Marine habitat use of wintering spectacled petrels *Procellaria conspicillata*, and overlap with longline fishery

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ABSTRACT: Satellite transmitters were used to determine the marine habitat utilization and fishery overlap of wintering spectacled petrels *Procellaria conspicillata* in the southwestern Atlantic Ocean in 2006 and 2007. Kernel density analysis of tracked birds demonstrated intense use of waters in the Brazilian Exclusive Economic Zone, from 26 to 31° S, mainly over the continental shelf break and off-shore waters (mean depth in the < 20 % kernel density areas = 1043 ± 794 m), over warm tropical and subtropical waters (mean SST = 22°C and 21°C in 2006 and 2007, respectively) and mesotrophic/ oligotrophic waters (chlorophyll *a* density = 0.301 and 0.281 mg m^{-3} in 2006 and 2007, respectively). These habitats used by spectacled petrels are remarkably different from those used by their sister species, the white-chinned petrel *P. aequinoctialis*, which occurs mainly over the continental shelf on sub-Antarctic and productive waters. A close association between spectacled petrels and the pelagic longline fishery was demonstrated through comparison of the main kernel areas used by spectacled petrels and the areas used by the pelagic longline fleet determined by fishing effort at resolution of 1 × 1° quadrants. Travel speeds and distances during night and daytime periods did not differ. The present study demonstrates the importance of high resolution fishing effort data to address relation-ships between bird marine habitat use and specific fishing fleets, and to determine marine habitats and investigate at sea segregation between closely related species.

KEY WORDS: Procellariiformes · Foraging grounds · *Procellaria conspicillata* · Wintering · Longline fishery · Kernel habitat use

INTRODUCTION

Incidental captures in longline fisheries are the most important global threat to the survival of most alba-tross populations (Gales 1998), and also adversely affect several petrel species (Weimerskirch et al. 1999, BirdLife International 2004). The threats frequently occur far from breeding grounds because Procellari-iformes travel thousands of kilometres to feed during breeding and wintering periods (Weimerskirch et al. 1999, Phillips et al. 2006). Since the development of satellite technologies for tracking birds during 1980s, a range of detailed information on movements of alba-

trosses and petrels away from breeding colonies was generated. Further improvements in location accuracy and device miniaturization were achieved, and, more recently, bird-borne satellite transmitters have been applied in the context of conservation of these highly endangered species by determining the overlap of seabird distribution and fishing activities (e.g. Hyren-bach & Dotson 2003, Cuthbert et al. 2005, Phillips et al. 2006), or the definition of appropriate marine protected areas for albatrosses and petrels (Awkerman et al. 2005, Terauds et al. 2006). For species with previous evidence of being affected by fisheries, determining seabird locations using remote sensors, such as satel-

lite transmitters or geolocators, and the simultaneous analysis of the distribution of the fishing fleet is of increasing conservation relevance (Phillips et al. 2007). By using this approach a range of conservation measures could be delineated by focusing on particular fleets interacting with the species, establishing responsibilities to particular countries, and establishing of spatial or temporal closures to reduce bycatch rates. In the present study we tracked a threatened species, the spectacled petrel *Procellaria conspicillata*, on their wintering grounds in the southwestern Atlantic Ocean and described their habitat use in relation to oceanographic variables and distribution of the key fishing fleets.

The spectacled petrel was considered a subspecies of the white-chinned petrel *Procellaria aequinoctialis* until recently (Ryan 1998). It is endemic to Inaccessible Island, in the Tristan da Cunha Archipelago, with a global breeding population of 9000 pairs (Ryan et al. 2006), and is currently identified as 'vulnerable' to extinction (BirdLife International 2008). The species probably declined severely during 19th and early 20th century due to predation by feral pigs (Ryan 1998, Ryan et al. 2006). Population models indicate that the population is now at risk of extinction primarily due to incidental capture in longline fisheries (Ryan et al. 2006).

The at-sea distribution of spectacled petrels was initially described to be throughout the South Atlantic in a band from Africa to South America between 25 and 40° S (Enticott & O'Connell 1985). However, it appears to be a regular, but scarce visitor off the African coast, with only 30 birds recorded in 2000 during 629 ten minute counts (Camphuysen & van der Meer 2000). In the SW Atlantic Ocean, it is recorded from the Brazilian state of Bahia (12° S, Lima et al. 2004) to the Falkland Islands (Islas Malvinas, ca. 52° S), but is rare south of 40° S (Imberti 2002). Large concentrations occur in southern Brazil, where up to 300 birds (about 1.5% of the entire species' population) have been recorded following a single vessel (Neves et al. 2006a). In this region it is the most common pelagic seabird throughout the year in both continuous and snapshot censuses, with a strong tendency to follow longline fishing vessels (Olmos 1997, Neves et al. 2006b). It has been suggested that the species occurs preferentially over warm (Olmos 1997) and deep waters (Olmos & Bugoni 2006).

The domestic Brazilian pelagic longline fleet is based at southern and southeastern ports and operates mainly in this area during winter and early spring months, targeting tuna, swordfish and sharks (Bugoni et al. 2008c). Considerable numbers of albatrosses and petrels are incidentally captured by the fleet, mostly black-browed *Thalassarche melanophris* and Atlantic yellow-nosed *T. chlororhynchos* albatrosses, and white-chinned and spectacled petrels (Neves et al. 2006b, Bugoni et al. 2008c). Despite spectacled petrels frequently attending longline vessels in higher numbers than the white-chinned petrel (Olmos 1997, Neves et al. 2006a) the latter has higher bycatch rates in the area (Jiménez & Domingo 2007, Bugoni et al. 2008c). The reasons for differential capture rates among these similar sized and closely related species are unclear. Nocturnal foraging (unusual among most Procellariiformes) has been suggested as an important factor determining the incidental capture of white-chinned petrels in South Africa and Kerguelen (Barnes et al. 1997, Ryan & Boix-Hinzen 1998, Weimerskirch et al. 2000), and setting hooks at night has been postulated as an effective mitigation measure to reduce bycatch of most seabirds (Cherel et al. 1996, Barnes et al. 1997). In the SW Atlantic, longline setting frequently takes place at night and this practice has been advocated as an effective measure for reducing incidental capture of albatrosses and most petrels (Neves et al. 2006b). The effectiveness of nocturnal setting for avoiding spectacled petrel bycatch remains to be determined. Seabird associations with fisheries could be both detrimental, by reducing prey species used by birds or incidental mortality, or beneficial in the short term by providing bait and discards otherwise unavailable to birds (Furness 2003). Whether spectacled petrels benefit by feeding extensively on fishery discards (Neves et al. 2006a) or are adversely affected by the bycatch mortality they experience in this fishery (Bugoni et al. 2008c) remains unclear. Improving knowledge of the ecology and behaviour of both spectacled and white-chinned petrels is crucial to understanding the differences in bycatch rates of these species, as well as our ability to propose effective mitigation measures to aid their conservation.

