

# Differential use of the Argentine shelf by wintering adults and juveniles southern giant petrels, *Macronectes giganteus*, from Patagonia

Gabriela S. Blanco <sup>a,\*</sup>, Flavio Quintana <sup>a,b</sup>

<sup>a</sup> Centro Nacional Patagónico (CONICET), Boulevard Brown 3500, U9120ACF Puerto Madryn, Argentina

<sup>b</sup> Wildlife Conservation Society, Buenos Aires, Argentina

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## ABSTRACT

To study habitat use and at-sea movements of southern giant petrels (SGP) during non-breeding period, we deployed 15 satellite transmitters (six adults, nine juveniles) at Isla Arce and Isla Gran Robredo colonies in Patagonia, Argentina. Birds were instrumented during  $81.4 \pm 37$  days. Adult birds used 74% of the Argentine shelf concentrating mainly at the shelf break, middle shelf waters, and the surroundings of the colony. After fledging, juveniles spread to the Argentine, Uruguayan and Brazilian shelves within the South Atlantic. Adults alternated at-sea excursions ( $12 \pm 5$  days) with periods at the colony of  $3 \pm 0.3$  days. Contrarily, juveniles moved first to the shelf break and then traveled northwards reaching the south of Brazil. There was some spatial overlap between age classes, but only during the first 30 days after juveniles had fledged; thereafter there was not overlap between the areas used by both age classes. The Argentine shelf is widely used by different species offering a suitable environment for foraging; this may be why adults SGP from Patagonian colonies spend all year-round within the Argentine shelf. The identification of used areas of non-breeding SGP fills a gap in the species knowledge contributing not only to the preservation the species, but also to the management of marine areas globally recognized as important for many other Procellariiformes.

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## 1. Introduction

Pelagic birds in general, and albatrosses and petrels in particular, commonly breed at remote colonies spending most of their time at-sea (Mackley et al., 2010, 2011) and dispersing widely through the oceans (Phillips et al., 2005). They play a primary role as predators and scavengers in the Southern Oceans and have been widely studied increasing our knowledge of their behavior during their pelagic stage and their complex ecological relationships at sea (González-Solís et al., 2007; Pinaud and Weimerskirch, 2007; Mackley et al., 2010; Copello et al., 2013). Although most spatial ecology studies focused their attention on foraging seabirds during breeding periods more recently researchers have started to concentrate their efforts on the non-breeding period (Croxall et al., 2005; Phillips et al., 2006; Mackley et al., 2010, 2011; Gutowsky et al., 2014). In addition, few novel studies focused on the

dispersion of juveniles during their first year at sea, which have a high mortality risk, disperse over wide distances, and must obtain foraging skills in order to survive (Thiers et al., 2014; Weimerskirch et al., 2014). The southern giant petrel (SGP, *Macronectes giganteus*) has a circumpolar distribution restricted to the Southern Ocean (Hunter, 1984a). In Argentina, they breed at four colonies, two of them are located in north Patagonia, Chubut Province: Isla Arce and Isla Gran Robredo, and two reside in Tierra del Fuego: Isla Observatorio and Isla de los Estados (Quintana et al., 2005). Population trends for the northern Patagonian colonies have reached stable levels and they may be increasing (Quintana et al., 2006).

SGP from Arce and Gran Robredo Islands arrive at the colonies during early October and three weeks later, egg laying begins. Hatching takes place in late December and fledging starts mid March through late April (Copello and Quintana, 2009a). During the breeding season, adult birds widely use the Argentine shelf (south of 40°S) showing sexual segregation in the use of feeding areas (Quintana et al., 2010). The species has a crucial role in the Argentinean Sea mainly as scavengers but also as predators (Copello and Quintana, 2003; Forero et al., 2005; Copello et al., 2008; Raya Rey

\* Corresponding author.

E-mail addresses: [gblanco@cenpat.edu.ar](mailto:gblanco@cenpat.edu.ar), [gabrielasblanco@gmail.com](mailto:gabrielasblanco@gmail.com) (G.S. Blanco).

et al., 2012). Their diet is based mainly on carrion (sea lion, penguins and other flying birds) and cephalopods; with the squid *Illex argentinus* the most frequently consumed (Copello et al., 2008).

Most of the knowledge related to SGP at-sea behavior comes from studies on breeding adults from readily accessible colonies (González-Solís and Croxall, 2005; Copello and Quintana, 2009b; Quintana et al., 2010; among others). However, some information is available about non-breeding dispersal of SGP described through tracking or recapture of banded adults and juveniles (Tickell and Scotland, 1961; Hunter, 1984b; Keith et al., 2002; González-Solís et al., 2008; Copello et al., 2009; Thiers et al., 2014). Recapture studies are a useful tool to gain knowledge on animals that use their habitats at a broad scale, but this methodology only offers point to point information and presents difficulties in the recovery of individuals in open ocean (González-Solís et al., 2007). Moreover the results of such studies may be influenced by areas where recaptures are more likely such as fishing locations, highly populated coastal zones (where birds may wash ashore sick or dead) or countries that are characterized by high observer interest (Patterson and Hunter, 2000).

