Characterization of the seascape used by juvenile and wintering adult Southern Giant Petrels from Patagonia Argentina

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ABSTRACT

The characterization of the seascape used by marine top predators provides a wide perspective of pelagic habitat use and it is necessary to understand the functioning of marine systems. The goal of this study was to characterize the oceanographic and biological features of marine areas used by adult and first year juvenile southern giant petrels (SGP, *Macronectes giganteus*) from northern Patagonian colonies (Isla Arce and Gran Robredo) during the austral fall and winter (2005, 2006, 2007, and 2008). The marine environment exploited by the SGP was characterized using sea surface temperature (SST), SST gradients, chlorophyll-a concentration, water depth, oceanographic regimes, and ocean surface winds. In addition, the biological seascape was defined by considering the distribution of squid during the months of study. Juveniles SGP exploited a wide range of environments focusing mainly on productive neritic waters using a variety of oceanographic regimes. Juveniles were exposed to eutrophic and enriched waters, probably because of the frequent presence of thermal fronts in their utilization areas. Adults' environments lacked of thermal fronts remaining the majority of their time within the oceanographic regime "Continental Shelf", in water depths of 100—200 m, exploiting mesotrophic and eutrophic environments, and remaining in areas of known food resources related to the presence of squid. For the most part, juveniles were exposed to westerly winds, which may have helped them in their initial flight to the shelf break, east of the colony. Wintering adults SGP also explored areas characterized by westerly winds but this did not play a primary role in the selection of their residence areas. Juveniles during their first year at sea have to search for food exploring a variety of unknown environments. During their search, they remained in productive environments associated to fronts and probably also associated to fisheries operating in their foraging areas. The understanding of pelagic birds' habitat selection and preferences through the year is crucial for the monitoring of anthropogenic impacts over these species. Further studies should focus on the prediction of variables that determine the distribution of these species though the year and during different life stages.

1. Introduction

The marine environment of continental shelves of Southwestern Atlantic is characterized by abundant coastal fronts, covering numerous scales of space and time. These front patterns are part of the complexity of this pelagic area at the seascape scale, and play a major role in the ecological processes of the ocean allowing for an extraordinarily large primary production (Acha et al., 2004). At the Southwestern Atlantic Ocean, the most important feature is the

Brazil—Malvinas confluence (BMC) which generates an intense and highly variable thermohaline front (Legeckis and Gordon, 1982). The instabilities caused by the interaction between the warm Brazil Current (BC) and the cold Malvinas Current (MC) results in meso-scale features such as meanders and eddies (Legeckis and Gordon, 1982; Lentini et al., 2006). In the Argentine Continental Shelf (ACS) many frontal systems are produced in summer due to tidal mixing, continental runoff and surface heat flux (Acha et al., 2004); but several of these vanish during winter (Rivas and Pisoni, 2010). The shelf-break front separates the MC and ACS waters. The MC provides nutrient rich subpolar waters at the northern most latitude in the southern hemisphere (Piola et al., 2013), creating a region of high biological activity (Longhurst, 1998; Romero et al., 2006) and

significant fisheries resources (Acha et al., 2004). This outstanding feature is not only exploited by squid fishing vessels over the shelf-break (Rodhouse et al., 2001), but serves also as a feeding area for many species of pelagic birds throughout the year (Croxall and Wood, 2002; Croxall et al., 2005; Mackley et al., 2010; Copello et al., 2011, 2013; Thiers et al., 2014). The freshwater discharge of La Plata river (~23,000 m^3 s^{-1}, (Piola et al., 2008)) is the major freshwater inflow into the Southwestern Atlantic recorded. The intense salinity front associated with the Plata plume (Simionato et al., 2001) reaches ~1000 km northward from the estuary in winter, when the northeastward wind prevail (Piola et al., 2008).

Understanding the processes that determine the distribution of organisms is a key topic in ecology. The characterization of the seascape used by marine top predators provides a wide perspective of pelagic habitat use and is crucial to understand the range of their distribution (Louzao et al., 2011). Moreover, knowing how top predators use their environment at individual and population level is necessary to understand the functioning of marine systems, specially the interactions between large scale dynamic of predators and the lower trophic levels (González-Solís et al., 2007). When little is known about the ecology of a species, models can be used to predict distribution of animals in relation to the characteristics of the environment (Redfern et al., 2006). Animals inhabiting marine environments at high latitudes are exposed to heterogeneous resources varying in space and time (Bost et al., 2009). Due to this variability of resources; pelagic animals are able to track highly productive areas generating changes in their migratory strategies and marine distribution depending on food availability (Péron et al., 2010).

The Southern Giant Petrel (SGP, *Macronectes giganteus*) is a wide ranging Procellariiform with a circumpolar breeding distribution restricted to the Southern Ocean (Hunter, 1984) considered one of the main scavenger and predator of the Southern Atlantic Ocean (Copello et al., 2008). In Patagonia Argentina, they breed at four colonies, two of them are located at Chubut province (Isla Arce and Isla Gran Robredo) and the other two are situated at Tierra del Fuego, Isla de los Estados (Quintana et al., 2006; Copello and Quintana, 2009a). The Patagonian colonies are surrounded by temperate waters, contrarily, most of the SGP colonies worldwide are located in cold Antarctic and Subantarctic waters (Patterson et al., 2008); this characteristic makes the SGP population from Patagonian colonies distinctive.

Adult SGP from Patagonian colonies spend all year-round within the ACS; while juveniles after fledging move northwards reaching Brazilian waters (Petry et al., 2010; Quintana et al., 2010; Blanco and Quintana, 2014). In previous studies, Copello et al. (2011) characterized the oceanographic landscape used by adults SGP from Patagonian colonies during the breeding period; demonstrating that birds spent most of their time at high productive waters associated to oceanic fronts. The goal of this study was to characterize the oceanographic and biological features of the marine areas used by adults and first year juveniles SGP from Islas Arce and Gran Robredo during the austral fall and winter.

