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At-sea distribution of breeding Tristan albatrosses *Diomedea dabbenena* and potential interactions with pelagic longline fishing in the South Atlantic Ocean

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Abstract

The endangered Tristan albatross *Diomedea dabbenena* is restricted to Gough and Inaccessible Islands. The species is killed as bycatch by longline fisheries in the South Atlantic, but the impact of this mortality is unknown. We satellite tracked 38 breeding Tristan albatrosses and assessed the seasonal and annual at-sea distribution of these birds in relation to reported pelagic longline fishing effort. These birds ranged across the South Atlantic from 50°W to 15°E with most (97%) daytime satellite fixes between latitudes 30°S and 45°S. Considerable fishing effort occurred within the same latitudes. Although there was no correlation between their at-sea distributions, there was a broad overlap between birds and fishing effort. Estimated bycatch rates for Tristan albatross and other *Diomedea* species in the South Atlantic, and the spatio-temporal overlap between birds and hooks, yield a predicted annual mortality of 471–554 birds, sufficient to cause population decreases of 3.6–4.3% per year. An index of bird × hook interactions (proportional density of birds multiplied by number of hooks by decadal period for each 5° square of longitude and latitude) indicated that 47% of annual interactions occurred in areas around Gough Island, and 11% and 15% of interactions in areas of the west and east Atlantic, respectively. There were also within seasonal differences in the key areas of overlap. The fishing fleets of Taiwan and Japan are likely to be responsible for most interactions based upon the reported magnitude of effort expended in the South Atlantic by these fleets. Ensuring that licensed fishing vessels within the Tristan da Cunha Exclusive Economic Zone (EEZ) operate using best-practise mitigation measures and with fisheries observer programs, could reduce the potential bycatch mortality of breeding Tristan albatrosses in this region by nearly one third. Thorough implementation of international agreements is required in areas of the high seas where most remaining interactions are predicted to occur.

1. Introduction

Incidental bycatch from longline fishing operations has been identified as a major source of mortality for many albatross species throughout the Southern Oceans (Brothers, 1991). While relatively few birds may be killed by any individual vessel, the massive scale of fishing effort in the Southern Hemisphere (Tuck et al., 2003) means that longline mortality is likely to be the main factor responsible for the observed decreases in many albatross species (Weimerskirch and Jouventin, 1987; Croxall et al., 1990). Of the world's 21 albatross species 19 are globally threatened and two are near threatened. Longline fishing is thought to be the principal threat in all cases (BirdLife International, 2004). While long-term studies of some Procellariiformes have provided evidence for the impact of bycatch mortality (e.g. Weimerskirch et al., 1997a), establishing a link between longline activities and the conservation status of less well-studied species is more difficult. Consequently, persuading a reluctant fishing industry to adopt best-practice mitigation measures within a species' range, or forcing the closure of certain areas to fishing, is extremely difficult. To overcome this problem, researchers

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have used remote tracking to study the at-sea distribution of albatross species. This information, along with data on the distribution of fishing effort can identify the overlap between birds and fishing and consequently assess the susceptibility of threatened species to longline mortality (e.g. Brothers et al., 1998).

In this study we used satellite tracking to investigate the at-sea distribution of the endangered Tristan albatross *Diomedea dabbenena* with respect to the distribution of reported pelagic longline fishing effort in the South Atlantic Ocean. The Tristan albatross is restricted to Gough and Inaccessible Islands in the Tristan da Cunha group, central South Atlantic Ocean. Tristan albatrosses are killed as by-catch in longline fisheries (Ryan et al., 2001), and given that populations of the closely related wandering albatross *Diomedea exulans* have decreased as a result of longline mortality (Weimerskirch et al., 1997a), there is a strong presumption that bycatch from longline fisheries may also be causing a decrease in numbers of the Tristan albatross (BirdLife International, 2004). Demographic data support the species' threat designation, with population models predicting a population decreasing at an annual rate of 3–5% (Cuthbert et al., 2004). Despite these concerns, knowledge of the at-sea distribution of the Tristan albatross is extremely poor (Ryan et al., 2001) and the spatiotemporal overlap with longline fishing is unknown. The vulnerability of the species to longline mortality is likely to depend on the spatial correlation between the density distribution of foraging birds and of longline fishing. Under a worst case scenario, both fishing vessels and birds may be attracted to the same oceanic "hotspots", thus causing a disproportionately large potential mortality within a few specific areas. Consequently, we estimate the density distribution of birds over the breeding season, along with the spatial distribution of longline fishing effort, to identify the at-sea areas where the potential conflict between birds and longlining is highest. We identify the ocean areas where most mortality is likely to occur, and estimate the potential annual mortality and its consequent impact on the population. Lastly, we determine the distribution of breeding Tristan albatrosses with respect to the 200 nautical mile Exclusive Economic Zone (EEZ) around Tristan da Cunha and Gough Island, and predict the effectiveness of managing fishing effort in this area at reducing bycatch mortality of Tristan albatross.

2. Methods

2.1. Study site and field-methods

The study was undertaken from September 2000 to September 2001 on Gough Island (40°21′S, 9°53′W), part of the UK Overseas Territory of Tristan da Cunha. Gough is a volcanic island, 65 km^2 in area, with steep mountainous terrain. Tristan albatrosses are biannual breeders; incubation is from January to March, and chicks fledge in November–December. Following a successful nesting attempt, breeding adults spend a year at sea before returning to the island to breed again. Thirty-eight breeding birds were tracked (Table 1) using ST10 Platform Transmitter Terminals (PTTs) manufactured by Telonics (USA) and packaged by Sirtrack Ltd. (New Zealand). PTTs weighed 45 g (ca. 0.6% of body weight) and were attached to feathers on the upper back of birds (between the wings) using adhesive tape. Breeding birds were captured immediately after they had been relieved from an incubation or brooding shift by their partner, or immediately after they had fed the chick. During incubation, devices were recovered after each foraging trip and were placed on another departing bird. During the brood/guard stage and chick-rearing period, devices were left on for several successive foraging trips.

