Bycatch of great albatrosses in pelagic longline fisheries in the southwest Atlantic: contributing factors and implications for management

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ABSTRACT

Pelagic longline fisheries in the southwest Atlantic are a major conservation concern for several threatened seabirds, including four species of great albatrosses: wandering albatross (*Diomedea exulans*), Tristan albatross (*D. dabbenena*), southern royal albatross (*D. epomophora*) and northern royal albatross (*D. sanfordi*). The aim of this study was to examine the spatial and temporal variation in bycatch rates of these species, and to identify the contributing environmental and operational factors. We used data collected by observers on board pelagic longliners in the Uruguayan fleet in 2004-2011, and on Japanese vessels operating in Uruguay under an experimental fishing license in 2009-2011. Bycatch rates for northern and southern royal albatrosses were higher than expected based on previous reports, particularly over the shelf break. Wandering and Tristan albatrosses were caught predominantly in pelagic waters, where there are numerous fishing fleets from other flag states. Bycatch of great albatrosses was highest in April-November, with the peak for royal albatrosses in June-July, and for wandering and Tristan albatrosses in September-November. A range of vessel operational practices and habitat variables affected bycatch rates, among which setting time, moon phase, area and season are useful in terms of risk assessment, and in the development and improvement of conservation measures for these highly threatened species.

Keywords: Incidental mortality, Fisheries Impacts, Non-target species, Seabirds, Fishery Management

1. Introduction

Incidental mortality (bycatch) in fisheries is one of the major threats facing many populations of seabirds (Croxall et al., 2012; Žydelis et al., 2013). The global extent of seabird bycatch in commercial longline fisheries alone is likely to be at least 160,000 birds per year (Anderson et al., 2011). A high proportion of this bycatch is albatrosses (family Diomedeidae) (Brothers, 1991; Anderson et al., 2011). Particularly in the southwest Atlantic, pelagic longline fisheries appear to be a major conservation problem for several species, including great albatrosses (*Diomedea* spp.) (Jiménez et al., 2009a, 2012a). Although captured in very low numbers (Bugoni et al., 2008; Jiménez et al., 2009a, 2010), the great albatrosses originate from small breeding populations and, given these are biennially breeding species, the naturally low productivity means there is limited capacity for recovery following depletion (Croxall and Gales 1998).

The great albatrosses caught incidentally by the pelagic longline fishery in the southwest Atlantic include wandering albatrosses from the South Georgia population (*Diomedea exulans*), Tristan albatrosses (*D. dabbenena*) that are endemic to Gough Island, and southern royal albatross (*D. epomophora*) and northern royal albatross (*D. sanfordi*) from New Zealand (Jiménez et al., 2012a). These are all globally threatened according to the World Conservation Union (IUCN) (http://www.birdlife.org/datazone/home). The first two populations number ca. 1500 breeding pairs each year, and are declining dramatically because of incidental capture in longline fisheries (Croxall et al., 1998; Poncet et al., 2006), exacerbated for the Tristan albatross by predation of chicks by invasive mammals (Cuthbert et al., 2004; Cuthbert and Hilton, 2004; Wanless et al., 2007, 2009). The population trend for northern royal albatross in the Chatham Islands is unknown, and southern royal albatrosses at Campbell Island appear to be stable (ACAP, 2009a; 2009b). Birds breeding at these two archipelagos account for > 99% of the respective global populations (ca. 5,800 and 7,800 annual breeding pairs, respectively; ACAP, 2009a and ACAP, 2009b). Despite the parlous conservation status of these four species and the potentially major impact of pelagic longline fishing, very little attention has been directed at understanding the factors that make the great albatrosses susceptible to fisheries interaction. Even the overall bycatch rates are uncertain because these species are caught in low numbers, only a small proportion of fishing effort is observed, bycatch rates vary a great deal by fleet, vessel, season, location, time of day etc., and very often *Diomedea* albatrosses are not identified to species level (Jiménez et al., 2009a).

Because of the patchy nature of the marine resources upon which albatrosses depend, they should disproportionally target particular habitats or suites of environmental conditions where prey are more abundant or predictable (Pinaud and Weimerskirch 2005; Wakefield et al., 2009; 2011; Louzao et al., 2011). Such areas are usually highly productive and as a result are often exploited by commercial fisheries. Seabirds are opportunistic foragers, and so are attracted to discards provided by fishing vessels (Tasker et al., 2000; Furness, 2003). An overlap between the distributions of fishing effort and seabirds is an obvious prerequisite for bycatch; however, broad-scale spatio-temporal overlap does not necessarily indicate interaction, as not all birds follow vessels (Granadeiro et al., 2009; Torres et al., 2013), and those that do will only be injured or killed if they have a close encounter with fishing gear, which in longline fisheries involves access to baited hooks (Jiménez et al., 2012a). Great albatrosses can dive to <1 m (Prince et al. 1994), and so on their own can only access baited hooks at the sea surface. However, they easily and routinely displace smaller species, and so the risk of bycatch is much greater where they co-occur with petrels and *Thalassarche* albatrosses that can reach hooks at greater depths and return them to the surface (Brothers 1991; Jiménez et al., 2012b).

Past studies indicate that a number of aspects of fishing operations, including time of setting in relation to daylight, twilight and moon phase, and the use of mitigation measures, influence access to baited hooks and hence the bird bycatch rate (Brothers 1991; Brothers et al., 1999; Jiménez et al., 2009a; Trebilco et al., 2010). In addition, particular environmental conditions may lead to aggregation of birds around vessels, increasing the likelihood of interaction. These factors presumably explain some of the high inter-specific variation in susceptibility to bycatch. Identifying such factors could be useful for preventing seabird bycatch, by highlighting specific areas and operations where mitigation needs to be particularly effective. Within this framework, and given the broad similarity in the behaviour of great albatross species around vessels, we hypothesized that operational variables affect their bycatch likelihoods in a similar way. On the other hand, environmental variables could lead to differences in bycatch rates because of species-specific preference for particular habitats, which is likely to affect the relative overlap of birds with fisheries operations and potentially increase the likelihood of bird-vessel interactions (see Table 1). These species show some degree of inter-specific niche partitioning, particularly in the relative preference for foraging over continental shelves, shelf-slope or deep waters (Nicholls et al., 2002; Xavier et al., 2004; Cuthbert et al., 2005; Reid et al., 2013). In addition, the northern and southern royal albatrosses occurring in the southwest Atlantic are migrants from New Zealand, whereas the wandering and Tristan albatrosses include both breeding and nonbreeding birds, with the relative proportions depending on the time of year. Therefore, bycatch rates are likely to be temporally and spatially heterogeneous. Here, we used the largest data set available on the incidental capture of great albatrosses in pelagic longline fisheries in the southwest Atlantic, including information on specimens collected for further examination, to determine the spatial and temporal variation in bycatch rates of each species, and the contributing environmental and operational variables. The results are discussed in the context of developing effective strategies for mitigating bycatch of these highly threatened species.

2. Methods

2.1. Fishery and study area

The analyses were of observer data from the "Programa Nacional de Observadores a bordo de la flota atunera uruguaya" (PNOFA) of the "Dirección Nacional de Recursos Acuáticos" (DINARA), collected on board Uruguayan pelagic longline vessels in 2004-2011, and on Japanese vessels operating in Uruguay under an experimental fishing license in 2009-2011 (see Appendix A for details). The Uruguayan pelagic longline fleet targets swordfish (*Xiphias gladius*), yellow-fin tuna (*Thunnus albacares*), bigeye tuna (*T. obesus*), albacore (*T. alalunga*), and pelagic sharks (mainly *Prionace glauca*). Most of these vessels (20-37m length) employed an American-style longline (monofilament mainline), and the remainder (two freezer vessels) used a Spanish-style longline (multifilament mainline). Both types of fishing gear are described in Jiménez et al. (2009a) and Domingo et al. (2012). The hook depth during soak time rarely exceeds 80 m for the Uruguayan vessels (DINARA unpublished data). During the study period the fishing area encompassed between 19-47ºS and 20-60ºW (Fig. 1). Vessels using American-style longlines operated mainly in Uruguayan waters (92% of sets), and those using Spanish-style longlines mostly (91% of sets) in deeper, international waters (Appendix A). The Japanese vessels (48-52 m length) targeted bigeye tuna and albacore with a Japanese-style longline (see Domingo et al. 2011a). The fishing area was between 34-37ºS and 49-54ºW, and vessels concentrated their effort in Uruguayan waters (99.1% of the sets) near the shelf break (Fig. 2, Appendix A). The average hook depth for Japanese vessels was 133m (range = 75-210m; Miller et al., 2012). The main oceanographic influence on the region is the confluence of the Brazil and Malvinas currents, which includes complex frontal systems and the simultaneous presence of warm and cold eddies (Olson et al., 1988; Acha et al., 2004; Ortega and Martínez, 2007).

