Hydrobiologia (2008) 612:251–268
DOI 10.1007/s10750-008-9501-2

FISH HABITAT MAPPING

Results of a short study of interactions of cetaceans and longline fisheries in Atlantic waters: environmental correlates of catches and depredation events

Gema Hernandez-Milian · Sabine Goetz · Catuxa Varela-Dopico · José Rodriguez-Gutierrez · Jorge Romón-Olea · José R. Fuertes-Gamundi · Edelmiro Ulloa-Alonso · Nick J. C. Tregenza · Andy Smerdon · Monserrat G. Otero · Vicente Tato · Jianjun Wang · M. Begoña Santos · Alfredo López · Rebeca Lago · Julio M. Portela · Graham J. Pierce

Abstract In the Atlantic, economic losses have been reported from shark, swordfish and tuna longline fisheries due to depredation by cetaceans. We examined interactions of odontocete cetaceans with commercial longliners operating in waters off Brazil and the Azores archipelago during 2006–2007, analysing relationships between catches, depredation on hooked fish, cetacean sightings, acoustic records of cetacean presence and environmental variables. Data were provided by skippers of six vessels and by on-board observers for two vessels. The percentage of longline sets depredated by cetaceans was low (ranging from 1% to 9% of total sets per ship) but the proportion of fish damaged was high (up to 100%) when depredation occurred. Catches were related to the phase of the moon, cloud cover, sea surface temperature and water depth whereas cetacean sightings were primarily related to catches. In particular there was a positive association between *Delphinus delphis* sightings and catches of swordfish, and between *Stenella frontalis* sightings and mako catches. Acoustic detection was low when depredation by false killer whales occurred although high

---

Guest editor: V. D. Valavanis
Essential Fish Habitat Mapping in the Mediterranean

G. Hernandez-Milian (✉) · J. Wang · G. J. Pierce
University of Aberdeen, Tillidrone Avenue, Aberdeen
AB24 2TZ, UK
e-mail: g.hernandez-m@abdn.ac.uk

S. Goetz · M. B. Santos · J. M. Portela · G. J. Pierce
Instituto Español de Oceanografía, Centro Oceanográfico
de Vigo, Cabo Estai, Canido, 36200 Vigo, Spain

C. Varela-Dopico
Estación de Biología Mariña da Graña, University of
Santiago de Compostela, Casa do Hórreo e Casa da
Estrela, Rúa da Ribeira 1-4, A Graña, 15590 Ferrol, Spain

C. Varela-Dopico · J. Rodriguez-Gutierrez ·
J. Romón-Olea · J. R. Fuertes-Gamundi ·
E. Ulloa-Alonso
Cooperativa de Armadores de Pesca del Puerto de Vigo,
Sociedad Coop. Ltda., Puerto Pesquero, Edif.
Cooperativa de Armadores, Apdo. 1078, 36202 Vigo,
Spain

N. J. C. Tregenza
Chelonia Limited, Beach Cottage, 5 Beach Terrace, Long
Rock, Cornwall TR20 8JE, UK

A. Smerdon
Aquatec Group Ltd., High Street, Hartley Wintney,
Hampshire RG27 8NY, UK

M. G. Otero · V. Tato
MG Otero Consultores SL, Porto Pesqueiro, Nvo Tinglado
Xeral Empaque Of. 8, PO Box 1132, 36202 Vigo, Spain

A. López · R. Lago
CEMMA, Apdo. 15, 36380 Gondomar, Pontevedra, Spain

rates of clicks were detected when delphinids were sighted and false killer whales were by-caught. This may indicate that false killer whales are not echolocating when feeding on fish hooked on a longline.

Keywords Cetaceans · False killer whale · Longline fishery · Depredation · Hydrophones · Behaviour · Habitat modelling

Introduction

Pelagic longline fisheries in the Atlantic usually operate in offshore waters, mainly targeting tuna, swordfish, billfishes (Istiophoridae) and sharks (Brothers et al., 1999a). In contrast to the Pacific, catches of these species have not increased over the last decade (ICCAT, 2007). The most important Atlantic fishing grounds for longliners are located in the South Central tropical area and NW-W Azores waters (Lewison et al., 2004). The Spanish tuna and swordfish longline fishery is one of the most important in the Atlantic (ICCAT, 2007), a significant source of income for the Spanish fishing sector (Garza Gil et al., 2003). The lines used are approximately 50 miles long and typically carry 1200–1250 hooks.

Toothed whales (Odontoceti) are attracted to longlines because they provide an easily accessible source of food and the fish caught on them are often large. Cetaceans cause significant economic losses due to damage and removal of bait and hooked fish in a range of longline fisheries around the world (Northridge, 1984; Dahlheim, 1988; Ashford et al., 1996; Capdeville, 1997; Dalla Rosa & Secchi, 2002, 2007; Donoghue et al., 2002; Gilman et al., 2006; Zollett & Read, 2006; Ramos-Cartelle & Mejuto, 2007). Odontocetes are believed to develop familiarity with the sounds produced by longliners (such as the sound of the engine, the gear haulers and the electric equipment) and are frequently observed to follow vessels for days in order to take advantage of the catches (Gilman et al., 2006; Ramos-Cartelle & Mejuto 2007). Depredation rates tend to be higher for longer soak times (Gilman et al., 2007a, b).

In tropical and subtropical Atlantic waters, the killer whale (*Orcinus orca*, Linnaeus 1758*)* and the false killer whale (*Pseudorca crassidens*, Owen 1846) are known to interact with the pelagic longline fishery for tuna and swordfish (Dalla Rosa & Secchi, 2002, 2007; Dalla Rosa et al., 2006; Ramos-Cartelle & Mejuto, 2007). Killer whales and false killer whales are distributed in all oceans, the former best known from cooler waters and the latter preferring tropical, subtropical and warm temperate waters. Killer whales are found from the surf zone to 800 km from the coast, with large concentrations over the continental shelf, whereas false killer whales inhabit deep offshore waters. Both species mainly feed on fish, cephalopods and other marine mammals (Jefferson et al., 1993; Stacey et al., 1994; Carwadine, 1995). Environmental and oceanographic features, such as water temperature, bathymetry, oceanic fronts, lunar cycle, and spatio-temporal factors are believed to play an important role in the distribution of the cetaceans and their prey (e.g. Damalas et al., 2007; Romo et al., 2007; De Stephanis et al., 2008).

Marine mammal presence in offshore waters is usually determined by means of sightings recorded from vessels. However, use of passive acoustic methods, e.g. deployment of T-PODs (www.chelonia.com), can increase the detection rate, especially when visibility is low or the animals spend little time on the surface, and the range of detection may be wider than if only visual observation is used (Carstensen et al. 2006; Leeney & Tregenza 2006; Philpott et al., 2007).

The present short study aimed to describe the interactions of cetaceans, in particular killer and false killer whales, with longline fisheries for swordfish and tuna in two regions of the Atlantic (Brazil and Azores), determining the relationships between catches, cetacean presence, the incidence of depredation and environmental variables. Specifically: (1) Are the fish caught in particular places and is the size of catch related to environmental conditions? (2) Is cetacean presence and/or the occurrence of depredation related to particular environmental conditions? (3) Is depredation associated with the presence of particular cetaceans species and is it related to the amount of fish caught? Finally, since turtle by-catches were frequent we also investigated possible relationships between turtle by-catch, fish catch and environmental conditions.

Materials and methods

Sampling effort and study area

Data were gathered from eight Spanish commercial pelagic surface longline vessels, operating in Atlantic waters (1) off Brazil and extending into mid-Atlantic waters and (2) to the west of the Azores archipelago, between June 2006 and June 2007 (Fig. 1, Table 1). The two vessels with observers were fishing off Brazil (V7) and west of the Azores (V8), respectively.

The oceanography of the study area off Brazil is dominated by the South Equatorial Current, which has an offshoot along Brazil's North Coast (the North Brazil Current) and to the South (the Brazil Current). Offshore, in the waters of the Brazil Current, important fishery resources include *Thunnus albacares* in the southern region and *T. alalunga* in the northern region (Zavala-Camin & Antero da Silva, 1991), which are caught around seamounts and banks. The Brazil Current is a weak western boundary current carrying warm subtropical water with a temperature range of 18–28°C, which runs south along the coast of Brazil from about 9° S to about 38° S and is generally confined to the upper 600 m of the water column (Memery et al., 2000; Zavilov et al., 1999).

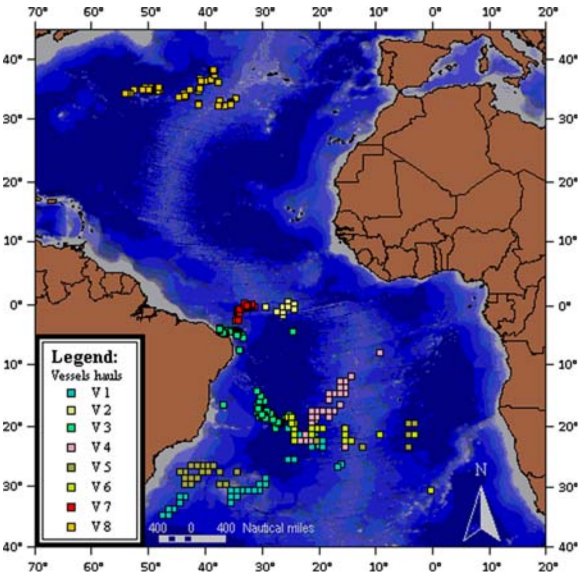


Fig. 1 Fishing areas of vessels V1–V8 in the Atlantic Ocean. Squares indicate where fishing operations took place

The second study area is to the west of the Azores archipelago, a group of nine volcanic islands situated on the Mid-Atlantic ridge, in an area dominated oceanographically by the Gulf Stream. The richness of fishing resources in the Azores originates from the complex relations between intermediate depth hydrothermal fields and seamount ecosystems. Tuna and swordfish are the most important target groups in the vicinity of the islands, although sharks—mainly blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*)—can outnumber swordfish 10:1 in longline catches (Morato et al., 2001).

