

1 ***Sex-related variation in the vulnerability of wandering albatrosses to pelagic longline fleets***

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1 ABSTRACT

2 The population of wandering albatrosses (*Diomedea exulans*) at South Georgia is decreasing because of
3 bycatch in longline fisheries. Until at least the early 1990s, the survival rate of females was lower than
4 males, consistent with the adult female-biased bycatch reported for fisheries operating around the
5 Brazil-Falklands Confluence (BFC). Here we use extensive tracking data (1990-2012) from breeding birds
6 at South Georgia to investigate overlap with longline fishing effort reported to the International
7 Commission for the Conservation of Atlantic Tunas (ICCAT). Using data from multiple years, we conclude
8 that breeding females are at higher risk than males from all the main pelagic longline fleets in the
9 southwest Atlantic. Our overlap index (based on fishing effort and bird distributions) correlated
10 positively with numbers of ringed birds reported dead on longliners, indicating that the metric was a
11 good proxy of bycatch risk. The consistent sex-bias in overlap across years, and the likely resulting sex-
12 biased mortality, could account for lower adult female survival rate at the colony. The risk from fisheries
13 changed seasonally; both sexes overlapped with pelagic longline effort during incubation (January-
14 March), and particularly during post-brood chick-rearing (May-December), whereas overlap was
15 negligible during brooding (April). The highest percentage of overlap was with the Taiwanese fleet, then
16 vessels flagged to Brazil, Uruguay, Spain, Japan and Portugal. Females were consistently at greatest risk
17 in the BFC region, whereas males showed lower and more variable levels of overlap with fisheries from
18 35° to 45°S. Our results have important implications for management of ICCAT longline fisheries and
19 conservation of this highly threatened albatross population.

20

21 *Keywords: Fisheries impacts; Ecological risk assessment; seabirds; satellite-transmitters; GPS loggers;*
22 *Southwest Atlantic; Regional Fisheries Management Organisation*

23

1 Introduction

2 Fisheries bycatch represents a major concern in the conservation of marine biodiversity, given the risk
3 posed to large marine predators (Hall *et al.*, 2000; Lewison *et al.*, 2004). Pelagic seabirds are wide-
4 ranging, interact with many fisheries and are captured incidentally in a wide range of fishing gears
5 (Anderson *et al.*, 2011; Favero *et al.*, 2011; Žydelis *et al.*, 2013). Albatrosses are the seabird family most
6 affected by bycatch (Croxall *et al.*, 2012), with the greatest impact in the southern hemisphere, where
7 most species are exposed to numerous longline and trawl fisheries (Baker *et al.*, 2007; Jiménez *et al.*,
8 2010; Favero *et al.*, 2011). The situation appears to be particularly serious in the South Atlantic, with
9 very high bycatch reported for pelagic longline (Jiménez *et al.*, 2009; Petersen *et al.*, 2009), demersal
10 longline (Barnes *et al.*, 1997; Favero *et al.*, 2003) and trawl fisheries (Sullivan *et al.*, 2006; Watkins *et al.*,
11 2008), and long-term monitoring indicates severe declines in several globally-important albatross
12 populations (Poncet *et al.*, 2006; Cuthbert *et al.*, 2014).

13 The wandering albatross (*Diomedea exulans*) provides a clear example of regional variation in the effect
14 of fisheries. In total, an estimated ca 8,000 pairs breed each year at four main island groups (ACAP,
15 2009). Populations in the Indian Ocean are recovering after rapid decreases in the 1970s to 1980s linked
16 to longline bycatch (Weimerskirch *et al.*, 1997; Nel *et al.*, 2002a; ACAP, 2009). In contrast, at South
17 Georgia (South Atlantic), a long-term decline from the early 1960s accelerated to >4% per year from the
18 mid 1990s to mid 2000s (Poncet *et al.*, 2006), and although numbers stabilized subsequently, as yet
19 there is no sign of a recovery (British Antarctic Survey, unpublished data). Formerly the second, and now
20 the third largest breeding population, the South Georgia population represents ca 19% of the global
21 total (ACAP, 2009). This is also considered to be the seabird species most affected by pelagic longline
22 fishing in the southwest Atlantic (Jiménez *et al.*, 2012, 2014). The small population size and very low
23 fecundity (adults may not recruit until aged ≥ 10 years, and at most fledge one chick every two years;
24 Croxall *et al.*, 1998), make this species highly vulnerable even to the low recorded bycatch rates (Bugoni
25 *et al.* 2008; Jiménez *et al.*, 2009, 2014).

26 An increase in the use of satellite and archival tracking devices in recent decades has greatly improved
27 our understanding of the exposure of seabirds to anthropogenic threats, including overlaps in
28 distribution with fisheries and hence potential bycatch risk (Phillips *et al.*, 2006, 2007). As central-place
29 foragers during breeding, seabird foraging strategies can change substantially depending on constraints
30 associated with each breeding stage (Weimerskirch *et al.*, 1993; Phillips *et al.*, 2004; Phalan *et al.*, 2007).

1 The fasting capability of adults is high, and trips during incubation can last several weeks. After hatching,
2 both adults alternate brooding with feeding at sea, and potential trip duration is much reduced. Then,
3 once the chick is thermally independent and better able to defend itself from predation, both parents
4 forage simultaneously; not only does potential feeding range increase, but twice the number of
5 breeding adults are at sea. Sex-related variation in distribution is also apparent; females often travel
6 farther north than males, which makes them more vulnerable to fisheries operating in subtropical
7 regions (Prince *et al.*, 1992; Nel *et al.*, 2002b; Xavier *et al.*, 2004).

8 An early study of ring recoveries of wandering albatrosses from South Georgia indicated that adult
9 females in particular interacted with pelagic longline fisheries around the Brazil-Falklands Confluence
10 (BFC) (Croxall & Prince, 1990). This matched with subsequent tracking data which revealed sex
11 differences in foraging range (Prince *et al.*, 1992; 1998), and lower survival of adult females than males
12 in the 1980s and early 1990s (Croxall *et al.*, 1990, 1998). This sex difference in mortality is still evident
13 (British Antarctic Survey, unpublished data), consistent with female-biased bycatch of adult wandering
14 albatrosses reported for the Uruguayan pelagic longline fishery (Jiménez *et al.*, 2008). Although previous
15 assessments suggested that sex-biased bycatch rates in seabirds reflect behavioral factors (e.g.
16 dominance hierarchy behind vessels; Ryan & Boix-Hinzen, 1999), a recent review considered that the
17 underlying cause was probably sex differences in distribution rather than susceptibility *per se* (Bugoni *et al.*,
18 2011). On this basis, relative overlap with fishing effort should provide an effective proxy for bycatch
19 risk.

20 For seabirds in general, the risk posed by particular fisheries varies depending on movements between
21 water masses (reflecting fluctuations in natural food availability, seasonal reproductive constraints,
22 weather conditions etc.), and shifts in fishing effort. In addition, as different fleets (vessels from a
23 particular flag state) differ in operational practises which affect bycatch rates (e.g. recommended
24 mitigation measures and degree of compliance), overall bycatch risk reflects the contribution of each
25 fleet to the total fishing effort that overlaps with bird distributions. Hence, coastal countries or leased
26 fleets using Economic Exclusive Zones and adjacent waters (Bugoni *et al.*, 2008; Jiménez *et al.*, 2014),
27 and high-seas fleets fishing over vast regions (Huang, 2011), may have quite distinct impacts. Given the
28 severity of the population decline for wandering albatrosses, better information on seasonal and annual
29 changes in relative risk may provide valuable details for targeting of conservation efforts. In this study,
30 we use extensive tracking data from breeding birds at South Georgia to quantify overlap with pelagic

1 longline fisheries in the southwest Atlantic. Our aims were: (1) to examine seasonal, annual and sex-
2 related variation in fisheries overlap; (2) to determine whether breeding females are consistently at
3 greater overall risk than males, and; (3) to partition the bycatch risk posed by each fleet to each sex.
4 Because the overlap of bird distributions and fishing effort does not necessarily indicate interaction, and
5 a direct correlation with bycatch rate cannot be assumed (nor easily tested, given the limitations of
6 current vessel-based bycatch estimation; Phillips, 2013), we also (4) test whether albatross-fisheries
7 overlap metrics reflect bycatch risk using ring recoveries as a proxy. The results are discussed in the
8 context of mitigating the risk that fisheries pose to this highly threatened population.

9

10 **Materials and Methods**

11 **Tracking data**

12 An extensive tracking program on wandering albatrosses has been carried out at Bird Island (54°00'S,
13 38°03'W), South Georgia, since the early 1990s. Analyses were of data from 263 breeding albatrosses of
14 known age and sex (142 males and 121 females) tracked during 399 complete foraging trips (205 by
15 males and 194 by females) either with Argos satellite-transmitters (Platform Terminal Transmitters or
16 PTTs) from 1990 to 2004 (Prince *et al.*, 1992, 1998; Xavier *et al.*, 2003, 2004; Phillips *et al.*, 2009) or
17 global positioning system (GPS) loggers from 2003 to 2012 (Phalan *et al.*, 2007; Phillips *et al.*, 2009; Ceia
18 *et al.*, 2012; Froy *et al.*, 2015) (for more details see Appendix S1, Table S1).

19

20 **Overlap with longline fishing effort**

21 Overlap of breeding males and females with longline fishing effort was determined separately for each
22 breeding stage: incubation, brood and chick-rearing (see Appendix S1). Overlap analyses were restricted
23 to years where ≥ 8 foraging trips per sex were tracked (mean: females=13 trips, males=14 trips).

24 Although a small proportion of birds were tracked for more than one trip, these were rarely to the same
25 area and so multiple tracks from the same individual were included in our analyses to increase sample
26 size and explore overlap in different years. Data for incubation were available in 2004 and 2012, for
27 brood in 1998, 2003 and 2004, and for chick-rearing in 1999, 2000, 2002, 2004, 2006 and 2009 (see
28 Appendix S1, Table S1, for sample sizes). In order to match with fishing effort, breeding stages were

1 considered to approximate to the following months: incubation = January-March, brood = April and
2 chick-rearing = May-December.

3 We used the proportion of time spent per unit area (days per each 5x5° cell) for each breeding stage as
4 the albatross density metric. To quantify bird-fisheries overlap, this was multiplied by the number of
5 hooks (Tuck *et al.*, 2011) obtained from the International Commission for the Conservation of Atlantic
6 Tunas (ICCAT) to produce an overlap index which accounts for the proportion of time spent by the
7 females / males in a given breeding stage and the potential number of hooks which may be encountered
8 in a given cell (for more details see Appendix S1).

9 **Factors affecting overlap and contribution by the main fleets during chick-rearing**

10 For each year, we estimated the total fishing effort (number of hooks) deployed in those 5x5° cells used
11 by each sex during chick-rearing, which was multiplied by the sum of the albatross density metric (see
12 above) to produce an overall index of overlap with the ICCAT pelagic longline fishery (hereafter termed
13 “ICCAT overlap index”). This analysis was then repeated for each longline fleet of the main ICCAT flag
14 states (hereafter termed “fleet overlap index”) to estimate their percentage contribution to the overall
15 overlap with males and females in chick-rearing. The ICCAT and fleet overlap indices are for the Atlantic
16 sector used by birds, but do not account for spatial variation. Therefore, another dataset was
17 constructed with all the possible overlap index values for the principal fleets in the 5x5° cells, by sex and
18 year (for more details see Appendix S1).

19 The effect of the sex on the ICCAT overlap index was analyzed using a Linear Model (LM). Additionally,
20 the effects of sex, year and fleet on the fleet overlap indices and the overlap at 5x5° cell level during
21 chick-rearing were analyzed using Generalized Linear Models (GLM) for the. Best fit in both cases
22 included a two-step analysis: 1) the occurrence of overlap was modeled using a binomial distribution;
23 then 2) overlap index values different from zero were modeled assuming a Gaussian distribution (for
24 more details see Appendix S1). All statistical analyses were conducted in R (<http://www.r-project.org/>).

25 **Correlation between overlap and bycatch risk**

26 Ring recoveries of wandering albatrosses from Bird Island, South Georgia, reported to the British Trust
27 for Ornithology or directly to the British Antarctic Survey, were used to test whether the bird-fisheries
28 overlap metric was a useful proxy of bycatch risk. Adults and chicks have been ringed intermittently at

1 Bird Island since the late 1950s, and annually since the mid 1970s (Croxall *et al.*, 1990; Croxall & Prince,
2 1990). We examined all reported recoveries of dead birds in fisheries (longline, trawl or unknown gear)
3 between 1999 and 2012 from the southwest Atlantic. Birds were classified as breeders or non-breeders,
4 based on the last sighting as a breeder at the colony. For each sex, we determined the number of rings
5 recovered from birds killed incidentally in each 5x5° cell during the chick-rearing months for all
6 albatrosses (breeding and non-breeding), and separately just for breeding albatrosses. The correlation
7 between average overlap index for chick-rearing birds (1999-2009) and the number of recoveries (1999-
8 2012; note the slightly larger year range to increase sample sizes) was tested using the Spearman
9 correlation coefficient (r), including values for all 5x5° cells with fishing effort.

10 **Results**

11 During breeding, wandering albatrosses from South Georgia were distributed widely in the southwest
12 Atlantic as far north as 28°S and east to 15°W (Fig. 1). A few birds travelled through the Drake Passage to
13 the southeast Pacific, and some as far south as the Antarctic Peninsula during incubation (both sexes)
14 and chick-rearing (only males). Constraints imposed by breeding were evident in distributions, with a
15 very restricted range apparent during brooding compared with the other two stages (Fig. 1).