The pricipal threat facing the vulnerable spectacled petrel is longline fishery bycatch in the SW Atlantic Ocean, making this the key area for its conservation. In the present study we compare the marine habitats used by wintering spectacled petrels with fishing effort in quadrants of $1 \times 1°$, thus providing a fine-scale comparison of habitat utilization by birds and fisheries over the same time period. We additionally investigated (1) relationships between the distribution of birds and oceanographic features such as sea surface temperature (SST), chlorophyll *a* (chl *a*) and bathymetry; (2) the behaviour of birds during night and daytime periods as an indicator of foraging behaviour and potential interaction with the usual nocturnal setting of longline hooks; and (3) the segregation in wintering areas between the spectacled and white-chinned petrel sister species, by comparing data with previous information on white-chinned petrel from Phillips et al. (2006).

MATERIALS AND METHODS

Transmitter deployment and data filtering. Spectacled petrels scavenging for discards at a pelagic longline vessel in southern Brazil were trapped using a cast net as described by Bugoni et al. (2008a). Captured birds were measured, ringed with metal bands, checked for plumage moult which indicated if birds were first year juveniles (no feather moulting) or older birds (signs of moult evident), and 1 ml of blood was collected. Molecular sexing was carried out based on DNA extraction from blood and PCR amplification of chromodomain-helicase-DNA binding (CHD) genes with primers 2550F (Fridolfsson & Ellegren 1999) and 2757R (R. Griffiths unpubl. data).

Satellite transmitters were attached to back feathers using waterproof Tesa® tape 4651 (Wilson et al. 1997). One 30 g battery-powered Platform Transmitter Terminal (PTT) from Microwave Telemetry was deployed in August 2006 and four 20 g battery PTTs (North Star Science and Technology) were deployed in August 2007. They correspond to 1.6 to 2.3% of petrels' body mass (1277.8 g, n = 20, Ryan 1998) and were configured to transmit continuously because we were interested in gathering as much data as possible on fine spatial and temporal scales to allow determination of day- and night-time movements and association with fishing vessels. Potential detrimental effects were minimized by limiting devices to <3% of petrels' body mass, using waterproof tape instead of harnesses, and by tracking birds for short periods, as recommended by satellite tracking of Procellariiformes (Phillips et al. 2003). Egg laying at Inaccessible Island occurs around 20 October (Ryan 1998), thus all birds were in their wintering period when PTTs were deployed off Brazil in August.

Only standard locations (i.e. Location Classes 3 to 0) derived from at least 4 satellite uplinks (ARGOS 1996) were used. Auxiliary locations accounted for only 13.5% of all gathered locations (n = 7400), but because they are considered less accurate than standard ones (but see Hays et al. 2001) they were not used here. The remaining set of data was filtered to remove unrealis-

tic locations assuming a maximum flight speed of 90 km h^{-1} (Phillips et al. 2006). Time interval between valid locations varied between PTTs, from 21 to 44 min on average. With a larger battery, the PTT deployed in 2006 resulted in 3167 valid locations during 49 tracked days, while the 4 PTTs deployed in 2007 resulted in a mean of 741 ± 146 locations (range 577 to 905) and tracked petrels during 17 to 20 d each (Table 1). In total, 6132 bird locations were used for the analysis.

Marine habitat utilization. The nonparametric fixed kernel density estimator (Wood et al. 2000) was used to determine the 80, 60, 40 and 20% density contour areas. Densities contours corresponding to kernels were calculated for locations in a Lambert Equal-Area Azimuthal projection centred on the South Pole. Arcview GIS 9.x was used for calculations with Hawth's Analysis Tools for ARGIS (Beyer 2004), setting cell size at 5 km and parameter smoothing factor (*h*) at 40 km.

Study area and oceanographic features. In the SW Atlantic Ocean the coastal branch of the Falkland (or Malvinas) Current flowing northward and transporting sub-Antarctic waters (4 to 15°C) reaches warm waters of the Brazilian Current flowing southward and transporting tropical waters >20°C (Garcia 1998). The convergence and mixture between the tropical and sub-Antarctic waters form the Subtropical Convergence (Garcia 1998), a highly productive area that supports important fish stocks and considerable numbers of top predators (Seeliger et al. 1998). The coastal areas over the continental shelf further benefit from mixing with the outflow of continental waters. The separation between the Brazilian and Falkland Currents varies seasonally, from 35.8 to 38.6° S, forming a heterogeneous area between both currents up to 1000 km wide with many eddies and fronts (Olson et al. 1988). Farther north up to 23° S, the penetration of relatively cold waters (14 to 17°C) occurs frequently in winter, mainly on the shelf break (Campos et al. 1996), which has an important influence on the composition of the seabird community (Olmos 1997).

SST and chl *a* concentrations (mg m^{-3}) were obtained from Aqua MODIS mapped products at 4 km cell resolution from the National Atmospheric and Space Ad-

Table 1. *Procellaria conspicillata*. Summary of data from the 5 tracked spectacled petrels in the southwestern Atlantic Ocean in 2006 and 2007

Bird	Sex	Tracking period	Tracked days	Number of valid locations	Total distance travelled (km)	Overall mean speed (km h^{-1})	40% kernel area (km^2)
07783	Unknown	17 Aug–04 Oct 2006	49	3167	17891	15.3	75406
75850	Male	01–20 Aug 2007	20	905	10124	22.6	116325
75851	Male	01–18 Aug 2007	18	814	7310	18.4	39784
75852	Male	01–17 Aug 2007	17	669	4501	12.0	17645
75853	Male	06–24 Aug 2007	19	577	5853	13.4	16753

ministration (NASA) (http://oceancolor.gsfc.nasa.gov/) through the mirror site at the University of São Paulo (http://orion.io.usp.br/los/). Bathymetry was obtained from the General Bathymetric Chart of the Ocean (GEBCO) at www.bodc.ac.uk/data/online_delivery/gebco/.

