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Seabird mortality on factory trawlers in the Falkland Islands and beyond

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ABSTRACT

Specifically tasked seabird observers were placed onboard demersal (bottom) finfish trawlers operating in the Falkland Islands in 2002/2003 to investigate the level of seabird mortality caused by the fleet. The observers were tasked to record seabird interactions during shooting, trawling and hauling operations during 157 days of coverage. It is estimated that >1500 seabirds, predominantly Black-browed albatross (*Thalassarche melanophris*), were killed by finfish trawlers during this period. Significant levels of mortality were also recorded on the Patagonian Shelf, north of the islands. Birds were killed after being dragged underwater by the warp cable while feeding on factory discharge at the stern of the vessel. An unknown proportion of these birds slide down the cable and become impaled on a splice in the cable, which was situated on average at 90 ± 40 m from the waters surface, and are subsequently hauled onboard. The incidence of mortality caused by the many large trawling fleets around the world that discharge factory waste and attract large bodied seabirds (e.g. albatross and large petrels) requires immediate investigation.

1. Introduction

Declines of many albatross and petrel species throughout the world have been attributed to mortality in longline fisheries (Croxall et al., 1990; Brothers, 1991; Weimerskirch et al., 1997, 2000; Robertson and Gales, 1998; Nel et al., 2002) and mortality caused by stern trawlers operating in a range of fisheries has been recorded around the Southern Hemisphere (Bartle, 1991; Weimerskirch et al., 2000; SC-CCAMLR, 2001, 2002; Sullivan and Reid, 2003). The causes of mortality in trawl fisheries are varied and depend on the nature of the fishery (pelagic or demersal) and the species targeted, however, it may be categorised into two broad types: cable-related mortality, including collisions with netsonde cables, warp cables and paravanes; and net-related mortality, which includes all deaths caused by net entanglement.

Traditionally, documented seabird mortality caused by trawlers has been associated with netsonde cable collisions (e.g. Bartle, 1991; Weimerskirch et al., 2000). Netsonde cables are now prohibited in many Southern Hemisphere fisheries (e.g. New Zealand, Convention for the Conservation of Antarctic Marine Living Resources, CCAMLR waters), but are still commonly used in several regions (e.g. South Africa and Alaska). Mortality have also been reportedly caused by birds becoming caught on warp splices during hauling operations (in Goni, 1998; Kock, 2001).

In recent years significant levels of trawler-induced mortality have been documented in pelagic trawl fisheries

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(Williams and Capdeville, 1996; Weimerskirch et al., 2000; SC-CCAMLR, 2001, 2002). This is typically caused by birds diving into the net and becoming entangled, particularly in intermediate size meshes (ranging from 120 to 200 mm, Hooper et al., 2003). In recent years the level of mortality recorded for the mackerel icefish (*Champsocephalus gunnari*) trawl fishery at South Georgia (CCAMLR Subarea 48.3), exceeded by several times the estimated total seabird bycatch mortality for all regulated longline fishing in the area in the same year (SC-CCAMLR, 2002, 2003, 2004).

Here, we provide the first detailed account of seabird mortality caused by collision with warp cables during trawling operations on factory trawlers. We also quantify the level of seabird mortality associated with these trawlers targeting a range of finfish species in the Falkland Island waters and adjacent environs and indicate the potential global scale of the problem.

2. Methods

2.1. Study area

The Falkland Islands lie between 51°S and 53°S and 57°W and 62°W on the southern end of the Patagonian Shelf. The islands are surrounded by shelf waters to 200 m that extend 100 km to the north, 25 km to the east, and 40 km to the south. Water depths increase rapidly to the east and south of the islands, whereas to the west and north/northwest the Patagonian Shelf gently slopes away to more than 400 m. The area of continental shelf, which extends from Argentina south to Tierra del Fuego and east around the Falkland Islands, is probably the largest domain of its kind in the world (Croxall and Wood, 2002).

2.2. Falkland Islands trawl fisheries

Since the mid 1970s multinational squid and finfish fisheries developed in the southwest Atlantic, including extensive fishing in waters around the Falkland Islands. In the Falkland Islands fishing effort is regulated by limiting licenses (i.e. effort limitation) for each target species. Most trawling takes place within 40 miles of the coast to the east and south, but extends up to 150–200 nautical miles to the west and northwest.

