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MARINE MAMMALS AND DEMERSAL LONGLINE FISHERY INTERACTIONS IN CROZET AND KERGUELEN EXCLUSIVE ECONOMIC ZONES: AN ASSESSMENT OF DEPREDATION LEVELS

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Abstract

Interactions between killer whales (*Orcinus orca*), sperm whales (*Physeter macrocephalus*), fur seals (*Arctocephalus* spp.) and longline fishing operations were reported by observers on board fishing vessels targeting Patagonian toothfish (*Dissostichus eleginoides*) in the Crozet and Kerguelen Islands Exclusive Economic Zones (EEZs) between 2003 and 2005. In the Crozet EEZ, the reported interactions involved killer whales and sperm whales. These two species, alone or in co-occurrence with each other, were observed in 71% of the 1 308 longlines set. In the Kerguelen EEZ, the reported interactions involved sperm whales and fur seals. These two species, alone or in co-occurrence with each other, were observed in 54% of the 6 262 longlines monitored. Interactions were observed in all fishing areas. The effect of depredation was assessed by comparing catch-per-unit-effort (CPUE) (fish weight/hook) of each longline set in the absence/presence of marine mammal species alone or in co-occurrence. In the Crozet EEZ, CPUE was found to be reduced by 22.5% in the presence of killer whales, 12.1% by sperm whales, and 42.5% when both species were present together. An extensive photo-identification effort, primarily focussing on killer whales, allowed a total of 103 individual whales to be identified. The analysis of photo-identification indicated that a small number of individual killer whales were responsible for most of the interactions with the fishery. In the Kerguelen EEZ only sperm whales, alone or in co-occurrence with fur seals, were found to impact negatively on CPUE.

Résumé

Les interactions entre les orques (*Orcinus orca*), les cachalots (*Physeter macrocephalus*), les otaries (*Arctocephalus* spp.) et les opérations de pêche à la palangre ont été enregistrées par les observateurs à bord des navires de pêche visant la légine australe (*Dissostichus eleginoides*) dans les Zones Économiques Exclusives (ZEE) des îles Kerguelen et Crozet entre 2003 et 2005. Dans la ZEE de Crozet, les interactions signalées concernaient des orques et des cachalots. Ensemble ou séparément, ces deux espèces ont été observées lors de 71% des 1 308 poses de palangre. Dans la ZEE de Kerguelen, les interactions signalées concernaient des cachalots et des otaries. Ces deux espèces, ensemble ou séparément, ont été observées lors de 54% des 6 262 poses de palangre. Des interactions ont été observées sur l'ensemble des secteurs de pêche. L'effet de la déprédation a été évalué en comparant la capture par unité d'effort (CPUE) (poids du poisson/hameçon) de chaque palangre posée, en l'absence et en présence des espèces de mammifères marins seuls ou ensemble. Dans la ZEE de Crozet, la CPUE a été trouvée réduite de 22,5% lorsque les orques étaient présentes, de 12,1% en présence de cachalots et de 42,5% lorsque les deux espèces étaient présentes simultanément. Un effort important d'identification photographique, consacré essentiellement aux orques, a permis d'identifier 103 individus différents. L'analyse des résultats de photo-identification indique qu'à elles seules, quelques orques étaient responsables de la plupart des interactions avec la pêcherie. Dans la ZEE de Kerguelen, ce sont les cachalots qui, seuls ou en association avec les otaries, auraient un impact négatif sur la CPUE.

Резюме

О взаимодействии между косатками (*Orcinus orca*), кашалотами (*Physeter macrocephalus*), морскими котиками (виды *Arctocephalus*) и ярусным промыслом сообщали наблюдатели, находившиеся на судах, ведущих промысел патагонского клыкача (*Dissostichus eleginoides*) в исключительных экономических зонах (ИЭЗ) о-вов Крозе и Кергелен в период 2003–2005 гг. В ИЭЗ о-вов Крозе сообщалось о взаимодействии с косатками и кашалотами. Эти два вида, по отдельности или вместе, наблюдались в 71% всех постановок яруса (1308). В ИЭЗ о-вов Кергелен сообщалось о взаимодействии с кашалотами и морскими котиками. Эти два вида, по отдельности или вместе, наблюдались в 54% всех наблюдений ярусов (6262). Взаимодействия наблюдались во всех промысловых районах. Результат нападения хищников оценивался путем сравнения улова на единицу усилия (CPUE) (вес рыбы/крючок) для каждой постановки яруса при наличии/отсутствии видов морских млекопитающих поодиночке или вместе. Было подсчитано, что в ИЭЗ о-вов Крозе CPUE сокращался на 22.5% при наличии косаток, на 12.1% при наличии кашалотов и на 42.5%, когда присутствовали оба вида вместе. Была проведена большая работа по фото-идентификации, в основном, косаток, которая позволила идентифицировать в общей сложности 103 отдельных кита. Анализ результатов фото-идентификации показал, что большинство взаимодействий с промыслом приходится на небольшое количество отдельных косаток. В ИЭЗ о-вов Кергелен было выявлено, что только кашалоты, иногда совместно с морскими котиками, отрицательно воздействовали на CPUE.

Resumen

Observadores a bordo de barcos dedicados a la pesca de palangre de austromerluza negra (*Dissostichus eleginoides*) en las Zonas de Exclusividad Económica (ZEE) de las Islas Crozet y Kerguelén entre 2003 y 2005 informaron sobre las interacciones entre las orcas (*Orcinus orca*), los cachalotes (*Physeter macrocephalus*), los lobos finos (*Arctocephalus* spp.) y las operaciones de pesca. Las interacciones observadas en la ZEE de Isla Crozet comprendieron orcas y cachalotes. En el 71% de los 1 308 lances de palangre se observaron estas dos especies actuando por sí solas o en conjunto. En las interacciones observadas en la ZEE de Kerguelén participaron cachalotes y lobos finos. En 54% de los 6 262 lances de palangre observados se detectó estas dos especies actuando por sí solas o en conjunto. Se observaron interacciones en todas las zonas de pesca. El efecto de la depredación fue evaluado comparando la captura por unidad de esfuerzo (CPUE) (peso del pez/anzuelo) para cada lance de palangre en ausencia/presencia de las especies de mamíferos marinos observadas, ya sea separadamente o en conjunto. Se encontró que la CPUE en la ZEE de Isla Crozet disminuyó 22.5% en presencia de orcas, 12.1% en presencia de cachalotes y 42.5% en presencia de ambas especies. La intensa labor de identificación fotográfica dedicada principalmente a las orcas permitió identificar un total de 103 ballenas. El análisis de la identificación fotográfica indicó que un pequeño número de orcas solitarias fue responsable de la mayoría de las interacciones con la pesquería. En la ZEE de Kerguelén se encontró que sólo los cachalotes, por sí solos o conjuntamente con los lobos marinos, afectaron negativamente la CPUE.