16 **Overlap with pelagic longline fisheries in terms of effort**

17 Vessels from Taiwan accounted for a higher proportion of reported pelagic longline fishing effort than
18 any other fleet in the area used by the tracked albatrosses during 1990-2012 (Fig. 2). Other important
19 fleets, ordered by decreasing number of hooks reported, were Spain, Brazil, Uruguay, Japan and
20 Portugal. The distribution of the ICCAT fishing effort during the incubation, brood and chick-rearing
21 periods in the years with ≥ 8 trips tracked per sex is shown in Figures 3, 4 and 5, respectively.

22 There was no overlap with pelagic longline fisheries during brood in 1998, 2003 and 2004. If the analysis
23 is expanded to include all complete trips during brood (see Appendix S1, Table S1), i.e., from every year
24 in which data are available, only two tracked males overlapped with fishing effort in one of the
25 southernmost 5 x 5 °cells, in 1992, where < 10,000 hooks were reported (Fig. 4). Brooding females were
26 tracked to two cells in which fishing has occurred, but in years without reported effort. In contrast, both
27 males and females overlapped with pelagic longline effort during incubation (Fig. 3) and, particularly,
28 during chick-rearing (Fig. 5). During incubation in 2004 and 2012, females showed greater overlap with

1 ICCAT longline effort than males; indeed, the overlap with reported effort was nil for males in 2004 (Fig.
2 3).

3 There were sufficient tracking data from males and females for a more detailed analysis of annual
4 variation in fisheries overlap during chick-rearing. Overall, the overlap of chick-rearing females with
5 ICCAT fishing effort was considerably higher than that of males (LM, $R^2 = 0.46$, $F = 8.65$, $d.f = 1$, $p = 0.015$,
6 $n = 12$, Table 1). The fleet overlap index (binomial GLM) also varied significantly with sex, and was lower
7 for males (Table 2). Considering only cells in which tracked birds overlapped with vessels, the overlap
8 index (ln transformed) varied significantly (Gaussian GLM) with fleet (% of explained deviance = 56.0, χ^2
9 test < 0.01 , $n = 44$), and sex (% of explained deviance = 44.0, χ^2 test < 0.01 , $n = 44$). Coefficient estimates
10 indicated significantly greater overlap with the Taiwanese than any other fleet, and lower fisheries
11 overlap overall for males than females (Table 2). There were no significant differences among years in
12 the overlap index.

13 Across all pelagic longline fleets, the overlap index was always higher for females (Fig. 6A). On average,
14 by far the greatest overlap for both sexes was with the Taiwanese fleet, then, in descending order, Brazil
15 (again for both sexes), followed by Uruguay, Spain, Japan and Portugal for females, and Spain, Japan,
16 Uruguay and Portugal for males (Fig. 6A). The highest percentage contribution was by the Taiwanese
17 fleet in every year for females (mean = 70.4%, range = 54.1 – 90.5%) and in most years for males except
18 2009 (68.0%, 0 – 94.1%; Fig. 6B, see Appendix S2, Fig. S2). The other fleets in terms of decreasing
19 contribution to the overlap index for females were Brazil (13.2%, 0.4 – 32.4%), Uruguay (7.0%, 0.2 –
20 19.8%), Spain (5.0%, 0 – 13.9%), Japan (4.0%, 0.1 – 21.8%) and Portugal (2.6%, only data for 2009), and
21 for males (excluding 2009), were Spain (14.4%, 0 – 59.0%), Japan (2.0%, 0 – 9.7%), Brazil (1.7%, 0 – 4.8%)
22 and Uruguay (0.3%, 0 – 1.2%). In 2009, only two fleets overlapped with the distribution of males, vessels
23 from Portugal accounted for 78.2% of the index, and from Uruguay for the remainder (Fig. 6B).

24 **Spatial differences in overlap during chick-rearing**

25 On average, the greatest overlap index was for females in the region of the BFC (30 – 40°S, and up to
26 40°W; Fig. 5). Overlap index values were also the most consistent across years for females in this area,
27 according to the coefficients of variation (Fig. 5). During chick-rearing, males showed less spatial overlap
28 with fisheries than females both in terms of total number of cells (Table 1) and overlap index values (Fig.
29 5). Males mainly overlapped with longline fishing effort from 35–45°S, and off southern Brazil (30–35°S).
30 The overlap index for each 5x5° cell was highly variable (Fig. 5); fleet, sex and year explained the most

1 deviance in occurrence in the binomial GLM, followed by the sex-by-year interaction, and latitude was
2 least important (Table 3). Based on the coefficient, the greatest contribution to overlap was by the fleet
3 of Taiwan, followed by Brazil, Uruguay, Spain and Japan (Table 4). The occurrence of overlap varied
4 between years (coefficient only significant for 2009), and the sex-by-year interaction indicated that
5 males had a significantly lower overlap than females, decreasing over time from 2004 (marginally non-
6 significant) to 2009. Finally, the occurrence of overlap increased toward the north, as expected given the
7 high concentration of pelagic longline effort around the BFC (see above). For cells in which overlap
8 occurred, there were significant effects (Gaussian GLM) of, in order of importance, fleet, the sex-by-year
9 interaction, and year (Table 3). The only fleet with a significant coefficient was Taiwan, which showed a
10 strong positive relationship with the overlap index (Table 4). Similar to the binomial model, the
11 interaction between sex and year indicated negative relationships with the overlap index in the Gaussian
12 model for some of the regression parameters (Table 4).

13 **Relationship between overlap and ring recoveries**

14 A total of 167 ringed wandering albatrosses were recovered at sea during 1999-2012, with 134 reported
15 killed on longliners. Remaining records included birds captured on vessels, mostly in trawl or unknown
16 fishing gear (n=24), or in unknown circumstances (n=9). Of the 134 birds killed by longliners, 89 (66.4%),
17 36 (26.9%) and 7 (5.2%) were reported from fisheries in the Atlantic, Indian and Pacific oceans,
18 respectively. Overall, 85.4% (n=76 birds) of the captures in the Atlantic were in the southwest, i.e., the
19 area in which we focus the overlap analyses (see Appendix S3, Fig. S8). A total of 116 albatrosses (86.6%
20 of those caught by longliners) were killed during the months of chick-rearing (May-December), 54 of
21 which were unknown sex (birds that fledged from Bird Island but had yet to return). Amongst the
22 remaining 62 birds, the sex ratio was strongly biased to females (females=46, males=16; $\chi^2_{\text{Yates}} = 13.56$,
23 d.f. = 1, $p < 0.01$). Fifty of these birds were captured by longliners in the region where breeding
24 wandering albatrosses overlap with ICCAT fishing effort, of which two were excluded from further
25 analysis as the recovery location was unavailable. Within this region, these reports of ringed birds as
26 bycatch were strongly female-biased (females=37, males=11; $\chi^2_{\text{Yates}} = 13.02$, d.f. = 1, $p < 0.01$), including if
27 the sample is split into birds killed while breeding (females=21, males=9; $\chi^2_{\text{Yates}} = 4.03$, df = 1, $p < 0.05$), or
28 as non-breeders (females=16, males=2; $\chi^2_{\text{Yates}} = 9.39$, d.f. = 1, $p < 0.01$). Restricting the analyses to females
29 (because there are so few data for males), the correlation between the average overlap index and the
30 number of ringed adults reported killed on longliners in each cell in May-December was marginally non-

1 significant for all females (breeding and non-breeding) ($r = 0.34$; $p = 0.058$; $n = 32$), and significant just
2 for breeding females ($r = 0.46$; $p < 0.01$; $n = 32$) (Appendix S3, Fig. S9).

3 **Discussion**

4 This is the first detailed quantitative assessment of overlap between pelagic longline fisheries and
5 wandering albatrosses that examines both sex-related variation across breeding stages, and the
6 contribution of individual longline fleets to the bycatch risk. Based on extensive tracking and fisheries
7 data, breeding females showed consistently higher overlap than males with pelagic longline fisheries in
8 the southwest Atlantic, including all the main fleets. The correlations between the overlap index and
9 number of ringed females reported killed by longliners in each $5 \times 5^\circ$ square provided strong evidence
10 that the degree of overlap is reflected in the bycatch rate. Hence, the consistently high overlap of
11 females with these longline fisheries, and the resulting sex-biased mortality, would account for the
12 lower adult female survival rate observed at South Georgia since the 1970s (Croxall *et al.*, 1990, 1998;
13 BAS unpublished, data).

14 **Sex-related differences in overlap with pelagic longline fishing**

15 Breeding female wandering albatrosses were at greater risk of bycatch in pelagic longline fisheries than
16 males, except during brooding when both sexes feed closer to South Georgia (see Fig. 4). Around South
17 Georgia, of the order of 10s of wandering albatrosses were killed each year during the mid to late 1990s
18 in demersal longline fisheries for Patagonian toothfish (*Dissostichus eleginoides*) (Moreno *et al.*, 1996);
19 however, bycatch has been far lower in this fishery since the early 2000s (Waugh *et al.*, 2008). Only
20 when reproductive constraints are reduced, i.e., during incubation and post-brood chick-rearing, can
21 seabirds routinely reach more distant waters where fleets from a range of flag states target tunas,
22 swordfish and sharks. However, during incubation, wandering albatrosses still remain mostly in southern
23 areas (Fig. 1), and birds of both sexes are commonly sighted from demersal longliners at the southern
24 Patagonian shelf (Croxall *et al.*, 1999; Otley *et al.*, 2007). Hence in terms of the number of $5 \times 5^\circ$ cells
25 occupied, and the overlap index, overlap with pelagic longliners is considerably higher during chick-
26 rearing when not only are breeding adults spending most of their time at sea, increasing densities in
27 each cell, but females in particular visit northern areas (Figs. 1, 3 and 5). Our fine-scale spatial analysis
28 confirmed that females were consistently at greatest risk around the BFC, whereas males showed a
29 lower and more variable level of overlap with fisheries in the area from 35° - 45° S. Moreover, fishing

1 effort is consistently highest in the north (Fossette *et al.*, 2014) (see Fig. 5). These results are supported
2 further by the distribution of ring recoveries (this study) and previous bycatch assessments (Jiménez *et*
3 *al.*, 2014); most incidental captures of wandering albatrosses by the Uruguayan fleet, and a Japanese
4 fleet operating under license in the Uruguayan EEZ, occurred between May and November.

5 The female-biased mortality in the north is unlikely to be counterbalanced by bycatch of males in
6 southern areas, given the general reduction in bycatch rates in demersal longline fisheries reported
7 since the early 2000s (see above) and the low incidence of ring recoveries in trawl fisheries (see Results).
8 Females might be expected to recruit at younger ages to buffer the expected skew in the sex ratio.
9 Indeed, in the early 1990s there was a significant trend towards a lower mean age at first breeding in
10 females in particular; however, the small reduction (by <1 year) in age at recruitment had a minimal
11 effect on the overall population trend, and did not compensate for the increase in mortality of adult
12 females (Croxall *et al.*, 1998).

13 **Overlap with individual longline fleets**

14 We found that for all longline fleets, the highest overlap with breeding female wandering albatrosses
15 was during chick-rearing, underlining that they were at greatest risk. Based on the contribution of each
16 longline fleet to the overlap indices, the highest overlap with females and males was with the Taiwanese
17 fleet, which deploys by far the most hooks (Fig. 2), followed to a lesser extent by a few other fleets
18 (Brazil, Uruguay, Spain, Japan and Portugal). The importance of the Taiwanese fleet was evident both at
19 large (the southwest Atlantic) and fine (5x5° cells) scales (see Table 2 and 4). The variation in overlap
20 related to sex (see above) and fleet was also apparent at the 5° scale, reflecting annual variation both in
21 the proportion of time spent by albatrosses, and in the number of hooks deployed by each fleet in each
22 cell (Fig. 5, and see Appendix S2, Figs. S2-S7). Changes in order of importance of fleets by year were
23 slight. Perhaps the most noteworthy was the greater overlap of Brazilian and Uruguayan fleets with
24 females than males, presumably reflecting the preference of females for shelf-slope waters in the region
25 of the BFC (Prince *et al.*, 1998).

26 **Relationship between overlap and bycatch risk**

27 Ecological risk assessments of the effects of fishing on seabirds often make the assumption that the
28 overlap between fishing effort and distribution of a given population provides a reasonable proxy of
29 vulnerability to bycatch (Tuck *et al.*, 2011; Small *et al.*, 2013). Ideally, this would be validated by

1 comparing estimated overlap with bycatch data collected on board fishing vessels (Croxall *et al.*, 2013).
2 However, few wandering albatrosses are recorded in observer programs (Bugoni *et al.*, 2008; Jiménez *et*
3 *al.*, 2014), largely because the population is so much smaller than that of other species. Moreover, bird
4 bycatch data for most fleets is unavailable, poorly representative both spatially and temporally, or of
5 dubious reliability (Phillips, 2013). However, we were able to analyse the recoveries of ringed birds from
6 South Georgia that were killed in fisheries to assess the relationship between overlap calculated from
7 the distribution of fishing effort and of males and females of known breeding status, and likely bycatch
8 risk.