2. Materials and methods

2.1. At sea movements and distribution

Movements of SGP during winter were studied using satellite telemetry. We deployed 15 satellite transmitters (PTTs-100, "Platform Terminal Transmitters", Microwave Telemetry, Columbia, MD, USA) to nine first-year juveniles (hereafter juveniles, four females and five males) and six adults (three males and three females). Animals were fitted with satellite transmitters at the end of the breeding period in April 2005, 2006, 2007, and 2008 at two neighboring colonies: Isla

Arce, 45°00′ S; 65°29′ W, and Isla Gran Robredo 45°08′ S; 66°03′ W, in Patagonia, Argentina. Sex of birds was determined using morphometric measurements according to discriminant functions described by Copello et al. (2006). Transmitters were attached using Tesa Tape to the mid-dorsal mantle feathers following Wilson et al. (1997) and weighed 45 g, representing less than 2% of the body weight (see Copello et al., 2006). Juvenile birds were tracked at sea for 58.2 ± 30 days (range 17–105 days) and adults were instrumented during 109.7 ± 24.8 days (range: 77–151 days). The data set used and analyzed in this study derived from the same general database used in previous studies on the same species (Blanco and Quintana, 2014; see Supplementary Fig. 1).

SGP location data were filtered using the *argosfilter package* for the R software (R Development Core Team, 2008; Freitas, 2012). We used *sdafilter function* that uses an algorithm developed by Freitas et al. (2008) that removes unrealistic locations based on the horizontal flying speeds. The flying speed threshold for the species was 80 km h^{-1} (Spear and Ainley, 1997). Each individual track was then re-sampled every one hour to ensure that individual variation in the number of transmissions did not influence the analysis; re-sampling of tracks was conducted using the *adehabitat package* for R using the *disltraj function* (Calenge, 2006). Additionally we calculated the flying speed and turning angle between consecutive locations using the *argosfilter package* for R.

In order to discriminate different stages at sea (residence and displacement) during the tracking period, we used the flying speed and turning angle (Awkerman et al., 2005). We calculated the normalized cumulative frequencies of flying speed with resolution of 1 km h^{-1}. The cumulative histogram showed two different categories (see Supplementary Fig. 2a). One of them, with high percentage of occurrence at low flight speed (referred to residence) and one with low percentage of occurrence at high flight speed (referred to displacement). The threshold to separate both categories was defined as the flight speed in the cumulative frequency plot that minimized the distance to the extreme (0 km h^{-1}, 100%, Supplementary Fig. 2a). The threshold for the flying speed was 12 km h^{-1} (which equals to 15 when flying speed is normalized from 0–80 km h^{-1} to 0–100 km h^{-1}). The same process was carried out for the turning angle (at 1° resolution). Again, two categories were depicted from the cumulative histogram; one with high percentage of occurrence at low turning angles and the other with low percentage of occurrence at high values of turning angles (Supplementary Fig. 2b). The threshold for this variable was 48° (which equals to 26 when turning angle is normalized from 0–180° to 0–100°). Therefore, we considered that fixes with flying speeds ≤12 km h^{-1} and turning angles ≥48° indicated residence behavior and those with flying speeds ≥12 km h^{-1} and turning angles ≤48° were classified as displacement (Supplementary Fig. 3). Overall, we obtained 17% of the juveniles' fixes classified as displacement and the remaining 83% were classified as residence. This pattern was repeated for adults where 20% of all fixes were classified as displacement whereas 80% were classified as residence.

For all mapping, spatial referencing, and plotting of bird tracks we used ArcGIS 9.3 (www.esri.com).

2.2. Oceanographic variables

The marine environment exploited by the SGP was characterized using sea surface temperature (SST), SST gradients, chlorophyll-a concentration, water depth, oceanographic regimes, and ocean surface winds. SST data were obtained from MODIS/Aqua sensor, with a spatial resolution of 4 km (Physical Oceanography DAAC, http://podaac.jpl.nasa.gov/). Since high biological production is usually related to the occurrence of ocean fronts (Franks,

1992; Mann and Lazier, 1996; Acha et al., 2004), thermal fronts using horizontal gradients of the monthly SST were detected. SST derivatives were computed using a centered difference scheme in both directions, zonal and meridional. The monthly gradient intensity was calculated for each grid point. Before calculating the

derivatives, temperatures were smoothed using a third-order Gaussian filter (Nixon and Aguado, 2008).

Chlorophyll-a images were obtained from Garver-Siegel-Maritorena (GSM) product (Maritorena et al., 2002). This product is a binned imagery from SeaWiFS and MODIS-Aqua sensors, with a
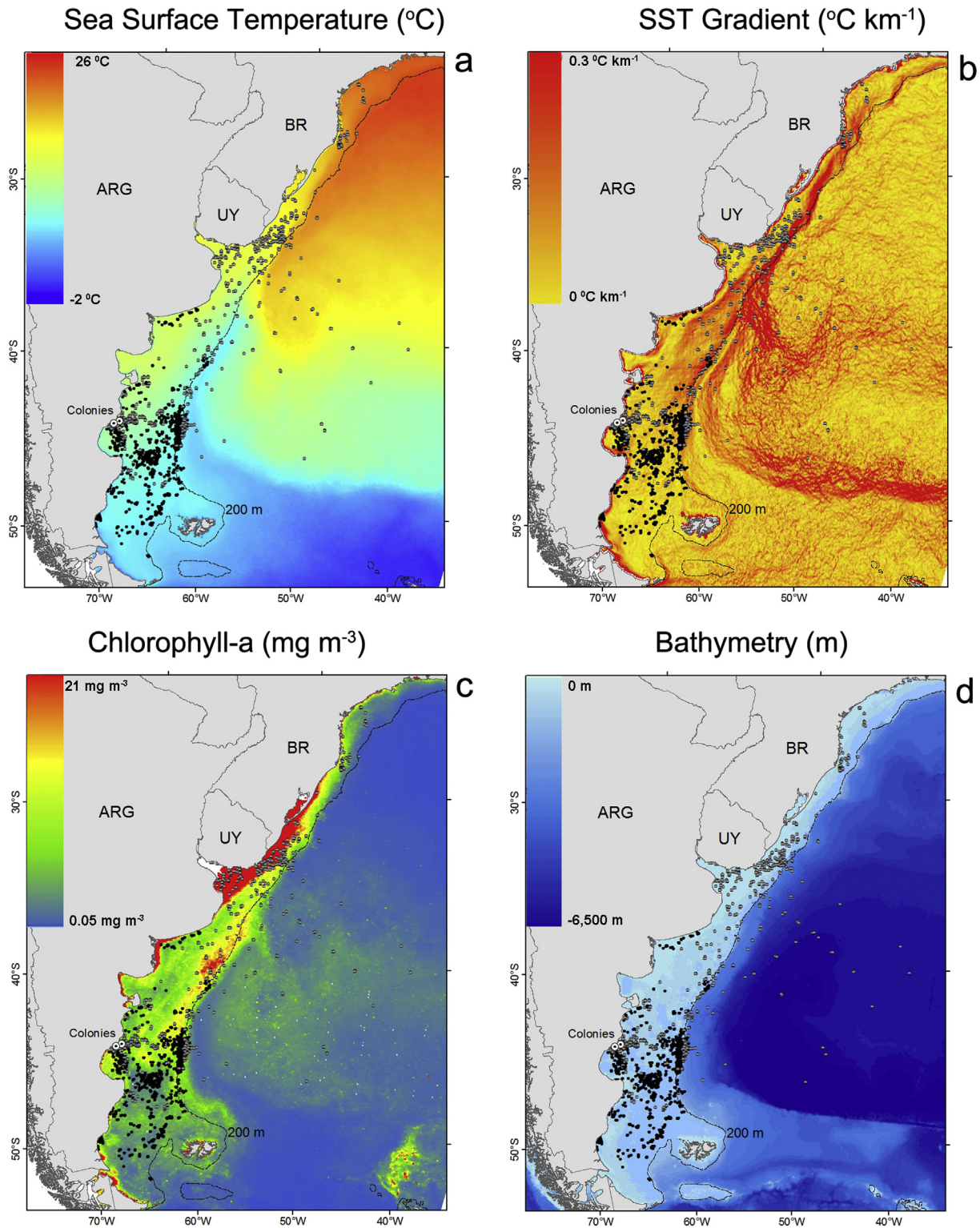

