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Occurrence of seabirds and marine mammals in the pelagic zone of the Patagonian Sea and north of the South Orkney Islands

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Abstract The Patagonian Sea is one of the most productive ecosystems in the Southern Hemisphere. Unlike other coastal regions, however, few studies exist on the top predators in its pelagic zone. In March 2017, a survey of seabirds and marine mammals was carried out on board the R/V *Puerto Deseado* in the Patagonian Sea, which extends from the South Atlantic Ocean to the north of the South Orkney Islands, Antarctica. Four of the five oceanographic regimes described in this region were studied, and 23 seabird species and five marine mammal species were recorded. Great shearwater *Puffinus gravis*, Antarctic prion *Pachyptila desolata*, and fin whale *Balaenoptera physalus* were the most abundant species. In the 2615 km traveled, two hotspots for top predators were found, coinciding with frontal zones: one in the shelf-break front and the other in the Southern Front of the Antarctic Circumpolar Current. The highest bird diversity and the greatest cetacean concentrations were recorded in the polar regime in the presence of low ice-field debris (5%). The results suggest that at the end of the austral summer, the distribution of top predators in this section of the South Atlantic Ocean is highly unequal. Some oceanic areas have a few species aggregations which contrast with the vast pelagic areas that have scarce species presence and activity. The hotspots were associated with high-productivity areas, but it is likely that they were also facilitated by the time of year (post-reproductive season), as most of the species were concentrated and had fed prior to their migrations.

Keywords **Antarctica, top predators, marine megafauna**

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1 Introduction

The southwestern Atlantic Ocean includes two different marine environments: the Patagonian Sea to the west and the rest of the South Atlantic Ocean, the pelagic zone, to the east. The Patagonian Sea, which includes the coastlines of Argentina, Chile, Uruguay, and Brazil, is an ecosystem exposed to the ecological effects of the Malvinas and Brazilian currents (Falabella et al., 2009). As in other ocean regions, many upper-trophic-level species are associated with certain water masses or frontal zones that determine their distribution (Acha et al., 2004). The Patagonian Sea is one of the most productive ecosystems in the Southern Hemisphere. Its community of top predators has been well documented for decades (Favero and Rodríguez, 2005; Orgeira, 2004, 2001a, 2001b, 1996, 1995a, 1995b; Montalti and Orgeira, 1998, 1997; Jehl, 1974; Cooke and Mills, 1972). The region is home to more than 60 seabird species and 44 of the 129 marine mammals species described worldwide (Miloslavich et al., 2011).

Most of the top predator studies conducted in the South Atlantic Ocean have been limited to the Patagonian

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Shelf, which is one of the five oceanographic regimes identified in the Patagonian Sea (Falabella et al., 2009). Thus, the top predators that inhabit the boundaries of the Patagonian Sea are less well known (Miloslavich et al., 2011). Moreover, the pelagic environments of this sea have been the most ignored by conservation efforts (Falabella et al., 2009).

This is concerning given that the region faces threats from overfishing, invasive species, habitat destruction, and increasing human activities on its shores. For example, considerable seabird mortality is caused by overfishing and illegal fishing (Favero et al., 2003), as well as pollution from oil, and plastic waste. This can have a negative impact on the entire trophic web. Studying the community of top predators would allow us to understand the importance of this area for marine megafauna and evaluate the potential impacts of human activities. Therefore, the aim of our study was to document the distribution of the top predator community in the pelagic zone of the South Atlantic Ocean in late summer 2017.

2 Materials and methods

From 4 to 10 March 2017, birds and marine mammals were observed and documented. The study was conducted on board the R/V *Puerto Deseado* and extended from Mar del Plata, Buenos Aires, to the north of the South Orkney Islands, Antarctica (Figure 1). The cruise covered the areas within and outside of the boundaries of the Patagonian Sea, as well as most of the five oceanographic regimes of the Southwestern Atlantic: Patagonian Shelf (PS), Subtropical (ST), Subantarctic-Subtropical (SA-ST), Subantarctic (SA), and Polar (PO) (Falabella et al., 2009).