The use of tracking devices provides detailed information on the paths used for migration and individual migratory strategies allowing a more complete understanding on this stage of their life cycle (Weimerskirch et al., 2014). Thus, the objectives of this study were to analyze the movements of both juveniles and adults SGP and to determine areas of importance in terms of use during the non-breeding season. Also, we strived to reveal differences in the behavior of age classes analyzing their spatio-temporal relationship.

## 2. Materials and methods

### 2.1. Satellite telemetry

To study the movements of the SGP during non-breeding season, we deployed a total of 15 satellite transmitters (PTTs-100, “Platform Terminal Transmitters”, Microwave Telemetry, Columbia, MD, USA) in April 2005, 2006, 2007, and 2008. We instrumented

nine first year juveniles (hereafter juveniles, four females and five males) and six adults (three males and three females) from two neighboring colonies (separated only by 47 km): Isla Arce, 45°00' S; 65°29' W, and Isla Gran Robredo, 45°08' S; 66°03' W, at Patagonia, Argentina (Fig. 1a, Table 1) close to the end of the fledgling period (Copello and Quintana, 2009a). Adults and juveniles were captured from the nest indicating that adults had been successful breeders during that season. Sex of birds was determined by morphometric measurements according to discriminant functions obtained from individuals of the same colonies by Copello et al. (2006). The transmitters weighed 45 g, representing less than 2% of the body weight (see Copello et al., 2006). They were attached using Tesa Tape to the mid-dorsal mantle feathers following Wilson et al. (1997) and were programmed to transmit every 60 s with duty cycles of 8 h on – 19 h off to increase battery life. None of individuals equipped showed signs of discomfort due to the handling and attachment of devices, and to our knowledge they continued traveling normally during the study period. Adults birds were instrumented for (Mean  $\pm$  SD) 109.7  $\pm$  24.8 days (range: 77–151 days,  $N = 6$  birds, Table 1). In particular, juveniles departed from the colony 4  $\pm$  3 days after deployment. Eight of the nine tracked juveniles left the colony between April 23rd and April 26th independently of the year, the remaining individual left the colony on April 17th. This age class was tracked at-sea for 58.2  $\pm$  30 days (range 17–105 days,  $N = 9$  birds) (see Table 1).

Data on the geographic position of the instrumented animals were obtained from the ARGOS service provider (CLS, Toulouse, France). Each one of the obtained positions was automatically classified according to its estimated error [Type 0: >1500 m, Type 1: 500–1500 m, Type 2: 250–500 m, Type 3: 0–250 m and Type A or B: without an estimated error, Type Z: invalid location (Argos-CLS, 2011)].

### 2.2. Analysis of satellite data

We filtered Argos satellite data using the Argosfilter 0.62 Package for the R software package (R Development Core Team, 2008)

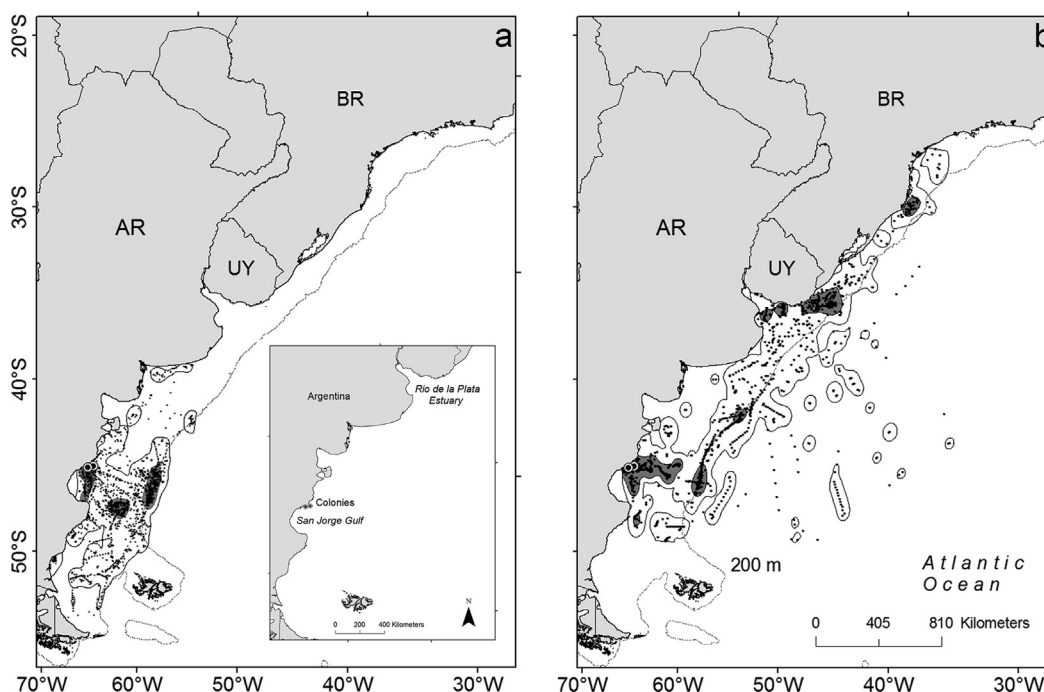


Fig. 1. Winter at-sea distribution and marine areas represented by 95% (white polygon) and 50% (dark gray polygon) Kernel Density Analysis used by adult (a) and juvenile (b) southern giant petrels, *Macronectes giganteus*. Circles indicate the location of colonies Isla Arce and Isla Gran Robredo. BR: Brazil, UY: Uruguay, AR: Argentina.