The region supports three major trawl fisheries, all of which are conducted by ocean-going freezer factory stern trawlers. (Stern trawlers are defined as vessels that deploy and retrieve a net and associated fishing gear from the stern of the vessel, Fig. 1). The Patagonian longfin squid (*Loligo gahi)* fleet targets two cohorts (autumn and spring) of *Loligo* in their feeding grounds off the east coast of the islands (at depths of 120–250 m depths). A diverse fleet of finfish trawlers also operates throughout the year targeting predominantly southern blue whiting (*Micromesistius australis australis*), hoki (*Macruronus magellanicus*), hake (*Merluccius hubbsi* and *M. australis*), kingclip (*Genypterus blacodes*) and red cod (*Salilota australis*). The majority of finfish trawling effort is concentrated west of the Falkland Islands at water depths up to 400 m, but typically between 100 and 200 m. The finfish fleet also comprises two or three vessels, which seasonally target southern blue whiting for the surimi market (the reconstituted fish market). A small fleet of trawlers (2–4 vessels) also target Rajidae, the most commonly caught skates being *Bathyraja griseocauda*, *Bathyraja albomaculata*, *Bathyraja brachyurops* and *Raja flavirostris*.

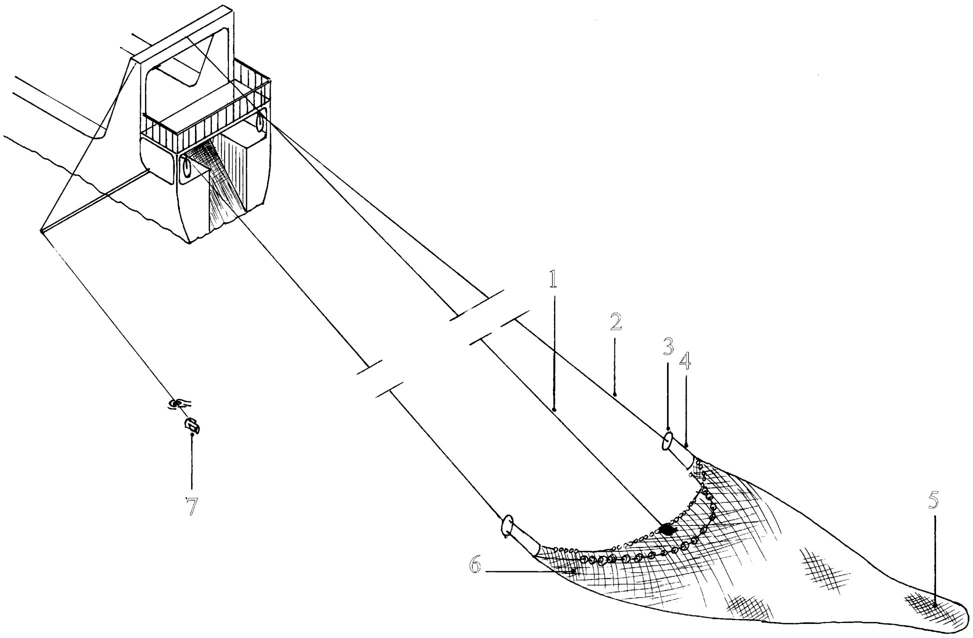

Fig. 1 – The working gear of a typical factory stern trawler. (N.B. Trawlers are unlikely to operate with both a netsonde cable and paravane, both are shown simply for clarification). Legend: 1, netsonde cable; 2, warp cable; 3, trawl door; 4, bridle and sweep; 5, codend; 6, net wings; 7, paravane.

2.3. Seabird abundance

Seabird abundance was estimated for shots, hauls, and hourly during trawl observation periods by conducting approximately 10-min counts from the stern gantry in a 500 × 500 m sampling area (500 m astern and 250 m on the starboard and port side). Shots are defined as the deployment of trawl gear (codend, net, bridle and sweep, trawl doors and warp cable, Fig. 1) until the operational trawl depth is reached and hauls are defined as the retrieval of all fishing gear. Due to the high densities of birds around the ship (often >1500 birds), it was not possible to obtain exact counts. Instead bird numbers were estimated as precisely as possible (cf. Abrams, 1983; Weimerskirch et al., 2000). In addition, a range of environmental and operational variables were also recorded during shooting, trawling and hauling.

2.4. Seabird interactions

Contacts between seabirds and fishing gear were recorded during shooting, trawling and hauling, using methods developed by the Australian Antarctic Division and Australian Fisheries Management Authority (for detail of data recording protocols see Table 1 Wienecke and Robertson, 2001). Generally, for each contact the observer recorded species, the type of gear contacted, the nature of the contact (flying or on the water; heavy or light contact), and the outcome of the contact (no apparent injury, minor or major injury, death or suspected death). These data were collected for periods of 0.5–3 h, commencing during shots and continuing either through to the next haul, the completion of factory processing or when observer fatigue necessitated a break. More than one observation period was often conducted during a single trawl.