Keywords: Crozet EEZ, Kerguelen EEZ, fishery, depredation, killer whales, *Orcinus orca*, sperm whales, *Physeter macrocephalus*, légine, Patagonian toothfish, *Dissostichus eleginoides*, CCAMLR

Introduction

Over the past decade, pelagic fisheries, and longline fishing in particular, have undergone a rapid expansion. Since the United Nations' prohibition of large-scale high-seas driftnet fishing in 1994, a number of fleets have increased their longline effort. Furthermore, some demersal longline fisheries have also expanded rapidly. Concomitant with the expanding longline fishing effort, the scale of interactions between longline fisheries and cetaceans has increased (Donoghue et al., 2002). Interactions are classified as either biological or operational. While biological interactions are indirect, and involve competition between fisheries and marine mammals for food sources, operational interactions are direct, and include the removal of fish from lines or nets by marine mammals, or entanglements with equipment. Reports on the removal by marine mammals of fish caught on commercial longlines (depredation) indicate an increase in both the frequency of such events and in the number of cetacean species involved. The problem is now documented in all oceans and concerns many fisheries (Barlow et al., 1994; Mussi et al., 1998; Space et al., 1998; Lauriano et al., 2004; Baird and Gorgone, 2005).

Interactions between marine mammals and Patagonian toothfish (*Dissostichus eleginoides*) fishery operations have been reported in the Southern Ocean (Kock et al., 2006), off South Georgia (Ashford et al., 1996; Purves et al., 2004), the Falkland/Malvinas Islands (Nolan et al., 2000), Crozet, Kerguelen (Capdeville, 1997) and Heard Islands (unpublished data). Killer whales (*Orcinus orca*) and sperm whales (*Physeter macrocephalus*) are the two main cetacean species reported as interacting with this fishery (SC-CAMLR, 2003; Hucke-Gaete et al., 2004). However, further investigations are needed to address the problems of cetacean depredation on longlines which could have serious implications on both fish stock management and marine mammal conservation. Losses due to depredation are in fact not usually accounted for in fish stock assessment and quota allocation processes. Depredation could also have a serious impact on marine mammal species by increasing the risk of mortality by entanglement and also modifying marine mammal foraging behaviour and energy balance by providing access to a source of prey usually inaccessible or not part of their usual diet. This is particularly important within the context of a rapid decrease in the population numbers of Crozet archipelago killer whales (Poncelet, 2003). Moreover, a major decrease in the standardised catch-per-unit-effort (CPUE) from 2000 to 2003 was reported by the Patagonian toothfish fishery in the Crozet Exclusive Economic Zone (EEZ). Two possible explanations for this CPUE decrease are proposed: (i) an overexploitation of the fish stock due mainly to the high total removals in 1996 and 1997; and/or (ii) a possible cumulative effect of fishing in combination with the killer whale depredation on longlines. Indeed, observers reported that Crozet archipelago killer whales use Patagonian toothfish on the longlines opportunistically as a source of food.

The objectives of this study were: (i) to characterise and quantify interactions between marine mammals and the fishery; (ii) to assess the level of depredation, and the consequent financial losses, caused by the various marine mammal species; and (iii) to identify the marine mammal species which interact with the fishery in the Crozet and Kerguelen EEZs, and in the case of the Crozet EEZ, to use the photo-identification method to identify individual killer whales which interact with the fishery.

Materials and methods

Between 9 September 2003 and 3 October 2005 a total of 1 308 and 6 263 longlines were set by seven fishing vessels in the Crozet and Kerguelen EEZs respectively. The vessels operated all year round, with the exception of February in the Kerguelen EEZ when the fishery was closed in accordance with measures aimed at reducing incidental seabird mortality (Weimerskirch et al., 1999). During this period, three different species of marine mammals were observed to be interacting with the fishery: sperm whales, killer whales and fur seals. Both single- and mixed-species interactions were observed.

Fishing technique

Fishing vessels operating in the Crozet and Kerguelen EEZs use autoline-system longlines set in a series of 1 km long sections (up to eight sections) with 1 000 hooks each. Longlines are maintained at depths ranging between 800 and 1 200 m by weights attached to each end of the line. While sperm whales are able to dive to these depths, killer whales (Bowers and Henderson, 1972) and fur seals (*Arctocephalus* spp.) can only access fish when the longlines are hauled to the surface, and consequently have to come close to the fishing vessel to retrieve the fish.

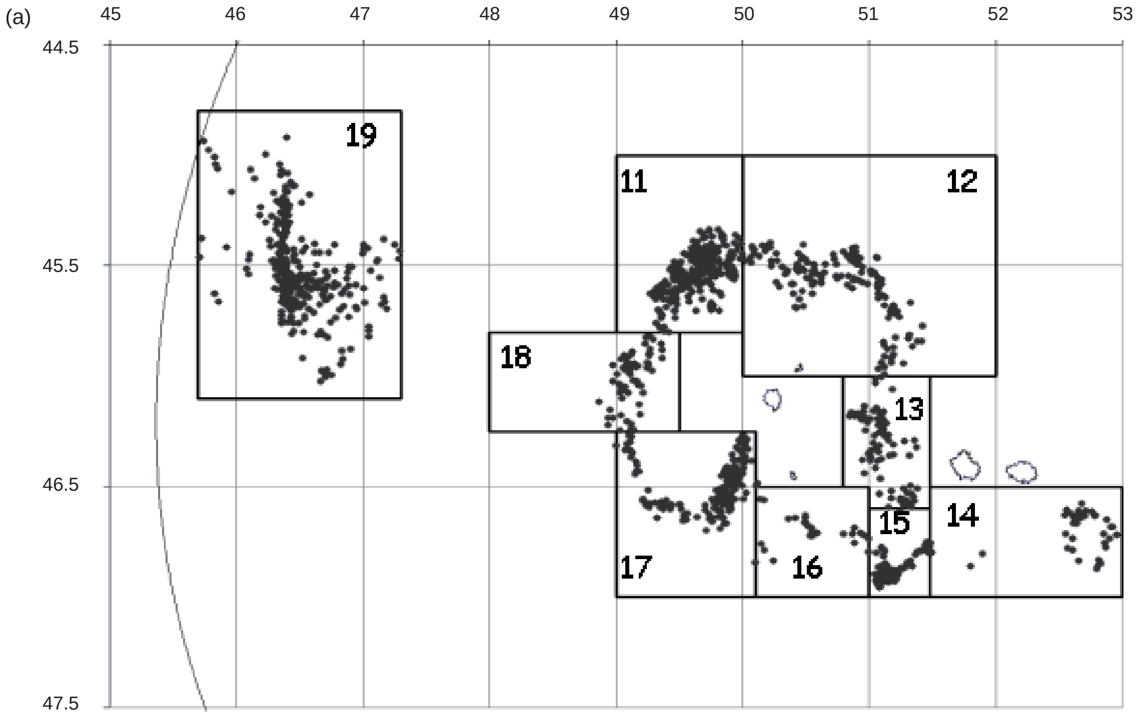
Fishing grounds in the Kerguelen EEZ were subdivided into 10 contiguous fishing sectors (labelled from 1 to 10), and those in the Crozet EEZ, into nine fishing sectors (labelled from 11 to 19) (Figures 1a and 1b). In this paper, depredation is defined as the loss of longline-caught fish to marine mammals.

