Animal Conservation. Print ISSN 1367-9430

Seabird mortality associated with ice trawlers in the Patagonian shelf: effect of discards on the occurrence of interactions with fishing gear

M. Favero[1,2], G. Blanco[3], G. García[1,2], S. Copello[1,2], J. P. Seco Pon[1,2], E. Frere[1,4,5,6], F. Quintana[1,5], P. Yorio[1,5], F. Rabuffetti[7], G. Cañete[8] & P. Gandini[1,4,5]

1 Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Buenos Aires, Argentina
2 Vertebrados, FCEyN, UNMDP, Mar del Plata, Argentina
3 Instituto Nacional de Investigación y Desarrollo Pesquero, Programa Observadores a Bordo, Mar del Plata, Argentina
4 Universidad Nacional de la Patagonia Austral, Puerto Deseado, Santa Cruz, Argentina
5 Wildlife Conservation Society, Wildlife Conservation Society, Bronx, NY, USA
6 BirdLife International, Buenos Aires, Argentina
7 Aves Argentinas, Programa Aves Marinas, Buenos Aires, Argentina
8 Fundación Viva Silvestre Argentina, Programa Marino, Mar del Plata, Argentina

Keywords
seabirds; albatrosses; petrels; incidental mortality; trawlers; Patagonia; Argentina.

Correspondence
Marco Favero, Grupo Vertebrados, Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Mar del Plata – CONICET, Funes 3250 (B7602AYJ) Mar del Plata, Argentina.
Email: marco.favero@acap.aq

Editor: T. Katzner
Associate Editor: M. Schaub

Received 1 October 2009; accepted 30 August 2010

doi:10.1111/j.1469-1795.2010.00405.x

Abstract

This study investigated the level of seabird mortality caused by the domestic trawl fleet (freshies) for hake (among other less important targets) operating in waters off central Patagonia (37–48°S), analyzing the effect of environmental and operational variability on the level of seabird interactions. With a total of 135 vessels, the fleet is one of the largest in Argentina. Specifically tasked seabird observers were placed onboard trawlers during the summer and winter seasons of the years 2006 and 2007. The type and number of seabird interactions (i.e. contacts with fishing gear) were recorded during shooting and hauling operations, covering 72 days of observation and 328 trawls. Black-browed albatrosses, white-chinned petrels *Procellaria aequinoctialis*, southern giant petrels *Marconectes giganteus* and southern royal albatrosses *Diomedea epomophora* were the most abundant species interacting with trawlers. Confirmed mortalities of black-browed and southern royal albatrosses were the result of collisions and entanglement with the warp cable while birds were scavenging. The estimated total mortality rate was 0.017 birds h^{-1} and 0.105 birds per vessel per day. The intensity of interactions (in terms of the number of contacts per unit time) was largely explained by the distribution of the fishing effort. Seasonality and the incidence of discards were the strongest factors explaining the occurrence of seabird interactions. The total annual mortality in the trawl fleet under investigation was roughly estimated to be from several hundred to over a thousand albatrosses. However, these figures should be considered preliminary due to the limited spatial and temporal coverage of data and the fact that estimations were based on a low number of observed mortalities. The implementation of a strategic discard management may significantly reduce the number of seabird mortalities from collisions with warp cables or improve the effectiveness of other complementary mitigation methods. Urgent implementation of mitigation measures is needed in this fleet to reduce the mortality of albatrosses and petrels along the Patagonian shelf.

Introduction

Most of the studies analyzing the effects of interactions between seabirds and fisheries and the impact of fisheries on seabird populations commenced during the 1980s and were focused on the effects of longline vessels (see Brothers, 1991; Gales, Brothers & Reid, 1998; Løkkeborg, 1998; Robertson, 1998; Brothers, Gales & Reid, 1999; Kock, 2001). However, trawl fisheries became recognized as a threat to seabirds during the 1990s (see Bartle, 1991; Williams & Capdeville, 1996, among others) and nowadays, considering that *c*. 30% of the global annual fishery catch is taken by trawl gear (Watson, Revenga & Kura, 2006), it is estimated that 45% of the total annual seabird bycatch may be associated with these fisheries (Baker *et al*., 2007). In the southern ocean, there is partial evidence showing that the impact of trawl fisheries on seabirds can be at least of the same magnitude as longlining (González-Zevallos & Yorio, 2006; Sullivan *et al.*, 2006*a*). Strikes with the vessels and warp and net sonde cables, and entanglements with nets and other components of the fishing gear are the recorded causes of mortalities and serious injuries for seabirds (Wienecke & Robertson, 2002; González-Zevallos, Yorio & Caille, 2007; Watkins, Petersen & Ryan, 2008). However, birds captured in the nets or killed after colliding with warps and hauled onboard are considered to represent a small proportion of those killed during fishing operations (Weimerskirch, Capdeville & Duhamel, 2000; Sullivan, Reid & Bugoni, 2006*b*). Among seabird species, albatrosses and petrels have been extensively recognized as the most vulnerable group (see Gales, 2008). In fact, increased mortality rates due to interactions with fisheries were linked to the global declines in a number of seabird populations (Croxall *et al.*, 1990; Brothers, 1991; Weimerskirch, Brothers & Jouventin, 1997; Weimerskirch *et al.*, 1999; Lewison & Crowder, 2003).