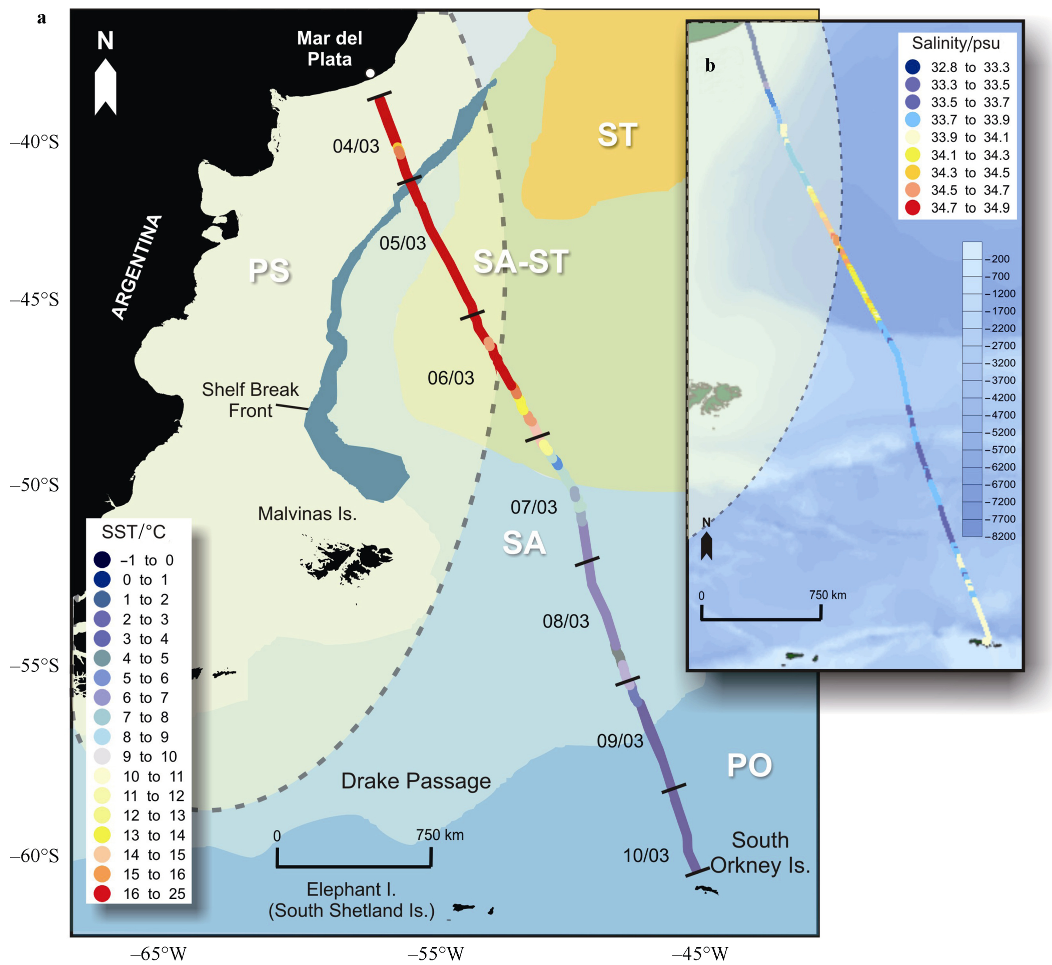

Figure 1 Survey carried out on board R/V *Puerto Deseado* in March 2017. **a**, sea surface temperature (SST), and approximate location of oceanographic regimes: Patagonian Shelf (PS); Subtropical (ST) water; Subantarctic-Subtropical (SA-ST) water; Subantarctic (SA) water; and Polar (PO) front. Dashed-line shadow represents the Patagonian Sea boundaries (modified from Falabella et al. (2009) and Acha et al. (2004)). **b**, salinity values.

Existing methodologies were adapted and modified to allow two observers to simultaneously record taxa and associations between species, including trophic interactions between birds and between birds and marine mammals. For birds, a modification of the 10-min count method proposed by Tasker et al. (1984) was used. The observations of marine mammals were based on the method used by Reyes Reyes and Iñiguez (2013) and Reyes Reyes et al. (2014).

Sea surface temperature (SST) was continuously recorded using a Sea-Bird Scientific SBE 21 SeaCAT thermosalinograph, which obtained a reading every 30 sec at a 3 m depth. As visibility was excellent throughout the study, the observations were not disrupted by poor weather. Photographs were taken with a digital camera Sony DSC-HX300 equipped with a 60× zoom lens to assist in the identification of species through comparisons with catalogs (Orgeira, 2014; Shirihai, 2009) and personal photograph files. Sea ice cover (% concentration) was obtained from observer estimation and updated continuously. This estimate was obtained by calculating the percentage of ice present in the 180° visual field. The different types of ice were categorized into tabular icebergs, icebergs (not tabular), and ice-field debris. An analysis of variance (ANOVA) was used to detect significant differences in SST and salinity throughout the cruise (Di Rienzo et al., 2011; Table 1).