Table 1
Numbers of Tristan albatross satellite-tracked and foraging trips recorded during the incubation, brood/guard and chick-rearing periods of the 2001 breeding season

Period	Females		Males	
	Individuals	Trips	Individuals	Trips
Incubation	8	9	9	11
Brood/guard	4	14	5	13
Chick-rearing	6	39	6	38
Total	18	62	20	62

2.2. Analysis of tracking data

Because *Diomedea* albatrosses are diurnal foragers (Weimerskirch and Wilson, 1992) and birds are far more susceptible to longline mortality during the day (Gales et al., 1998), we only included daytime satellite locations in the analysis. The day or night status of every location record was determined by calculating the time of dawn and dusk for the latitude, longitude and date of the satellite fix. All daytime fixes were included in the analysis unless the bird was on Gough Island or an at-sea location was implausible according to a predicted maximum flying speed (>80 km/h; Weimerskirch et al., 1993). We did not separate at-sea locations into "foraging" or "travelling" categories (e.g. Nel et al., 2000), but instead included all fixes in the calculation of the density distribution regardless of the associated flight speed (assuming it was beneath the maximum plausible speed). Wandering albatrosses are opportunistic foragers (Cherel and Klages, 1998) and consequently, birds are likely to be vulnerable to longline mortality wherever longline boats are encountered.

Satellite locations were used to determine the at-sea density distribution of birds over the breeding season within each 5° square of longitude and latitude where

Tristan albatrosses were located foraging. While this is a relatively low spatial resolution, analysis at this scale enabled us to make comparisons with levels of longline fishing effort, which is often reported at the same scale (Tuck et al., 2003). Percentage frequency tables of the distribution of locations within 5° grid squares were constructed for each individual and the mean proportion of locations from all individuals was used to create an overall density distribution (e.g. Barlow et al., 2002). This was undertaken separately for each stage of the breeding season (incubation, brood/guard and chick-rearing) and these distribution densities were then multiplied by the length of each breeding period (78, 30 and 248 days, respectively; Warham, 1990; R. Cuthbert unpublished data) to correct for the duration of the different periods. Using this information and the fact that time at-sea during incubation and the brood/guard periods was split evenly between the sexes (R. Cuthbert unpublished data), the density distributions of the incubation, brood/guard and at-sea chick stages were multiplied by 39 (78/2), 15 (30/2) and 248, respectively. The sum of these totals gives an overall estimated density distribution of annual "at-sea bird days" for each of the forty-five 5° squares that Tristan albatrosses were located within and for the area encompassed by the Tristan EEZ.

Seasonal variation was further examined for each quarterly period to facilitate comparison with fishing effort data. Satellite tracking was undertaken from 7/2/2001 to 30/06/2001, and these data could therefore be analysed separately for the first two quarters of the year ($n = 22$ and 21 birds, respectively). In order to assess the potential distribution of birds during the last two quarters of the year, we used data from 12 birds that were tracked from 18/5 to 30/06/2001. The chicks of these 12 birds were all 2–3 months old and the duration and range of foraging trips of these 12 birds were significantly greater ($t_{2,102} = 3.15$, $P = 0.002$ and $t_{2,102} = 2.83$, $P = 0.006$) than birds feeding small chicks (<2 months age), but were no longer in duration than the foraging trips ($n = 53$) of six birds whose behaviour was monitored in the study area from 6/6 to 22/9/2001 ($t_{2,91} = 1.87$, NS). Consequently, their foraging behaviour over this period (when they were not constrained by feeding small chicks) may be representative of their foraging behaviour over the rest of chick rearing.

2.3. Fishing effort

We only used pelagic longlining data in the analysis as Tristan and wandering albatrosses are almost exclusively captured by pelagic (tuna) rather than demersal longliners (Gales et al., 1998; Ryan and Boix-Hinzen, 1998; Olmos et al. in Cooper, 2000) and because the at-sea distribution of the Tristan albatross (see Section 3) does not overlap with the Patagonian toothfish *Dissostichus eleginoides* fishery, which is a major source of mortality of the more southerly breeding wandering albatross (Nel et al., 2002a). Fisheries data for the South Atlantic came from the International Commission for the Conservation of Atlantic Tuna (ICCAT), which includes the major pelagic fisheries operating in the South Atlantic with the exception of Illegal Unreported and Unregulated (IUU) fishing for which there is no available data (Tuck et al., 2003). Total reported fishing effort aggregated for all nations was available for each 5° square within the area of 30–50°S and 60°W to 20°E for the periods 1970–1979, 1980–1989 and 1990–1998. Fishing effort data were not available for areas north of 30°S, however only 0.6% of bird locations were found at latitudes north of 30°S. Fishing effort data were used to calculate average annual effort for the period from 1970 to 1998, and for each decade separately, within each 5° square. In order to assess the spatial interaction between Tristan albatrosses and longline fishing effort we multiplied, for each 5° grid cell, the number of at-sea bird-days by average annual fishing effort. This calculation results in an annual index of "bird × hook interactions" for each 5° square ($\text{index} = b * e$, where b is the proportional density of birds in each 5° grid cell and e is the number of hooks by 10-year period in each 5° grid cell). Seasonal variation in reported fishing effort was available for each quarter averaged over each decade. To quantify the spatial association between fishing effort and at-sea bird days we correlated the density of birds with the average annual fishing effort for each 5° grid cell. In order to estimate the extent of longline fishing within the Tristan EEZ we calculated the area covered by the EEZ within the six 5° squares that the Tristan EEZ covers (Fig. 1) and the total area of each square. We assumed that fishing effort was uniformly distributed within each 5° square and estimated quarterly fishing effort from the proportion of the square covered by the EEZ. Violation of this assumption will alter the proportion of fishing effort and interactions predicted to occur within the EEZ, but will not affect the overall results which are presented at a 5° scale.