The Patagonian shelf and its shelf-break is a very important foraging area for seabirds among other local and non-resident marine top predators (Croxall & Wood, 2002; Gonzalez-Solis, Croxall & Briggs, 2002; Favero & Silva, 2005; Arata *et al.*, 2009; Pütz *et al.*, 2009; Quintana *et al.*, 2009), increasing the likelihood of interactions with fishing vessels that also operate extensively in the region. In Argentina, the growth of fisheries in the 1980s caused considerable concern among conservationists with regard to their possible effects on fish stocks and marine predators (Bastida *et al.*, 2005). These concerns triggered a process that firstly addressed the threats posed to seabirds by the domestic longline fishery (Favero *et al.*, 2003; Gandini & Frere, 2006; Gómez Laich *et al.*, 2006; Gómez, Laich & Favero, 2007; Seco Pon, Gandini & Favero, 2007) and the intention was then to tackle the trawl and other fisheries. However, the identification and understanding of seabird–fishery interactions and of the methods to minimize negative effects on seabird populations in the region is still incomplete. The completion of this process is particularly crucial for the trawl fisheries, given their prevalence in Argentine waters and the relatively low level of attention they have received to date, combined with the fact that a very large proportion of the fishing effort in Argentina is conducted by trawl vessels. Hence, information on the levels of interaction, their characteristics and mortality rates is fundamental to improve the conservation status of many seabird species breeding in the southern hemisphere and using the target area during different stages of the annual cycle.

Both environmental and operational conditions affect the way in which albatrosses and petrels interact with fishing vessels and their chances of becoming hooked, entangled or colliding with the vessel or the fishing gear (Klaer & Polacheck, 1998; Weimerskirch *et al.*, 2000; González Zevallos & Yorio, 2006; Gómez Laich & Favero, 2007). For example, collisions may increase as a function of the aerial extent of the warp cable, the type of discharge and its location relative to the warp cables (Dietrich & Melvin, 2007). However, these effects may vary in different fisheries due to prevailing weather conditions in the region where it operates and also due to important or subtle differences in the fishing practices. Hence, this study was conducted to characterize the interactions between seabirds and the high-seas trawl ice fleet operating in the Argentine Economic Exclusive Zone by (1) determining the level of seabird mortality caused by this fleet; (2) analyzing the effect of environmental and operational variability on the occurrence of contacts with the fishing gear.

Methods

Ice-trawl fishery under study

With some 135 operative vessels, the ice-trawl fleet (hereafter called 'freshies') is one of the largest in Argentina. Vessels are roughly longer than 60 ft and in general fishers do not process the catch onboard, preserving the fish in ice within plastic cubes (*c.* $0.06\,m^3$) during trips that last between 4 and 15 days. Each vessel operates a minimum of 130–150 days per year and performs some 600 hauls per year. The fishing effort is distributed in the continental Patagonian shelf and shelf break between 37 and 48°S, and is particularly concentrated between 42 and 46°S. The total catch per year between 2006 and 2008 averaged 286 000 metric tonnes, representing one-third of the total catch of the entire Argentine fishery. The most important target is the Argentine hake *Merluccius hubbsi* (almost 70% of the catch), followed by the squid *Illex argentinus*, kingclip *Genypterus blacodes* and hoki *Macruronus magellanicus*, among others (http://www.sagpya.mecon.gov.ar/SAGPyA/pesca/).

Seabird abundance and interaction with fisheries

Seabird observers from the National Observers Programme (INIDEP, National Fisheries Research Institute, Argentina) were trained and specifically tasked onboard freshies trawlers between the years 2006 and 2007. The abundance of seabirds attending vessels and the number of contacts with fishing gear, both fatal and non-fatal (herein referred also as interactions), were recorded during trawling operations, covering 72 fishing days, 576 h of observation and 328 trawls. During these trips, observers were dedicated full time to the observation of seabird interactions with fishing gear. Observed fishing trips operated in the major fishing area used by the ice-trawl fishery (Fig. 1).

Data collected during the fishing operation followed in general terms the protocols developed by the Australian Antarctic Division and further used in neighboring waters (Wienecke & Robertson, 2002; Sullivan *et al.*, 2006*a*), and included the geographic position, time of day, season, wind speed (in knots), wind direction relative to the vessel (1: ahead, 2: 45–135° and 3: astern), cloudiness (scaled from 0: no clouds to 8: overcast) and sea state (in Beaufort scale in four categories, 1: ≤ 2, 2: 3, 3: 4 and 4: ≥ 5). Fishery discard were scaled into three categories as 0: no (or negligible)

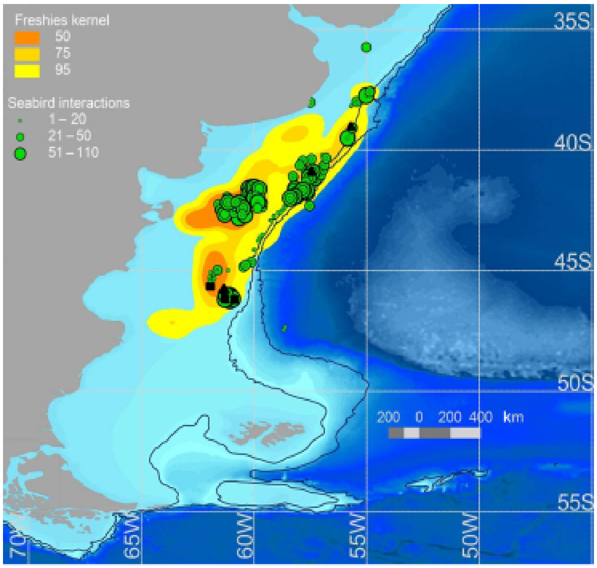

Figure 1 Kernel analysis of the sampled fishing effort (orange and yellow) of ice trawlers operating in the Patagonian shelf, Argentina, superimposed to the intensity (in number of contacts with fishing gear per hour) of albatross and petrels' interactions (shown by scaled green circles). Black triangles and squares show, respectively, the locations of observed black-browed and southern royal albatross mortalities.

discards, 1: low to moderate discards (volumes smaller than 10% of the total catch and generally in the order of a few hundred kilograms) and 2: a large amount of discards (volumes larger than 10% of the total catch). For the general linear model (GLM) analysis, only the presence or absence of discards was considered (0: no or negligible discards, 1: discards occurred during the fishing operation). Prevailing environmental conditions were considered constant during each observation period unless they changed drastically.