2.2. Fishing operations

During the study period, longline vessels operating in Uruguay were required to use a single tori (streamer or bird-scaring) line and night setting as seabird mitigation measures; however, implementation took several years (see below). There were no regulations regarding the use of weighted branch lines (a minimum weight within a specified distance from the hook).

In the Uruguayan fleet, the longline is set over the stern, usually around sunset, and setting is generally completed before midnight. A single tori line was first used as a seabird bycatch mitigation measure in 2008, and by 2010 all the trips with observers used tori lines. During the study period, the longline set effort varied between 400 and 2000 hooks (mean = 1117 hooks, SD = 299 hooks) for American longlines, and between 360 and 3740 hooks (mean = 2570 hooks, SD = 647 hooks) for Spanish longlines. The mean distance between the start and end locations of the longline set involving these gear types was 46.9 km (SD= 15.7 km, range 0-94.3 km) and 68.9 Km (SD= 21.5 km, range 8.0-135.3 km), respectively. The baits were squid (*Illex argentinus*) or mackerel (*Scomber* spp., *Trachurus* spp.) thawed a few hours before line setting, and occasionally shark belly.

On Japanese vessels the longline was set over the stern, mainly after midnight, and the set completed before sunrise. Night setting was practiced to reduce seabird bycatch, with the exception of the initial fishing period from March to late April 2009 when some sets were in daylight, and the occasional set thereafter that began during darkness and was not completed until after sunrise. Japanese vessels used tori lines on all trips; however, the original design was replaced by the Uruguayan style (see below) on 31 April 2009. In total, 1000 to 3360 hooks were set per day (mean ± SD = 2329 ± 275 hooks). The mean distance between the start and end of the set was 71.0 km (SD= 14.8 km, range 9.4-116.0 km). The baits were squid, mackerel and other small pelagic fishes (*Sardinops sagax*, *Decapterus macrosoma*), usually mixed along the same set.

2.3. Observer data

A total of 1599 sets and 3,311,113 hooks were observed during 81 commercial fishing trips by Uruguayan vessels from January 2004 to November 2011 (Appendix A). The temporal distribution of the observed fishing effort for the period 2004-2007 is detailed in Jiménez et al. (2010). Data were available from all months except November and December 2004. Additionally, observer data from two trips in 2007 were included, one in June-August and another in September-November. In the later years (2008-

2011), data were available for all months except January and February in 2008, February and October in 2009, January, February and May-July in 2010, and March-April, June, August and December 2011. Over the entire study period, observed effort was 989,881 hooks, 833,925 hooks, 993,254 hooks and 494,043 hooks, in the first (January-March), second (April-June), third (July-September) and fourth (October-December) quarters, respectively. These values represent a substantial proportion of the total fishing effort by quarter (28%-55% of hooks). For Japanese vessels, a total of 1114 sets and 2,589,465 hooks were observed in 26 trips in 2009-2011, during March-September, May-September and April-August in 2009, 2010 and 2011, respectively (Appendix A).

A substantial proportion of annual fishing effort (26%-75% of hooks) by the Uruguayan fleet, and all trips and sets by the Japanese fleet during 2009-2011 were observed. The variables recorded during setting were as follows: date, position and several operational and environmental variables (time, type of gear, number of hooks, moon phase and sea surface temperature). A proportion of each haul was observed (100% coverage on Uruguayan and 60-100% on Japanese vessels). The observer identified and classified all species as catch, discard, bycatch (retained or released), or lost, and recorded biological information; they were tasked specifically to record the total number of birds caught per set, identify the species and collect samples (head and tarsus, or entire specimens) and any bird rings. If a great albatross was captured incidentally, the entire carcass was collected. All bycaught albatrosses were identified in the laboratory by analysis of the retained whole or part specimens. Some birds recorded alive were identified by combination of photos, videos and measurements taken by observers. The species of royal albatross were distinguished by their plumage according to Onley and Bartle (1999) and Onley and Scofield (2007). Wandering albatrosses were separated from Tristan albatrosses by a morphometric discriminant function (Cuthbert et al., 2003). Ringing authorities or groups confirmed species identifications for all ringed birds, including 15, 2, and 2 wandering, Tristan, and northern royal albatrosses, respectively.

2.4. Operational and habitat variables

A number of operational and habitat (static and dynamic) variables (see Table 1) were included in analyses of bycatch rates. These were selected either because they are important predictors of habitat preference of albatrosses (Louzao et al., 2009, 2011; Kappes et al., 2010; Wakefield et al., 2011; Žydelis et al., 2011) or because they influenced bycatch rates in other studies (Murray et al., 1993; Klaer and Polacheck, 1998; Brothers et al., 1999; Gandini and Frere 2006; Jiménez et al., 2009a; Trebilco et al., 2010). Variables obtained from observer data included: latitude and longitude at the start of the set, date and moon phase (i.e. new moon, first quarter, full moon and last quarter; following Jiménez et al., 2009a). Operational variables included the time of the set (day vs. night setting), presence and type of tori line, and fishing effort (numbers of hooks). Given the differences in the fishing operation between fleets (see above), all sets by Uruguayan vessels that started before sunset were considered as day sets (even though some finished in darkness) following Jiménez et al. (2009a), and for Japanese vessels, daytime sets were considered to be those that finished after sunrise; otherwise, sets were classified as night. Details of the tori lines used by the different fleets are included in Appendix A.

Satellite remote-sensed and other environmental variables were extracted automatically using custom-written scripts in R (R Development Core Team, 2012) for the start position of each set as follows: sea surface temperature (SST; MODIS sea surface temperature product, 4 km resolution, 8 day grids, http://oceancolor.gsfc.nasa.gov/), chlorophyll a concentration (CHLOa; MODIS Chlorophyll product, 4km resolution, 8 day grids, http://oceancolor.gsfc.nasa.gov/), ocean surface wind speed (wind) and eddy kinetic energy (EKE). The dataset (5 day datasets, 0.25 degree x 0.25 degree grid resolution) combines multiple instrument data (scatterometers and microwave radiometers, http://podaac.jpl.nasa.gov/dataset/CCMP_MEASURES_ATLAS_L4_OW_L3_5A_5DAY_WIND_VECTORS_FLK) and cross calibration (Atlas et al., 2011) to produce a homogenous dataset for a long time series. The zonal and meridional geostrophic currents derived from satellite altimetry products were used to calculate EKE using the following formula: $EKE=1/2\ (U^2+V^2)$, where U and V are zonal and meridian geostrophic currents components, respectively (Kappes et al., 2010). Data were supplied by AVISO (http://www.aviso.oceanobs.com/) on 7 day grids at 0.33 x 0.33 degree resolution. Data on bathymetry were from GEBCO – 30 arc second grid, http://www.gebco.net/). In addition, we estimated the spatial gradients of SST (SSTG), CHLOa (CHLOaG) and BAT (BATG) by estimating their proportional change (PC) within a surrounding 3 × 3 cell grid (12km x 12km for SSTG and CHLOaG; 90x90 arc seconds [~ 3km x 3km] for BATG) using a moving window as follows: PC = [(maximum value –minimum value) × 100]/maximum value (Louzao et al., 2009). Finally, the distances between longline sets and the shelf break (200 m isobath) and the coast were calculated.