Observer protocol

Fishery observers on board fishing vessels were required: (i) to collect data for fishery management purposes (e.g. species targeted, tonnes landed, area fished) and assessment of resources (e.g. sampling of fish lengths and weights); (ii) to record the by-catch level (e.g. number of non-target species landed); and (iii) to record interactions between the fishery and protected species (e.g. species and number of seabirds and marine mammals present in the vicinity of the longlines, incidental seabird mortality).

Interaction and depredation level estimates

During each haul, observers had to follow a precise protocol for recording data on the presence of marine mammals. They were required: (i) to note the species involved – killer whales, sperm whales and/or fur seals; (ii) to estimate visually the total number of animals and, if possible, to evaluate the number of males and females; and (iii) to report interactions between different marine mammal species and/or between marine mammals and fishing activities. In this paper the interaction between marine mammals and the fishery is defined as an event during which marine mammals remained in the vicinity of the longline during the haul for a



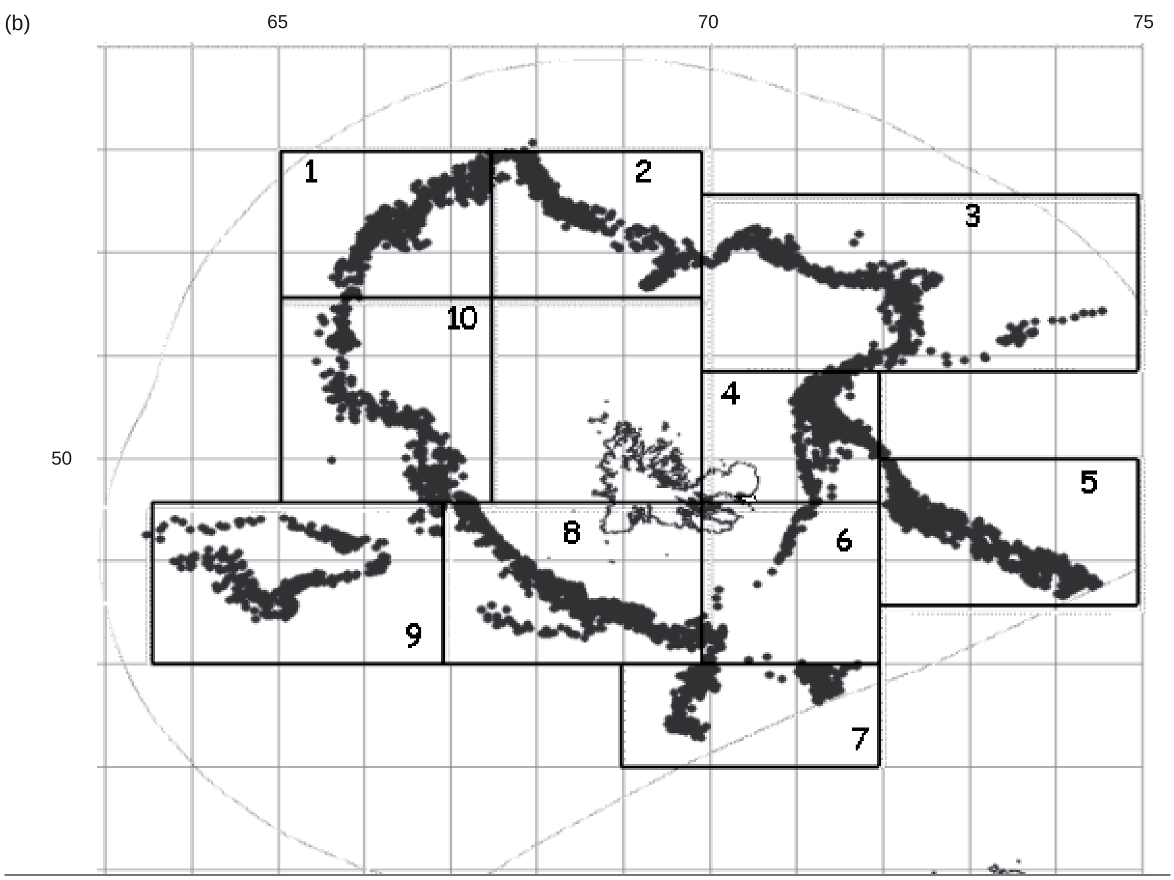


Figure 1: Spatial distribution of longline sets in (a) the nine fishing sectors in the Crozet EEZ, and (b) the 10 fishing sectors in the Kerguelen EEZ, between 2003 and 2005. Narrow black lines represent the boundaries of the EEZs; thick black lines represent the boundaries of the fishing sectors.

period extending from 5 minutes to hours. Initially, no data on the arrival and/or departure time of marine mammals from the line-hauling site were recorded. Only their presence was therefore recorded. The co-occurrence of two species was recorded as an event during which animals of both species were reported at least once during the same haul.

The rate of interaction with killer or sperm whales for a given fishing sector was expressed as the ratio of the number of longline hauls in the presence of cetaceans divided by the total number of longlines set by a given fishing vessel.

The assessment of fish damaged by depredation was mostly qualitative. However, as generally agreed, depredation often results in many fish being entirely removed from the longlines, and taking into account damaged fish only would, therefore, lead to an underestimate of the depredation level. In order to assess whether depredation rates vary through the year, comparisons of CPUE were performed during the fishing season in the absence of marine mammals and in the presence of any combination of the three marine mammal species. Analysis of covariance (ANCOVA) was used to compare the mean CPUE in different combinations of marine mammal species observed within each of the fishing sectors and fishing periods.

Photo-identification

Five observers were asked to take as many photographs as possible of killer whales and sperm whales interacting with the fishery, in order to photo-identify them. Observers took photographs of completely exposed dorsal fins and saddle patches of surfacing killer whales and dorsal fins and tail flukes of sperm whales.

In the case of killer whales, close-up photographs of dorsal fins and saddle patches allowed individuals to be identified from natural features or 'marks' on their dorsal fins (shape, notches, scars); (Bigg et al., 1983) and characteristics of their saddle patch(es) (colour, form and scars). Individuals without dorsal fin notches were only identified from their left saddle patch. The anterior part of the eye patch was also used as an identifier in this study. A database of all killer whales observed around Crozet was created with details on sighting location and other relevant data, and a catalogue produced, showing the best image of each identified individual. Photo-identified killer whales observed interacting with fishing vessels in offshore waters of the Crozet and Kerguelen EEZs were compared with the existing database of killer whales identified from Possession Island, in the Crozet archipelago.

The work on the photo-identification of sperm whales observed in the Crozet and Kerguelen EEZs is still in progress and has not been included in this study.

Results

Estimates of interaction and depredation levels

Sperm whales were commonly encountered interacting with the fishery both in the Crozet (57.6% of the longlines set) and Kerguelen (33.6% of the longlines set) EEZs, alone or in co-occurrence with other species.

A difference in the interactions of the main species of marine mammals with longlines during the haul was observed between the Crozet and Kerguelen EEZs. In the Crozet EEZ, interactions with killer whales occurred in 43% of the hauls, whereas in the Kerguelen EEZ it occurred in less than 1%. However, as regards fur seals in the Kerguelen EEZ, interactions were observed in 39.3% of the longlines hauled, but in the Crozet EEZ, only in 1% (Table 1). In the Crozet EEZ, both sub-Antarctic fur seals (*Arctocephalus tropicalis*) and Antarctic fur seals (*A. gazella*) breed, and it would be possible for both species to interact with the fishery. Therefore, in the Crozet EEZ, both species are referred to as fur seals (*Arctocephalus* spp.). In the Kerguelen EEZ on the other hand, *A. gazella* is the only breeding species. Therefore, in this area, fur seals are referred to as Antarctic fur seals only.