2.4. Estimating total potential bycatch

We estimated annual bycatch by using seasonal fishing effort data for each decade and estimated bycatch rates for those oceanic areas where there was an overlap between birds and hooks. These calculations assumed that bycatch rates (i.e. deaths per hook) were constant in all 5° squares where there was overlap between birds and hooks, and that the number of deaths is simply a product of fishing effort and bycatch rate. The only direct estimate of Tristan albatross bycatch comes from the Brazilian and Brazilian joint venture pelagic fleet. The fleet is estimated to kill 41 (range 29–53) birds each year (Olmos et al. in Cooper, 2000). Annual reported

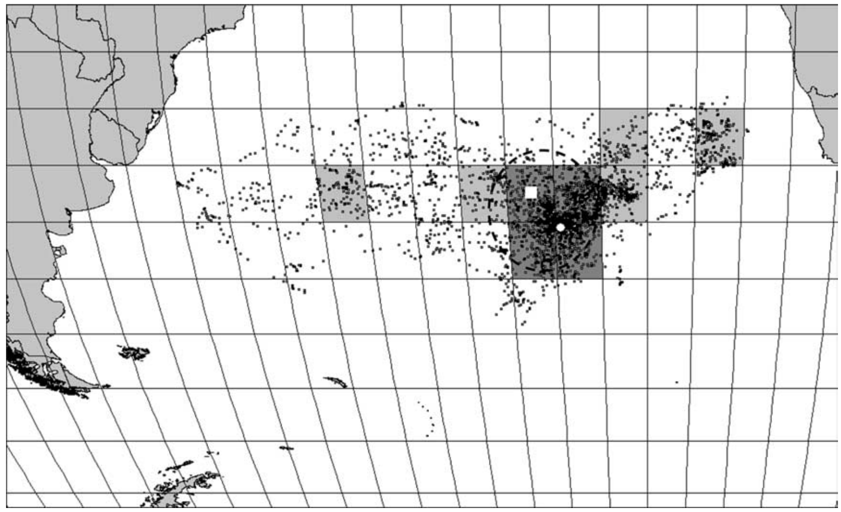

Fig. 1. All daytime satellite locations of Tristan albatrosses during the 2001 breeding season and the density distribution of at-sea bird-days over the whole year after correcting for the duration of the incubation, brood/guard and chick periods. Density distributions are grouped into categories of <2% of all bird-days (no shading), 2–10% (light grey) and 10–20% (dark grey shading). Gough Island (unfilled circle) is located at 40°S 10°W and Tristan da Cunha (unfilled square) is located at 37°S 12°W. The approximate limits of the Tristan 200 nm Exclusive Economic Zone are indicated (dashed oval).

fishing effort (1980–2001) by this fleet south of 30°S varied from 1 to 3 million hooks. Assuming an average fishing effort of 2.0 million hooks, then bycatch rates are estimated to be around 0.020 birds per 1000 hooks. This capture rate is similar to that found for "great albatrosses" (likely to be *D. dabbenena* and *D. exulans*) killed by Japanese tuna vessels operating in waters off southern Africa (0.017 birds per 1000 hooks), but is higher than capture rates for great albatrosses (most likely to be *D. epomophora* and *D. exulans*) by Japanese vessels off Australasia (0.009 *Diomedea* albatrosses per 1000 hooks; Ryan and Boix-Hinzen, 1998). Because of this uncertainty we estimate mortality using all three capture-rates. These bycatch estimates do not detail the age or sex of captured birds. Consequently, in order to make a first estimate on the total impact of longline mortality, we assumed that bycatch deaths were distributed uniformly across the whole population.

The annual breeding population of Tristan albatrosses is highly variable and is estimated to vary between 1500 and 2400 pairs (Ryan et al., 2001; Cuthbert et al., 2004) and we used an annual population of 2000 pairs for the calculation. Assuming that the annual population represents 59% of the total breeding population and that the number of juvenile and immature birds is about 82% of the total breeding population (Weimerskirch et al., 1997a), then the world population of Tristan albatross is approximately 12,500 individuals. Assuming the population growth rate (r) could reach 0.3% per year in the absence of longline mortality and breeding failures due to mice *Mus musculus* predation (Cuthbert et al., 2004; Cuthbert and Hilton, 2004), we estimate the population's predicted growth rate for each decade after accounting for the estimated levels of bycatch mortality.

3. Results

3.1. At-sea distribution of Tristan albatrosses

Breeding Tristan albatrosses were found over an extensive area of the South Atlantic Ocean, from 50°W to 15°E and from 29°S to 50°S (Fig. 1). Most (83.5%) satellite fixes were located between latitudes 35°S and 45°S. Over the whole breeding season, (after correcting for the duration of each breeding period) birds are concentrated within nine 5° grid cells (Fig. 1), which account for 80% of all at-sea bird days. A total of 41% of annual at-sea bird days are estimated to occur within the Tristan EEZ (Table 2).

