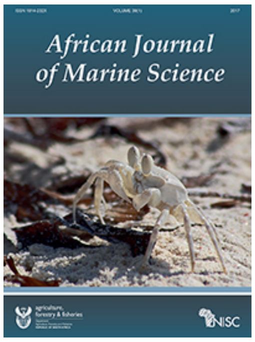

African Journal of Marine Science

ISSN: 1814-232X (Print) 1814-2338 (Online) Journal homepage: http://www.tandfonline.com/loi/tams20

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African Journal of Marine Science 2017, 39(1): 9–25

AFRICAN JOURNAL OF MARINE SCIENCE
ISSN 1814-232X EISSN 1814-2338
http://dx.doi.org/ 10.2989/1814232X.2017.1303396

Patterns and trends in seabird bycatch in the pelagic longline fishery off South Africa

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Both foreign and domestic pelagic longline fishing vessels operate in South Africa's Exclusive Economic Zone and adjacent international waters where they kill hundreds of seabirds each year as bycatch. To update assessments of the impact of the pelagic longline fishery on seabirds off South Africa, information on necropsied seabirds and national fisheries observer bycatch records were summarised for 2006–2013. Foreign-flagged (Asian) vessels had 100% observer coverage throughout the study period, whereas only 6% of the fishing effort by South African-flagged vessels was observed (with no coverage in 2011–2013). Vessels with observers caught seabirds at a rate of 0.132 birds per 1 000 hooks, resulting in an estimated mortality of 2 851 individuals (356 per year) comprising 14 species. Extrapolation of the observed fishing sets to the unobserved fishing sets by the South African domestic longline fleet suggested that approximately 750 additional birds were likely killed during the study period, therefore a combined 450 birds were killed per year. White-chinned petrel *Procellaria aequinoctialis* was the most frequently killed species (66%), followed by 'shy-type' albatrosses *Thalassarche cauta/steadi* (21%), black-browed albatross *T. melanophris* (7%), Indian yellow-nosed albatross *T. carteri* (3%), and Cape gannet *Morus capensis* (2%). The seabird bycatch rates were lower than in 1998–2005. Nationality of the vessel, time of line-setting, moon phase, year, season, fishing area, and seabird bycatch mitigation measures all influenced seabird mortality. Concurrent with 100% observer coverage, significant reductions in the seabird bycatch rate occurred in the Asian fleet in the latter years of the study, and these rates now approximate the national target (0.05 birds per 1 000 hooks). However, seabird bycatch rates remained high in the South African fleet, where no observers were deployed during 2011–2013, highlighting the need for independent observer programmes in fisheries—a matter of global interest. Suggestions are made as to how seabird bycatch by pelagic longline fisheries off South Africa may be further reduced.

Keywords: fishery observers, Asian-flagged vessels, mitigation measures, mortality, tuna longline fishery

Introduction

Incidental catch by fisheries is causing significant decreases in many seabird populations globally, particularly among albatrosses and the larger species of petrels (Croxall et al. 2012), with commercial longline fishing considered one of the types most affecting seabirds (Croxall 1998). Pelagic longline fleets are active throughout the world's oceans (Anderson et al. 2011); however, seabird bycatch in longline fleets is of greatest concern in the Southern Hemisphere, where large numbers of threatened seabirds forage and are regularly recorded as bycatch (Nel and Taylor 2003).

For several decades the productive waters off South Africa have supported fleets of pelagic longline vessels targeting primarily tunas *Thunnus* spp. and swordfish *Xiphias gladius*, but also blue shark *Prionace glauca* and shortfin mako *Isurus oxyrinchus* (Petersen et al. 2009a). These waters also support large numbers of foraging seabirds (Crawford et al. 1991). Previously, 11 seabird species were recorded as bycatch in pelagic longline fleets operating off South Africa (Petersen et al. 2009a), including one species listed by the IUCN as Critically Endangered, two as endangered, and two as vulnerable (IUCN 2015).

Historically, pelagic longline fishing killed far greater numbers of seabirds off southern Africa than demersal longline fishing (Petersen et al. 2009a, 2009b). Between 1998 and 2000, the seabird bycatch rate for the pelagic longline fleet operating in South Africa's Exclusive Economic Zone (EEZ) and adjacent international waters was 1.60 birds per 1 000 hooks, killing an extrapolated estimate of between 19 000 and 30 000 birds per year (Ryan et al. 2002). Between 1998 and 2005, the bycatch rate decreased to 0.44 birds per 1 000 hooks, or 2 890 birds per year (Petersen et al. 2009a). Both these estimates are well above the South African National Plan of Action (NPOA-Seabirds) target for reducing seabird bycatch, which aims to limit the bycatch rate to 0.05 birds per 1 000 hooks for vessels fishing in South African waters (DEAT 2008). Here, we assess the reported seabird bycatch rates for the period 2006–2013.

The seabird bycatch mitigation measures within South African fishing-permit conditions were slightly amended

Table 1: Summary of amendments to seabird bycatch mitigation measures in South African permit conditions for foreign-flagged vessels targeting tunas and South African vessels targeting swordfish within the South African EEZ

Mitigation measure	2006	2007	2008	2009	2010	2011	2012	2013
Asian vessels								
Night-setting only	NA	Yes	Yes	Yes	Yes	Yes	Yes[a]	Yes[b]
Bird-scaring line present	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Line-weighting (achieving 0.3 m s^{-1})	NA	Yes	Yes	Yes	No	No	No	No
Line-weighting (60 g <2 m from hook)	NA	No	No	No	Yes	Yes	Yes	Yes
Thawed bait before setting	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Reduced lighting	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Offal management	NA	Yes	Yes	Yes	No	No	No	No
25-bird bycatch limit per year	NA	No	Yes	Yes	Yes	Yes	Yes	Yes
South African vessels								
Night-setting only	No	No	No	No	No	No	No	No
Bird-scaring line present	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Line-weighting (achieving 0.3 m s^{-1})	Yes	Yes	Yes	Yes	No	No	No	No
Line-weighting (60 g <2 m from hook)	No	No	No	No	Yes	Yes	Yes	Yes
Thawed bait before setting	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Reduced lighting	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Offal management	Yes	Yes	Yes	Yes	No	No	No	No
25-bird bycatch limit per year	No	No	Yes	Yes	Yes	Yes	Yes	Yes

[a] Daytime line-setting is permitted for one vessel at any given time with the South African EEZ, provided that the vessel has obtained prior permission and ensuring that the vessel uses line-weighting and flies two bird-scaring lines
[b] Daytime line-setting is permitted for vessels fishing in international waters, provided that the vessel has obtained prior permission from the South African Department of Agriculture, Forestry and Fisheries, and ensuring that the vessel uses line-weighting and flies two bird-scaring lines

over the course of the study (Table 1); however, some of the most important mitigation measures stipulated that foreign-flagged vessels fishing under joint-venture agreements within South Africa's EEZ must ensure that lines are set between nautical sunset and nautical sunrise, with a bird-scaring line deployed during setting operations. When fishing under joint venture agreements on the high seas, foreign-flagged vessels are permitted to set lines during the daytime as long as a minimum of 60 g of weight is attached to branchlines within 2 m of the hook (DAFF 2013). Permit regulations are similar for South African-flagged vessels targeting swordfish. However, fishers need to ensure that a minimum of 60 g of weight is added to branchlines within 2 m of the hook at all times. Given this additional weight, these vessels are allowed to set fishing lines by day or night, provided they use a bird-scaring line.

In 2006, the Albatross Task Force (ATF) was created to reduce seabird bycatch in fisheries. The first team was hosted by BirdLife South Africa, which commenced work within the deep-sea hake trawl fishery, pelagic longline fishery, and hake longline fleet. The ATF was involved in implementing new permit conditions after the 2005 termination of foreign bilateral agreements meant that no Asian-flagged vessels were issued with South African fishing permits in 2006. Permits were re-issued in 2007 to Japanese and Korean vessels (although almost all were Japanese-flagged) operating under joint venture agreements and required that scientific observers collect data related to fishing operations, including catch and bycatch (DEAT 2008). In 2008, permit regulations were changed to include vessel-specific seabird bycatch limits. Vessels catching 25 birds in a calendar year were required to return to port for inspection of mitigation measures (e.g. adequately designed bird-scaring lines) and then to stop fishing for the remainder of the year, unless they were able to demonstrate that they complied with seabird bycatch permit regulations (DEAT 2008). The permits called for fishing to cease if a further 25 birds were caught, and then to resume only with a researcher onboard to assess why bycatch rates were so high, but this regulation was not enforced.

We estimated seabird bycatch associated with the pelagic longline fishery operating off southern Africa for the period 2006–2013, updating the previous assessment for the period 1998–2005 (Petersen et al. 2009a). We investigated the effect of environmental and vessel-specific variables on seabird bycatch, extrapolated the number of birds killed in unobserved fishing sets, and here provide recommendations for further improvements in the seabird bycatch regulations. This information could prove important for the adoption of seabird bycatch mitigation requirements by relevant regional fisheries management organisations (RFMOs). The combination of mandatory night-setting for the foreign-flagged (Asian) fleet and the prevalence in the bycatch of white-chinned petrel *Procellaria aequinoctialis* in South African waters, a species known to forage efficiently at night (Barnes et al. 1997; Jiménez et al. 2009), leads us to hypothesize that (i) seabird bycatch rates tend to differ between the Asian and South African fleets, and (ii) lunar luminance (which facilitates nocturnal foraging) notably affects seabird bycatch within this fishery.