Table 1 Sea surface temperature (SST) for daily transects from 4 to 10 March 2017. Data are presented as means ± standard error. Different lowercase letters indicate significance, $P<0.05$ among treatments (transects)

	Transect 04/03	Transect 05/03	Transect 06/03	Transect 07/03	Transect 08/03	Transect 09/03	Transect 10/03
SST/°C	16.7±0.16 e	17.67±0.17 f	16.34±0.18 e	9.23±0.17 d	6.38±0.17 c	4.26±0.17 b	2.18±0.18 a

2.1 Seabirds

Observations of seabirds were made during daylight hours (~05:00 to 20:00 h). While sailing at a speed of ⩾9.3 km·h^{-1}, two individuals made simultaneous observations from the ship's bridge (15 m above sea level) and both outdoor ailerons. This allowed a visual field of 180° in the width of the transect. Previous studies of top predators on board ships (Orgeira et al., 2017, 2015, 2013) have shown that species can be identified at distances greater than 300 m. Species were detected with the naked eye and then identified at the lowest possible taxonomic level using 16×50 binoculars. When identification was not possible, the individual was recorded as "unidentified". In the case of prions, at least three species of the genus *Pachyptila* coexist in the Patagonian Sea and in the rest of the South Atlantic Ocean: the slender-billed prion *Pachyptila belcheri*, the fairy prion *P. turtur*, and the Antarctic prion *P. desolata*, which is the only species with an Antarctic distribution (Shirihai, 2009; Rodriguez Mata et al., 2006). Therefore, prions observed north of the Antarctic convergence were recorded as *Pachyptila* spp., while those seen in the south were recorded as *P. desolata*.

Birds were recorded by means of 10-min counts, each of which were followed by a 10-min break, for a total of three sampling units per hour. The number of following birds (birds waiting for wast) was updated at the beginning of each hour of observation. Sampling efforts were restricted to times when sea conditions ranged from 0 to 7 on the Beaufort scale.

2.2 Marine mammals

Observations of marine mammals were carried out simultaneously with those of the seabirds, following the same observation protocols on the bridge and bridge-wings. Because marine mammals are less conspicuous than birds, observations were performed without a 10-min break, and sampling efforts were restricted to times when sea conditions ranged from 0 to 4 on the Beaufort scale. The density of cetaceans is presented as cetacean encounter rate (number of sighted cetaceans per km; Reyes Reyes and Iñíguez, 2013). The "passing mode" method, in which the vessel continues traveling along the established transect line even after a group of marine mammals has been seen (Dawson et al., 2008), was used during the surveys.

For both birds and mammals, a day was considered one transect, as the observations were completed continuously during daylight hours.

3 Results

A distance of 2615 km between Mar del Plata and the South Orkney Islands was covered. The changes in SST identified four of the five marine regimes described by Falabella et al. (2009): PS, SA-ST, SA, and PO (Figure 1). While SST varied significantly ($P<0.05$) among most transects, except on 4 and 6 March (Table 1), salinity did not. The SST values showed oscillations and abrupt decreases in PS and SA (Figure 2). Only 5% coverage of ice-field debris in PO was found. The bird survey covered 551 km, which represents 21% of the total distance between Mar del Plata and the South Orkney Islands. A total of 1318 birds belonging to 23 species were recorded in 223 10-min counts. Fifty-eight percent of the total abundance was represented by only two species: the great shearwater (two aggregations in SA-ST totaling 354 individuals or 30.9%) and Antarctic prion (an aggregation in PO of 255 individuals or 26.9%; Table 2). Five of the 23 recorded species were present in all four oceanographic regimes, including: the black-browed albatross, great shearwater, *Pachiptila* spp., white-chinned petrel, and black-bellied storm petrel. Meanwhile, the following species were present in only one of the four oceanographic regimes: the light-mantled sooty albatross in PS; Arctic skua in SA-ST; Atlantic petrel and great-winged petrel in SA; and chinstrap penguin, royal albatross, Antarctic prion, and imperial shag in PO. The highest bird density and richness were recorded in the PO regime (Table 2).