Bathymetric domains were defined as continental shelf (0 to 1000 m), shelf break (1000 to 3000 m) and pelagic (>3000 m). SSTs were classified according to the definition of water masses expected to occur in the Subtropical Convergence, following Garcia (1998): tropical waters (>20°C), sub-Antarctic waters (4 to 10°C) and subtropical waters resulting from the mixture of both (10 to 20°C). In fact, the SST range of the sub-Antarctic waters from the Falkland Current is from 4 to 15°C, and salinity is used with temperature to define water masses, but because we did not obtain salinity data and to avoid overlap between temperature ranges, waters were defined arbitrarily. Chlorophyll concentrations were divided into 4 classes after Hyrenbach et al. (2002): oligotrophic (concentration <0.1 mg m^{-3}), mesotrophic (0.1 to 0.3 mg m^{-3}), eutrophic (0.3 to 1 mg m^{-3}) and enriched waters (>1 mg m^{-3}).

Fishing effort. Pelagic longline fishing effort for the domestic fleet was obtained through weekly visits to Itajaí and Santos harbours by Projeto Albatroz Team and in Itajaí by daily visits by the Grupo de Estudos Pesqueiros, Universidade do Vale do Itajaí (GEP-UNI-VALI). Logbooks were obtained from captains and complemented with interviews, and contained information on fishing grounds (1 × 1° lat–long resolution) and number of hooks deployed per day or for the whole trip, restricted to the tracking period of birds. The coverage was over 70% of the total effort for the domestic pelagic longline fleet.

Nighttime and daytime movements. Each satellite location was classified as nocturnal or diurnal using the nautical dawn and dusk definitions (i.e. the time when the center of the sun is 12° below the horizon, using the calculation provided at www.srrb.noaa.gov/highlights/sunrise/sunrise.html) which are accurate to ± 1 min. Nighttime and daytime travelled distances were calculated using the great circle distance and speeds of tracked petrels calculated for each night or day period based on the first and last locations. Differences between speeds during night and day periods were tested by the Wilcoxon signed-rank test and differences between birds by the Kruskal-Wallis test.

RESULTS

General movement characteristics and kernel density

All spectacled petrels tracked in 2007 were males (based on molecular sexing), and were greater than one year old, because they were moulting body feathers (dorsum, ventral and head) when PTTs were deployed in August. The PTT deployed in 2006 worked for 1176 h or 156% of the expected lifetime of 750 h. All PTTs deployed in 2007 provided uplinks for similar periods (17 to 20 d) (Table 1), suggesting that all PTTs stopped transmitting due to battery exhaustion.

The single bird tagged in 2006 and 3 out of 4 birds tagged in 2007 foraged predominantly in waters of the Brazilian exlusive economic zone (EEZ) in southern Brazil. The distribution of these 4 birds formed a band oriented NE–SW, corresponding to the shelf break, from 25 to 33° S (Fig. 1). The bird tagged in August 2006 at 28° S over the continental shelf stayed over the shelf break for about 1 mo, during which it had a trip of 1 wk to offshore waters 500 km east of the shelf break. From 23 September it headed towards Tristan da Cunha and Inaccessible Island in the mid-Atlantic where the species breeds. When close to the islands the bird moved northwest, crossing close to the Rio Grande Plateau where the signal was lost.

Three birds tagged in 2007 in the southern portion (33 to 34° S) over relatively cold waters moved northeastward 2 d after tagging. The other bird (75850) also moved northeastward, but over deep waters off the Brazilian EEZ, stayed for a couple of days over the Rio
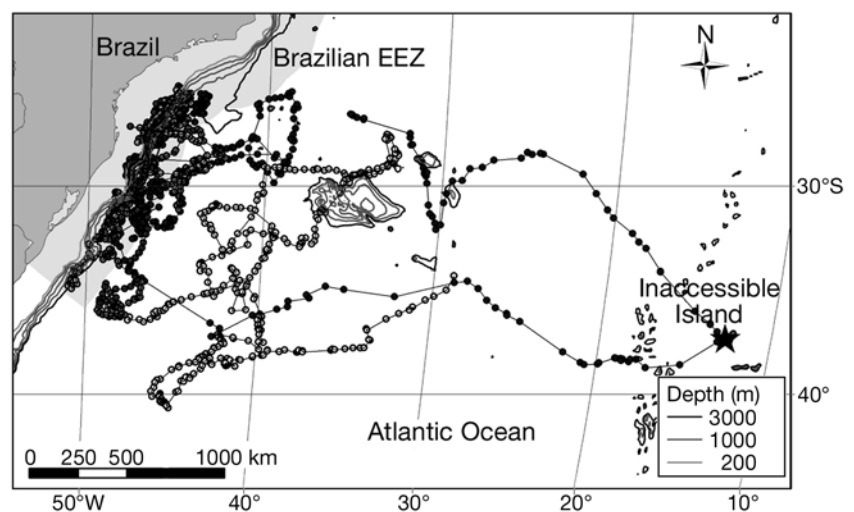

Fig. 1. *Procellaria conspicillata.* Distribution of satellite locations (n = 6132) and movements of 5 spectacled petrels tracked in winter 2006 (closed circles) and 2007 (open circles) in relation to bathymetry. EEZ: exclusive economic zone

Grande Plateau, after heading south-west up to 41° S and northwest again.

Core home range areas defined by kernel densities 20 and 40% demonstrated intense use of the shelf break between 25 and 31° S (Fig. 2), with 40% kernel areas between 16753 to 116325 km^2 (Table 1). The largest home range area belonged to the bird that did not stay over the shelf break as all the others, but wandered considerably over offshore waters. The kernel area generated by all 2006 and 2007 locations was 34007 km^2 at 20% density and 596545 km^2 at 80%, and included some small offshore patches (Fig. 2).