Methods

Data were collected by independent fishery observers onboard South African- and Asian-flagged pelagic longline vessels from 2006–2013. Hereafter, the 'South African pelagic longline fishery' refers to the combined Asian and South African fleets. These data are primarily from within South Africa's EEZ, yet also include data from vessels that obtained South African fishing permits and also fished in

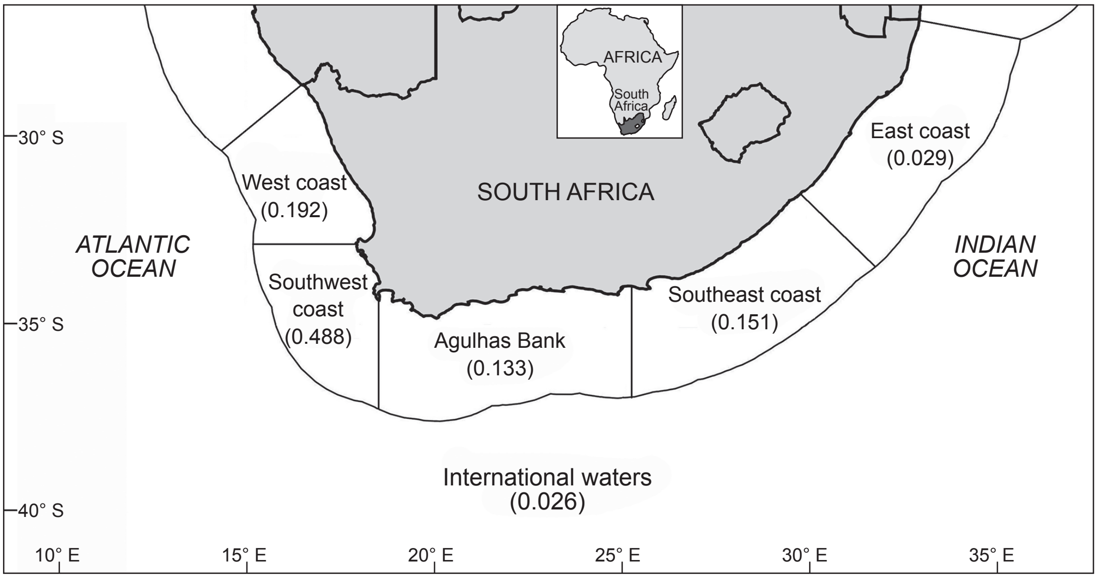

Figure 1: Map of South Africa's Exclusive Economic Zone showing the areas used in the generalised linear models of seabird bycatch, with associated catch rates (birds per 1 000 hooks). The seabird bycatch rate for international waters indicates only vessels that obtained a South African fishing permit

adjacent international waters. Vessels that fished in international waters outside the South African EEZ and so without a South African fishing permit were ignored since we lacked information for these vessels: they did not carry South African observers and were not permitted to offload catches in South Africa. Permit regulations stipulate that any seabirds killed are frozen and returned to port, although compliance with this requirement on vessels without observers is low (roughly 60%: Petersen et al. 2009a). Post-mortem examinations were conducted by the authors on all returned carcasses to determine species, age, and sex (by examination of the gonads). Two closely related species pairs—the giant petrels *Macronectes halli/giganteus* and the royal albatrosses *Diomedea sandfordi/epomophora*—could not always be reliably identified to species level and were thus lumped. Molecular analysis confirmed the species identity of 253 individual 'shy-type' albatrosses (shy *Thalassarche cauta* or white-capped *T. steadi*); the remaining shy-type albatrosses killed in the fishery could not be identified to species level and so were also lumped.

Those birds for which only heads were returned to port could not be sexed with confidence and so were excluded from analyses of sex ratios. Chi-squared tests with the Yates correction for continuity were used to test for any deviation from 50:50 sex ratios. For those species for which the sex ratio differed from parity, chi-squared tests were performed to test for sex bias in two different age classes: immatures (including juveniles and subadults) and adults. Age classes were determined for albatrosses using a combination of bill colour, plumage variation and feather wear/moult, and for white-chinned petrel by the amount of scarring on bill plates, moult pattern and gonad development (Hockey et al. 2005). Breeding status of adult birds was determined by the presence of a brood patch and the size of testes or ovarian follicles.

To assess the likelihood of variables affecting a bycatch event, fishing sets were scored as '1' (where birds were killed) or '0' (no birds killed). Only birds recorded as dead were used in these models since the few birds that were released alive most likely had been hooked during hauling (Gilman et al. 2014). Generalised linear models (GLMs) with a binomial distribution and a probit link function were used to test the effect of a number of possible explanatory variables on the likelihood of seabird bycatch occurring. To assess whether variables affected the numbers of birds killed per set, GLMs with a Poisson distribution and a logarithmic link function were used on sets where seabird bycatch was ≥1.

The possible explanatory variables investigated were: year, season, time of setting, branchline length, wind speed, fishing area, lunar luminance and use of a bird-scaring line. Season was classified as summer (December–February), autumn (March–May), winter (June–August) or spring (September–November), although little fishing occurred in summer. Time of setting was classified as day (lines set after nautical sunrise and finished before nautical sunset), night (lines set after nautical sunset and finished before nautical sunrise), or twilight (sets that straddled nautical sunrise or sunset). Wind speed was recorded by fisheries observers at the commencement of setting, and scored using the Beaufort scale (0–8). Fishing areas were divided into international waters and five regions within South Africa's EEZ (Figure 1). Lunar luminance was calculated as the proportion of overlap of moon presence during setting operations, multiplied by moon phase (0–1) to give a score between 0 and 1, with '0' meaning no moon influence during setting and '1' meaning the entire setting process occurred under a full moon. However, we were unable to control for cloud cover. Bird-scaring lines were only recorded as having been 'used' if they were deployed before commencement of line setting and left out until completion of line setting. The vessels used either one or two bird-scaring lines; however, for simplicity, neither the number of bird-scaring lines deployed nor their design was incorporated into the analyses. To control for fishing effort, the number of hooks deployed was used as an offset term in the models. Sets for which explanatory data were incomplete (8.1% of observed sets) were excluded from the GLM analyses. The most appropriate model was selected using Akaike's information criterion (AIC) as well as the proportion of variance explained by the models.

Due to large differences in gear-set configuration and operations between the Asian and South African fleets, separate GLMs were used to test the influence of variables affecting seabird bycatch for each fleet. GLMs were also used to test the effect of variables on the likelihood and amount of bycatch associated with Asian-flagged vessels for the four most commonly recorded species or species group: white-chinned petrel *Procellaria aequinoctialis*, shy-type albatrosses *Thalassarche cauta/steadi*, black-browed albatross *T. melanophris*, and yellow-nosed albatrosses *T. carteri/chlororhynchos*. Too few birds were reportedly caught by South African-flagged vessels to run similar analyses. The two species of yellow-nosed albatrosses were lumped because they were not always differentiated by fisheries observers, and only 51% of those caught (*n* = 186) were available for necropsy (Table 2). We used linear extrapolations from observed trips to estimate the overall mortality recorded on unobserved trips by South African-flagged vessels for two periods (pre- and post-2008) by area (5×5° squares) and by season.

Results

Fishery characteristics

During the period 2006–2013, 35.1 million hooks (17 448 sets) were set by 66 vessels: 29 Asian-flagged vessels targeting tuna (67% total effort) and 37 South African-flagged vessels targeting swordfish (33% total effort). Observer coverage was 100% on Asian vessels but variable (average of 6.2% p.a.) on South African vessels with 10.9 million hooks unobserved (31% of total fishing effort, and 94% of effort by South African vessels). Fishing effort was greatest in 2011, with a combined total of 6.4 million hooks set by both fleets, whereas only 1.1 million hooks were set by South African-flagged vessels in 2006 (with zero Asian-flagged fishing effort in 2006). Asian-flagged vessels set an average of 3.3 million hooks per year, whereas South African vessels set an average of 1.4 million hooks per year for the same period (Figure 2). Asian fishing effort peaked between April and October (Figure 2), with fishing conducted throughout the South African EEZ and regularly venturing into international waters (Figure 3a). South African vessels fished throughout the year (Figure 2), concentrating their effort within the EEZ (Figure 3b).

Due to differences in targeted fish species (Figure 4), Asian vessels used longer branchlines (36 m [SD 4.7], with 93% of sets having branchlines >30 m) than the South African vessels (21 m [SD 9.1], and 82% of sets having branchlines <30 m), and unlike the South African fleet they do not use light-sticks. South African vessels averaged fewer hooks per set than Asian vessels (1 300 m [SD 240] and 2 700 m [SD 380], respectively) and typically set their lines mostly around sunset (68%; Figure 5), whereas Asian vessels set mostly at night (89%).

Seabird bycatch

From 2006–2013, 2 851 seabird mortalities were recorded as bycatch in the (observed) pelagic longline fishery off South Africa, of which 2 345 birds (83%) were returned to port for necropsy. A further 307 birds (11% of total reported bycatch) were caught alive and released. The seabird bycatch comprised 14 species, seven of which are assessed by the

Table 2: Species composition of seabird bycatch from both the South African and Asian pelagic longline fleets off South Africa, 2006–2013, as reported by fisheries observers and confirmed by seabird necropsies

Common name	Scientific name	IUCN status	Reported		Confirmed	
			n	%	*n*	%
Shy/white-capped albatrosses	*Thalassarche cauta/steadi*	Near Threatened	508	17.8	482	20.5
Black-browed albatross	*Thalassarche melanophris*	Near Threatened	130	4.6	159	6.8
Indian yellow-nosed albatross	*Thalassarche carteri*	Endangered	–	–	77	3.3
Atlantic yellow-nosed albatross	*Thalassarche chlororhynchos*	Endangered	–	–	18	0.8
Yellow-nosed albatross spp.	*Thalassarche carteri/chlororhynchos*		186	6.5	–	–
Northern/southern royal albatrosses	*Diomedea sandfordi/epomophora*	Endangered/Vulnerable	2	<0.1	3	0.1
Wandering albatross	*Diomedea exulans*	Vulnerable	10	0.4	5	0.2
Unidentified albatrosses			65	2.3	–	–
Northern/southern giant petrels	*Macronectes halli/giganteus*	Least Concern	16	0.6	7	0.3
White-chinned petrel	*Procellaria aequinoctialis*	Vulnerable	1 768	62.0	1 541	65.7
Grey petrel*	*Procellaria cinerea*	Near Threatened	1	<0.1	1	<0.1
Cape petrel*	*Daption capense*	Least Concern	2	<0.1	1	<0.1
Unidentified petrels			84	2.9	–	–
Great shearwater	*Puffinus gravis*	Least Concern	2	<0.1	2	0.1
Subantarctic skua	*Catharacta antarctica*	Least Concern	3	0.1	2	0.1
Cape gannet	*Morus capensis*	Vulnerable	73	2.6	45	1.9
King penguin*	*Aptenodytes patagonicus*	Least Concern	1	<0.1	1	<0.1
Total			2 851	100	2 344	100

*First seabird necropsy records from the South African pelagic longline fishery (although not all caught within the South African EEZ)

IUCN as threatened (Table 2). Post-mortems confirmed that white-chinned petrel was the most frequently caught species, comprising 66% of total bycatch. Collectively, the five species of albatrosses commonly killed represented 32% of the seabird bycatch: shy/white-capped 21%, black-browed 7%, Indian yellow-nosed 3%, and Atlantic yellow-nosed 1% (Table 2). The remaining 2% of seabird bycatch comprised an additional nine species or species groups, but was dominated by Cape gannet *Morus capensis* (Table 2). From 2006–2009, the bycatch rate was 0.148 birds per 1 000 hooks; from 2010–2013, the bycatch rate was 0.07 birds per 1 000 hooks.