Due to the difference described above and the fact that CPUE in the absence of marine mammals was significantly higher in the Kerguelen EEZ compared to the Crozet EEZ, data from both localities were analysed separately.

Kerguelen EEZ

The mean numbers of killer whales, sperm whales and fur seals observed in longline fishery interactions were 4.8 ± 1.7 (n = 18, range 1–7), 2.5 ± 1.8 (n = 2 097, range 1–15), and 5.7 ± 5.6 (n = 2 459, range 1–50) individuals respectively.

Due to the low number of observed killer whale interactions in the Kerguelen EEZ over the study period, depredation was only estimated for the following four categories of interactions: (i) fur seals only; (ii) sperm whales only; (iii) sperm whales and fur seals together; and (iv) no marine mammals. A total of 6 244 longline sets were analysed.

Table 1: Number and percentage of longlines observed with interactions involving different combinations of marine mammal species (*Orcinus orca* – *Oo*; *Physeter macrocephalus* – *Pm*; *Arctocephalus* spp. – *A.* spp.), in the Crozet and Kerguelen EEZs, between 2003 and 2005.

Type of interaction	Crozet EEZ		Kerguelen EEZ	
	Number	%	Number	%
No marine mammals	373	**28.5**	2 839	**45.3**
A. spp.	4	0.3	1 313	**21.1**
Oo	178	**13.6**	7	0.1
Pm	361	**27.6**	944	**15.1**
Oo + *A.* spp.	0	0	1	0
Pm + *A.* spp.	4	0.3	1 148	**18.3**
Pm + *Oo*	386	**29.5**	11	0.2
Pm + *Oo* + *A.* spp.	2	0.2	0	0
Total	1 308	100	6 263	100

The effect of fishing period on CPUE was tested for different time groupings of the data, from one month to the whole study period, and for the different fishing sectors when no marine mammals were detected interacting with the fishing operations. No significant effect and no discernable trend in CPUE could be detected in the data for any period in any given fishing sector.

CPUE was found to vary according to fishing sector ($F = 8.3$, $ddl = 9$, $P < 0.001$) and category of interaction ($F = 17.0$, $ddl = 3$, $P < 0.001$), while fishing period was not found to have an effect.

Compared to observations where no marine mammals were present, fur seals had no significant negative effect on CPUE. But in three of the cases analysed, significantly higher CPUEs were obtained in their presence (Table 2). Sperm whales alone and in co-occurrence with fur seals had a significant negative impact on CPUE in several fishing sectors (Table 2) and, when present, were responsible for a mean decrease in CPUE of 12 ± 23% and 21 ± 15% respectively.

In four of the 10 fishing sectors, CPUE was significantly and negatively related to the presence of sperm whales during the depredation events. No significant effects (positive or negative) were found for the remainder of the fishing sectors (Table 3). CPUE was found to be negatively correlated with the number of fur seals depredating on the line for three of the 10 sectors, while a positive correlation was found for one sector, and no relationships for the other six sectors.

Overall, taking into account the observed level of interaction of each marine mammal category, it was estimated that sperm whales alone, and sperm whales in co-occurrence with fur seals, resulted in the loss of 176 and 172 tonnes respectively of Patagonian toothfish which, combined, comprised 3.2% of the total catch of 10 902 tonnes. Consequently, it was estimated that the actual removal of Patagonian toothfish from the Kerguelen EEZ amounted to 11 250 tonnes (i.e. 10 902 tonnes caught plus 348 tonnes depredated from the longlines by sperm whales and fur seals). With a selling price of Patagonian toothfish of around US$12/kg, losses estimated due to depredation by marine mammals would amount to approximately US$2.1million/year in the Kerguelen EEZ.

Crozet EEZ

During the observation period in the Crozet EEZ, fur seals were recorded interacting with the fishery (alone or in co-occurrence with other species) only 10 times and therefore were not analysed. The following four categories of interactions were analysed: (i) no marine mammals; (ii) killer whales only; (iii) sperm whales only; and (iv) killer whales and sperm whales together. In addition, seven longline sets from outside the Crozet EEZ were excluded from the analyses, i.e. a total of 1 291 longline sets were analysed.

Both killer whale and sperm whale interactions with longlines were observed over the whole range of the fishery. However, the level of interaction varied according to the fishing sector for killer whales, and to a lesser extent for sperm whales (Figure 2). The mean number of killer whales and sperm whales observed interacting was 8.2 ± 4.7 ($n = 552$, range 1–20) and 4.1 ± 3.4 ($n = 737$, range 1–30) individuals respectively.

Table 2: Number of hooks set, CPUE in g/hook (±CV) in the absence of marine mammals (MM) or for different combinations of cetaceans present and results of paired *t*-test on the CPUE in the absence or presence of marine mammals (significant values are indicated in bold, while marginally significant values are indicated in italics) by fishing sector in the Kerguelen EEZ (see Figure 1b). *Physeter macrocephalus* – *Pm*; *Arctocephalus* spp. – *A.* spp.

Fishing sector	No MM			*Arctocephalus* spp.			*Physeter marcorcephalus*			*Pm* + *A.* spp.			*t*-test *P* values		
	Hooks	CPUE	*n*	Hooks	CPUE	*n*	Hooks	CPUE	*n*	Hooks	CPUE	*n*	No MM - *A.* spp.	No MM - *Pm*	No MM - *Pm* + *A.* spp.
1	2 504 231	185.6 (118.4)	244	23 260	99.6 (17.0)	3	2 448 921	185.3 (109.2)	250	136 103	122.7 (119.4)	13	0.211	0.979	*0.063*
2	4 010 678	188.2 (87.4)	392	613 533	185.9 (120.7)	75	936 028	149.0 (91.7)	92	796 184	167.9 (125.8)	94	0.845	**<0.001**	*0.066*
3	3 066 618	189.1 (99.2)	381	556 389	259.9 (146.2)	73	1 191 444	201.2 (136.7)	136	919 027	154.0 (98.7)	113	**<0.001**	0.273	**0.001**
4	2 808 442	209.1 (134.0)	316	2 581 621	259.4 (186.2)	300	1 187 843	184.9 (113.4)	124	2 419 823	192.7 (161.7)	313	**<0.001**	*0.068*	0.16
5	4 048 317	198.6 (88.4)	435	1 972 604	217.3 (97.0)	221	547 440	223.7 (91.3)	56	2 377 916	173.8 (94.5)	241	**0.014**	**0.047**	**0.001**
6	614 940	219.0 (280.1)	84	580 860	237.1 (192.4)	74	52 819	80.0 (63.1)	6	136 192	112.8 (89.2)	22	0.651	0.228	*0.082*
7	1 716 936	205.2 (97.3)	153	923 609	194.0 (69.3)	103	95 850	217.3 (71.5)	6	60 980	119.3 (71.2)	6	0.314	0.763	0.883
8	3 532 271	196.6 (160.7)	390	3 110 924	209.6 (144.7)	354	1 170 378	120.7 (64.9)	119	1 612 425	176.3 (120.2)	163	0.246	**<0.001**	0.148
9	1 674 159	174.4 (109.6)	174	708 437	153.9 (81.7)	71	436 190	153.9 (95.6)	48	1 539 388	166.9 (122.2)	130	0.155	0.239	0.572
10	2 584 154	177.5 (117.7)	262	343 868	162 (110.9)	40	1 163 394	170.8 (100.4)	106	480 887	136.4 (81.2)	49	0.438	0.608	**0.02**
Total	26 560 746		2 831	11 415 105		1 314	9 230 307		943	10 478 925		1 144			

Table 3: Correlation between CPUE and the number of sperm whales interacting with the line for the 10 Kerguelen EEZ fishing sectors (see Figure 1b).

