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Factors affecting the number and mortality of seabirds attending trawlers and long-liners in the Kerguelen area

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Abstract The factors affecting the number and the mortality rates of seabirds attending long-liners and trawlers fishing in the Kerguelen area were studied during four successive seasons (1994–1997), based on observations carried out onboard by dedicated observers. Twenty-four species of seabirds were observed attending fishing vessels, representing an average of 591 birds/census. The total numbers attending varied mainly according to the year, the cloud cover and the presence of offal from long-liners. The dumping of offal increased the numbers of birds attending the vessel, especially when the offal could be easily handled by birds. The activity of the vessels also affected the numbers attending, birds being more abundant during line setting and trawl hauling. White-chinned petrels were the most abundant ship-following seabirds, followed by black-browed albatrosses, giant petrels and cape petrels. The number of white-chinned petrels, black-browed and grey-headed albatrosses attending fishing vessels increased in the time between spring and autumn, whereas it was the reverse situation for giant petrels and cape petrels. Four species of seabirds were caught by fishing gear, mainly by long-lines: white-chinned petrels, and black-browed, grey-headed and wandering albatrosses. Taking into account the number of birds from each species attending long-liners and known to be potential by-catch, some species appear to be more susceptible to being caught than others. White-chinned and grey-headed albatrosses are caught in much higher proportions than the numbers present, whereas black-browed albatrosses are caught in lower numbers. Giant petrels are abundant around long-liners but were never caught. In long-liners, most birds were killed when the lines were set during the day or when the deployment of the scaring device was not successful, with an overall figure of 0.47 birds/1000 hooks. Only one albatross was caught when the lines were set during the night. White-chinned petrels represented 92.2% of all birds killed by long-liners. The number of birds caught varied significantly among months and among years. The type of bait used also affected the catch rate. The catch rate was related to the number of birds attending the long-liner only for black-browed albatrosses. Most birds killed by trawlers were entangled by the netsonde cable. The efficiency of mitigation measures in order to reduce seabird mortality is discussed and it is stressed that night setting is the most efficient way to reduce mortality and should be enforced everywhere when possible. However, further methods should be developed to reduce the mortality of species active at night, especially white-chinned petrels whose populations in the Indian Ocean may by threatened by long-line fisheries.

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Introduction

Several seabird species such as gulls, petrels and albatrosses are well known to be attracted to vessels at sea. They are especially attracted to fishing vessels to scavenge on fishing waste, but also to take baits from hooks or fish caught by drift nets. From the seabird perspective, interactions between fishing units and seabirds are therefore positive by providing additional food (e.g. Thompson 1992) but they can be negative by inducing mortality. For example, high numbers of seabirds, especially alcids and shearwaters, are entangled and drowned by gillnet fisheries in the North Pacific Ocean (DeGange and Day 1991) and high numbers of albatrosses and petrels are drowned after taking baits from long-lines in the Southern Ocean (Brothers 1991;

Murray et al. 1993; CCAMLR 1996). Some fisheries can also have an indirect effect on seabirds: for example trawling can produce mortality indirectly, by collision with netsonde cables used by some trawlers, or by entanglement in the trawl (Bartle 1991; Duhamel 1991). The interactions between seabirds and fishing vessels are therefore complex and the impact of fisheries on populations of seabirds is generally difficult to assess.

In the Southern Ocean, several species of albatross have decreased over the past 20 years (Weimerskirch and Jouventin 1987; Croxall et al. 1990; de la Mare and Kerry 1994; Prince et al. 1994a, b; Croxall et al. 1998; Weimerskirch and Jouventin 1998; Waugh et al. 1999). Long-line fishing has been identified as a major source of albatross mortality (Brothers 1991; Murray et al. 1993), possibly of sufficient magnitude to account for the observed population decreases in some species (Weimerskirch et al. 1997). Studies using satellite tracking of large seabirds allow the identification of contact zones between fisheries and seabird populations. With their extensive foraging ranges, albatrosses and petrels can indeed forage near fisheries far from their breeding sites (e.g. Croxall and Prince 1990; Weimerskirch et al. 1997; Weimerskirch 1998). In sub-Antarctic and subtropical waters of the Southern Ocean, one major threatening fishery has been that for southern bluefin tuna *Thunnus maccoyii* (Brothers 1991; Ardill 1994; Tuck and Polacheck 1997; Gales et al. 1998), probably responsible for the decrease of wandering albatross on sub-Antarctic islands such as the Crozet Islands (Weimerskirch et al. 1997). The development of a recent demersal long-line fishery for Patagonian toothfish *Dissostichus eleginoides* in sub-Antarctic and *D. mawsoni* in Antarctic neritic waters has raised concern about its possible impact on seabird population in these areas. The overall decrease in abundance in these populations and the observed rates of decrease have raised serious concerns about the status and viability of many of these species (e.g. Moloney et al. 1994; Weimerskirch et al. 1997), and underline the importance of quantifying by direct observations the mortality due to fishing in order to establish if this is likely to affect these populations.

Few studies have been able to relate directly long-line fishing effort to seabird population trends (but see Weimerskirch et al. 1997), as the major difficulty is to obtain accurate measures of seabird by-catch. Until recently, studies of by-catch have been either undertaken for short periods only by trained observers dedicated to record seabird mortality (e.g. Brothers 1991; Ashford et al. 1994, 1995; Cherel et al. 1996; Ashford and Croxall 1998), or have used longer data sets that were gathered by fisheries observers not dedicated and trained for seabird observation and recoveries of seabird by-catch (e.g. Duhamel 1991; Murray et al. 1993; Klaer and Polachek 1997; Gales et al. 1998). Furthermore, few studies have tried to link directly the effect of external variables such as weather conditions, season and type of bait used on seabird by-catch. No study has looked at the species and the number of birds attending the fishing vessels to examine whether the number of seabirds affected by fishing equipment is related to the number of birds attending the vessels. The purpose of this paper is to provide an analysis of the main factors affecting seabird attendance and mortality in the Exclusive Economic Zone of the Kerguelen Islands, based on information collected during four successive seasons between 1993/1994 and 1996/1997. Another objective of the study is to examine the efficacy of mitigation measures of seabird mortality which are beginning to be used in some areas such as the sub-Antarctic sector of the Southern Ocean (area of the CCAMLR, Commission for the Conservation of Antarctic Marine Living Resources). These mitigation measures include the setting of lines at night, the use of streamer-lines, the dumping of offal on the side of the ship opposite to where the line is set, and the fishing restricted to particular time of season.

Materials and methods

Data were collected by fishery observers, who are trained for seabird identification and mortality assessment, while they were on board fishing vessels, during four successive fishing campaigns from 1993/1994 to 1996/1997 in the Kerguelen Exclusive Economic Zone (EEZ).