The two most commonly killed species in the returns to port showed significant deviation in the expected 50:50 sex ratio. White-chinned petrel exhibited a slight male-bias (53%; $\chi^2 = 5.6$, $p = 0.02$; Table 3), whereas mortality of shy-type albatrosses was female-biased (57%; $\chi^2 = 7.3$, $p < 0.01$). However, this was driven by sex-biased mortality of immature birds (male biased [58%] in white-chinned petrel, $\chi^2 = 17.8$, $p < 0.01$; female biased [57%] in shy-type albatrosses, $\chi^2 = 5.8$, $p = 0.02$), because no sex bias was found for adults of either species.

Of the necropsied birds for which age could be determined, most (57%) were immatures, but this varied greatly among species (Table 3). Immatures dominated for both black-browed and shy-type albatrosses; similar numbers of immatures and adults were recorded for white-chinned petrel; and most yellow-nosed albatrosses (both species) and all Cape gannet killed were adults (Table 3).

Of the 739 white-chinned petrel adults autopsied, 73 (10%) had either brood patches or enlarged gonads, which would suggest successful breeding or a recently abandoned breeding attempt. In total, 41% ($n = 17$) of the Atlantic yellow-nosed albatross adults and 40% ($n = 45$) of the Cape gannet adults caught showed signs of breeding activity. All Cape gannets were killed within approximately 250 km of the coastline, with 72% killed off the west or southwest coasts, and the remainder on the Agulhas Bank or off the southeast coast (see Figure 1 for regions).

Between 2006 and 2013, the observed seabird bycatch from the Asian- and South African-flagged vessels totalled 2 743 and 108 birds, respectively (Table 4). Asian-flagged vessels caught an average of 343 birds per year between 2006 and 2013; seabird bycatch was relatively high between 2006 and 2009 (458 birds per year), but was reduced to an average 228 birds per year between 2010 and 2013. South African vessels averaged 22 birds killed per year between 2006 and 2009, with no observer coverage between 2010 and 2013. Extrapolation from the observed bycatch to the 2 256 unobserved sets from South African-flagged vessels suggested that an additional 94 birds (SE 17.3) were caught per year by that fleet (Table 4). The total seabird bycatch for both fleets combined (recorded and extrapolated) averaged 451 birds per year between 2006 and 2013; however, bycatch was reduced to 361 birds killed per year between 2010 and 2013 (Table 4), down from 563 birds per year between 2006 and 2009.

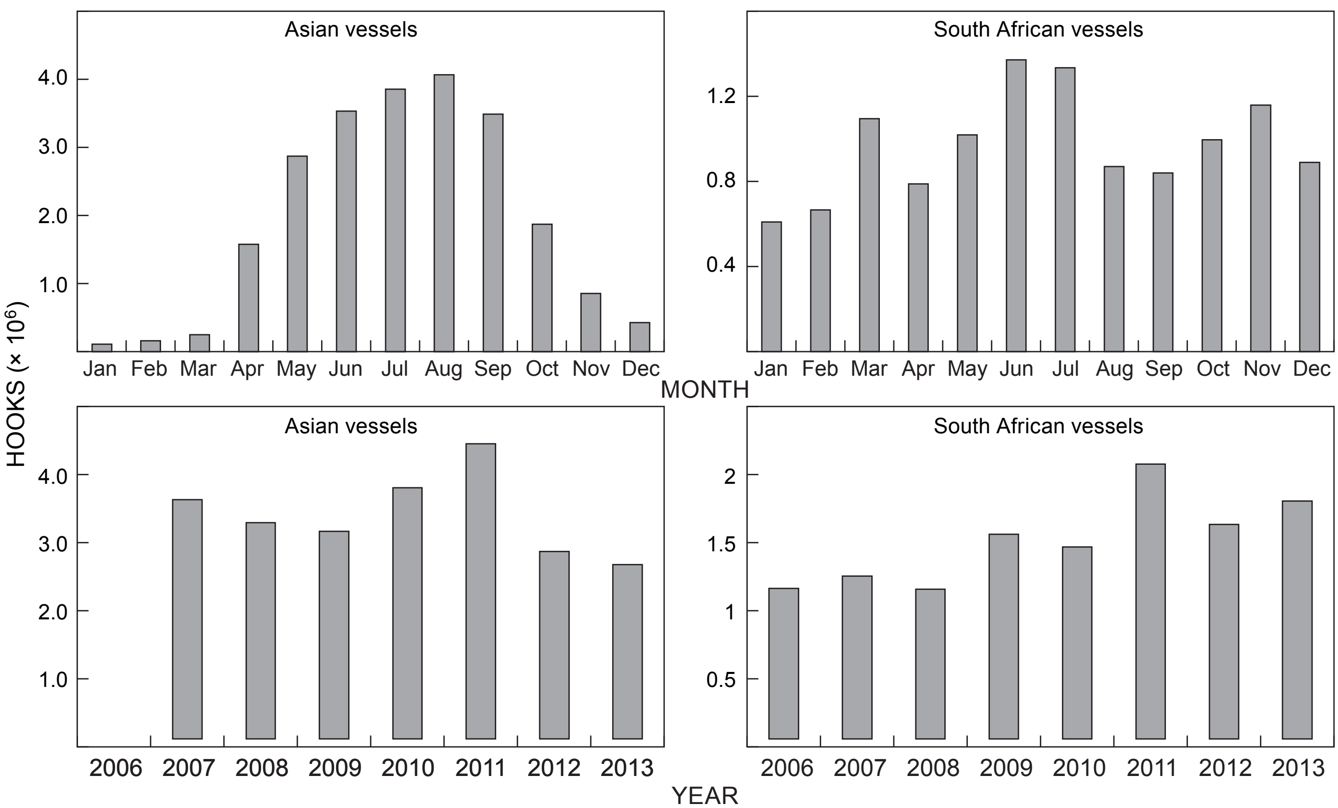

Figure 2: Number of hooks set, according to month and year, for Asian and South African tuna longline vessels, 2006–2013, fishing within the South African EEZ and adjacent international waters

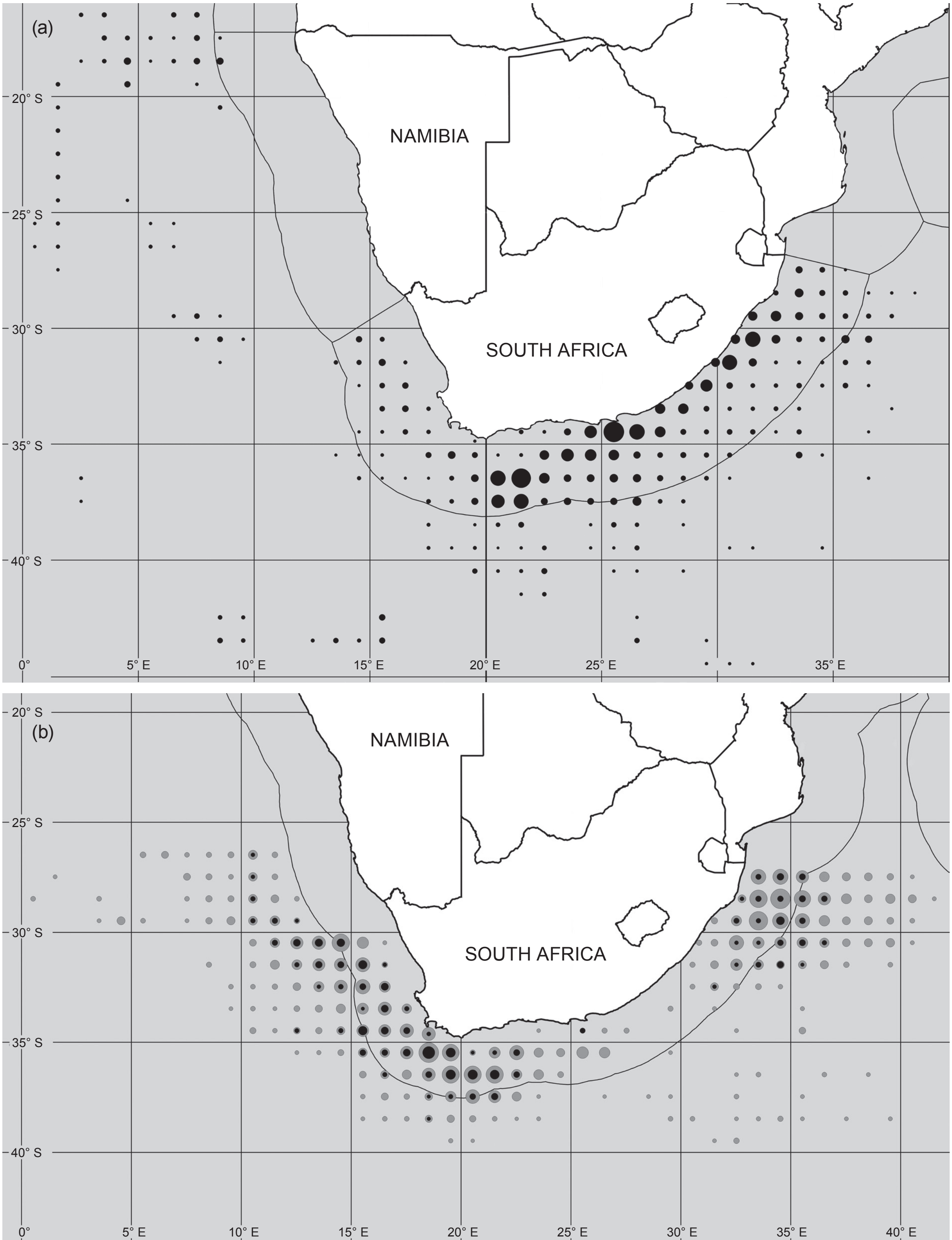

Figure 3: Distribution of fishing effort of (a) Asian vessels and (b) South African vessels off southern Africa, in relation to national EEZs, 2006–2013. Grey circle size is a proportional measure of number of hooks set per 1° square, and black circle size represents a proportional measure of observer coverage. Asian vessels had 100% observer coverage