Table 2. *Procellaria conspicillata*. Activity levels of spectacled petrels in the southwestern Atlantic Ocean in 2006 and 2007 during day- and nighttime periods as measured by distance travelled and speed. *Significant at p < 0.05; ns: differences not significant

Bird	Distance travelled day (km)	Distance travelled night (km)	Mean speed day (km h^{-1})	Mean speed night (km h^{-1})
07783[a]	184.8 ± 174.3	104.0 ± 95.8*	18.0 ± 13.8	13.8 ± 10.8^{ns}
75850	227.3 ± 84.6	232.1 ± 100.9^{ns}	21.2 ± 7.9	23.5 ± 9.7^{ns}
75851	215.8 ± 113.0	166.4 ± 83.8^{ns}	19.2 ± 9.0	17.2 ± 7.5^{ns}
75852	97.9 ± 56.2	132.0 ± 88.1^{ns}	9.0 ± 4.5	14.4 ± 7.5^{ns}
75853	125.9 ± 122.6	129.0 ± 83.7^{ns}	12.7 ± 12.3	14.7 ± 7.7^{ns}

[a]During last 10 d it headed towards Inaccessible Island where the species breeds, travelling a mean of 426.1 ± 250 km during the day (speed 38.4 ± 16.3 km h^{-1}) and 168.2 ± 131.7 km at night (speed 22.6 ± 14.4 km h^{-1})

Diel travelled distances and speed

Mean speed varied between birds (Kruskal-Wallis, $H = 31.9$, df = 4, p < 0.001), but there was no difference between day and night (Wilcoxon signed-rank test, p = 0.9). Every bird moved from 98 to 227 km on average during daylight hours, with average speed varying from 9 to 21 km h^{-1} (Table 2). At night the average distance varied from 104 to 232 km, and speed varied from 14 to 24 km h^{-1}. Results were similar when analysing each bird individually, with no difference between speeds during day and night, with the exception of the bird tracked in 2006 which travelled further during daylight (Table 2). Thus, in spite of individual differences, the spectacled petrel has similar activity levels during night and day. Furthermore, distances

and speed during daytime were correlated with distances and speed during the subsequent night in 4 out of 5 birds (correlation coefficients from r = 0.27 to r = 0.66, n = 15 to 44, all p < 0.05). Thus, the tracked birds spent several days travelling between foraging grounds, during which periods they sustained high speed and travelled farther. These spectacled petrels also exhibited periods of low mobility, travelling short distances more slowly. The latter case is expected to represent periods of foraging activity intercalated with periods of rest on the water.

Oceanographic domains

The 4 bathymetric domains were not used evenly by the birds, which clearly preferred the shelf break and offshore deep waters (Figs. 1 & 2) rather than the continental shelf (Fig. 3). Fifty-two percent of locations were over water >3000 m, 34% between 1000 and 3000 m and 14.3% over the continental shelf (<1000 m). Average water depth at kernel 20% was 1043 ± 794 m and at 40% was 2250 ± 1353 m (Table 3).

Birds stayed over warm subtropical and tropical waters (mean SST = 22.05 ± 0.31°C and 20.95 ± 1.25°C in 2006 and 2007, respectively). Only 1% of locations were over cold waters of the Falkland Current (Fig. 3), which were present in the area over the continental shelf and southward (Fig. 4). Birds sampled in 2007 were tagged over cold waters, but moved northward or offshore soon after PTT deployment. There was a clear prefer-
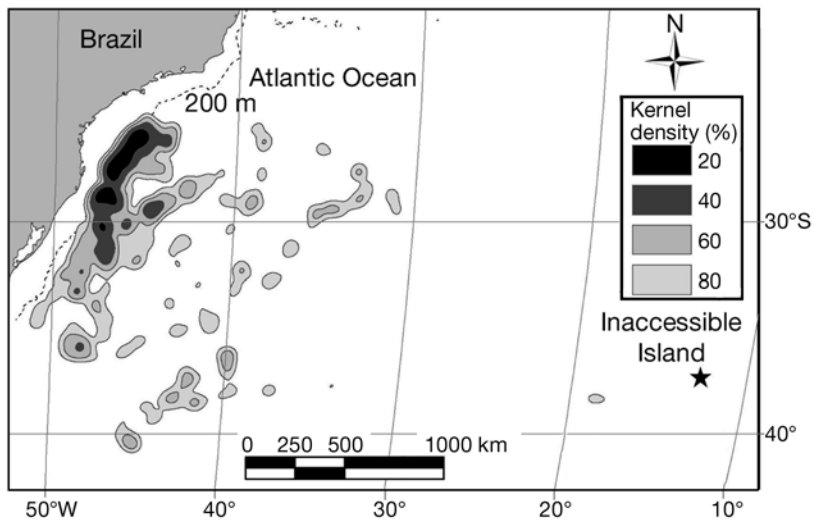

Fig. 2. *Procellaria conspicillata*. Kernel density distribution of 5 spectacled petrels tracked during wintering period in 2006 and 2007

ence for subtropical and, to a lesser extent, tropical waters (Fig. 3).

Mesotrophic waters (chl *a* density between 0.1 and 0.3 mg m^{-3}) represented 81% of all locations, with
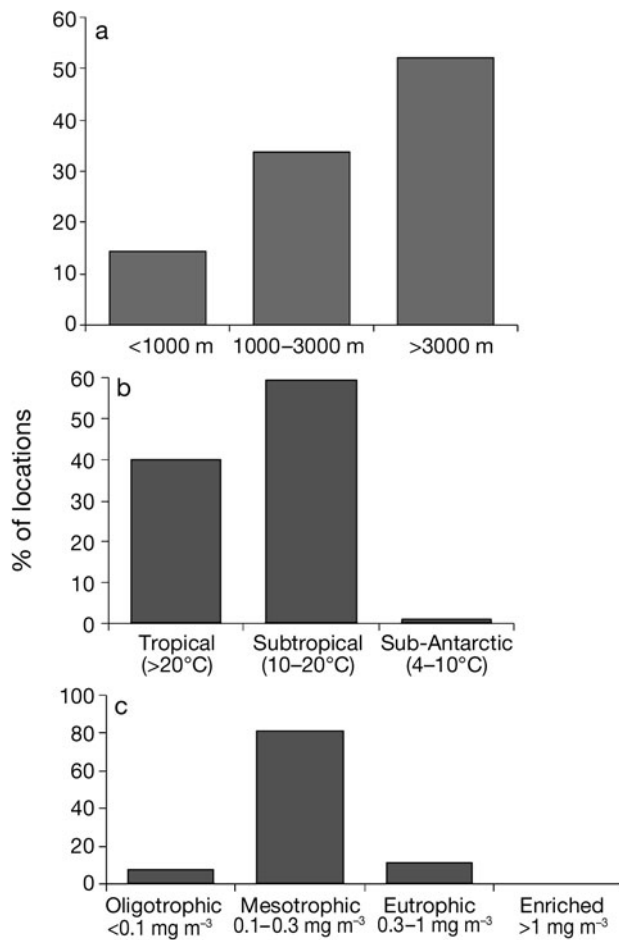

Fig. 3. *Procellaria conspicillata*. Frequency of locations (%) of spectacled petrels within each (a) bathymetric domain, (b) sea surface temperature range and (c) chl *a* concentration class (mg m^{-3})

minor proportion of oligotrophic and eutrophic waters (8 and 12%, respectively) (Figs. 3 & 5). Eutrophic and even enriched waters were present at the area during the tracking period near the coast and southward, but were not used frequently by birds. The 20% kernel density areas used by birds occurred over waters with chl *a* densities between 0.14 and 0.95 mg m^{-3}, averaging 0.301 ± 0.71 mg m^{-3} in 2006 and 0.281 ± 0.65 mg m^{-3} in 2007 (Table 3).