9 There are caveats associated with the interpretation of ring recovery data, which reflect biases arising
10 from differences in reporting effort and practices (Croxall & Prince, 1990). Vessel-based studies of
11 seabird bycatch in the southwest Atlantic started in the late 1980s (Vaske, 1991), but fisheries observer
12 programs were not established until the late 1990s and early 2000s (Jiménez *et al.*, 2009; Pons *et al.*,
13 2010; Yeh *et al.*, 2013). In addition, the variability in observer coverage influences recovery rates, and in
14 particular, ringed birds are much less likely to be reported from vessels without observers. Some
15 national fishery bodies and NGOs actively encourage fishermen to collect and report bird rings, for
16 example on vessels from Uruguay (Jiménez *et al.*, 2008, 2012) and other states that use the port of
17 Montevideo. In addition, recoveries have been reported from the late 1980s onwards by fishermen on
18 Brazilian vessels (Olmos, 2002). While acknowledging that there may be inequalities in reporting rates,
19 these should tend towards Type 2 rather than Type 1 errors in terms of our analyses. We therefore
20 interpret the positive correlations (one significant, one marginally non-significant) between the overlap
21 index and number of ringed adult female wandering albatrosses reported killed on longliners as
22 evidence that our overlap metric was a good proxy of the bycatch risk. Although overlap analyses are
23 often used to estimate bycatch risk for seabirds (Tuck *et al.*, 2011; Croxall *et al.*, 2013; Small *et al.*, 2013),
24 our study is a rare example where the assumption of a direct relationship with capture rates has been
25 corroborated by independent evidence.

26 **Implications for conservation**

27 The six species of great albatrosses (*Diomedea* spp.) are all listed as globally threatened by the
28 International Union for Conservation of Nature and Natural Resources (IUCN;
29 <http://www.birdlife.org/datazone/home>); Tristan (*D. dabbenena*) and Amsterdam (*D. amsterdamensis*)
30 albatrosses are Critical, northern royal albatross (*D. sanfordi*) is Endangered, and wandering, southern

1 royal (*Diomedea epomophora*) and Antipodean (*D. antipodensis*) albatrosses are Vulnerable. However,
2 the substantial wandering albatross population from South Georgia is at particularly high risk from
3 pelagic longline fisheries (Jiménez *et al.*, 2012, 2014; Tuck *et al.*, 2011). Between 1984 and 2004,
4 numbers dropped from 2,230 to only 1,553 breeding pairs, and at a particularly high rate (4% per year)
5 since 1997 (Poncet *et al.*, 2006). The longer time-series of counts at Bird Island, which holds 60% of the
6 South Georgia population, indicate a drop from 1,922 pairs in 1962 to 948 pairs in 2004 (Croxall *et al.*,
7 1990; Poncet *et al.*, 2006). At a regional and biogeographic level, this sustained decline meets IUCN
8 criterion A2 for Endangered (an estimated population size reduction of $\geq 50\%$ over three generations,
9 where the reduction or its causes may not have ceased), based on sub criteria b (an appropriate index of
10 abundance, i.e. breeding pairs) and d (actual or potential levels of exploitation, i.e. bycatch) (for full
11 definitions see http://www.iucnredlist.org/static/categories_criteria_3_1). For the *Diomedea* species
12 that occur in the southwest Atlantic (see Table 5), this decline for wandering albatross is comparable
13 with the annual decrease of 3% estimated for Tristan albatross, which is considered to be Critical
14 because of the negative impact of longline fishing exacerbated by predation of chicks by invasive
15 rodents (Cuthbert *et al.*, 2014).

16 Although our study provides further evidence of the risk from ICCAT-registered pelagic longline fleets in
17 the southwest Atlantic, we were unable to account for potential Illegal, Unreported and Unregulated
18 (IUU) fishing, the extent of which is entirely unknown. Nevertheless, this study provides a breakdown of
19 the contribution of fleets from each flag state to the overall bycatch risk, which is extremely useful for
20 focusing efforts within the framework of existing international conservation initiatives (including the
21 Agreement on the Conservation of Albatrosses and Petrels; ACAP), and in sub-groups of fisheries
22 management organizations which have delegated responsibility for providing advice to minimise
23 bycatch or wider ecosystem-level impacts. So far, monitoring of bycatch of wandering albatrosses and
24 other seabirds on pelagic longline vessels operating in the southwest Atlantic has been largely limited to
25 observer programmes for the Brazilian and Uruguayan fleets (Bugoni *et al.*, 2008; Jiménez *et al.* 2009,
26 2014), and recently for Japanese vessels operating in Uruguay under an experimental fishing licence
27 (Jiménez *et al.*, 2014). No bycatch data with sufficient information on species composition are available
28 to properly assess bycatch at the species level for the other 11 fleets that reported fishing effort to
29 ICCAT in the southwest Atlantic in the last two decades. This includes the fleets of Taiwan, which
30 showed the greatest overlap with wandering albatrosses, and of Spain and Portugal, which also operate
31 on the high seas. The Taiwanese longline fleet is the largest in the Atlantic; an observer program was

1 established in the 2000s, data from which were recently included in the first assessment for this fleet of
2 seabird bycatch for the entire Atlantic Ocean (Yeh *et al.*, 2013). No wandering albatrosses were reported
3 as bycatch for the southwest sector; however, this was presumed to reflect the very small percentage
4 (1.3%) of fishing effort that was observed (Phillips, 2013).

5 It is imperative for this population that effective mitigation measures be enforced on all ICCAT-
6 registered longline vessels in the southwest Atlantic, with appropriate monitoring of compliance. Based
7 on the overlap index, mitigation actions are required most urgently during the chick-rearing period
8 (May-December) in waters from 25° to 45° S, and particularly, because of the risk to adult females,
9 around the BFC (30°- 40°S and east to 35°W). The implementation of measures to reduce the mortality
10 of this highly threatened population would directly benefit all species of albatrosses and petrels at risk
11 from longline fishing in the southwest Atlantic, which are caught in many of the same areas and seasons
12 (Table 5).

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Table 1. Metrics of overlap between breeding female and male wandering albatrosses tracked from South Georgia, and pelagic longline fishing effort in the southwest Atlantic during the post-brood chick-rearing period in different years. N of cells = number of 5x5° cells with overlap; Proportion of time spent = overall proportion of time spent by each sex in the 5x5° cells with fishing effort; Millions of hook = total reported for the 5x5° cells within the albatross distributions; Overlap index = proportion of time spent x no. of hooks.

Year	Females				Males			
	N of cells	Proportion of time spent	Millions of hooks	Overlap index	N of cells	Proportion of time spent	Millions of hooks	Overlap index
1999	13	0.16	6.40	1,000,061	11	0.18	8.52	1,569,505
2000	10	0.22	6.01	1,345,617	8	0.22	0.36	77,355
2002	11	0.20	10.47	2,053,823	8	0.09	8.43	757,956
2004	10	0.34	6.46	2,182,667	4	0.03	0.68	19,122
2006	13	0.21	7.83	1,608,181	2	0.00	0.30	907
2009	6	0.20	3.11	607,860	1	0.01	0.12	1,248
Average	10.50	0.22	6.71	1,466,368	5.67	0.09	3.07	404,349

Table 2. Estimated coefficients and standard errors (SE) for the factors affecting the overall overlap between tracked wandering albatrosses and pelagic longline fleets in the southwest Atlantic. Results for the Binomial and Gaussian (ln transformed response) GLM are presented. Note that for every factor, one category is fixed (intercept), which serves as the standard for comparisons with other levels. Significant coefficients are highlighted in bold. JAP=Japan, SPA=Spain, TAI=Taiwan, URU=Uruguay.

Model		Coefficients	SE	z	p
Binomial	(Intercept)	3.258	1.019	3.197	0.001
	Sex Males	-2.565	1.098	-2.336	0.019
Gaussian (ln)	(Intercept)	10.992	0.751	14.638	<0.001
	Sex Males	-2.745	0.663	-4.141	<0.001
	Fleet JAP	-0.982	1.202	-0.817	0.419
	Fleet SPA	-0.239	1.018	-0.235	0.816
	Fleet TAI	2.458	0.971	2.531	0.016
	Fleet URU	-1.478	0.990	-1.492	0.144

Table 3. Percentage of the deviance explained by each factor affecting the overlap between tracked wandering albatrosses and pelagic longline fleets in each 5x5° cell in the southwest Atlantic. Results for the Binomial and Gaussian (ln transformed response) GLM are presented. Significant factors are highlighted in bold.

Model		Df	Deviance	Residual Df	Residual deviance	<i>p</i>	% Deviance explained
Binomial	NULL			1735	1280.6		
	Sex	1	43.117	1734	1237.5	<0.001	28.5
	Fleet	5	52.114	1729	1185.4	<0.001	34.5
	Year	5	33.639	1724	1151.8	<0.001	22.2
	Latitude	1	5.084	1723	1146.7	0.024	3.4
	Sex:Year	5	17.266	1718	1129.4	0.004	11.4
Gaussian (ln)	NULL			209	1046.3		
	Year	5	47.869	204	998.4	0.028	15.5
	Fleet	5	196.956	199	801.5	<0.001	63.9
	Year:Sex	6	63.279	193	738.2	0.011	20.5

Table 4. Estimated coefficients and standard errors (SE) for the factors affecting the overlap between tracked wandering albatross and pelagic longline fleets in each 5x5° cells in the southwest Atlantic. Results for the binomial and Gaussian (ln transformed response) GLM are presented. Note that for every factor, one category is fixed (intercept), which serves as the standard for comparisons with other levels. Significant coefficients are highlighted in bold. JAP=Japan, POR=Portugal, SPA=Spain, TAI=Taiwan, URU=Uruguay.

Model		Coefficients	SE	z	p
Binomial	(Intercept)	-1.013	0.250	-4.048	<0.001
	Sex Males	-0.576	0.328	-1.757	0.079
	Fleet JAP	-0.878	0.360	-2.436	0.015
	Fleet POR	-0.382	0.668	-0.572	0.568
	Fleet SPA	-0.646	0.248	-2.608	0.009
	Fleet TAI	0.580	0.203	2.862	0.004
	Fleet URU	-0.538	0.241	-2.227	0.026
	Year 2000	-0.601	0.320	-1.878	0.060
	Year 2002	-0.210	0.302	-0.698	0.485
	Year 2004	-0.400	0.318	-1.257	0.209
	Year 2006	-0.345	0.315	-1.094	0.274
	Year 2009	-0.958	0.342	-2.801	0.005
	Latitude	-0.175	0.078	-2.245	0.025
	Sex Males:Year 2000	-0.327	0.521	-0.627	0.530
	Sex Males:Year 2002	0.129	0.456	0.283	0.777
	Sex Males:Year 2004	-1.157	0.612	-1.893	0.058
	Sex Males:Year 2006	-1.745	0.711	-2.454	0.014
	Sex Males:Year 2009	-1.803	0.822	-2.195	0.028
	Gaussian (ln)	(Intercept)	4.599	0.409	11.239
Year 2000		0.447	0.561	0.797	0.426
Year 2002		1.362	0.504	2.704	0.007
Year 2004		2.306	0.548	4.206	<0.001
Year 2006		0.935	0.534	1.753	0.081
Year 2009		1.411	0.607	2.323	0.021
Fleet JAP		0.782	0.683	1.145	0.253
Fleet POR		1.493	1.334	1.120	0.264
Fleet SPA		0.881	0.461	1.911	0.057
Fleet TAI		2.382	0.357	6.681	<0.001
Fleet URU		0.127	0.457	0.277	0.782
Year 1999:Sex Males		0.681	0.562	1.211	0.227
Year 2000:Sex Males		-0.613	0.754	-0.813	0.417
Year 2002:Sex Males		-0.506	0.557	-0.909	0.365
Year 2004:Sex Males		-2.648	0.969	-2.732	0.007
Year 2006:Sex Males		-2.967	1.203	-2.466	0.015
Year 2009:Sex Males		-0.574	1.549	-0.371	0.711

Table 5. Populations of albatrosses and petrels that are most affected by pelagic longline fishing in the southwest Atlantic (see Jiménez *et al.*, 2012) and the areas and seasons of highest bycatch risk (peaks in bycatch rates in parentheses).

Species	Global status *	Population: Islands or island groups	Main bycatch areas	Main bycatch seasons (peak)
<i>Diomedea exulans</i>	VU	South Georgia	28° S to 46° S and shelf-break to 43° W ¹ ; 25° S to 46° S and shelf-break to 30° W ²	Abril-November (November) ¹ ; May-December ² ; July-November (October-November) ³
<i>Diomedea dabbenena</i>	CR	Gough	28° S to 37° S and international and deep Uruguayan waters ¹ ; 29° S to 35° S and 45° W to 52° W ⁴	July-November (September-November) ¹ ; May-January ⁴
<i>Diomedea epomophora</i>	VU	Campbell	34° S to 41° S and shelf-break to 49° W ¹	April-November (June-July) ¹
<i>Diomedea sanfordi</i>	EN	Chatham	34° S to 37° S and shelf-break to 51° W ¹	April-November (June-July) ¹
<i>Thalassarche melanophris</i>	NT	Falklands & South Georgia	27° S to 37° S and shelf-break to 40° W ⁵ ; 27° S to 46° S and shelf-break to 39° W ⁶	March-December (July) ⁵
<i>Thalassarche chlororhynchos</i>	EN	Tristan da Cunha & Gough	22° S to 37° S and shelf-break to 33° W ⁵ ; 22° S to 40° S and shelf-break to 30° W ⁶	May-November (September) ⁵
<i>Thalassarche steadi</i>	NT	Auckland Islands	shelf-break off Uruguay ⁷ and off southern Brazil ⁸	April-November (?) ⁷
<i>Procellaria aequinoctalis</i>	VU	South Georgia	27° S to 37° S and shelf-break to 41° W ⁵ ; 27° S to 42° S and shelf-break to 39° W ⁶	May-November (August) ⁵
<i>Procellaria conspicillata</i>	VU	Tristan da Cunha	27° S to 37° S and shelf-break to 41° W ⁶	April-December (?) ⁶
<i>All seabirds</i>			27° S to 37° S and shelf-break to 28° W ⁹ ; 24° S to 36° S and shelf-break to 42° W ¹⁰	(May-November) ⁹ ; (June-October) ¹⁰ ; (June-November) ¹¹