Fig. 1. Distribution of satellite tracked first-year juveniles (gray dots) and adults (black dots) Southern Giant Petrel (*Macronectes giganteus*) during residence behavior in relation to (a) mean sea surface temperature (SST) during the study period at 4 km spatial resolution, (b) mean SST gradients (thermal fronts) during the study period at 4 km spatial resolution, (c) mean chlorophyll-a concentration during the study period at 9 km spatial resolution; and (d) bathymetry at 2 km spatial resolution. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

spatial resolution of 9 km. During winter, chlorophyll-a images for each sensor at a higher resolution (i.e. 4 km) have several gaps in the data due mainly to cloud cover and low sun angles (Yoder and Kennelly, 2003). For that reason 9 km resolution images were used to determine habitat characteristics, and although at a smaller resolution, we believe that these images provided a representative scenario of the environment utilized by the SGP. Both variables (SST and chlorophyll-a) have monthly temporal resolution and the images corresponded to autumn–winter 2005 to 2008, which overlay with the SGP tracking period. Bathymetry was obtained from the GEBCO data base (General Bathymetry Chart of the Oceans, www. gebco.net) with spatial resolution of 2 km.

Oceanographic regimes were adapted for the austral winter from Piola and Falabella (2009) by calculating the average SST of July from the years of tracking (2005–2008). This showed the presence of different oceanographic regimes based on the properties of surface waters, ocean fronts, and marine circulation. Thus, we considered seven oceanic regimes for winter: Subtropical, Subpolar, Mixed (of the two previous regimes), Plata, El Rincón, Continental Shelf, and Magellan.

Sea surface winds were obtained from PO.DAAC, Cross-Calibrated, Multi-Platform Ocean Surface Wind Product, CCMP (ftp://podaac.jpl.nasa.gov/ocean_wind/ccmp/). This product is a 5-day composite with a spatial resolution of 25 km. Each composite included zonal and meridional components, from which wind direction and wind speed were calculated.

We calculated the percentage of time that birds spent in areas of particular SST, SST gradient, chlorophyll-a, water depth, wind speed, wind direction, and in oceanographic regimes. In order to describe SST areas we defined eight temperature ranges: 0-1, 1-4, 4-8, 8-12, 12-15, 15-19, 19-23, and 23-27 °C. Three ranges of SST gradients were defined as: non-thermal fronts ($0-0.05$ °C km^{-1}); transition ($0.05-0.08$ °C km^{-1}) and thermal fronts (>0.08 °C km^{-1}) based on previous knowledge of frontal systems in the region (Saraceno et al., 2004; Rivas and Pisoni, 2010). Considering the low dimension of frontal areas, for the variable SST gradient, the percentage of time that birds spent in the different SST gradients was standardized by dividing the total time

by the average of SST gradients for the study period (No Frontal: 84.2%, Transition: 10.3%, Frontal: 5.5%). Four productivity regimes were considered following Hyrenbach et al. (2002) and Copello et al. (2011) based on chlorophyll-a concentrations: oligotrophic (<0.1 mg m^{-3}), mesotrophic ($0.1-0.3$ mg m^{-3}), eutrophic ($0.3-1$ mg m^{-3}), and enriched (>1 mg m^{-3}). In order to relate the SGP utilization areas with water depth, four bathymetric domains were defined based on the gentle bottom slope around the ACS and the abrupt increase of depth of the shelf break (<100 m, $100-200$ m, $200-1000$ m, and >1000 m) (see Copello et al., 2011). Finally, wind speed was discretized every 1 m s^{-1} based on the speeds that occurred during the study period (from 0 to 15 m s^{-1}). Wind direction was divided into eight categories in a range of 45° according to the oceanographic convention. All oceanographic variables were mapped and analyzed using ArcGIS 9.3 (extensions *Multidimension* and *Spatial Analyst*).

Only those locations classified as residence were considered to calculate the percentage of time that birds spent in those oceanographic features. Each individual track was first divided monthly; then we overlaid the residency locations with the variable (grid image) that corresponded to the same month and year. Each residence location was then assigned with a value of SST, chlorophyll-a, SST gradient, depth, and oceanographic regime using the tool *Spatial Analyst* for ArcGIS. Similar methodology was employed to determined wind characteristics to which birds were exposed. As mentioned before, grid images for winds (wind speed and wind direction) were obtained in a 5-day composite; therefore, locations of each individual were divided in 5 day segments and then overlaid with the grid image which overlapped in space and time. This process was also repeated for the locations indicating displacement.

A Wilcoxon Mann–Whitney Test was used to determine statistical difference between age classes for each oceanographic variable. Data are expressed in X ± SD.