Fishing method

On the Kerguelen shelf, three types of commercial fishing vessels operated from 1993/1994 to 1996/1997, mainly from the end of October (spring) to mid-April/early May (fall) to avoid bad sea conditions. These were:

1. Three Ukrainian trawlers ("Mys Ostrovskogo", "Tchatyr-Dag", "Vorodoznoye", respectively 83, 84 and 102 m long) targeting Patagonian toothfish (*D. eleginoides*) and mackerel icefish (*Champsocephalus gunnari*). These trawlers are factory deep-freezer trawlers using bottom trawls. The trawls usually stayed 3 h on the bottom, in water 170–240 m deep in the northeastern shelf when targeting icefish, and 350–750 m deep in the western shelf area when targeting toothfish (Fig. 1). One trawler used a netsonde with cable (electronic connection between the net and the vessel). No offal from fish caught as target species was available to seabirds from these trawlers, but a limited quantity of fish and squid by-catch was discarded.
2. Two French trawlers ("Austral" and "Kerguelen de Tremarec", 78 and 87 m length, respectively), targeting Patagonian toothfish in the same way as Ukrainian trawlers, but without a netsonde cable. Trawling was concentrated in the north and northeastern fishing grounds (Fig. 1). Offal (head, gut, bones) was released at the time fishes are processed.
3. Three Ukrainian long-liners ("Nikolay Reshetnyak", "Pantikopey" and "Primoretz", each 54 m in length), targeting Patagonian toothfish only in the western part of the shelf (Fig. 1), used the fishing method described by Duhamel (1991) and Cherel et al. (1996). The hooks of the Mustad autoliners type (Norway) were baited with horse mackerel (*Trachurus trachurus capensis*), icefish, Alfonsino (*Beryx splendens*) or butterfish (*Epigonus* sp.). The last two species were only used during the second part of the 1995/1996 campaign. The efficiency of the Mustad automatic baiter was, on average, 70.9% of hooks for 91 lines observed. Long-lines were set along shelf slopes at depths of 400–645 m. Setting and hauling of the lines (typically 2400 hooks) occurred continuously by night and day until December 1996. Thereafter, setting occurred only at night. Homogenised offal (chopped fish heads, tails and

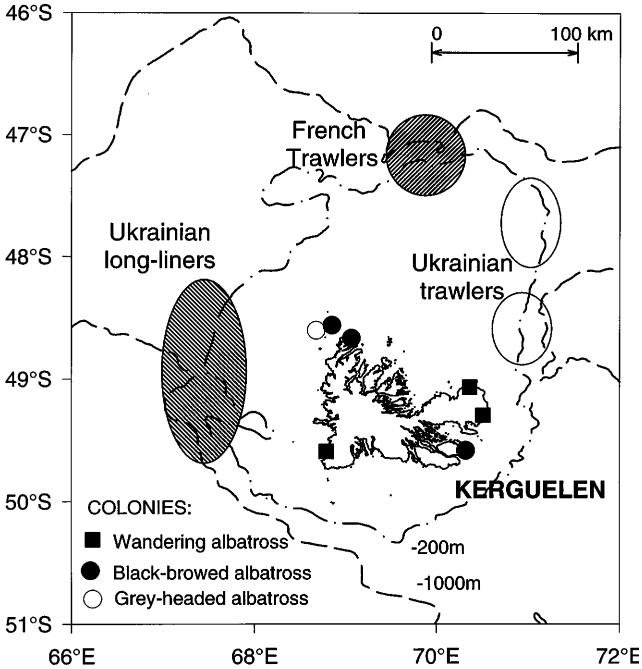

Fig. 1 Map of the Kerguelen shelf area indicating the location of fishing areas used by Ukrainian long-liners and trawlers and by French trawlers, and the location of albatross colonies. The Japanese long-liner fished all around the archipelago from the shelf break to deep sea

guts) was discharged from the opposite side of the vessel from the line setting, providing potential food for the seabirds (see Cherel et al. 1996). Offal was discharged during day setting and on nights close to full moons and when there were no clouds. The amount of offal discharged was a function of the catch of fish during the previous setting. A streamer line was used in order to reduce seabird by-catch during the two last fishing trips. The purpose of the streamer line is to scare the birds and to limit the accessibility to the lines. One or two scaring devices of length 150–175 m with floats of bright colours were deployed onto the water to stern. This line was equipped with propylene ribbons of 2 m length every 2–3 m. Additional weights on the fishing line were used at the same time (two last fishing trips) to speed up long-line sumersion and to avoid entanglement with the streamer line. All deck illumination was cut off during night setting. Finally, an exploratory deep-sea fishing cruise was conducted with a Japanese long-liner ("Anyo Maru 22", 50 m length) targeting Patagonian toothfish. A streamer line was used and lines were set during the day and at night. Lines (3900 hooks) were set at water depths of 320–1450 m and hooks hand-baited (with a 100% efficiency) with squid (*Illex argentinus*). Lines were set along slopes of the shelf edge all around Kerguelen in February/April 1996 (1995/1996) in order to estimate stocks of Patagonian toothfish.

Counts of seabirds attending fishing vessels

Seabirds and marine mammals were counted during 20 fishing cruises lasting 12–34 days, spread throughout the 4 years. The numbers of seabirds and marine mammals were counted regularly in the vicinity of the ships by means of 10-min counts, made from the flying-bridge. All birds within 360° of the ship and in a range of 500 m were counted during each 10-min record. Numbers were estimated in the case of large concentrations.

During these cruises, observations of seabirds by-catch were gathered during the normal work of the fishery observer (analysis of catch and fishing effort, fish sampling tasks), or during observations connected with the quantification of by-catch of non-commercial fish species, interactions with marine mammals and attractiveness of vessels on seabirds. Meteorological data, together with the presence of offal and of the streamer line, were noted. Seabird by-catch related to trawlers was observed only during 1994/1995 season. All phases of the trawling operations were closely observed during the voyage, from either the bridge (meshes and codend) or the factory. Special attention was also paid to the netsonde cable during observations aboard Ukrainian trawler "Mys Ostrovskogo".

Statistical analyses

To examine the factors affecting the number of birds attending trawlers and long-liners of the ten most abundant seabird species, we used a General Linear Modelling (GLM) analysis using Systat 7.0 (Wilkinson 1997). This technique allows a test for interdependence of variables, many of which are auto-correlated here without significance. We used the following environmental- and ship-related variables in the analyses: year, month, time elapsed from the beginning of the cruise, hour of the census, wind strength, sea condition, cloud-cover, ship activity and dumping of offal. Counts made while the ships were steaming between fishing sectors were excluded from analyses. Preliminary tests for normality and homogeneity of variances indicated that the abundance data were positively skewed by a strong observer effect. Therefore we used only data from one observer (D.C.) who carried out the majority of observations for the GLM analysis of seabirds' numbers. Sampling biases were further reduced by the exclusion of data collected when visibility was naturally poor (gale, rain, fog, snow and night censuses).

Water and air temperatures were not used because these parameters are redundant with the month of the year and because fishing vessels are operating all through the fishing season in the same sector. Trawlers and long-liners were analysed separately because they differed in fishing grounds, type of fishing gear and water depth. The GLM analyses are not meant to be taken as inferential tests of hypotheses, but rather as characterisations of associations between seabirds, fishing vessels and environmental features.

To examine the factors affecting the seabirds' by-catch in long-lining fishery, a stepwise procedure in the GLM analysis (Systat 7.0, Wilkinson 1997) was used. We introduced the following variables into the analyses: ship/year, month, moon phase, setting by night or by day, wind strength, sea condition, angle between ship course during setting and/or wind direction, bait used, use of a streamer line and dumping of offal.