Table 2
Proportion of annual at-sea bird days, pelagic fishing effort (from 1970 to 1998) and bird × hook interactions occurring within the Tristan Exclusive Economic Zone

	At-sea bird days	Fishing effort	Interactions
January–March	42%	2.8%	33%
April–June	49%	2.6%	44%
July–September	(36%)	1.7%	(10%)
October–December	(36%)	4.4%	(30%)
Annual total	41%	2.6%	32%

The proportion of at-sea birds days in the last two quarters of the year are estimated from the distribution of birds tracked from 18/5 to 30/06/2001 (see Section 2), consequently values of at-sea bird days and interactions in parentheses are estimated using this data.

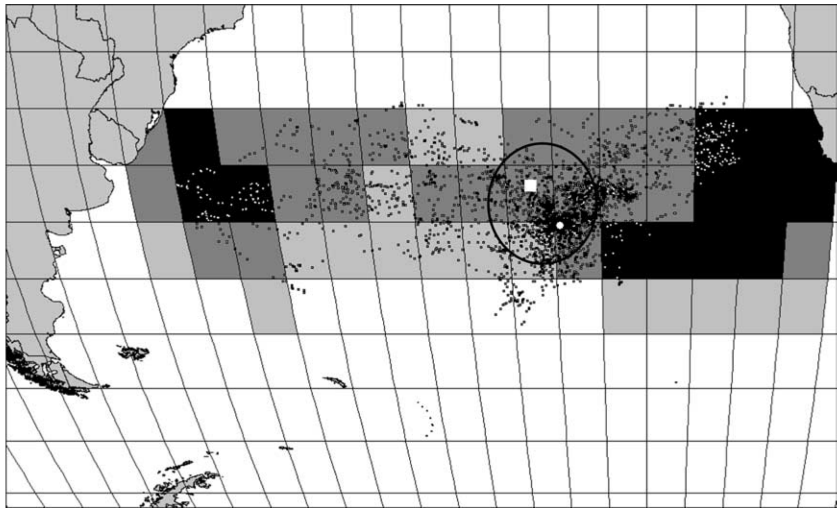

Fig. 2. Average annual reported pelagic fishing effort for the period 1970–1998 within the area of 30–50°S and 60°W to 20°E, grouped into categories of <10,000 hooks (no shading), 10,000–250,000 hooks (light grey), 250,000–1,000,000 hooks (dark grey) and >1,000,000 hooks (black shading) and the distribution of Tristan albatrosses during the 2001 breeding season. Gough Island (unfilled circle) is located at 40°S 10°W, Tristan da Cunha (unfilled square) is located at 37°S 12°W, and the approximate limits of the Tristan 200 nm EEZ (dashed oval) are indicated

3.2. Pelagic fishing effort

99.4% of annual reported longline fishing effort south of 30°S was between latitudes 30°S and 45°S, and concentrated into two discrete areas in the western and eastern South Atlantic (Fig. 2). Seasonal variation in fishing effort was consistent across all three decades, with peak fishing effort in the second quarter of the year falling to low levels in the last quarter (Fig. 3). Annual reported fishing effort within the South Atlantic (from 30–50°S and 60°W to 20°E) has increased each decade, from 25.2 million hooks in the 1970s to 48.3 million hooks in the 1990s. Over the whole time-period (1970–1998), 49.9% of all fishing effort occurred in the second quarter of the year, with 21.0% in the first, 23.2% in the third and 5.9% in the last quarter. Seasonal fishing effort also varied longitudinally, with most fishing occurring between longitudes 0°E and 20°E in the first two quarters (Fig. 4), and additional peaks of fishing effort between longitudes 40°W and 50°W in the second and third quarters. Assuming fishing effort was uniformly distributed with each 5° square, only 2.6% of annual reported fishing effort was undertaken within the Tristan EEZ (Table 2).

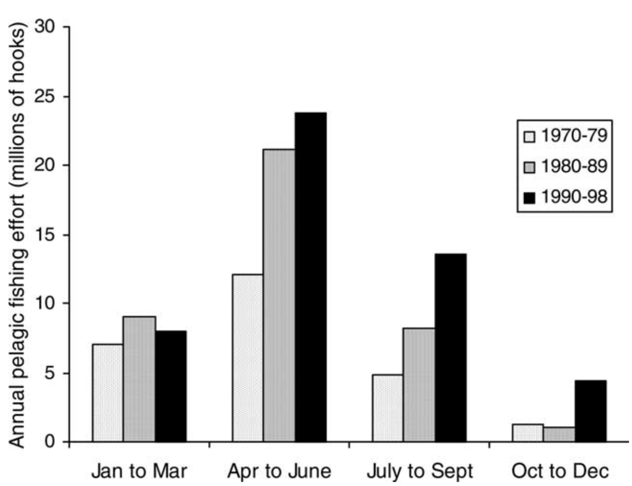

Fig. 3. Seasonal trends in annual reported pelagic fishing effort for each quarter for the periods 1970–1979, 1980–1989 and 1990–1998.

3.3. Tristan albatross and longline interactions

The interaction index calculated from the density distribution of at-sea bird days and the density distribution of regulated longline fishing effort suggests that 86% of all interactions occurred within ten 5° squares (Fig. 5), with the remaining thirty-five 5° squares that breeding birds use accounting for just 14% of interactions. The four grid squares of highest overlap account for 63% of all estimated interactions (Fig. 5). Considerable overlap (47%) occurred within the four grid squares closest to Gough Island, with just two of these squares producing 38% of all interactions. The other two key areas of overlap occurred to the west and east of Gough Island in areas closer to South America (11% of all interactions) and South Africa (15%). Although there was considerable spatial overlap between longline fishing and breeding birds there was no significant correlation between fishing effort (averaged for 1970–1998) and the density distribution of birds (Pearson's $r = -0.04$, NS). Differences in the at-sea distribution of male and female birds indicate that females will experience 57% of all bird × hook interactions.