During all setting and hauling operations we quantified the level of discharge into one of five classes (0 = nil, 1 = intermittent, 2 = low, 3 = medium and 4 = high). These categories were based primarily on a subjective judgement of the broad species composition of each landing and the proportion of each species discarded, filleted and ‘headed and gutted’. Therefore, discharge categories predominantly represent the intensity rather than duration of discharge, i.e. it is possible to have a high level of discharge over a short time period. Provided there were fish to be processed, waste was discharged from the factory during all operations (shooting, trawling and hauling).

Table 1 – Temporal stratification of trawling effort around Falklands Islands in 2002–2003 (breeding cycle of the black-browed albatross) and number of fishing days observed during each strata

Breeding cycle		Observed days
Winter	May–August 20	34
Prospecting	August 21–September 30	53
Laying	October	43
Eggs	November–December	25
Young chicks	January–February	20
Old chicks	March–April	0

Analysis of Variance (ANOVA) were conducted on the mean hourly contact rate with the warp cable of black-browed albatross and giant petrel species (*Macronectes* spp.) for a limited number of environmental and operational variables. Contact rates were log transformed after data screening identified that they were not normally distributed.

2.5. Seabird mortality

Mortality figures for each trawler trip were based on corpses, or part thereof, hauled onboard. These figures are likely to be an underestimate, as many birds become dislodged from the cable prior to hauling (see Section 4.4 for further explanation). The estimated number of seabirds killed by the finfish fleet and the variance of this estimate were calculated by temporal–spatial strata using methods adapted from Klaer and Polacheck (1995). This technique follows methods in Cochran (1977) for multi-stage sampling with unequally sized primary and secondary sampling units. This method increases the accuracy of mortality estimates by stratifying the data, and then sub-sampling from those strata. Ideally, hauls should be observed randomly from within strata, but given the difficulties of at sea transfers and observer placement, this was not possible. Vessels used for observations were chosen randomly. The estimated seabird mortality for finfish vessels, included skate and ray vessels, but excluded ‘surimi’ vessels, which have fish-meal plants onboard and are thought to produce less factory discharge, although vessel access could not be organised to verify this assumption. Data were stratified temporally and spatially. Temporal divisions were based on the various stages of the breeding cycle of black-browed albatross (Table 1), which largely determines their density and behaviour in the Falkland Islands in general, and around trawlers. The spatial component of the stratification process was based on dividing the study area into approximately equal latitudinal and longitudinal zones. This resulted in five zones, four of which are located in the Falkland Islands and one which was created to capture observed trawling effort that occurred on the high seas, north of the Falkland Islands.

An estimate of the total number of each species killed was made using the proportion of each species killed in each stratum multiplied by the estimated number of birds killed for that stratum. As described in Klaer and Polacheck (1995, 1997) an estimate of the variance for a proportion can be obtained by assuming that the proportions represent a multinomial sample within a stratum of all seabirds caught. Within each stratum, variance comes from proportions of birds sampled, differences in catch rates between cruises, and between sets within a cruise. The variance of the estimated total species catch was calculated from the variance of the total birds caught and the variance of the proportion of each of the species caught, following Seber (1973). As detailed in Klaer and Polacheck (1995), if no observations were made in a stratum, the total proportion of mortality for each species from observed strata was used.

Due to unusually dense concentrations of *Loligo* on the outer Patagonian shelf, approximately 100 km to the north of Falkland Island waters (between 46°S and approximately 47°30′S) from mid-September to late October 2002 most trawlers licensed to fish locally (including finfish, skate and ray and

Loligo vessels) operated in international waters. From 21 September to 13 October observations were made in this region by Seabird at Sea Team (SAST) observers on three trips aboard two trawlers. These data were used to estimate the mean by-catch rate for this area during this period. A mortality estimate for this region in this period was calculated using the methods described above and an estimate of the number of vessels observed each day (this figure represents the minimum number of trawlers actually present for each day).

All mortality was identified to species level. Since September 2001, we conducted three trips on *Loligo* vessels, and recorded zero mortality, so no mortality estimate was made.