Fishing sector	Slope	Sample size	*t*-values	*P* values
1	–17.77	264	–4.07	**<0.001**
2	–4.83	186	–0.94	0.35
3	–3.54	249	–0.93	0.35
4	–0.66	438	–0.197	0.84
5	–21.90	297	–4.12	**<0.001**
6	6.51	28	0.44	0.66
7	21.8	12	1.36	0.204
8	–11.55	286	–2.60	**0.01**
9	–0.71	181	0.13	0.90
10	–7.32	156	–2.20	**0.03**

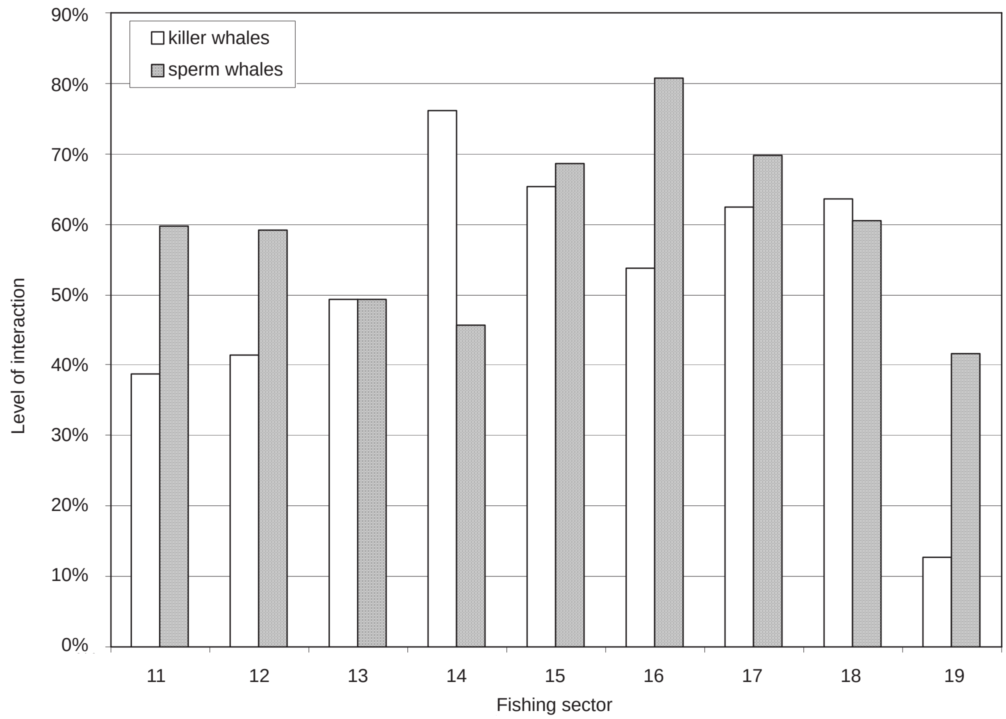


Figure 2: Rate of interaction in the Crozet EEZ per fishing sector and marine mammal species.

The effect of fishing period on CPUE was tested for different time groupings of the data from one month to the whole study period, and for the different fishing sectors when no marine mammals were detected interacting with the fishing operations. No significant effects and no discernable trends in CPUE could be detected in the data for any period in any given fishing sector. No seasonal trends in the level of interaction were found for sperm whales or killer whales.

The CPUE of longlines was found to vary significantly according to fishing sector (F = 36.8, ddl = 8, P < 0.001) and category of interaction (i.e. killer whales only, sperm whales only, and killer whales and sperm whales) (F = 25.9, ddl = 3, P < 0.001) (Figure 2).

Consequently, analyses were conducted over the whole study period for the nine fishing sectors and the four categories of interactions previously defined. Results are summarised in Table 4. Depredation was assessed for each of the fishing sectors independently according to the four combinations of cetaceans observed in the Crozet EEZ. For each sector, t-tests were performed on the CPUE in the presence of sperm whales only, killer whales only, and sperm whales and killer whales together, and compared to the CPUE when no marine mammals were observed.

None of the tests performed revealed any significant effect of sperm whale depredation on CPUE. A negative effect on CPUE in the presence of sperm whales was detected in only one of the fishing sectors (Table 4). However, for seven of the nine fishing sectors, mean CPUE was lower in the presence of sperm whales than it was when no marine mammals were present, and in one sector, a higher CPUE was obtained in the presence of sperm whales. Killer whales alone were found to negatively affect CPUE in three fishing sectors, while no significant effect could be detected in the other sectors. The simultaneous occurrence of killer whales and sperm whales was found to negatively affect CPUE in six of the nine fishing sectors. Furthermore, compared to the presence of sperm whales alone, CPUE was found to be lower when killer whales only were present for seven of the nine fishing sectors.

When killer whales only were interacting with the fishery, the number of killer whales involved in the depredation event was found to have no significant effect on CPUE for any of the fishing sectors. When sperm whales only were interacting with the fishery, the number of sperm whales involved in the interaction events was found to impact negatively on CPUE for three of the nine Crozet fishing sectors.

Overall, by comparing CPUE in the presence or absence of cetaceans, sector by sector (Figure 3),

Table 4: Number of hooks set, CPUE in g/hook (±CV) in the absence of marine mammals (MM) or for different combination of cetaceans present and results of paired t-test on the CPUE in the absence or presence of marine mammals (significant values are indicated in bold) by fishing sector for the Crozet EEZ (see Figure 1b). Fishing sectors for which there are insufficient data to allow comparison are indicated in italics.