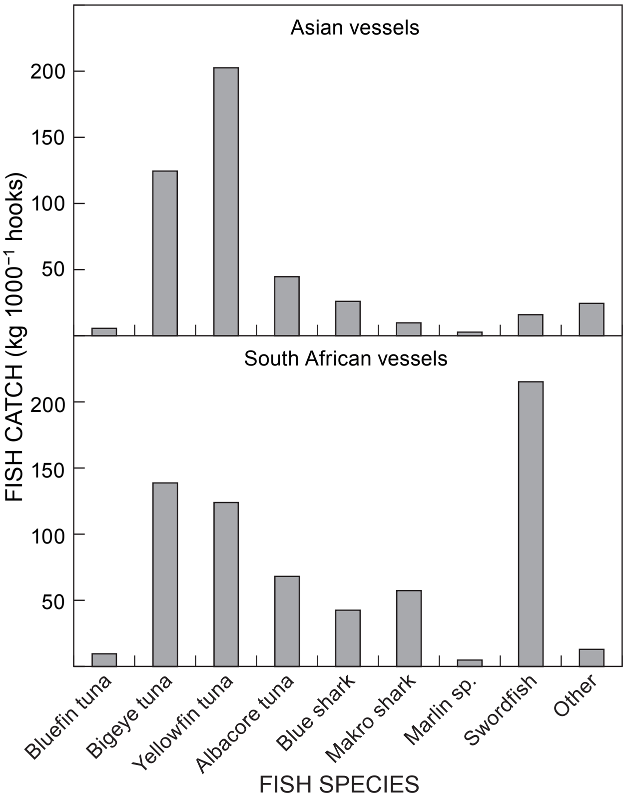

Figure 4: Fish catch rates for Asian and South African tuna longline vessels, from 2006–2013

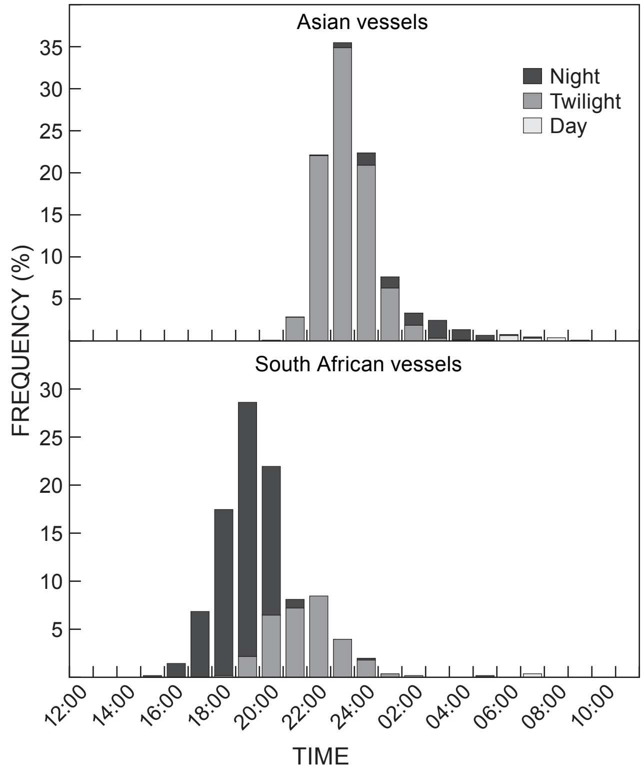

Figure 5: Time of commencement of longline-setting for Asian and South African vessels, from 2006–2013. See Methods section for definitions of night, twilight and day sets

Table 3: Age composition and sex ratios (percentage females = %F) of the most commonly recorded seabird bycatch species off South Africa. Age and sex were determined by post-mortem examination. Breeding adults are expressed as a percentage of adults caught

Common name	% Immature (%F)	% Adult (%F)	% Breeding adults (%F)	Total (%F)
White-chinned petrel	51 (42)	49 (51)	10 (5)	47
Shy/white-capped albatrosses	84 (57)	16 (53)	3 (50)	57
Black-browed albatross	78 (50)	23 (57)	11 (0)	53
Indian yellow-nosed albatross	25 (39)	75 (35)	14 (25)	44
Atlantic yellow-nosed albatross	11 (100)	89 (53)	41 (43)	57
Cape gannet	0	100 (47)	40 (26)	47
Total	57 (55)	43 (51)	12 (13)	49

Table 4: Summary of yearly seabird bycatch of the four most commonly recorded bycatch species or species groups, and all species recorded as bycatch. The figures represent the entire seabird bycatch for the fishery, with figures for the Asian bycatch/South African bycatch/extrapolated bycatch included in parentheses

Year	Shy/white-capped albatrosses	Black-browed albatross	Yellow-nosed albatrosses	White-chinned petrel	All species
2006	45 (0/16/29)	2 (0/0/2)	0	11 (0/3/8)	76 (–/29/47)
2007	279 (236/7/36)	23 (15/3/5)	87 (87/0/0)	657 (638/5/14)	1 253 (1 171/15/67)
2008	132 (79/6/47)	18 (12/1/5)	9 (8/0/1)	107 (103/2/2)	236 (167/9/60)
2009	90 (39/17/34)	46 (33/3/10)	15 (10/1/4)	365 (360/1/4)	597 (495/35/67)
2010	61 (33/0/28)	22 (7/5/10)	15 (12/1/2)	147 (142/1/4)	293 (207/20/66)
2011	73 (21/–/52)	25 (8/–/17)	66 (64/–/2)	274 (266/–/8)	602 (416/–/186)
2012	32 (11/–/21)	7 (1/–/6)	1 (0/–/1)	118 (115/–/3)	269 (137/–/132)
2013	62 (0/–/62)	8 (0/–/8)	5 (3/–/2)	135 (132/–/3)	278 (150/–/128)
Total	774 (419/46/309)	151 (76/12/63)	198 (184/2/12)	1 814 (1 756/12/46)	3 604 (2 743/108/753)
Average for 2006–2009	137 (89/12/37)	22 (15/2/6)	28 (26/1/1)	285 (275/3/7)	563 (458/22/60)
Average for 2010–2013	57 (16/–/41)	16 (4/–/10)	22 (16/–/2)	169 (164/–/5)	361 (228/–/128)
Average for 2006–2013	97 (52/9/39)	19 (9/2/8)	25 (23/1/2)	227 (220/2/6)	451 (343/22/94)

Effects of vessel flag, vessel identification and branchline length

In models including vessel flag but not vessel identification or branchline length, flag was an important variable affecting the numbers of seabirds killed (p < 0.001); however, it did not affect the likelihood of a bycatch event occurring (p = 0.434). Asian-flagged vessels caught birds at a lower rate (0.129 birds per 1 000 hooks) than South African vessels (0.209 birds per 1 000 hooks), although the Asian fleet's much greater fishing effort and observer coverage meant that these vessels accounted for 96% of the recorded seabird bycatch during the study period. Seabird bycatch occurred throughout the subregion for the Asian-flagged vessels, but was restricted to the west coast, southwest coast and Agulhas Bank for the South African-flagged vessels (Figure 6).

In models where vessel identification (both fleets) was included but vessel flag and branchline length were excluded, vessel identification was an important factor affecting both the likelihood of seabird bycatch (p < 0.001) and the average number of birds killed (p = 0.002). Five Asian vessels (setting about 40% of total hooks) accounted for >50% of the total seabird bycatch mortality. Of these vessels, one vessel (setting about 7% of total hooks) caught >330 birds over six years (11% of the total seabird bycatch) at a rate of 0.200 birds per 1 000 hooks, although that rate varied substantially across years.

For the Asian fleet, branchline length affected both the likelihood (p = 0.004) and average number of seabird bycatch (p < 0.001; Table 5), with bycatch increasing with branchline length. However, this variable did not vary significantly for the South African fleet, which used shorter branchlines and for which there were fewer data.

Effects of time of setting, lunar luminance and sea state

Time of setting did not significantly affect seabird bycatch rates for either fleet. Despite this, the highest bycatch rates overall occurred when setting took place around sunrise (0.232 birds per 1 000 hooks). Surprisingly, the lowest bycatch rates occurred during daylight sets (0.022 birds per 1 000 hooks). However, 86% of day sets were in international waters, where seabird abundance is lower than along the continental shelf, a situation that may have affected the bycatch rates.