* <http://www.birdlife.org/datazone/species/search>. 1: Jiménez *et al.*, 2014; 2: this study; 3: Jiménez *et al.*, 2008; 4: Dénes *et al.*, 2007; 5: Jiménez *et al.*, 2010; 6: DINARA, unpublished data; 7: Jiménez *et al.*, 2015; 8: Gianuca *et al.*, 2011; 9: Jiménez *et al.*, 2009; 10: Neves & Olmos, 1998; 11: Bugoni *et al.*, 2008

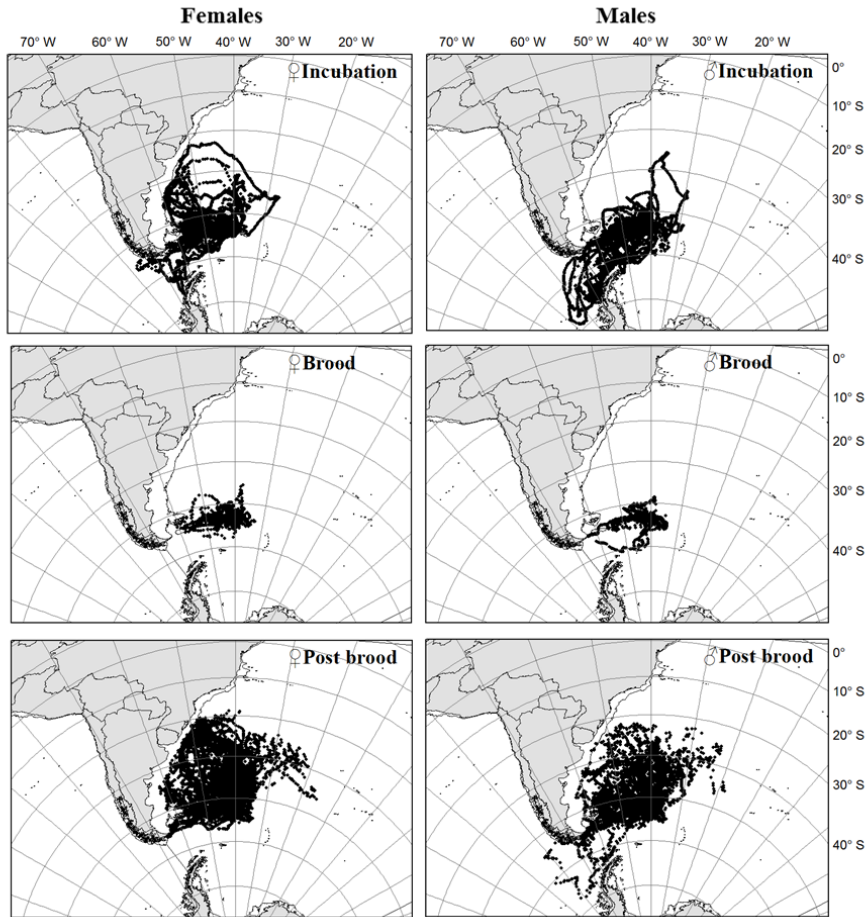


Figure 1. Distribution of breeding female and male wandering albatrosses tracked using satellite-transmitters (PTTs) and GPS loggers from Bird Island, South Georgia, during incubation (1992, 1996, 2004, 2006 and 2012), brood (1991, 1992, 1998, 2000, 2003 and 2004) and post-brood chick-rearing (1990-1992, 1995-2002, 2004, 2006 and 2009) (details about sample sizes in Appendix S1, Table S1). Tracks were linearly interpolated at 30 min intervals. The 200 m isobath is represented by a black line.

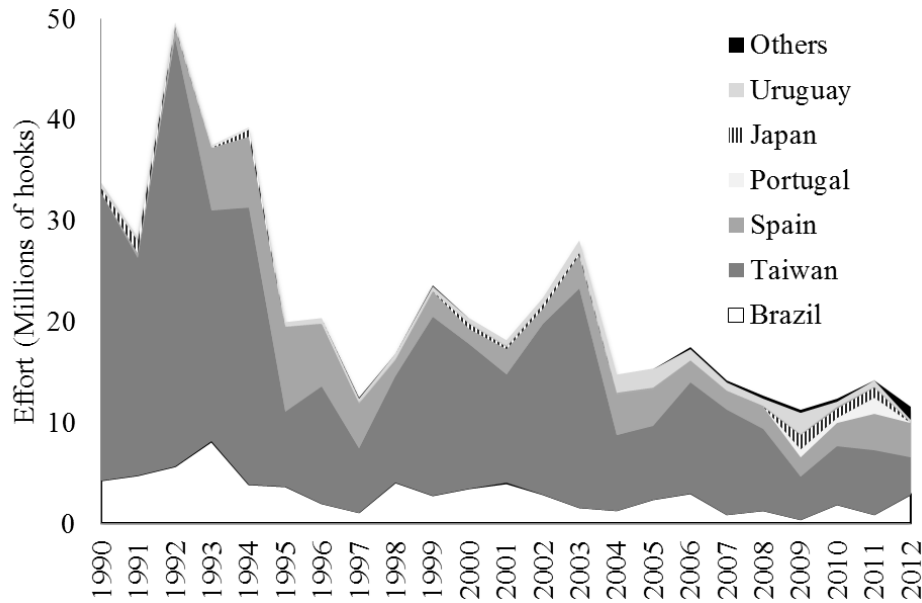


Figure 2. ICCAT fishing effort reported in number of hooks for the southwest Atlantic (south to 25°S and east to 15°W) used by breeding wandering albatrosses tracked from Bird Island, South Georgia in 1990-2012. The category “Others” includes fleets from Belize, St Vincent and Grenadines, Vanuatu, Philippines, Panama, South Korea, China and Namibia (in decreasing order of hooks reported).

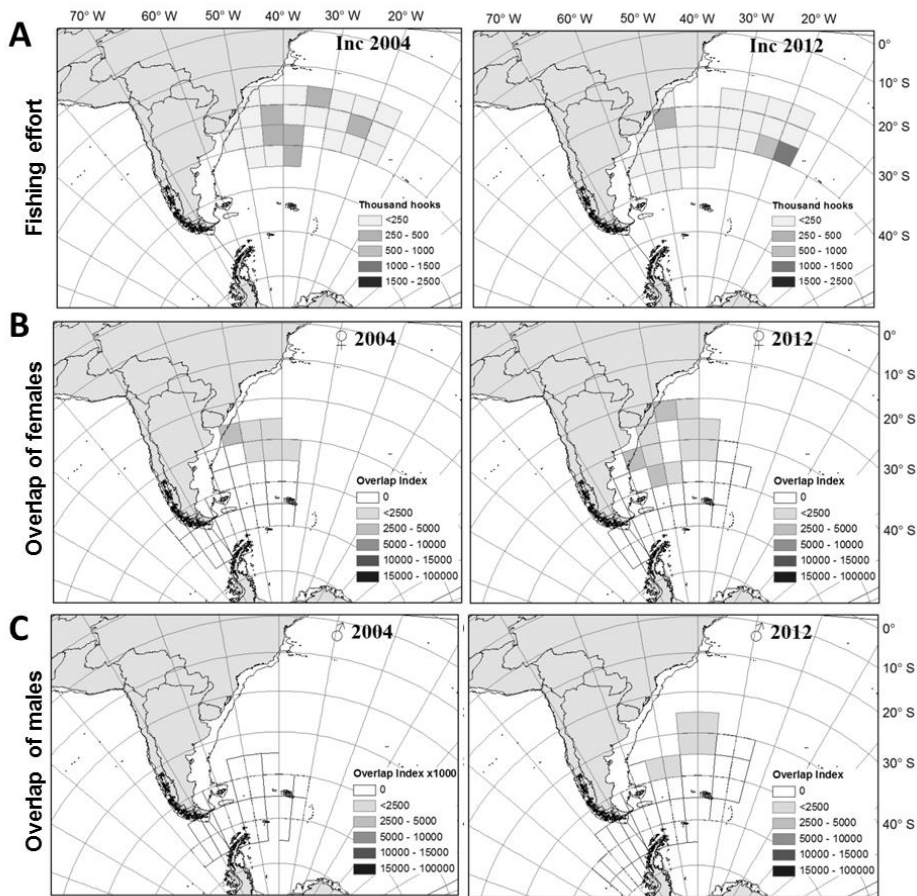


Figure 3. (A) ICCAT longline fishing effort (number of hooks) reported for January-March (corresponding to the incubation period = Inc) and its overlap with the distribution of (B) breeding females and (C) breeding male wandering albatrosses from South Georgia in 2004 and 2012. Overlap index = $\frac{1}{2} \times$ proportion of time spent \times no. of hooks \times N of hooks (see definitions in Methods).

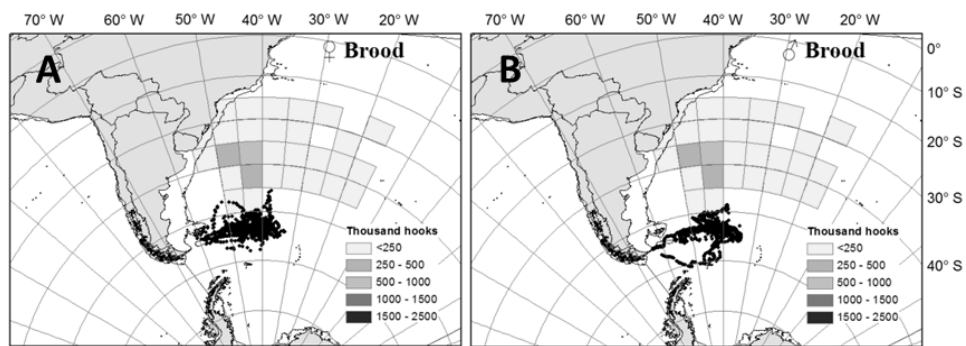


Figure 4. Overlap of breeding male and female wandering albatrosses tracked from South Georgia during brooding, and mean pelagic longline fishing effort (number of hooks) reported to ICCAT for the same period (in 1991, 1992, 1998, 2000, 2003 and 2004).

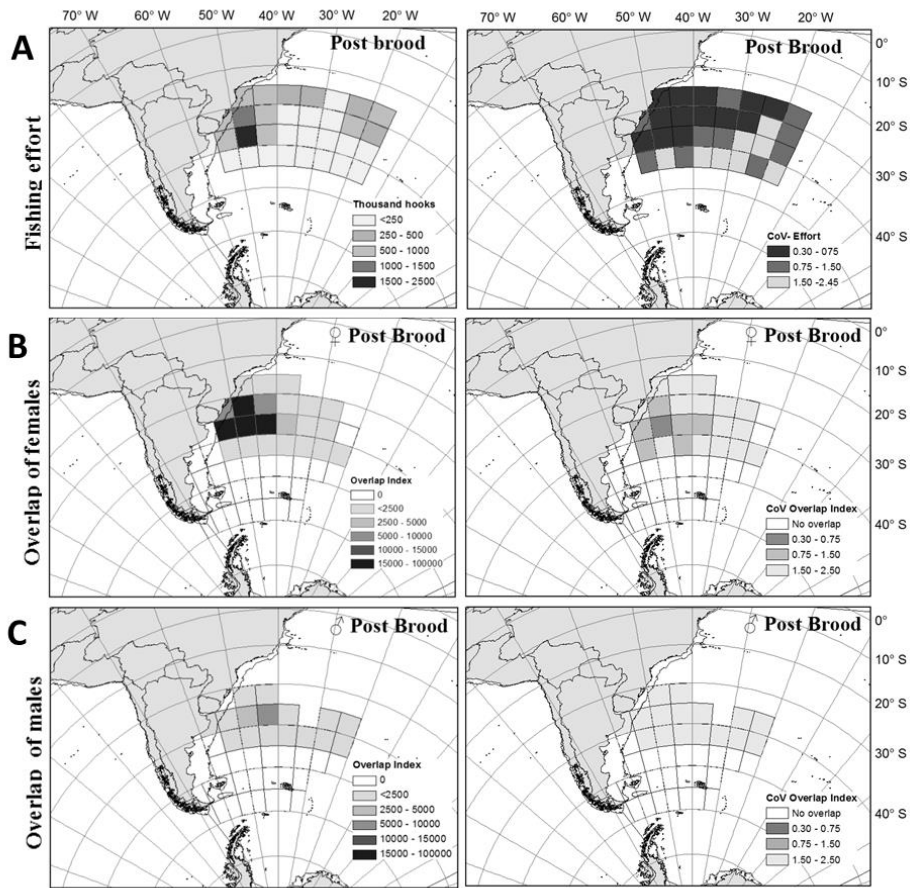


Figure 5. Mean (for 1999, 2000, 2002, 2004, 2006 and 2009) and coefficient of variation (CoV) of (A) ICCAT longline fishing effort (number of hooks) reported for May-December (corresponding to the post-brood chick-rearing period = Post brood) and overlap with the distribution of (B) breeding females and (C) breeding male wandering albatrosses from South Georgia. Overlap index = proportion of time spent * N of hooks (see definitions on Methods and annual overlaps in Appendix S2, Fig S1). In panels showing the CoV, darker cells represent lower variation (i.e. higher inter-annual consistency).