Overlap with longline fishery

The pelagic longline fishery effort in August 2007 was concentrated along the shelf break off southern Brazil, in a SW–NE oriented band, similar to the distribution of satellite locations and the kernel distributions of birds (Fig. 6). The fishing effort of the domestic longline fleet was concentrated between 26 and 32° S, where 77.5% of hooks were deployed during the tracking period (n = 787 834 hooks sampled). The areas with the highest density utilization by birds (kernel density < 40%) were those with highest fishing effort. Considering all 2007 locations, 47% were inside quadrants where pelagic longline hooks were deployed, even considering one bird that spent all time far offshore in an area where fishing data was not available. Furthermore, the number of locations was higher in quadrants with the highest number of hooks deployed (Spearman rank correlation, $r_S = 0.47$, n = 23, p = 0.027), demonstrating that birds stayed longer in areas of intense pelagic longline fishery. It is also noticeable that although birds were tagged in the southern areas where the fishing effort was low, they subsequently moved and stayed in areas with intense fishing activities to the north. One bird had no association with this fleet by moving over a vast area over international waters where the fleet was not operating during this time.

Table 3. *Procellaria conspicillata*. Mean ± SD (range) of water depth, sea surface temperature (SST) and chl *a* concentration within different kernel density distributions of spectacled petrels in the southwestern Atlantic Ocean

| Kernel density (%)	Kernel area (km^2) 2006 and 2007	Depth (m) 2006 and 2007	SST (°C) 2006	SST (°C) 2007	Chl *a* (mg m^{-3}) 2006	Chl *a* (mg m^{-3}) 2007
20	34 008	1043 ± 794 (153–2138)	22.05 ± 0.31 (21.40–22.60)	20.95 ± 1.25 (15.40–21.70)	0.301 ± 0.71 (0.14–0.83)	0.281 ± 0.65 (0.15–0.95)
40	105 194	2250 ± 1353 (121–4758)	20.79 ± 1.20 (17.60–22.60)	19.36 ± 2.71 (4.20–21.90)	0.273 ± 0.63 (0.12–2.50)	0.253 ± 0.53 (0.12–2.29)
60	254 733	3229 ± 1493 (105–5165)	18.84 ± 2.91 (6.90–22.60)	18.10 ± 3.03 (3.20–22.00)	0.253 ± 0.57 (0.08–2.56)	0.203 ± 0.53 (0.07–2.55)
80	596 545	3701 ± 1324 (93–5186)	17.76 ± 2.87 (6.80–22.60)	17.21 ± 3.16 (2.59–22.10)	0.243 ± 0.55 (0.07–3.70)	0.176 ± 0.54 (0.07–3.70)
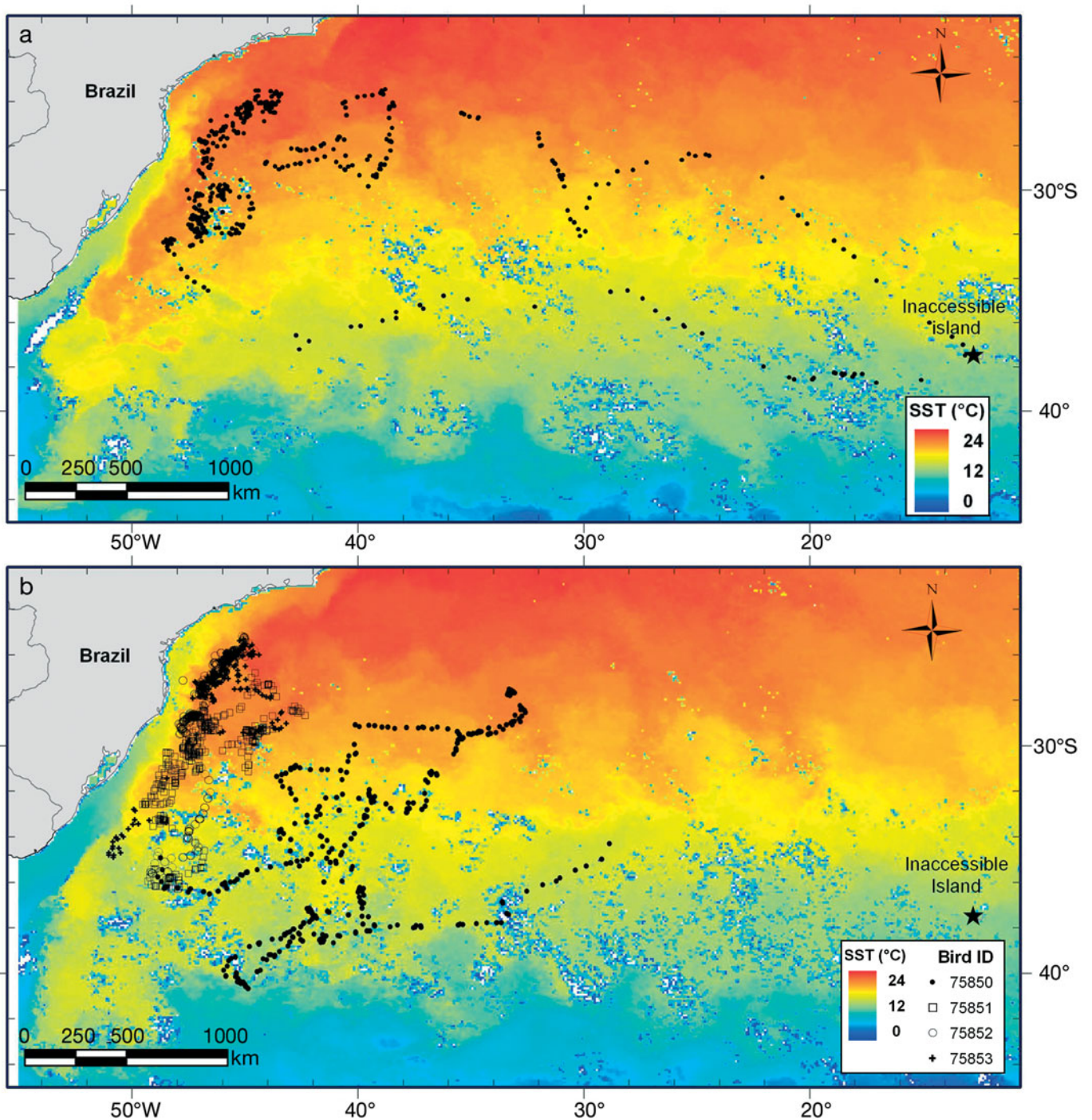
Fig. 4. *Procellaria conspicillata.* Habitat preference of spectacled petrels tracked during wintering period in (a) 2006 and (b) 2007 in relation to water masses defined according to sea surface temperature (SST)