2.5. Data analysis

The seabird bycatch data in longline fisheries are characterized by a large proportion of zero catch observations (Delord et al., 2010; Jiménez et al., 2010; Trebilco et al., 2010; Winter et al., 2011). Great albatrosses have very small populations and therefore the proportion of zeros is much greater than with abundant species captured in longline fisheries (e.g. black browed albatross *Thalassarche melanophris*). In the present study, the bycatch of great albatrosses was modelled at species level and by fleet using generalized linear mixed models (GLMMs). Sets during one trip or from one particular vessel could be more similar (e.g. observer, specific gear configurations) than those on other trips or by other vessels, respectively. Therefore, for each case (see below) we alternatively fitted three GLMMs using "fishing trip", "vessel" or the fishing trip nested in vessel as a random factor to model bycatch as a function of the explanatory variables. Considering the few captures of most species, this type of analysis was restricted to bycatch of wandering albatross by the Uruguayan fleet and both species of royal albatross by Japanese vessels. Best fit (applying the Likelihood Ratio Test) included "fishing trip" as a random factor for wandering and southern royal, and "vessel" for northern royal albatross. Therefore, only these scenarios are presented.

2.5.1. Explanatory variables

Records with incomplete variable information (e.g. remotely sensed data were not available because of cloud cover) were removed. This eliminated 12.4 % and 20.6% of the Uruguayan and Japanese datasets, respectively. In order to maximise sample sizes, any explanatory variable that was unavailable for >10% of captures was excluded. This applied to CHLO and CHLOG for the Uruguayan and Japanese fleets. Additionally, the variables year and use of a tori line were dropped for both fleets either because no species was caught every year (by Uruguayan vessels) or the analyses were unbalanced. Wind data were unavailable for the last half of 2011, resulting in the removal of many longline sets from the analysis, but only one capture of a northern royal albatross. However, given the potential of wind speed to explain albatross distribution and bycatch rates (Brothers et al., 1999; Shaffer et al., 2001; Phillips et al., 2004), this variable was retained but the time factor (year) was removed.

For all the remaining explanatory variables, the effects of outliers and collinearity were investigated, the latter by examining variance inflation factors (VIF; Zuur et al., 2010, 2012). After dropping highly correlated variables, the following candidate covariates were standardized to have a mean of 0 and an SD of 1, and included in the model to explain the bycatch of great albatrosses in the Uruguayan pelagic longline fishery: SST, SSTG, BATG, EKE and wind. The same covariates and latitude were included in the model to explain bycatch by Japanese vessels. Models also included other potentially important categorical covariates, including season (May-November and December-April; Jiménez et al., 2009a), moon phase and time of set (day vs. night). The interaction between time of the set and moon was also considered.

2.5.2. Bycatch modelling

Because bycatch of great albatross species in the Uruguayan fishery was a very rare event and in most cases only one bird was caught per set, the bycatch of wandering albatross was modelled using a GLMM with a logit link function, assuming a binomial distribution. Longline set was the sampling unit. In contrast, several birds (particularly northern royal albatross) were often caught in the same set by Japanese vessels. Bycatch for this fleet was therefore modelled initially using a binomial GLMM as for Uruguayan vessels, and subsequently for sets in which at least one northern royal albatross was caught, by using a Poisson distribution with fishing effort (log transformed) included as an off-set variable, and using a canonical log link function. The same set of explanatory variables was used in both models. A likelihood Ratio Test was used to test the significance of each covariate. Sequential deletions of non-significant terms were conducted until only significant covariates remained in the model. All the analyses were carried out in R using lme4 (Bates et al., 2011) for the GLMMs and AED (http://www.highstat.com/Book2/AED_1.0.zip) to calculate the VIF values based on the *corvif* function (Zuur et al., 2009).

2.5.3. Independent comparisons

The effect of including or excluding certain variables on bycatch rates (i.e. bird capture per unit of effort, BCPUE; birds/1000 hooks) of royal albatrosses was explored independently for the Japanese fleet because: 1) night setting was implemented as a mitigation measure and the Uruguayan toriline replaced the Japanese style after mid-2009 (see above), and; 2) some variables had a potential influence (year, type of tori line, time of the set and moon phase; Jiménez et al., 2009a) on the BCPUE, but not necessarily on bycatch occurrence as explored in the logistic models. The effect of tori line (considering three categories: without tori line and each of the two tori line types; see Appendix A) on the BCPUE of wandering albatross was also tested using Kruskal-Wallis (with post hoc Mann-Whitney test comparisons, Bonferroni corrected) and Mann-Whitney U tests in R (R Development Core Team, 2012).

3. Results

3.1. Bycatch of great albatrosses

A total of 193 great albatrosses (0.033 albatrosses/1000 hooks) were recorded as bycatch during the study period, 71 of which (0.0214 albatrosses/1000 hooks) were caught by Uruguayan vessels in 2004-2011, and 122 (0.0471 albatrosses/1000 hooks) by Japanese vessels in 2009-2011. Because only a proportion of each haul was observed on Japanese vessels (see Methods), overall bycatch values for this fleet should be interpreted as minimum numbers. Additionally, an unknown proportion of great albatrosses could have been detached from fishing gear and not hauled on board vessels (see Brothers et al. 2010; Jiménez et al. 2012b) in both fleets. Of the great albatrosses recorded as bycatch, just 4 and 13 birds were recorded alive for the respective fleets, all of which were entangled in the branch lines by their wings or hooked at the bill, probably during hauling. The condition at release for most of these birds was unknown and some may die subsequently from their injuries.

In the Uruguayan fishery, the most common great albatross recorded as bycatch was the wandering albatross (38.0%; n=27 birds; 0.0082 albatrosses/1000 hooks), followed by southern royal albatross (21.1%; n=15 birds; 0.0045 albatrosses/1000 hooks), Tristan albatross (16.9%; n=12 birds; 0.0036 albatrosses/1000 hooks) and northern royal albatross (5.6%; n=4 birds; 0.0012 albatrosses/1000 hooks). However, 13 great albatrosses could not be identified to species, at least eight of which were either northern or southern royal albatrosses. Thus, the relative BCPUE of the two royal albatrosses is slightly greater than indicated by the breakdown at species level. Results for Japanese vessels contrasted both in terms of numbers and proportions of each species, with bycatch of great albatrosses dominated by royal albatrosses, more than half of which were northern royal (52.5%, n=64 birds; 0.0247 albatrosses/1000 hooks), followed by southern royal (25.4%; n=31 birds; 0.0120 albatrosses/1000 hooks), with very few captures of wandering and Tristan albatrosses (4.9%, n=6, 0.0023 albatrosses/1000 hooks and 0.8%, n=1, 0.0004 albatrosses/1000 hooks, respectively). Of the 20 great albatrosses not identified to species level for the Japanese fleet, at least 15 were royal albatrosses, which is very similar to the overall proportion among those identified.

3.2. Spatial and temporal variation

Wandering albatrosses were caught by Uruguayan vessels in both Uruguayan and international waters between 28° and 46° S (Fig. 1A). With one exception, all captures of Tristan albatross occurred in international waters between 28° and 37° S. This was the most frequent species caught in the eastern portion of the fishing range; indeed, it was the only species caught east of 42° W (Fig. 1B), and on average was captured further from the shore that any of the other great albatrosses (Appendix A). Tristan albatrosses were also caught further from the shelf break than wandering albatrosses (Appendix A). Southern royal albatrosses were caught over the shelf slope off Uruguay and in international waters (34°-41° S; Fig. 1C). Finally, all captures of northern royal albatrosses were over the shelf-break (Fig. 1D). Moreover, there was a significant effect of bathymetry and distance to the shelf break on the incidence of bycatch of this albatross compared with that of the other three species (Appendix A).

All captures of great albatrosses by Japanese longliners were west of 51° W, over the shelf break and slope of Uruguay, where fishing effort by this fleet was concentrated (Fig. 2). Only a few wandering albatrosses (n=6; Fig. 2A) and one Tristan albatross (Fig. 2B) were caught over the slope. However, captures of both royal albatross species were common and widely distributed in this area (Fig. 2C and 2D). The single capture of a Tristan albatross was over waters that were relatively deep and far from the shelf break and shore, again underlining the more pelagic range of this species (Appendix A).

For the Uruguayan fleet, bycatch rates varied between years for all species (Fig. 3). No species was captured in every year, highlighting the extreme rarity of bycatch events. The highest BCPUE of wandering albatross was observed in 2009. The BCPUE of southern royal albatross was low in most years except 2008 and 2010. In the three years (2009-2011) where there are comparable data, catch rates of wandering and Tristan albatrosses were lower on Japanese than Uruguayan vessels. In contrast, royal albatrosses (particularly northern) were caught much more frequently by Japanese vessels in 2009 (Fig. 3). The BCPUE of both royal albatrosses decreased dramatically from 2009 to 2011 (Fig. 3). Result of independent comparisons showed that catch rate varied significantly between years for southern (Kruskal-Wallis = 15.5, d.f. = 2, $p < 0.01$, n=1108) and northern royal albatrosses (Kruskal-Wallis = 12.7, d.f. = 2, $p < 0.01$, n=1108).