**Table 1**

Summary of satellite transmitters deployments on adult and juvenile southern giant petrels, *Macronectes giganteus*, from Isla Arce (45°00' S; 65°29' W), and Gran Robredo (45°08' S; 66°03' W) during the non-breeding period.

| Individual | Sex | Colony     | Breeding season | Stage    | Start tracking | End tracking | Total days recorded | Days at sea post-fledgling |
|------------|-----|------------|-----------------|----------|----------------|--------------|---------------------|----------------------------|
| 56,509     | M   | Arce       | 2004            | Juvenile | 21-Apr-05      | 12-May-05    | 21                  | 17                         |
| 56,505     | F   | Arce       | 2004            | Juvenile | 21-Apr-05      | 06-Aug-05    | 107                 | 105                        |
| 56,506     | M   | G. Robredo | 2004            | Adult    | 22-Apr-05      | 08-Aug-05    | 108                 | .                          |
| 56,507     | M   | G. Robredo | 2004            | Adult    | 22-Apr-05      | 20-Sep-05    | 151                 | .                          |
| 56,508     | M   | G. Robredo | 2004            | Adult    | 22-Apr-05      | 08-Jul-05    | 77                  | .                          |
| 44,281     | F   | G. Robredo | 2005            | Adult    | 24-Apr-06      | 23-Aug-06    | 121                 | .                          |
| 56,505     | F   | G. Robredo | 2005            | Adult    | 24-Apr-06      | 05-Aug-06    | 103                 | .                          |
| 39,791     | F   | G. Robredo | 2005            | Adult    | 24-Apr-06      | 31-Jul-06    | 98                  | .                          |
| 39,792     | M   | G. Robredo | 2005            | Juvenile | 24-Apr-06      | 13-Jul-06    | 80                  | 79                         |
| 44,282     | F   | G. Robredo | 2005            | Juvenile | 24-Apr-06      | 25-May-06    | 31                  | 29                         |
| 56,507     | F   | G. Robredo | 2006            | Juvenile | 17-Apr-07      | 18-May-07    | 31                  | 26                         |
| 56,509     | M   | G. Robredo | 2006            | Juvenile | 17-Apr-07      | 18-Jul-07    | 92                  | 83                         |
| 56,508     | M   | G. Robredo | 2006            | Juvenile | 17-Apr-07      | 22-Jun-07    | 66                  | 61                         |
| 79,964     | F   | Arce       | 2007            | Juvenile | 15-Apr-08      | 12-Jul-08    | 88                  | 79                         |
| 79,965     | M   | Arce       | 2007            | Juvenile | 15-Apr-08      | 01-Jun-08    | 47                  | 45                         |

developed by Freitas (2012). We used *sdfilter* function that uses an algorithm developed by Freitas et al. (2008). The algorithm removes location class = Z, and unrealistic locations based on the horizontal flying speeds. The flight speed threshold used for this species was 80 km/h (Spear and Ainley, 1997; González-Solís et al., 2000a). For all mapping, spatial referencing, and plotting of bird fixes we used ArcGIS 9.3 (www.esri.com).

### 2.3. Habitat use

The total area covered by each individual, age and sex classes was estimated using the Minimum Convex Polygon Analysis (Worton, 1989), which provides an acceptable measure of the minimum area covered by birds considering the outer most locations at sea. To analyze habitat utilization, we first re-sampled each individual's track every two hours to ensure that the individual variation in the number of daily transmissions did not influence the analysis (following BirdLife-International, 2004). Re-sampling of tracks was conducted using the *adehabitat* package for R using the function: *disltraj* (Calenge, 2006). We then calculated the contour areas used by adults and juveniles by conducting a fixed Kernel Density Analysis (KDA) using the least-squares-cross-validation method (LSCV) to calculate the smoothing factor (*h* of 50 km; Worton, 1989). The same smoothing factor was applied to both age classes in order to make them comparable. Contour areas were determined by the 50 and 95% Utilization Distribution (UD), output cell size was 5 km for both age classes. For these analyses we used Home Range Tools for ArcGIS (Rodgers et al., 2005).

To investigate the habitat utilization through time, we carried out KDAs for both age classes in periods of 30 days. These analyses were estimated categorizing fixes collected from 1 to 30 days, 31–60 days, and 61–90 days of tracking. We then analyzed the spatial overlap between them using the Spatial Analyst Tools for ArcGIS. Percentage of overlapped areas were calculated as the percentage of 50 and 95% UD of juveniles which intersected the 50 and 95% UD of adults, and the percentage of adult's areas that overlapped juveniles' utilization areas (González-Solís et al., 2000a).

### 2.4. Foraging behavior

Given that adult birds returned to the colony even during wintering (see results), we considered that a complete trip started when birds were 3 km away from the colony from a period of at least one day, following Quintana et al. (2010). These non-breeding

trips ended when the individual returned to an area less than 3 km away from the colony independently of the duration of the trip. For each trip performed by adult individuals we calculated trip duration, total distance traveled, and maximum distance to the colony (foraging range). We also derived the number of days at the colony between trips. Given that juveniles spread across the sea with no return to the colony (see results), for this age class, we recorded a single at-sea excursion during the entire sample period (up to 3.5 months). Thus, foraging variables reported for each juvenile, represent a single value derived from the period recorded at-sea rather than a mean value derived from the trips as the case of the adults. For both age classes, we also calculated the overall mean distance to the main marine areas (calculated as the mean of distances between the colony and the center of the 50% UD). Additionally, for juveniles we achieved a 30 day value of mean distance to the main marine areas (see above).