DISCUSSION

Foraging areas of wintering birds

The distribution of spectacled petrels at sea is poorly known, and this is the first study to describe the forag-

ing areas of the species based on satellite telemetry. Most studies using satellite technologies to track seabirds deploy PTTs in colonies and are restricted to periods of breeding, just after chick fledging or when adults fail to breed (but see Hyrenbach & Dotson 2003, Suryan et al. 2007). During wintering periods seabirds
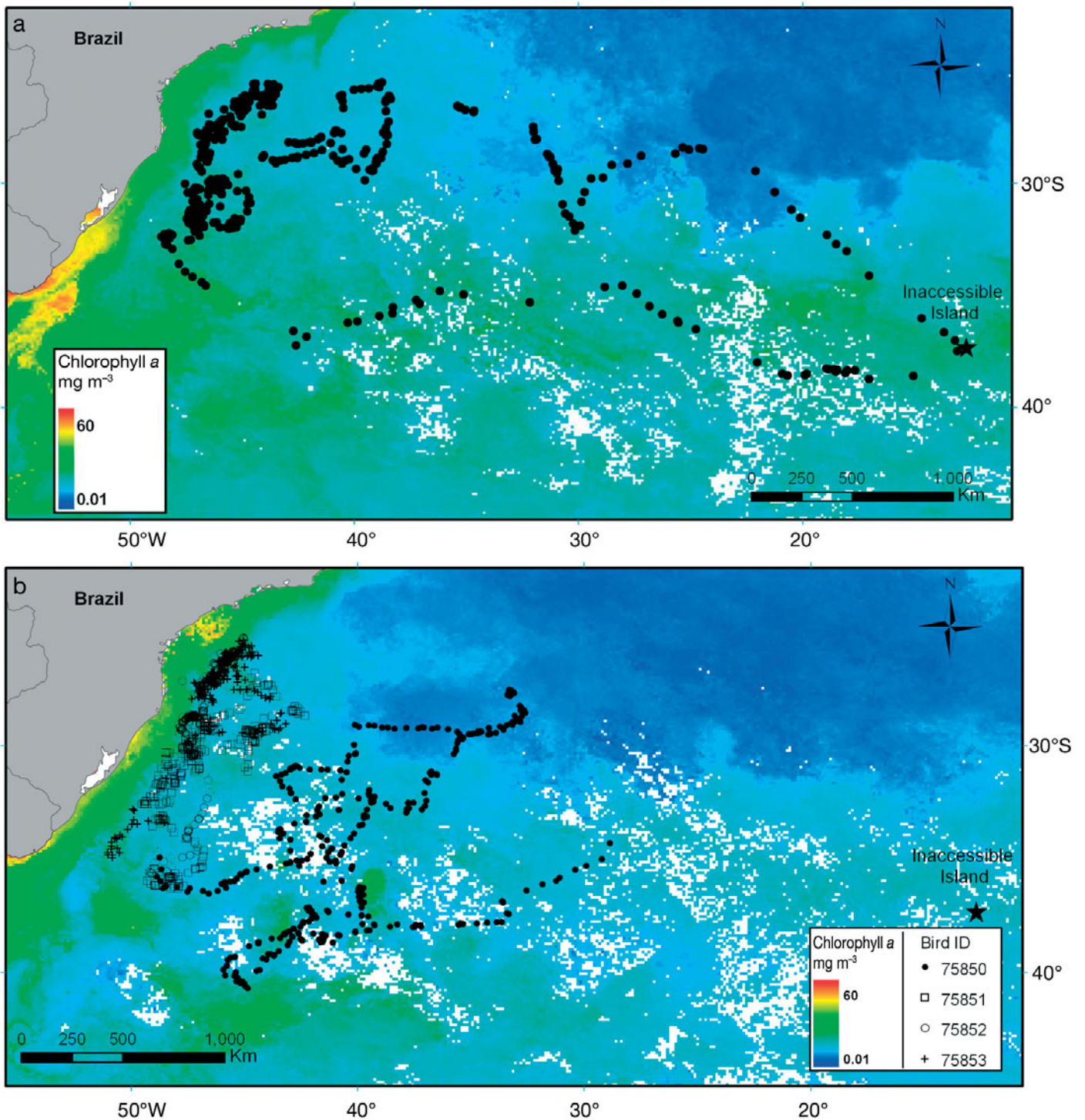
Fig. 5. *Procellaria conspicillata*. Habitat preference of spectacled petrels tracked during wintering period in (a) 2006 and (b) 2007 in relation to chl *a* concentration

are no longer central place-foragers, and are able to explore the marine environment more widely, changing foraging grounds if convenient or remaining within particular oceanographic areas or fisheries (Bugoni et al. 2005, Phillips et al. 2007). The long displacement of

3 birds just after tagging, from 34° S to 29–30° S, is explained by birds taking advantage of polar fronts crossing the area, which typically have strong S–SW winds and are common during winter and spring. During satellite deployment, calm wind conditions
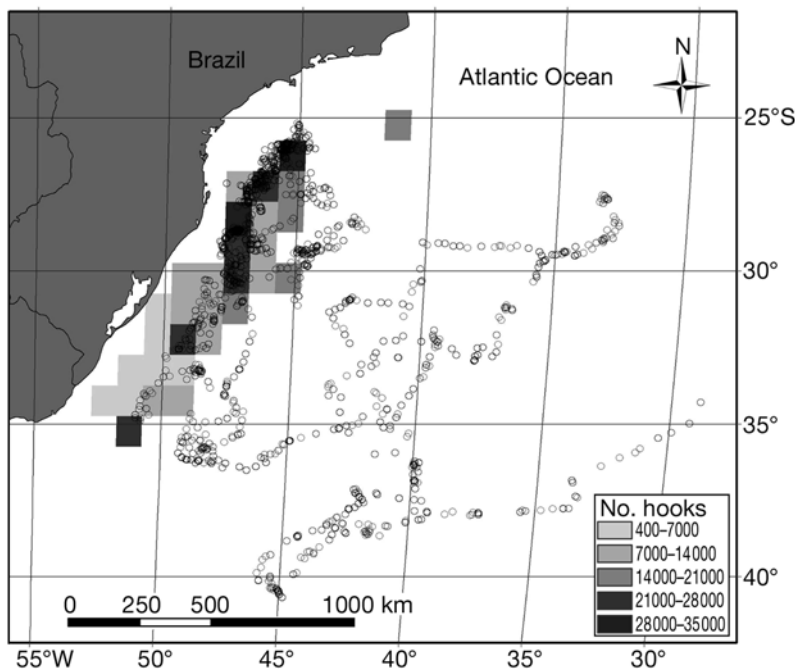
Fig. 6. Distribution of fishing effort in number of hooks deployed by the Brazilian domestic longline fleet during the 2007 tracking period of spectacled petrel