Great albatrosses were caught during all months from April to November by Uruguayan pelagic longliners (Fig. 4). Additionally, a few captures of wandering and Tristan albatrosses were recorded in January, towards the south and east, respectively, of the fishing area, which included some of the closest sets to the breeding sites at South Georgia or Gough islands (Figs. 1A and 1B). During April-November, wandering albatross was the most frequently captured species, with records in all months and a peak in BCPUE in November (Fig. 4). Tristan albatrosses were caught mainly in July-November, particularly in September-November (Fig. 4). The highest BCPUE of southern royal albatross was observed in July, whereas no monthly pattern was obvious for northern royal albatrosses given the low number observed. On Japanese vessels, great albatrosses were captured in all fishing months with the exception of March. During April-August, the incidental catch of great albatrosses was dominated by royal albatrosses, peaking in June (Fig. 4). The only capture of a Tristan albatross occurred in April, whereas wandering albatrosses were caught from June to September (Fig. 4). It is important to note that in September, Japanese vessels set only 8 longlines yet caught two wandering and two northern royal albatrosses, resulting in a BCPUE per species for that month of 0.1036 albatrosses/1000 hooks (Fig. 4). This value is an order of magnitude higher than the catch rates observed in other months by either fleet, but should not be considered representative of the general pattern because of the small sample.

3.3. Factors affecting bycatch

The bycatch of a great albatross was an extremely rare event, occurring during only 3.33% and 5.30% of the sets observed on Uruguayan and Japanese vessels, respectively. The average percentage of positive sets among species on Uruguayan vessels was 0.73%, the highest proportion of which involved wandering albatross (1.38%) and the lowest involved northern royal albatross (0.25%). For Japanese vessels, this average was 1.39%, with the highest incidence for northern royal albatross (i.e. 2.96%) and the lowest for Tristan albatross (i.e. 0.09%).

Results of the modeling are summarized in Table 2 (for details on model selection see Appendix A). For wandering albatross in the Uruguayan fishery, the final model (binomial GLMM) included time of the set, wind speed and SST. Most of the captures of wandering albatross (25 from 27 birds) occurred in sets during daylight (Fig. 5). The rate of change in odds showed that the chance of a wandering albatross being caught during night setting was much lower (7%, 95% confidence limit=1-48%) than during sets in daylight. Coefficient estimates indicated that bycatch occurrence increased significantly with wind speed, and decreased (although marginally significant) with increasing SST (Table 2). For captures of southern royal albatross by Japanese vessels, the final model (binomial GLMM) included moon phase, latitude, SST and EKE. The estimated coefficients indicated that bycatch occurrence increased with latitude and showed a declining trend, albeit non-significant, with SST and EKE (Table 2). For northern royal albatross, the final model (binomial GLMM) included moon phase, SST and time of the set. The rate of change in odds showed that the chance of a northern albatrosses being caught during night setting is 30% (95% confidence limit=3 - 77%) of that during daylight sets. Bycatch occurrence also decreased with increasing SST (Table 2). Considering only sets with captures (Poisson GLMM), the only significant covariate was SST, which was negatively associated with the number of birds caught (coefficient = -0.42, SE=0.14, p<0.01).

Independent comparisons showed that bycatch rate varied significantly with the time of the set for both southern (Mann-Whitney, p=0.036, n=1108) and northern royal albatrosses (Mann-Whitney, p=0.031, n=1108), and was higher in daylight (Fig. 5). However, several individuals were caught during night setting (Fig. 5). For those sets, the BCPUE varied strongly with the moon phase in southern (Kruskal-Wallis, df=3, p<0.001, n=926) and northern royal albatrosses (Kruskal-Wallis, df=3, p<0.001, n=926). For both species, the BCPUE was higher during the full moon (Fig. 6). There was no significant effect on BCPUE of the type of tori line for both royal albatrosses species (Kruskal-Wallis, df=2, p > 0.05, n=1108) caught by Japanese vessels. Nor was there a significant differences in the BCPUE of wandering albatrosses between sets with (including both types, see Methods) and without a tori line by the Uruguayan fleet (Kruskal-Wallis, df=2, p > 0.05, n=1491).

4. Discussion

This is the first detailed study of variation in bycatch rates of great albatrosses by pelagic longline fisheries in the southwest Atlantic. It also identifies the main contributing operational and environmental factors, and provides the first bycatch assessment for Japanese vessels operating under license in Uruguayan waters. High bycatch levels of northern and southern royal albatrosses were recorded for the first time in this region, particularly over the shelf break. Previously, very few captures of royal albatrosses had been reported over the Patagonian shelf in demersal longline (Favero et al., 2003) or trawl fisheries (Favero et al., 2011), or in Brazilian waters in the pelagic longline fishery (Bugoni et al., 2008 and references therein). This result is therefore both a major conservation concern and a demonstration of the importance of this habitat for nonbreeding birds of both species. Similarly, the consistently high bycatch of wandering and Tristan albatrosses in pelagic waters is a major issue, particularly because many other fleets also operate in this region. These include vessels flagged to Belize, Brazil, Chinese Taipei, Spain, Portugal, Japan, Philippines, St. Vincent and Grenadines, and Uruguay, which reported to the International Commission for the Conservation of Atlantic Tunas (ICCAT) a total of 15.5.-21 million hooks annually in 2004-2009 from 20°–45°S and 20°–55°W (Jiménez et al. 2012a; http://iccat.int/Data/t2ce.rar). Vanuatu also reported fishing effort within this region in 2010-2011.

4.1. Spatial and temporal patterns in bycatch

Despite the differences in fishing effort distribution between fleets, there was clear temporal and spatial heterogeneity in bycatch rates of the four great albatross species. Much of this seems to reflect differences in at-sea distribution of each species, providing new evidence to support the reported niche segregation among these species (Nicholls et al., 2002; Cuthbert et al., 2005; Reid et al., 2013). Bycatch was influenced by bathymetry, distance to the shelf break and distance to the shore (Appendix A). Tristan albatross was the most pelagic species, followed by wandering albatross, reflected in the spatial pattern in bycatch by both fleets. These species were captured in very low numbers by Japanese vessels, which concentrated their fishing effort near the shelf break. However, these vessels captured a high number of northern royal albatrosses, suggesting that this species is widely distributed over the shelf break. This is supported by the data from Uruguayan vessels, which only captured northern royal albatrosses in this area even though this fleet operated over a much wider region of the southwest Atlantic. Finally, although bycatch rates of southern royal albatross were highest for both fleets over the shelf break and slope, suggesting those are the habitats in which this species is most abundant, some birds were caught in deeper Uruguayan and international waters indicating that they also exploit oceanic waters. This is supported by a few ring recoveries reported from vessels in international waters (Moore and Bettany, 2005).

Analysis of the observer data showed that the bycatch of great albatrosses was highest from April to November. Together the data from both longline fleets indicate a peak in bycatch of northern and southern royal albatrosses in June or July, and of wandering and Tristan albatrosses from September to November. The latter was clearest for the Uruguayan fleet, as this has the greatest overlap between the fishing area and the pelagic waters used by wandering and Tristan albatrosses. Clearly, the peaks in bycatch rates are likely to be explained largely by the time of greatest spatial overlap between the species and fishery in question. Northern royal albatross pre-breeders and failed breeders migrate from New Zealand to the southwest Atlantic in February and have departed by September (Nicholls et al., 2002). Analysis of ring recoveries of southern royal albatrosses suggest that juveniles, non-breeding adults and, particularly, immature birds, visit the southwest Atlantic over a broadly similar period, February to October (Moore and Bettany, 2005). However, at-sea observations of both species in December indicate that some birds remain for longer in the region (Jiménez et al., 2011). Over the Uruguayan shelf break and slope, where northern and southern royal albatrosses were mainly captured by both fleets, they are more abundant from May/June to August (Jiménez et al., 2011), perhaps because prior to this time, the bulk of the birds are concentrated in colder, more southerly latitudes (Nicholls et al., 2005) and so do not overlap with this fleet.