2.3. Biological landscape

The main prey item described for SGP of Isla Arce and Gran Robredo is the squid (*Illex argentinus*) (Copello et al., 2008). During
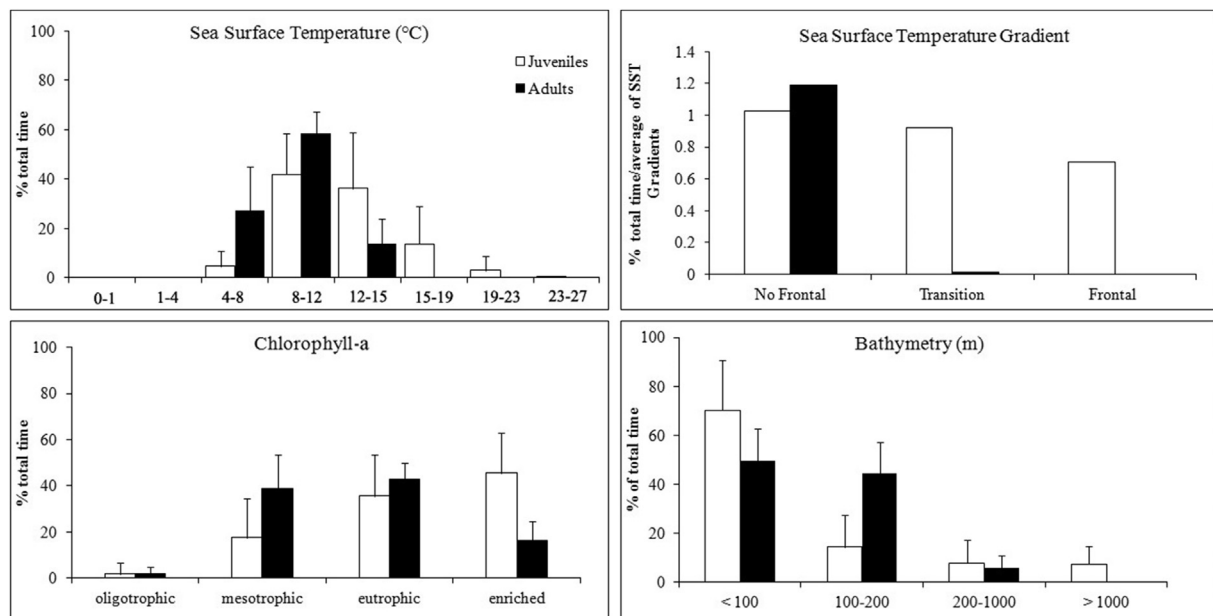

Fig. 2. Percentage of time spent by first year juveniles and adults Southern Giant Petrel (*Macronectes giganteus*) at sea surface temperature (SST) ranges, chlorophyll-a concentrations, and bathymetric domains. Frontal systems (SST gradients) were standardized by dividing the total time by the average of SST gradients for the study period (No Frontal: 84.2%, Transition: 10.3%, Frontal: 5.5%).

the breeding season SGP also feed on carrion at Magellanic Penguin (*Spheniscus magellanicus*), and Southern Sea Lion (*Otaria flavescens*) colonies (Copello et al., 2008). During winter, penguins and sea lions are not breeding; therefore there are not breeding aggregations of these species in the surroundings of the SGP colonies and carrions are not easily available for these birds. For that reason, we defined the biological landscape by considering only the distribution of squid during the months of study. Maps of squid stocks were created using records of abundance and distribution from Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP, Argentina) adapting fall and winter distribution of squid stocks from Brunetti et al. (1998). To determine the percentage of overlap between SGP and squid distribution we first classified locations for both age classes in fall (April, May, June) and winter (July, August, September). Contour areas (95%) used by birds during fall and winter were obtained 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). We then calculated the percentage of spatial overlap between SGP core areas and squid stocks distribution. For these analyses we used the *Analysis Tools* and the extension *Home Range Tools* for ArcGIS (Rodgers et al., 2005).

3. Results

3.1. Sea surface temperature and SST gradients

During their first at sea incursion, juveniles from Isla Arce and Gran Robredo resided in marine areas with SST that ranged between 4 and 27 °C (Fig. 1a), although they spent 78.4% of the tracking time between 8 and 15 °C (Fig. 2). Wintering adult birds used remained in waters of SST between 4 and 15 °C, where they spent more than half of their tracking time in temperatures between 8 and 12 °C (58.5% ± 8.7%) using a smaller SST range than juveniles. Despite the fact that juveniles spent time in higher temperatures than adults (Figs. 1a and 2), there were not statistical differences between the temperature ranges used by both age classes (W = 26, p > 0.05).

During the study period, juveniles distributed over a wide range of SST gradients exploiting frontal, transition and no frontal systems almost at the same rate. On the other hand, adults were mostly distributed in a particular region where no thermal fronts were detected in winter (Figs. 1b and 2).

3.2. Chlorophyll-a concentration

Both age classes exploited environments of different productivity levels, from mesotrophic to enriched waters (Fig. 1c) spending a small amount of time at low productive (oligotrophic) environments. Juveniles during their first at sea incursion used mainly enriched (45.4% ± 17.3%) and eutrophic (35.4% ± 18.0%) waters, spending less time at mesotrophic environments (17.4% ± 16.9%, Fig. 2). It is important to consider that part of the enriched class in the residence area could be due to the high turbidity of the region (see discussion). On the contrary, adults remained significantly more time than juveniles in mesotrophic waters (W = 44, p < 0.05), spent similar time exploiting eutrophic waters (W = 38, p > 0.05) and only 16.4% ± 7.2 of their time made excursions to enriched waters (Fig. 2).

3.3. Bathymetry

Most of juveniles' time was spent at depths shallower than 100 m (70.2% ± 20.6), but this age class explored also a vast range of bathymetric domains (from less than 100 m to depths higher than

1000 m). Adults partitioned their time between waters with depths shallower than 100 m (49.7% ± 13.1%) and waters between 100 and 200 m depth (44.4% ± 12.9%) showing a significant difference in the time spent in this last domain when compared to juveniles (W = 52, p < 0.01) (Figs. 1d and 2).