Lunar luminance significantly influenced the bycatch rates for both the Asian- and South African-flagged vessels. For the Asian fleet, increasing lunar luminance

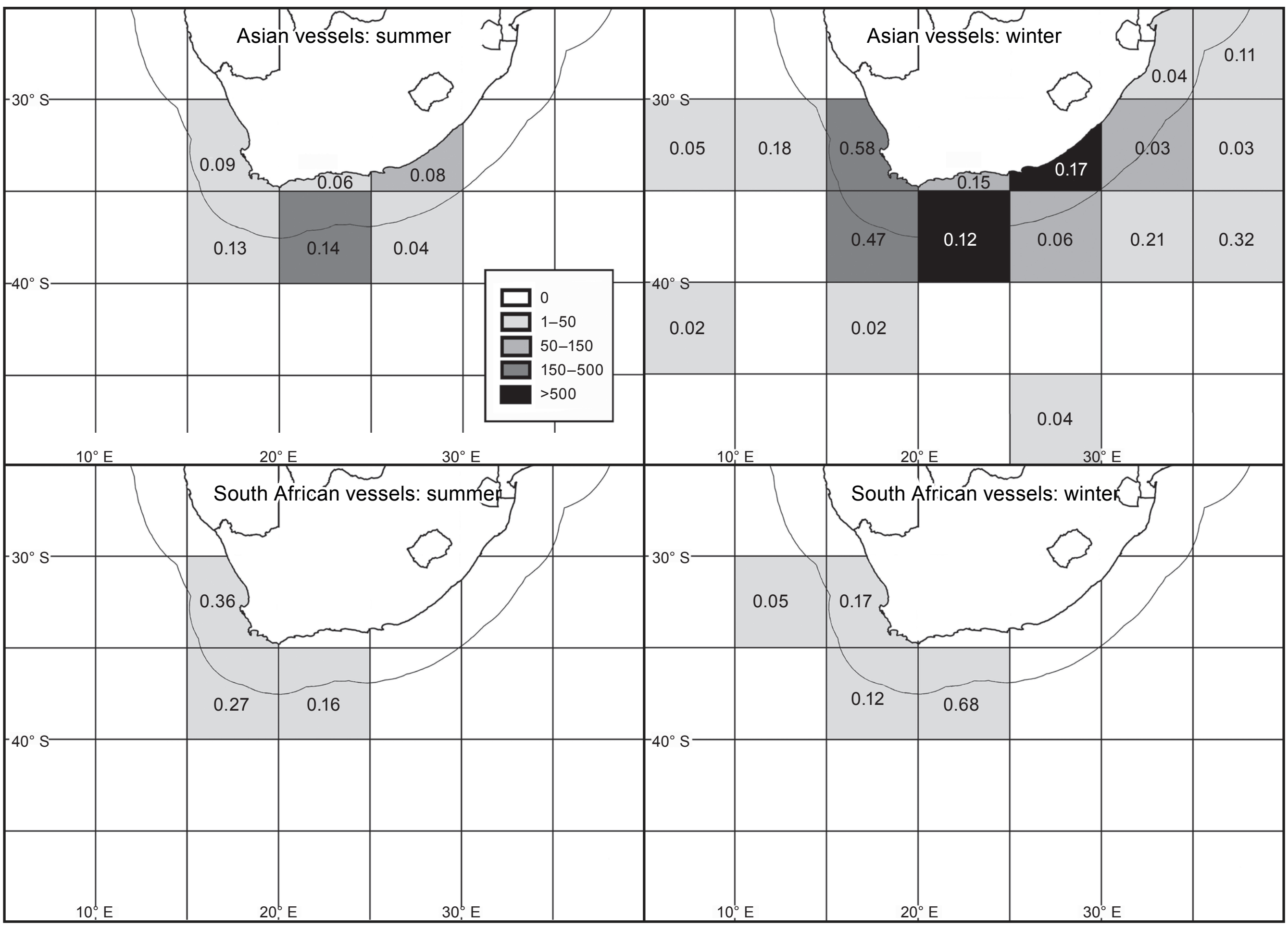

Figure 6: Numbers (denoted by shades of grey) and rate (birds per 1 000 hooks) of seabirds caught by Asian and South African vessels from May–October (winter) and November–April (summer), divided into 5×5° squares

increased both the likelihood and the average numbers of birds killed ($p < 0.001$; Table 5) while for the South African fleet, only the average numbers of birds killed increased with lunar luminance ($p = 0.032$; Table 6). Overall bycatch rates peaked (at 0.378 birds per 1 000 hooks) when lunar luminance was greatest (>0.9), and the rates were more than eight-times higher than during periods of lowest (<0.1) lunar luminance (0.047 birds per 1 000 hooks; Figure 7).

Wind strength and the resultant sea state did not statistically influence either the likelihood or average numbers of seabird bycatch in either fleet. This factor did, however, influence bycatch of yellow-nosed albatrosses among the Asian fleet, with both the likelihood ($p = 0.022$) and average numbers ($p < 0.001$) of bycatch decreasing with increasing wind strength.

Effects of year, season and fishing area

Between 2006 and 2013, seabirds were caught at a combined average rate of 0.132 birds per 1 000 hooks (foreign vessels = 0.129 per 1 000 hooks; local vessels = 0.209 per 1 000 hooks). However, this rate varied

Table 5: The effect of different variables on seabird bycatch for Japanese vessels, based on the best-fit generalised linear model. Bold font highlights significant variables

Variable	Estimate	SE	z-value	*p*
		Asian: bycatch likelihood		
Intercept	220.6	26.81	8.227	**<0.001**
Year	−0.115	0.013	-8.578	**<0.001**
Branchline length	<0.001	<0.001	2.901	**0.004**
Time of setting (night)	−0.269	0.261	−1.033	0.301
Time of setting (sunrise)	0.259	0.257	1.011	0.312
Time of setting (sunset)	−5.059	0.028	−0.018	0.985
Lunar luminance	1.043	0.060	17.515	**<0.001**
Season (spring)	−0.046	0.091	−0.504	0.614
Season (summer)	0.907	0.326	2.785	**0.005**
Season (winter)	−0.030	0.077	−0.386	0.699
Area (southwest coast)	−4.761	192.6	−0.025	0.980
Area (east coast)	−0.902	0.240	−3.765	**<0.001**
Area (international waters)	−0.300	0.387	−0.776	0.438
Area (southeast coast)	−0.296	0.102	−2.895	**0.004**
Area (west coast)	−3.763	349.4	−0.011	0.991
Bird-scaring line present	−0.263	0.103	−2.548	**0.011**
Interaction (spring × southwest coast)	5.069	192.6	0.026	0.979
Interaction (summer × southwest coast)	4.252	192.6	0.022	0.982
Interaction (winter × southwest coast)	5.225	192.6	0.027	0.978
Interaction (spring × east coast)	0.215	0.286	0.752	0.452
Interaction (summer × east coast)	−4.697	56.35	−0.083	0.934
Interaction (winter × east coast)	0.478	0.263	1.816	0.069
Interaction (spring × international waters)	−0.436	0.418	−1.043	0.297
Interaction (summer × international waters)	−5.525	64.65	−0.085	0.932
Interaction (winter × international waters)	−0.879	0.438	−2.008	**0.045**
Interaction (spring × southeast coast)	0.335	0.140	2.390	**0.017**
Interaction (summer × southeast coast)	−5.235	114.0	−0.046	0.963
Interaction (winter × southeast coast)	0.386	0.119	3.243	**0.001**
Interaction (spring × west coast)	3.936	349.4	0.011	0.991
Interaction (summer × west coast)	2.023	349.4	0.006	0.995
Interaction (winter × west coast)	4.607	349.4	0.013	0.989
		Asian: bycatch numbers		
Intercept	36.16	28.38	1.275	0.202
Year	−0.022	0.014	−1.558	0.119
Branchline length	<0.001	<0.001	6.423	**<0.001**
Time of setting (night)	−0.099	0.321	−0.308	0.758
Time of setting (sunrise)	0.333	0.325	1.025	0.306
Lunar luminance	0.354	0.061	5.770	**<0.001**
Season (spring)	0.275	0.075	3.684	**<0.001**
Season (summer)	−0.897	0.233	−3.851	**<0.001**
Season (winter)	0.233	0.065	3.592	**<0.001**
Area (southwest coast)	0.480	0.105	4.563	**<0.001**
Area (east coast)	−0.262	0.121	−2.170	**0.030**
Area (international waters)	−1.109	0.176	−6.303	**<0.001**
Area (southeast coast)	0.141	0.045	3.130	**0.002**
Area (west coast)	−0.306	0.176	−1.741	0.082
Bird-scaring line present	−0.550	0.080	−6.849	**<0.001**

Table 6: The effect of different variables on seabird bycatch for South African vessels, based on the best-fit generalised linear model. Bold font highlights significant variables

Variable	Estimate	SE	z-value	*p*
South African: bycatch likelihood				
Intercept	−8.404	0.311	−27.012	**<0.001**
Season (spring)	−0.988	0.460	−2.148	**0.032**
Season (summer)	−0.334	0.260	−1.284	0.199
Season (winter)	0.205	0.295	0.697	0.486
Area (southwest coast)	−0.721	0.308	−2.341	**0.019**
Area (east coast)	−5.177	271.404	−0.019	0.985
Area (international waters)	−5.171	302.928	−0.017	0.986
Area (southeast coast)	−4.126	1 459.236	−0.003	0.998
Area (west coast)	−0.278	0.331	−0.840	0.401
Bird-scaring line	0.415	0.292	1.421	0.155
South African: bycatch numbers				
Intercept	−6.924	0.332	−20.872	**<0.001**
Lunar luminance	0.889	0.414	2.146	**0.032**

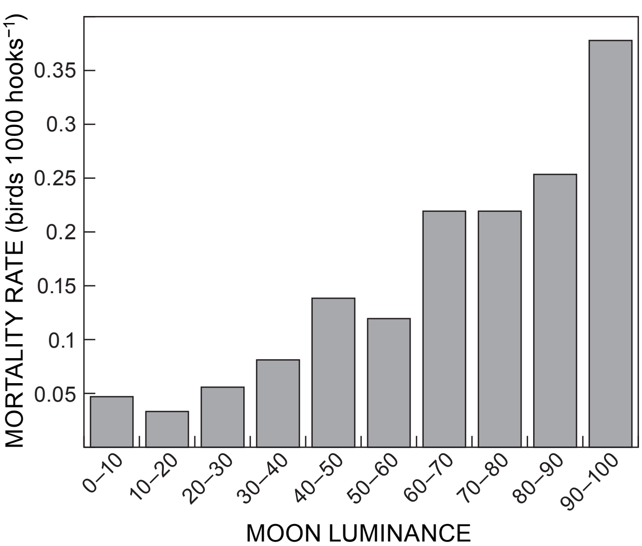

Figure 7: The effect of moon influence on seabird mortalities from longlines set at night, for vessels off South Africa, 2006–2013. Moon influence was calculated as the proportion of overlap of moon presence during setting operations, multiplied by moon phase (0–1), to give a score between 0 and 1 ('0' means no moon influence during setting, and '1' indicates that the entire setting process occurred under a full moon)