Seabirds were identified to the species level and, when possible, age class was determined. The number of birds attending the vessels was estimated by conducting counts ($n = 257$) from the stern of the vessel, lasting from 10 to 20 min. Counts, covering a 200 m radius sampling area (200 m astern and 200 m on the starboard and port sides), were conducted once per trawl and approximately in the middle of the towing operation in between the observations of seabird interaction with gear. Abundances were scaled as follows: 1: $\leq$ 10 individuals, 2: 11–50, 3: 51–200, 4: 201–500 and 5: $>$500 birds. For this study, only black-browed albatross *Thalassarche melanophris* abundances were analyzed in detail; this single species represented over 50% of the overall seabird abundance in a total of 442 counts.

All seabird interactions with the vessel or fishing gear were recorded in two periods, during shooting/early trawling and late trawling/hauling, each one lasting *c.* 60 min. Observations were focused on the warp cable and the side of the vessel where the offal discharge took place and most of the seabird activity occurred. Observers recorded the number of birds colliding or becoming entangled with: (1) warp cable; (2) trawl doors; (3) brides; (4) net; (5) vessel; (6) net sonde cables, following protocols adapted from previous studies (see Sullivan *et al.*, 2006*a*). Types of contact with the vessel or fishing gear were defined as: (1) bird on water, light contact; (2) bird on water, heavy contact causing at least part of the bird to be dragged underwater; (3) bird flying, light contact, bird does not deviate from course; (4) bird flying, heavy contact, bird deviates from course and/or dragged underwater; (5) bird snagged on loose wire ends; (6) bird caught in net. The fate of birds contacting with gear or vessel was classified into the following: (1) no apparent damage; (2) possible minor injury; (3) possible major injury; (4) death; (5) unknown (see Wienecke & Robertson, 2002; Sullivan *et al.*, 2006*a*).

Statistical analyses

Kruskal–Wallis analyses were performed to test the effect of environmental (e.g. wind direction and speed) and operational (e.g. importance of fishing discards) conditions on the intensity of seabird interactions, considering as a response variable the number of total contacts per fishing operation (irrespective of the final fate of the bird) as a proxy of the risk of mortality for seabirds attending vessels. The distribution and intensity of seabird–fishery interactions was analyzed in conjunction with the fishing effort by using Kernel plots (Worton, 1989). The fishing effort was modeled in order to define range (95%), focal (75%) and core (50%) areas (Hyrenbach, Fernández & Anderson, 2002).

GLM was performed considering the occurrence of interactions per species during a given trawl as a response variable. Two values were possible for the response variable: 0 for no interactions occurred and 1 if at least one interaction with fishing gear occurred, irrespective of the type of contact or the final fate of the bird. The relationships between predictor variables were tested through GLM with a binomial error and a log link function (Crawley, 2007). Explanatory variables included seasonality, time of day, wind speed, relative wind direction and the occurrence of discards through the fishing operation. For model selection, we considered models with all possible combinations of the explanatory variable. Akaike's information criterion corrected for overdispersion and a small sample size (QAICc) was calculated for each model (Burnham & Anderson, 2002). Smaller QAICc values indicate more parsimonious and thus better-approximating models. We compared candidate models using ΔQAICc as the difference between the QAICc for each respective model and the lowest observed QAICc (Burnham & Anderson, 2002). Models with ΔQAICc = 2 are considered to have strong support from the data (Burnham & Anderson, 2002). Support for model parameters was evaluated by summing QAICc weights for all models that included each parameter. All statistical analyses were carried out using R software, version 2.5.1 (R Development Core Team, 2006).

Results

A total of 17 species was identified attending trawl vessels, with black-browed albatrosses, cape petrels, white-chinned petrels and giant (mostly southern) petrels accounting for over 80% of the total abundance (Table 1). All seabirds interacting (i.e. colliding) with fishing gear during the fishing operations comprised tube-nosed (Procellariform) birds. From 14 671 observed contacts with the fishing gear, 56% corresponded to black-browed albatrosses (70% of them were adult individuals), cape petrels *Daption capensis* (17%), white-chinned petrels *Procellaria aequinoctialis* (12%), southern giant petrels *Marconectes giganteus* (6%), and southern royal albatrosses *Diomedea epomophora* and northern royal albatrosses *Diomedea sanfordi* (7%), among others (Table 1). A rate of 25.47 contacts per hour was estimated during the sampling period. Over 98% of the interactions corresponded to light contacts with the warp cables occurring while birds were either on the water or flying. Kernel analysis showed that the intensity of interactions (in terms of the observed number of contacts with gear) was largely explained by the distribution of the fishing effort (i.e. most of the contacts observed in focal and core areas) in most areas (Fig. 1).

A total of 22 heavy contacts with fishing gear or the vessel (82% of them corresponding to black-browed albatrosses) represented a rate of 0.04 heavy contacts per hour (Table 1). Confirmed mortalities included seven black-browed albatrosses and three southern royal albatrosses. In the first species, all individuals were adult birds and mortalities were caused by severe collisions with the warp cable (five cases) and entanglements with the net while birds were scavenging during the hauling operation. Five of these mortalities occurred in fall and the other two in winter (all but one occurred north of 41°50′S in the vicinity of the shelf break). Southern royal albatrosses (one of them a juvenile) died as the result of contacts with the warp cable while in the water, collision with the net-sonde cable and entanglement with the net (one case each). Two mortalities occurred in winter and the other one in fall, all of them observed south of 46°S (Fig. 1). The estimated total mortality rate was 0.017 birds per hour and 0.105 birds per vessel per day, considering an average of three hauls per day and not including in the estimations the first in the day with no or very rare seabird interactions due to the absence of discards.