Wandering and Tristan albatrosses are more difficult to differentiate at sea and thus are usually pooled in counts from vessels (Bugoni et al. 2008, Jiménez et al., 2009b, 2011). This would suggest that abundance of both species attending vessels is highest over the Uruguayan shelf slope from August to November (Jiménez et al., 2011). However, bycatch specimens (this study) and ring recoveries (Croxall and Prince, 1990; and see Jiménez et al., 2012a), indicate that the majority of birds in these waters during this particular period are wandering albatrosses. This species is highly migratory, and most birds from South Georgia spend much of the nonbreeding period in the Indian or Pacific oceans (Mackley et al., 2010). The last visit to the colony by successful breeders is in November - December when the chick fledges, and by immatures and breeders that fail in incubation is in April - May (Tickell, 2000). As this is a biennial breeder that lays in December, the number of birds in the southwest Atlantic will peak in November, to include both breeders from the current year still provisioning well-grown chicks, and birds about to breed in the coming season. Tristan albatross appears to remain for much of the year in warmer deeper waters, and towards the east and north of Uruguay. The number of breeding and nonbreeding adults should peak in the southwest in late winter to spring (Cuthbert et al., 2005; Dénes et al., 2007; Reid et al., 2013; this study).Therefore the period of highest bycatch for both wandering and Tristan albatrosses coincides with the highest abundances expected for both species in the southwest Atlantic.

The dramatic decrease in the bycatch of both royal albatross species by Japanese vessels from 2009 to 2011 is more difficult to explain. However, it probably relates partly to the introduction of night setting as a mitigation measure in 2009, which led to a significant decline in BCPUE. In addition, the replacement of the Japanese by the Uruguayan design of tori line in 2009 standardised the use of this mitigation measure thereafter. Several captures occurred during winter after the implementation of these measures. However, the only factor that had a significant effect on the bycatch of northern royal albatross in the Japanese fishery was SST, which suggests that the reduction in the number of birds captured from 2009 to 2010-11 may largely reflect a shift in bird distribution in response to water temperature rather than a change in operational practices on board vessels. An alternative explanation would be local population depletion following the high bycatch levels experienced in 2009; however, this is less probable since these are highly mobile species and this area is part of the main winter range (Robertson et al., 2003; Nicholls et al., 2002; Moore and Bettany, 2005).

4.2. Effect of habitat and operational variables

Results of the modeling indicated that operational variables (time of the set) affected the bycatch likelihood of the great albatross species in a similar way. The evidence for an influence of variables related to habitat use was weaker; however, each species might nevertheless show strong habitat preferences that affect their overall at-sea range, even if distributions overlap.

The time of the set was an important determinant of bycatch occurrence (as observed for wandering and northern royal albatrosses on Uruguayan and Japanese vessels, respectively; see Table 2) as well as the BCPUE (see Fig. 5). Both bycatch occurrence and rates were higher in daylight than night-time sets, probably because albatrosses detect prey largely by sight, although they might also use olfactory cues at this small scale (Nevitt, 2008). They fly less and have lower foraging success at night because prey are more difficult to locate, and so active searching on the wing is less effective (Phalan et al., 2007). However, wandering albatrosses during the night significantly increase their activity (e.g. time in flight) with a brighter moon (Phalan et al., 2007). This explains the bycatch of great albatrosses during the night, particularly during the full moon, followed by the first quarter (and none during the new moon phase), for both royal albatross species (Fig. 6, Table 2). Of the eight captures of wandering albatross recorded at night by the two fleets, seven were during the first quarter and the full moon, and the three captures of Tristan albatross at night were during the first quarter. Higher seabird bycatch rates during the brightest moon phases are consistent with the patterns observed in previous studies (Vaske, 1991; Gandini and Frere, 2006; Jiménez et al., 2009a).

Sea surface temperature and wind also influenced the bycatch likelihood and could be associated mainly with habitat use by the great albatrosses. It is important to note that the preference of each species for particular habitat characteristics could be masked by the much stronger effect of operational practices (e.g. time of the set) on bycatch rates. Typically, seabird bycatch data are zero-inflated because birds do not overlap with vessels (i.e. they are not present in that type of habitat at that time of year), or they overlap but are not caught. The latter is often the case; on 13-41% of seabird counts conducted during setting and hauling in 2005-2008, one or more of the four species of great albatross were associated with a Uruguayan vessel (Jiménez et al. 2012a), yet on only a small minority of sets was a bird caught in this fishery (this study). Similar results were obtained in previous studies (Weimerskirch et al., 2000; Bugoni et al., 2008). This is because hooks can only be accessed for a limited time, largely determined by the activity of other birds (including small species that are more proficient divers) and by the type of fishing gear, use of tori lines, available light levels etc. (Brothers, 1991; Robertson et al., 2010; Jiménez et al., 2012b).

Sea surface temperature is indicative of water mass. For the three species with sufficient captures for analysis, bycatch occurrence decreased with increasing SST (although marginally significant in two cases). Uruguayan vessels fished over a wide area, as far as 19°S. A relationship between bycatch rate and SST is expected for the wandering albatross, since this species in the southwest Atlantic prefers oceanic waters from the sub-Antarctic to the subtropics and is rare in tropical waters north of 30° S (Prince et al., 1998; Xavier et al., 2004; Phillips et al., 2009). Both royal albatrosses occur in the area where bycatch is highest (the Uruguayan slope; Jiménez et al., 2011) and the oceanography of this region is dominated by an influx of sub-Antarctic waters (Ortega and Martínez, 2007). Bycatch of these species by Japanese vessels occurred mainly over the southern Uruguayan slope (Fig. 2), where colder waters ingress during winter (Ortega and Martínez, 2007). Over the Uruguayan slope, increased bycatch occurrence towards the south was also evident for the southern royal albatross (Table 2). This species is common during winter in the colder shelf waters of Argentina and southern Uruguay around trawlers (Favero et al., 2011; Jiménez pers. obs.). The only significant factor explaining the bycatch (Poisson GLMM) of northern royal albatross by Japanese vessels was SST, increasing with colder temperatures, denoting again a preference for sub-Antarctic waters.

Wind may affect bycatch at different scales (Table 1). Firstly, it may reflect favourable habitat; flight speed is determined mainly by wing loading, and thus windier regions are more optimal for large albatrosses (Shaffer et al., 2001; Phillips et al., 2004) where they may overlap more with the fishery. Indeed, this seems a plausible explanation for the pattern observed in our study. Secondly, wind speed (and also direction) could influence access to baited hooks by changing the effectiveness of tori lines, affecting flight maneuverability, or the energetic cost of take-offs and landings by birds. Unfortunately, the resolution of the remote sensed data used here is too low for an analysis at a sufficiently fine scale to test the latter.

The edges of mesoscale meanders and eddies (where EKE values are highest) exhibit increased levels of marine productivity and zooplankton biomass, and lead to prey aggregation (see Bost et al., 2009).

Several studies have found evidence supporting the association of albatrosses with these features (Nel et al., 2001; Petersen et al., 2008; Wakefield et al., 2011; but see Kappes et al., 2010), including in the oceanic waters of the Brazil–Malvinas Confluence (Wakefield et al., 2011). We found only limited evidence of such relationships from the bycatch analysis; although there was a weak negative relationship between EKE and bycatch of southern royal albatross, this was of marginal statistical significance and would need to be confirmed by further studies.

4.3. Implications for management

Great albatrosses are among the species most affected by pelagic longline fishing in the southwest Atlantic (Bugoni et al., 2008; Jiménez et al., 2012a). Therefore, any measure that could reduce or eliminate negative interactions between birds and vessels in this region should be considered a high priority for fisheries management organizations. This paper identified key factors affecting their bycatch, which are extremely useful for developing or improving conservation measures of these highly threatened species. Firstly, we determined the areas and seasons where the interaction between great albatrosses and pelagic longliners is most intense. Considering the time of year in which recorded bycatch rates are highest (with conservative temporal bounds of ± 1 month), bycatch of both royal albatross species could be reduced by the strict use of mitigation measures (see below) in May-August in the region of the Uruguayan shelf break. Bycatch of wandering and Tristan albatrosses was less restricted spatially, but highest in pelagic areas from the shelf break to international waters, mainly around the Brazil-Malvinas confluence. Efforts to implement and ensure compliance with mitigation measures for these species should occur throughout this region, and be focused during August to December.