2.6. *Contact rates and environmental variables*

A stepwise GLM process using the step module in S-Plus 2000 was used to identify which environmental variables were important in affecting levels of contact rates of black-browed albatrosses. The following variables were tested: levels of offal discharge, sea state (Beaufort scale), sea height, sea direction, swell height, swell direction, wind speed, wind direction, wind direction relative to the ship's course, day light period, abundance of black-browed albatrosses, fishing area, fishing season and number of vessels present around the vessel (as determined by their reported midday position).

2.7. *Contact rates and mortalities*

Integer values of mortality were so highly skewed it was not possible to transform them to normality. Therefore, in order to make a comparison between contact rates and mortalities, a Spearman rank correlation was used to find levels of correlation, and their probability. Mortalities were initially compared to total contact rates of all species apart from Cape petrels (*Daption capense*), which are small bodied birds and appeared to not suffer injury or mortality from contacts with warp cables. As the majority of mortalities were black-browed albatrosses, we then compared mortalities with all black-browed albatross contacts and because most mortalities occurred with birds sitting on the water, and all were due to heavy contacts (those that pushed birds, or parts of birds, under the water).

3. Results

3.1. *Observer coverage*

During 2002/2003 we conducted nine cruises, on seven different vessels. This represented 157 days of coverage on finfish trawlers (in the second season of 2002 and the first season of 2003) and >600 h of observation during shots and trawls and >150 h during hauls. We also conducted eight days on a *Loligo* trawler, operating in the shortened first season of 2003. Our trawler coverage was spread throughout Falkland Island waters, and broadly reflected finfish trawling effort for 2002/2003. While onboard, 420 shots and 421 hauls were conducted, of which 404 (96.2%) and 419 (99.5%), were observed respectively. The greatest number of fishing days was observed in the Prospecting period. Greatest fishing effort occurred in the SW area; the greatest percent of observer coverage (7.2%) occurred in the same area.

3.2. *Relative seabird abundance*

In total, 23 species of bird were recorded around trawlers. Generally, Black-browed albatrosses and Southern and Northern giant-petrels (*Macronectes giganteus* and *Macronectes halli*) were the most common species present throughout the year (Table 2). Cape petrels were also very common during winter and until December. Southern royal albatrosses (*Diomedea epomophora*) were present throughout the year, though often in numbers of less than ten. White-chinned petrels (*Procellaria aequinoctialis*), sooty shearwaters (*Puffinus griseus*), and Wilson's storm-petrels (*Oceanites oceanicus*) were also seasonally common.

3.3. *Seabird interactions*

We recorded 46,554 contacts between seabirds and fishing gear onboard finfish trawlers. The vast majority of contacts recorded during trawls were heavy and light contacts between birds on the water and the warp cable, which resulted in no apparent injury. Over 46,000 were contacts with the warp cable and almost 40,000 of these contacts occurred

Table 2 – Species observed during hourly trawl counts within each of the temporal strata, with the median count, where 1 = 1–10 birds; 2 = 11–50 birds; 3 = 51–200 birds; 4 = 201–500 birds; 5 = 501 + birds, and the number of occasions on which the median value was recorded

Species	Winter	Prospecting	Laying	Eggs	Young chicks
Counts	86	267	150	110	79
Wandering albatross	1(4)	1(10)	1(4)	1(2)	1(17)
Southern royal albatross	2(35)	1(132)	1(63)	1(81)	1(50)
Black-browed albatross	3(32)	3(101)	4(62)	4(42)	3(33)
Northern giant-petrel	3(20)	1(78)	1(15)	2(21)	1(16)
Southern giant-petrel	2(22)	1(87)	2(18)	2(20)	2(13)
Giant-petrel sp	3(26)	3(36)	1(49)	3(36)	1(20)
Cape Petrel	5(34)	3(75)	3(54)	3(43)	1(2)
Antarctic fulmar	1(41)	1(67)	1(4)		
White-chinned petrel	1(8)	1(39)	2(55)	2(48)	1(31)
Sooty shearwater	1(28)	1(125)	1(77)	1(44)	1(32)
Wilson's storm-petrel	1(12)	1(64)	1(61)	1(33)	3(23)
Kelp gull	1(28)	1(97)	1(4)		

when birds were on the water. More than 34,000 (73%) of these comprised contacts between Cape petrels and warp cables that resulted in no apparent injury, and over 10,000 were by black-browed albatrosses, 9900 of which resulted in no apparent injury.

During most hauls several hundred birds surrounded the net as it reached the surface and seized at fish until the codend was retrieved. It was impossible to quantify these interactions due to the high numbers. Nevertheless, because of the relatively small mesh size of demersal nets compared to pelagic ones, there were only two mortalities recorded due to net entanglement.