Means were determined for each individual and then pooled to calculate overall mean values. We then compared the MCP values between age classes, using a Wilcoxon MannWhitney Test. Data are expressed in  $X \pm SD$ .

## 3. Results

### 3.1. Habitat use

#### 3.1.1. Adults

During the first four/five months of the non-breeding period, adult SGP from the two colonies were widely distributed on the Argentine shelf. They reached approximately 38° S to the north, and the southernmost location recorded was at Tierra del Fuego (54° S) (Fig. 1a). Birds used closely 74% of the Argentine shelf (MCP: 741,318 km<sup>2</sup>). The total marine area used by adult females was only 11% greater than the used by adult males (MCP: 579,857 and MCP: 517,868 km<sup>2</sup>, respectively).

Utilization areas of adults during the studied period were estimated as kernel probability contours of 50 and 95% (Fig. 1a). Post-breeding adults spent 95% of their time at-sea in an area of 457,971 km<sup>2</sup>, which expands from the coast to the shelf break (Fig. 1a). They also used coastal, middle shelf and shelf break waters to the north (up to 39° S; 59° W, 840 km from the colony) and to the south (up to 53° S; 64° W, 960 km from the colony) (Fig. 1a). Three main marine areas (defined by the kernel contour 50%) were identified for SGP during the first four/five months of the non-breeding period: one situated at the shelf break, other in the middle shelf waters, and a third one at coastal waters surrounding the colony and the south of the San Jorge Gulf (Fig. 1a). The shelf break area

was located east of the colony at approximately 400 km from the nesting grounds; the middle shelf was the area among 47° S; 63° W between 250 and 300 km southeast of the nesting sites.

### 3.1.2. Juveniles

During their first at-sea excursion, juveniles SGP occupied an extensive region of the Southwest Atlantic, covering areas of the Argentine, Uruguayan and Brazilian shelves (Fig. 1b). Juveniles birds reached approximately 49° S; 62° W to the south, 42° S; 42° W to the west and the northernmost location recorded was at the south of Brazil at 25° S; 47° W (Fig. 1b). The total marine area (MCP) used by juveniles was 3,600,644 km<sup>2</sup>. The extent of the area used by juvenile males was 24% greater (MCP: 2,588,846 km<sup>2</sup>) than the area used by juvenile females (MCP: 1,966,700 km<sup>2</sup>).

Utilization areas of juvenile SGP after leaving the colony were estimated as kernel probability contours of 50 and 95% (Fig. 1b). Juveniles spent 95% of their time at-sea in an area of 913,300 km<sup>2</sup> which expands from the colony to the shelf break, reaching up to 2870 km northwards from the nesting grounds at the south of Brazil (Fig. 1b). Four main marine areas were identified for this age class: 1) a corridor between the colony and the middle shelf; 2) a shelf break area composed by two small regions situated approximately at 430 and 750 km west of the colony; 3) an Argentine/Uruguayan shelf area comprised by a wide region on the Uruguayan waters (1650 km from the colony) and two small at the Río de la Plata Estuary (1380 km from the colony); and 4) a South Brazilian shelf area at a distance of 2470 km from the breeding site (Fig. 1b).

### 3.1.3. Age segregation

Marine areas used by both age classes were clearly different. The extent of the area used by juveniles was 80% larger than the area used by non-breeding adults (MCP: 741,318 vs. 3,600,644 km<sup>2</sup>). The largest overlap corresponded to the activity range of 50% UD where almost 75% of juvenile areas intersected those of adults, and vice versa (Fig. 2). Spatial overlap only occurred during the first 30 days of at-sea dispersion where both age classes used the same region of the Argentine shelf (Fig. 2). When considering the 95% kernel contour, a smaller overlap was depicted, as 25% of the adult's area was occupied by juveniles, while adults occupied 20% of juvenile's area (Fig. 2). During the following 31–60 days of tracking (see methods), there was no spatial overlap among age classes given that adults remained in the same areas and juveniles moved northwards (Fig. 2). We found the same pattern during the third month (see methods), in which juveniles reached areas even farther north (Fig. 2).

## 3.2. Movement patterns

### 3.2.1. Adults

The non-breeding adult SGP of both sexes alternated at-sea excursions with periods at the colony (Fig. 3a). Only one individual (ID: 56508) moved south following the coast up to 50° S and did not visit the colony after the breeding season during the 77 days of tracking. Although duration of trips was extremely variable (range: 3–81 days), on average, the non-breeding adults alternated trips of  $12 \pm 5$  days with periods of  $3 \pm 0.3$  days at the colony where, 87% of the non-breeding trips lasted less than 15 days. During the total tracking period (77–151 days), adult birds remained in areas relatively close to the colony with no birds performing long distance wintering migrations. The maximum distance traveled from the nesting sites was 973 km but, on average, adult birds moved a maximum of  $826 \pm 134$  km away from their colonies (Table 2). However, the overall mean distance to the main marine areas for non-breeding adults was  $323.4 \pm 144.7$  km.

