and observers. The sighting rate (SR = SD/FD * 100) of killer whales per month is presented.

Month	FD	SD	SR (%)
1	116	0	0.000
2	166	2	1.205
3	197	10	5.076
4	231	29	12.554
5	254	14	5.512
6	147	8	5.442
7	153	7	4.575
8	238	12	5.042
9	223	11	4.933
10	158	1	0.633
11	193	5	2.591
12	112	1	0.893

1877 fishing events were included in the analysis to model the occurrence of killer whales in the south-western Atlantic. Exploratory analysis indicated a strong correlation between SSTMax and SSTMin ($R^2 = 0.864$). Lack of or weak correlation was found between SSTd and SSTMax ($R^2 = 0.019$) and between SSTd and SSTMin ($R^2 = 0.243$). Hence, the variable SSTMax was never included together with SSTMin to build the models. No correlation was found between any pair of the remaining variables which were, therefore, included in the model. Among the 62 models generated, only seven presented ΔAIC values lower than 2 and all of them explained approximately 23% of the deviance of the data (Table 4). The model that best explains (lowest AIC) the occurrence of killer whales included the following explanatory variables: boat, distance from shore, month and maximum SST. Among all the variables of the selected model, distance from shore and maximum SST showed a significant contribution (Table 5).

In the south-western Atlantic, the killer whales observed by skippers and observers of the longline fishing vessels are found mainly at distances from the coast varying between 150 and 400 nm (average = 250 nautical miles (nm)), in waters with temperatures ranging between 19 and 24°C (average = 22°C) (Table 5; Figure 5). According to the Akaike criterion, the GLMs indicate that the presence of killer whales is also influenced by the vessel and the month. However, these variables were not significant for the adjustment of the data (Table 5).

DISCUSSION

The non-systematic surveys with opportunistic records of cetaceans made by skippers and trained observers generate a large database with high spatial and temporal coverage (e.g. Hernandez-Milian *et al.*, 2008). The present study provides the first comprehensive information on killer whale distribution and sighting frequency for the south-western Atlantic Ocean. Despite possible biases, considering data are