The analysis of the effect of environmental conditions on contact rates indicated that wind direction and wind speed had a significant effect on the intensity of interactions measured as the number of observed collisions per hour (Kruskall–Wallis $H = 8.72$, d.f. $= 2, 815$, $P < 0.05$; $H = 9.53$, d.f. $= 3, 833$, $P < 0.05$, respectively) (Fig. 2a and b). The intensity of interactions differed significantly between

Table 1 Abundance (Ab), percentual occurrence (F%), number of observed contacts, interaction and mortality rates of seabird attending ice trawlers in the Patagonian shelf, Argentina

	Birds attending vessel		Number of contacts observed (interaction rate) [a]					
Species	Ab (max)[c]	F%	WL	FL	WH	FH	NET	Mortality rate[b]
Black-browed albatross *Thalassarche melanophris*	2 (5)	96.3	5134 (8.92)	2994 (5.20)	7 (0.01)	11 (0.02)	12 (0.02)	0.012
Cape petrel *Daption capense*	2 (3)	68.9	1215 (2.11)	1327 (2.30)				
White-chinned petrel *Procellaria aequinoctialis*	2 (3)	72.8	1121 (1.95)	663 (1.15)				
Southern/northern giant petrel *Macronectes giganteus/halli*	1 (3)	52.5	795 (1.38)	26 (0.05)				
Wilson's storm petrel *Oceanites oceanicus*	1 (3)	33.5	147 (0.26)	21 (0.04)		2 (0.00)		
Southern/northern royal albatross *Diomedea epomophora/sanfordi*	1 (2)	25.7	958 (1.66)	101 (0.18)	1 (0.00)	1 (0.00)		0.005
Wandering albatross *Diomedea exulans*	1 (2)	12.5						
Greater shearwater *Puffinus gravis*	1 (2)	11.3	38 (0.07)	27 (0.05)			1 (0.00)	
Kelp gull *Larus dominicanus*	1 (2)	6.2						
Sooty shearwater *Puffinus griseus*	1 (2)	3.9	27 (0.05)	33 (0.06)				
South American tern *Sterna hirundinacea*	1 (2)	3.1						
Southern fulmar *Fulmarus glacialoides*	1 (2)	2.3						
Soft-plumaged petrel *Pterodroma mollis*	1 (2)	2.0						
Gray headed albatross *Phoebetria palpebrata*	1 (1)	1.2						
Yellow -nosed albatross *Diomedea chlororhynchos*	1 (1)	1.6						
Spectacled petrel *Procellaria conspicillata*	1 (1)	0.4						

[a]Contacts with gear per hour trawl.

[b]Mortalities per hour trawl.

[c]Modal and maximum abundance categories observed according to the following categories: 1: ≤ 10 individuals; 2: 11–50; 3: 51–200; 4: 201–500 and 5: >500 birds.

Blank cells = no contacts/mortality observed; 0.00 = contact/mortality rates <0.005.

WL, bird on water, light contact; WH, bird on water, heavy contact; FL, bird flying, light contact; FH, bird flying, heavy contact; NET, bird on the water contacting the net or entangled.

seasons ($H = 204.95$, d.f. $= 3, 833$, $P < 0.0001$) (Fig. 2c), being particularly lower during the first quarter (i.e. austral summer), a fact that can be, at least partially, attributed to lower abundances in this quarter as it can be seen in the comparison of the size of black-browed albatross' flocks attending vessels (Fig. 3). Interactions were significantly affected by the level of fishing discards, with a larger number of contacts observed as the level of discards increased ($H = 83.99$, d.f. $= 2, 833$, $P < 0.0001$) (Fig. 2d).

GLM indicated that the incidence of discards (parameter likelihood > 0.996) and seasonality (parameter likelihood > 0.988) were the strongest factors explaining the occurrence of interactions of black-browed albatrosses, southern royal albatrosses, southern giant petrels and white-chinned petrels. In smaller species such as the cape petrel and Wilson's storm petrels, wind intensity largely explained the frequency of occurrence of interactions (Tables 2 and 3).

Discussion

Mortalities associated with collisions with warp cable have been reported previously in trawl fisheries around the world including the south Atlantic (Sullivan & Reid, 2002; Wienecke & Robertson, 2002; González-Zevallos & Yorio, 2006; González-Zevallos *et al.*, 2007; Watkins *et al.*, 2008). As a result of these strikes, birds are often trapped and

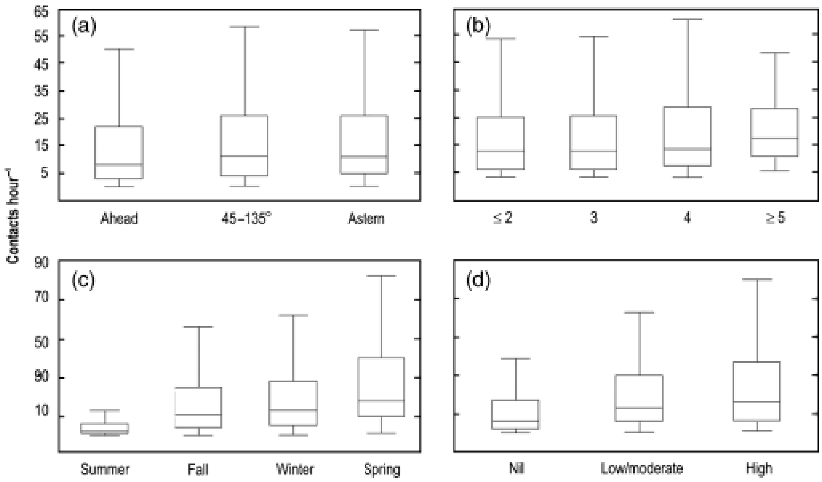

Figure 2 Intensity of interactions (in seabird contacts with fishing gear per hour) under different relative wind directions (a), sea state in Beaufort scale (b), time of the year (c) and discard amount (d), recorded at ice trawlers operating in the Patagonian shelf, Argentina.