### 3.2.2. Juveniles

Once juveniles left the islands after fledgling, they did not return to the nesting grounds for the entire tracking period ( $81.4 \pm 36.7$  days; Fig. 3b). Instead, they dispersed by moving at first directly to the edge of the Argentine shelf, where they started showing evidence of foraging behavior. Once reached the shelf break, they traveled northwards using the edge of the shelf as a corridor (Fig. 3b), and gradually moved away from the breeding grounds performing long distance wintering migrations. Only one individual (ID: 56508 see Table 1), after reaching the Uruguayan shelf break, started moving east, in what it could have been a trans-Atlantic migration. The maximum distance traveled from its colonies was almost 3000 km but, on average, birds moved  $1776 \pm 876$  km away from the islands during the study period at an average rate of  $92 \pm 22$  km/day. The overall mean distance to the main marine areas for juveniles was  $917.9 \pm 677.4$  km and varied greatly between months, increasing with time ( $476.6 \pm 565.8$  km for the first 30 days of tracking,  $1514.8 \pm 510.7$  km from 31 to 60 days, and  $2037.0 \pm 498.2$  km from 61 to 90 days of tracking).

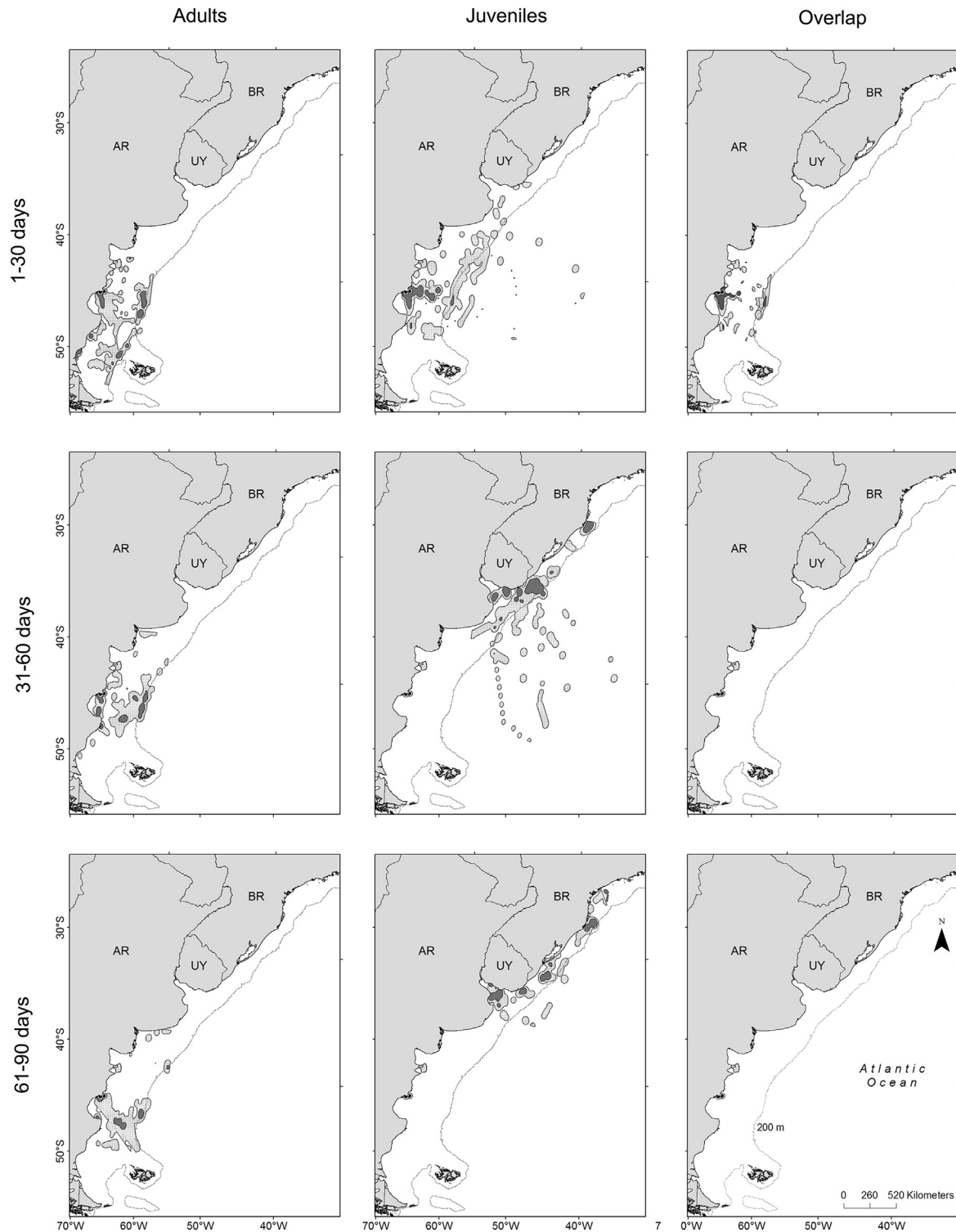
## 4. Discussion

Most pelagic seabirds such as albatrosses and large petrels spend most of their time at sea during non-breeding periods, have a broad at-sea distribution and return to land only at time of reproduction (Croxall et al., 2005). During the last 10 years, telemetry studies reinforced the information on the distribution of non-breeding adults and on early life-history stages for a considerable number of albatrosses and petrels (Croxall et al., 2005; Copello et al., 2013; Åkesson and Weimerskirch, 2014; Gutowsky et al., 2014; Thiers et al., 2014; Weimerskirch et al., 2014). Despite of this, telemetry studies on SGP during non-breeding period are scarce and represent a gap in the knowledge on the ecology of this species (see Thiers et al., 2014). Here we presented insights on at-sea distribution and foraging behavior of post-fledging juvenile and adult SGP during the non-breeding period from two colonies of northern Patagonia.