Fishing sector	No MM			*Orcinus orca*			*Physeter macorcephalus*			*O. orca* and *P. macrocephalus*			*t*-test *P* values				
	Hooks	CPUE	*n*	Hooks	CPUE	*n*	Hooks	CPUE	*n*	Hooks	CPUE	*n*	No MM - *Oo*	No MM - *Pm*	No MM - *Pm* + *Oo*	*Oo* - *Pm*	*Pm* - *Oo* + *Pm*
11	572 353	136.9 (102.9)	77	220 461	68.0 (56.8)	28	647 877	78.8 (67.3)	82	639 571	50.1 (52.9)	76	**<0.001**	**<0.001**	**<0.001**	0.412	**0.003**
12	277 988	102.2 (93.9)	38	148 336	36.0 (67.0)	22	405 917	96.2 (71.7)	48	329 715	28.6 (37.9)	38	**0.002**	0.744	**<0.001**	**0.001**	**<0.001**
13	207 577	175.5 (95.4)	26	132 540	58.0 (51.7)	18	129 867	140.8 (84.1)	18	182 776	51.2 (61.5)	24	**<0.001**	0.211	**<0.001**	**0.001**	**0.001**
14	34 750	105.4 (175.5)	7	105 692	44.1 (79.3)	18	25 600	330.0 (249.5)	4	108 900	110.2 (141.2)	17	0.487	0.181	0.939	0.104	0.176
15	134 964	250.5 (240.0)	26	158 778	285.6 (260.1)	31	171 590	318.0 (327.5)	37	484 370	184.6 (239.1)	90	0.599	0.349	0.224	0.651	**0.029**
16	13 950	*152.3 (214.3)*	*2*	20 176	*86.6 (65.6)*	*3*	50 250	*63.1 (95.7)*	*10*	97 485	*44.8 (67.8)*	*11*	0.739	0.659	0.604	0.285	*0.615*
17	148 869	110.1 (106.8)	23	185 297	81.3 (72.2)	26	283 850	103.9 (94.5)	37	636 260	36.4 (45.3)	75	0.282	0.823	**0.004**	0.765	**<0.001**
18	63 891	115.0 (81.5)	9	132 479	85.3 (48.9)	17	114 620	91.3 (61.8)	15	198 671	45.1 (44.1)	25	0.337	0.464	**0.035**	0.393	**0.019**
19	1 602 069	104.3 (73.1)	166	154 564	62.3 (101.8)	16	1052 814	85.9 (92)	106	232 724	49.1 (67.4)	24	0.126	*0.083*	**0.001**	0.393	**0.03**
Total	3 056 411		374	1 258 323		179	2 882 385		357	2 910 472		380					

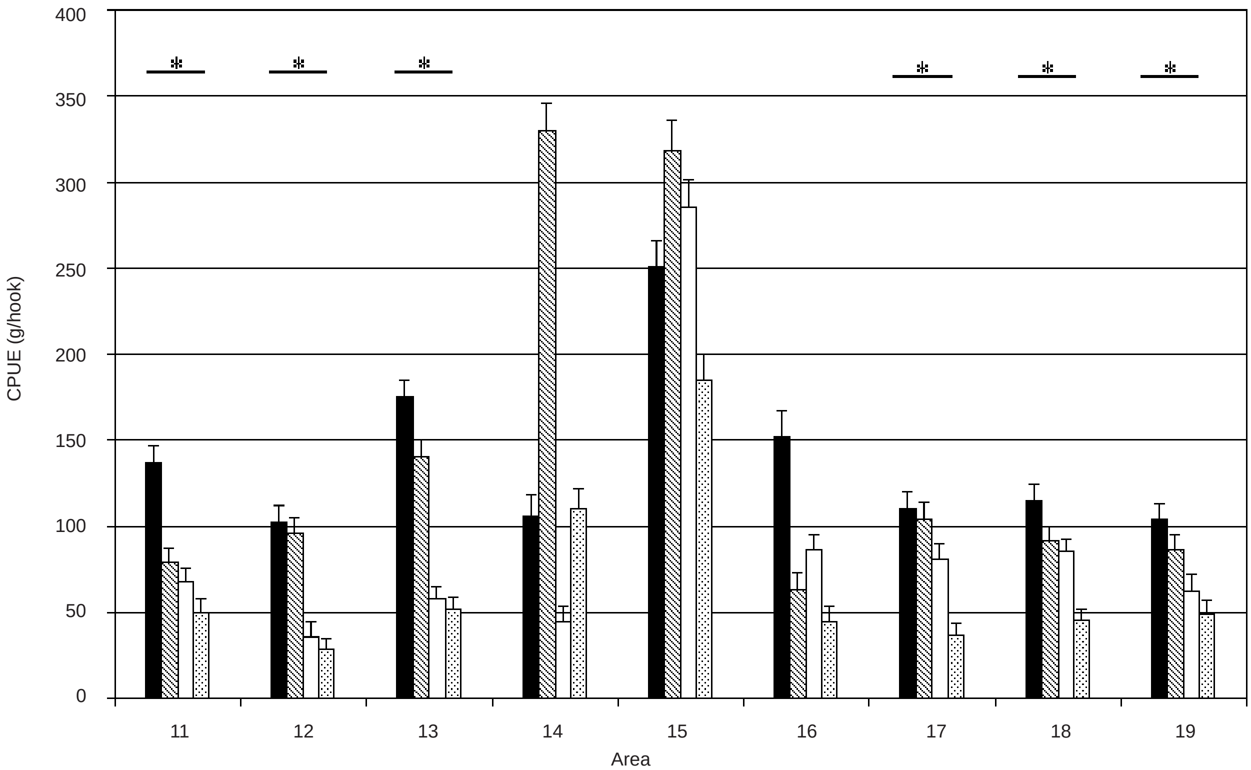


Figure 3: CPUE relating to species and fishing sector in the Crozet EEZ. Black bars represent CPUE in the absence of marine mammals, hatched bars represent CPUE when sperm whales only were present, white bars represent CPUE when killer whales only were present and, stippled bars represent CPUE when both species were present together. * represents fishing sectors in which significant differences were observed in the absence or presence of both sperm whales and killer whales (stippled bars).

it was estimated that killer whales alone, sperm whales alone and the combined presence of killer whales and sperm whales resulted in a mean loss of fish of 22 ± 21%, 12 ± 27% and 42 ± 33% respectively when compared to CPUE in the absence of marine mammals. Taking into account the level of interaction by fishing sector, the presence of sperm whales alone, killer whales alone and sperm whales and killer whales together, the estimated losses were 53, 58 and 222 tonnes of fish (i.e. 33%) of a total declared catch of 991 tonnes. Consequently, it was estimated that the actual removal of Patagonian toothfish from the Crozet EEZ was 1 324 tonnes (i.e. 991 tonnes fished plus 333 tonnes depredated from the longlines by killer whales and sperm whales) over the two-year study period. This corresponds to a loss of one-third (333 tonnes) of the total declared catch (991 tonnes) due to depredation by marine mammals. With a selling price of Patagonian toothfish of around US$12/kg, losses estimated due to depredation by marine mammals would amount to approximately US$2million/year in the Crozet EEZ.

Photo-identification of killer whales in the Crozet EEZ

Photographs of killer whales have been taken in the Crozet EEZ since 1998. However, most of the offshore photo-identification effort was carried out between 2003 and 2005. The 4 546 photographs taken during these three years allowed a total of 96 different killer whales interacting with the fishery to be identified (Figure 4), nine of which had previously been sighted along the coasts of Possession Island (Guinet, 1991; Guinet et al., in press).

The frequency of observation of identified killer whales was highly variable (Figure 5). Of the identified individuals, 60% were photo-identified on two or three occasions, while three individuals were observed interacting with the fishery more than 20 times.