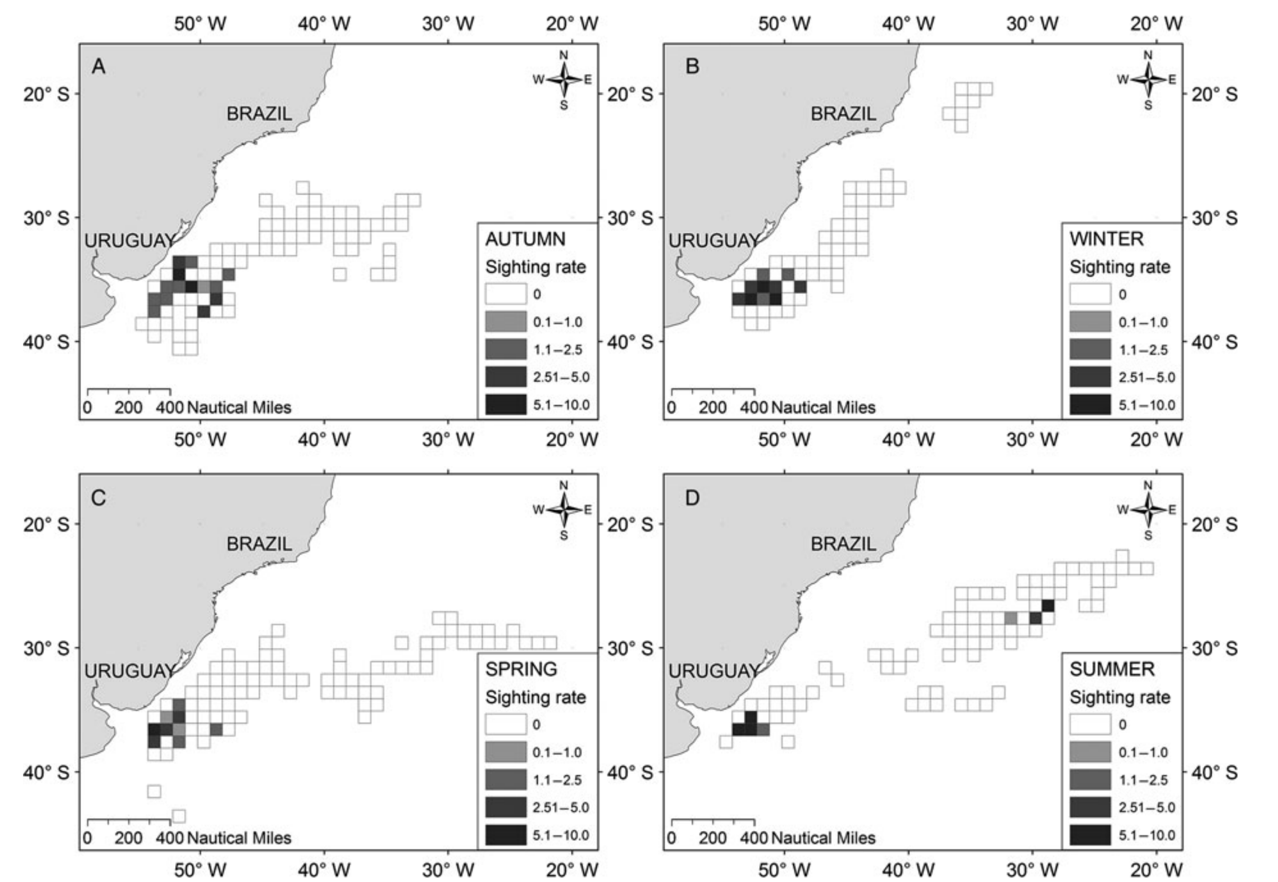

Fig. 4. Killer whales sighting rate (SR = sightings days/fishing days * 100) in areas of 1 × 1 degree accumulated seasonally for the period 1996–2007: (A) autumn; (B) winter; (C) spring; (D) summer.

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Table 4. Binomial models obtained in the stepwise process to explain the occurrence of killer whales detected by surface longline vessels. Model terms are described in Table 1. The models with better fit to the data are presented sorted according to Akaike information criterion (AIC) values. Note that 7 models presented values of ΔAIC lower than 2. The explained deviance (D^2) is shown.

Models	AIC	ΔAIC	D^2
BOAT + COAST + MONTH + SSTMax	606.74	0.00	23.40
BOAT + COAST + MONTH + SSTMax + GEAR	606.74	0.00	23.40
BOAT + COAST + MONTH + SSTMax + SSTd	607.43	0.69	23.59
BOAT + COAST + MONTH + SSTMax + DEPTH	608.10	1.36	23.57
BOAT + COAST + MONTH + SSTMax + DUR	608.29	1.55	23.49
BOAT + COAST + MONTH + SSTMax + SLOPE	608.42	1.68	23.47
BOAT + COAST + MONTH + SSTMax + SET	608.54	1.80	23.45
BOAT + COAST + MONTH + SSTd	608.88	2.14	23.43
BOAT + COAST + MONTH	609.85	3.11	23.10

fishing-dependent and that there is some evidence that killer whales can be attracted to fishing vessels to depredate the catch (e.g. Donoghue *et al.*, 2002), we consider our results a good proxy of the actual pattern of killer whale occurrence in temperate waters beyond the continental slope. To minimize these possible biases, we considered the whole Uruguayan pelagic longline fishing area (19°–40°S; 21°–54°W), during an extended period (1996–2007) and standardized the sightings by observation effort (i.e. sighting rates). Although neither skippers nor observers displayed what would usually be considered an effort searching for whales, this approach using days of fishing effort as observation effort could be used to model marine mammal habitat when no other information is available or when it does not cover such extended periods or areas.

Spatial and temporal distribution of killer whales

Despite the large fishing area, most of the killer whale sightings between 1996 and 2007 occurred in a restricted area of the south-western Atlantic Ocean (34°–37°S; 48°–53°W). A similar pattern has been registered regarding the interaction between killer whales and bottom longline fishery where the interactions were also restricted to relatively small areas (Yates & Brickle, 2007).

The spatial components were important for explaining the occurrence of killer whales in this region, which was higher between 150 and 400 nm offshore, near the shelf break and the continental slope, and in higher latitudes of the study area, which is consistent with overall patterns of global distribution of this species (Heyning & Dahlheim, 1988; Forney & Wade, 2007).