3.4. Oceanographic regimes

During the entire tracking period juveniles used marine areas included in six of the seven oceanographic regimes defined for the study area (Fig. 3a) spending 54.2% ± 24.8% of their time at the Continental Shelf regime (Fig. 3b). They also made incursions into
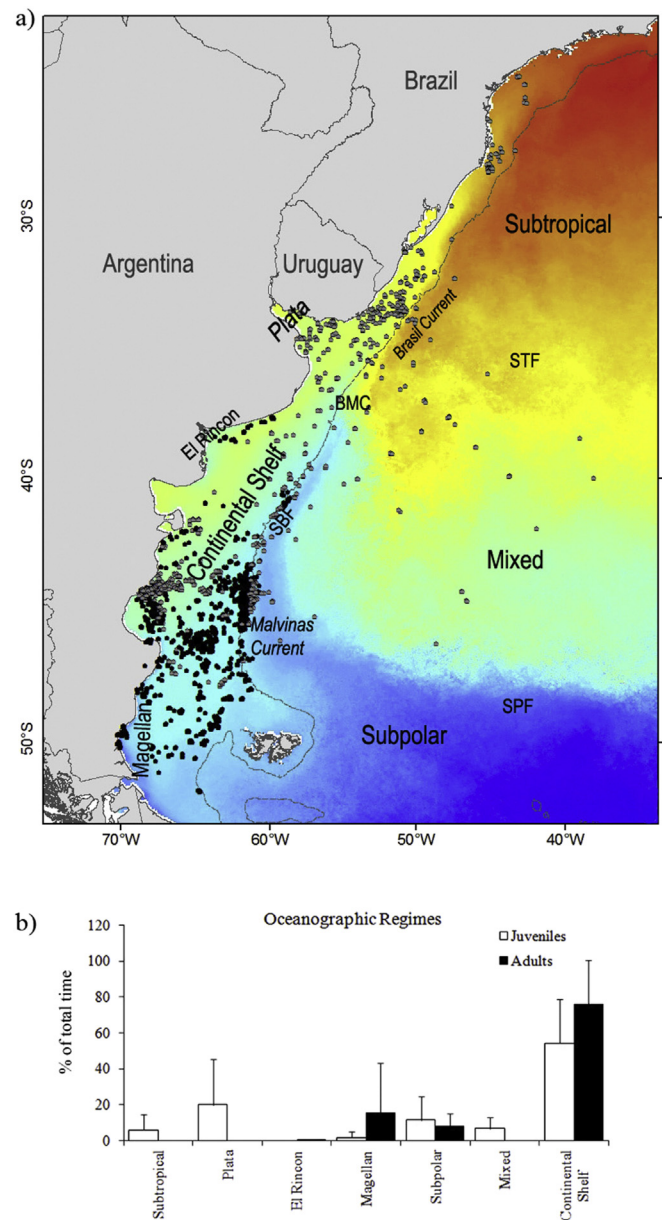

Fig. 3. (a) Distribution of satellite tracked first-year juveniles (gray dots) and adults (black dots) Southern Giant Petrel (*Macronectes giganteus*) during residence behavior in relation to oceanographic regimes. Oceanographic regimes were adapted for the austral winter (from Piola and Falabella, 2009). Regimes were calculated using the average SST (4 km spatial resolution) of July from years of tracking (2005–2008). (b) Proportion of time spent by first year juveniles and adults in the oceanic regimes present at the study area.

regimes Plata and Subpolar (20% ± 25.3% and 11.3% ± 13% of juveniles' time at sea respectively). On the contrary; wintering adults only used three of the seven regimes (Fig. 3a) remaining mainly at the Continental Shelf (76.0% ± 24.6%). During the remaining time they were distributed over the Magellan (15.4% ± 28.0%) and the Subpolar regime (8.3% ± 6.5%, Fig. 3b).

3.5. Sea surface wind

Overall there were no significant differences in wind speeds of areas used by both juveniles and adults (W = 107, $p > 0.05$, Fig. 4). Juveniles made incursion into waters with surface 5-day winds from 2 to 6 m s^{-1} (74.3%), spending a short amount of time in areas with winds higher than 11 m sec^{-1} (Fig. 5a). Similarly, wintering adults remained in areas where sea surface winds varied between 3 and 7 m sec^{-1} (76.4% of their total time) making no incursion into waters with wind speeds higher than 10 m sec^{-1} (Fig. 5a).

There was a predominant westerly wind in areas used by juveniles (SW, W, NW; 65% of total time). This pattern was stronger for wintering adults during the study period, spending 80% of their time in areas with those wind direction (Fig. 5b).

During traveling (displacement), there was a similar wind pattern in the utilized areas for both age classes and it was similar to those reported for residence locations (no significant differences between speeds experienced during traveling or residence time, $p > 0.05$). Juveniles used areas with wind speeds ranging from 0 to 12 m s^{-1}; however during most of their time at sea (80%) this group traveled in marine zones of wind speeds between 2 and 7 m s^{-1} (Fig. 5c). Similarly, adults displacing were exposed to different wind speeds (0–10 m s^{-1}), spending 82% of their total time at sea in areas of wind speeds ranging between 2 and 7 m s^{-1} (Fig. 5c). While moving to different areas, juveniles were exposed mainly to westerly and northerly winds while adults experienced the same wind directions as when residing in their preferred areas (westerly 81% of the total time, Fig. 5d).