Secondly, restriction on longline setting only to the hours of darkness is unambiguously a key mitigation measure for reducing the bycatch of great albatrosses in the Uruguayan, Japanese and indeed all other pelagic longline fisheries in this region. The effectiveness of this approach to mitigation has strong scientific support (see reviews in Bull, 2007 and Løkkeborg, 2011), and reflects the lower seabird bycatch rates reported for night than daylight sets in a wide range of pelagic and demersal longline fisheries (Murray et al., 1993; Brothers et al., 1999; Gómez-Laich et al., 2006; Jiménez et al., 2009a). However, our results also indicate that BCPUE increases during bright moon phases, in line with previous studies (Vaske, 1991; Brothers et al., 1999; Gandini and Frere, 2006; Jiménez et al., 2009a). Indeed, bycatch by Japanese vessels in sets during full moon was higher than those in daylight for both royal albatross species (Fig. 5 and 6). However, these daytime sets were conducted mostly in April 2009 before many migrant royal albatrosses had returned to the study area, and the implementation of night setting by Japanese vessel in May-July coincided with the peak in arrival, which probably explains the higher BCPUE during the full moon.

We found no evidence that the use of a tori line by Uruguayan vessels reduced bycatch of wandering albatross. However, comparisons were made between lines set in different years, which may make the effect difficult to detect if bycatch varies for other reasons. A controlled study on Uruguayan vessels showed a significant reduction in bycatch of all seabirds associated with tori line usage (Domingo et al., 2011b), but these data are not sufficient to draw conclusions for individual species. Nor did we detect an effect of tori line use or type on bycatch of either royal albatross species by Japanese vessels, but again the comparisons of the two designs involved data from different periods. In addition, the Uruguayan design of tori line was not adopted until late May 2009 after which the abundance of great albatrosses in the area increases.

Current mitigation measures recommended for pelagic longline fisheries include the combined use of night setting, tori line and appropriate weighting in the branch-lines (Løkkeborg, 2011). The ICCAT recommendation 11-09 (http://www.iccat.int/en/RecsRegs.asp) stipulates that in the area south of 25° S, ICCAT members shall ensure that all longline vessels use at least two of these mitigation measures, including minimum technical standards and specifications. Strict night setting is useful to reduce bycatch of great albatrosses (this study) and tori lines demonstrably reduce bycatch of seabirds in pelagic longline fisheries (Brother, 1991; Murray et al., 1993; Domingo et al., 2011b; Melvin et al., 2013). Despite this, our results (Fig. 6) suggest that the combined use of night setting and tori line are not sufficient to reduce the bycatch of great albatrosses during the full moon. At least during this period of the lunar cycle, a precautionary approach for these highly threatened species would be the combined used of all three mitigation measures (ACAP, 2013; Melvin et al., 2014). Current mitigation research and advice on branch-line weighting are focused on determining the effects of different weights and distances of the point of attachment from the hook (see Robertson et al., 2010; ACAP, 2013). By incorporating this information into the development and updating of best practice guidelines, international initiatives such as those of the Agreement on the Conservation of Albatrosses and Petrels (ACAP) can promote the implementation of effective branch-line weighting regimes that, along with tori lines and night setting, would greatly reduce bycatch rates in ICCAT and other fisheries. Because great albatrosses obtain pelagic longline baits mainly through secondary interaction, an effective mitigation regime must also reduce access to baited hooks by medium sized petrels (*Procellaria* and *Puffinus* spp.) and, to a lesser extent, *Thalassarche* albatrosses (Jiménez et al. 2012b).

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Table 1. Explanatory variables used in models to characterise the bycatch of great albatrosses (*Diomedea* spp.) in the southwest Atlantic. Variables dropped prior to analyses are indicated with an asterisk (see text section *2.5.1.*).

Variables (Unit or categories)	**Process and hypothesized link with habitat preference or bycatch likelihood**
Habitat covariates	***Dynamic variables***
Sea surface temperature, SST (º C)	Indicative of water mass distribution, affects the distribution of albatrosses.
SST gradient, SSTG	Indicative of frontal systems, potential prey aggregation and increased seabird density.
Chlorophyll a *, CHL, (mg m^{-3})	Indicative of ocean productivity domains, may affect the distribution of albatrosses.
CHL gradient *, CHLG	Indicative of frontal systems, potential prey aggregation and increased seabird density.
Wind Speed (m s^{-1})	Effect on albatross flight, and therefore on their abundance in the area. Potential effect on tori line performance or access to baits, affecting great albatrosses (mostly as secondary species).
Eddy kinetic energy, EKE (cm^2 s^{-2})	Increased local enhancement of productivity or prey aggregation, and therefore potential increase in seabird density.
Moon phase (New, First quarter, Full, Last quarter)	Moon light facilitates the access to bait for seabirds, affecting great albatrosses (mostly as secondary species).
	Static variables
Latitude (degree and minutes in decimal scale)	May affect the distribution of albatrosses.
Longitude (degree and minutes in decimal scale)	May affect the distribution of albatrosses.
Bathymetry (m)	Spatial usage of albatrosses may vary because bathymetric regimes are characterized by different levels of productivity (e.g. neritic mesotrophic vs. oceanic oligotrophic domains).
Bathymetry gradient	Usage of albatrosses may vary because the presence of topographic features (shelf break, seamounts).
Distance from the shelf break, i.e. 200m isobath (km)	Proximity with shelf break, slope currents, vertical mixing and prey concentration, potential increase in seabird density.
Distance from the shore (km)	Spatial usage of albatrosses may vary according onshore-offshore distribution patterns.
Operational covariates	
Tori line * (see main text for categories)	The presence of this mitigation measure could reduce access to bait for seabirds, affecting great albatrosses (mostly as secondary species).
Time of the set (Day, Night)	Daylight facilitates the access to bait for seabirds, affecting great albatrosses (mostly as secondary species).
Vessel/Fishing trip	Some factors are intrinsically linked to vessels throughout the entire trip (e.g. observer, specific gear configurations), therefore, either "vessel" or “fishing trip” were considered as a random factor in GLMMs.
Fishing effort (Hooks)	Including as part of the response variable, as off set in the models formulation, when Poisson model was fitted.
Temporal covariates	
Year * (from 2004 to 2011 and from 2009 to 2011 for Uruguayan and Japanese vessels, respectively)	Annual variation in either distribution of albatrosses or vessels may affect their overlap.
Season (May-November and December-April)	Seabird bycatch seasons reported for longliners in the study region. Variation in distribution and abundance of albatrosses due to breeding phenology and migration patterns may affects bycatch rates.

Table 2. Estimated coefficients and standard errors (SE) of the GLMM (Binomial) for wandering albatross captured by Uruguayan vessels, and southern and northern royal albatrosses captured by Japanese vessels. The rate of change in the odds is presented for categorical variables. EKE= eddy kinetic energy; SST= sea surface temperature.

Species	**Fixed Effects**	Coefficient	SE	z	p	Rate of change in odds (%) [1]	95% confidence limits (%)
Wandering albatross	(Intercept)	-5.32	0.58	-9.115	0.0000	-	-
	SST	-0.94	0.49	-1.912	0.0559	-	-
	wind	0.85	0.30	2.824	0.0048	-	-
	Time Set Night	-2.68	0.98	-2.716	0.0066	7	1 - 48
Southern Royal Albatross	(Intercept)	-4.17	0.61	-6.886	0.0000	-	-
	Latitude	0.64	0.29	2.217	0.0267	-	-
	SST	-0.39	0.25	-1.596	0.1105	-	-
	EKE	-0.91	0.65	-1.396	0.1626	-	-
	Moon Full	1.00	0.61	1.650	0.0989	272	82 - 901
	Moon Last Quarter	-2.07	1.19	-1.737	0.0824	13	1 - 134
	Moon New	-16.81	2097.25	-0.008	0.9936	0	-
Northern Royal Albatross	(Intercept)	-2.05	0.51	-3.990	0.0001	-	-
	SST	-0.68	0.21	-3.190	0.0014	-	-
	Moon Full	0.48	0.41	1.172	0.2414	161	72 - 363
	Moon Last Quarter	-2.95	1.08	-2.742	0.0061	5	1 - 44
	Moon New	-16.71	1261.33	-0.013	0.9894	0	-
	Time Set Night	-1.21	0.48	-2.537	0.0112	30	3 - 77

Variance and standard deviation values of the random variable “Trip” were 3.48 and 1.87 for wandering, 0.39 and 0.62 for southern royal. These values for the random variable “Vessel” was 0.26 and 0.51 for northern royal albatross. [1]The rate of change in the odds is calculated as the exponent of the parameter estimate, and is a measure of the change of catching an albatross under one condition compared with the change of catching an albatross under another condition. The 95% confidence limits are calculated using the exponent of the parameter plus or minus 1.96 times the standard error and presented as a percentage.