Although the sighting rate (SR) for the entire period was 4.57%, values were higher between 35°–36°S and 51°–53°W during all seasons, with particular areas presenting SR of up to 10%. This area is highly influenced by the Brazil–Malvinas Confluence, where two SST fronts can be distinguished, one corresponding to the southern tip of the Brazil Current and the other to the northernmost limit of the Falkland/Malvinas Current. The distance between these two thermal fronts varies from 50 to 100 km and within this zone a maximum in concentration of chlorophyll-*a* occurs (Barré *et al.*, 2006). The flows of both currents away from the coast form a series of large-scale meanders around 38°S, triggering very strong upwelling of deep waters and eddies (Brandini *et al.*, 2000; Piola & Matano, 2001; Acha *et al.*, 2004). This is one of the most productive areas in the region (Bisbal, 1995; Acha *et al.*, 2004) and is identified as a high abundance zone for sea birds, sea turtles and pelagic fish (Domingo *et al.*, 2007, 2009; Jimenez *et al.*, 2008, 2010; Pons *et al.*, 2010). A study combining PNOFA sighting data for the period 2002–2006 and satellite images of sea SST showed that the presence of killer whales closely matches surface temperature fronts found in the Confluence area (Passadore *et al.*, 2007). This supports the global distribution pattern proposed by Forney & Wade (2007), using remote data on chlorophyll-*a* concentration as a proxy for productivity, where densities of killer whales are higher in more productive areas.

Although killer whales occurred year round in the south-western Atlantic, the sighting rate was higher in autumn and winter. Whether the sighted individuals correspond to year round residents or the area is seasonally occupied by different groups widely distributed in the south-western Atlantic (e.g. coastal: Iriarte, 2006; oceanic: Secchi & Vaske Jr, 1998;

Table 5. Estimates of the selected binomial distribution model to explain the occurrence of killer whales detected by skippers and observers of the surface longline vessels. Model terms are described in Table 1. The value of each of the estimates is shown; for categorical variables, the category is presented in parentheses before the value. Significance of each model term: ***, $P = 0–0.001$; **, $P = 0.001–0.01$; *, $P = 0.01–0.05$; $P = 0.05–0.1$; °, $P > 0.1$.

Variable	Estimate
(Intercept)	−21.7513
Factor (BOAT)	(2) 0.8394, (3) 1.5850, (6) 1.9116, (7) 1.2231, (8) 1.4564, (10)−14.5233, (11) −1.6182, (12) 4.3368, (13) 2.8962, (14) −0.4483, (15) 1.1034, (16) 0.8171, (17) −16.5670, (18) 1.0686, (21) 1.7067
Coast	0.7421***
Factor (MONTH)	(2) 14.8511, (3) 16.1804, (4) 16.6068, (5) 15.3545, (6) 16.4436, (7) 16.3759, (8) 16.4951, (9) 16.4534, (10) 14.0173, (11) 15.1647, (12)−0.5960
SSTMax	0.1844*

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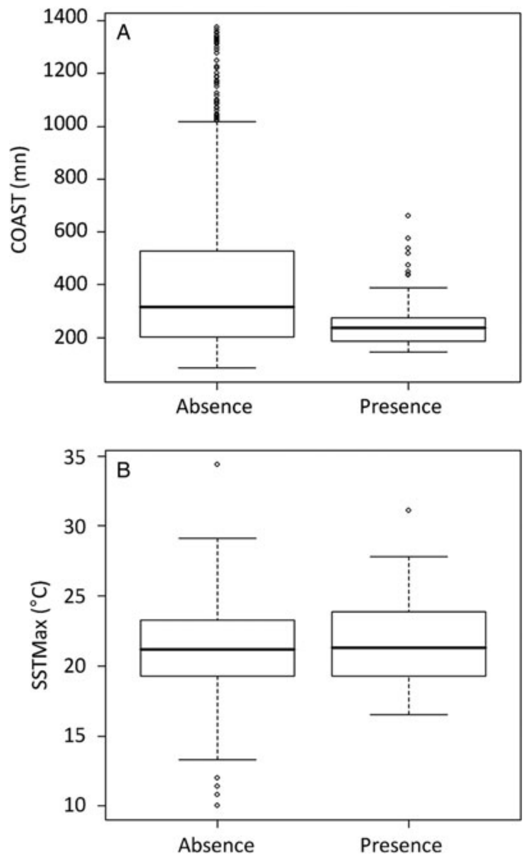

Fig. 5. Killer whales presence/absence of the selected explanatory variables of the GLM: (A) distance from the coast in nm (COAST); (B) maximum sea surface temperature in °C (SSTMax).