### 4.1. Habitat use and foraging behavior

Wintering adult SGPs were widely distributed over the Argentine shelf during the study period, but did not perform long distance migrations. The utilization areas of adult birds identified in the current study were similar (albeit 26% larger) as those during the breeding period (Quintana and Dell'Arciprete, 2002; Quintana et al., 2010). The use of the same areas all year-round does not appear to be common into the Procellariiform group (i.e. SGP (Thiers et al., 2014); wandering albatrosses, *Diomedea exulans* (Weimerskirch et al., 2014); white-chinned petrels, *Procellaria aequinoctialis* (Phillips et al., 2006); among others). However, it has been reported for specific populations such as shy albatrosses, *Thalassarche cauta*, from Albatross Island, which spend the breeding and non-breeding period in Tasmanian waters (Hedd and Gales, 2005). Similarly, Raya Rey et al. (2012) suggested through the study of stable isotopes that SGP breeding at Observatorio Island (southern Patagonia) forage year-round over similar areas (sub-tropical waters and continental shelf). On the contrary, SGP females from Crozet Islands seem to use larger areas during non-breeding periods within the Indian Ocean (Thiers et al., 2014). A similar pattern was described for the Barolo Shearwater, *Puffinus baroli baroli*, which extends 10-times their foraging areas during the non-breeding period (Neves et al., 2012). The fact that adults remained at the Argentine shelf could be explained by the existence of a trophic offer in the area, demonstrated by the presence of several species of marine top predator foraging at the Argentine shelf



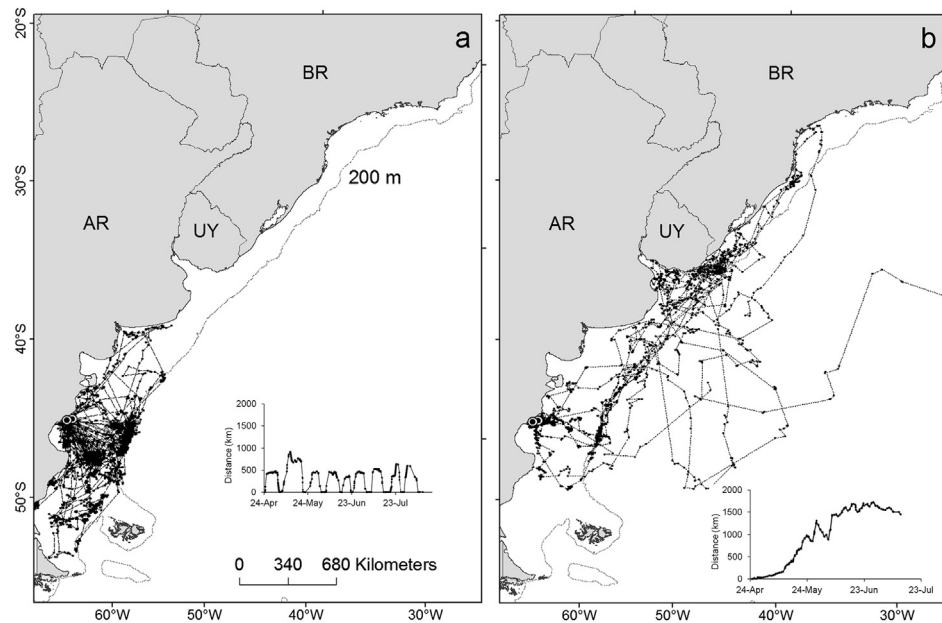


**Fig. 2.** Winter at-sea distribution of adult and juvenile southern giant petrels, *Macronectes giganteus*, from 1 to 30, 31–60, and 61–90 days of tracking and areas of overlap of 50% (dark grey) and 95% (light grey) kernel contours. BR: Brazil, UY: Uruguay, AR: Argentina.

(Croxall and Wood, 2002; see below). In such case, migration may not be necessary for adult birds.