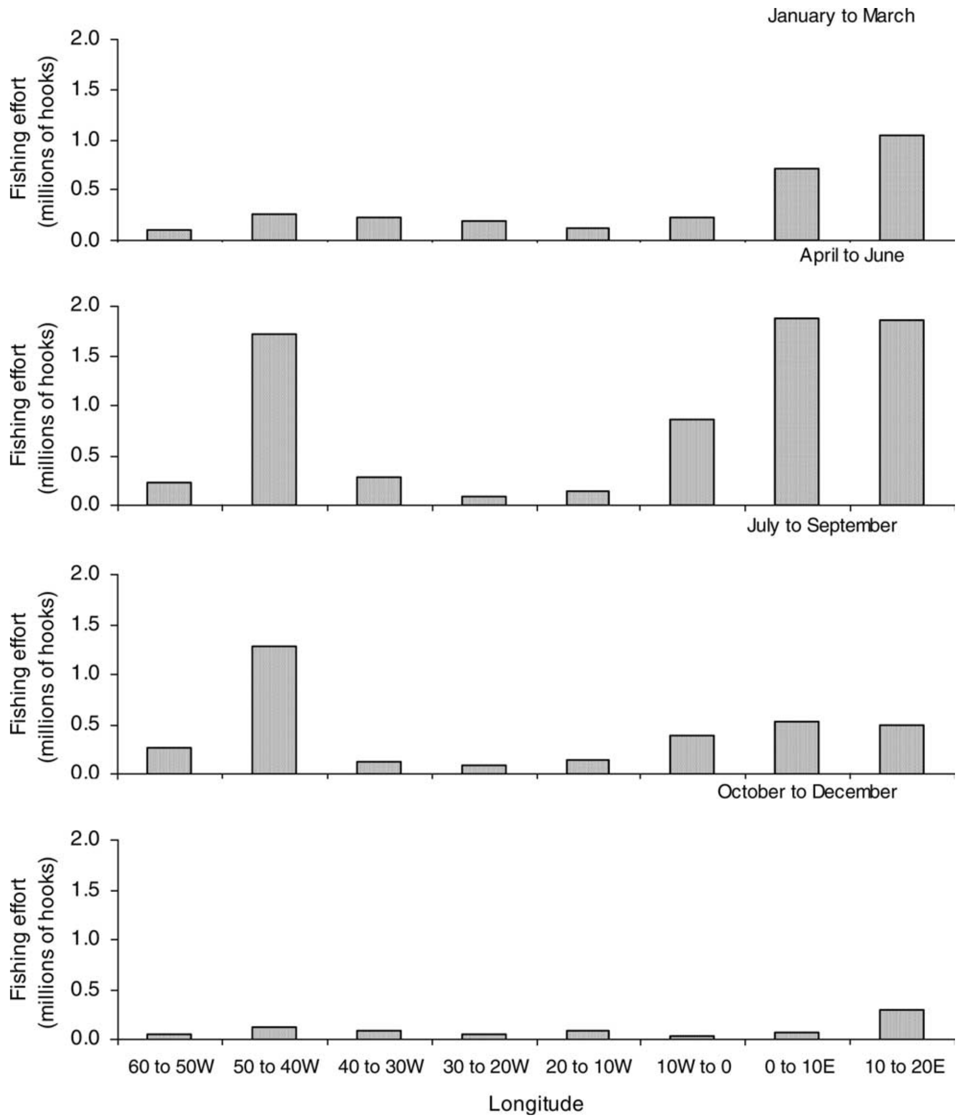

Fig. 4. Longitudinal trends in seasonal reported pelagic fishing effort (data averaged from 1970 to 1998).

3.4. Seasonal variation in bird × hook interactions

Seasonal variation in the location and intensity of fishing effort and bird use produces major spatiotemporal variation in bird × hook interactions. In the first quarter birds were mostly distributed within latitudes 35–50°S, ranging across to 48°W but no further than 10°E (Fig. 6). Consequently, with most reported fishing effort in the first quarter concentrated in areas from 0°E to 20°E (Fig. 4), there is relatively little overlap with breeding birds. Most bird × hook interactions at this time occurred in the two grid squares to the north of Gough Island (Fig. 6). In contrast, birds in the second quarter foraged further north (>99% of at-sea bird days between latitudes 30°S and 45°S) and ranged from 50°W to 10°E, when areas of high bird–hook interactions are found around Gough Island and in the eastern and western regions of the Atlantic (Fig. 6). If the distribution of birds from mid-May to the end of June accurately reflects the at-sea distribution of birds in the third quarter, then the highest areas of bird × hook interactions are found in the western and eastern Atlantic (Fig. 6). We estimate that around 47% of all interactions occur from April to June, with 26% in the third quarter, 20% in the first quarter and 7% in the last quarter. There was no significant correlation between the quarterly distribution of at-sea bird days and quarterly fishing effort. In total 32% of bird × hook interactions are estimated to have occurred within the Tristan EEZ (fishing effort data averaged from 1970 to 1998), varying from 10% in the third quarter to 44% in the second quarter of the year (Table 2).