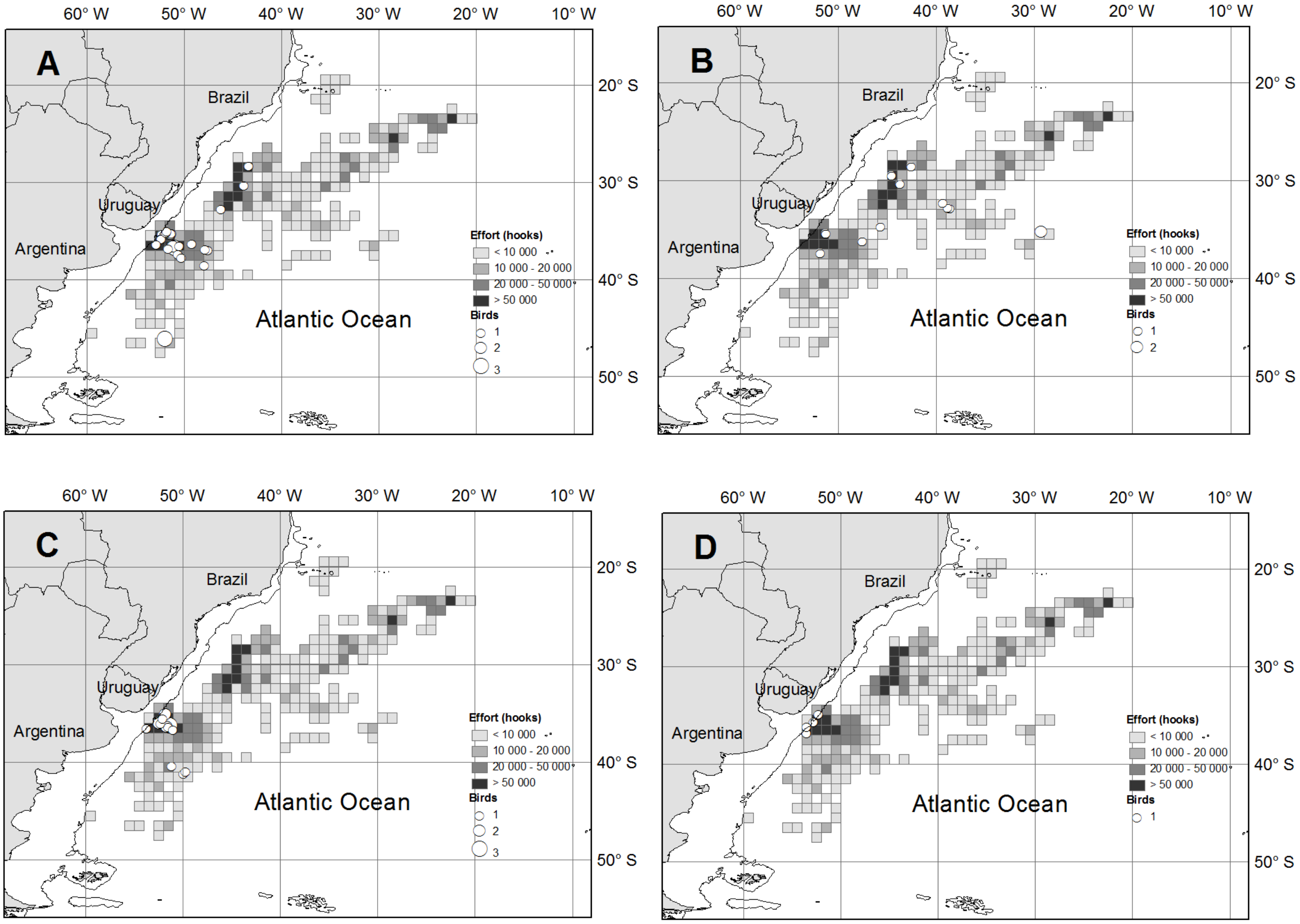


Figure 1. Spatial distribution of the observed fishing sets and incidental captures of great albatrosses (circles) observed in the Uruguayan pelagic longline fishery (2004-2011). A = wandering albatross; B = Tristan albatross; C = southern royal albatross; D = northern royal albatross. The 200m isobath is represented by a black line.

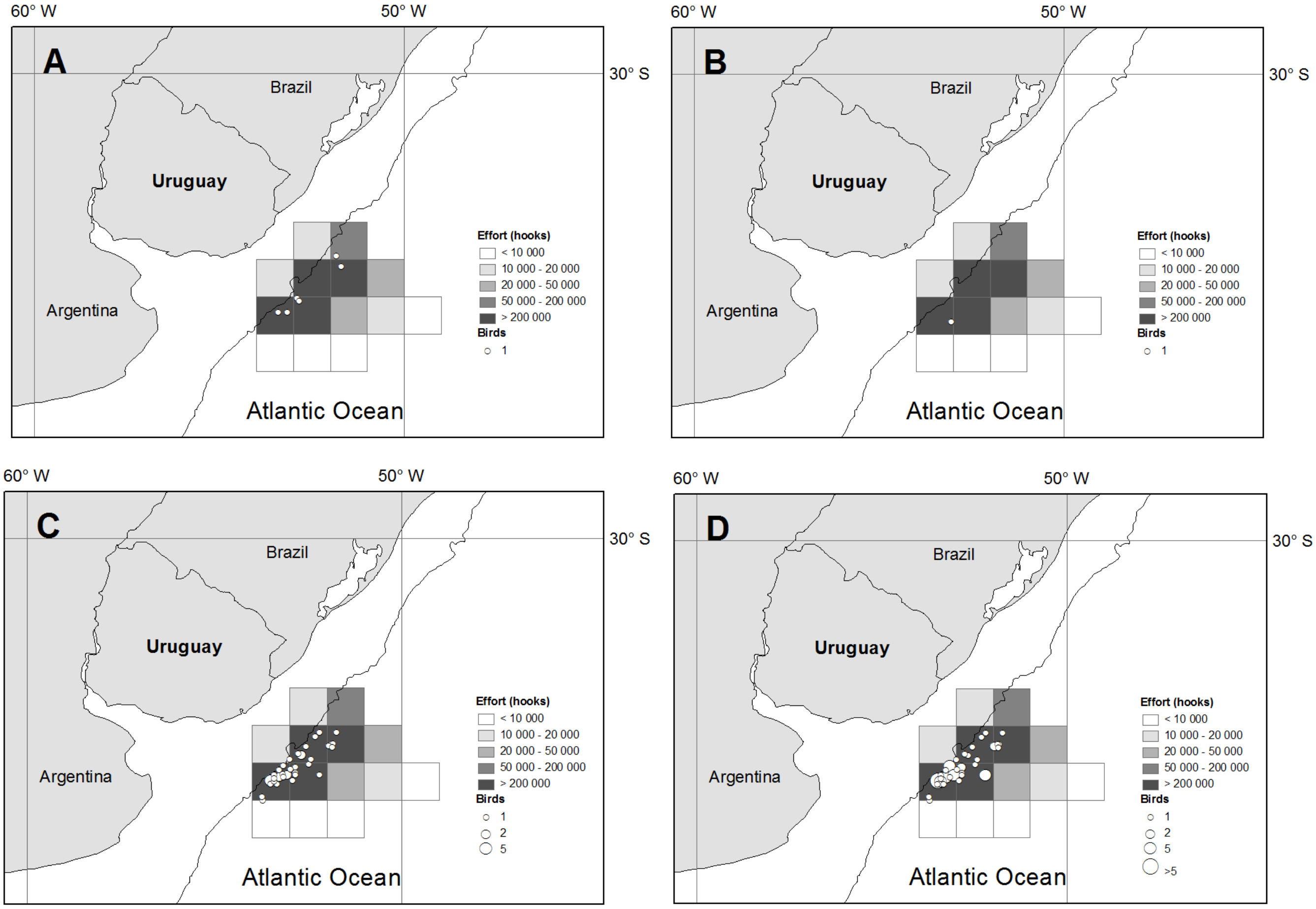


Figure 2. Spatial distribution of the observed fishing sets and incidental captures of great albatrosses (circles) observed on board Japanese longline vessels operating in Uruguay (2009-2011). A = wandering albatross; B = Tristan albatross; C = southern royal albatross; D = northern royal albatross. The 200 m isobath is represented by a black line.