Discussion

Interactions between sperm whales and longline fisheries have been well documented in the Southern Ocean, in particular off South Georgia, the Kerguelen Islands, and southern Chile. Such interactions include entanglements in gear (Ashford

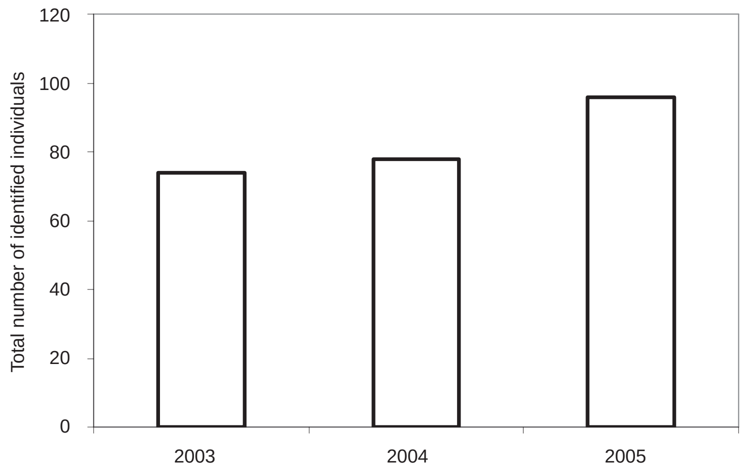


Figure 4: Total number of killer whales photo-identified offshore from operating fishing vessels between 2003 and 2005.

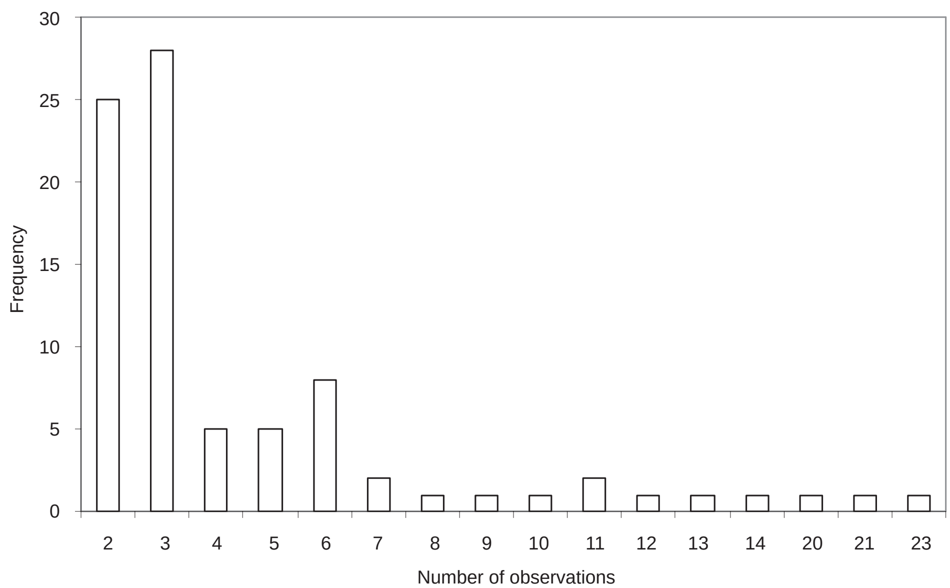


Figure 5: Frequency of observation for the most commonly encountered killer whales. The x-axis represents the number of times any given killer whale was identified and the y-axis represents the number of identified individuals (e.g. the bar on the left represents 25 killer whales photo-identified twice and the bar on the right represents two killer whales identified on 23 different occasions).

et al., 1996; unpublished data from Kerguelen) and whales following vessels for periods of days (Ashford et al., 1996; Capdeville, 1997) or observed feeding off gear (Crespo et al., 1997). This evidence, combined with anecdotal reports, reveals that interactions between sperm whales and longline operations are widespread in Southern Ocean waters. The results presented here confirm these reports, as sperm whales were found to interact with the Patagonian toothfish fishery over its whole range both in the Crozet and Kerguelen EEZs. On the other hand, killer whale and fur seal interactions were mostly observed in the Crozet EEZ and the Kerguelen EEZ respectively. These differences in the level of interaction between localities according to marine mammal species are likely to reflect differences between localities in terms of population size or density of these marine mammal species.

Estimates of the level of depredation by marine mammals in the Southern Ocean are rare (Capdeville, 1997; Gonzales and Olivarria, 2002; Kock, 2001). However, a significant impact on

CPUE by killer whales and sperm whales when present together and of sperm whales has also been reported in South Georgia waters (Purves et al., 2004).

Sperm whales are known to feed naturally on Patagonian toothfish (Abe and Iwani, 1989; Korabelnikov, 1959; Vukhov, 1972) and unlike killer whales, their diving ability allows them to reach this fish species without interacting with the fishery. Presently it is not known whether sperm whales interact with the longline only during the haul, which allows them to retrieve fish from a shallower depth, and/or when the longline is still on the sea floor. However, we could postulate that it would be easier and require less effort to remove the fish from the longlines when the fish were closer to the surface. When killer whales and sperm whales are present simultaneously, interactions between both species have been reported and demonstrated by the defensive behaviour of sperm whales (tight grouping of individuals, synchronous diving…; Pitman et al., 2001). When these species occur together, sperm whales, due to their greater diving abilities, are likely to interact with the longline at a greater depth than killer whales, but this requires further investigation.

The number of both killer whales and sperm whales interacting with the fishery was twice as great in the Crozet EEZ than in the Kerguelen EEZ. Ninety-six different killer whales were photo-identified interacting with the fishery, but only a few (~58) were involved in most of the interactions when photo-identification was conducted. This suggests inter-individual, or more likely inter-social group differences (i.e. long-lasting social bonds between individuals are observed in this species (Heimlich-Boran, 1986)) in the levels of interaction with fishing operations.

The individual identification of sperm whales interacting with the fishery still requires more comprehensive and dedicated work on photo-identification analyses.

The negative impact exercised by marine mammals on CPUE was highlighted by the fact that CPUE was (i) negatively affected in the presence of these species; and/or (ii) by the negative correlations found for several sectors of the Crozet and Kerguelen EEZs between the number of sperm whales and fur seals present and CPUE. This suggests a cumulative effect of the number of animals present on the depredation rate. Such a relationship was not found for killer whales.

However, and surprisingly, in some fishing sectors of the Crozet and Kerguelen EEZs, CPUE was higher in the presence of fur seals and sperm whales. Furthermore there was a tendency for sperm whales to be present more frequently in fishing sectors with high CPUE. One hypothesis for this is that sperm whales tend to concentrate in areas of high density of Patagonian toothfish, on which they prey naturally. Similar results were found in South Georgia (Purves et al., 2004). The relationship of fur seals with Patagonian toothfish abundance is more likely to be an indirect one, with fur seals concentrating in areas where the usual prey of Patagonian toothfish (myctophids and squids) are also abundant.

Previous studies have suggested differences in the level of interaction between fishing vessels (Hucke-Gaete et al., 2004). Further studies within the Kerguelen and Crozet EEZs should be conducted in the near future to investigate the matter in greater detail.