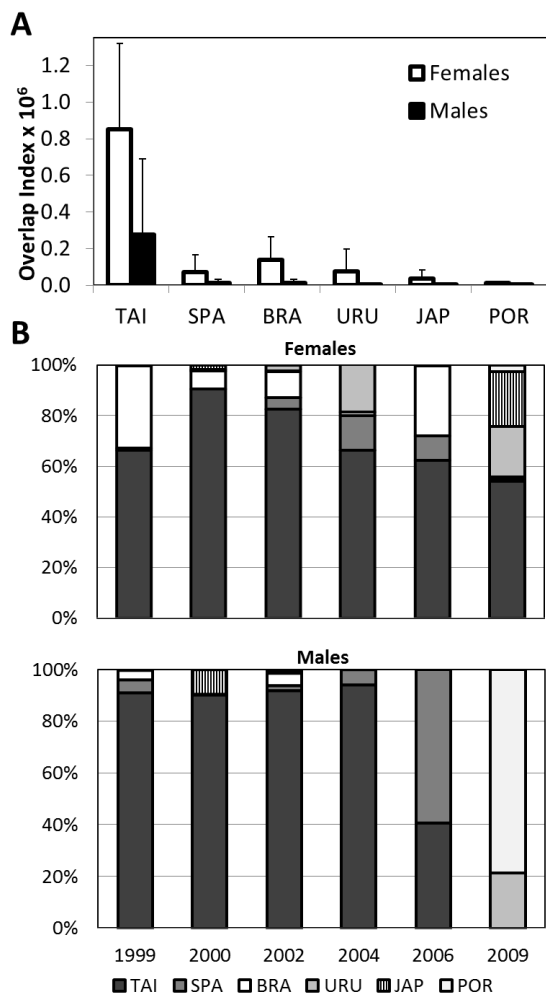


Figure 6. A) Mean (\pm SE) overlap index (proportion of time spent x no. of hooks) for male and female wandering albatrosses during post-brood chick-rearing (May-December) in 1999, 2000, 2002, 2004, 2006 and 2009 with the six main pelagic longline fleets operating in the southwest Atlantic. B) Relative contribution of each longline fleet by year to the overlap index. TAI=Taiwan, SPA=Spain, BRA= Brazil, URU=Uruguay, JAP=Japan and POR=Portugal. Note that the reduced overlap of males with the fleet of Taiwan and increased overlap with the Portuguese fleet in 2009 reflects a shift in the distribution of birds (based on tracking data) rather than in the fishing effort (see Appendix S2, Figs S1, S2 and S7).

The following supplement accompanies the article:

Sex-related variation in the vulnerability of wandering albatrosses to pelagic longline fleets

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Appendix S1. Tracking data and overlap analyses

Breeding cycle and tracking data

On South Georgia, wandering albatrosses lay their eggs in late December. During incubation (ca 72 days), the parents alternate shifts on the egg with foraging trips to sea, which last on average 8-12 days. The egg hatches around mid-March and during the brood period (ca 32 days), parents attend the chick continuously by alternating one to a few days at the nest with foraging trips. The rest of the breeding period (post-brood chick-rearing; hereafter termed chick-rearing) lasts ca 245 days, during which time both parents feed at sea, returning at intervals varying from one day to several weeks to feed the chick, which usually fledges in November (although the range is from late October to January) (Tickell, 2000). Biparental care is maintained at least until shortly before fledging.

Analyses were of data from 263 breeding albatrosses of known age and sex (142 males and 121 females) tracked during 399 complete foraging trips (205 by males and 194 by females) either with Argos satellite-transmitters (Platform Terminal Transmitters or PTTs) from 1990 to 2004 or by global positioning system (GPS) loggers from 2003 to 2012 (Table S1). Birds with PTTs were usually fitted concurrently with a 17 g radio transmitter attached to a plastic band on one tarsus, allowing the exact arrival and departure times to be determined using a remote radio-receiver logger system (Televilt) (Berrow & Croxall, 2001); otherwise, arrival and departure times were estimated from satellite or GPS fixes and visual observations (Phillips *et al.*, 2009). PTTs weighed up to 180 g in the early 1990s (Prince *et al.*, 1992), and 20-30 g in the late 1990s to early 2000s (Phillips *et al.*, 2009; Xavier *et al.*, 2004). GPS loggers weighed between 19.5 g (Ceia *et al.*, 2012) and 68 g (Fukuda *et al.*, 2004). Instrument loads (0.2 to 2.0% of body mass) were well below the threshold where deleterious effects might be expected (Phillips *et al.*, 2003). All satellite-transmitter locations in ARGOS System Location Class 3,2,1,0, A and B were filtered using an iterative forward/backward averaging filter (McConnell *et al.*, 1992) to remove any that indicated unrealistic flight speeds (filter velocity >90 km h⁻¹ to allow for occasional rapid flights) (Phillips

et al., 2009). The mean sampling frequencies for the foraging trips with PTTs and GPS loggers were 122 and 29 minutes, respectively.

Table S1. Number of birds and foraging trips tracked of wandering albatrosses breeding at Bird Island, South Georgia. F= females, M = males. The overlap between breeding stage and fishing effort was restricted to years with at least 8 tracked trips per sex (indicated by numbers in italic and bold). All albatrosses from 1990 to 2002, plus a male in 2004, were equipped with a Platform Terminal Transmitter (PTT); the remaining birds were equipped with Global Positioning System (GPS) loggers.

Year	Breeding stage												Breeding season					
	Incubation				Brood				Post-brood				F	Trips	M	Trips	Birds	Trips
	F	Trips	M	Trips	F	Trips	M	Trips	F	Trips	M	Trips						
1990		-		-		-		-	1	3	1	2	1	3	1	2	2	5
1991		-		-	4	9	4	5	4	5	8	15	6*	14	8*	20	14	34
1992	3	3	2	2	2	5	3	4	1	2	2	2	6	10	7	8	13	18
1995		-		-		-		-		-	1	1	0	0	1	1	1	1
1996		-		-		-		-	1	2	1	3	1	2	1	3	2	5
1997		-		-		-		-		-	2	3	0	0	2	3	2	3
1998	4	4	3	3	8	9	9	9	2	4	4	11	14	17	14*	23	28	40
1999		-		-		-		-	9	10	9	9	9	10	9	9	18	19
2000		-		-	4	4	5	5	10	13	10	11	14	17	15	16	29	33
2001		-		-		-		-	1	1			1	1	0	0	1	1
2002		-		-		-		-	13	24	13	24	13	24	13	24	26	48
2003		-		-	8	8	16	16		-			8	8	16	16	24	24
2004	7	8	8	8	8	10	8	9	9	15	10	12	24	33	26	29	50	62
2006	1	1	1	1		-		-	8	23	4	15	9	24	5	16	14	40
2009		-		-		-		-	14	14	13	13	14	14	13	13	27	27
2012	15	17	20	22		-		-		-			15	17	20	22	35	39
Total	30	33	34	36	34	45	45	48	65*	116	73*	121	121*	194	142*	205	263*	399

*Note that in some cases the total number of tracked birds do not match the sum of the annual number of birds tracked as a few birds were tracked in two or three years. Similarly, in few cases, birds were tracked in two breeding stages in the same year.

Overlap with longline fishing effort

We used the proportion of time spent per unit area (days per each 5x5° cell) for each breeding stage, after linear interpolation of PTT or GPS locations on each foraging trip at 30 min intervals using the R package *trip* version 1.1-10 (Sumner, 2011) as the albatross density metric to overlap with fishing effort distribution. Because only half of the breeding birds are at sea during incubation and brood, the proportions calculated as above should be divided by 2. However, wandering albatross distribution overlaps very little with pelagic longline fisheries during brood (see Results), and therefore this correction was only applied for incubation. Pelagic longline fishing effort for the southwest Atlantic (number of hooks at 1x1° and 5x5° cells, by month) was obtained from the International Commission for the Conservation of Atlantic Tunas (ICCAT) available at <http://iccat.int/en/accesingdb.htm>. To quantify bird-fisheries overlap, the albatross density metric was multiplied by the number of hooks (Tuck *et al.*, 2011). This produces an overlap index which accounts for the proportion of time spent by the females / males in a given breeding stage and the potential number of hooks which may be encountered in a given cell. Because we were concerned with differences between males and females within each breeding stage, it was not necessary to account for the unequal duration of each stage.

Factors affecting overlap and contribution by the main fleets during chick-rearing

For each year, we estimated the total fishing effort (number of hooks) deployed in those 5x5° cells used by each sex during chick-rearing, which was multiplied by the sum of the albatross density metric (see above) to produce an overall index of overlap with the ICCAT pelagic longline fishery (hereafter termed “ICCAT overlap index”). This produced 12 separate index values (six for each sex). This analysis was then repeated for each longline fleet of the main ICCAT flag states in the study area, obtaining for each year as many overlap index values as fleets (hereafter termed “fleet overlap index”), multiplied by two (males and females), and resulting in 54 overlap index values (44 distinct from zero, with Portugal excluded; see below). This allows estimation of the percentage contribution of each fleet to the overall overlap with males and females in chick-rearing. Note that the ICCAT and fleet overlap indices are for the southwest Atlantic sector used by wandering albatrosses, but do not account for the spatial variation. Therefore, another dataset was constructed with all the possible overlap index values for the principal fleets at 5x5° cells, by sex and year. Excluding cells not used by either sex, there were 1776 values for the overlap index, of which 210 were distinct from zero. Only four fleets (Brazil, Spain, Taiwan and Uruguay; see Results) operated in all six years of the study; however, the Japanese and Portuguese fleets showed considerable overlap with tracked wandering albatrosses in three or one of the six years, respectively. The Japanese fleet was included in all analyses, whereas that of Portugal was sometimes excluded to fit models.

The effect of the categorical variable, sex, on the ICCAT overlap index was analyzed using a Linear Model (LM). Additionally, the effects of sex, year and fleet on overlap during chick-rearing were analyzed using Generalized Linear Models (GLM) for the dataset of fleet overlap index and for the other dataset at 5x5° cells. Both datasets showed a strongly skewed distribution (particularly the second dataset, with 88% zero values). Best fit in both cases included a two-step analysis: 1) the occurrence of overlap was modeled using a GLM with a logit link function, assuming a binomial distribution; then 2) Overlap Index values different from zero were modeled using GLM assuming a Gaussian error distribution, with a canonical identity link function. The response variable (overlap index) was natural log (ln) transformed. For the dataset of fleet overlap index, only the categorical variable sex was included in the binomial sub-component, and sex, year and fleet in the Gaussian sub-component. However, in the largest dataset at 5x5° scale, the categorical variables sex, year and fleet, and the first order interactions between sex and fleet and sex and year were included in both binomial and Gaussian models. Additionally, we included latitude and longitude (at the centre of each 5x5° cell) as continuous variables. The best model was selected using AIC with a forward selection algorithm using R's default AIC statistics via the step function. Deviance analyses were used to test the significance (χ^2 test) of each explanatory factor and first order interaction. Additionally, the percent of deviance explained by each factor and first order interactions with respect to the total deviance of our resulting final model was estimated.

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Appendix S2. Overlap distributions of wandering albatross with pelagic longline fishing effort during the post-brood chick-rearing period.

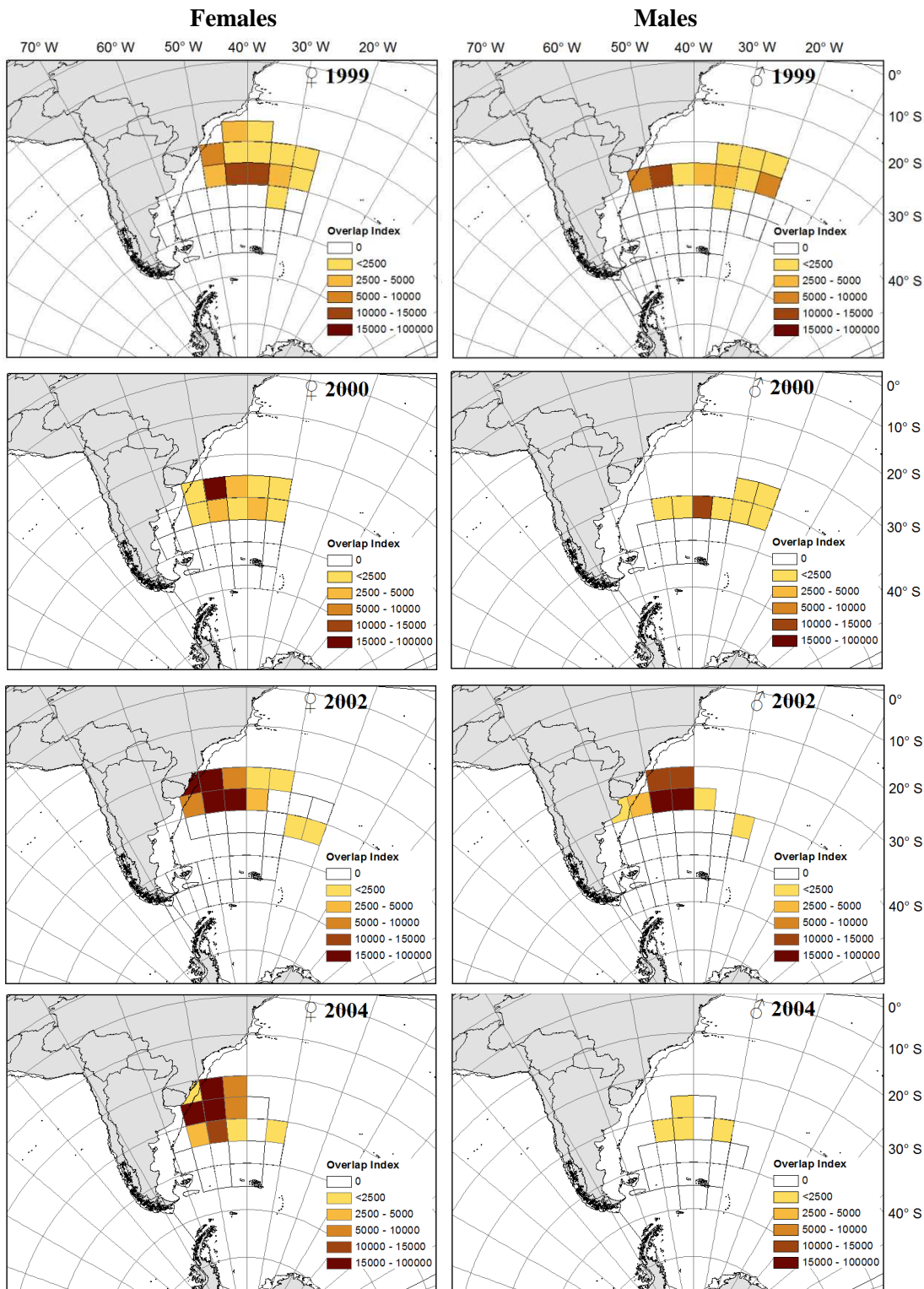


Figure S1. Overlap distributions of breeding females and males of wandering albatross with ICCAT pelagic longline fishing effort during the post-brood chick-rearing period.