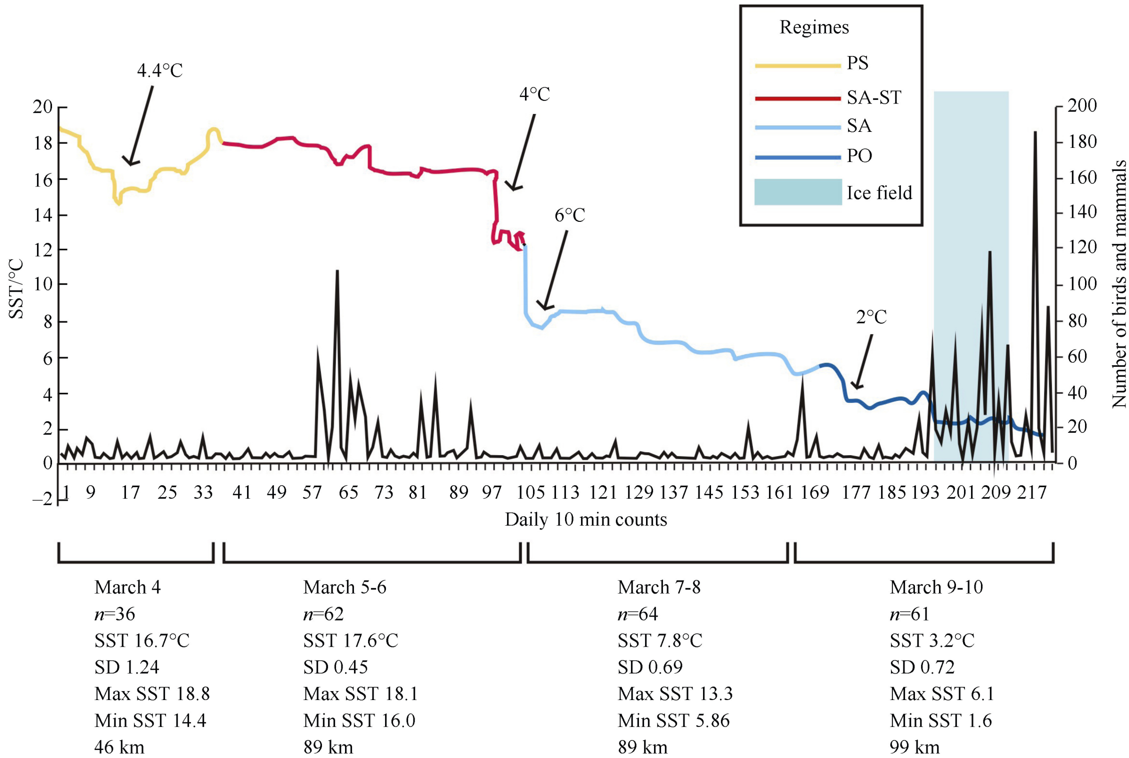

Figure 2 Changes in the SST (Y1) and in the abundances of top predators (Y2). The concentrations of birds and mammals observed on 5 and 6 March 2018 correspond to the shelf-break front, and those recorded on 9 and 10 March 2017 correspond to the Southern Front of the Antarctic Circumpolar Current (ACC). Arrows indicate the major SST decreases found during the cruise. Under the graph, *n* is the number of 10-min counts for bird surveys, SST indicates the mean sea surface temperature (°C) of the regime, and the total distance covered for whale surveys is represented in km. PS, Patagonian Shelf; SA-ST, Subantarctic-Subtropical; SA, Subantarctic; PO, Polar.

As for mammals, approximately 1102 km (42% of the total distance traveled) was surveyed, and 217 individuals belonging to five species were recorded (Table 2). The most numerous species was the fin whale (a single concentration of 118 individuals that accounted for 54.4% of all mammals) and hourglass dolphin (21.2%), both north of the South Orkney Islands in the PO regime. The highest cetacean encounter rate in the study was for the fin whale (0.07 individuals·km^{-1}). The largest mammal aggregations and densities were recorded in PO. The following cetaceans were recorded in just one of the oceanographic regimes: the sei whale in PS, pilot dolphin in SA-ST, and fin whale in PO.