Black-browed albatrosses made significantly more contacts with the warp cable with each increase in the category of black-browed albatross abundance (Table 3), except for abundance category 1, when only one observation was made.

Black-browed albatrosses had a significantly higher rate of contacts with the warp cable when there was discharge than when there was no discharge (Table 4). This was equally true for birds on the water, in the air, or heavy contacts (i.e. those that pushed part or all the bird under water). There were no significant differences in contact rate between different levels of discharge.

Giant-petrels were significantly more likely to make heavy contact with the warp cable when there was offal discharge. They also made significantly more contacts when the discharge level was low or higher than if it was level intermittent.

Black-browed albatrosses made significantly less contacts with the warp cable when the sea state was state 2 or less than if it was 4 or more (Table 5).

Black-browed albatrosses made significantly more contacts with the warp cable during tail winds than during head winds, or when the wind was from 45° or 135° from the bow (Table 6). There was no significant difference between the mean rate of contacts in tail winds and cross winds.

Table 3 – ANOVA of mean contact rate (contacts/h) of black-browed albatrosses on the water with the warp cable for different levels of abundance (1 = 1–10 birds; 2 = 11–50 birds; 3 = 51–200 birds; 4 = 201–500 birds; 5 = 501 + birds; 6 = birds present at night), n = number of shots, BBA = black-browed albatross

BBA abundance	*n*	Mean contact rate (contacts/h)
1	1	0.0
2	30	0.8
3	141	5.1
4	187	9.5
5	111	38.1
6	95	1.4
	$F_{5,559}$	67.8
	p	<0.001

Table 5 – ANOVA of mean contact rate (contacts/h) of black-browed albatrosses on the water with the warp cable for different groupings of Beaufort sea states

Sea state	*n*	Mean contact rate (contacts/h)
⩽2	84	3.5
3	172	8.9
4	165	16.3
⩾5	137	16.6
	$F_{4,561}$	4.97
	p	0.001

Table 6 – ANOVA of mean contact rate (contacts/h) of black-browed albatrosses on the water with the warp cable for different categories of wind direction relative to vessel course, *n* = number of shots

Relative wind direction	*n*	Mean contact rate (contacts/h)
Head	97	12.5
45° from bow	149	11.5
Cross	126	12.9
135° from bow	116	6.0
Tail	51	17.8
No wind	26	4.0
	$F_{5,559}$	3.08
	p	0.009

Note. Mean presented is the actual mean, while the *F*-test was performed on log-transformed contact rates.

Table 4 – ANOVA of mean contact rate (contacts/h) of black-browed albatross and giant-petrel species with the warp cable for different discharge levels, *n* = number of shots, BBA = black-browed albatross, GPS = giant-petrel species

Discharge	*n*	Mean contact rate (contacts/h)				
		BBA			GPS	
		On water	In air	Heavy	On water	Heavy
Nil	174	0.0	0.1	0.0	0.0	0.0
Intermittent	48	15.0	5.1	6.2	2.0	0.5
Low	100	14.4	5.3	6.0	3.9	1.3
Medium	138	20.7	5.1	8.1	5.4	2.1
High	108	17.1	2.5	7.1	7.5	3.2
	$F_{4,561}$	89.90	40.33	54.05	60.34	36.42
	p	<0.001	<0.001	<0.001	<0.001	<0.001

Table 7 – Summary of observed and estimated seabird mortality on finfish trawlers recorded in the Falkland Islands and on the 'high seas'

Variable	Falkland Islands waters	'High seas'
Observed mortalities	73	54
Observed fishing days	157	18
Observed catch rate (birds/day)	0.47	3.00
Estimated mortality	1529	630
CV	0.15	0.69
95% Confidence limits	454	853
Minimum	1075	54[a]
Maximum	1983	1483

CV, co-efficient of variation.

a Lower confidence limit 54 due to 54 mortalities being observed (hence, there could not be less than 54 mortalities in the 'high seas' zone).

3.4. *Seabird mortality*

We recorded 73 birds hauled aboard trawlers fishing within the waters of the Falkland Islands (Table 7; at an annual average rate of 0.47 birds/day), 70 of which were caused by the warp cable and three by the paravane cable (see Fig. 1). The highest number killed was recorded in the South-West area during the Prospecting period (39) at a mean mortality rate of 0.98 birds per fishing day. The Prospecting period was the time period with the greatest number of observed mortalities (39 at 0.93 birds/day), while the South-West had the greatest number of observed mortalities throughout the year (54 at 0.57 birds/day). The season with the lowest observed mortality rate within Falkland Islands waters was the Laying period (0.10 birds/fishing day). Nevertheless, very high mortality rates (6.71 birds/day) were observed in this period in international waters ('high seas') immediately north of local waters.