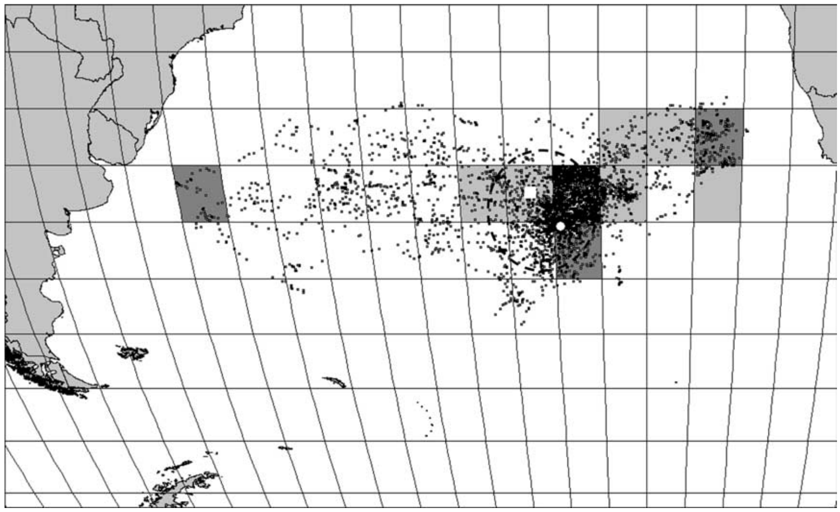

Fig. 5. Density distribution of bird × hook interactions calculated from the distribution of at-sea bird days during the 2001 breeding season (Fig. 1) and average annual reported pelagic longline fishing effort (from 1970 to 1998; Fig. 2). Density distributions of bird × hook interactions are grouped into categories of <2% of all interactions (no shading), 2–10% (light grey), 10–20% (dark grey) and >20% (black shading). Gough Island (unfilled circle) is located at 40°S 10°W, Tristan da Cunha (unfilled square) is located at 37°S 12°W, and the approximate limits of the Tristan 200 nm EEZ (dashed oval) are indicated.

3.5. Bycatch estimates and impact

Using bycatch estimates for Tristan albatrosses from the Brazilian fleet and bycatch estimates for *Diomedea* albatrosses in Southern Africa and Australasia, it appears that the potential annual mortality of Tristan albatrosses increased from the 1970s to the 1990s (Table 3). Mortality estimates for the South Atlantic (Brazilian and southern Africa bycatch data) are in the range 471–554 birds year^{-1} for the period from 1990–98, sufficient to cause population declines of 3.6–4.3% per year (Table 3).

4. Discussion

This study provides the first evidence for a substantial overlap between the at-sea distribution of breeding Tristan albatrosses and pelagic longline fishing, with birds concentrated between latitudes 30°S and 45°S and considerable pelagic fishing effort within these latitudes. As a consequence, breeding Tristan albatrosses are likely to be susceptible to bycatch mortality over much of their at-sea range. The at-sea distribution of breeding birds during the study and fishing effort indicates that the majority of interactions (86%) occur within just ten 5° squares. These areas are centred on Gough Island, but high numbers of interactions also occur in areas of the western and eastern South Atlantic. There are important seasonal variations, in the location and intensity of bird × hook interactions, because the distribution of both birds and fishing effort varies spatially and temporally. Most bird × hook interactions (47%) occurred during the second quarter of the year, which corresponds to the peak period of longline fishing effort.

Before discussing the results in more detail it is important to assess the reliability of the data. The validity of this study depends most critically on how accurately the distribution of breeding birds during the 2001 season reflects the normal foraging range of the species, and on how the foraging behaviour of birds feeding large chicks is likely to represent their behaviour in the last two quarters of the year when no tracking data were available. While considerable caution should be attached to the estimated distribution of birds in the second half of the year, other studies suggest that once birds are free from the constraint of feeding small chicks then their foraging behaviour is governed primarily by the need of the adult to maintain its own body condition (Weimerskirch et al., 1997b). Hence, it seems likely that once birds are feeding large chicks then they will continue to visit the same productive oceanic areas if these do not change. In support of this (see Section 3), the duration and range of the birds tracked from mid-May to June was no different to a group of birds monitored from June to September. Whether the results of this study represent the normal annual distribution of breeding Tristan albatrosses is unknown. Few studies have been able to examine inter-annual variation in the distribution of seabirds, although several years of tracking data indicate that the Antipodes albatross *D. antipodensis* appear to consistently visit the same oceanic regions (K. Walker, personal communication). Additionally, we have no tracking data on the at-sea distribution of non-breeding and immature birds, and further study is clearly required to fully understand the oceanic