for short periods attending the vessel (Bugoni 2008). Birds flew 100s of km immediately after PTT deployment to join areas of intense longline fishing with typical oceanographic characteristics for the species. The distribution of tracked birds from the present study is further corroborated by censuses of birds in the area (Olmos 1997, Neves et al. 2006a).

Diel foraging activities

Spectacled petrels travelled similar distances at similar speeds during day and night. These results contrast with previous studies of other albatrosses and petrels, for which day and night differences in these parameters were found. Some studies show albatrosses and petrels flying further and faster at night (Klomp & Schultz 2000, Nel et al. 2000, Hyrenbach et al. 2002) or landing more frequently during the day (Fernández & Anderson 2000, Phalan et al. 2007). Catry et al. (2004) found that grey-headed albatross *Thalassarche chrysostoma* spent 94 % of the night on the water, apparently sleeping as they consumed only 26 % of their prey during night. Nel et al. (2000) assumed that the speed of <10 km h^{-1} recorded for grey-headed albatross during daylight hours was indicative of concentrated foraging. In the present study, correlations between day and night speeds and distances travelled in subsequent periods suggest that spectacled petrel activity might be divided into 2 different types, representing different foraging strategies: (1) periods of one or more days performing long and fast flights, apparently commuting between foraging areas or between breeding and foraging grounds; and (2) periods when they stay relatively stationary over productive foraging grounds or when attending vessels. However, this pattern seems to be independent of day or night. Weimerskirch & Guionnet (2002) determined that 4 albatross species spent 55 to 65 % of their time in flight, and at night they spent most of their time sitting on the water. Catry et al. (2004), using stomach temperature loggers, satellite tracking and wet–dry activity loggers, demonstrated that when sitting on the water under complete darkness, grey-headed albatrosses were able to ingest a considerable amount of food. Pinaud & Weimerskirch (2007) also found long stationary periods at night when analysing 7 satellite tracked Procellariiformes, including the white-chinned petrel. From these results of diel activ-

predominated and there were just a few spectacled petrels over cold waters. Albatrosses and petrels commonly take advantage of tail and cross winds (Jouventin & Weimerskirch 1990, Falk & Møller 1995) since the costs of displacement are reduced with high-speed winds (Furness & Bryant 1996).

The bird tracked in 2006 headed towards Tristan da Cunha at the end of the tracking period after a long period in the SW Atlantic (Fig. 1), and thus was probably an adult bird or a prospecting immature. Birds tracked in 2007 were in late moult stage, probably preparing for breeding, as spectacled petrels are expected to replace wing and tail feathers before body feathers (Warham 1990).

All birds except one used the shelf break area extensively, as demonstrated by the kernel analysis (Fig. 2), with occasional incursions to offshore deep waters or movements to breeding grounds. However, these movements were rapid, with no particular area in international waters used preferentially. It has been demonstrated that the Rio Grande Plateau, a shallow area around 30° S to 35° W (Fig. 1), contains large flocks of spectacled petrels throughout the year and when they meet the Brazilian longline fleet during summer (Projeto Albatroz unpubl. data), and this area was clearly of interest to tracked birds. Despite being trapped behind longline vessels for PTT deployment, tracked birds are thought to be representative of the population because other banded birds of the same species remained

ity in a range of seabirds, it is not clear if lower activity levels at night, measured as speed or absolute travelled distance, represent foraging behaviour, birds resting on the water, or even opportunistic feeding during resting periods at night. Procellariiformes, and spectacled petrels in particular, are frequently observed roosting at sea in flocks after feeding to satiation or in early morning before the longline hauling starts (L. Bugoni pers. obs.). In addition, slow speed and short distances covered by birds following fishing vessels is also expected during longline hauling, when vessel speed is 5 to 10 km h^{-1}. When birds arrive in foraging grounds or find a profitable feeding area, they appear to move short distances and show lower mean speeds, adjusting the scale of movement and speed according to the species and environmental characteristics (Weimerskirch et al. 1997, Pinaud & Weimerskirch 2005, 2007). A complementary approach is necessary for a better understanding of diel foraging activities; this can be achieved by the simultaneous use of satellite transmitters and stomach temperature loggers (e.g. Catry et al. 2004).

Furthermore, some individuals appear to behave differently, by covering larger distances away from longline fishing grounds, such as bird 75850 (Figs. 4 & 5). The density distribution for this bird was not concentrated in a particular area (Fig. 2), which suggests that if this individual attended some fishing vessels it did so only for short periods. The other birds could be flying between vessels operating nearby, but to investigate the association of each bird with a particular vessel we would require higher resolution data, with birds and vessels tracked by GPS satellite transmitters. Whether Bird 75 850 was commuting from one vessel to another or feeding on naturally available prey is unknown, but individual feeding preferences, with some individuals more prone to scavenge for fishing discards or attend different foraging grounds, is a well described phenomenon in seabirds (Freeman et al. 2001, Phillips et al. 2005b) and could have occurred in this case.