Dalla Rosa *et al.*, 2007; Passadore *et al.*, 2007; from tropical regions: Lodi & Hetzel, 1998; Siciliano *et al.*, 1999; or from cold temperate regions: Iñiguez *et al.*, 1994) has yet to be determined either by photo-identification or satellite tracking. A recent study on killer whales tagged in the Antarctic Peninsula showed that they travelled south-western Atlantic waters (30°–37°S) as far as Uruguay and Brazil, one of them performing nonstop round trips in 42 days (Durban & Pitman, 2012). Therefore, combining satellite telemetry studies with remote sensing data of the ocean and fishery information would be especially useful to determine movement patterns, to identify pelagic habitats preferred by killer whales and their potential overlap with the distribution of fisheries.

Effect of environmental and operational variables on the occurrence of killer whales

Some studies suggest that the killer whales would be attracted to the fishing boats when hauling systems are active (Yano & Dahlheim, 1995; Donoghue *et al.*, 2002). Particularly in the south-western Atlantic, previous researches mention that killer whales might have the ability to recognize and follow the fishing boats (Secchi & Vaske Jr, 1998; Dalla Rosa & Secchi, 2007). However, the ability of the species to recognize fishing boats had not been previously assessed for this region. Our GLMs suggest that killer whale presence may be influenced by the boat, but which characteristics turn some vessels into killer whale attractors have to be investigated, so that structural changes can be designed to minimize depredation upon the catch (see Donoghue *et al.*, 2002).

The maximum SST also had a positive effect on the presence of killer whales in the south-western Atlantic. According to the SST values (range = 19–24°C; average = 22°C) the species occurred mainly in waters affected by Brazilian Current (Brandini *et al.*, 2000). The reason for this variable being selected as relevant to explain killer whale presence is unclear, but might be due to interactive effects with other variables not considered in this study such as presence of preys that could be associated with SST. For example, fishermen seek waters of 18° to 20°C in order to catch swordfish (Mora, 1988), the species mostly depredated by killer whales in longline fisheries (Secchi & Vaske Jr, 1998; Dalla Rosa & Secchi, 2007).

Killer whale groups and implications for conservation

Killer whales occurred as solitary animals or in small groups, mostly composed of 2 or 3 individuals, and occasionally up to 15. The groups interacting with longline fisheries in other areas of the South Atlantic are of similar sizes to the ones here reported (e.g. tropical waters of the Atlantic Ocean: Dantas, 2007; South Georgia: Purves *et al.*, 2002; Malvinas/Falkland Islands: Yates & Brickle, 2007; and south-eastern Africa: Williams *et al.*, 2009).

It is worth noting that the size of the population that interacts with the pelagic longline fishery in the Brazil–Malvinas Confluence remains unknown. In general, killer whales form small populations (e.g. Matkin & Sautilis, 1994; Baird, 2000) and this, coupled with the low reproductive rate and longevity of the species, make them highly vulnerable to anthropogenic threats (Heyning & Dahlheim, 1988).

It is suspected that interactions with fishing vessels are the most obvious conservation problem for killer whales, not only in Brazilian waters (Dalla Rosa *et al.*, 2007) but also in Uruguayan and adjacent international waters, where sometimes they are incidentally hooked or retaliated against by fishermen with harpoons and guns (Secchi & Vaske Jr, 1998; Brum & Marín, 2000; Dalla Rosa & Secchi, 2007; Passadore, 2010).

It is important to mention that in the present study 58% of fishing events with killer whale sightings also experienced interaction (i.e. the species preyed upon the fish captured in the longline). In 32% of the events with sightings, no fish were damaged by killer whales; and in the remaining 10% of the events information on depredation was not available (Passadore, this study). Therefore, other patterns besides fishery distribution would be affecting the occurrence of killer whales. Our data suggest that the Brazil–Malvinas Confluence is an area of high occurrence of killer whales. Nevertheless, dedicated cetacean surveys should be performed in the south-western Atlantic to investigate abundance and to determine detailed distribution patterns in order to improve our understanding on the species ecology and, eventually, to manage fishing activities.

Besides the interaction with killer whales, the longline fishery in the south-western Atlantic interacts with a group of threatened species such as sea birds (Jimenez *et al.*, 2008, 2010) and sea turtles (Domingo *et al.*, 2007, 2009). Therefore, all the interactions should be assessed and the environmental and fishing characteristics should be identified and monitored. The understanding of species distribution and of the interactions between the fishery and non-target species would guide resource managers to mitigate possible adverse interactions under a multi-species approach.

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Correspondence should be addressed to:
C. Passadore
Proyecto ODAS/Cetáceos Uruguay
Iguá 4225, C.P. 11400, Sección Etología–Facultad de Ciencias
Universidad de la República, Montevideo, Uruguay
email: cecipass8@gmail.com

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