3.1 Distribution of top predators by marine regimes

3.1.1 Patagonian Shelf

A southern fulmar pair was sighted 360 km off the coast, the only members of this species observed north of Antarctica. In this oceanographic regime, no bird aggregations were recorded. As for marine mammals, three unidentified pinnipeds were observed 265 km off the coast. They could have been any of the three pinniped species that breed on the coasts of the Patagonian Sea: the South American sea lion (*Otaria flavescens*), South American fur seal (*Arctocephalus australis*), or southern elephant seal (*Mirounga leonina*). In this regime, eight sei whales were sighted 444 km off the coast when SST was 17.2°C. This record is within the expected distribution pattern for this species since it prefers temperate and subtropical waters instead of cold Antarctic waters (Bastida and Rodríguez, 2003). A group of eight hourglass dolphins was recorded 343 km off the coast when SST was 16.5°C. A larger group (38 individuals) was registered on 10 March in the PO regime. Hourglass dolphins are the only small dolphins with a known distribution in both the coastal shelf waters and the deep Antarctic and subantarctic waters (Bastida et al., 2007; Bastida and Rodríguez, 2003).

3.1.2 Subantarctic-subtropical

In this regime, there was an aggregation of top predators interacting interacting in feeding attitude, coinciding with the Patagonian shelf-break front (Figures 4a and 4b). This hotspot took place at 43º39′S, 54º37′W (667 km off the coast) and consisted of two aggregations of great shearwaters for a total of 354 individuals (which may be an underestimate), 16 long-finned pilot whales, 25 unidentified dolphins, and other bird species (the black-browed albatross, white-chinned petrel, southern giant petrel, and parasitic jaeger, a nonbreeding resident from the Northern Hemisphere).

Table 2 Total numbers of seabirds and mammals registered between 4 and 10 March 2017. The records are grouped by the oceanographic regimes indicated in Figure 1. The four-letter codes following the scientific names of the birds identify the species in Figure 3. PS, Patagonian Shelf; SA-ST, Subantarctic-Subtropical; SA, Subantarctic; PO, Polar

Species	Marine regime			
	PS	SA-ST	SA	PO
Penguin sp. *Pygoscelis* sp. PYGS	0	0	3	14
Chinstrap penguin *Pygoscelis antarctica* PANT	0	0	0	112
Wandering albatross *Diomedea exulans* DEXU	0	3	6	0
Royal albatross *Diomedea epomophora* DEPO	0	0	0	1
Black-browed albatross *Thalassarche melanophris* TMEL	30	19	9	15
Grey-headed albatross *Thalassarche chrysostoma* TCHR	1	0	1	1
Light-mantled sooty albatross *Phoebetria palpebrata* PPAL	1	0	0	0
Southern giant petrel *Macronectes giganteus* MGIG	1	2	0	15
Northern giant petrel *Macronectes halli* MHAL	1	2	0	15
Cape petrel *Daption capense* DCAP	0	0	1	37
Southern fulmar *Fulmarus glacialoides* FGLA	2	0	0	19
White-chinned petrel *Procellaria aequinoctialis* PAEQ	4	8	25	13
Atlantic petrel *Pterodroma incerta* PINC	0	0	5	0
Soft-plumaged petrel *Pterodroma mollis* PMOL	0	11	17	1
Prion sp. *Pachyptila* sp. PASP	17	4	5	123
Antarctic prion *Pachyptila desolata* PDES	0	0	0	255
Great-winged petrel *Pterodroma macroptera* PMAC	0	0	1	0
Great shearwater *Puffinus gravis* PGRA	7	354	2	46
Wilson's storm petrel *Oceanites oceanicus* OOCE	0	1	3	75
Black-bellied storm petrel *Fregetta tropica* FTRO	1	4	1	18
Imperial shag *Phalacrocorax atriceps* PATR	0	0	0	1
Subantarctic skua *Catharacta (skua) antarctica* SKUA	1	2	0	1
Arctic skua *Stercorarius parasiticus* SPAR	0	1	0	0
Total number of birds	66	411	79	762
Total percentage of birds/%	5.00	31.2	6.00	57.8
Total bird species	11	12	13	18
Number of 10-min counts	36	62	64	61
Fin whale *Balaenoptera physalus*	0	0	0	118
Sei whale *Balaenoptera borealis*	8	0	0	0
Hourglass dolphin *Lagenorhynchus cruciger*	8	0	0	38
Long-finned pilot whale *Globicephala melas*	0	16	0	0
Unidentified dolphins	0	25	0	0
Total number of cetaceans	16	41	0	156
Cetacean encounter rate/(individuals·km^{-1})	0.10	0.25	0	0.90
Total cetacean species	2	2	0	2
Unidentified seals	3	1	0	0
Total seal abundance	3	1	0	0
Total seal species	1	1	0	0