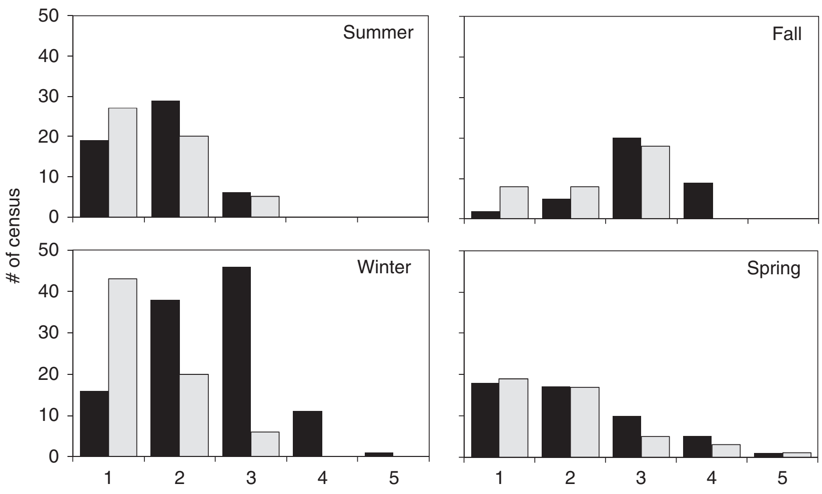

Figure 3 Abundance of adult (black) and juvenile (gray bars) black-browed albatrosses associated to ice trawlers operating in the Patagonian shelf, Argentina. Abundances scaled as follows: 1: ≤ 10 individuals, 2: 11–50, 3: 51–200, 4: 201–500 and 5: > 500 albatrosses ($n = 257$ censuses).

Table 2 Generalized linear models explaining variation in the occurrence of seabird interactions with ice trawlers operating in the Patagonian shelf, Argentina

Species	Model	Explanatory variables	Parameters	ΔQICc	QAICc weight	R^2
BBA	1	Season, time day, wind direction, wind speed, discard	7	0.00	0.33	0.30
	2	Season, wind direction, wind speed, discard	6	0.50	0.26	0.29
	3	Season, time, wind speed, discard	5	0.59	0.24	0.29
	4	Season, wind speed, discard	4	1.99	0.12	0.28
SGP	1	Season, time, wind direction, discard	6	0.00	0.69	0.16
	2	Season, time, discard	4	2.00	0.18	0.15
SRA	1	Season, time day, wind direction, wind speed, discard	8	0.00	0.51	0.14
	2	Season, time, wind direction, discard	6	1.10	0.29	0.13
WCP	1	Season, time, wind direction, discard	6	0.00	0.52	0.22
	2	Season, time, discard	4	1.10	0.30	0.21
WSP	1	Season, wind speed	4	0.00	0.44	0.22
	2	Season, wind speed, discard	5	1.74	0.18	0.22
	3	Season, time, wind speed	5	1.95	0.16	0.22
CAP	1	Wind speed, discard	3	0.00	0.21	0.06
	2	Wind direction, wind speed, discard	5	0.10	0.21	0.07
	3	Time, wind speed, discard	4	1.01	0.13	0.06
	4	Time day, wind direction, wind speed, discard	6	1.26	0.11	0.08
	5	Season, wind speed, discard	4	1.91	0.08	0.06

Only models with strong support are shown (i.e. ΔQAICc$<$2). Models are listed in decreasing order of importance.
BBA, black-browed albatross; SGP, southern giant petrel; SRA, southern royal albatross; WCP, white-chinned petrel; WSP, Wilson's storm petrel; CAP, cape petrel.

dragged underwater by the drag created by the forward motion of the fishing vessel (Sullivan & Reid, 2002; González-Zevallos & Yorio, 2006). In addition, the presence of wire splices that join sections of the warp cables may increase the mortality and its detection because birds hit the cable, slide down and become impaled on the splices (Goñi, 1998; Kock, 2001; Sullivan *et al.*, 2006*b*). In this study, a very large proportion of interactions and confirmed mortalities corresponded to collisions with the warp cables and entanglements with the net. The contact rates observed in the freshies fleet (25.47 contacts per hour) were about half those reported for freezer trawlers operating in neighboring areas (55. 8 per hour). However, the mortality rates for the freshies (0.017 per hour) were five times lower than the 0.082 mortalities per hour reported previously in the region (Sullivan *et al.*, 2006*a*). These differences can be the result of different sizes of vessels, capture volumes, fishing areas or other characteristics of the freezer fleet, as well as the different composition of seabird assemblages.

The analysis of environmental and operational variability affecting the interactions between albatrosses and petrels with the vessel and fishing gear indicated a clear seasonal variability in the contact rates (particularly lower in summer) and a strong incidence of discards in the occurrence and intensity of interactions. This finding is in line with recent investigations conducted in other trawl fisheries showing the significant effect of discards on the occurrence and intensity of seabird contacts with warp cables (Crofts, 2006; Gonzalez Zevallos & Yorio, 2006; Sullivan *et al.*, 2006*b*; Watkins *et al.*, 2008).