Results

Species and abundance

Twenty-four taxa of seabirds and 5 marine mammals were identified in the vicinity of fishing vessels, with a total of 497,416 seabirds and marine mammals counted during 826 observations (Table 1). Ten seabird species were regularly observed [with a mean attendance of more than one individual per census (>10%) of occurrence around trawlers or long-liners]. The most abundant species was the white-chinned petrel, representing 46.6% of all animals present, sometimes in large numbers (1 census exceeded 4000 birds). White-chinned petrels were almost always observed during the day as well as at night. There was no difference between trawlers and long-liners in the average numbers of white-chinned

Table 1 Frequency of occurrence, mean numbers and total number of seabirds and marine mammals observed in the vicinity of trawlers and long-liners, fishing off Kerguelen Islands for four fishing campaigns. The *F* value is given for the eight most abundant species when result is significant at 0.05 level

Species	Abbreviated name	Trawler (n = 344 observations)			Long-liner (n = 482 observations)			Difference between trawlers and long-liners	
		Frequency of occurrence (%)	Mean number	*N*	Frequency of occurrence (%)	Mean number	*N*	*F*	*P*
Birds									
Wandering albatross *Diomedea exulans*	WAN	76.2	4.7 ± 7.9	1630	89.6	11.06 ± 17.2	5336	40.42	<0.001
Black-browed albatross *D. melanophris*	BBA	91.3	103.5 ± 156.7	35618	95.8	73.57 ± 82.0	35462	12.70	<0.001
Grey-headed albatross *D. chrysostoma*	GHA	52.9	22.6 ± 62.8	7787	69.9	2.7 ± 3.9	1296	48.40	<0.001
Yellow-nosed albatross *D. chlororhynchos*		1.7	0.0	±0.1	4	1.0	0.0 ± 0.1	5	
Shy albatross *D. cauta salvini*					0.2	0.0 ± 0.1	1		
Light-mantled sooty albatross *Phoebetria palpebrata*		3.5	0.1 ± 0.5	25	7.7	0.1 ± 0.5	61		
Sooty albatross *P. fusca*					0.2	0.0 ± 0.1	1		
Giant petrels *Macronectes* spp.	GPE	72.1	88.6 ± 161.4	30473	85.9	112.4 ± 150.2	54193	4.75	0.029
Southern fulmar *Fulmarus glacialoïdes*	SFU	1.7	0.0 ± 0.1	3	12.2	0.9 ± 3.4	413	21.46	<0.001
Cape pigeon *Daption capense*	CAP	61.6	34.5 ± 84.2	11876	83.4	111.4 ± 193.3	53714	47.95	<0.001
White-chinned petrel *Procellaria aequinoctialis*	WCP	94.2	296.1 ± 404.9	101851	97.1	269.9 ± 353.5	130101	0.97	0.32
Grey petrel *Procellaria cinerea*		0.6	0.03 ± 0.1	1	0.2	0.02 ± 0.1	1		
Sooty shearwater *Puffinus griseus*		0.6	0.01 ± 0.2	5	0.2	0.01 ± 0.1	1		
Soft-plumaged petrel *Pterodroma mollis*		0.6	0.03 ± 0.1	1	1.9	0.05 ± 0.3	14		
Great-winged petrel *P. macroptera*		0.6	0.01 ± 0.1	1	0.2	0.02 ± 0.1	1		
White-headed petrel *P. lessoni*					1.4	0.02 ± 0.2	10		
Kerguelen petrel *P. brevirostris*					0.2	0.03 ± 0.1	1		
Prions sp. *Pachyptila* spp.	PRI	36.6	4.5 ± 26.4	1564	46.3	3.8 ± 10.5	1843		
Wilson's storm-petrel *Oceanites oceanicus*	WIP	33.7	11.3 ± 48.2	3900	36.3	11.4 ± 32.0	5519		
Black-bellied storm-petrel *Fregetta tropica*	BBP	10.5	1.4 ± 13.3	481	55.9	28.1 ± 53.0	13554	83.75	<0.001
Diving-petrel *Pelecanoides* spp.		1.7	0.01 ± 0.4	9	1.2	0.04 ± 0.2	10		
Arctic tern *Sterna paradisea*					0.6	0.01 ± 0.1	3		
Subantarctic skua *Catharacta lönnbergi*		4.6	0.04 ± 0.2	9	2.7	0.02 ± 0.1	13		
South polar skua *C. maccormicki*					0.2	0.01 ± 0.1	1		
Unidentified penguins		1.7	0.05 ± 0.1	3	1.9	0.04 ± 0.9	46		
Marine mammals									
Sperm whale *Physeter macrocephalus*					6.4	0.1 ± 0.4	43		
Longfinned pilot whale *Globicephala melaena*					0.4	0.1 ± 1.0	22		
Commerson's dolphin *Cephalorhynchus commersonii*		3.5	0.8 ± 7.5	268					
Unidentified dolphin					0.2	0.01 ± 0.1	1		
Fin whale *Balaenoptera physalus*		0.6	0.01 ± 0.2	3					
Kerguelen fur seal *Arctocephalus gazella*		2.3	0.03 ± 0.5	13	16.2	0.4 ± 1.4	213		
Total of animals observed		97.1	568.4 ± 608.9	195525	99.9	626.3 ± 574.2	301891		

petrels attending. The other nine species accounted for 53.2% of all animals observed. They were black-browed, wandering and grey-headed albatrosses and giant petrels (mainly the sub-Antarctic species *Macronectes halli* then small petrels; see Table 1). Most of the albatrosses and giant petrels were adults. All these species were also recorded at night but in lower numbers compared to daytime.

More species were present around long-liners than around trawlers. The numbers attending were also higher around long-liners than trawlers, except for black-browed and grey-headed albatrosses and prions. The 14 remaining species of birds and all mammals species except fur seals around long-liners were recorded only occasionally (<5% of occurrence) and were not observed to attend the fishing gear. Some species, like sub-Antarctic skua, arctic tern and yellow-nosed albatross, were probably attracted to and seen close to the vessel but the others seemed to be indifferent. Mammals were occasionally observed in low numbers, except for a pod of 80 Commerson's dolphin, which were seen twice. Similarly to birds, more mammal species occurred around long-liners.

For the rest of the study, we have considered only the ten most abundant species.

Factors affecting the numbers of seabirds

Trawlers

The total number of birds attending trawlers was mainly affected by meteorological conditions, more birds being observed during overcast conditions. The number of albatrosses, large- and medium-sized petrels was mainly affected by the time of year (month), with a tendency for the number of birds to increase with the progression of the austral summer (Table 2, Fig. 2). The activity of the ship, meteorological conditions and the presence of offal affected the presence of some species. The presence of offal had no significant influence on the number of birds attending trawlers.

Long-liners

Two factors mainly affected the number of birds attending long-liners: the release of offal and the year (Table 2). There were more birds attending long-liners in 1995/1996 than in 1994/1995. The release of offal from long-liners had a positive influence on the total number of birds attending, especially on the number of large species and white-chinned petrels (Table 2). The month of observation also had an influence on the numbers present of most species, but not on the total number for all species combined (Fig. 2). White-chinned petrels, black-browed and grey-headed albatrosses increased as the season progressed, whereas it was the reverse situation for giant petrels and cape petrels (Fig. 2). Most of the other medium-sized and small petrels, such as storm-petrels, did not show regular increases or decreases through the season. Southern fulmars were present around the fishing ships only in spring. Wind, sea conditions, meteorological factors and the activity of the ship only influenced the number of attending birds in a few species (Table 2).