Sampling methods

Skippers of six vessels (V1–V6) recorded data on catches of fish, cetacean sightings and depredation on catches. In addition, two vessels (V7 operating off North East Brazil between January and March 2007 and V8 operating South West of the Azores between April and June 2007) each carried a scientific observer on board, who registered data on fishing activity, cetacean sightings, acoustic detection of cetaceans, depredation on catches, and environmental data (Table 1).

Data on fishing activity included the time and location of each set, the number of hooks on the line, total catch (number and biomass of fish, by species) and any by-catch of marine mammals or sea turtles. The fish caught were identified as follows: swordfish (*Xiphias gladius*), shortfin mako (*Isurus oxyrinchus*), blue shark (*Prionace glauca*), tuna (*Thunnus* spp., mainly *T. alalunga*, *T. albacore*, and *T. Obesus*), marlin (Istiophoridae), dolphinfish (*Coryphaena hippurus*), barracuda (*Sphyraena* spp.) or garfish (Belonidae).

The number and species of fishes damaged by predators was logged and, based on the nature of the damage, the depredation was identified as due to cetaceans, sharks or other species, such as sea turtles. Fish damaged by cetaceans can be distinguished from shark-damaged fish since sharks typically bite the fish in half leaving clean borders or multiple smaller bites, whereas cetaceans such as killer whales and false killer whales tear the body of the fish, leaving bites with ragged borders and often just the head or the lips and upper jaw of the fish on the hook (Secchi & Vaske, 1998; Donoghue et al., 2002; Gilman et al., 2006; Varela-Dopico, pers. obs.). Fishermen report

Table 1 Fishing effort and depredation rates of eight Spanish commercial longline vessels operating in Atlantic waters (June 2006–July 2007): Vessel number (V1–V8), total no. of monitored sets per vessel, total no. of hooks deployed per vessel during monitored trips, average no. of hooks per set, average amount of catch per set (kg), percentage and number of sets with cetacean depredation, Spearman correlation coefficients (*r*) and associated probability (*P*) for the relationship between average weight of catches/set and total catch lost per vessel due to cetacean depredation (V1–V6: Both fish damaged and bait/fish removed from the hooks were considered; V7–V8: Only damaged fish was considered), and percentage and number of sets with sea turtle/marine mammal by-catch

Vessel	Sets	Hooks	Hooks/set	Average catch/set	Sets with cetacean depredation		Correlation between catch and depredation		% of Catch lost	Sets with by-catch		
										Sea turtles		Marine mammals
					%	No.	*r*	*P*		%	No.	No.
V1	76	102,600	1,350	1198.9	5.3	4	−0.07	0.547	1.6	10.5	8	0
V2	45	43,200	960	1574.7	8.9	4	−0.47	0.001	8.6	4.4	2	0
V3	126	163,800	1,300	886.1	5.6	7	−0.24	0.022	3.7	0	0	0
V4	137	185,358	1,353	1177.7	4.4	6	0.08	0.482	3.0	5.1	7	0
V5	94	116,100	1,235	1268.4	1.1	1	−0.01	0.934	0.2	10.6	10	0
V6	71	98,500	1,387	1715.6	4.3	3	−0.22	0.071	0.6	12.7	9	0
V7	30	37,673	1,256	2064.0	3.3	1	0.22	0.238	0.6	33.3	10	0
V8	56	62,198	1,111	1335.8	3.6	2	0.09	0.518	0.9	12.5	7	1
Total	635	809,429	1,275			28					53	1

Table 2 Number and percentage of sets monitored using different numbers of hydrophones (T-PODs), for vessels V7 (Brazil) and V8 (Azores)

Vessel	3 T-PODs		2 T-PODs		1 T-POD		No T-PODs		Total sets
	Sets	%	Sets	%	Sets	%	Sets	%	
V7	8	26.7	16	53.3	3	10.0	3	10.0	30
V8	55	98.2	0	0	0	0	1	1.8	56
Total	63		16		3		4		86

that cetaceans may occasionally also remove the fish entirely from the lines. Sea turtles leave several small bites on the fish, mainly eating the commercial parts (Varela-Dopico, pers. obs.).

Environmental data recorded on board by observers comprised sea state on the Douglas scale (Sea), cloud cover on a scale from 0 to 8 (Cd), moon phase (M1: new moon, M2: waxing moon, M3: full moon, M4: waning moon), sea surface temperature (SST) and water depth (Depth). In addition, bathymetry and coast line data for all trips were obtained from the GEBCO Atlas 2003, and a map was generated using ESRI Arc/View 3.3 (Fig. 1).

Sightings of cetaceans were recorded throughout fishing operations by the two observers, whereas sightings on the remaining six vessels were opportunistic. Geographic position, number of animals and species were recorded when they were sighted. The following categories were used: sperm whale (*Physeter macrocephalus*), killer whale (*Orcinus orca*), false killer whale (*Pseudorca crassidens*), common dolphin (*Delphinus delphis*), Atlantic spotted dolphin (*Stenella frontalis*), unidentified Odontoceti and Mysticeti.

Between one and three T-PODs (Table 2) were deployed along the line during most sets by vessels V7 and V8, in approximately 5 m water depth, one at each end and one in the middle. In order to prevent possible losses, they were attached to a buoy. The T-PODs used (version 5, www.chelonia.co.uk) detect clicks and click trains of specific cetacean species. They consist of a hydrophone, an analogue processor, a system to log echolocation clicks, and software that is able to filter cetacean clicks within a specific bandwidth. The T-PODs were programmed to detect false killer whales using parameters values calculated

Table 3 Number of clicks detected by the hydrophones for vessels V7 (Brazil) and V8 (Azores)

Vessel	CetHi		CetLo		Doubtful		Very doubtful		Positives		Negatives		Total
	Clicks	%	Clicks	%	Clicks	%	Clicks	%	Clicks	%	Clicks	%	
V7	17,186	21.3	21,253	27.0	21,782	27.0	20,400	25.3	68,268	84.7	12,352	15.3	80,621
V8	50,439	11.9	71,193	16.8	188,374	44.5	113,358	26.8	121,370	28.7	301,994	71.3	423,364
Total	67,625		92,446		210,156		133,758		189,638		314,346		503,985

CetHi, clicks with high probability of coming from a cetacean; CetLo, clicks with lower probability of coming from a cetacean; Doubtful, clicks which are often from cetaceans, but are sometimes unreliable; Very doubtful, click sequences which are more likely to arise from other sources; Positives, sum of CetHi + CetLo; Negatives, sum of doubtful and very doubtful; Total, Total number of clicks detected by the T-PODs regardless of source

for free-ranging false killer whales by Madsen et al., (2004) (filter A = 41 kHz, filter B = 16 kHz, bandwidth = 4–6, sensitivity = various, minimum click duration = 40 µs). They registered the number of clicks and classified the clicks according to the probability of coming from a false killer whale as high, low, doubtful or very doubtful (Table 3). *P. crassidens* produces echolocation sounds of 30–70 kHz (Madsen et al., 2004). However, this overlaps with the frequency range for other delphinid species, e.g. *Delphinus delphis* echolocation pulse frequency is between 20 and 100 kHz (Wood & Evans, 1980) and *Stenella* spp. emit clicks between 30 and 85 kHz (Lammers et al., 2003) or show bimodal click spectra with peaks at 40–60 kHz and 120–140 kHz (Schotten et al., 2003). Therefore the degree of species-specificity of the detections depends on the species present in the study area and in the present case was low due to the presence of both *Delphinus* and *Stenella*.

Data from the T-PODs were downloaded and stored on a laptop after hauling each line. Due to technical problems not all T-PODs worked all the time during the survey in Brazilian waters. In the Azores, T-PODs were used during all but one set. For each T-POD and each set, we extracted the number of clicks that were considered likely to come from delphinids (“positives”, the sum of “CetHi” and “CetLo” categories, also known as “CetAll”, see www.chelonia.co.uk) and the number of other clicks (“negatives”). Two additional indicators of cetacean activity were calculated (after Tougaard et al., 2004; Skov et al., 2002; Leeney & Tregenza, 2006): average click rate (the number of positive clicks divided by the total recording time) and click intensity (the mean number of positive clicks during minutes with clicks). Both indicators were calculated by T-POD and set.

Data analysis

Variables used for data analysis comprised descriptors of catch composition, occurrence and amount of depredation on catches, cetacean sightings, acoustic detections of cetaceans, and environmental data (see Table 4). Possible relationships between variables were initially explored using Spearman rank correlations, treating data from each set as a sample and analysing data from each vessel separately.