The at-sea movements of adult SGP from Isla Arce and Gran Robredo during the non-breeding season were also similar to that reported during the breeding stage (Quintana et al., 2010). Adults basically performed round trips between the colony and the areas of high intensity of use (50% Kernel contours, presumably foraging

areas), alternating short stays at the colony. Records of Procellariiformes returning and staying at the colony during winter are rare. However, this particular case was previously reported by Hedd and Gales (2005) for shy albatrosses, and authors suggested that the time spent in the colony during the winter could be beneficial (but not an ultimate explanation) to defend nesting sites and strengthen pair bonds. Although, in this specific case, the existence of round



**Fig. 3.** At-sea movements of adult (a) and juvenile (b) southern giant petrels, *Macronectes giganteus*, during the non-breeding period. The insert-graph shows an example of trips performed by adults (a) and juveniles (b). BR: Brazil, UY: Uruguay, AR: Argentina.

trips to the colony (even when they are not obligated central place foragers), may be associated to the proximity of colonies to marine areas where the birds feed and presumably, with abundant food resources during the whole year (see below). This seems to be the case of the shy albatrosses whose sedentary behavior suggests a year-round prey availability off southwest Australia (Hedd and Gales, 2005). Besides this, the relative proximity of the colonies to the preferred foraging areas may offer extra time to rest considering that sitting on land is less costly in terms of energy than resting at the sea surface (Luna-Jorquera and Culik, 2000; Humphreys et al., 2007; Weimerskirch et al., 2007).

Satellite tracking of juvenile SGP from Isla Arce and Gran Robredo showed wide at-sea dispersion to distant locations, more than 1500 km to the north of the breeding grounds. These long northward movements were made primarily along the shelf break and the utilization areas with higher concentrations of juveniles were mainly restricted to waters with upwelling zones, such as the Río de La Plata estuary off Argentina and Uruguay, and Cape Santa Marta Grande upwelling (28°S; 48°W) in Brazil (Acha et al., 2004). During the austral winter, juvenile SGP appear to be clearly associated with highly productive marine areas. A same at-sea distribution pattern was described for SGP fledglings from records of birds banded in sub-Antarctic Islands and recovered exclusively in areas of productive upwelling (van den Hoff, 2011). However, any conclusion about a preference for upwelling areas derived from banded studies should be taken with caution

because locations reported there may be biased by high recapture areas (see Section 1).

The at-sea movements of young birds from other species were also associated to high productivity areas, for example, juvenile northern royal albatrosses, *Diomedea sanfordi*, after fledging on Taiaroa Head, New Zealand undertake trans-Pacific migrations to the highly productive (due to the Humboldt current) shelf break off Chile (Thomas et al., 2010). On the contrary, juvenile SGP tracked from Crozet Islands made long circumpolar migrations exploring waters of the Southern Oceans (Thiers et al., 2014). Likewise, post-fledging SGP from Macquarie Island move in an easterly direction to South America and band recovery suggests that in some cases they also perform circumpolar journeys (Trebilco et al., 2008).

All juvenile SGP first moved eastward to the shelf break where they presumably started foraging; subsequently, they continued moving northwards using the shelf break mostly as a corridor to reach their foraging grounds. This particular at-sea performance does not seem to be erratic and was clearly different to that suggested for juveniles SGP and wandering albatrosses from Antarctic colonies, which initially disperse in several directions until they finish up using the adults' wintering areas (Åkesson and Weimerskirch, 2005; van den Hoff, 2011).

Although, the distances traveled by juvenile SGP to the main utilization areas were much longer than those traveled by adults, they were shorter than those reported for juvenile SGP banded in Crozet Islands by means of comparable telemetry techniques

**Table 2**

At-sea excursion of non-breeding adult southern giant petrels, *Macronectes giganteus*, during winter. Individual 56508 did not return to the colony during the 77 days of tracking. Data are expressed in Mean  $\pm$  SD.

| Individual    | Sex | Trips recorded | Days at colony | Trip duration (days) | Total distance traveled (km) | Maximum distance to colony (km) |
|---------------|-----|----------------|----------------|----------------------|------------------------------|---------------------------------|
| 56,506        | M   | 9              | 3.1 $\pm$ 1.3  | 7.9 $\pm$ 2.7        | 1354.3 $\pm$ 634.9           | 921                             |
| 56,507        | M   | 5              | 3.8 $\pm$ 1.8  | 21.3 $\pm$ 29.8      | 2486.6 $\pm$ 2801.1          | 973                             |
| 56,508        | M   | —              | —              | —                    | —                            | 697                             |
| 39,791        | F   | 7              | 3.2 $\pm$ 1.2  | 10.3 $\pm$ 8.11      | 1353.4 $\pm$ 1184.0          | 716                             |
| 44,281        | F   | 7              | 3.1 $\pm$ 1.3  | 12.3 $\pm$ 6.34      | 2240.8 $\pm$ 1104.0          | 947                             |
| 56,505        | F   | 9              | 2.9 $\pm$ 2.3  | 8.1 $\pm$ 6.9        | 386.4 $\pm$ 404.2            | 701                             |
| Mean $\pm$ SD |     |                | 3.2 $\pm$ 0.3  | 11.9 $\pm$ 5.5       | 1564.3 $\pm$ 834.3           | 825.8 $\pm$ 133.9               |

(Thiers et al., 2014). Reports of juvenile birds banded in South Georgia and Antarctic Islands indicated mean distances higher than 9000 km, with some birds covering such distances during the first month after fledging (Patterson and Hunter, 2000). Likewise, Thiers et al. (2014) described long circumpolar journeys after fledging. Our findings further agree with previous studies on band recoveries of juvenile SGP from the northern Patagonian colonies described by Copello et al. (2009), where most of the recaptures (83%) were at Argentinean, Uruguayan, and Brazilian waters, at a distance <3500 km from the colony. However, some recaptures were made at Australia and New Zealand, indicating that some juveniles from northern Patagonian colonies may perform longer trips than the ones reported here. Furthermore, the movement of one of the tracked juvenile of this study may indicate an initial trans-Atlantic migration (see Fig. 3b). In addition, we should state that in our study, juveniles were tracked for a maximum of 3.0–3.5 months, and subsequently some might have travelled further away after this period. Therefore, we believe that by increasing our sample size or tracking time, different juveniles foraging grounds may be found, but the general conclusion of most of the individuals remaining in South American waters is consistent.