Table 2 Results of the General Linear Modelling analyses for the ten most abundant bird species attending trawlers and long-liners (*WAN* wandering albatross; *BBA* black-browed albatross; *GHA* grey-headed albatross; *WCP* white-chinned petrel; *GPE* giant petrel; *CAP* cape pigeon; *PRI* prion; *WIP* Wilson storm-petrel; *BBP* black-bellied storm-petrel; *SFU*: Southern fulmar). Significance level is denoted by the number of symbols. Sign of variation corresponds to the symbol used

	Albatrosses			Petrels							All
	WAN	BBA	GHA	WCP	GPE	CAP	PRI	WIP	BBP	SFU	
Trawlers											
Year											
Month	+	+++	+	+++	+++	+++				++	
Date			+++								
Time										+++	
Wind											
Wave		–	–								
Cloud	+	–		–	–					–	–
Activity							–			–	
Offal		–	–	–						–	
Long-liners											
Year		+++	+++		+	+++		–	+		+++
Month			+++	+++	–	–	+		++	–	
Date		+++									+
Time		–									
Wind	+++										
Wave			+								
Cloud		–						+			
Activity			–					+	+		
Offal	+++	+++	+++	+++	+++				–	+	+++

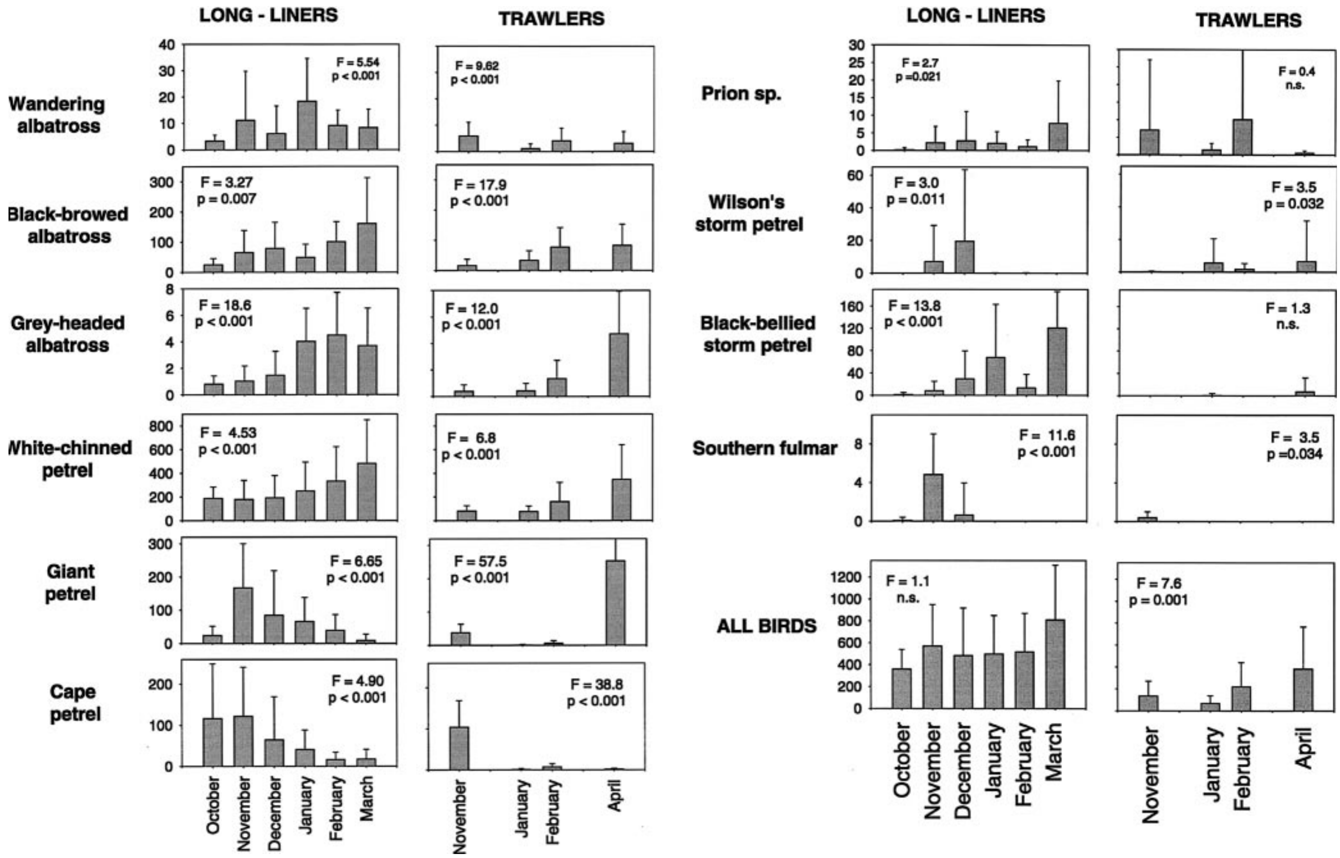

Fig. 2 Mean numbers of the ten most abundant bird species attending long-liners between October and March, and attending trawlers in November, January, February and April

Attractiveness of fishing units over time

We examined whether the numbers of birds increased significantly over time since the beginning of a fishing cruise (from the 1st day of operation on a fishing ground). The attractiveness (significant increase in numbers over time) was different according to seabird species considered and the type of vessel. When considering the total numbers of birds attending the fishing vessel, there were significant differences between the different cruises (ANCOVA $F_{8,377} = 3.82$, $P < 0.001$), suggesting different attractiveness between cruises. Overall, there was no tendency for trawlers to be more attractive to seabirds than long-liners ($F_{1,391} = 0.02$, NS), although the number of birds attracted by trawlers remained lower than for long-liners ($F_{1,391} = 43.76$, $P < 0.001$). Considering counts individually, the overall number of birds attending the fishing vessels significantly increased over time for half of the cruises only, and decreased significantly for the other half.

Ship activity

Considering the ship activity, the mean numbers of the three most abundant albatrosses showed different patterns (Fig. 3). The numbers of wandering albatrosses increased when the fishing gear was close to the sea surface, i.e. during setting, around trawlers and remained constant around long-liners. The numbers of black-browed albatrosses and white-chinned petrels around trawlers showed a maximum during hauling, i.e. when the codend reached the surface, these birds attempted to pick fish from its meshes. The maximum numbers of birds attending long-liners were observed at the end of long-line setting, when the release of offal ended, except for wandering albatrosses. The presence of offal significantly increased the number of albatrosses attending trawlers (ANOVA $F_{1,343} = 75.28$, $P < 0.001$) and long-liners ($F_{1,481} = 50.36$, $P < 0.001$).

Factors affecting mortality of seabirds

Seabird by-catch in trawlers

Mortality directly attributable to the trawl gear mostly affected white-chinned petrels (Table 3) when they were trying to seize items lost from the trawl. The petrels were either caught in the meshes of the upper front port near the headline of the net or in the codend, equally during setting or hauling (D. Capdeville, personal observation). All but one of the birds were killed in the icefish fishery.