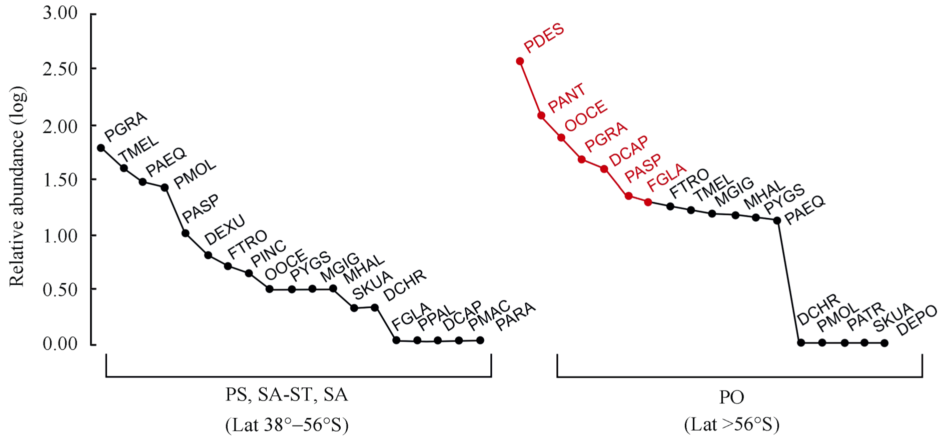

Figure 3 Rank abundance curve shows relative species abundance (log scale) in regimes PS, SA-ST, SA and PO. The species order represents their dominance position, in terms of relative abundance in each ecosystem. Species in red (PO regime) represent more than 50% of the total abundance obtained throughout the study. Species names as in Table 2.

3.1.3 Subantarctic

The lowest bird abundance and richness were recorded in this regime. However, we observed some cold-water birds such as unidentified penguins, the Cape petrel, and three *Pterodroma* species (the Atlantic petrel, soft-plumaged petrel, and great-winged petrel). No marine mammals were sighted.

3.1.4 Polar (PO)

In the PO, 18 of the 23 bird species recorded throughout the study were present. During the first day in this regime (9 March), a monospecific flock consisting of 46 great shearwaters was observed at 55º south latitude, which is the reported southernmost limit of its distribution (Shirihai, 2009; Onley and Scofield, 2007; Rodriguez Mata et al., 2006). On the second day (10 March), we crossed through ice-field debris with a maximum 5% estimated ice cover along 74 km. The highest percent abundances of birds and mammals in the entire PO regime were recorded in this transect (Figure 2, Table 3). Within the ice-field debris we observed the highest seabird and cetaceans aggregations: 118 fin whales in multiple groups of 6 to 22 individuals, two minke whales and 38 hourglass dolphins in three groups (made up of 6, 15, and 17 individuals), Antarctic prions (255 individuals) engaged in feeding near hourglass dolphins and fin whales, and mixed flocks of five species (black-browed albatross, southern giant petrel, southern fulmar, Antarctic prion, and Wilson's storm petrel) feeding.

Table 3 Numbers of Antarctic breeding seabirds and cetaceans recorded on 10 March in the PO region (PO), in the ice field only (ice field), and in the PO ice-free waters, as well as the percentages of animals recorded in the PO region that were also recorded in the ice field (% of PO ice field)

Antarctic Polar Front breeding birds and cetaceans	PO	Ice field	PO ice-free waters	% of PO in ice field
Chinstrap penguin	112	112	0	100.0
Penguin	14	0	14	0.0
Prion	123	0	123	0.0
Antarctic prion	225	162	63	72.0
Southern fulmar	19	1	18	5.3
Cape petrel	37	0	37	0.0
Black-bellied storm petrel	18	17	1	94.4
Southern giant petrel	15	3	12	20.0
Northern giant petrel	15	5	10	33.3
Black-browed albatross	15	5	10	33.3
Grey-headed albatross	1	0	1	0.0
Antarctic skua	1	0	1	0.0
Total number of birds	670	315	355	47.0
Total bird species	11	7	11	
Fin whale	118	63	55	53.4
Hourglass dolphin	38	23	15	60.5
Minke whale	2	2	0	100
Total number of cetaceans	158	88	70	