Mitigation methods like streamer (tori) lines, warp scarers, traffic cones or the Brady bafflers, among others, can reduce seabird contacts and mortalities associated with warp strikes while birds are flying or in the water (Melvin, Dietrich & Thomas, 2004; Sullivan, Liddle & Munro, 2004; Sullivan *et al.*, 2006*a*; González-Zevallos *et al.*, 2007). Some of these methods, such as streamer lines, have the advantage of low cost, require little storage space, are easy to maintain replace and deploy (Sullivan *et al.*, 2006*a*), and should be considered in management recommendations to be implemented in the short term in the fishery under investigation. However, management of discards, either through retention, strategic dumping, processing or a combination of these, should be considered as one potential measure to decrease the numbers of birds attending trawlers and consequently the intensity of interactions and mortalities in this fishery. Recent research conducted in the mid-water trawler hoki fishery in New Zealand showed the potential value of introducing mincing or mealing fish waste as a conservation measure to reduce the numbers of strikes or birds attending vessels (Abraham *et al.*, 2009). Although discard management can be considered to be the ultimate measure to bring mortality rates to negligible numbers in trawl fisheries, the temporary retention and/or processing of discards during fishing activities may be logistically difficult for many vessels, particularly for freshies. However, given its potential to reduce the number of birds attending vessels, further exploration of discard management effectivity and implementation likelihood is critical.

Considering a figure of three hauls per day, some 130 operative days per year per vessel and a fleet composed by 135 freshies as a proxy of the fishing effort by the studied fleet, the annual mortality in this fishery could be in the order of several hundreds or even over 1000 albatrosses.

Table 3 Parameter likelihoods by species and explanatory variables from generalized linear models (GLM) models explaining variation in the occurrence of seabird interactions with ice trawlers in Argentina

Species	Explanatory variables	Parameter likelihood
BBA	Season	0.99
	Time of day	0.61
	Wind direction	0.61
	Wind speed	0.96
	Discard	1.00
SGP	Season	1.00
	Time of day	0.84
	Wind direction	0.73
	Wind speed	0.19
	Discard	1.00
SRA	Season	1.00
	Time of day	0.93
	Wind direction	0.87
	Wind speed	0.61
	Discard	1.00
WCP	Season	1.00
	Time of day	0.96
	Wind direction	0.14
	Wind speed	0.63
	Discard	1.00
WSP	Season	1.00
	Time of day	0.27
	Wind direction	0.14
	Wind speed	1.00
	Discard	0.30
CAP	Season	0.28
	Time of day	0.37
	Wind direction	0.48
	Wind speed	0.98
	Discard	0.91

BBA, black-browed albatross; SGP, southern giant petrel; SRA, southern royal albatross; WCP, white-chinned petrel; WSP, Wilson's storm petrel; CAP, cape petrel.

Although these figures were drawn by following conservative premises, biases associated with the use of simple linear extrapolations (see Croxall, 2008; Moore & Zydelis, 2008; Ryan & Watkins, 2008) can be occasioned by the fact that: (1) over 98% of the observed interactions corresponded to light contacts and estimates of albatross mortality were based on a low number of birds killed (10 individuals out of over 14 600 contacts); (2) mortalities observed during the study period were restricted in time and space (only during fall and winter and in five trawls mostly along the shelf break); (3) fishing effort is not even along the year; (4) although sample size comprises an important number of observed trawls, this represents a small proportion compared with the annual effort for the entire fleet estimated in some 50–60 000 trawls. Hence, further studies including better observer coverage are needed for an adequate modeling of the total mortalities and the identification of core areas for albatrosses interacting with freshies.

The black-browed albatross accounted for a substantial part of the observed interactions and mortalities. During the last decades, this species had undergone a significant decline in its populations in the south Atlantic and the deterioration of its conservation status to the point that is currently considered endangered (see Agreement on the Conservation of Albatrosses and Petrels, 2009). High levels of mortality (black-browed albatrosses included) have already been reported in other fisheries in the south Atlantic (e.g. Sullivan *et al.*, 2006*a*,*b*; Watkins *et al.*, 2008). However, more fisheries in the region need to be investigated to determine where these albatrosses are killed and where conservation actions are urgently needed. Argentina has tackled the problem of incidental mortality of seabirds in the demersal longline fleet through the adoption in 2008 of a binding measure for the use of mitigation measures in its longliners (Federal Fisheries Council Resolution 08/08, http://www.cfp.gov.ar), and more recently, with the adoption of a National Plan of Action-Seabirds (NPOA-S) for the reduction of incidental mortality in all fisheries (Federal Fisheries Council Resolution 03/10). Our results, also considering the large size of the trawl fleet (freshies and freezer trawlers included), highlight the need for developing and implementing mitigation measures in trawlers. The exploration of measures adapted to the local needs and possibilities is an ongoing process as part of the NPOA-S implementation. The strategic dumping of discards during the fishing day, used in conjunction with other measures, should be considered as a method to decrease the number of seabirds attending freshies.

Acknowledgments

This study was financially supported by the Save the Albatross Campaign Chapter sponsored by IAATO and supported by Birds Australia, and the Aves Argentinas seabird program funded by Vogelbescherming Nederland. We also wish to especially thank Phillip and Marsha Dowd for the financial support. Observers of the National Observers Programme (INIDEP) contributed to the development of this study by following specific sampling protocols and by providing the feedback needed for its improvement.

References

Abraham, E.R., Pierre, J.P., Middleton, D.A.J., Cleal, J., Walker, N.A. & Waugh, S.M. (2009). Effectiveness of fish waste management strategies in reducing seabird attendance at a trawl vessel. *Fish. Res.* **95**, 210–219.