A detailed examination of the causes of seabird mortality was carried out on board "Mys Ostrovskogo"

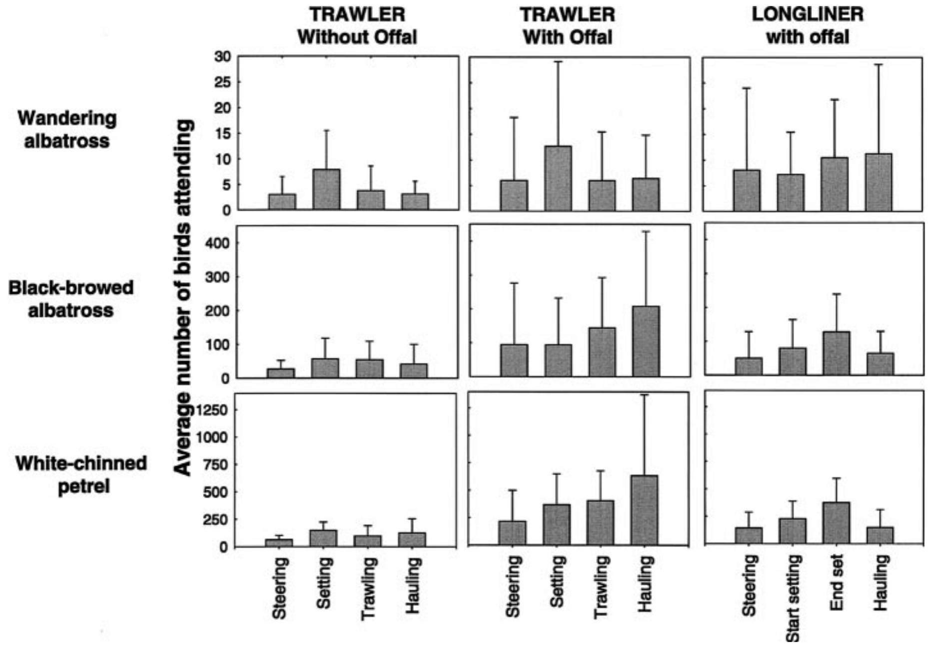

Fig. 3 Changes in the mean numbers of wandering albatrosses, black-browed albatrosses and white-chinned petrels attending trawlers with and without offal and long-liners according to the activity of the vessel

Table 3 Seabird by-catch observed on trawlers fishing in Kerguelen area during the 1994/1995 season (modified from Williams and Capdeville 1996). See Table 2 for abbreviation of bird names

Type of trawler	Netsonde cable	Target species	Trawls (n)	No. killed/trawl	WCP	BBA	GHA
With offal	No	Pat. toothfish	531	0.002	1		
Without offal	Yes	Pat. toothfish	33	0			
Without offal	No	Icefish	322	0.020	5	1	
Without offal	Yes	Icefish	149	0.114	13	3	1

during the February/March 1995 cruise when 17 birds were killed. Seven birds, including four albatrosses, were killed by the netsonde cable: they were found between this cable and the headline of the net. The mean mortality rate, including all species and causes of mortality, was 0.48 birds per day in this cruise.

Observation of seabird behaviour during the setting and hauling of trawls by "Mys Ostrovskogo" showed that the birds were capable of seeing the netsonde cable under some conditions, judging by the frequent observation of avoidance reactions. Mortality unequivocally caused by the netsonde cable was only observed during four trawls in particular meteorological conditions. For two trawls, the ship's speed relative to the wind was nil, i.e. the ship was moving in the same direction and at the same speed as the wind. In the other two cases, a strong wind was blowing at right angles to the ship's direction.

Seabird by-catch in long-liners

During long-line fishing in the area, birds attracted by baits were caught on baited hooks and drowned during line setting. A total of 957 birds was recovered from 611 lines hauled in 4 fishing seasons between 1994 and 1997, giving an overall rate of 1.56 birds/line and 0.59 birds/1000 hooks (Table 4). The maximum observed was 36 birds on a single line, i.e. 15.0 birds/1000 hooks. No bird was caught during hauling except one gentoo penguin (*Pygoscelis papua*) released alive. Four seabird species were caught during line setting. The first species as by-catch was the white-chinned petrel, representing 91.8% of the incidental by-catch and 879 birds, followed by 35 black-browed albatrosses, 31 grey-headed albatrosses and 12 wandering albatrosses.

The catch rate of birds varied between years and vessels. The maximum overall observed was 1.07 birds/1000 hooks in the 1995/1996 season on the Ukrainian long-liner. About 90% of all albatrosses were caught by this ship in the same season. All by-catch of wandering albatrosses except one occurred in the austral summer of 1995/1996. The second highest by-catch rate was observed on the first experimental cruise of the Japanese long-liner, again in the 1995/1996 season.

As the fishing zones and techniques were not the same, we have analysed the Ukrainian and Japanese long-liners separately.

Ukrainian long-liner

White-chinned petrel. Several factors influenced the by-catch of white-chinned petrels (Tables 5, 6). First, night

Table 4 Incidental capture of seabirds on long-liners targeting Patagonian toothfish in Kerguelen waters. Details for each species are numbers of birds for 1000 hooks (see Table 2 for abbreviations of bird names)

Ship	Year	Observed lines	Number of hooks	Number of birds killed	Catch rate/1000 hooks				
					Overall	WCP	BBA	GHA	WAN
N. Reshetnyak	1993/1994	72	174,000	34	0.195	0.185	0	0.012	0
Primoretz	1994/1995	42	88,000	12	0.136	0.080	0.034	0.023	0
N. Reshetnyak	1995/1996	185	392,800	483	1.232	1.067	0.077	0.064	0.028
N. Reshetnyak	1996/1997	225	628,900	178	0.283	0.318	0.002	0	0
Anyo Maru 22	1995/1996	87	330,600	246	0.745	0.744	0	0	0.003
Total	1993–1997	611	1,614,300	953	0.590	0.545	0.022	0.018	0.007

Table 5 Results of the General Linear Modelling analysis for the seabird by-catch by Ukrainian long-liners. Significance level is denoted by the number of symbols (*WCP* white-chinned petrels, *BBA* black-browed albatrosses, *GHA* grey-headed albatrosses, *WAN* wandering albatrosses)

Effect	WCP	BBA	GHA	WAN
Year/ship	+++			+
Month	+++		+++	
Moon				
Day/night	+++	+++	+++	
Bait	++		+++	+++
Wave strength	+++	+++		++
Streamer line				
Offal	+++			

Table 6 Results of the General Linear Modelling analysis for the seabird by-catch by Japanese long-liners. Significance level is denoted by the number of symbols (*WCP* white chinned petrels, *BBA* black-browed albatrosses, *GHA* grey-headed albatrosses, *WAN* wandering albatrosses)

Effect	WCP
Month	
Moon	
Day/night	+ + +
Wind direction	
Wave strength	
Streamer line	
Offal	

setting reduced the number of birds overall from 0.91 ± 1.72 birds/1000 hooks during the day to 0.17 ± 0.82 birds/1000 hooks at night (ANOVA $F_{1,514} = 38.72$, $P < 0.001$). The by-catch of white-chinned petrels was influenced by the month, with a tendency to be lower in December/January than during the months before or after this period. Dumping of offal also reduced the mortality in this species from 1.00 ± 2.06 to 0.46 ± 1.23 birds/1000 hooks ($F_{1,514} = 9.48$, $P = 0.002$). Bad sea conditions increased the mortality of this diving species. The fish species used as bait also had an influence (ANOVA $F_{3,512} = 4.84$, $P = 0.002$). When butterfish was used as bait, the numbers of white-chinned petrel killed increased. The streamer line had no significant influence on the numbers of white-chinned petrels killed (0.57 ± 1.38 vs 0.52 ± 1.40 birds/1000 hooks; ANOVA $F_{1,514} = 0.174$, NS). Effects of moon phase on seabird catch rates were also examined and showed no consistent effect on catch rates of seabirds at night.