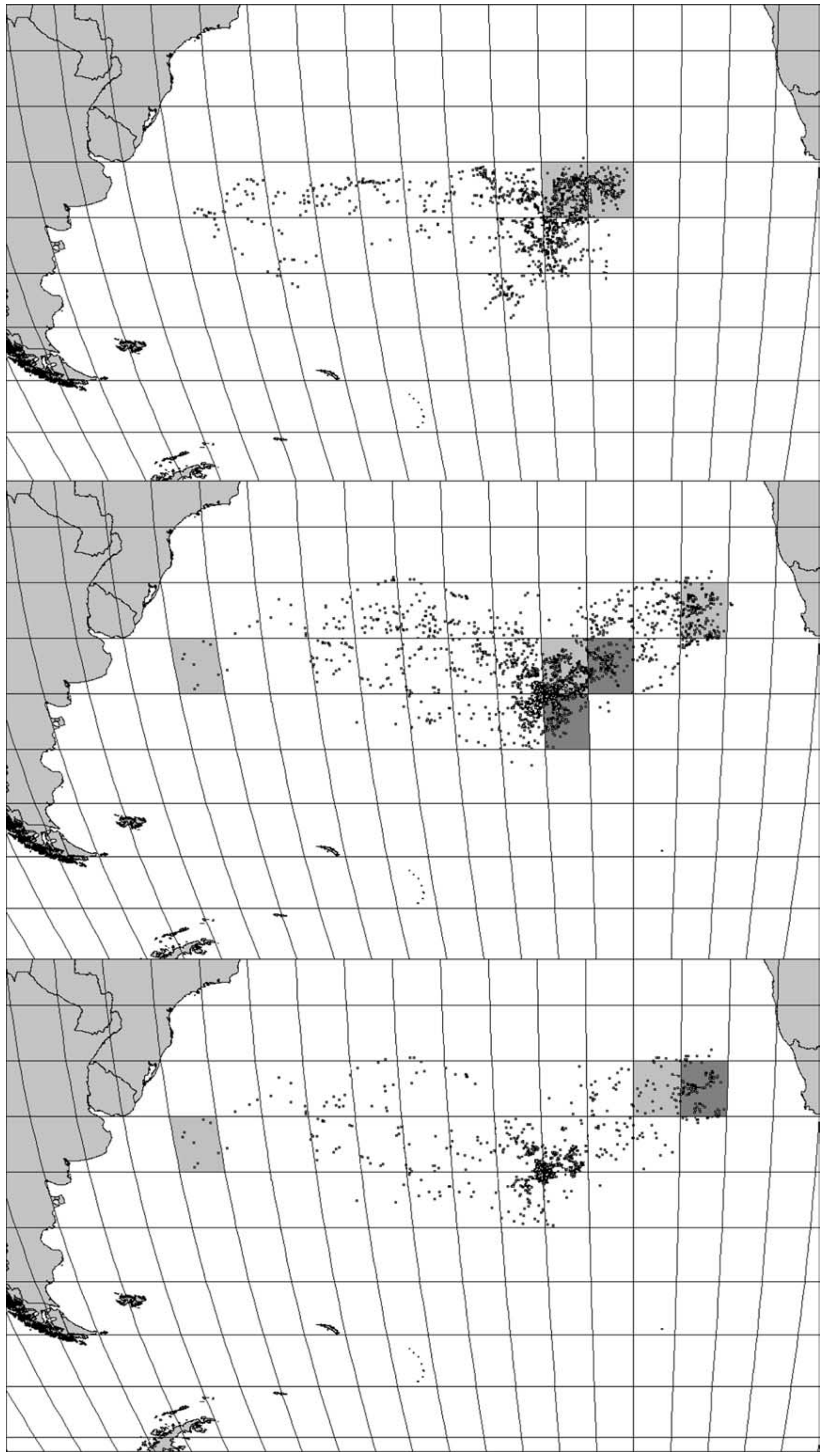

Fig. 6. Density distribution of bird × hook interactions during the first, second and third quarters of the year (top to bottom). Density distributions of annual bird × hook interactions are grouped into categories of <2% of all interactions (no shading), 2–10% (light grey) and 10–20% (dark grey shading). The distribution of birds in the third quarter was derived from bird tracked in the second quarter, see Methods.

distribution of the species during all life stages. Despite these caveats, the data presented in this study provides the best available indication of the overlap between breeding Tristan albatrosses and longline fishing.

4.1. Overlap with longline fisheries

Within the South Atlantic Ocean, Japan and Taiwan operate the largest regulated pelagic longline fleets, with

Table 3
Estimated annual mortality of Tristan albatrosses (assuming an annual breeding population of 2000 pairs and that mortality is uniformly distributed across the population, see Section 2) and the resulting predicted population growth rate in the South Atlantic Ocean (between 30–50°S and 60°W to 20°E) for the periods 1970–1979, 1980–1989 and 1990–1998, using bycatch rates of Tristan albatrosses estimated for Brazil, and bycatch of *Diomedea* albatrosses estimated for Southern Africa and Australasia

	0.020 birds per 1000 hooks (*D. dabbenena* Brazil)	0.017 birds per 1000 hooks (*D.* spp. Southern Africa)	0.009 birds per 1000 hooks (*D.* spp. Australasia)
1970–1979	228 (−1.6%)	194 (−1.3%)	103 (−0.5%)
1980–1989	420 (−3.2%)	357 (−2.6%)	189 (−1.2%)
1990–1998	554 (−4.3%)	471 (−3.6%)	249 (−1.7%)

Taiwan reporting 30–50 million hooks/year during 1987–1998 and Japan reporting 4–12 millions hooks/year during 1983 to 1998 (Tuck et al., 2003). Taiwanese longliners mainly fish north of 40°S targeting albacore *Thunnus alalunga*, whereas Japanese longliners fish farther south, mostly between 40°S and 45°S, targeting southern blue-fin tuna *T. maccoyii* and bigeye tuna *T. obesus* (Tuck et al., 2003). The narrow latitudinal band where Tristan albatrosses were found (ca. 65% of fixes were between 30° and 40°), together with the scale of Taiwanese fishing effort, suggests that this nation's fleet is likely to be responsible for most bird × hook interactions, with the Japanese fleet responsible for the bulk of the remainder.