In total, 1529 birds (co-efficient of variance CV = 0.15) were estimated to be killed in Falkland Islands waters in the 12-month period (Table 7). Only birds hauled aboard were included in the calculation of this estimate. Seasonally, the greatest levels of mortality were estimated to occur in the Prospecting and Egg Periods in the Central-West and South-West areas.

Including observations made on the 'high seas' to the north of local waters, 127 mortalities were recorded on finfish trawlers (118 black-browed albatross, five southern giant-petrels, three white-chinned petrels and one southern royal albatross). Proportions of these were used to estimate the numbers of birds of each species killed. We estimate that 1411 (CV = 0.13) black-browed albatrosses, 98 (CV = 0.87) southern giant-petrels, 12 (CV = 1.37) southern royal albatrosses and nine (CV = 0.04) white-chinned petrels, were killed during the year within Falkland Islands waters.

During September and October (Prospecting and Laying Periods) on the 'high seas' north of the Falkland Islands, 54 birds were observed killed during 18 observed fishing days (Table 7). Using the numbers of trawlers recorded each day by SAST observers as an estimate of effort, there were 210 fishing days in the area during the observed period. From this it was estimated that 630 birds (CV = 0.69) were killed in this period, including 583 black-browed albatrosses (CV = 0.69), 12 southern giant-petrels (CV = 0.97) and 35 white-chinned petrels (CV = 0.79).

3.5. *Contact rates and mortality*

There was a significant correlation between total mortalities, and contacts for all species except Cape petrels (Table 8). Significant correlations also existed for total mortalities and contacts with black-browed albatrosses, whether they were total contacts, contacts on the water, and heavy contacts. Values for ρ were similar for all of these correlations.

Table 8 – Spearman rank correlations between mortalities and rate of contacts during commercial finfish trips in Falkland Islands waters

Cruise	Total mortalities (all species)	All species		Black-browed albatross					
		Total		Total		On water		Heavy contacts	
		ρ[a]	p	ρ	p	ρ	p	ρ	p
a	14	0.47	0.001	0.49	0.007	0.48	0.008	0.41	0.003
b	13	0.49	<0.001	0.52	<0.001	0.52	<0.001	0.51	<0.001
c	27	0.40	<0.001	0.42	<0.001	0.41	<0.001	0.46	<0.001
d	56	0.39	<0.001	0.35	0.001	0.36	0.001	0.42	0.001
e	7	0.35	0.029	0.41	0.013	0.42	0.010	0.37	0.021
f	9	0.30	0.007	0.33	0.003	0.35	0.002	0.34	0.002
g	9	0.55	<0.001	0.55	<0.001	0.52	<0.001	0.34	0.020
h	7	0.32	0.004	0.28	0.009	0.29	0.007	0.34	0.002
Total	143	0.35	<0.001	0.36	<0.001	0.37	<0.001	0.35	<0.001
Range		0.30–0.55		0.28–0.55		0.29–0.52		0.33–0.51	
Median by cruise		0.39		0.41		0.41		0.39	

Trips a–h are those where mortalities occurred (including those cruises outside the 2002/2003 season (cruise a and part of cruise h)). Correlations for total data included data from one short trip when no mortality was recorded. Of the total 143 mortalities, 130 were black-browed albatrosses. Total correlation, correlation of all records; Range, range of correlations for each cruise; Median by cruise, median value of correlations for each cruise.

a ρ, Spearman rank correlation co-efficient.

3.6. Contact rates and environmental variables

A stepwise generalised linear model (GLM) of contact rates of black-browed albatrosses while they were on the water identified the following variables as affecting the contact rate: offal discharge level, black-browed albatross abundance, wind speed and fishing season. This explained 59% of the deviance in the contact rate. When a similar process was applied to black-browed albatross heavy contacts, the same variables were identified, with the addition of relative wind direction. This explained 50% of the deviance in the heavy contact rate.

4. Discussion

4.1. Seabird abundance

The pattern of seabird abundance around the trawlers generally reflects the relative abundance of these species in three years of at-sea surveys in waters of the Falkland Islands (see White et al., 2002).

4.2. Seabird interactions

Throughout the year observer effort was concentrated on recording contacts with the warp cable because these had previously been identified as the primary cause of mortality in the Falkland Island finfish fleet (Sullivan and Reid, 2003).