Albatrosses. The main result of this study is that only one albatross was caught when line setting occurred at night. Night/day setting was therefore significant for all albatross species except for wandering albatross. Rough seas increased the mortality of black-browed albatrosses. Month of observation had a positive influence on the number of grey-headed albatrosses caught, this number increasing with the season. Butterfish used as bait increased the numbers of grey-headed and wandering albatrosses caught. Wave height also had a significant effect, more birds being caught with sea conditions, and there was a small year effect in the mortality in wandering albatross (Table 5).

Susceptibility to by-catch

The proportion of birds from different species caught in the long-line fisheries was different from the proportion of birds present that could potentially be caught (Table 7, $\chi^2_5 = 396.0$, $P < 0.0001$). There were more grey-headed and white-chinned petrels caught than could be expected from the proportion of birds attending ($\chi^2_1 = 15.8$, $P < 0.0001$, and $\chi^2_1 = 301.0$, $P < 0.0001$, respectively), while less black-browed albatrosses were caught than could be expected from their abundance ($\chi^2_1 = 76.2$, $P < 0.0001$). One of the greatest discrepancies was the giant petrel, which was one of the most abundant species observed but none were caught. The figure for wandering albatrosses was similar to what would be expected from their abundance ($\chi^2_1 = 2.4$, $P = 0.121$, NS).

Year effect and seasonal changes

The proportion of birds caught showed considerable inter-annual variability. The trends in annual changes were not consistent among months (Fig. 4), in relation to the period observed, its duration (i.e. number of

Table 7 Comparison between the proportionate abundance of the ten most abundant seabird species attending long-liners (calculated from average values of Table 1) and the proportion caught

Species	% of the birds attending	% of birds potential by-catch attending	% of the birds killed
White-chinned petrel	43.0	57.1	91.8
Giant petrel	17.7	23.8	0
Cape petrel	17.7	–	0
Black-browed albatross	11.8	15.4	3.7
Black-bellied storm petrel	4.5	–	0
Wilson's storm petrel	1.8	–	0
Wandering albatross	1.7	2.3	1.3
Prions	0.6	–	0
Grey-headed albatross	0.4	0.6	3.2
Southern fulmar	0.1	0.2	0

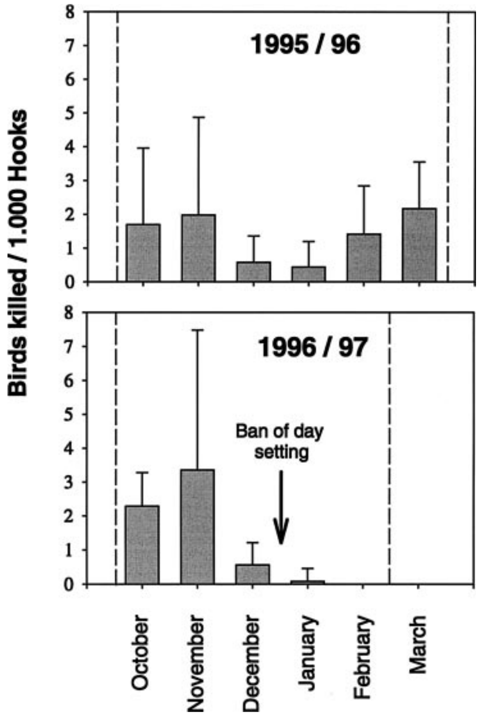

Fig. 4 Observed catch rates of seabirds from Ukrainian long-liner "Nikola Reshetnyak" (values are mean ± SE) according to the month. The *arrow* indicates the beginning of obligatory night setting

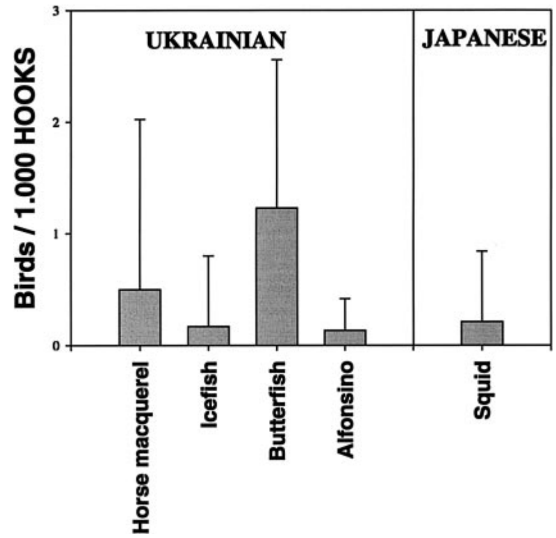

Fig. 5 Observed catch rate of seabirds from long-liners for five different types of baits used on the hooks

hooks) and the main mitigation measure used. The strong decrease in mortality observed on board "N. Reshetnyak" after December 1996 from a mean of 1.84 ± 2.90 to 0.03 ± 0.23 birds/1000 hooks is probably related to the ban of day setting (Fig. 4). Fish of poor baiting quality were used in February/March 1996 on the same vessel, and could induce the increase in mortality observed. Considering seasonal changes, the mean numbers of birds caught were higher during spring than in summer. The 1995/1996 season showed the highest records in seabird mortality, for both long-liners.

Bait quality

The mean number of seabirds caught showed different patterns considering the fish used as bait (Fig. 5). Butterfish used as bait increased significantly the numbers of white-chinned petrel, and grey-headed and wandering albatrosses caught.

Observer effect

Differences in number of birds caught by "Primoretz" in 1994/1995 exist according to the observer's activity. When the observer was watching line hauling, the number of birds caught was 0.25 ± 0.33 whereas it was only 0.05 ± 0.15 when the observer was measuring fish during hauling and recording the number of birds killed at the end of hauling ($F_{1,39} = 6.61$, $P = 0.014$).

Relationship between seabird numbers and mortality in long-liners

There was no significant relationship between the number of birds present during line setting and the number of birds caught in all species except for the black-browed albatross ($r = 0.362$, $P = 0.010$).

Japanese long-liner

Only two albatrosses were caught by the Japanese long-liner, of which one occurred during night-time line setting, so no analysis was performed for albatrosses. One factor mainly affected the numbers of white-chinned petrels caught on hooks of Japanese long-liners (Table 6): that of time of setting (night/day). Night setting decreased the number of white-chinned petrels caught.

Discussion

Species and abundance of ship-following seabirds

Most scavenger seabird species are attracted towards, and often follow, fishing vessels to feed on offal and discards (Griffiths 1982; Abrams 1983; Hudson and Furness 1989; Ryan and Moloney 1989; Thompson 1992; Garthe and Hüppop 1994; Thompson and Riddy 1995). In this study, ten species were regularly seen, sometimes in high numbers. All the bird species observed breed on most sub-Antarctic islands in the Indian part of the Southern Ocean including Kerguelen (Weimerskirch et al. 1989), except the shy albatross (Australasia) and arctic tern (Palearctic).