3.6. Biological landscape (squid distribution)

During the austral fall (April, May, June) squid stocks are distributed over the ACS from 52°S to 35°S (Brunetti et al., 1998; Chen et al., 2007). At that time, juveniles SGP spread over the shelf occupying 52.2% of the squid distribution areas, while adults occupied 36.6% of the squid utilization areas, concentrating on the southern part of the squid distribution (Fig. 6). Throughout the winter (July, August, September) the squid changes its distribution moving north, occupying a smaller area between 46°S and 36°S
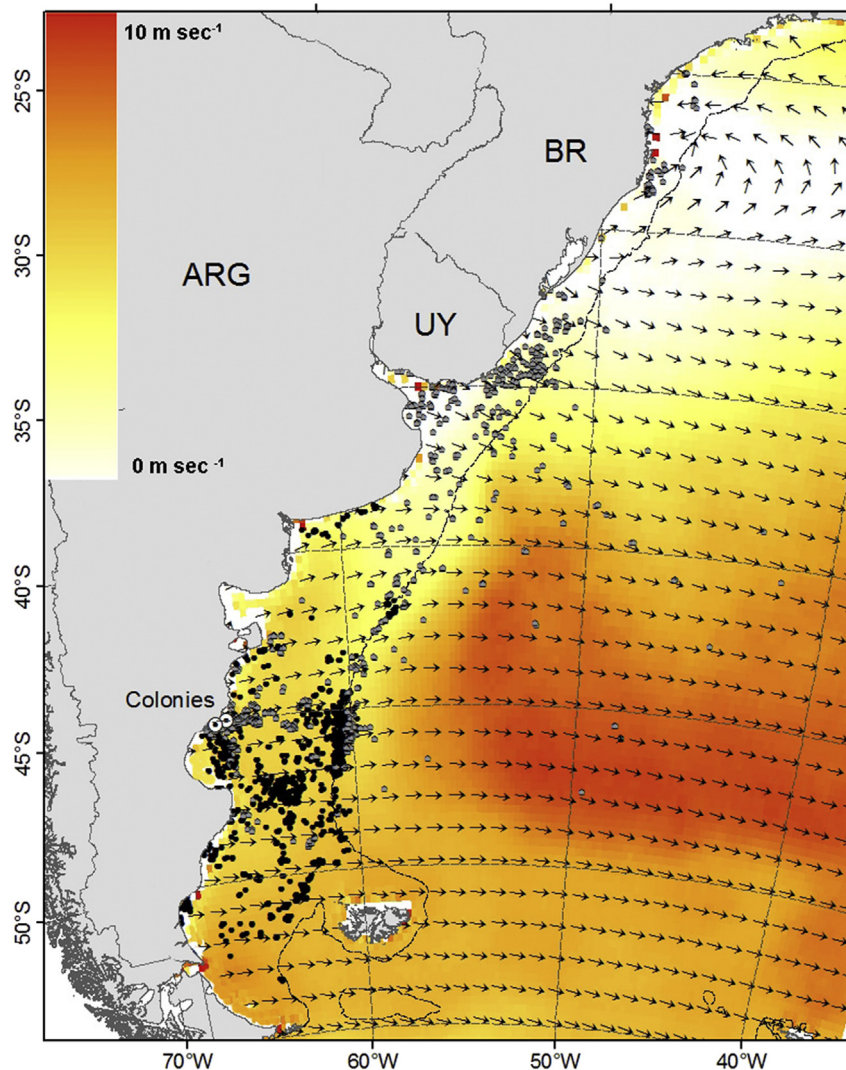

Fig. 4. Distribution of satellite tracked first-year juvenile (gray dots) and adult (black dots) Southern Giant Petrel (*Macronectes giganteus*) during residence behavior in relation to wind speed (background) at 4 km spatial resolution and wind direction (indicated by arrows) at 4 km spatial resolution.
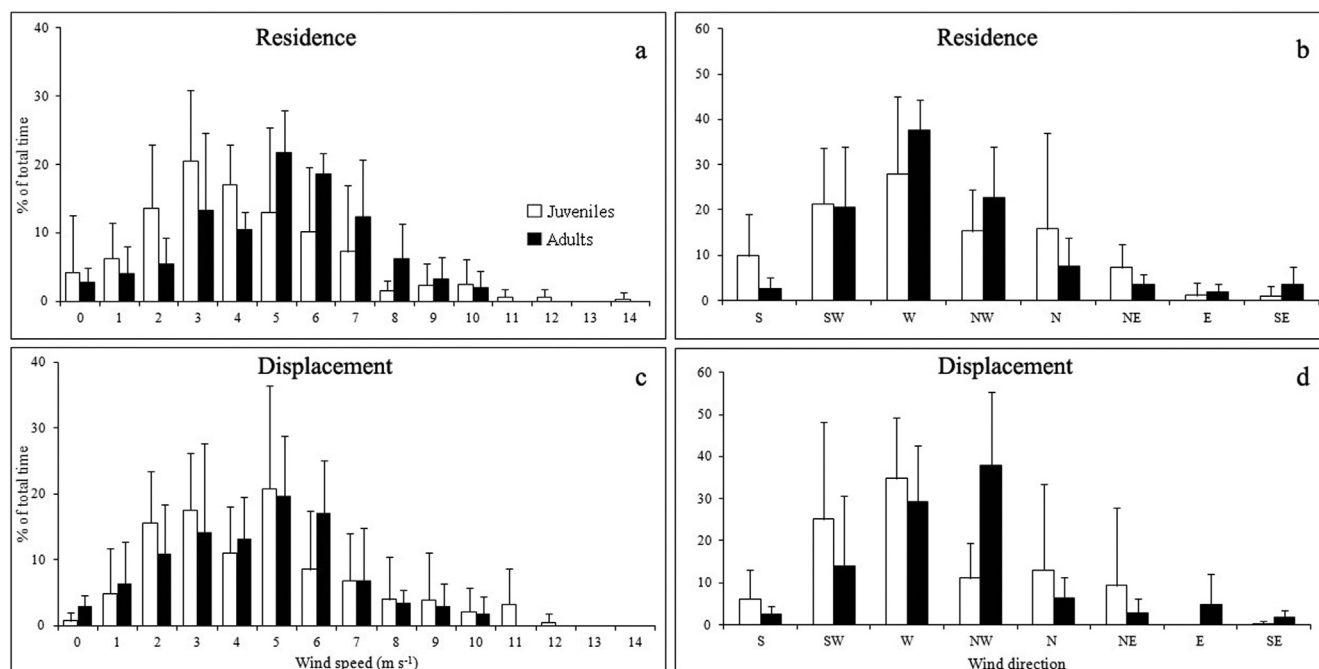
Fig. 5. Proportion of time spent by first year juveniles and adults Southern Giant Petrel (*Macronectes giganteus*) at (a) different wind speeds including only locations indicating residence behavior (b) different wind directions including only locations indicating residence behavior (c) different wind speeds including only locations indicating displacement behavior (d) different wind directions including only locations indicating displacement behavior.

(Brunetti et al., 1998). The occupancy rate from juveniles towards squid areas decreased completely; showing 0.1% of overlap. Contrarily, adults SGP (although at a smaller rate, 20.3%) still overlapped with areas occupied by squid (Fig. 6).

It is important to notice that no differences were visualized in the use of the habitat between sex classes, both in juveniles and adults. Statistical analyses were not performed due to the sample size.