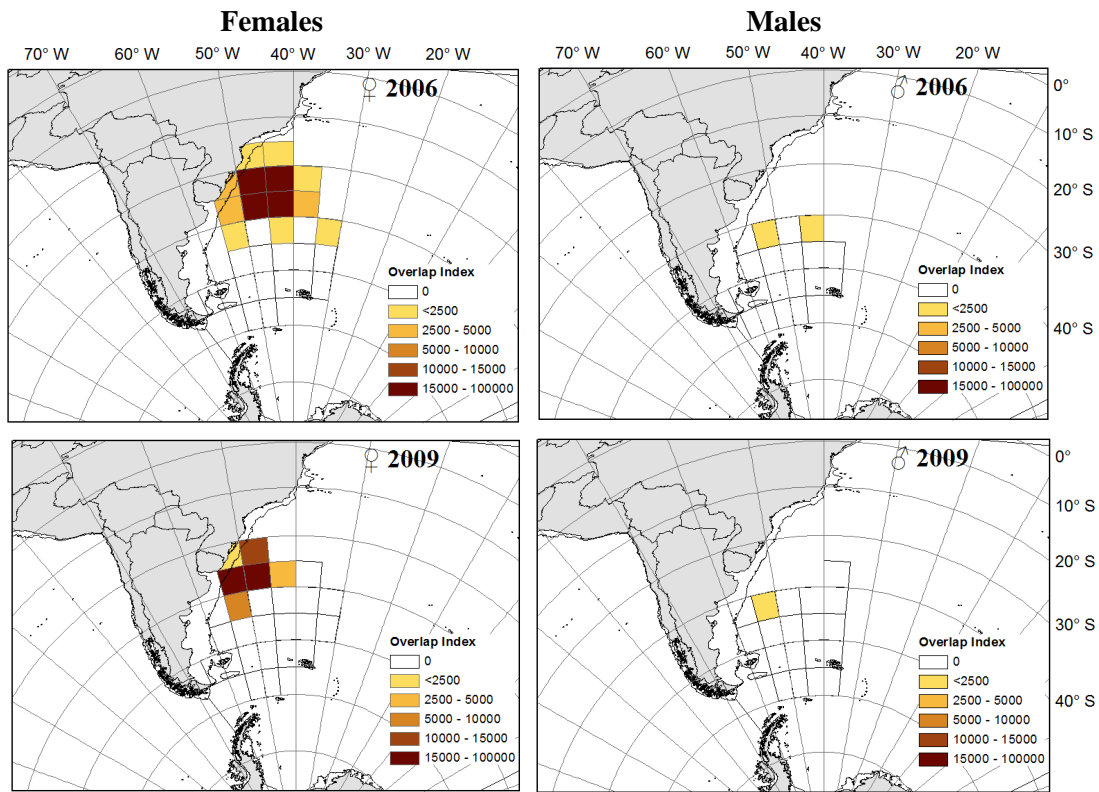


Figure S1. (continued).

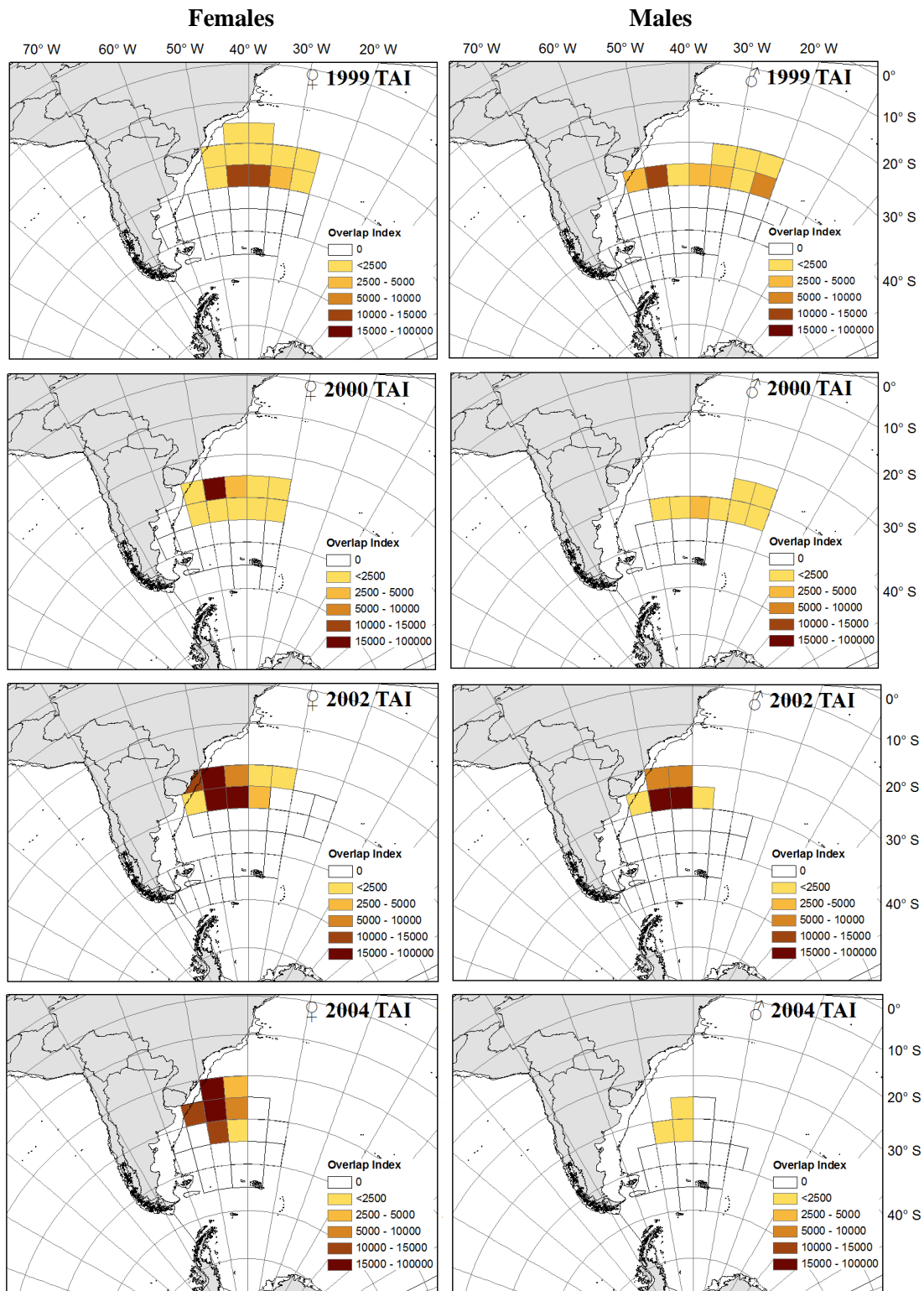


Figure S2. Overlap distributions of breeding females and males of wandering albatross with the reported pelagic longline fishing effort of Taiwan (TAI) the post-brood chick-rearing period.

Males

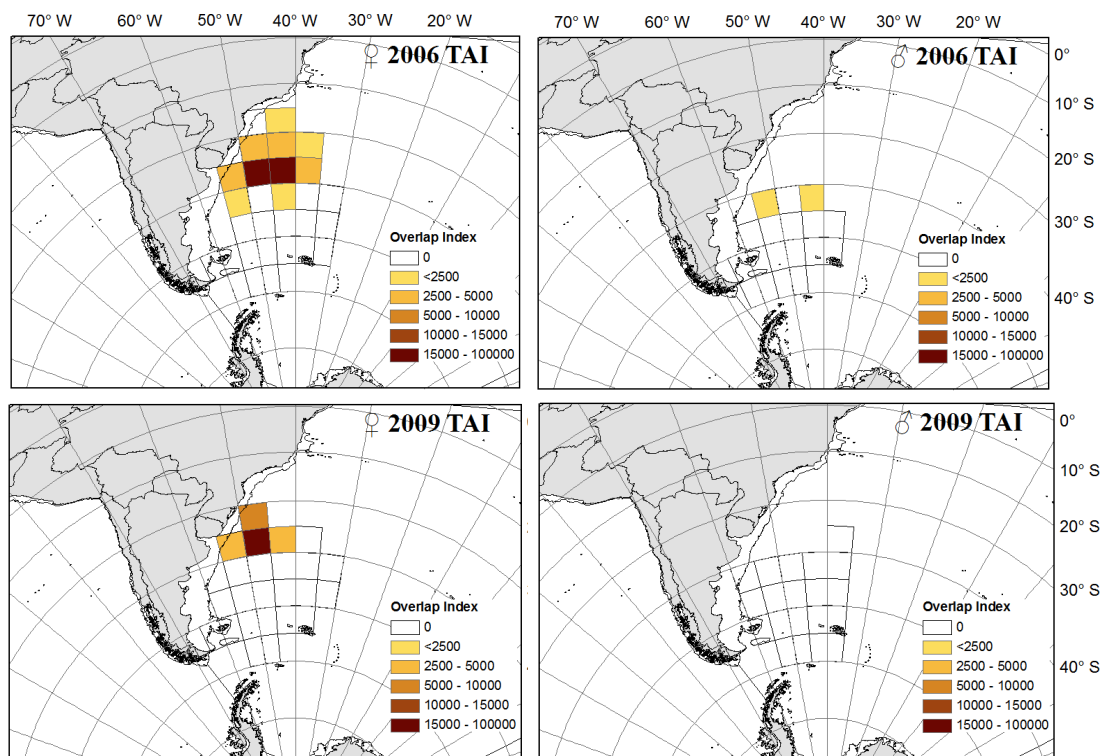


Figure S2. (continued).

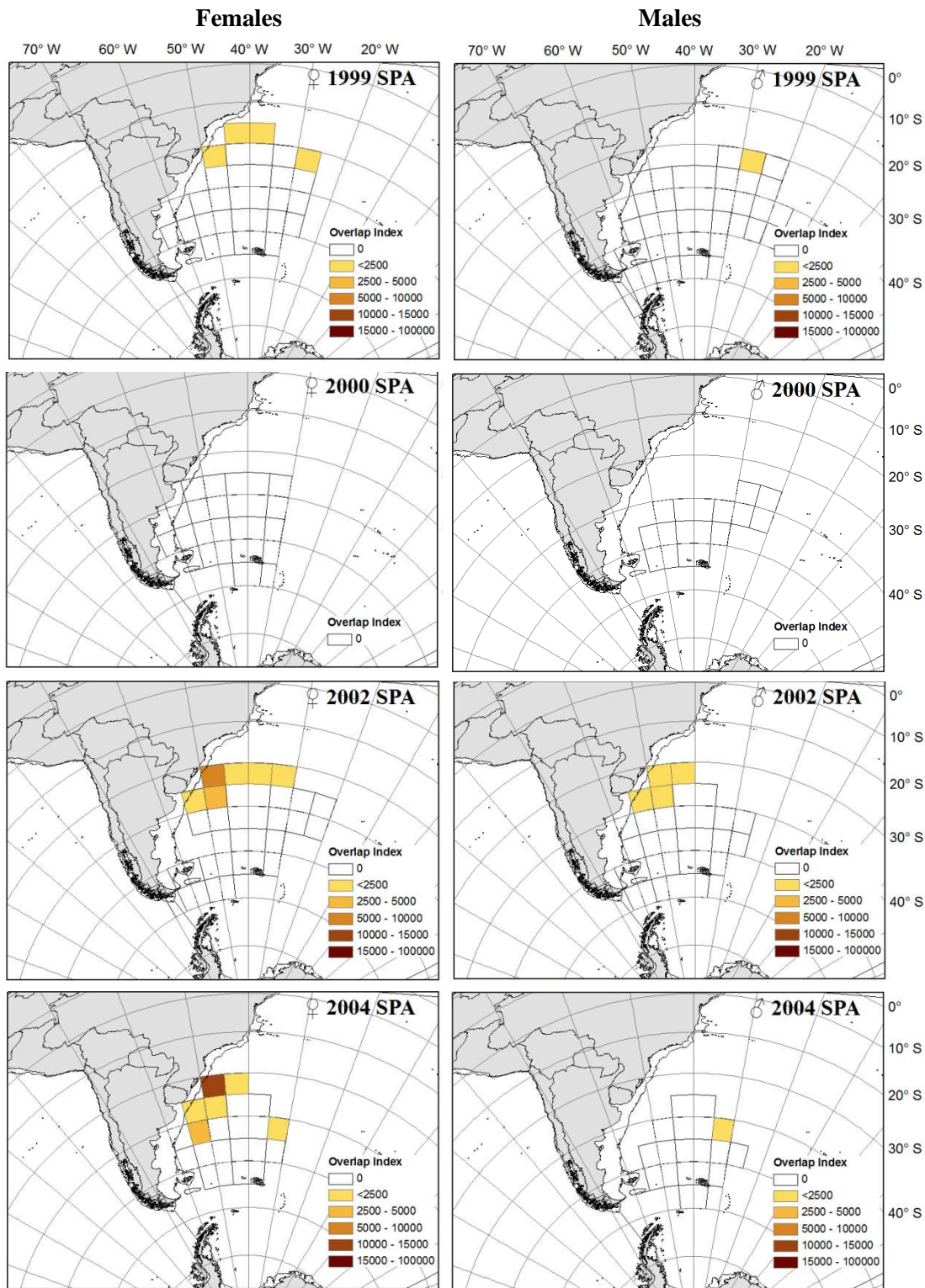


Figure S3. Overlap distributions of breeding females and males of wandering albatross with the reported pelagic longline fishing effort of Spain (SPA) during the post-brood chick-rearing period.