Other fishing operations in the South Atlantic include national and licensed foreign longline fleets operating off southern Africa and South America, distant-water longliners operated by Spain, IUU pelagic fishing, and the recently developed and largely unregulated fishery for Patagonian toothfish, which includes a large IUU component (Tuck et al., 2003). The latitudinal range of the Tristan albatross means that breeding birds rarely encounter fishing fleets operating south of 45°S and consequently the species is unlikely to be seriously affected by the Patagonian toothfish fishery, which is a major threat to the more southerly breeding wandering albatross (Nel et al., 2002a). The relative importance of the other fishing fleets is difficult to assess, although substantial levels of IUU fishing do occur within the South Atlantic (Tuck et al., 2003). Tristan albatrosses are known to be killed in pelagic fisheries off South America and southern Africa (Neves and Olmos, 1998; Ryan et al., 2002; Favero et al., 2003), and both of these areas have high bycatch rates (Vaske, 1991; Ryan et al., 2002) and expanding fishing fleets (Tuck et al., 2003). Moreover, fishing effort of these two fleets is concentrated into areas of the western Atlantic (north of 40°S and west of 30°W for the Brazilian fleet; Tuck et al., 2003) and the eastern Atlantic (between 25–35°S and 5–15°E for the South African offshore fleet; Ryan et al., 2002), resulting in high bird × hook interactions (Fig. 5). Consequently, while fishing effort by these nations may be relatively low, their impact on Tristan albatross may be disproportionately high.

4.2. Estimated mortality and impact

Olmos et al. (in Cooper, 2000) estimated that 29–53 Tristan albatross were killed each year by Brazilian pelagic vessels. Assuming the total population of Tristan albatrosses is around 12,500 birds, then the Brazilian fleet kills between 0.2% and 0.4% of the population in each year. Fishing effort by the Brazilian and Brazilian joint venture operations is small (ca. 5%) in comparison to fishing effort in the South Atlantic by the Taiwanese and Japanese fleets, and we estimate that the overall annual bycatch mortality of Tristan albatrosses during the 1990s was in the order of 249–554 birds. While these estimates should be used with caution (see above; Ryan et al., 2002) the results do illustrate the probable scale of mortality. A population model using Tristan albatross demographic parameters predicts a population decreasing at around 2.9% a year (Cuthbert et al., 2004). The similarity of this independently modeled rate of decline to that estimated here from bycatch mortality in the South Atlantic (decreases of 3.6–4.3%) suggests that the levels of bycatch estimated by this study may be realistic. The increase in the estimated bycatch from the 1970s to the 1990s (a ratio of 1:2.4) is greater than the increase in fishing effort over the same two periods (a ratio of 1:1.9), suggesting that the estimated rise in mortality is a product of increasing fishing effort as well as greater overlap between pelagic fishing and areas where Tristan albatrosses are concentrated.

4.3. Conservation recommendations

Practical measures to reduce bycatch mortality of albatrosses include the exclusion of fishing vessels from areas where birds are concentrated, and the implementation of best-practice mitigation measures and fishery observer programs (Brothers et al., 1999; Ryan and Watkins, 2002). Several studies have recommended the establishment of exclusion zones around breeding islands, particularly during certain periods of the breeding season when foraging birds are constrained to remain close to the island (Prince et al., 1998; Weimerskirch, 1998). The advantages of such an approach are that these exclusions zones could legally be enforced within the 200 nm EEZ around breeding islands, potentially offering legal and practical protection to threatened species (Nicholls et al., 2000).

This study suggests that breeding Tristan albatrosses spend 41% of annual at-sea bird days within the Tristan da Cunha EEZ and that 32% of the annual bird × hook interactions occurred within this region. This high proportion of potential interactions occurs despite the EEZ accounting for just 2.6% of reported annual pelagic fishing effort (assuming fishing effort is uniformly distributed within each 5° square). Consequently, the mortality of breeding Tristan albatrosses could be reduced by either excluding longline fishing from the region, or more practically by exercising strong control over a licensed fishing fleet within the Tristan EEZ that is forced to comply with mitigation measures and observer coverage. Having a well-controlled legal fishery is also likely to help limit IUU fishing with the area (Nel et al., 2002b), which almost certainly continues within the Tristan EEZ (Ryan et al., 2001). Reducing IUU fishing and the adoption of best-practise mitigation measures would also benefit other albatross and petrel species breeding on Gough and Tristan da Cunha that are also threatened by longline fishing (BirdLife International, 2004; Cuthbert et al., 2003). The other key areas of bird × hook interactions are in the Western and Eastern South Atlantic, in international waters. Fishing effort data indicate that Taiwan, Japan, Brazil and South Africa are likely to be the principal nations responsible for interactions in these areas, although fishing by IUU, Spanish and South Korean vessels are also likely to cause interactions but are more difficult to quantify (Tuck et al., 2003). Protecting the Tristan albatross in these areas of the High Seas will require the fishing nations involved to adopt and comply with international efforts to protect seabirds from bycatch mortality under the recently ratified Bonn Convention on Migratory Species 'Agreement on the Conservation of Albatrosses and Petrels' (ACAP) and the United Nations Food and Agriculture Organisation's 'International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries' (IPOA-Seabirds).

In summary, this study has attempted to go beyond simply providing evidence for an overlap between birds and fishing effort, and has integrated spatiotemporal data on the distribution of birds with equivalent data on fishing effort to identify key areas of longline interactions and seasonal variation in interactions. While the results of this study need to be refined, with further data on the at-sea distribution of immature and non-breeding birds clearly required, the approach may be of use to other studies in efforts to identify key oceanic areas of birds and fishery interactions. Conservation actions, through exclusion of fishing vessels from the Tristan EEZ or through the enforcement of best-practice mitigation measures in the EEZ and international waters, are required to protect breeding Tristan albatrosses.

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