To provide a more detailed insight into relationships between response and explanatory variables, redundancy analysis (RDA) and generalised additive models were used with data from vessels 7 and 8 (recorded by observers). Data for Brazil and the Azores were analysed separately. For both surveys, (a) catches (numbers) of swordfish, tuna, shortfin mako and blue shark and (b) acoustic data on cetacean presence (click rate and click intensity) could be used as response variables for the RDA. For the Azores survey, there was sufficient data to also treat (c) cetacean sightings (numbers seen for *Delphinus delphis*, *Stenella frontalis*, *Orcinus orca*, *Pseudorca crassidens*, *Physeter macrocephalus*, Mysticetes and unidentified Odontocetes) and (d) incidence of depredation (numbers of damaged fish for swordfish, shortfin mako and escolar) as response variables. Thus, six RDA analyses were carried out in total (Table 5). In each case, all remaining variables were treated as explanatory variables. When using acoustic or depredation variables as response variables, cetacean sightings were converted to presence–absence data for use as explanatory variables, since we

Table 4 List of variables

Variables		Abbreviation	Descriptor
Fishery data	Catches of:		No. of fish caught or biomass of fish caught (kg)
	Swordfish (*X. gladius*)	XGL	
	Shortfin mako (*I. oxyrinchus*)	IOX	
	Blue shark (*P. glauca*)	PGL	
	Tuna (*Thunnus* spp.)	THU	
	Marlin (Istiophoridae)	IST	
	Dolphinfish (*C. hippurus*)	CHI	
	Barracuda (*Sphyraena* spp.)	SPH	
	Sharks (sum of all shark species)	Shark	
	Dimension of longline	Hook	No. of hooks
	Turtle by-catch	Turt	No. of animals by-caught
Acoustic data	Likely false killer whale clicks	Pos	No. of clicks
	Unlikely false killer whale clicks	Neg	
	Average click rate	Rate	No. of clicks/recording time
	Intensity of clicks	Ints	No. of clicks/minutes with clicks
Cetacean sightings	Sperm whale (*P. macrocephalus*)	PMA	No. of animals seen or presence of animals
	Killer whale (*O. orca*)	OOR	
	False killer whale (*P. crassidens*)	PCR	
	Common dolphin (*D. delphis*)	DDE	
	Atlantic spotted dolphin (*S. frontalis*)	SFR	
	Unidentified Odontoceti	ODO	
	Mysticeti	MIS	
Depredation	Swordfish (*X. gladius*)	XGLd	No. of fish damaged or presence of damage
	Shortfin mako (*I. oxyrinchus*)	IOXd	
	Escolar (*L. flavobrunneum*)	LFLd	
	Depredation (sum of all species)	dprd	
Environmental data	Sea state	Sea	Douglas scale: from 0 to 9
	Cloud cover	Cd	Scale: from 0 to 8
	Moon phase	M	M1: New moon
			M2: Waxing moon
			M3: Full moon
			M4: Waning moon
	Sea surface temperature	SST	in °C
	Water depth	Depth	in m

considered the visually confirmed presence or absence of cetaceans to be more important than the precise number present. RDA output indicates the proportion of variation in the response variables explained by the explanatory variables. The statistical significance of the effects of explanatory variables was obtained using a Monte Carlo permutation test with $n = 4{,}999$ permutations. The relationships between the response and explanatory variables were also displayed as point-vector biplots (see Zuur et al., 2007).

When RDA detected significant relationships between response and explanatory variables, these were further investigated using Generalised Additive Models (GAMs) and Generalised Linear Models (GLMs) for individual response variables within each of the four groups (catch, acoustic detections, sightings, and depredation), thereby allowing non-linearity in the relationships to be taken into account. Response variables could generally be assumed to follow binomial (presence–absence data) or Poisson

Table 5 Numerical output of the Redundancy analysis (RDA) for vessels V7 (Brazil) and V8 (Azores) indicating individual eigenvalues of the first and second axis (λ_1, λ_2), sum of all canonical eigenvalues (Sum), and results of *F* tests (*F* and associated probability, *P*) for the significance of effects of individual explanatory variables (only explanatory variables with significant effects are shown)

Vessel	Response variables	λ_1	λ_2	Sum	Explanatory variables	*F*	*P*
V7	Fish catches	17.91	12.21	0.46	Turt	2.92	0.010
					M4	2.40	0.032
	Acoustic data	33.62	0.68	0.34	M2	4.94	0.027
V8	Fish catches	24.59	13.69	0.47	M3	5.99	0.000
					Depth	3.14	0.017
					SST	3.00	0.019
					M4	0.04	0.037
	Acoustic data	46.68	0.54	0.47	DDE	8.27	0.004
					SFR	5.37	0.016
	Sightings	14.38	8.44	0.40	XGL	2.94	0.012
					M3	2.08	0.032
					Rate	2.10	0.034
					dprd	4.45	0.039
					IOX	2.70	0.045
	Depredation	30.42	6.95	0.44	PCR	21.72	0.001

When one set of variables (see Table 4) was used as response variables, all variables from the other four sets were potentially available as "explanatory" variables

(count data) distributions, with an addition parameter for dispersion included in the model if overdispersion was detected, and using appropriate link functions. The exceptions were click intensity, which was log-transformed to achieve an approximately Gaussian distribution, and average click rate, which had an approximately Gaussian distribution. For the Brazil data set both average click rate and click intensity were consistently low so the number of positive clicks was used as the response variable in GAMs. Cetacean sightings and depredation data were converted to presence–absence for use in GAMs and GLMs. Cloud cover (on a scale of 0–8) was treated as a continuous variable. For all continuous explanatory variables, degrees of freedom were constrained to be less than 5 to avoid overfitting.

The fitted GAMs had the general form:

$$y_i = \alpha + f_1(x_{i1}) + \ldots + f_m(x_{im}) + \beta_n x_{in} + \ldots + \beta_p x_{ip} + \varepsilon_i \quad \varepsilon_i \sim N\left(0, \sigma^2\right)$$

where y_i is the response variable, $f_j()$ are the smoothing functions, β_q are coefficients for parametric terms (e.g. dummy variables generated from categorical variables) and ε a random error parameter (Zuur et al., 2007). Models were fitted using a combination of forwards and backwards selection until all remaining terms were significant or none remained. Where none of the explanatory variables remaining was a continuous variable or could be treated as such, model fitting continued using generalised linear modelling (GLM). Plots of residuals were examined to confirm goodness of fit. RDA, GAMs and GLMs were performed using Brodgar 2.5.2 (www.brodgar.com). More information about these techniques can be found in Zuur et al. (2007).

Since turtle by-catch occurred quite frequently we also examined possible causal factors (environmental conditions and catch). Kruskal-Wallis tests were used to compare fish catches and environmental conditions during sets with and without turtle by-catch.

Results

Overall fishing effort, catches, by-catch and losses due to depredation

The fishing effort of the eight longline vessels monitored was located in the South Equatorial Current (V1–V7) and the Gulf Stream (V8) (Fig. 1). Between July 2006 and June 2007 the vessels performed 635 sets, deploying an average number of 1,275 hooks per set and catching a total of 1185.5 tons of marketable fish. Depredation by cetaceans occurred during between 1% and 9% of sets per vessel, with overall estimated losses (per vessel) between 0.2% and 8.6% of the total catch (V1–V6: Both fish damaged and bait/fish removed from the hooks were considered; V7–V8: Only damaged fish was considered) (Table 1).

By-catch of turtles was reported for all vessels, except for V3, occurring on an average in 11.2% of all sets. The number of turtles by-caught ranged between 1 and 5 animals per set. Leatherback turtle *Dermochelys coriacea* (39% of turtle individuals by-caught) and green turtle *Chelonia mydas* (31%) were the most frequently caught species, followed by loggerhead turtle *Caretta caretta* (19%) and Olive Ridley turtle *Lepidochelys olivacea* (11%). Most turtles were caught alive and released. Marine mammal by-catch was registered only once: during one set off the Azores, two false killer whales were caught on the longline (Table 1).

Catches and depredation on non-observer vessels

For the non-observer trips (V1–V6), skippers recorded that all catch damaged was due to cetacean depredation, based on the type of bite marks seen. The average percentage of sets depredated was low (4.6%) but when depredation occurred, between 2% and 100% of the catch was lost, with over 25% of the catch lost on two-thirds of these occasions. For two of the six vessels, the occurrence of depredation was significantly negatively correlated with catch (V2: $r = -0.47$, $P = 0.001$; V3: $r = -0.24$, $P = 0.022$) (Table 1), suggesting that depredation may significantly reduce catches.

Catches, by-catches and depredation on vessels with observers

The total catch of the two vessels with observers on board (V7 and V8) was 136.7 tonnes (3,645 individuals) of fish, of which 87% (by number) were marketable. The main species caught off Brazil (V7) by number were tuna (54.5%), swordfish (29.4%) and marlin (7.5%). Off the Azores (V8), the principal species caught by number were sharks (73.6%, blue sharks and shortfin mako sharks) and swordfish (24.6%). Depredation of catches occurred during 19 out of 86 sets: nine times off Brazil and ten times off the Azores. However, based on visual inspection of the damaged fish, this was attributed to cetaceans, presumed to be false killer whales, on only three occasions, once off Brazil (3.3% of sets) and twice off the Azores (3.6% of sets) (Table 1). This compares to twelve instances of depredation by sharks and four that were attributed to turtles. The overall proportion of catches (by number) damaged by cetaceans across all sets was only 0.2% and 0.9% of total catch, respectively. The fish damaged by cetaceans were swordfish (85.7% by number) and shortfin mako (14.3% by number).