4 Discussion

In the austral summer, a highly diverse top-predator community and biomass are concentrated in the Argentine continental shelf and its coastal areas, where 16 seabird species have nests (Yorio et al., 1998) and 33 marine mammal species live (Bastida and Rodríguez, 2003). All these species feed on the continental shelf, which has several coastal and marine frontal zones that were described in detail by Acha et al. (2004). The presence of such fronts, the shallow depth (<200 m), and the influence of the Malvinas Current play an important ecological role in the top-predator communities, which have been extensively documented over time (Orgeira, 2011, 2001; Bost et al., 2009; Falabella et al., 2009; Montalti and Orgeira, 1998; Veit, 1995; Jehl, 1974; Cook and Mills, 1972). In contrast, the pelagic ocean zone, beyond the 200-m isobaths, is not uniformly productive and the marine food web is concentrated in the frontal zones. It is well accepted that fronts are likely to be characterized by high phytoplankton biomass, and in many cases, enhanced activity at higher trophic levels as well (Le Févre, 1986). In this study, the only multi-specific bird and mammal aggregation recorded throughout the pelagic zone (SA-ST and SA) coincided with the Patagonian shelf-break front (Figure 4). This front is formed by the temperate waters from the platform and the colder waters of the Malvinas Current. It is a remarkable ecosystem of significant regional and global importance and is known as a strong seasonal CO_2 sink associated with highly productive shelf waters and important fishery resources (Carreto et al., 2016). The shelf-break front has a key ecological and functional role in the Patagonian marine ecosystem because it supports a complex trophic web that includes the spawning areas of commercially important species, as well as feeding areas and migratory passages for top predators (Falabella et al., 2013).

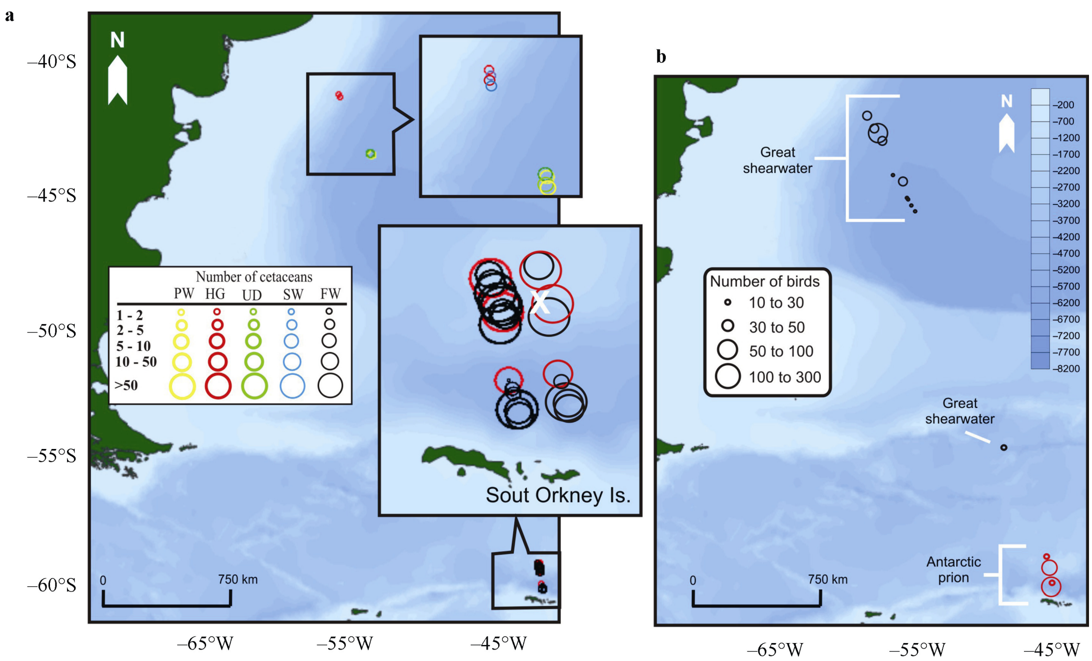

Figure 4 Aggregations of cetaceans (**a**) and seabirds (**b**). The white X in **a** indicates the location of ice-field debris. PW, long-finned pilot whale; HG, hourglass dolphin; UD, unidentified dolphin; SW, sei whale; FW, fin whale.