While mortality is a serious threat to the long-term survival of many species, it is nevertheless a statistically rare event, which causes extreme skewness in the data, and difficulties in obtaining a sufficient sample for analysis (Reid and Sullivan, 2004). We identified a significant correlation of increasing mortalities with increasing rates of contacts. This is an important finding because it suggests contact rates could be used as an index of mortality in models that investigate the relationship between a range of operational and environmental variables and mortality. This would of course require fishery specific validation.

Modelling contact rates of black-browed albatrosses upon the warp cable suggested discharge level, black-browed albatross abundance, wind speed, direction of the wind in relation to the vessel, and fishing season were important. Contact rates increased with increasing levels of offal discharge, abundance of black-browed albatrosses and wind speeds. Observers noted greater rates of contacts with increasing sea or swell heights, so it is likely that the effect of wind speed, and sea and swell height are highly confounded. Contact rates also increased in cross winds and tail winds. Similar results have been obtained in trawl fisheries in Kerguelen (Weimerskirch et al., 2000) and the Falkland Islands Patagonian toothfish longline fisheries (Reid and Sullivan, 2004).

Black-browed albatrosses made significantly more contacts with the warp cable with each increase in the category of black-browed albatross abundance, except for abundance category 1 (1–10 birds), when only one observation was made. It is likely that an increased number of black-browed albatross leads to increased mortality due to increased competition for discharge.

Black-browed albatross have been shown to be significantly more susceptible to longline mortality in cross and tail winds (Reid and Sullivan, 2004). Increased mortality in our study under similar wind conditions appears to be also caused by the ability of birds to fly into the wind (down the side of the vessel) and land on the water adjacent to the point where the cable enters the water.

4.3. *Loligo* fleet

Due to the typically homogenous nature of *Loligo* catches (e.g. target specific) and processing practices, whereby the fish are packed whole for freezing, there is relatively little offal discharge produced in this fishery compared to finfish trawlers. There is therefore a significantly reduced mean hourly rate of contacts between seabirds and warp cables (SAST unpubl. data), which greatly reduces the likelihood of mortality.

4.4. Seabird mortality

All mortalities occurred at times of factory discharge (suggesting that eliminating factory discharge would virtually eliminate mortality). The most vulnerable situation for large birds is when they have their wings out after landing adjacent to, or under the warp cable, and when several birds on the water fight over a single piece of discharge, using their wings to provide backwards propulsion. In these situations if the cable strikes a bird in the scapular region, it can cause their wings to wrap around the cable and the forward motion of the vessel (trawling at around four knots) and the downward force of the cable as the vessel pitches pulls the birds down the cable. Black-browed albatross made significantly more contacts with cable in sea states 4 and above than 2 and below. Increased sea state (wind strength, swell and wave height) leads to vessels pitching more rapidly, which cause the warp cable to cut through the water faster and harder. This situation appears to be exacerbated by new cables, which are coated with sticky grease to which feathers readily adhere (pers. obs.).

Observations of birds hauled aboard on the warp splices have previously been attributed to their becoming impaled during the hauling (in Goni, 1998; Kock, 2001, various pers. comms.). Since September 2001, we directly observed over 600 trawls. During this period, we did not record a single contact between a warp splice and seabirds during hauling or shooting. It is likely that these previous observations have been caused by birds being struck by the warp during trawling, as described above, but due to a lack of tasked observers, were assumed to occur during hauling.

The average trawl depth for 45 trawls during which mortalities were observed was 245.7 + 84.4 m. The distance between splices varied slightly between vessels, but most vessels had cable splices every 500 m. Using onboard charts that determine the length of cable deployed depending on the trawl depth, the average depth of the splice on these shots was 90 + 40 m, with a range of 20–170 m. This is well below the dive depth of any species recorded killed, and thus impaled birds would have drowned prior to reaching the splice.

In other trawl fisheries around the world it is accepted that due to birds becoming dislodged from the netsonde cable the actual level of mortality is considerably higher than that recorded by onboard observers (Bartle, 1991; Weimerskirch et al., 2000).

Although we recorded instances when splices were just below the surface of the water, such events were rare. Therefore, neatly trimming 'sprags' from warp splices and wrapping the splice with rope or tape to prevent birds becoming impaled on splices during hauling operations would not reduce mortality in the Falkland Islands' finfish fishery. In fact, we suggest that such a measure is likely to only reduce the effective documentation of mortality rather than reducing mortality per se.