RDA results indicated that catches of the principal target species off Brazil were significantly related to turtle by-catch and moon phase (waning moon) (Table 5, Fig. 2). GLM results indicated weakly significant relationships between swordfish catches and both cloud cover and the interaction between moon phase and cloud cover. In the case of tuna catches the only effect that was marginally significant

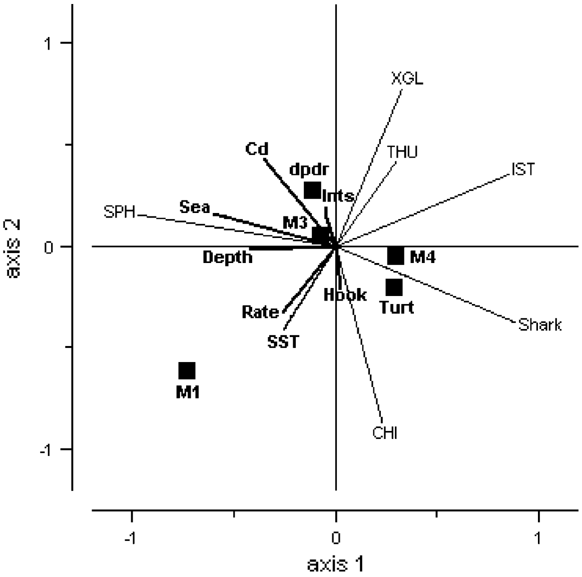


Fig. 2 RDA biplot for catch data from vessel V7 (Brazil). Response variables (represented by thin lines): Catches of swordfish (XGL), tuna (THU), barracuda (SPH), dolphinfish (CHI), marlin (IST), garfish (AGU) and sharks (Shark). Explanatory variables (represented by thick lines if continuous and by squares if nominal): see Table 4 for abbreviations. The plot shown was based on re-running the RDA having removed the least important (non-significant) explanatory variables, to achieve greater visual clarity

Table 6 GAM and GLM results using data from vessel V7 (Brazil, $N = 30$ sets)

Response variables	Explanatory variables	Type	t	F	P	Sign	edf	%dev	AIC
XGL								29.2	211.6
	Moon	N			All >0.05				
	Cd	L	2.22		0.0364	+			
	Cd-M3	N	−2.08		0.0492	−			
THU								45.2	302.6
	Moon	N			All >0.05				
	Cd	N	1.71		>0.05				
	M2-Cd	N	−2.12		0.0448	−			
Pos								51.9	838.2
	M1	N	−2.93		0.0084	−			
	M2	N	2.45		0.0237	+			
	Depth	S		3.49	0.0263		3.64		

The response variables were catches (number) of swordfish and tuna per set, and the number of likely delphinid echolocation clicks. In all cases, a quasi-Poisson distribution was assumed for the response variable. Results displayed are as follows: explanatory variables (and interactions) included in the final model, whether they were included as smoothers (S), linear terms (L) or nominal variables (N), their significance (based on F or t tests, with P-value), the direction (sign) of the effect (+ or −) and degrees of freedom for smoothers. Also given are the overall percentage of deviance explained (%dev) and AIC value for the model. Full moon (M4) was used as the reference value when evaluating effect of moon phase (since there was only one record with new moon). Explanatory variables used: Table 4

was the interaction term, with both main effects (cloud cover, moon phase) non-significant (Table 6). The co-plot (Fig. 3) illustrates the interaction between the effects of cloud cover and moon phase in relation to swordfish catches. Due to the small sample size, further investigation of these relationships is not possible.

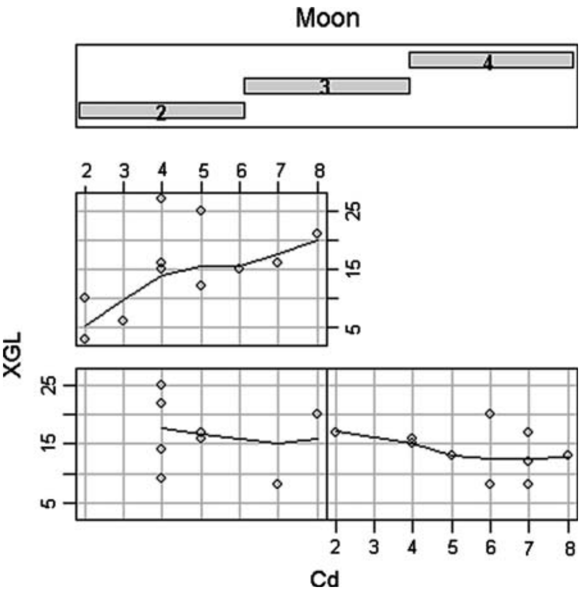


Fig. 3 Co-plot for swordfish catches by vessel V7 (Brazil), illustrating the interactions between effects of moon phase and cloud cover

Off the Azores, RDA showed catches of the three main fish species were related to moon phase, water depth and SST (Table 5, Fig. 4). GAMs showed that swordfish catches were related to water depth, moon phase, cloud cover and sightings of *Stenella frontalis* (Table 7). Catches peaked at a cloud cover value of 2 (Fig. 5a), showed a minimum value at around 3,000 m depth (increasing in shallower and deeper waters) (Fig. 5b) and decreased in the presence of *Stenella*. Given that spotted dolphins are unlikely to remove large fish from the lines, the interpretation of the latter relationship is unclear.

Mako catches off the Azores showed significant relationships with moon phase, SST, click rate and sightings of *Delphinus delphis* and *Stenella frontalis* (Table 7). Catches were lower at higher temperatures and lower at the highest values for click rate (Fig. 5c). Catches were strongly negatively associated with presence of common dolphins and positively associated with presence of spotted dolphins. Finally blue shark catches were related to moon phase, with higher catches around full moon (Table 7).

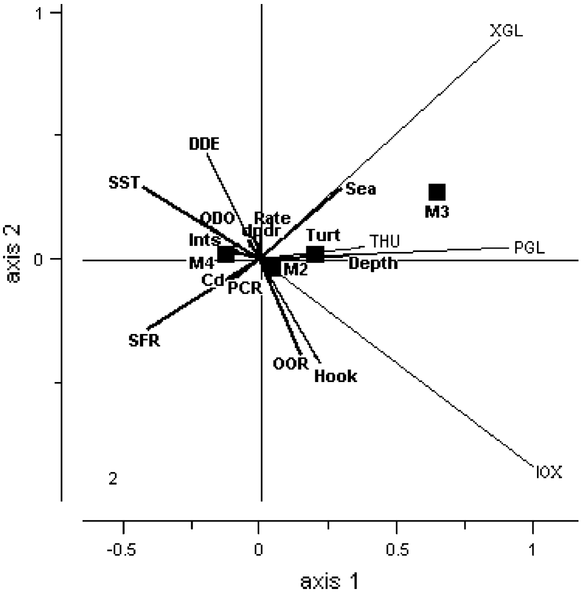


Fig. 4 RDA biplot for catch data from vessel V8 (Azores). Response variables (represented by thin lines): catches of swordfish (XGL) tuna (THU), shortfin mako (IOX) and blue shark (PGL). Explanatory variables (represented by thick lines if continuous and by squares if nominal): see Table 4. The plot shown was based on re-running the RDA having removed the least important (non-significant) explanatory variables, to achieve greater visual clarity

In the Brazil survey, turtle by-catch occurred during 10 out of 30 sets and was not related to depth, SST, moon phase, sea state or catches of tuna or swordfish. Turtle by-catch was associated with higher catches of sharks (Kruskal-Wallis test, $P = 0.002$) and “other species” ($P = 0.001$). In the Azores survey, turtle by-catch occurred during seven of 56 sets, and was weakly positively associated with shortfin mako catches ($P = 0.035$).

Acoustic data collected during observer trips

T-PODs were deployed on 96.5% of lines. It was not always possible to set three T-PODs in each line, but 92% of the lines had two or three T-PODs that registered acoustic data (Table 2). Data were obtained covering approximately 96% of the time that the T-PODs were in the water, the remaining 4% being lost due to technical problems.

Off Brazil, hydrophones registered a low number of click trains, of which 84.7% were classified as “positive”, i.e. likely to have been produced by delphinids. Off the Azores, the number of clicks registered was considerably higher but only 28.7% of clicks were “positive” (Table 3). During both surveys, when depredation by false killer whales occurred, click intensity was low (Fig. 6a, b). However, on one occasion five swordfish were removed and two false killer whales were by-caught during the same set (set 20) off the Azores, and click intensity registered by the T-POD closest to the by-caught animals was high.

Redundancy analysis for the acoustic data from Brazil showed that the number of likely delphinid clicks recorded was affected by moon phase (waxing moon) (Table 5, Fig. 7). GAM showed that the detection of likely delphinid clicks was highest over the deepest water and confirmed the effect of moon phase (Table 6; Fig. 5d). During this survey depredation by false killer whales was recorded for only one fish.