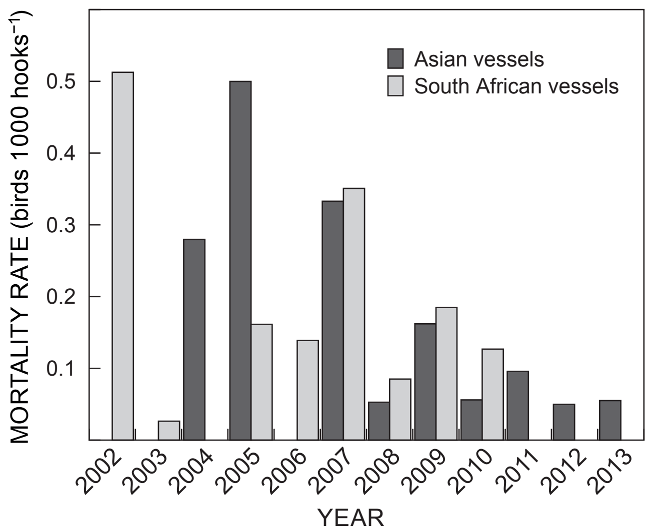

Figure 8: Seabird mortality for the study period (2006–2013) and the years preceding the study (2002–2005) for observed Asian and South African tuna longline vessels, expressed as birds per 1 000 hooks. No observer data were acquired on South African vessels in 2004 and 2011–2013 or on Asian vessels in 2002 (but with zero fishing effort in 2003 and 2006). Vessel-specific limits on seabird bycatch were implemented in 2008. The Asian fleet prior to 2006 consisted of both Japanese and Taiwanese vessels fishing under joint-venture agreements, but only Japanese and Korean vessels were issued joint-venture fishing licenses after 2006

substantially throughout the study period. Year was an important variable influencing the likelihood of seabird bycatch in the Asian fleet (p < 0.001; Table 5). Seabird bycatch was greatest in 2007 (0.333 and 0.350 birds per 1 000 hooks for the Asian and South African vessels, respectively), but then decreased following the changes to permit regulations in 2008, which placed vessel-specific limits on seabird catches. Bycatch rates during 2008–2013 averaged 0.080 and 0.141 birds per 1 000 hooks for the Asian and South African vessels, respectively (Figure 8).

Season affected both the likelihood and average numbers of birds killed by the Asian fleet, but season affected only the likelihood of capture among the South African vessels (Tables 4 and 5). Overall, birds were caught at higher rates during winter (0.128 birds per 1 000 hooks) and spring (0.110 birds per 1 000 hooks) than during autumn (0.070 birds per 1 000 hooks) and summer (0.053 birds per 1 000 hooks). Similar seasonal trends occurred in the bycatch rates of the four most commonly caught species or species groups for both fleets combined (Figure 9).

The fishing area influenced both the likelihood and average numbers of seabirds killed by Asian vessels and it strongly influenced the likelihood of seabird bycatch occurring among South African vessels. For Asian vessels, significant differences were found in the number of birds killed between the Agulhas Bank and most other areas, with the highest bycatch rate recorded along the southwest coast (p < 0.001; Table 5). For South African vessels the likelihood of a bycatch event was reduced when fishing off the southwest coast (p = 0.019; Table 6) as compared to on the Agulhas Bank. Overall, seabirds were caught at the greatest rates off the southwest coast (0.488 birds per 1 000 hooks) and west coast (0.192 birds per 1 000 hooks), while the lowest rates occurred off the east coast and in international waters (both regions 0.03 birds per 1 000 hooks; Figure 1), with similar results for the four most commonly recorded species or species groups (Figure 10).

The interaction between season and fishing area affected the likelihood of seabird bycatch for the Asian vessels only. The likelihood of seabirds being killed was reduced when fishing in winter in international waters (p = 0.045), but increased when fishing off the southeast coast in spring (p = 0.017) or winter (p = 0.001) (Table 5).

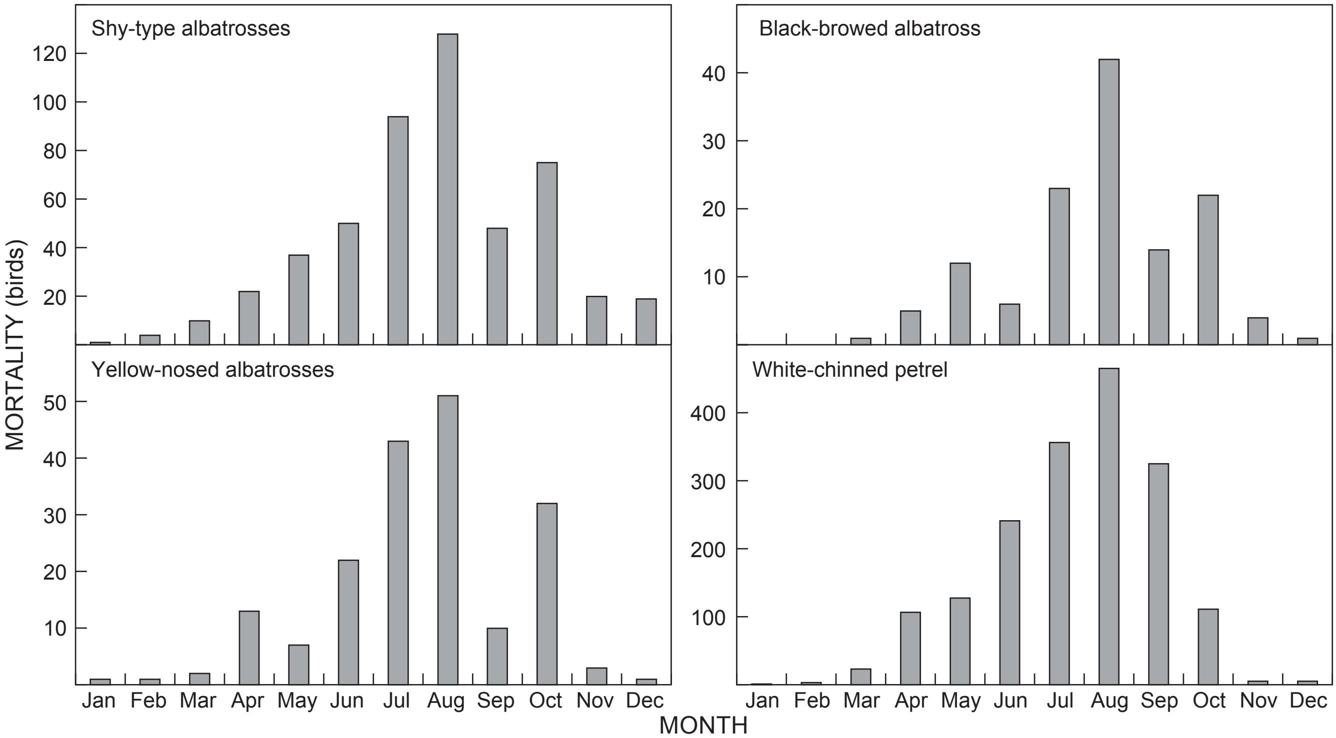

Figure 9: Mortality of the four most commonly caught species or species groups: shy-type, black-browed and yellow-nosed albatrosses and white-chinned petrels, according to month, for the South African and Asian fleets combined

Effect of bird-scaring lines

The use of bird-scaring lines reduced the likelihood ($p = 0.011$) and average numbers ($p < 0.001$) of seabirds killed among the Asian vessels (Table 5). Use of the lines did not statistically affect either the likelihood or numbers of seabirds killed on South African vessels, probably as they were deployed selectively in areas with larger numbers of birds. Many of the South African sets that used a bird-scaring line (76%) were in high-bycatch areas, compared to 62% bird-scaring line compliance for sets in low-bycatch areas. Correctly deployed bird-scaring lines reduced the seabird bycatch threefold for Asian vessels (from 0.333 to 0.110 and 0.160 birds per 1 000 hooks), but had no apparent benefit on South African vessels (0.110 and 0.010 birds per 1 000 hooks). Compliance with the requirement to use bird-scaring lines was far greater for Asian vessels than for observed South African vessels, and improved with time for both fleets (Table 7).

Discussion

Numbers and rates of seabird bycatch

The seabird bycatch rates for 2006–2013 were generally similar to or lower than those reported by other seabird studies associated with pelagic longline fisheries in the Southern Hemisphere. South American fisheries recorded higher seabird bycatch rates (range 0.095–5.03 birds per 1 000 hooks; see review by Bugoni et al. 2008), with a slight decrease in bycatch rates in recent years attributable to better sampling coverage rather than to improved conservation actions. Rates within the eastern tuna and billfish fishery off Australia (2001–2006: Trebilco et al. 2010) were similar to the rates in our study, with bycatch rates lower in later years (2004–2006). According to Waugh et al. (2008), an estimated 500 birds were killed per year between 1998 and 2004 (no rate per 1 000 hooks supplied) in the New Zealand pelagic longline fishery. This is a large reduction from the 1988–1992 figures (attributable to improved mitigation measures), where an estimated 3 600 birds were killed in one year (Murray et al. 1993).

Seabird bycatch rates in the South African pelagic longline fishery during 2006–2013 (2 851 observed mortalities; 0.132 birds per 1 000 hooks) were 3–12 times lower than bycatch estimates for this fishery prior to 2006 (Figure 8) (Ryan et al. 2002; Petersen et al. 2009a). However, the most important change occurred in 2008, when vessel-specific bycatch limits were put in place for both the South African and Asian vessels. This resulted in a significant drop in the seabird bycatch rate for both fleets. From 2010–2013, bycatch rates were reduced to 0.07 birds per 1 000 hooks (range 0.05–0.10 birds per 1 000 hooks). Clearly, the presence of observers and the imposition of a meaningful monetary penalty for catching large numbers of seabirds changed fishers' behaviour, which reduced seabird bycatch. However, low observer coverage, dislodgement of hooked birds from lines (cf. Gilman et al. 2005), and release of live-captured but badly injured birds are all likely to result in mortality rates higher than those recorded in our study.