We also recorded instances of birds being dragged down the cable after diving for discharge astern of the point where the cable enters the water. In contrast to the process described above, which increases in rough seas, the frequency of diving attempts seemed to increase in calm sea conditions when visual cues are more acute.

Given that we have an estimate of mortality caused by the Falkland Islands finfish fleet for only one 12 month period (2002/2003), we lack the necessary time series of data required to determine the role of the finfish trawling in the decline of the Falkland Islands' black-browed albatross population (sensu Huin, 2001). However, given the level of finfish effort of the last 10 years has remained relatively constant (unpubl. data) and the fact that fishing practices have changed very little, specifically in regard to factory discharge practices it seems reasonable to assume that the local finfish trawl fishery has caused significant mortality for many years. In addition to the impact on the local black-browed albatross population, the estimated level of southern giant-petrel mortality is also cause for concern as around 100 birds constitutes 0.3% of the Falkland Island population (approximate population estimate derived using calculations in Gales, 1998).

4.5. *Trawler mortality on the wider Patagonian Shelf*

In September/October 2002 when SAST observers worked on trawlers fishing for *Loligo* in international waters north (between 46°S and approximately 47°30′S) of the Falkland Islands, we gained an insight into potential seabird mortality problems associated with trawlers on the wider Patagonian Shelf. The high level of mortality recorded on these vessels compared to that recorded on vessel targeting *Loligo* within Falkland Island waters was thought to be because the catches in international waters included high levels of finfish bycatch, which increased the level of factory discharge. As previously stated, it was difficult to obtain an accurate estimate of the total trawling effort in the area for the 21 days that we were present (and impossible for days when we were not present) and our estimated level of mortality was based on the maximum number of vessels observed each day. This figure ranged from 5 to 27 vessels and undoubtedly represents the minimum number of trawlers actually present and the skipper of one vessel suggested there were more than 40 vessels present in the region, which means the level of mortality would most likely have been considerably higher than estimated here.

The situation described above is not a typical scenario as the density of vessels present was unusually high. However, it does exhibit that high levels of seabird mortality are not restricted to the Falkland Islands and may be more widespread across the Patagonian Shelf. Recent data suggest that small artesenal trawlers that operate in the coastal waters of Argentina between 41°S and 52°S kill very few birds (Yorio and Caille, 1999); however, the level of mortality associated with the large fleet of factory/freezer trawlers is unknown. That fleet target comparable species and have similar levels of discharge to the Falkland Islands fleet, so it seems likely that at certain times of the year, particularly in the winter (non-breeding) months and during incubation when breeding adult black-browed albatross forage north on the Patagonian Shelf (Gremillet et al., 2000; Huin, 2002b), they have the potential to cause significant levels of mortality. Black-browed albatross from the Falkland Islands spend almost 50% of winter within the Argentine EEZ (Huin, 2002a).

4.6. *Global context*

A wide range of environmental and operational variables influence the level of seabird bycatch and the spatial and temporal nature of fishing effort has been shown to be critical factor (Klaer and Polacheck, 1998; Brothers et al., 1999; Tuck et al., 2001; Reid and Sullivan, 2004). In the case of longlining the proximity of fishing effort to seabird breeding colonies has been shown to critically influence bycatch rates in many fisheries (Moreno et al., 1996; Nel et al., 2002; Cuthbert et al., 2004). During the breeding season, albatrosses (and other seabirds) commence foraging trips from the breeding colony, hence the probability of encountering fishing vessels increases when a fishery is concentrated close to the breeding grounds, resulting in very high breeding season mortality rates (Nel et al., 2002; Weimerskirch et al., 2000; Reid et al., 2004). Therefore, given the nature of many trawl fisheries, particularly demersal fisheries that are restricted to regions of shelf and shelf-break, which is also the typical location of seabird breeding islands, trawl fisheries could potentially have a disproportionately high impact on seabird mortality and therefore associated population declines.

Given the large size and extensive coverage of factory trawler fleets around the world, in many such shelf regions (e.g. Patagonian Shelf, Gulf of Alaska, Agulhas Bank, Chatham Rise) it is critical that observer programmes are established to investigate the nature of seabird interactions with these fleets and where appropriate, that effective mitigation measures are identified as soon as possible. The most effective means of reducing contacts, and therefore also mortality to negligible levels is undoubtedly by limiting factory discharge to 'dirty water' resulting from processing, that does not attract large numbers of seabirds (cf. Wienecke and Robertson, 2001). However, in the interim the development and testing of appropriate bird-scaring devices may be critical to mitigating the problem in the short-term.

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