In the Azores survey, RDA analysis revealed that acoustic detections were related to sightings of small delphinids (*Delphinus delphis* and *Stenella frontalis*) (Table 5, Fig. 8). GLM results indicated that click intensity was weakly related to sightings of spotted dolphins and moon phase (waning moon) although unrelated to other environmental factors or to catches. Average click rate, however, was positively related to depth (Table 7).

Cetacean sightings recorded by observers

The number of cetacean sightings differed for the two study areas: off Brazil, only 12 false killer whales and one sperm whale were sighted. No further analysis of these data was carried out.

Off the Azores 613 individual cetaceans were sighted, of which 94% were Odontoceti species (*Stenella frontalis*, *Delphinus delphis*, *Pseudorca crassidens*, *Physeter macrocephalus* and *Orcinus orca* in descending order of occurrence). Peaks of clicks were detected by the T-PODs when sightings of dolphins, false killer whales and killer whales were reported. RDA analysis showed that cetacean sightings were related to catches of swordfish and shortfin mako, moon phase, click rate and occurrence of depredation (Table 5, Fig. 9).

Satisfactory models could be fitted only for the two most commonly sighted species (*Delphinus delphis* and *Stenella frontalis*). The presence of

Table 7 GAM and GLM results using data from vessel V8 (Azores)

Response variables	Explanatory variables	Type	t or z	F or χ^2	P	Sign	edf	%dev	AIC
XGL								55.9	305.5
	M2	N	−2.83		0.0068	−			
	SFR	N	−2.92		0.0054	−			
	Cd	S		3.52	0.0138		2.9		
	Depth	S		5.96	0.0006		2.6		
IOX								70.8	276.7
	M2	N	2.90		0.0058	+			
	M3	N	2.74		0.0089	+			
	M4	N	−2.12		0.0393	−			
	SST	S		13.78	0.0006		1		
	Rate	S		4.57	0.0036		4		
	DDE	N	−4.63		0.0016	−			
	SFR	N	3.88		0.0020	+			
PGL								16.4	443.9
	M3		2.54		0.0141	+			
Ints								22.8	83.3
	M4	N	−2.29		0.0263	−			
	SFR	N	2.12		0.0390	+			
Rate								24.1	391.0
	Depth	S		16.82	0.0001		1		
DDE								38.7	52.2
	XGL	L	2.56		0.0105	+			
	IOX	L	−2.24		0.0252	−			
	Ints	L	1.97		0.0486	+			
SFR								45.7	54.2
	M2	N	−2.53		0.0114	−			
	M3	N	−2.68		0.0073	−			
	XGL	L	−2.69		0.0072	−			
	IOX	L	2.28		0.0225	+			
	Rate	L	3.02		0.0025	+			
dpdr								25.9	46.8
	Rate	L	2.053		0.0400	+			
	DDE	N	−2.13		0.0332	−			
	SFR	N	−2.60		0.0094	−			

The response variables were catches (number) of swordfish, shortfin mako and blue shark per set, intensity of clicks, average click rate, sightings of *Delphinus delphis* and *Stenella frontalis* and depredation. In all cases, a quasi-Poisson distribution was assumed for the response variable. Results displayed are as follows: explanatory variables (and interactions) included in the final model, whether they were included as smoothers (S), linear terms (L) or nominal variables (N), their significance (based on F, χ^2, z or t tests, with P-value), the direction (sign) of the effect (+ or −) and degrees of freedom for smoothers. Also given are the overall percentage of deviance explained (%dev) and AIC value for the model. New moon (M1) was used as the reference value when evaluating effect of moon phase. Explanatory variables used: Table 4

D. delphis was related to higher catches of swordfish and lower catches of shortfin mako catches. The presence of *Stenella frontalis* was associated with higher mako catches and lower swordfish catches. Both species were more frequently sighted when detection of "positive" clicks was high. In addition,

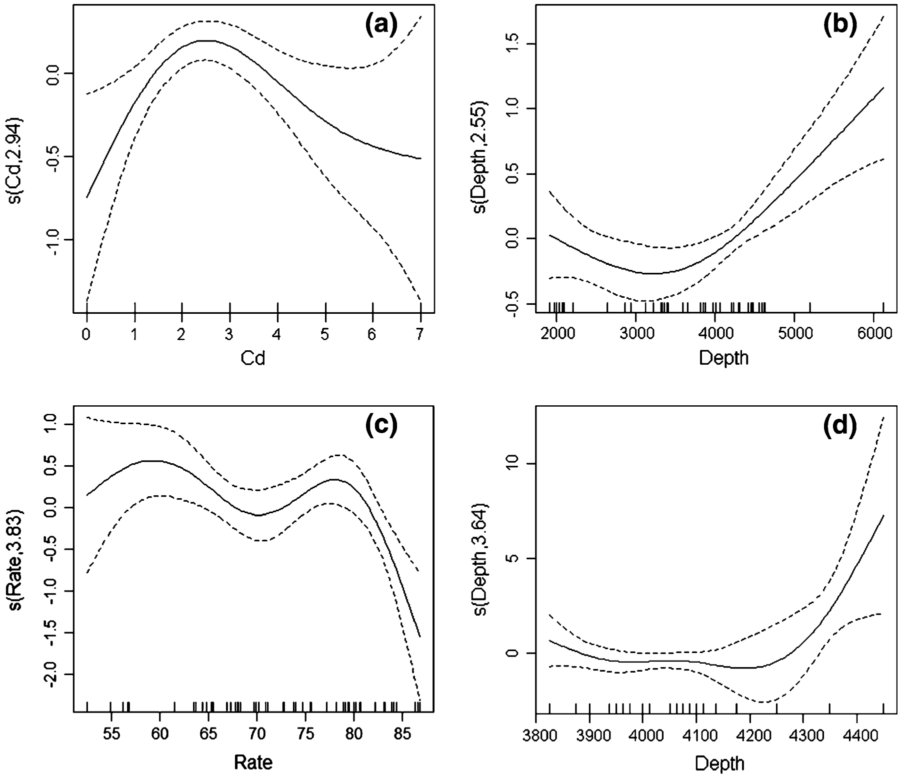


Fig. 5 GAM results: Azores (V8)—smoothing curves for partial effect of (**a**) cloud cover and (**b**) water depth on swordfish catches, and (**c**) click rate on mako catches. Brazil (V7)—smoothing curve for partial effect of (**d**) water depth on the number of likely delphinid clicks recorded. Dotted lines indicate 95% confidence bands

sightings of *Stenella frontalis* were lower during full and waxing moon (Table 7).

Depredation

Nine fish were depredated during the Brazil survey of which only one may have been depredated by false killer whales. Further statistical analysis was therefore not possible.

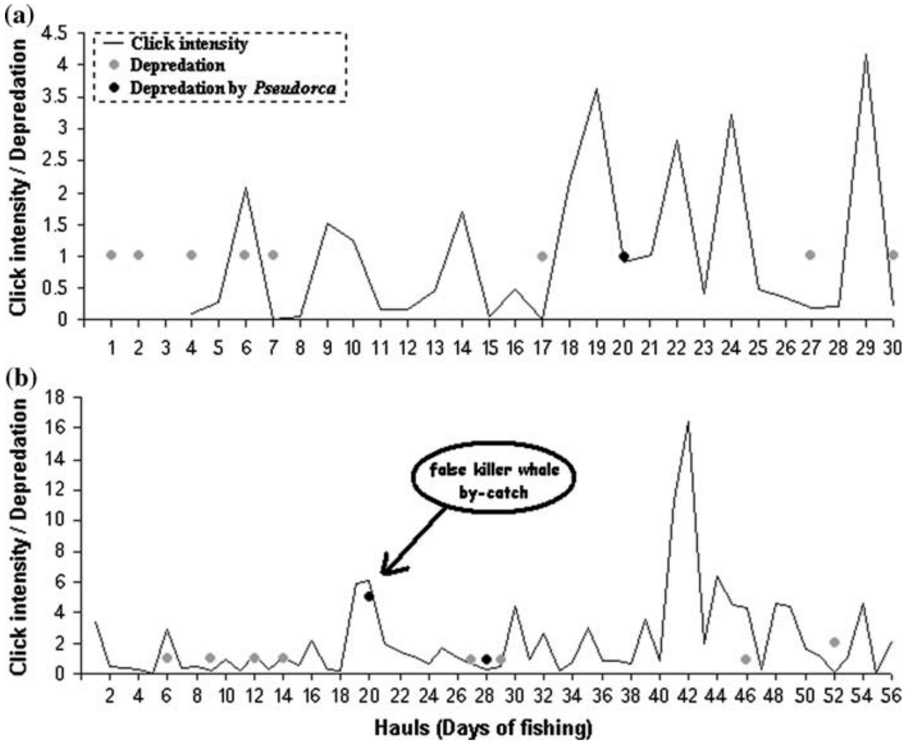
During the Azores survey, depredation affected three species (swordfish, shortfin mako and escolar), but false killer whales probably mainly removed swordfish. RDA suggested that depredation was related with sightings of false killer whales (Table 5, Fig. 10). The GLM, however, revealed that the occurrence of depredation increased when click rate was high and sightings of small delphinids (*D. delphis* and *S. frontalis*) were low (Table 7).