4. Discussion

Here, we characterized the wintering areas used by post-fledging juveniles and post-breeding adults SGP from northern Patagonian colonies. During their first at-sea incursion, juveniles must go through their most critical stage (where mortality risk is higher) acquiring foraging skills over unknown areas (Riotte-Lambert and Weimerskirch, 2013). Despite the importance of this, juvenile dispersion in Procellariiformes is not well documented due to their high mortality and the difficulty on the recovery of devices because of their long periods at sea (Blanco and Quintana, 2014; Gutowsky et al., 2014). As far as we know, the at sea dispersion of this age class and its relationship with oceanographic features has been described in SGP and Northern Giant Petrel *Macronectes halli* through the study of ringed individuals (van den Hoff, 2011); and for the Wandering Albatross, *Diomedea exulans*, (Riotte-Lambert and Weimerskirch, 2013; Åkesson and Weimerskirch, 2014), the Scopoli's Shearwater, *Calonectris diomedea*, (Péron and Grémillet, 2013), and the Black-footed Albatross, *Phoebastria nigripes*, (Gutowsky et al., 2014) through the use of satellite telemetry. This is the first study characterizing the oceanographic and biological features of the marine areas used by first year juveniles SGP based on accurate data of at sea positions through satellite telemetry.

Our results suggested that juveniles exploited a wide variety of environments focusing mainly on productive waters. We found no

indications of differential use of environments between males and females. During their first at sea incursion juveniles used mostly neritic waters, exploring a variety of oceanographic regimes with warmer SST than adults. During that journey, post fledging juveniles were exposed to eutrophic and enriched waters, probably because of the frequent presence of thermal fronts in the juveniles' utilization areas. This pattern was also described by van den Hoff (2011), where ringed juvenile SGP from Antarctic and Sub Antarctic colonies were recovered in areas of strong upwelling. Because juveniles used a large area next to La Plata River mouth, it is important to notice that the values of satellite derived chlorophyll-a concentration could be overestimated at the La Plata River marine front due to the turbidity of the area (Acha et al., 2008; Carreto et al., 2008; Piola et al., 2008). However, *in situ* values at the area of influence of the La Plata estuary showed high chlorophyll-a concentration indicating high productivity of the area (Acha et al., 2008; Carreto et al., 2008). Even if it has been described that post-fledging Procellariiformes remain in areas of productive upwelling (van den Hoff, 2011), the most productive zones are commonly occupied by adults birds (Péron and Grémillet, 2013; Gutowsky et al., 2014). This is significantly different from the findings of this study, where areas used by adults were less productive in terms of chlorophyll-a levels and presence of thermal fronts than those utilized by juveniles.

Interestingly, wintering adults SGP remained the majority of their time at sea in areas lacking of thermal fronts within the oceanographic regime "Continental Shelf", in bathymetric domains of 100–200 m characterized by mesotrophic and eutrophic waters, showing no indication of age specific use of the area. During summer, breeding adults SGP from Patagonian colonies spend a high proportion of their time in areas of enriched and eutrophic waters (Copello et al., 2011). This high chlorophyll-a levels in breeding SGP environments, may be explained by the presence of oceanographic fronts of high productivity in the vicinities of the colony (Copello et al., 2011). Although adult SGP use similar areas
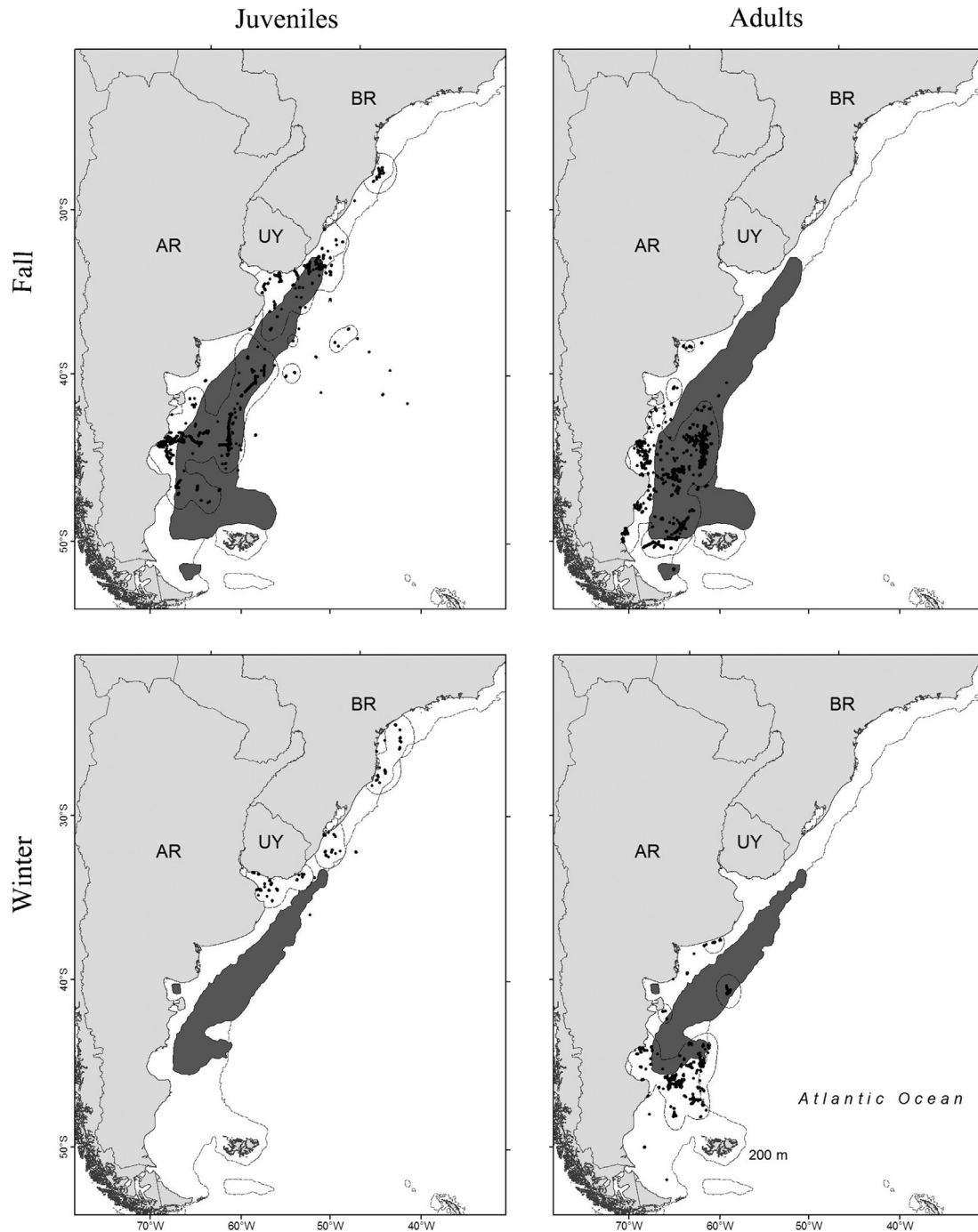
Fig. 6. Distribution of squid (gray polygons) and Southern Giant Petrel (*Macronectes giganteus*) contour areas (white polygons) during fall (April, May, June) and winter (July, August, September). Squid distribution was created using records from Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP, Argentina) adapted from Brunetti et al. (1998). Contour areas (95%) were obtained by conducting a fixed Kernel Density Analysis (KDA) with locations of birds indicating residence behavior.