Agreement on the Conservation of Albatrosses and Petrels. (2009). Species assessment: black-browed albatross *Thalassarche melanophrys*. Available at http://www.acap.aq (1 September 2009)..

Arata, J., Croxall, J., Huin, N., Nicholls, D., Phillips, R., Quintana, F., Robertson, C.J.R., Robertson, G., Tratan, P. & Falabella, V. (2009). Parte 2. Albatros. In *Atlas del*

Mar Patagónico: Especies y Espacios: 45–97. Falabella, V., Campagna, C. & Croxall, J. (Eds). Argentina: Proyecto Modelo del Mar/Wildlife Conservation Society/CONI CET/BirdLife International.

Baker, G.B., Double, M.C., Gales, R., Tuck, G.N., Abbott, C.L., Ryan, P.G., Petersen, S.L., Robertson, C.J.R. & Alderman, R. (2007). A global assessment of the impact of fisheries-related mortality on shy and white-capped albatrosses: conservation implications. *Biol. Conserv.* **137**, 319–333.

Bartle, J.A. (1991). Incidental capture of seabirds in the New Zealand subantarctic squid trawl fishery. *Bird Conserv. Int.* **1**, 351–359.

Bastida, R., Rodriguez, D., Scarlatto, N. & Favero, M. (2005). Marine biodiversity of the south-western Atlantic Ocean and main environmental problems of the region. In *Mankind and the oceans*: 172–207. Miyazaki, N., Adeel, Z. & Ohwada, K. (Eds). New York: United Nations University Press.

Brothers, N. (1991). Albatross mortality and associated bait loss in the Japanese longline fishery in the southern ocean. *Biol. Conserv.* **55**, 255–268.

Brothers, N., Gales, R. & Reid, T. (1999). The influence of environmental variables and mitigation measures on seabird catch rates in the Japanese tuna longline fishery within the Australian fishing zone, 1991–1995. *Biol. Conserv.* **88**, 85–101.

Burnham, K.P. & Anderson, D.R. (2002). *Model selection and multimodel inference: a practical information–theoretic approach*. 2nd edn. New York: Springer-Verlag.

Crawley, M.J. (2007). *The R book*. New York: John Wiley and Sons Inc.

Crofts, S. (2006). *Seabird interactions in the Falkland Islands Loligo trawl Fishery 2005/2006*. Stanely: Falklands Conservation.

Croxall, J.P. (2008). Seabird mortality and trawl fisheries. *Anim. Conserv.* **11**, 255–256.

Croxall, J.P., Rothery, P., Pickering, S.P.C. & Prince, P.A. (1990). Reproductive performance, recruitment and survival of wandering albatrosses *Diomedea exulans* at Bird Island, South Georgia. *J. Anim. Ecol.* **59**, 775–796.

Croxall, J.P. & Wood, A.G. (2002). The importance of the Patagonian Shelf for top predator species breeding at South Georgia. *Aquat. Conserv.: Mar. Freshw. Ecosyst.* **12**, 101–118.

Dietrich, K.S. & Melvin, E. (2007). *Alaska trawl fisheries: potential interactions with north Pacific albatrosses, WSG-TR 07-01*. Seattle: Washington Sea Grant.

Favero, M., Khatchikian, C., Arias, A., Silva, M.P., Cañete, G. & Mariano-Jelicich, R. (2003). Estimates of seabird by-catch along the Patagonian shelf by Argentine Longline fishing vessels, 1999–2001. *Bird Conserv. Int.* **13**, 273–281.

Favero, M. & Silva, M.P. (2005). Estado actual y conservación de aves pelágicas que utilizan la plataforma continental Argentina como área de forrajeo. *Hornero* **20**, 95–110.

Gales, R. (2008). Flagship species at half mast. In *Albatross their world, their ways*: 148–151. De Roy, T., Jones, M. & Fitter, J. (Eds). Aukland: David Bateman Ltd.

Gales, R., Brothers, N. & Reid, T. (1998). Seabird mortality in the Japanese tuna longline fishery around Australia, 1988–1995. *Biol. Conserv.* **86**, 37–56.

Gandini, P.A. & Frere, E. (2006). Spatial and temporal patterns in the bycatch of seabirds in the Argentinean longline fishery. *Fish. Bull.* **104**, 482–485.

Gómez Laich, A. & Favero, M. (2007). Spatio-temporal variability in mortality rates of white-chinned petrels *Procellaria aequinoctialis* interacting with longliners fishing in the south-west Atlantic. *Bird Conserv. Int.* **17**, 359–366.

Gómez Laich, A., Favero, M., Mariano-Jelicich, R., Blanco, G., Cañete, G., Arias, A., Silva Rodriguez, M.P. & Brachetta, H. (2006). Environmental and operational variability affecting the mortality of black-browed albatrosses associated to long-liners in Argentina. *Emu* **106**, 21–28.

Goñi, R. (1998). Ecosystem effects of marine fisheries: an overview. *Ocean Coast. Mgmt.* **40**, 37–64.

Gonzalez-Solis, J., Croxall, J.P. & Briggs, D.R. (2002). Activity patterns of giant petrels, *Macronectes* spp., using different foraging strategies. *Mar. Biol.* **140**, 197–204.

González-Zevallos, D. & Yorio, P. (2006). Seabird use of discards and incidental captures at the Argentine hake trawl fishery in the Golfo San Jorge, Argentina. *Mar. Ecol. Prog. Ser.* **316**, 175–183.

González-Zevallos, D., Yorio, P. & Caille, G. (2007). Seabird mortality at trawler warp cables and a proposed mitigation measure: a case of study in Golfo San Jorge, Patagonia, Argentina. *Biol. Conserv.* **136**, 108–116.