Fishing effort in the current study period (2006–2013) was slightly lower than in the previous study period (1998–2005; Petersen et al. 2009a) for South African-flagged vessels (1.3 million versus 1.4 million hooks per year), which was

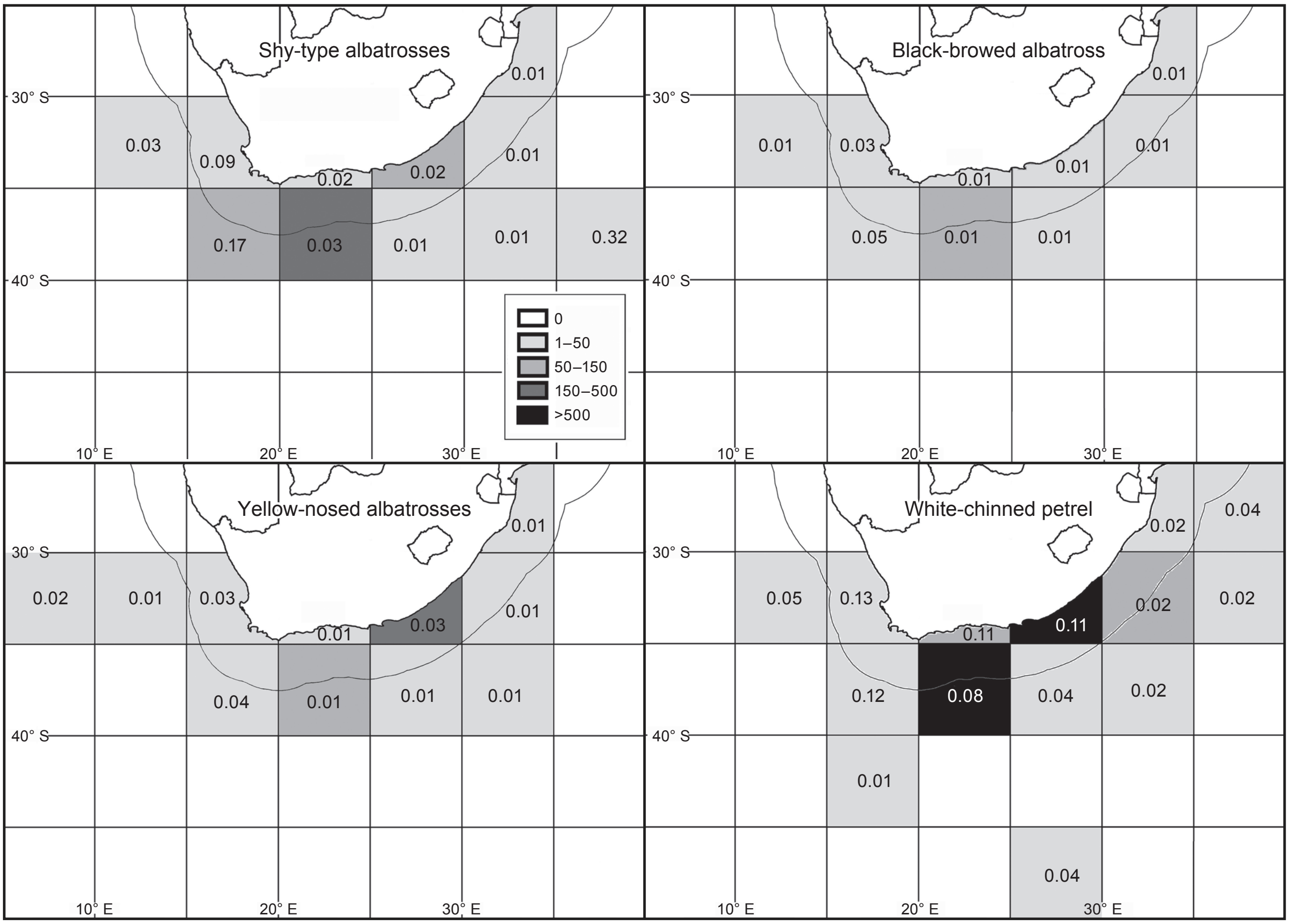

Figure 10: Numbers (denoted by shades of grey) and rates (birds per 1 000 hooks) of the four most commonly caught species or species groups, divided into 5×5° squares, for both the South African and Asian fleets

Table 7: Summary of bird-scaring line deployment for the Asian vessels and the observed South African vessels for which bird-scaring-line data were available for 2006–2013

Fishing sets	Number of sets observed			Percentage with bird-scaring lines		
	Asian	South African	Total	Asian	South African	Total
2006	0	139	139	–	38.8	38.8
2007	1 329	37	1366	81.8	48.6	80.9
2008	1 148	80	1 228	96.4	78.8	95.3
2009	1 128	138	1 266	99.9	84.0	98.2
2010	1 319	121	1 440	99.8	81.0	98.3
2011	1 557	6	1 653	99.9	100	99.9
2012	1 014	0	1 014	99.7	–	99.7
2013	1 003	0	1 003	100	–	100
Total	8 498	521	9 019	96.6	68.1	94.9

significantly lower than for Asian-flagged vessels (3.3 million versus 5.2 million hooks per year). Fishing effort varied considerably per year in our study; after fishing effort peaked in 2011 (6.3 million hooks), it was considerably reduced in 2012 (4.3 million hooks) and 2013 (4.7 million hooks).

Estimation of seabird bycatch from the unobserved sets deployed by South African vessels, using area and season as two predictive variables, yielded approximately 753 additional birds likely to have been killed between 2006 and 2013. However, based on simple extrapolation, this estimate should be treated with caution, as actual seabird bycatch on unobserved trips may be higher than on observed trips due to probable lower levels of compliance with bycatch mitigation regulations (Gales 1998).

In longline fisheries, large numbers of observed birds hooked during setting (as many as 50%: Brothers et al. 2010) may become dislodged from the hooks due to fish predation, currents, or mechanical actions during the line soak or haul (Gilman et al. 2005). Thus, it is possible that approximately 1 400 additional birds (50% of total recorded bycatch) were killed by the fishery during line setting without their carcasses retrieved during line hauling. An additional 307 live birds were recorded as caught during hauling, but were subsequently de-hooked and released. In most cases it is impossible to determine whether such birds survive or not. Gilman et al. (2014) reported that all birds caught during hauling were alive when brought aboard, and we have assumed that live birds caught during our study were caught during hauling operations.

Impact on species

White-chinned petrel (*Procellaria aequinoctialis*) is the most frequently caught seabird species off South Africa, accounting for almost two-thirds of bycatch in the South African pelagic longline fishery, and it is also the most commonly caught species throughout the Southern Hemisphere (Ryan et al. 2012). They are proficient divers, capable of reaching depths of up to 16 m (Rollinson et al. 2014). It has been suggested that they increase the bycatch numbers of larger, shallower-diving species, such as albatrosses, because they raise baits to depths accessible to the shallow-diving species and hence may be displaced by larger birds (Jiménez et al. 2012).

A bias in the bycatch towards the deeper-diving males (Rollinson et al. 2014) has been found previously in white-chinned petrel longline bycatch studies (Robertson et al. 2006; Petersen et al. 2009a). Male white-chinned petrels may be caught at greater rates than females, since due to their larger sizes they are able to scavenge more successfully than females (Ryan and Boix-Hinzen 1999). Another possible explanation is that there is sexual segregation in foraging zones, but previous studies have not found this (Berrow et al. 2000, PGR unpublished data). A sex bias is of particular concern in relation to seabirds as many species have strong pair-bonds wherein both sexes are required to successfully raise the chicks (Delord et al. 2005), a situation thus further exacerbating the effects of seabird bycatch.

The only white-chinned petrel populations known to forage regularly in South African waters are those from the Prince Edward Islands (Rollinson et al. 2014), Crozet Island (Weimerskirch et al. 1999) and Kerguelen Island (Péron et al. 2010), where the populations of breeding pairs number 36 000 (Ryan et al. 2012), 23 000 (Barbraud et al. 2008) and 234 000 (Barbraud et al. 2009), respectively. Molecular studies confirm that white-chinned petrel caught by longlines off South Africa are from the subspecies *P. a. aequinoctialis*, which breeds on Atlantic and Indian Ocean islands, and that none of the birds caught belonged to the subspecies *P. a. steadi*, which breeds on New Zealand's sub-Antarctic islands (Techow et al. 2016). A yearly bycatch of 227 birds (including recorded and extrapolated bycatch) within the South African pelagic longline fishery represents <0.1% of the overall population of *P. a. aequinoctialis*, a portion unlikely to have a significant impact on the subspecies; however, this bycatch may be contributing to the decline of the Crozet Island population, which is already under pressure from the Patagonian toothfish fishery operating around the island (Barbraud et al. 2008).

'Shy-type' albatrosses, represented off South Africa by the very similar-looking shy albatross *Thalassarche steadi* (95%) and white-capped albatross *T. cauta* (5%) (Baker et al. 2007; Petersen et al. 2009a; this study), are the most commonly recorded albatross species in South African waters. The proportion of immature birds killed is similar to the proportion observed in South African waters (Hockey et al. 2005). There was a female bias in bycatch of shy-type albatrosses, but females were only present as immature birds. Adult female albatrosses tend to disperse further afield from breeding islands than adult males (Weimerskirch et al. 2005), thus a high proportion of immature females recorded as bycatch might reflect sexual segregation of foraging zones among immatures. We estimated that approximately 97 shy-type albatrosses were killed each year by the South African pelagic longline fishery (approximately 5 *T. cauta* and 92 *T. steadi*), roughly six-times less than bycatch levels in 1998–2005 (Petersen et al. 2009a). The current bycatch estimates of shy-type albatrosses in the pelagic longline fishery off South Africa are unlikely to have significant effects on the global populations (Baker et al. 2007), with possibly <0.01% and 0.01% of the total population of *T. cauta* and *T. steadi*, respectively, killed annually.

Immature birds comprised the greatest proportion of black-browed albatross (*T. melanophris*) killed during the period of our study. These immature birds are probably resident in South African waters for their first 3–4 years (Hockey et al. 2005). The species' breeding numbers have increased in recent years, particularly at the Falklands and islands off Chile, resulting in the species being down-listed to Near Threatened (IUCN 2015). However, the population on South Georgia continues to decrease, apparently due to mortality caused by various fisheries (Croxall 2008; Poncet et al. 2017). There are an estimated 56 000 breeding pairs on South Georgia, totalling about 200 000 birds, including immature and non-breeding birds (Agreement on the Conservation of Albatrosses and Petrels [ACAP], unpublished data). The annual bycatch of approximately 19 birds (roughly six-times lower than in 1998–2005: Petersen et al. 2009a) represents <0.01% of the South Georgian population, and is thus unlikely to be a major driver of this population's ongoing decline.