through the year (see Blanco and Quintana, 2014) the oceanographic characteristics of those areas fluctuate seasonally (Rivas and Pisoni, 2010). The shelf break zone (one of the most used area by adults SGP through the year (Quintana et al., 2006; Blanco and Quintana, 2014)), is characterized by a quasi-permanent boundary between shelf waters and colder and nutrient rich waters of the MC flowing to the north along the shelf break (Rivas et al., 2006). During the cold period (austral winter), surface cooling produces a decrease in SST of shelf waters producing a SST homogenization of the shelf break zone, and as a consequence, thermal frontal probabilities decrease in the area (Rivas and Pisoni,

2010). A similar pattern is observed with tidal fronts, which vanished as soon as the period of surface cooling starts (Rivas and Pisoni, 2010). As a consequence, the environment used by adults during winter seems less productive in terms of chlorophyll-a and presence of thermal fronts than those used during summer. In this framework it is important to consider that some seabirds and marine mammal species are associated to sub-surface chlorophyll maximum and high variance in bottom topography, but not necessarily with the locations of strong horizontal temperature gradients (thermal fronts) or high surface chlorophyll concentration (Scott et al., 2010).

The distribution of Procellariiformes is highly influenced by wind conditions, being this group of birds more diverse in areas of high wind speeds (Davies et al., 2010; Weimerskirch et al., 2012). In our case, we found no differences in wind directions or wind speeds in the areas utilized by juveniles during displacement and residence behaviors, suggesting that winds at a macro-scale do not influence juvenile distribution; however, as indicated by Gutowsky et al. (2014) wind speed and direction may affect juvenile movement choices at a fine scale. For the most part, juveniles were exposed to westerly winds, which may have helped them on their initial flight to the shelf break, east of the colony. The same pattern has been described for juvenile wandering albatrosses which initial flight is wind assisted traveling in the same direction as the wind (Åkesson and Weimerskirch, 2014). Contrarily to most Procellariiformes; wintering SGP from northern Patagonian colonies does not perform long distance migrations (Blanco and Quintana, 2014). In this particular case, wind conditions would not play a primary role in the selection of their residence areas; although the use of wind to facilitate flying is a characteristic of this group of birds (Davies et al., 2010). This is opposite to what has been suggested for the Cory's Shearwater, *Calonectris diomedea*, where wind patterns determine their migration routes (Felicísimo et al., 2008). These differences could be an indication of use of winds in long distance migrations considering that Cory's shearwater are known to perform trans-oceanic migrations flying up to 35,000 km to reach their foraging areas (Felicísimo et al., 2008).

High squid concentrations disperse over the Argentine, Uruguayan and Brazilian shelves through the year (Brunetti et al., 1998; Sacau et al., 2005; Chen et al., 2007). During the austral summer (Jan–Feb), squids are found at 45–46° S, moving southwards to feed and grow from March through May. Thereafter, they start migrating northwards off Argentina and Uruguay to spawn and die (July–Aug) (Brunetti et al., 1998; Sacau et al., 2005; Chen et al., 2007). Interestingly, juveniles partially overlapped with squid distribution over the ACS during fall and did not intersect during winter. On the contrary, areas used by adults overlapped with areas of high squid densities through the study period, indicating that squid may also be a key prey item even during the non-breeding period. Previously, Copello et al. (2011) indicated that while breeding, SGP from Patagonian colonies shows a high spatio-temporal overlap with the distribution range of squid. This cephalopod, occurs at sea bottom during the day, and do not float when dead (Xavier et al., 2013). Therefore, it can be captured alive at night when it swims close to the surface, or it is highly probable that this prey item is obtained through discards of commercial fisheries operating in the area (trawlers and jiggers, http://earthobservatory.nasa.gov/Features/Malvinas/) (Copello et al., 2008; Copello and Quintana, 2009b). This may also be the case for non-breeding adults SGP which use areas of high concentration of squid where fisheries activities are occurring (Alemany et al., 2014; Copello et al., 2014). The presence of fisheries has also been reported for the marine areas used by juveniles during the study period (Wallace et al., 2013; Alemany et al., 2014; Copello et al., 2014; Jiménez et al., 2014) and this age class may also be foraging from fisheries discards at the Uruguayan and Brazilian shelves, where presence of cephalopods in stomach contents of SGP was demonstrated (Petry et al., 2010). Additionally, interactions of seabirds and fisheries have been indicated for other pelagic species (Favero et al., 2013; Copello et al., 2014; Jiménez et al., 2014). Furthermore, the fishery effort (principally the jigging fleet targeting on squid) seems not evenly distributed over the ACS; instead they are associated to oceanic fronts (Alemany et al., 2014).

In summary, first year juveniles searched for food exploring a variety of unknown environments. During their search, they remained in productive environments associated to fronts and probably also associated to fisheries operating in their foraging areas. On the contrary, wintering adults remain at the ACS where thermal fronts and as a consequence, primary productivity decrease during winter; but the large overlap with squid distribution suggested the presence of important food sources for this last age class. The oceanographic characteristics of the ACS and the presence of squid may be the optimal environment for this species, the fact that naive juveniles explored a variety of oceanographic environments may be due to the inferior foraging skills and the learning process that this age class have to overpass during the first months after fledging (Riotte-Lambert and Weimerskirch, 2013; Gutowsky et al., 2014).

The understanding of pelagic birds' habitat selection and preferences through the year is crucial for the monitoring of anthropogenic impacts over these species (Copello et al., 2011). Considering that the study of seabirds distribution and habitat use through their life cycle is very scarce; further studies should focus on the prediction of variables that determine the distribution of these species though the year and during different life stages. We believe that those studies should mainly focus on distribution of fisheries and squid for adults and presence of oceanic fronts and chlorophyll concentration for juveniles.

Acknowledgments

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ecss.2014.12.007.

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