Discussion

Our results suggest that catches of the main target species of the fishing vessels observed were affected by environmental variables such as light conditions (cloud cover and moon phase), water temperature and water depth. Tuna, swordfish and sharks are all oceanic migratory species, which are mostly found in temperate surface waters where thermal fronts and upwelling processes occur (Collette & Nauen, 1983; Bigelow et al., 1999; Brill et al., 1999; Dagorn et al., 2000; De Stephanis et al., 2008). They show diel vertical movement patterns, feeding at the surface layer during the night (Nakamura, 1985; Bigelow et al., 1999; Domokos et al., 2007) and descending to deeper waters during the day. Therefore, longlines targeting these species are usually set in surface waters around sunset, soaking during the night, and hauled around sunrise.

Based on this small data set, moon phase appears to have an important effect on swordfish and shark catches. This was also found in other areas, e.g. the Pacific (Pallares & Garcia-Mamolar, 1985; Bigelow et al., 1999) and the Mediterranean (Damalas et al., 2007). Cloud cover also affects seabird by-catch on longlines. A higher intensity of moon and daylight (depending on moon phase and cloud cover) may improve the visibility of bait on the lines and

Fig. 6 Click intensity and occurrence of depredation for (**a**) vessel V7 (Brazil) and (**b**) vessel V8 (Azores), by set



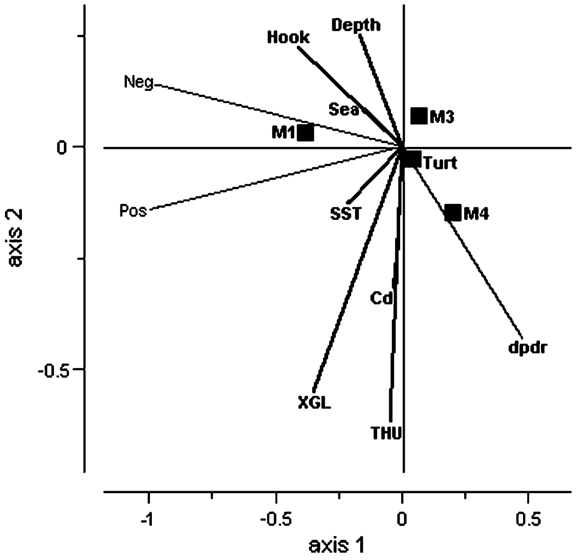


Fig. 7 RDA biplot for acoustic data from vessel V7 (Brazil). Response variables (represented by thin lines): likely delphinid clicks (Pos) and unlikely delphinid clicks (Neg). Explanatory variables (represented by thick lines if continuous and by squares if nominal): see Table 4. The plot shown was based on re-running the RDA having removed the least important (non-significant) explanatory variables, to achieve greater visual clarity

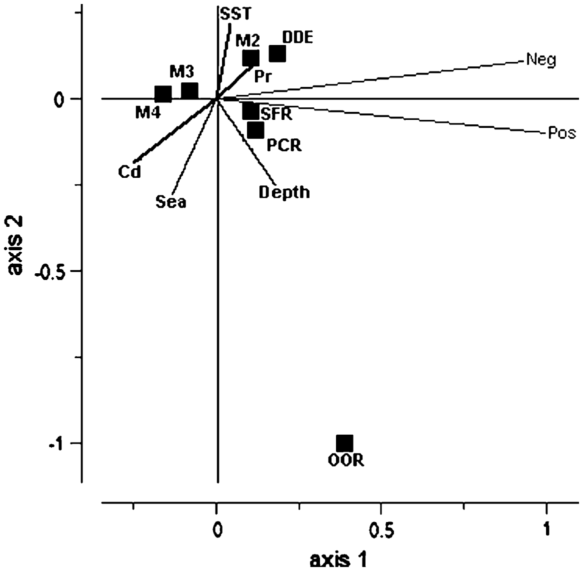


Fig. 8 RDA biplot for acoustic data from vessel V8 (Azores). Response variables (represented by thin lines): likely delphinid clicks (Pos) and unlikely delphinid clicks (Neg). Explanatory variables (represented by thick lines if continuous and by squares if nominal): see Table 4. The plot shown was based on re-running the RDA having removed the least important (non-significant) explanatory variables, to achieve greater visual clarity

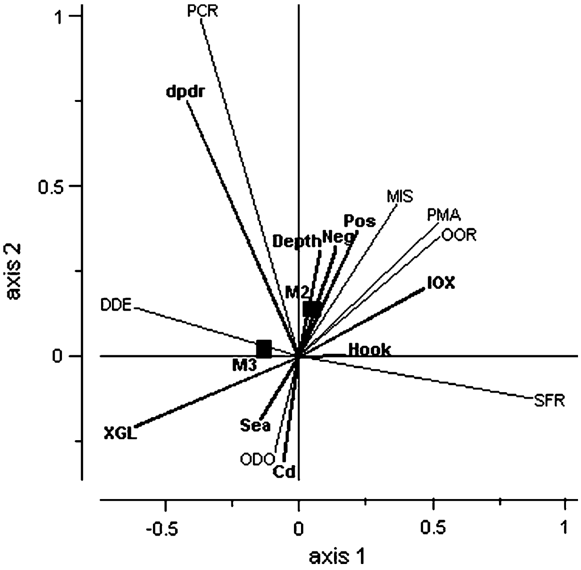


Fig. 9 RDA biplot for cetacean sightings data from vessel V8 (Azores). Response variables (represented by thin lines): Sightings of Mysticetes (MIS), *Delphinus delphis* (DDE), *Stenella frontalis* (SFR), *Pseudorca crassidens* (PCR) and *Orcinus orca* (OOR), *Physeter macrocephalus* (PMA) and not identified odontocetes (ODO). Explanatory variables (represented by thick lines if continuous and by squares if nominal): see Table 4. The plot shown was based on re-running the RDA having removed the least important (non-significant) explanatory variables, to achieve greater visual clarity

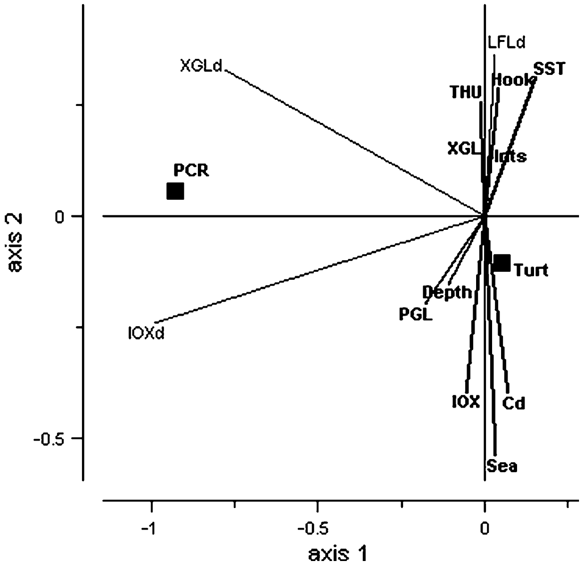


Fig. 10 RDA biplot for depredation data from vessel V8 (Azores). Response variables (represented by thin lines): Depredation on swordfish (XGLd), shortfin mako (IOXd) and Escolar (LFLd). Explanatory variables (represented by thick lines if continuous and by squares if nominal): see Table 4. The plot shown was based on re-running the RDA having removed the least important (non-significant) explanatory variables, to achieve greater visual clarity

therefore attract more fish (and sea birds) to the fishing gear (Cherel et al., 1996; Brothers et al., 1999a, b).

Bigelow et al. (1999) found that swordfish CPUE in the northern Pacific Ocean was lowest over a range of 2,000–3,000 m bottom depth, and then increased in deeper water. Our results suggest that a similar relationship applies in Atlantic waters.

The by-catch rate of cetaceans during our study was very low and similar to rates reported by Dalla Rosa & Secchi (2002). Two false killer whales were by-caught during one set off the Azores. This is consistent with the observation by Perrin et al. (1994) that, although cetacean by-catch is a major issue in fishing gear such as gillnets and trawls, with longlines it occurs only occasionally.

The frequency of false killer whale sightings was very low, perhaps because they were primarily feeding underwater on fishes hooked on the line (between 15 and 100 m water depth) and were therefore not visible for observers. Other delphinids, however, were frequently sighted. *Delphinus delphis* sightings off the Azores were more frequent when catches of swordfish were high and mako catches were low, while for sightings of *Stenella frontalis* it was the other way around. This might indicate that both delphinid species share the same habitat, but feed on different prey. However, other studies suggest that the trophic ecology of *Delphinus delphis* and *Stenella frontalis* is quite similar (Aguiar dos Santos & Haimovici, 2001).

Although they are unlikely to prey directly on large swordfish and mako sharks, respectively, they may feed on the same fish and squid species that are taken by these species. The association between swordfish and dolphins may be similar to the strong tuna-dolphin (*D. delphis* and *Stenella* species) association found in other areas (e.g. Hall & Donovan, 2002; Reeves & Reijnders, 2002). This association was originally exploited by fishermen in the Eastern Tropical Pacific where yellowfin tuna swam underneath dolphins and were thus located.

T-PODs are useful to give insight into cetacean activity under water. However, analysis of acoustic data in relation to sightings data suggested that most of the recorded clicks came from small delphinids, which produce echolocation sounds in the same frequency range as those emitted by false killer whales. False killer whales, like other odontocete species, use biosonar to echolocate their prey. Fishes hooked on a surface longline are easy to prey on and the use of echolocation may not be necessary for feeding on them.