To some extent, winter use of the waters of the Argentine shelf and the shelf break, and even those corresponding to southern Brazil and Uruguay was not surprising. The entire Argentine shelf and its areas of influence are widely used by different species of albatrosses and petrels and are internationally recognized as important marine areas for the conservations of this group of birds (Birdlife-International, 2004; Favero and Silva Rodríguez, 2005; Favero et al., 2013). The use of this part of the South Atlantic Ocean has been described for other species nesting in near colonies (Pütz et al., 2002; Copello et al., 2013) as well as those located in remote nesting sites (González-Solís and Croxall, 2005; Phillips et al., 2006; Bugoni et al., 2009; Mackley et al., 2011). The area is also important for marine mammals such as sea lions, elephant seals (Campagna et al., 2001, 2006) and cetaceans (Croxall and Wood, 2002). The observed habitat use pattern of wintering SGP, added to the foraging coexistence of at least other 40 species in the Argentine shelf and surroundings (Yorio and Caille, 1999), suggests the existence of an important source of food throughout the year. This could be explained by the oceanic characteristics of these marine areas, which have high primary productivity as a result of the presence of nutrient-enhanced waters (Romero et al., 2006), tidal fronts, and convection mixing at the mid-shelf (Acha et al., 2004). Additionally to the permanent front of the shelf break (Acha et al., 2004), the high abundance of squid, *Illex argentinus*, (Brunetti et al., 1998; Sacau et al., 2005), and the abundant food supply from fisheries discards (Dato et al., 2006; Favero et al., 2011, 2013). All these characteristics together, offer a suitable marine environment for foraging, which may be one of the reasons why SGP from northern Patagonian colonies spend all year-round mostly within the Argentine shelf.

#### 4.2. Habitat segregation

At-sea movements and foraging patterns of adults and juveniles during the non-breeding season was markedly different. During the course of this study, the main areas used by adults and juveniles only overlapped at the shelf break during the first month of tracking developing subsequently a pronounced age segregation with time. During the first month at sea, the shelf break was probably the best possible place of foraging for both age classes because of the proximity to the colonies and the high prey availability (Brunetti et al., 1998; Sacau et al., 2005). The overlap in the first month was less than 25% (see results) but may constitute a

potential for intra-specific competition, where juveniles could have been displaced by adults after reaching the shelf break, causing them to move gradually to the north. This idea was recently highlighted by (Gutowsky et al., 2014) who suggested that juvenile black-footed albatrosses, *Phoebastria nigripes*, move to less productive waters than adults, resulting in an ontogenetic niche divergence, possibly produced by historical competitive exclusion by experienced adults. Age class competition was also previously suggested by Weimerskirch et al. (2006) indicating that dispersal of juveniles may be a result of competition with adults for resources. Åkesson and Weimerskirch (2005) even mentioned the presence of a genetically encoded behavior selected to avoid competition that will cause the dispersion of juveniles to more distant, safe, and suitable feeding grounds (Weimerskirch et al., 2006; Åkesson and Weimerskirch, 2014). On the other hand, size of individuals may play a primary role in competition over food as demonstrated between males and females SGP (González-Solís et al., 2000b; Thiers et al., 2014). Although juveniles and adults SGP are of similar overall body size, bill and wings are larger in adults (Copello et al., 2006), suggesting that size may at least be part of this competition. Therefore, we believe that the small overlap between age classes and the consequent behavioral differences may be a consequence of the interaction between adults and juveniles; where more experienced adults are able to optimize foraging behavior being more successful in gaining food than naive juveniles, causing the displacement of this last group and forcing them to develop different foraging strategies.

#### 4.3. Conservation issues

Although world SGP population trend is increasing (BirdLife International, 2012), trends vary among regions and colonies (Patterson et al., 2008). For example, Patagonian colonies are increasing in numbers, and that increase has been partially attributed to the increase in additional food supply by discard of fisheries operating at the Argentine shelf where the fishery industry has increased 60% from 2000 to 2009 (Copello and Quintana, 2009b). The fact that this population uses high productivity areas during breeding periods and does not need to migrate long distances to reach their preferred foraging grounds even during the non-breeding period, may help to maintain the observed increase. The results of this study provided new insights on the use of marine areas for adults and juveniles of the SGP. This information covers a lack of knowledge recognized as a key to the conservation of albatrosses and petrels (Birdlife-International, 2004; ACAP, 2011). Also, our results offered important facts to protect critical marine sites for the conservation of one the most threatened group of seabirds. The identification of migratory routes and foraging areas of non-breeding SGP is essential not only for the conservation of the species but also to manage and protect marine areas globally recognized as important for many other species of albatrosses and petrels.

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