Males

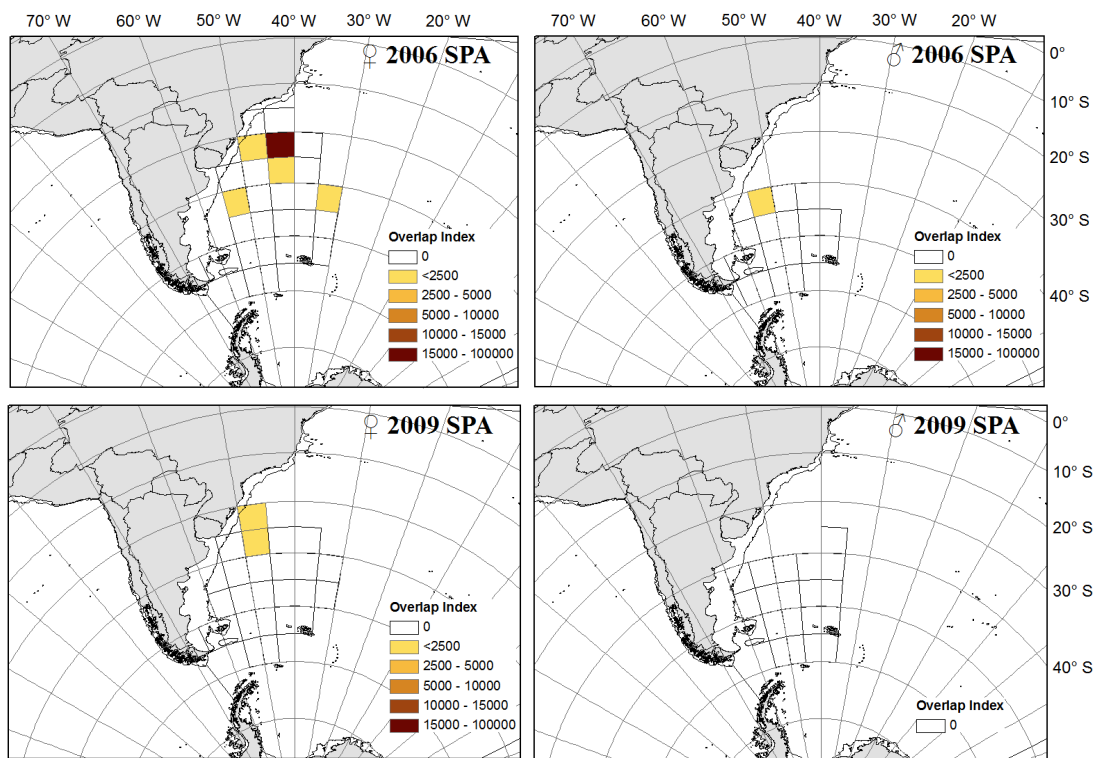


Figure S3. (continued).

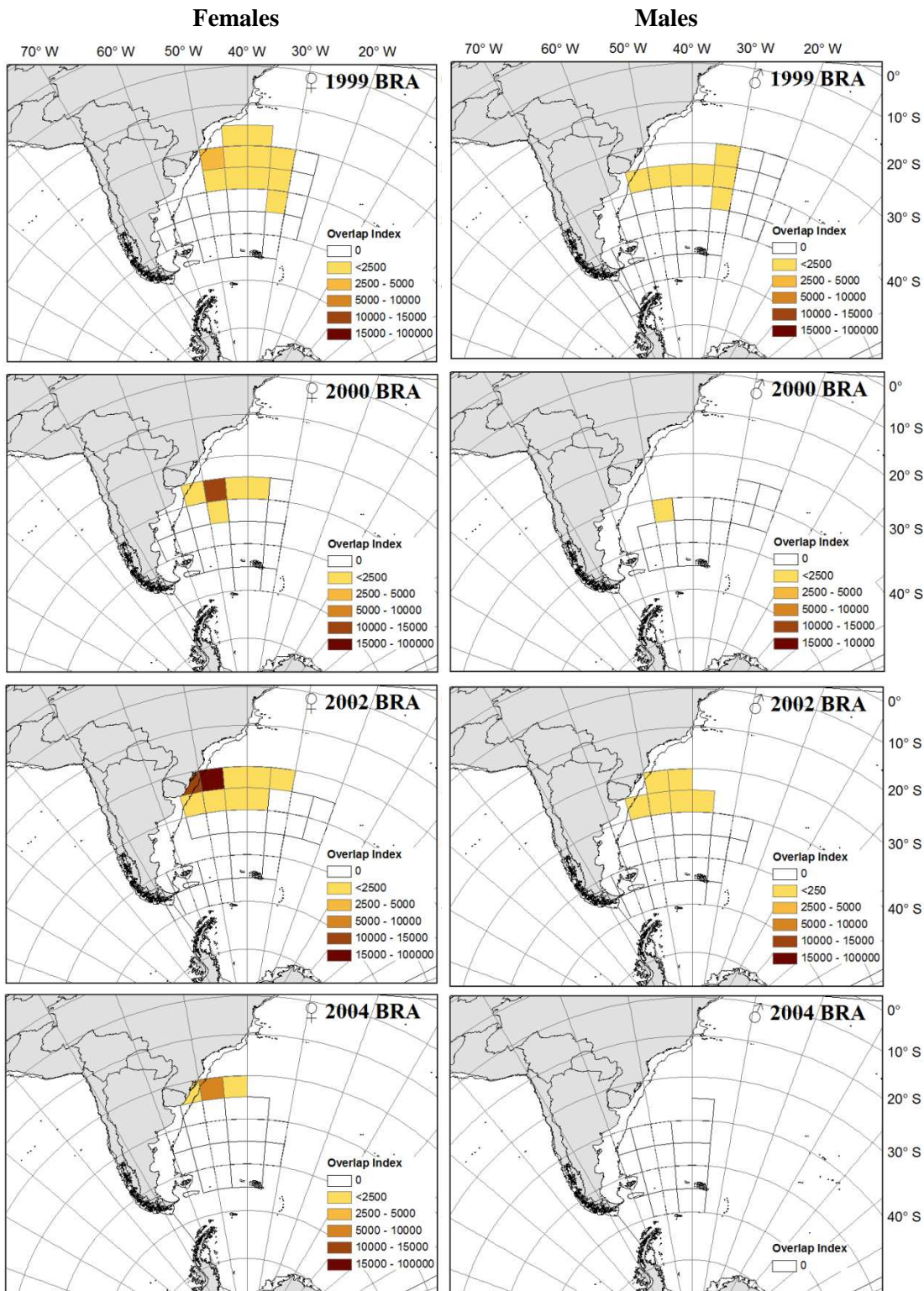


Figure S4. Overlap distributions of breeding females and males of wandering albatross with the reported pelagic longline fishing effort of Brazil (BRA) the post-brood chick-rearing period.

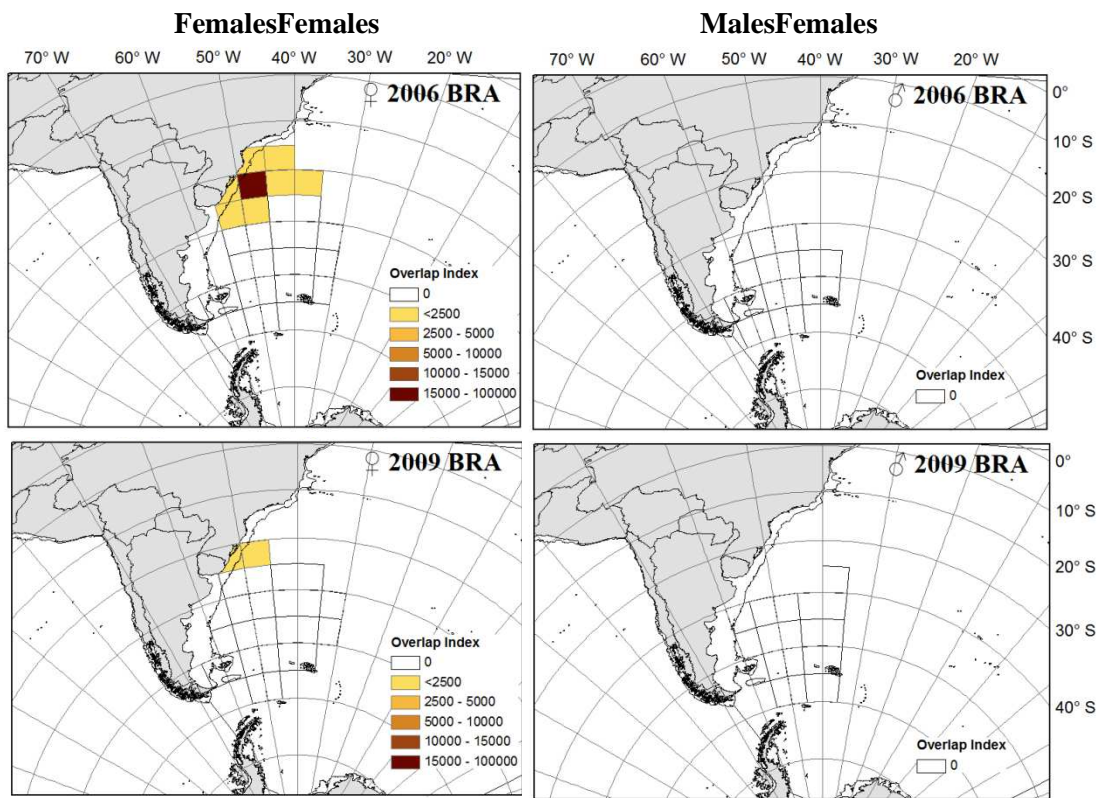


Figure S4. (continued).

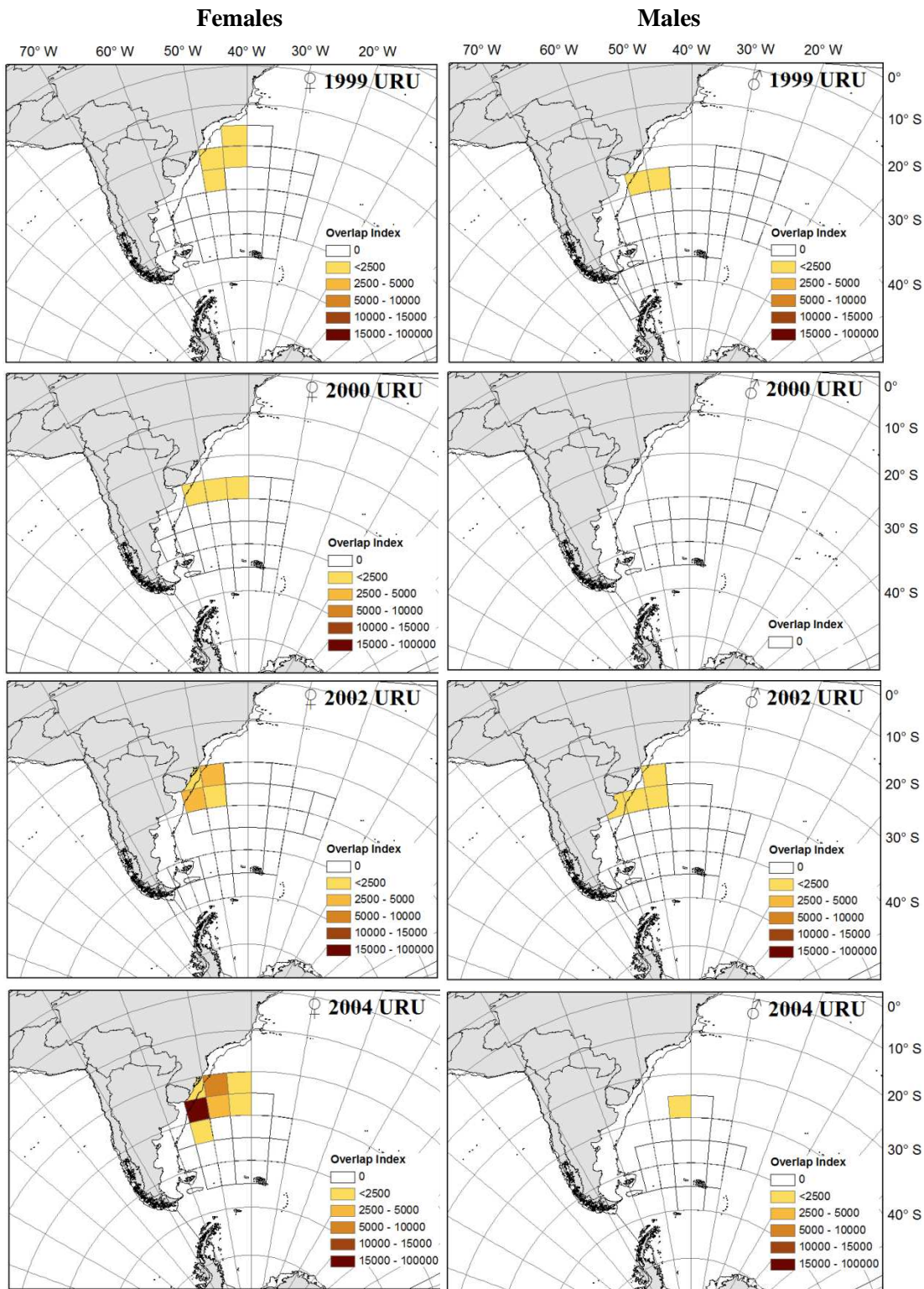


Figure S5. Overlap distributions of breeding females and males of wandering albatross with the reported pelagic longline fishing effort of Uruguay (URU) during the post-brood chick-rearing period.