In our study, both observer and skipper data indicate that the frequency of depredation on pelagic longlines operating in Atlantic waters was low. Less than 1% of the overall catch per trip was lost during both trips when scientific observers were on board. However, if depredation occurred, the amount of catch lost per set reported by skippers exceeded 25% on most occasions and could reach up to 100%. Similar results were reported by Dalla Rosa & Secchi (2007), Kock et al. (2006), Poisson et al. (2007) and Ramos-Cartelle & Mejuto (2007). When depredation occurred, the economic loss could be as high as 40% of the value of the catches, including vessel operation costs and fishing time lost (ARVI, unpublished data). A possible reason for the low incidence of depredation is that skippers avoid fishing areas where cetacean presence is known to be high in order to reduce interactions (Dahlheim, 1988). However, fishermen think that these animals learn to follow the longline vessels (e.g. Poisson & Taquet, 2000; Donoghue et al., 2002). It should be noted that depredation rates may be underestimated because only damaged fish were counted when calculating depredation rates, while fish removed entirely from the hooks could not be quantified.

Our results suggest that false killer whale was the main marine mammal predator removing catch from the longlines, although few instances were recorded and depredation by sharks was four times as frequent as that attributed to marine mammals. Although the species most frequently sighted in our study were *D. delphis* and *S. frontalis*, dolphins were hardly ever observed when depredation occurred which indicates that they were most likely not feeding on the hooked fish. Therefore, the co-occurrence of depredation and cetacean clicks may have been coincidental. For two of the non-observer vessels, the amount of fish caught was significantly lower when depredation by false killer whales occurred. In addition, RDA suggested a relationship between the occurrence of depredation and sightings of *Pseudorca* for the observer vessels and the only by-catch of false killer whales coincided with the removal of five swordfish from the line during one set. Dalla Rosa & Secchi (2007) reported that depredation on longline fisheries targeting swordfish in Brazilian waters was primarily caused by killer whales, but occasionally by other cetaceans such as false killer whales. However, their research was carried out closer to the coast where killer whales are more abundant (Jefferson et al., 1993).

False killer whales mainly feed on fish and cephalopods (Koen-Alonso & Pedraza, 1999; Hernandez-Garcia, 2002; Ramos-Cartelle & Mejuto, 2007). Previous studies (Secchi & Vaske, 1998; Gilman et al., 2006; Zollett & Read, 2006) demonstrated that fish hooked on longlines was becoming a new resource, changing the feeding customs of the cetaceans. According to Ramos-Cartelle & Mejuto (2007), the cetaceans learnt to use the bait and catches retained on the fishing gear as an ‘easy’ prey to capture and thereby reduce the energy costs of feeding. They seem to be selective when taking fish from the lines (Kock et al., 2006). In our study, the main fish species consumed by cetaceans was swordfish. This was also found by Poisson & Taquet (2000) and Dalla Rosa & Secchi (2007). However, off Brazil tuna was the main fish captured and sharks were the main target species (followed by swordfish) off the Azores. Thus the consumption of swordfish might indicate a preference of the cetaceans for this species, as suggested by Dalla Rosa & Secchi (2007) and Poisson and Taquet (2000).

While observers reported depredation by sharks and other animals, skippers on the other six vessels reported depredation in general, with the assumption that false killer whales were responsible being based on sightings of this species alongside the boats. Donoghue et al., (2002) indicated that fish damaged by sharks may be inaccurately reported. Skippers may not distinguish between different types of bite marks.

Turtle by-catch was frequent, especially when a higher number of sharks were caught, and involved at least four different turtle species. Carranza et al. (2006) found that mako sharks preyed upon various species of sea turtles in the Equatorial Eastern Atlantic. This might also apply in our study area. Several instances of damage to hooked fish were attributed to turtles. Although in this study most turtles were apparently released alive, turtle by-catch remains a major issue in longline fisheries, one which can possibly be reduced by use of alternative hook designs and bait or by fishing deeper (e.g. Gilman et al. 2007a, b).

Conclusions

In our study, catch rates were influenced by environmental parameters such as light conditions, SST and water depth, whereas cetacean presence was mainly related to the catch rates of particular fish species, possibly indicating trophic relationships between species. Acoustic recordings probably reflected the presence of delphinids in general rather than false killer whales in particular and it is possible that false killer whales preying on longlines do not need to use biosonar to locate their prey. The depredation rate and the overall amount of catch consumed during our survey were low, but when depredation occurred, the proportion of catch lost mostly exceeded 25%. Although the statistical analysis revealed some potentially interesting relationships between catches, cetacean presence, depredation and environmental variables, it is important to note that this was a small-scale study: we analysed data from 86 observed sets and more data are needed to further explore and quantify these relationships.

Acknowledgements We would like to thank the Spanish Secretaría General de Pesca Marítima for funding the present study 'Developing an Acoustic Prototype to Reduce Depredation by Marine Mammals on Swordfish Fisheries (Pingers)'. GHM, SG and GJP received additional support from the EU-funded projects Envi-EFH (SSA 022466), ECOSUMMER (MEST-CT-2005-020501) and ANIMATE (MEXC-CT-2006-042337), respectively. Furthermore, we would like to address our special thanks to all captains and fishermen for their cooperation and to the members of CEMMA (Coordinadora para los estudios de mamíferos marinos) who helped with the design of the cetacean surveys and the review of the results. We also like to thank Colin MacLeod and Alain Zuur for assisting with the statistical analysis and Gema Martinez for assisting with production of maps.

References

Aguiar dos Santos, R. & M. Haimovici, 2001. Cephalopods in the diet of marine mammals stranded or incidentally caught along southeastern and southern Brazil (21–34°S). Fisheries Research 52: 99–112.

Ashford, J. P., P. S. Rubilar & A. R. Martin, 1996. Interactions between cetaceans and longline fishery operations around South Georgia. Marine Mammal Science 12: 452–457.

Bigelow, K. A., C. H. Boggs & X. He, 1999. Environmental effects on swordfish and blue shark catch rates in the US North Pacific longline fishery. Fisheries Oceanography 8: 178–198.

Brill, R. W., B. A. Block, C. H. Boggs, K. A. Bigelow, E. V. Freund & D. J. Marcinek, 1999. Horizontal movements and depth distribution of large, adult yellowfin tuna (*Thunnus albacares*) near the Hawaiian Islands, recorded using ultrasonic telemetry: implications for the physiological ecology of pelagic fishes. Marine Biology 133: 395–408.

Brothers, N. P., J. Cooper & S. Løkkeborg, 1999a. The incidental catch of seabirds by longline fisheries: worldwide review and technical guidelines for mitigation. FAO Fisheries Circular 937. FAO, Rome.

Brothers, N. P., R. Gales & T. Reid, 1999b. The influence of environmental variables and mitigation measures on seabird catch rates in the Japanese tuna longline fishery within the Australian Fishing Zone, 1991–1995. Biological Conservation 88: 85–101.

Capdeville, D., 1997. Interaction of marine mammals with the longline fishery around the Kerguelen Islands (Division 58.5.1) during the 1995/96 cruise. CCAMLR Science 4: 171–174.

Carranza, A., A. Domingo & A. Estrades, 2006. Pelagic longlines: a threat to sea turtles in the Equatorial Eastern Atlantic. Biological Conservation 131: 52–57.

Carstensen, J., O. D. Henriksen & J. Teilmann, 2006. Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echolocation activity using porpoise detectors (TPODs). Marine Ecology Progress Series 321: 295–308.

Carwadine, M., 1995. Whales, Dolphins and Porpoises. Dorling Kindersley, London.

Cherel, Y., H. Weimerskirch & G. Duhamel, 1996. Interactions between longline vessels and seabirds in Kerguelen waters and a method to reduce seabird mortality. Biological Conservation 75: 63–70.

Collette, B. B. & C. E. Nauen, 1983. FAO species catalogue. Scombrids of the world. An annotated catalogue of tunas, mackerels, bonitos and related species known to date. FAO Fisheries Synopsis 125-2. FAO, Rome.

Dagorn, L., P. Bach & E. Josse, 2000. Movement patterns of large bigeye tuna (*Thunnus obesus*) in the open ocean, determined using ultrasonic telemetry. Marine Biology 136: 361–371.

Dahlheim, M. E., 1988. Killer Whale (*Orcinus orca*) Depredation on Longline Catches of Sablefish (*Anoplopoma fimbria*) in Alaskan Waters. Alaska Fisheries Science Centre, Seattle, Washington. NWAFC Report 88-14.

Dalla Rosa, L. & E. R. Secchi, 2002. Comparative analysis of the interactions between killer whales/sharks and the tuna/swordfish fishery in southern and southeastern Brazil. In Donoghue, M., R. R. Reeves & G. S. Stone (eds), Report of the Workshop on Interactions Between Cetaceans and Longline Fisheries. Apia, Samoa, 2002.

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

Dalla Rosa, L., E. R. Secchi & D. Monteiro, 2006. Killer whale depredation on longline catches in Brazilian waters. Proceedings of the Workshop on Fisheries Depredation by Killer and Sperm Whales: Behavioural Insights, Behavioural Solutions, British Columbia, Canada, 2006.

Damalas, D., P. Megalofonou & M. Apostolopoulou, 2007. Environmental, spatial, temporal and operational effects on swordfish (*Xiphias gladius*) catch rates of eastern Mediterranean Sea longline fisheries. Fisheries Research 84: 233–246.