The endangered Atlantic yellow-nosed albatross (*T. chlororhynchos*) is endemic to Gough and Tristan da Cunha islands, but in the non-breeding season it disperses, in part towards southern Africa, mainly off the south and west coasts, avoiding the east coast (Hockey et al. 2005; ACAP 2009). This albatross is one of the most frequently caught species in pelagic longline operations off Namibia (Petersen et al. 2007) and Brazil (Bugoni et al. 2008), but with smaller bycatch numbers off South Africa (Petersen et al. 2009a; this study). Based on confirmed proportions of the two species of yellow-nosed albatrosses caught (20%; Table 2), only an estimated 5 birds were killed each year by pelagic longlining off South Africa, which in isolation is unlikely to have an impact on the global populations.

The Indian yellow-nosed albatross (*T. carteri*) breeds on four island groups in the southern Indian Ocean, but it is thought that only birds from Crozet and the Prince Edward islands regularly visit South African waters (Weimerskirch et al. 1985). The species has a global population (~41 580 breeding pairs: BirdLife International 2016) comparable to the Atlantic yellow-nosed albatross (~40 000 breeding pairs: ACAP 2009) and is likewise listed as Endangered (IUCN 2015). Large numbers are killed by tuna longliners in subtropical waters (Weimerskirch and Jouventin 1998) off Australia (Gales et al. 1998) and South Africa (Petersen et al. 2009a; this study). The estimated 20 birds killed each year by longline fleets off South Africa is unlikely to significantly affect the global population, however the bycatch of combined fisheries may influence some populations.

Almost four-times as many Cape gannet (*Morus capensis*) were killed by pelagic longline fisheries off South Africa during the study period as compared to between

1998 and 2005 (Petersen et al. 2009a). The Cape gannet is restricted to just six breeding islands off southern Africa and their numbers have steadily decreased over the last 50 years (Crawford et al. 2007). Even though the only south-coast breeding locality (Bird Island in Algoa Bay, Eastern Cape) now supports more than half of the world population (Crawford et al. 2007), larger numbers of these birds were killed off the west and southwest coasts and on the Agulhas Bank, having likely originated from declining west-coast colonies (Pichegru et al. 2007). With more limited foraging opportunities available off the west coast, gannets in that region may be forced to scavenge from pelagic longline vessels more regularly than gannets from Bird Island (Moseley et al. 2012; Grémillet et al. 2016).

Diomedea albatrosses are noteworthy for the small numbers reportedly killed during the period of our study as compared to reports of studies off South America (Bugoni et al. 2008), Australia (Gales et al. 1998), and New Zealand (Waugh et al. 2008). Petersen et al. (2009a) also did not record any wandering albatross (*D. exulans*) in bycatch autopsies from the South African pelagic longline fishery from 1998–2005. The paucity of *Diomedea* bycatch mortalities off South Africa is likely explained by their relatively low abundance in South African waters; the ratio between *Diomedea* and shy-type albatrosses attending pelagic longline vessels in offshore waters off southern Africa has been recorded as 1:8 (DPR, unpublished data). However, the bycatch ratio between these two species groups off South Africa is much larger (1:60)—thus another reason likely exists for the low *Diomedea* bycatch. Barbraud et al. (2013) put forward the theory that there has been selection since the 1960s against wandering albatross, which are susceptible to being killed at fishing vessels through differential mortality, thus the more susceptible individuals may have already been killed as part of the longline bycatch.

Factors affecting seabird bycatch

The higher seabird bycatch rates by South African vessels as compared to the Asian fleet is most likely related to the differences in target species, fishing operations, and hence permit conditions between these fleets. Longer branchlines increase the risk of seabird bycatch because of their slower sink rates, which allows scavenging seabirds more time to access baited hooks (Petersen et al. 2009a). During our study, the South African fleet had higher seabird bycatch rates than the Asian fleet despite their use of shorter branchlines; however, differences in branchline length between the two fleets is likely to be trivial as compared to the large differences in bird-scaring line usage, line-weighting and setting times.

Lunar luminance played an important role in explaining bycatch rates, probably because there is increased nocturnal seabird activity around the time of the full moon (Mackley et al. 2011) and moonlight allows birds to scavenge more effectively (Jiménez et al. 2009). Fishing year was also an important variable affecting seabird bycatch numbers in the Asian fleet. It is likely that year was not identified as significant for South African vessels due to the much smaller sample size for this fleet, with no observer data acquired for the final three years of the study (Figure 8).

Both fishing area and season were important factors affecting seabird bycatch. This is to be expected as many of the seabird species visiting South African waters are primarily seasonal migrants to the region. Most seabird species that breed in the Southern Hemisphere visit South African waters during their non-breeding seasons of winter and spring (Crawford et al. 1991), which is when bycatch off South Africa was highest. Larger numbers of seabirds are found in the relatively productive waters off Cape Point, along the west coast, and on the Agulhas Bank (Crawford et al. 1991). These areas had substantially higher rates of seabird bycatch than off the east coast and in international waters, where seabird numbers are known to be lower (Crawford et al. 1991).

Bird-scaring lines have proven particularly effective at reducing seabird bycatch in pelagic longline fisheries (Petersen et al. 2009a; Melvin et al. 2013). Bird-scaring lines were used on 95% of the sets and thus reduced seabird bycatch for the Asian fleet as compared with sets without the lines. Bird-scaring lines on South African-flagged vessels did not reduce seabird bycatch, probably because the lines are deployed more regularly when fishing in areas of high seabird abundance. The use of bird-scaring lines on 95% of observed sets during the study period represents a marked improvement from 1998–2005, when they were used on 51% of sets (Petersen et al. 2009a).

Wind strength affected the bycatch of yellow-nosed albatrosses only. Surprisingly, bycatch decreased with increasing wind strength (although wind direction was not considered); bird-scaring lines become less effective when high winds blow them sideways, allowing birds to settle behind the vessel and access baited hooks. Melvin et al. (2013) found that most birds were caught during the lowest and highest Beaufort values (1 and 6–7, respectively). Bird-scaring-line efficacy is perhaps reduced during periods of little or no wind as streamers are no longer blown around unpredictably and thus do not protect the area behind the vessel from scavenging seabirds.

Management recommendations

Despite a number of stipulations pertaining to seabird bycatch within South African pelagic longline permit conditions, rates still remain higher than the South African target of 0.05 birds killed per 1 000 hooks (DEAT 2008). However, seabird bycatch rates for the Asian fleet have been close to the national target since 2010, with significant reductions in the last four years of our study (2010–2013). Unfortunately, there were no observer data for the South African fleet in recent years (2011–2013). Better compliance with the use of seabird bycatch mitigation measures in the Asian fleet as well as improved seabird bycatch legislation are almost certainly the reasons for the reductions in bycatch rates.

Despite improved permit conditions, a number of the sections could be further improved. The only reference to moon phase in the permit conditions states that, when fishing on the high seas, once a vessel has reached a limit of 25 seabird mortalities the vessel is prohibited from fishing for three days around the time of the full moon (DAFF 2013). Given the strong influence of lunar luminance on seabird bycatch, we suggest that permit conditions should require additional mitigation measures over periods of high lunar luminance as a matter of course, not just after catching >25 birds. Such measures could include a second bird-scaring line, adding more weight to lines, or moving weights closer to the hook.

Bird-scaring lines were used to good effect by the Asian vessels for most sets during the study period. However, observers reported they were rarely used by the South African vessels, and are even less likely to be used on unobserved trips. In addition, bird-scaring lines are sometimes incorrectly deployed or have broken or missing streamers, thus providing inadequate protection. Regularly checking and maintaining bird-scaring lines would ensure better compliance with permit requirements (DAFF 2013).

Despite time of setting not proving to be a significant variable affecting seabird bycatch for the South African fleet, other studies have reported this aspect as influencing seabird bycatch (Gales et al. 1998; Petersen et al. 2009a; Trebilco et al. 2010). In particular, the effectiveness of night-time setting in reducing seabird bycatch in the pelagic longline fishery has been well documented (Brothers et al. 1999). Consequently, we suggest that the exemption allowing South African vessels to set lines during daylight hours should be amended, unless vessels can demonstrate a seabird bycatch rate below 0.05 birds per 1 000 hooks.

Seabird bycatch rates are expected to be higher on unobserved trips than on observed trips, as compliance with seabird mitigation measures is likely to be lower on unobserved trips. Observer programmes for a number of locally relevant RFMOs require a minimum of 5–20% observer coverage (ICCAT 2014; IOTC 2014). We believe this figure should be higher when fishing in areas of high seabird abundance south of 25º S. Another option to ensure compliance with mitigation measures is electronic monitoring (via video cameras) of various fleets. Piasente et al. (2012) concluded that electronic monitoring was an effective alternative to onboard observers in the eastern tuna and billfish fishery off Australia, wherein seabird bycatch, mitigation measure compliance, and seabird abundance data were all comparable to onboard observer data.

Although seabird bycatch rates have decreased from rates by longlines previously reported in the large-pelagics fishery off South Africa (Petersen et al. 2009a), and especially since 2008 (when significant changes to permit regulations were made), the rates in recent years have seldom met the target of no more than 0.05 birds per 1 000 hooks as stipulated in South Africa's NPOA–Seabirds (DEAT 2008). As a result, unacceptably large numbers of seabirds continue to be killed each year by fishing fleets in South African waters, including species of conservation concern. Thus, better compliance with existing regulations should further reduce seabird bycatch. Additional study of the factors affecting seabird bycatch could further assist by ultimately improving and strengthening the regulations.

Acknowledgements — We thank the South African Department of Agriculture, Forestry and Fisheries, as well as CapFish, for access to fishery observer data, particularly assistance from Victor Ngcongo, Jan Wissema, Willem Louw and Wendy West. We are grateful for the efforts of the fishery observers who collected this information. Useful insights into the fishery were provided by Bronwyn Maree and other members of the BirdLife South Africa – Albatross Task Force. We are appreciative of the advice provided by Dominic Henry and Chevonne Reynolds for data analyses. Martin Slabber advised on calculating the lunar luminance score. Theresa Burg and Mike Double provided information on the genetic identity of shy-type albatrosses. Funding for this research was obtained through the National Research Foundation (South Africa) and the FitzPatrick Institute of African Ornithology.

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Manuscript received July 2016 / revised December 2016 / accepted December 2016