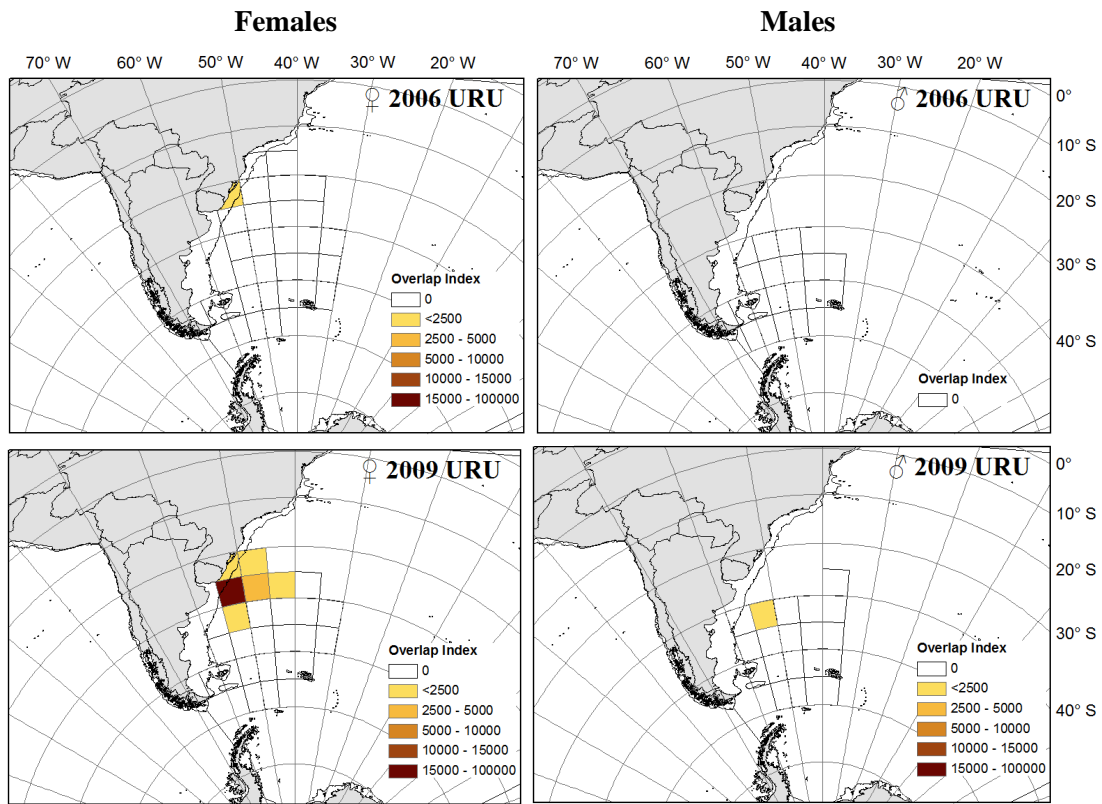


Figure S5. (continued).

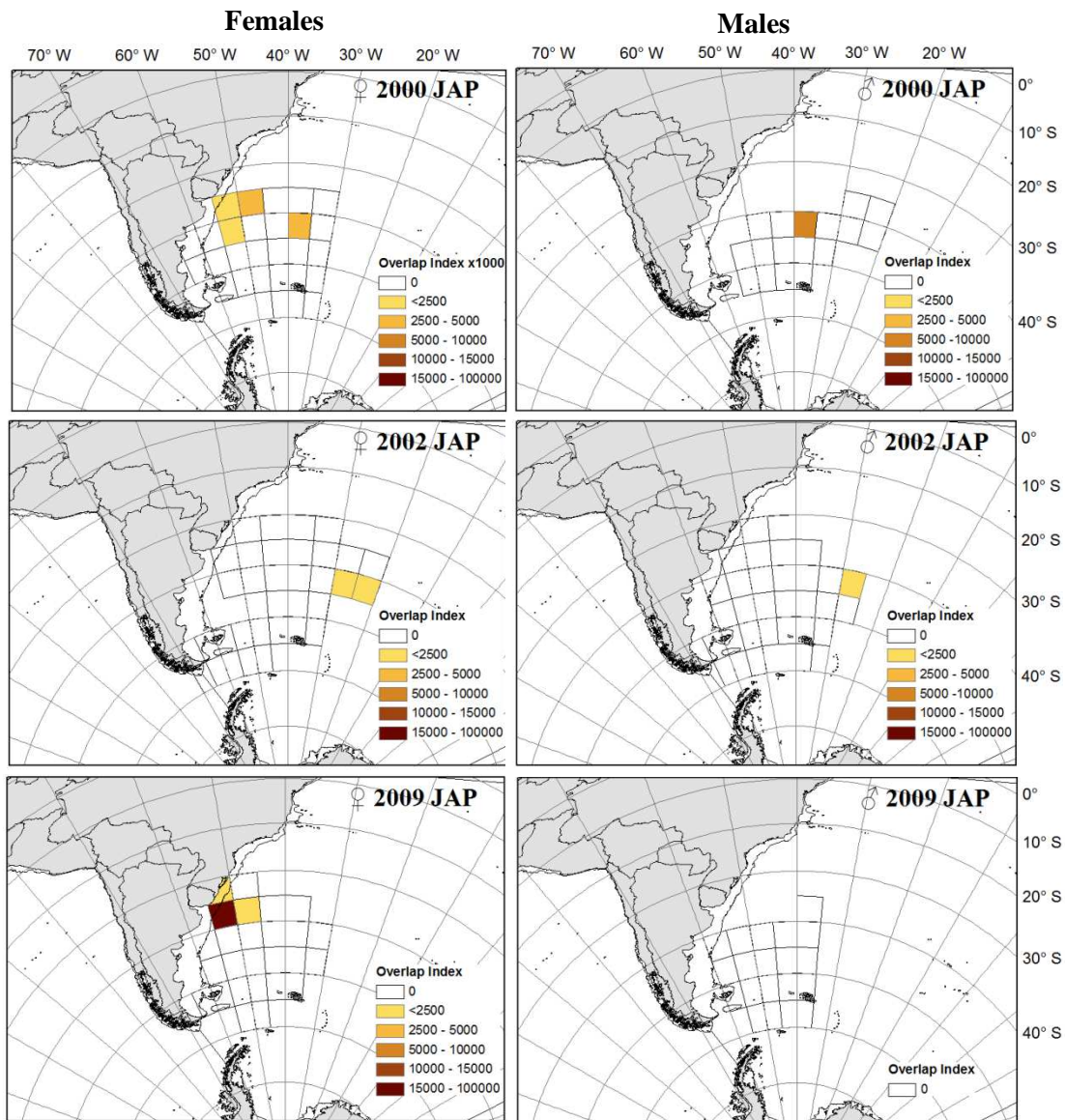


Figure S6. Overlap distributions of breeding females and males of wandering albatross with the reported pelagic longline fishing effort of Japan (JAP) during the post-brood chick-rearing period.

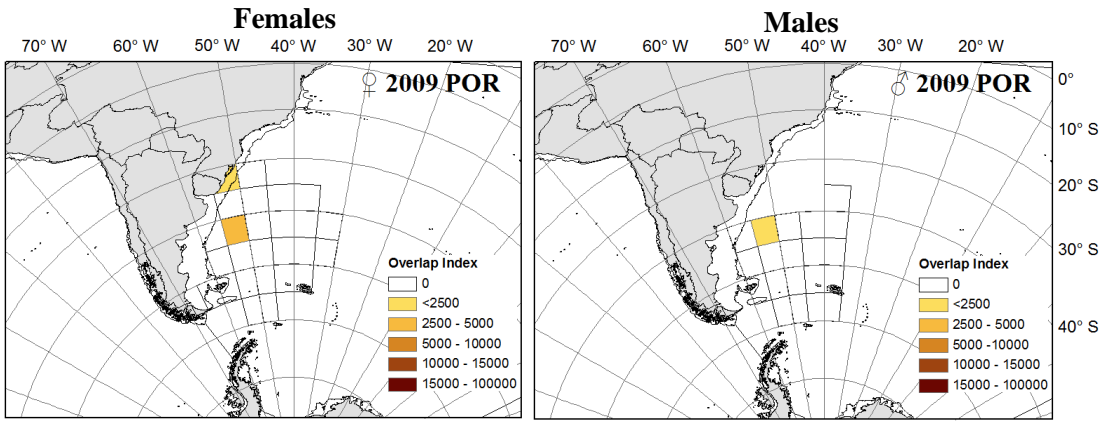


Figure S7. Overlap distributions of breeding females and males of wandering albatross with the reported pelagic longline fishing effort of Portugal (POR) during the post-brood chick-rearing period.

Appendix S3. Distribution of the ringed birds reported dead on longliners in the southwest Atlantic

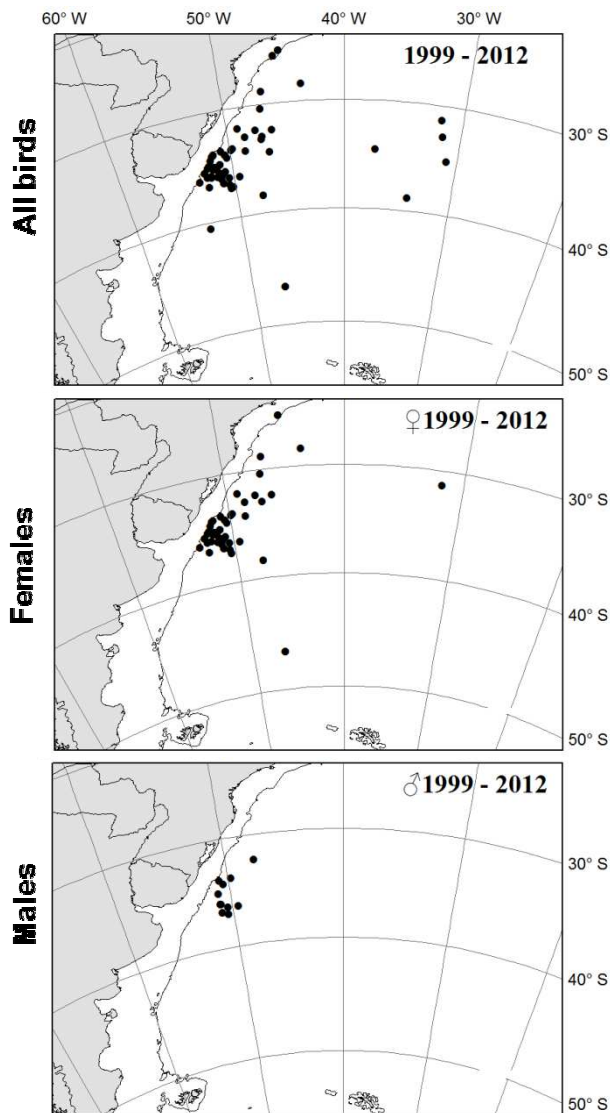


Figure S8. Distribution of the ringed birds reported dead on longliners in the southwest Atlantic region where pelagic longline fishing is regulated by ICCAT.

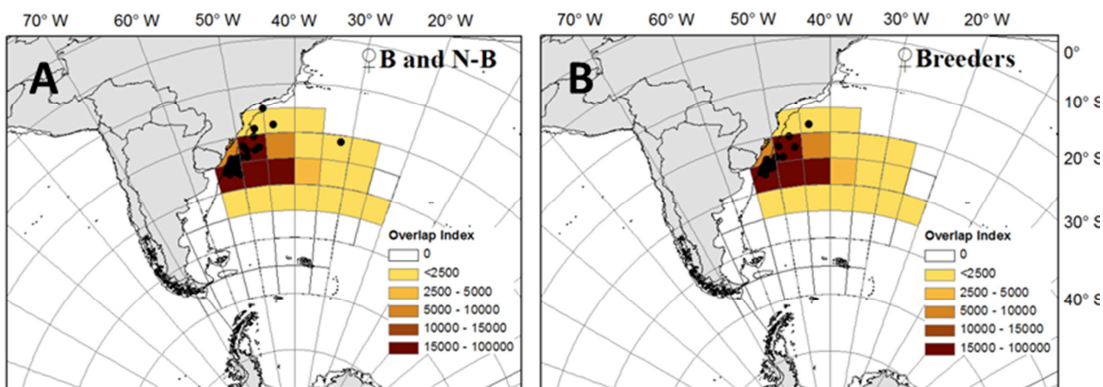


Figure S9. Mean overlap index (1999-2009) for post-brooding females (see details on Fig. 5 of the main text) and distribution of the ringed adult females reported killed on longliners (1999-2012) in the southwest Atlantic region regulated by ICCAT during May-December (corresponding to the post-brood chick-rearing period). (A) Recoveries of breeders and non-breeders (B and N-B). (B) Recoveries of breeders.