Oceanography and segregation with white-chinned petrel

Spectacled petrels prefer warm, offshore and mesotrophic or oligotrophic waters of the SW Atlantic Ocean. The cold waters of the Falkland Current are more evident over the continental shelf and north up to around 30° S adjacent to southern Brazil, where productivity is high (Figs. 4 & 5). Coastal cold and productive waters are used extensively by wintering white-chinned petrels (Phillips et al. 2006), but were clearly avoided by spectacled petrels, as they were tagged in

the south but moved quickly to the north, and high density use of the region by both species did not overlap extensively. The density distribution in 2006 and 2007 also demonstrated a clear preference for warm and mesotrophic waters found offshore and further north. The segregation pattern demonstrated here is in accordance with low numbers of spectacled petrels among stranded birds on the coastline, while the white-chinned petrel is more common (Colabuono & Vooren 2006). Additionally, the high abundance of spectacled petrels in southeastern Brazil (Olmos 1997) and their association with deep waters has been demonstrated by at-sea censuses and canonical analysis (Neves et al. 2006a). That these closely related species show remarkably different at-sea distributions and association with SST, bathymetry and productivity gives additional support for the distinctiveness of taxa and the specific status proposed by Ryan (1998) for the spectacled petrel based on morphometric data, plumage characteristics, vocalizations and playback responses. Furthermore, while both are associated with the pelagic longline fishery occurring over the shelf break, white-chinned petrels are expected to interact more extensively with a range of other fisheries taking place over the continental shelf, such as bottom trawling, gillnet and bottom longline. Environmental heterogeneity such as that found in the Subtropical Convergence area in the SW Atlantic Ocean, coupled with habitat selection, spatial segregation and differences in behavior, provide a basis for species coexistence in albatrosses and petrels (Waugh & Weimerskirch 2003, Phillips et al. 2005a, 2007).

Interactions with fisheries

The Brazilian pelagic longline fishing effort targeting swordfish *Xiphias gladius*, tunas *Thunnus* spp. and sharks (mainly blue shark *Prionace glauca*) has varied over recent years, with an increase in the proportion of the domestic fleet to detriment of the leased fleet, and an overall effort of 9 million hooks in 2006 (Bugoni et al. 2008c). This fishery and the similar Uruguayan pelagic fleet (Jiménez & Domingo 2007) incidentally capture spectacled petrels mainly during winter months, when the fleet concentrates efforts between 20 and 50° S. In addition, spectacled petrels are captured in a range of hook-and-line fisheries during summer months (Bugoni et al. 2008b): the highest capture rate per species occurs in the handlining fishery targeting tuna, but high rates also occur in the slow trolling fishery targeting bigeye tuna *Thunnus obesus*. The surface longline fishery for dolphinfish *Coryphaena hippurus* also has a high potential for interaction with

spectacled petrels during summer (Bugoni et al. 2008b). Moreover, birds are expected to spend considerable time in Uruguayan and Argentinean waters during the summer, when their preferred warm waters spread south. They will also spend time in international waters, where longline fleets from these and other countries such as Japan, Taiwan, Korea and Spain deploy considerable numbers of hooks (Tuck et al. 2003).

The global spectacled petrel population was estimated to be at least 20 000 ind., continuing an apparent recovery from a very small population in early 20th century (Ryan et al. 2006). The longline fishery is the common cause for concern for the conservation of several species of albatross and petrel from Tristan da Cunha and Gough Islands (Cuthbert et al. 2003, 2005, Neves et al. 2006a). A crucial step in the conservation of albatross and petrel populations affected by fisheries is describing the population range, assessing the susceptibility of birds and highlighting national responsibilities (Hyrenbach & Dotson 2003). In this way, the present study determined the distribution of spectacled petrels and demonstrated a substantial overlap with the Brazilian pelagic longline fleet during winter.

Similar to our results, Terauds et al. (2006) found high overlap between the distributions of satellite tracked black-browed albatrosses and trawler fishing around Macquarie Island. On the other hand, little overlap between longline fishing and satellite tracked black-footed *Phoebastria nigripes* and Laysan *P. immutabilis* albatrosses was found in the North Pacific Ocean (Hyrenbach et al. 2002), a discrepancy attributed to different sampling periods. In the S–SW Atlantic Ocean, some attempts have been made to quantify the overlap between longline fisheries and tracked albatrosses and petrels (e.g. Cuthbert et al. 2005, Phillips et al. 2006). However, data on fishing effort used for comparison is frequently temporally non-overlapping with bird tracking periods, and is often based on incomplete datasets (Tuck et al. 2003), or fishing effort is only available on large scales; for example, data provided by the International Commission for the Conservation of Atlantic Tuna (ICCAT) is in quadrants of $5 \times 5°$. In addition to the problems of using incomplete, large-scale data or temporal incongruence among fishing and bird data, the inherent dynamic nature of pelagic fisheries causes severe limitations in data analysis and interpretation (Hyrenbach & Dotson 2003, Bugoni et al. 2008c). In investigations of seabird distributions and overlap with fisheries, both temporal scale and a fine-scale spatial resolution are essential (Hyrenbach & Dotson 2003).

Phillips et al. (2006) found higher travelled distances and speeds of white-chinned petrels at night, suggesting low foraging activities, which contrasts with results from the present study indicating similar speeds and distances travelled by day and night for the spectacled petrel. The role of this behavioural difference between white-chinned and spectacled petrels is unclear, as is how it relates to risk of incidental capture on longlines. A possible explanation for the higher mortality of white-chinned petrel in comparison with spectacled petrel in the pelagic longline fishery (Bugoni et al. 2008c) could be differential age distribution in the study area, as the former are mostly juveniles and the latter are mostly subadults and adults (Bugoni 2008).

Conservation implications

Recently, the bycatch of seabirds has been addressed by the Brazilian government and non-governmental organizations with the launch of the National Plan of Action for the Conservation of Albatrosses and Petrels in 2006 (Neves et al. 2006b); the ratification of the Agreement for the Conservation of Albatrosses and Petrels (ACAP) in July 2008; the testing of mitigation measures such as bird scaring lines and blue-dyed baits (Neves et al. 2008); the satellite tracking of each longline vessel of the leased fleet, the tracking of the domestic fleet, implemented in 2006; and the proposed coverage of the fleet by onboard observers, currently under consideration by the Brazilian Environmental Agency. These actions constitute significant progress towards the mitigation of the global problem of incidental capture of albatrosses and petrels in fisheries. However, no mitigation measure is expected to be effective without strong enforcement (Bugoni et al. 2008b). The importance of Brazilian waters and the implications of the national longline fleet for the conservation of spectacled petrel have been demonstrated in the present study, which certainly extends to other jurisdictional countries and international fleets at different periods of the annual cycle of the species. Overall, spectacled petrels have been demonstrated to prefer relatively warm and oligotrophic waters over the shelf break and offshore, with great overlap with the pelagic longline fishery. The spectacled petrel remains a vulnerable, poorly known species that is strongly associated with fishing vessels, with a population concentrated in the SW Atlantic Ocean. Therefore, Brazil and other countries fishing in the area under the ICCAT Regional Fishery Organization jurisdiction have a critical role in the conservation of this species.

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