Conclusion

The level of depredation is nearly 10 times as high in the Crozet EEZ (33%) as it is in the Kerguelen EEZ (3.2%). This appears to be the result of: (i) the greater number of sperm whales and killer whales involved in the interactions in Crozet waters compared to Kerguelen; and (ii) the fact that killer whale interactions with the fishery activities were almost exclusively observed in the Crozet EEZ. To the authors' knowledge, this is the first time that the loss of Patagonian toothfish due to sperm whales and killer whales has been quantified. However, losses estimated in the Kerguelen EEZ are likely to increase significantly in the coming years due to an increasing trend in the number of interactions involving killer whales (171%, unpublished data) between 2003 and 2005, and due to the fact that, for the first time, killer whales interacting with the fishery in the Crozet EEZ were also observed in interaction with this fishery within the Kerguelen EEZ (unpublished data).

In order to address problems arising from marine mammal and fishery interactions, additional studies have been planned to assess fishing efficiency in areas in which: (i) the presence/absence of sperm whales have been previously detected (killer whales are generally silent); and/or (ii) new fishing techniques are in use (e.g. shorter longlines, potlines). Fishing with potlines, in spite of some disadvantages (e.g. damage of benthos by pots dragged over the sea floor during the haul) will have the added benefit of eliminating the incidental by-catch of seabirds on longlines and depredation by marine mammal species. It would also allow finer management of the Patagonian toothfish stocks by avoiding fish losses due to depredation and the need to take the effects of depredation into account for stock assessments and quota allocations.

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Tableau 2: Nombre d'hameçons posés, CPUE en g/hameçon (±CV) en l'absence de mammifères marins (MM) ou pour différentes combinaisons de cétacés présents, et résultats du test *t* par paires sur la CPUE en l'absence et en présence de mammifères marins (les valeurs significatives sont indiquées en gras, les valeurs peu significatives en italique) par secteur de pêche pour la ZEE de Kerguelen (voir figure 1b). *Physeter macrocephalus – Pm* ; *Arctocephalus* spp. – *A.* spp.

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Tableau 4: Nombre d'hameçons posés, CPUE en g/hameçon (±CV) en l'absence de mammifères marins (MM) ou pour différentes combinaisons de cétacés présents, et résultats du test *t* par paires sur la CPUE en l'absence et en présence de mammifères marins (les valeurs significatives sont indiquées en gras) par secteur de pêche pour la ZEE de Crozet (voir figure 1b). Les secteurs de pêche pour lesquels les données sont insuffisantes pour permettre une comparaison sont indiqués en italique.

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Figure 3: La CPUE selon les espèces et les secteurs de pêche de la ZEE de Crozet. Les barres noires représentent la CPUE en l'absence de mammifères marins, les barres hachurées représentent la CPUE lorsque seuls les cachalots étaient présents, les barres blanches représentent la CPUE lorsque seuls les orques étaient présentes, et les barres pointillées représentent la CPUE lorsque les deux espèces étaient présentes. * représente les secteurs de pêche dans lesquels des différences significatives ont été observées selon que les cachalots et les orques étaient absents ou présents (barres pointillées).

Figure 4: Nombre total d'orques identifiées au large par photographie depuis des navires de pêche en opération entre 2003 et 2005.

Figure 5: Fréquence d'observation des orques rencontrés le plus souvent. L'axe des x représente le nombre de fois qu'une orque donnée était identifiée et l'axe des y, le nombre de spécimens identifiés (par ex., la barre de gauche représente 25 orques identifiées par photographie deux fois, celle de droite représente deux orques identifiées en 23 occasions différentes).

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Табл. 1: Количество и доля ярусов, с которыми, по наблюдениям, взаимодействовали виды морских млекопитающих в разных комбинациях (*Orcinus orca* – *Oo*; *Physeter macrocephalus* – *Pm*; виды *Arctocephalus* – *A*.spp.), в ИЭЗ о-вов Крозе и Кергелен в период 2003–2005 гг.

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Рис. 5: Частота наблюдений наиболее часто встречающихся косаток. На оси x показано количество раз, когда та или иная косатка была идентифицирована, а на оси y показано число идентифицированных особей (напр., столбик слева обозначает 25 косаток, которые были фото-идентифицированы дважды, а столбик справа – двух косаток, идентифицированных в 23 различных случаях).

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Tabla 1: Número y porcentaje de palangres observados donde se presenciaron interacciones entre la pesca y distintas combinaciones de especies de mamíferos marinos (*Orcinus orca* – *Oo*; *Physeter macrocephalus* – *Pm*; *Arctocephalus* spp. – *A.* spp.), en las ZEE de las Islas Crozet y Kerguelén, entre 2003 y 2005.

Tabla 2: Número de anzuelos calados, CPUE en g/anzuelo (±CV) en ausencia de mamíferos marinos (MM) o para distintas combinaciones de cetáceos presentes; y resultados de la prueba *t* para muestras apareadas de la CPUE en ausencia o presencia de mamíferos marinos (los valores significativos se indican en negrita, mientras que los valores ligeramente significativos se indican en cursiva), por zona de pesca en la ZEE de Kerguelén (véase la figura 1b). *Physeter macrocephalus* – *Pm*; *Arctocephalus* spp. – *A.* spp.

Tabla 3: Correlación entre la CPUE y el número de cachalotes que interactuaron con la línea en las 10 zonas de pesca de la ZEE de Kerguelén (véase la figura 1b).

Tabla 4: Número de anzuelos calados, CPUE en g/anzuelo (±CV) en ausencia de mamíferos marinos (MM) o para distintas combinaciones de cetáceos presentes; y resultados de la prueba *t* para muestras apareadas de la CPUE en ausencia o presencia de mamíferos marinos (los valores significativos se indican en negrita), por zona de pesca en la ZEE de Crozet (véase la figura 1b). Las zonas de pesca para las cuales no hay suficientes datos para efectuar una comparación se indican en cursiva.

Lista de las figuras

Figura 1: Distribución espacial de los lances de palangre en (a) las nueve zonas de pesca en la ZEE de Crozet, y (b) las 10 zonas de pesca en la ZEE de Kerguelén, entre 2003 y 2005. Las líneas negras delgadas representan los límites de las ZEE; las líneas negras más gruesas delimitan las zonas de pesca.

Figura 2: Tasa de interacción en la ZEE de Isla Crozet por zona de pesca y especie de mamífero marino.

Figura 3: CPUE para cada especie y zona de pesca en la ZEE de Isla Crozet. Las barras negras representan la CPUE en ausencia de mamíferos marinos; las barras achuradas representan la CPUE en presencia de cachalotes solamente; las barras en blanco representan la CPUE en presencia de orcas solamente; y las barras punteadas representan la CPUE en presencia de ambas especies. * representa las zonas de pesca donde se observaron diferencias significativas en ausencia o presencia tanto de cachalotes como de orcas (barras punteadas).

Figura 4: Número total de orcas identificadas en alta mar mediante fotografías tomadas desde los barcos de pesca que operaron entre 2003 y 2005.

Figura 5: Frecuencia de observación de las orcas encontradas habitualmente. El eje x representa el número de veces que se identificó una orca en particular y el eje y representa el número de animales identificados (p.ej. la barra de la extrema izquierda indica que 25 orcas fueron identificadas dos veces de fotografías, y la barra a la extrema derecha indica que dos orcas fueron identificadas en 23 ocasiones distintas).