There were notable differences in the species diversity and abundance between PO and the other regimes. Of the 23 bird species registered in PO, only seven comprised more than 50% of the total abundance. In contrast, in the PS, SA-ST, and SA regimes, all 19 species made up only 42% of the total abundance (Figure 3). As for marine mammals, the highest concentration of cetaceans was obtained in PO (fin whales and hourglass dolphins). Another large concentration of 103 fin whales was recorded in 2014 in the same area, about 11 km north of the islands (Orgeira et al., 2017; Figure 5). This scenario where few species exhibit high abundances is a typical Antarctic marine ecosystem and was already described decades ago (Watson, 1975), but as is common in other oceans, these hotspots occurred in the presence of highly productive coastal or marine fronts. All of our observations in PO were obtained at the Southern Front of the Antarctic Circumpolar Current (ACC), which has been described as a critical component of the global ocean circulation (Orsi et al., 1995) that provides predictable productive foraging for many species (Tynan, 1998). The presence of large concentrations of top predators in PO, where feeding areas overlap considerably, had been reported previously in a five-year study (Orgeira et al., 2015) confirming food predictability. The low ice percentage in PO (5%) seems to have modified the relationships between the species and the marine environment north of the South

Orkney Islands as seen on 10 March (Table 3). Birds and mammals were observed actively feeding, maybe facilitated by the predictable food concentration in a relatively small area. Ice-field debris and water formed ice-water interfaces. For decades, these interfaces have been recognized as “energetic” or ergocline zones (Ferreyra and Schloss, 1993), which have high primary productivity (Plötz et al., 1991) associated with epontic algae, that, in turn, attract a high diversity of marine invertebrates. The ice-field debris, therefore, was an important environmental factor that had a direct influence on all trophic levels. In terms of biodiversity, the PO region is the most important area. The ice field in particular is a key feature within the PO region because it sustains a high biomass of krill that disperse to adjacent open waters and represents a critical foraging habitat for ice-dependent species.

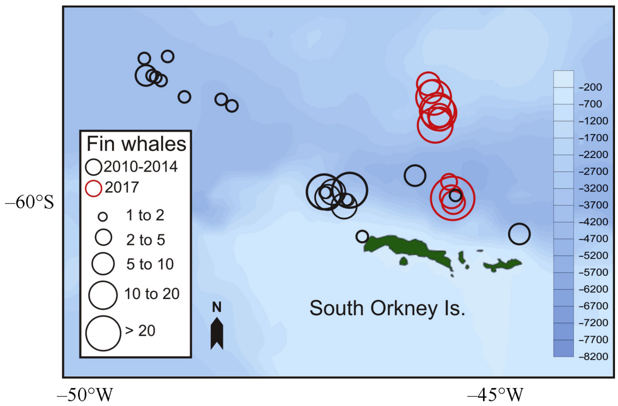

Figure 5 Distribution and abundance of fin whales north of the South Orkney Islands between late summer 2010 to 2014 (Orgeira et al., 2017, 2015) and in this study.

In conclusion, the highest densities of top predators in the 2615 km surveyed were found in two relatively small transects: one that was 60 km long (shelf break, SA-ST regime) and the other, 150 km long (Southern Front of the ACC, PO regime). This shows that the distribution of megafauna in this part of the South Atlantic Ocean is highly unequal at the end of the austral summer. This study was carried out in late summer (post-breeding season) when most of the species fed and were concentrated in specific areas prior to their migrations; it is thus likely that this favored hotspots. This also may have been the case, for example, for the 118 fin whales reported in this study and another 103 individuals in 2014 in the same area and at the same time of year (Orgeira et al., 2015).

Finally, the ecological integrity of the shelf-break front and the Southern Front of the ACC seem to have an uncertain future. Because of their high productivity, both unprotected marine areas are being subject to intense commercial fisheries activities. As Acha et al. (2015) pointed out, the most accepted effects of the fronts over biodiversity are their impact on species turnover or beta diversity. Therefore, the monitoring of top predators in these areas should be a priority so as to know their health status and particularly how they evolve over time under anthropic and environmental effects.

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