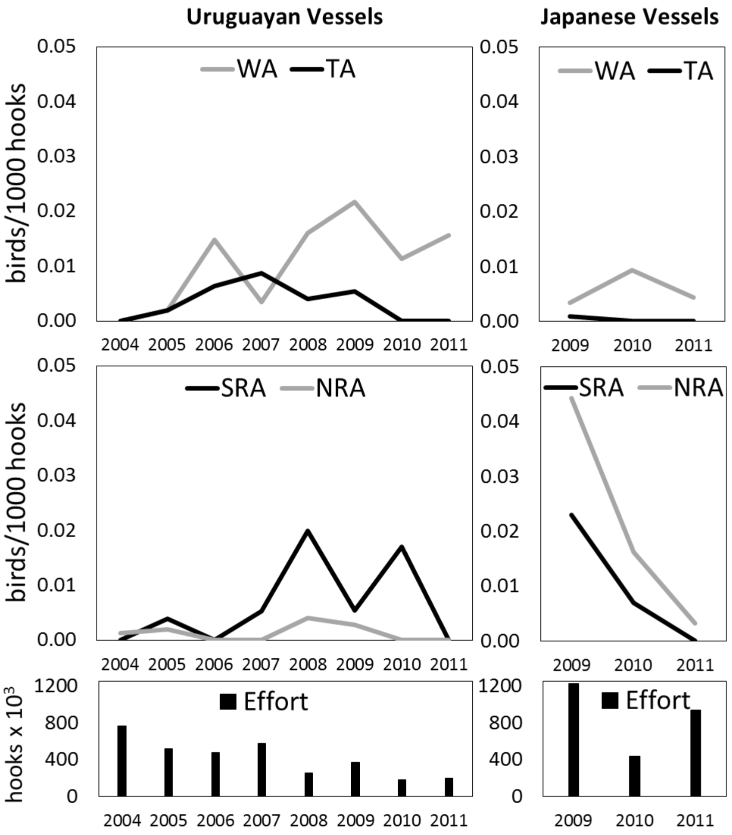
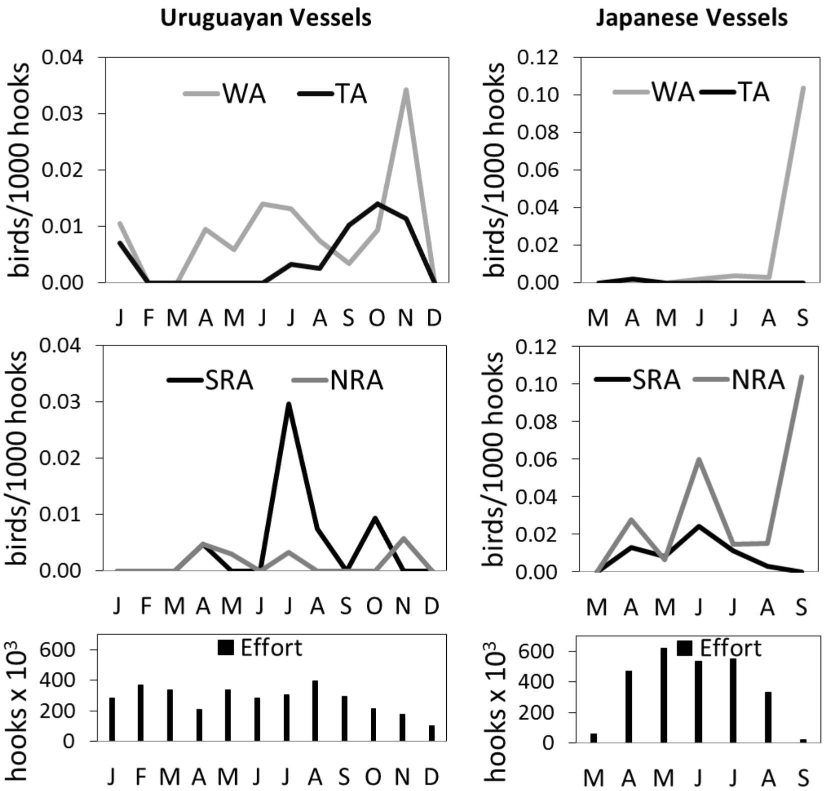


Figure 3. Annual variation in the observed bird capture per unit of effort (BCPUE, birds/1000 hooks) for great albatross species incidentally captured and for the observed fishing effort. Left column: Uruguayan pelagic longline fleet in 2004-2011; Right Column: Japanese pelagic longline vessels operating in Uruguay and adjacent waters under an experimental fishing license in 2009-2011. WA = wandering albatross, TA= Tristan albatross, SRA=southern royal albatross and NRA= northern royal albatross.


Uruguayan Vessels

Japanese Vessels

Figure 4. Monthly variation in the observed bird capture per unit of effort (BCPUE, birds/1000 hooks) for great albatross species incidentally captured and for the observed fishing effort. Left column: Uruguayan pelagic longline fleet in 2004-2011; Right Column: Japanese pelagic longline vessels operating in Uruguay and adjacent waters under an experimental fishing license in 2009-2011. These vessels operated from March to September. Species codes as in Fig. 3.

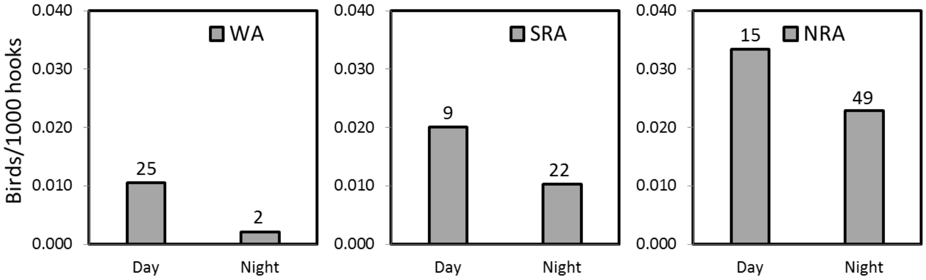


Figure 5. Bird capture per unit of effort (birds/1000 hooks) of great albatross species incidentally captured during day and night sets. The number above the bar indicates the number of birds captured. Wandering albatross (WA) captured in the Uruguayan pelagic longline fleet during 2004-2009. Southern (SRA) and northern royal (NRA) albatrosses captured in Japanese pelagic longline vessels (2009-2011) operating in Uruguay and adjacent waters under an experimental fishing license.

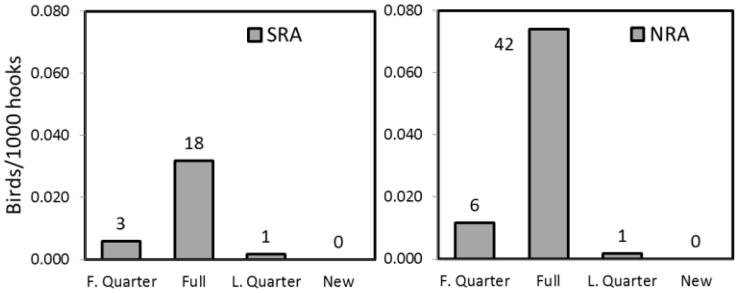


Figure 6. Bird capture per unit of effort (birds/1000 hooks) of southern (SRA) and northern (NRA) albatrosses according to the moon phase for night sets conducted in Japanese pelagic longline vessels (2009-2011) operating in Uruguay and adjacent waters under an experimental fishing license. The number above the bar indicates the number of birds incidentally captured.