Hyrenbach, K.D., Fernández, P. & Anderson, D.J. (2002). Oceanographic habitats of two sympatric North Pacific albatrosses during the breeding season. *Mar. Ecol. Prog. Ser.* **233**, 283–301.

Klaer, N. & Polacheck, T. (1998). The influence of environmental factors and mitigation measures on by-catch rates of seabirds by Japanese longline fishing vessels in the Australian region. *Emu* **98**, 305–316.

Kock, K. (2001). The direct influence of fishing and fishery-related activities on non-target species in the Southern Ocean with particular emphasis on longline fishing and its impact on albatrosses and petrels - a review. *Rev. Fish Biol. Fish.* **11**, 31–56.

Lewison, R.L. & Crowder, L.B. (2003). Estimating fishery bycatch and effects on a vulnerable seabird population. *Ecol. Appl.* **13**, 743–753.

Løkkeberg, S. (1998). Seabird by-catch and bait loss in long-lining using different setting methods. *ICES J. Mar. Sci.* **55**, 145–149.

Melvin, E., Dietrich, K.S. & Thomas, T. (2004). *Pilot tests of techniques to mitigate seabird interactions with catcher processor vessels in the Bering Sea pollock trawl fishery:*

final report. *WSG-AS 05-05*. WA: University of Washington.

Moore, J.E. & Zydelis, R. (2008). Quantifying seabird by-catch: where do we go from here. *Anim. Conserv.* **11**, 257–259.

Pütz, K., Frere, E., Boersma, D., Gandini, P., Quintana, F., Raya Rey, A., Schiavini, A., Wilson, R., Yorio, P. & Falabella, V. (2009). Parte 4. Pingüinos. In *Atlas del Mar Patagónico: Especies y Espacios*: 43–79. Falabella, V., Campagna, C. & Croxall, J. (Eds). Argentina: Proyecto Modelo del Mar/Wildlife Conservation Society/ CONICET/BirdLife International.

Quintana, F., Croxall, J., González-Solís, J., Phillips, R., Tratan, P. & Falabella, V. (2009). Parte 3. Petreles. In *Atlas del Mar Patagónico: Especies y Espacios*: 43–75. Falabella, V., Campagna, C. & Croxall, J. (Eds). Argentina: Proyecto Modelo del Mar/Wildlife Conservation Society/ CONICET/BirdLife International.

R Development Core Team. (2007). R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Robertson, G. (1998). The culture and practice of long line tuna fishing: implications for seabird by catch-mitigation. *Bird Conserv. Int.* **8**, 211–221.

Ryan, P.G. & Watkins, B.P. (2008). Estimating seabird bycatch by fisheries and its impact on seabird populations. *Anim. Conserv.* **11**, 260–262.

Seco Pon, J.P., Gandini, P. & Favero, M. (2007). Effect of longline configuration on the seabird mortality in the Argentine semi-pelagic kingclip *Genypterus blacodes* fishery. *Fish. Res.* **85**, 101–105.

Sullivan, B.J., Brickle, P., Reid, T.A., Bone, D.G. & Middleton, D.A.J. (2006*a*). Mitigation of seabird mortality on factory trawlers: trials of three devices to reduce warp cable strike. *Polar Biol.* **29**, 745–753.

Sullivan, B.J., Liddle, G.M. & Munro, G.M. (2004). *Mitigation trials to reduce seabird mortality in pelagic trawl fisheries (subarea 48.3)*. *WG-FSA04/80*. Hobart: CCAMLR.

Sullivan, B.J. & Reid, T. (2002). *Seabird interactions/mortality with longliners and trawlers in Falkland Island waters 2001/2002*. *WG-FSA-02/36*. Hobart: CCAMLR.

Sullivan, B.J., Reid, T.A. & Bugoni, L. (2006*b*). Seabird mortality on factory trawlers in the Falkland Islands and beyond. *Biol. Conserv.* **131**, 495–504.

Watkins, B.P., Petersen, S.L. & Ryan, P.G. (2008). Interactions between seabirds and deep water hake trawl gear: an assessment of impacts in South African waters. *Anim. Conserv.* **11**, 247–254.

Watson, R., Revenga, C. & Kura, Y. (2006). Fishing gear associated with global marine catches I: database development. *Fish. Res.* **79**, 97–102.

Weimerskirch, H., Brothers, N.P. & Jouventin, P. (1997). Population dynamics of wandering albatross *Diomedea exulans* and Amsterdam albatross *D. amsterdamensis* in the Indian Ocean and their relationships with longline fisheries: conservation implications. *Biol. Conserv.* **79**, 257–270.

Weimerskirch, H., Capdeville, D. & Duhamel, G. (2000). Factors affecting the number and mortality of seabirds attending trawlers and long-liners in the Kerguelen area. *Polar Biol.* **23**, 236–249.

Weimerskirch, H., Catard, A., Prince, P.A., Cherel, Y. & Croxall, J.P. (1999). Foraging white-chinned petrels *Procellaria aequinoctialis* at risk: from the tropics to Antarctica. *Biol. Conserv.* **87**, 273–275.

Wienecke, B. & Robertson, G. (2002). Seabird and seal – fisheries interactions in the Australian Patagonian toothfish *Dissostichus eleginoides* trawl fishery. *Fish. Res.* **54**, 253–265.

Williams, R. & Capdeville, D. (1996). Seabird interactions with trawl and longline fisheries for *Dissostichus eleginoides* and *Champsocephalus gunnari*. *CCAMLR Sci.* **3**, 93–99.

Worton, B.J. (1989). Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* **70**, 164–168.