De Stephanis, R., T. Cornulier, P. Verborgh, J. Salazar-Sierra, N. Perez Gimeno & C. Guinet, 2008. Summer spatial distribution of cetaceans in the Strait of Gibraltar in relation to the oceanographic context. Marine Ecology Progress Series 353: 275–288.

Domokos, R., M. P. Seki, J. J. Polovina & D. R. Hawn, 2007. Oceanographic investigation of the American Samoa Albacore (*Thunnus alalunga*) habitat and longline fishing grounds. Fisheries Oceanography 16: 555–572.

Donoghue, M., R. R. Reeves & G. S. Stone, 2002. Report of the Workshop on Interactions Between Cetaceans and Longline Fisheries. New England Aquarium Press, Boston MA, USA.

Garza Gil, M. D., M. M. Varela-Lafuente & C. Iglesias Malvido, 2003. Spain's North Atlantic swordfish fishery. Marine Policy 27: 31–37.

Gilman, E., N. Brothers, G. McPherson & P. Dalzell, 2006. A review of cetacean interactions with longline gear. Journal of Cetacean Research and Management 8: 215–223.

Gilman, E., S. Clarke, N. Brothers, J. Alfaro-Shigueto, J. Mandelman, J. Mangel, S. Petersen, S. Piovano, N. Thomson, P. Dalzell, M. Donoso, M. Goren & T. Werner, 2007a. Shark Depredation and Unwanted By-catch in Pelagic Longline Fisheries: Industry Practices and Attitudes, and Shark Avoidance Strategies. Western Pacific Regional Fishery Management Council, Honolulu, USA.

Gilman, E., D. Kobayashi, T. Swenarton, N. Brothers, P. Dalzell & I. Kinan-Kelly, 2007b. Reducing sea turtle interactions in the Hawaii-based longline swordfish fishery. Biological Conservation 139: 19–28.

Hall, M. A. & G. P. Donovan, 2002. Environmentalists, fishermen, cetaceans and fish: is there a balance and can science help to find it? In Evans, P. G. H. & J. A. Raga (eds), Marine Mammals: Biology and Conservation. Kluwer Academic Press, New York: 491–521.

Hernandez-Garcia, V., 2002. Contents of the digestive tract of a false killer whale (*Pseudorca crassidens*) stranded in Gran Canaria (Canary Islands, central east Atlantic). Bulletin of Marine Science 71: 367–369.

International Commission for the Conservation of Atlantic Tunas (ICCAT), 2007. Report for the Biennial Period, 2006–2007, Part 1–2. http://www.iccat.int.

Jefferson, T., S. Leatherwood & M. Webber, 1993. FAO Species Identification. Marine Mammals of the World. FAO, Rome.

Koen-Alonso, M. & S. N. Pedraza, 1999. Stomach contents of false killer whales (*Pseudorca crassidens*) stranded on the coasts of the Strait of Magellan, Tierra del Fuego. Marine Mammal Science 15: 712–724.

Kock, K. H., M. Purves & G. Duhamel, 2006. Interactions between cetaceans and fisheries in the Southern Ocean. Polar Biology 29: 379–388.

Lammers, M. O., W. W. L. Au, R. Aubauer & P. E. Nachtigall, 2003. A comparative analysis of the pulsed emissions of free-ranging Hawaiian spinner dolphins (*Stenella longirostris*). In Thomas, J. E., C. F. Moss & M. Vater (eds), Echolocation in Bats and Dolphins. University of Chicago Press, Chicago.

Leeney, R. H. & N. J. C. Tregenza, 2006. Proceedings of the Workshop on Static Acoustic Monitoring of Cetaceans, Gdynia, Poland, 2006. ECS Newsletter 46, Special Issue.

Lewison, R. L., S. A. Freeman & L. B. Crowder, 2004. Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. Ecology Letters 7: 221–231.

Madsen, P. T., I. Kerr & R. Payne, 2004. Echolocation clicks of two free-ranging, oceanic delphinids with different food preferences: false killer whales *Pseudorca crassidens* and Risso's dolphins *Grampus griseus*. Journal of Experimental Biology 207: 1811–1823.

Memery, L., M. Arhan, X. A. Alvarez-Salgado, M. J. Messias, H. Mercier, C. G. Castro & A. F. Rios, 2000. The water masses along the western boundary of the south and equatorial Atlantic. Progress in Oceanography 47: 69–98.

Morato, T., S. Guénette & T. Pitcher, 2001. Fisheries of the Azores, 1982–1999. In Zeller, D., R. Watson, T. Pitcher & D. Pauly (eds), Fisheries Impacts on North Atlantic Ecosystems: Catch, Effort and National/Regional Data Sets, Vol. 9. Fisheries Centre Research Reports, University of British Columbia, British Columbia: 214–220.

Nakamura, I., 1985. FAO species catalogue. Billfishes of the World. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. FAO Fisheries Synopsis 125-5. FAO, Rome.

Northridge, S. P., 1984. World review of interactions between marine mammals and fisheries. FAO Fisheries Technical Paper 251. FAO, Rome.

Pallares, P. & J. M. Garcia-Mamolar, 1985. Efectos de las fases de la luna sobre los rendimientos de la flota atuneratropical española. Collective Volume of Scientific Papers. International Commission for the Conservation of Atlantic Tunas (ICCAT) 23: 228–236.

Perrin, W. F., G. P. Donovan & J. Barlow, 1994. Report of the International Whaling Commission. Gillnets and Cetaceans. International Whaling Commission, Special Issue 15, Cambridge, UK.

Philpott, E., A. Englund, S. Ingram & E. Rogan, 2007. Using T-PODs to investigate the echolocation of coastal bottlenose dolphins. Journal of the Marine Biological Association of the UK 87: 11–17.

Poisson, F. & M. Taquet, 2000. French Swordfish longline fishery in South-West Indian Ocean: preliminary results from the PPR Program. IOTC Proceedings, WPB00-06.

Poisson, F., C. Marjolet, K. Mete & M. Vanpouille, 2007. Interactions of cetaceans and sharks with the Reunion Island swordfish longline fishery in the Indian Ocean between 1997 and 2000. Report of the IOTC Workshop on the Depredation in the Tuna Longline Fisheries in the Indian Ocean, Victoria, Seychelles.

Ramos-Cartelle, A. & J. Mejuto, 2007. 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. Report of the Standing Committee on Research and Statistics SCRS of the International Commission for the Conservation of Atlantic Tunas (ICCAT) 25 (ICCAT/SCRS/07/25).

Reeves, R. R. & P. J. H. Reijnders, 2002. Conservation and management. In Hoelzel, A. R. (ed.), Marine Mammal Biology: An Evolutionary Approach. Blackwell Science, Oxford.

Romo, A., C. Casanova, J. Sanz, A. Calle & J. L. Casanova, 2007. Relation between meteorological conditions and the catching of red tuna (*Thunnus thynnus*) from the measurements of the TOVS and AVHRR sensors of the NOAA satellites. International Journal of Remote Sensing 28: 2671–2681.

Schotten, M., W. W. L. Au, M. O. Lammers & R. Aubauer, 2003. Echolocation recordings and localization of wild spinner dolphins (*Stenella longirostris*) and pantropical spotted dolphins (*S. attenuata*) using a four-hydrophone array. In Thomas, J. E., C. F. Moss & M. Vater (eds), Echolocation in Bats and Dolphins. University of Chicago Press, Chicago.

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

Skov, H., J. Teilmann, O. D. Henriksen & J. Carstensen, 2002. Investigations of harbour porpoises at the planned site for wind turbines at Horns Reef. Status report: 1/1/2001–31/12/2001. Commissioned by Tech-wise A/S. Ornis Consult A/S. http://www.hornsrev.dk/Miljoeforhold/miljoerapporter/Investigations_of_harbour_popoises.pdf.

Stacey, P. J., S. Leatherwood & R. W. Baird, 1994. *Pseudorca crassidens*. Mammalian Species 456: 1–6.

Tougaard, J., J. Carstensen, O. D. Henriksen, J. Teilmann & J. R. Hansen, 2004. Harbour porpoises on Horns Reef—effects of the Horns Reef Wind Farm. Annual Status Report 2003. Commissioned by Elsam Engineering A/S, National Environmental Research Institute (NERI).

Wood, F. G. & W. E. Evans, 1980. Adaptiveness and ecology of echolocation in toothed whales. In Busnel, R. & J. Fish (eds), Animal Sonar Systems. Plenum, New York.

Zavala-Camin, L. A. & J. N. Antero da Silva, 1991. Histórico da pesquisa e pesca de atuns com espinhel no Brasil. Atlantica, Rio Grande 13: 107–114.

Zavilov, P. O., I. Wainer & J. M. Absy, 1999. Sea surface temperature variability off southern Brazil and Uruguay as revealed from historical data since 1854. Journal of Geophysical Research 105: 21–32.

Zollett, E. A. & A. J. Read, 2006. Depredation of catch by bottlenose dolphins (*Tursiops truncatus*) in the Florida king mackerel (*Scomberomorus cavalla*) troll fishery. Fishery Bulletin 104: 343–349.

Zuur, A. F., E. N. Ieno & G. M. Smith, 2007. Analysing Ecological Data. Springer, New York.