The most abundant ship-following seabirds in spring and summer were the white-chinned petrels. The species is fairly abundant at Kerguelen and on other islands of the Indian Ocean. This species is able to forage far from the colonies even during their breeding season, and birds from Crozet, 1100 km west of Kerguelen, are known to visit the Kerguelen shelf (Catard and Weimerskirch 1999; Weimerskirch et al. 1999). They are present in large numbers on continental shelves, even in the absence of vessels (Stahl et al. 1985) and their natural foraging range may overlap with fishing vessels as has been shown for albatrosses (Weimerskirch 1998). They migrate outside the area in winter, and at this time in the southern Benguela current they are consistently attracted by trawlers and may have their distribution influenced by the fisheries in this region (Ryan and Moloney 1989).

Black-browed albatrosses were the most abundant albatrosses observed behind vessels in this study. This species forages mainly over the island shelf during the breeding season (Weimerskirch et al. 1988, 1997) and migrates to Australia in winter (Weimerskirch et al. 1985). Like white-chinned petrels, black-browed albatrosses are one of the most common ship-following seabirds in the Southern Ocean where they scavenge intensively from fisheries wastes (Thompson 1992). Observations of marked birds at Kerguelen suggest that most of the birds observed in the western sector of the Kerguelen shelf, where long-liners are operating, originate from the Nuageuses Islands, i.e. at only tens of kilometres from these fishing grounds (Weimerskirch et al. 1988, Fig. 1). Giant petrels were also observed regularly following the fishing vessels and were active scavengers behind long-line vessels during the release of offal. However, they did not compete with white-chinned petrels and albatrosses for baits during line setting. Small species (cape petrel, black-bellied and Wilson storm-petrels) were the most abundant species in numbers around long-liners; these species were also scavenging on fishery waste but feed on small particles, or even on oil.

Factors affecting the seabird abundance

Several factors probably affect the number of birds attending fishing vessels. Firstly, certain species are more abundant around Kerguelen during certain periods. Cape petrels and southern fulmars that breed mainly along the Antarctic continent are abundant around Kerguelen in spring but leave in summer. The numbers of white-chinned petrels, black-browed and grey-headed albatrosses increase as the breeding season progresses, suggesting that during the chick-rearing period they are attending vessels in larger numbers than during incubation. During chick rearing these species perform shorter trips on the shelf to increase provisioning (Weimerskirch 1998; Catard et al. in press), making them more likely to encounter fishing vessels. If data were available after mid-April they would likely show very reduced abundance of species such as black-browed albatross or white-chinned petrels, which migrate out of the region at this time. Secondly, observed differences may be related to the proximity of breeding colonies: the differences between trawlers and long-liners in number of black-browed and grey-headed albatrosses attracted can be related to the vicinity of main breeding colonies at the Nuageuses Islands from the fishing grounds of long-liners (Fig. 1, Weimerskirch et al. 1989). Additionally, differences in the marine environment exploited by seabirds may explain differences occurring between trawler and long-liners' fishing grounds, the former operating over shallower waters (150–200 m for ice-fish) than the latter.

The presence of offal provided by the vessels is probably a major factor affecting seabird numbers. The Ukrainian trawlers targeting icefish provide less offal because very few fish occur as by-catch and no discard are available because icefish are frozen whole. The French trawlers targeting Patagonian toothfish provide much large-sized discards (head, tails, guts) that are not homogenised, and are therefore difficult to handle by birds. In contrast, Ukrainian long-liners provide homogenised offal, an easy food source available close to major breeding grounds for the birds. These differences, not only in the quantity of food provided but also in the quality of discards, may explain the higher attractiveness of long-liners. For example the size of offal will affect the species that are able to utilise it, i.e. heads and tails are an easy food source for wandering albatrosses and giant petrels, while homogenised offal allows small species to utilise it.

Additional factors affecting the numbers attending could be related to the number of fishing vessels operating in the same fishing grounds, with birds partitioning between vessels. Such interactions were observed at the end of the 1995 season when two of the three trawlers left the fishing grounds inducing an increase of birds around the remaining vessel.

Mortality in trawl fishery

Our data show that trawling operations induce a much lower, but still substantial, seabird mortality than long-liners. In 1994/1995, only one white-chinned petrel and one young southern elephant seal (*Mirounga leonina*) were observed killed in the toothfish fishery, representing half of the fishing effort in the area. In the trawls targeting mackerel icefish, the bird mortality was higher with 0.027 birds per trawl. Most of this mortality was observed on the 1 vessel using a netsonde cable, where at least 7 of the total of 17 bird deaths, including all albatross deaths observed, were caused by the cable. The death of birds found in the codend could be either a result from collision with the netsonde cable or diving into the net. The estimate of mortality caused by the cable is therefore a minimum because some birds could be injured or killed by collision with the cable and fall in the water, ending up outside the net. As conditions of sea and weather appear to have a great influence on the mortality rate, the figure given is likely to be highly underestimated. For example, in 1984, a single observer on board a trawler targeting icefish (using a netsonde cable) recovered the bands of eight black-browed albatrosses during a season of 4 months. Since about 4% of the birds are banded in the Kerguelen population, it can be estimated that as many as 200 birds have been killed by a single trawler, and therefore nearly 1000 birds could have been killed during the entire season by the whole fishing fleet, suggesting a high mortality similar to that observed in the New Zealand sector for shy albatrosses (Bartle 1991). Netsonde cable are now banned from fisheries in the Kerguelen area, in addition to the rest of the CCAMLR area.

Trawling in the icefish fishery, even provided no netsonde cable is used, posed problems for diving birds, principally white-chinned petrels. The relatively small size of this fish (24–40 cm in total length) makes easier to ingest than toothfish (50–100 cm), for which only its offal can be ingested. Therefore the attractiveness of the fishing vessels may also be influenced by the target species and its by-products being made available. No evidence of seabird mortality was noticed in the toothfish fishery after the ban of the netsonde cable (G. Duhamel, unpublished data).

Mortality in long-line fishery

Long-lining is responsible for a high incidental mortality of seabirds at Kerguelen. Over the period of this study, the mean numbers of seabirds killed on long-line hooks varied greatly between years, with the peak mortality in 1995/1996. The by-catch figure given here is likely to be underestimated in 1994/1995 because of the observer effect: an observer dedicated only to observing seabird mortality will produce a higher mortality rate than an observer looking only at birds on the deck, probably due to the tendency of fishermen to discard birds before they are hauled on the deck (see also Gales et al. 1998).

Only one band recovery was reported during the four fishing seasons, an adult wandering albatross that bred at Ile de la Possession, Crozet Islands the year before. This suggests that wandering albatrosses caught in the western part of Kerguelen waters come from the Crozet Islands, as suggested by studies using satellite telemetry (Weimerskirch 1998). Wandering albatrosses from Crozet are known to regularly visit the western part of the Kerguelen shelf, and forage there before the long-line fishery operates in this area (Weimerskirch et al. 1993; Weimerskirch 1998; H. Weimerskirch, unpublished data). The Kerguelen population could be more at risk from this fishery since they breed closer to the fishery and forage mainly on the shelf edge around the island (H. Weimerskirch, unpublished data). Most black-browed and grey-headed albatrosses caught by the long-lining fishery are likely to come from Nuageuses Islands colonies, first because grey-headed albatrosses only breed there and Nuageuses black-browed albatrosses are known to forage in the western part of the shelf (Weimerskirch et al. 1988). Also, birds breeding on the southwestern colony of Canon des sourcils noirs do not forage in the western edge of the shelf (Weimerskirch et al. 1997; Weimerskirch 1998) and furthermore there is not a single band recovery of birds from this colony.

There appear to be extensive differences in the degree to which some species are more likely to be caught with respect to their abundance around long-liners and to their potential to be caught (Table 7). Grey-headed albatrosses and white-chinned petrels appear to be the species for which the potential threat from fisheries is the highest in the Kerguelen sector. During our survey, grey-headed albatrosses were caught in high numbers relative to their low abundance. White-chinned petrels formed the bulk of the by-catch but represented only around half of the birds present: this is not surprising since it is one of the few species diving regularly, being able to take baits even on submerged lines. The reason why grey-headed albatrosses are caught in higher numbers than expected is less clear, but was noted also in the South Atlantic by Ashford et al. (1995). Conversely, giant petrels were one of the most abundant species around long-liners, but not a single bird was caught in this study. At other sites giant petrels can be caught in significant numbers by long-liners (Ashford et al. 1995). These results indicate that the interactions between seabirds and fishing vessels are complex and probably depend also on the ecology and behaviour of the different species, as well as on the local conditions and the experience of birds. One important factor that may account for the differences among sites or species could be the dominance interactions between seabird species, which may change according to the relative abundance of each species in the composition of the community associated with fishing vessels. The results also indicate that the susceptibility of species may differ greatly among closely related species, and even between sites for the same species, making it difficult to estimate by-catch for one fishery from data from other sectors.

This study has shown that a dedicated observer being present during hauling of lines is essential to estimate accurately the actual seabird by-catch. This problem may cause strong bias in by-catch estimates. The most likely explanation for the difference between number caught with and without the presence of an observer on the deck is possibly that fishermen deliberately cut off the birds during hauling. Unreported by-catch is another serious cause of underestimation. For example, 178 birds killed were reported by an observer dedicated to seabird mortality (our data), whereas the official report gives a figure of 65 birds killed, reported for exactly the same period by the scientist but for which the work was not devoted to by-catch (Petrenko and Vertunov 1997). Asking captains to record seabird mortality is therefore misleading because they have other work to do and consider that it is damaging for further operations to report high number of birds killed. It appears therefore essential that, to estimate the effect of fishery on seabirds, the work is carried out by specialist observers dedicated to record only seabird mortality. This is almost never done at present.

Efficacy of mitigation measures

The three main mitigation measures for seabird mortality tested in the Kerguelen area are: (1) night setting with deck illumination doused; (2) use of a streamer line; and (3) dumping of offal. Night setting with deck-lights off seemed to be the most efficient measure in reducing seabird mortality when not associated with day setting. Only one albatross was caught at night, when the moon was close to full and the sky was without clouds. Albatrosses are reported to feed primarily during the day (Harper 1987; Weimerskirch and Wilson 1992; Croxall and Prince 1994) and it is therefore not surprising that few birds were caught at night. White-chinned petrels are also active at night, but the number of birds of this species caught at night is half that caught during the daytime. The number caught is still high, indicating that although this method is very effective, even for white-chinned petrels, it is still not sufficient to reduce the numbers caught to an acceptable figure.

The use of a streamer line seemed to be inefficient in the Ukrainian fishery with this species around Kerguelen. During the 1995/1996 cruise, we observed 13 failures in line deployment. The end buoy became entangled with the hooks and driven with the long-line. As a consequence the seabird mortality was 2.42 ± 1.60 birds/1000 hooks when deployment failed versus 1.08 ± 1.56 birds/1000 when it was successful, and 1.27 ± 2.19 birds/1000 without streamer line (ANOVA; $F_{3,176} = 22.51$, $P < 0.001$). Therefore the highest record of mortality in 1996/1997 should be linked to deployment failure of the scaring device. However, using a scaring device is efficient in other fisheries such as the pelagic tuna long-line fishery where it reduces bird mortality but also bait loss (Brothers 1991). In fisheries where the use of streamer lines is enforced, fishermen should be trained and properly designed streamer lines provided for this measure to be effective, otherwise it should be not used. The Kerguelen fishing grounds, especially on the west side of the plateau, are known to have particularly rough seas compared, for example, to sub-tropical waters, making the setting of streamer lines more difficult.

The dumping of homogenised offal greatly reduced the incidental capture of white-chinned petrels. Although the numbers of albatrosses were reduced with the dumping of offal, the differences are not significant. Offal greatly reduces incidental capture of seabirds in demersal long-lining because line setting is short (10–12 min setting vs 5–6 h) and seabirds adapt their feeding behaviour to the presence of the streamer line. However, the use of offal is not applicable to all fisheries where line setting is longer than an hour, such as the tuna long-line fishery where it last up to 10–12 h. Also, this measure is strongly affected by the number of fish caught on previous lines. In the case of poor catch in fish, the problem of seabird mortality and associated bait loss increased dramatically. Finally dumping of offals increases the attractiveness of the fishing vessels and should reinforce in the long-term the association that birds make between long-liners and food. For these reasons it can be concluded that the use of offal should not be recommended in other fisheries, unless the operations can be severely controlled so that dumping is done at each line setting.

Increasing the sinking rate of the line by weights on branch lines to avoid entanglement with scaring devices and to limit hooks' availability for species with good diving capacity, such as the white-chinned petrel (Huin 1994) especially during rough seas, may also reduce the catch rate of seabirds.

Conclusions

Compared with other studies on incidental capture of seabirds, the average observed catch rate during the current study is in the same order of magnitude in trawlers and in long-liners (e.g. Brothers 1991; Alexander et al. 1997). However, comparisons of observed seabird by-catch rates between studies are often flawed by the different ranges of data examined, as well as by the degree of confidence in the observations (see Petrenko and Vertunov 1997 compared to this study).

Line setting at night appears to be by far the best solution and is now enforced in the Kerguelen area and in the rest of the CCAMLR area. Of course it is not used in the illegal fisheries, which represent the greatest fishing effort in the Indian sector of the Southern Ocean and, therefore, is very likely to cause a very high mortality of seabirds. Additionally, even in the regulated fisheries and despite the use of line setting at night, mortality of white-chinned petrels remained at a relatively high rate that could not be sustainable for the Indian Ocean populations (A. Catard and H. Weimerskirch, unpublished work). During night setting, mortality can reach high rates for reasons that are still not clearly appreciated. For example, in the Kerguelen area a single set (double line, Spanish type) set at night has caused the death of 340 white-chinned petrels (N. Gasco, personal communication). More research is definitely needed to reduce the mortality of seabirds, such as on the setting of lines directly under water (under the vessel, or through a funnel), or the use of systems to increase the sinking speed of the baited line. The solutions found will have potential applications everywhere in the world where long-line fisheries are developing today.

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