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Contribution to the Theme Section 'Biophysical coupling of marine hotspots'

Spatio-temporal persistence of top predator hotspots near the Antarctic Peninsula

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ABSTRACT: We quantified species richness and abundance of seabirds and marine mammals in order to identify marine areas that are persistently attractive to top predators. Shipboard surveys across a 150 000 km^2 grid off the Antarctic Peninsula were conducted once or twice each year from 2003 to 2011 during which the distribution and abundance of top predators were mapped. We hypothesized that spatial organization of species richness and abundance hotspots reflect persistent habitat use and are regionalized according to distance from land and oceanographic boundaries. To test this, we used a new hotspot variance metric based on the percentage of time that the species richness or abundance estimate at any one location is greater than 1 standard deviation above the long term means for the entire survey grid. Species richness hotspots were based on all species sighted, while abundance hotspots were based on concentrations of 16 species: 13 seabirds (penguins, petrels and albatrosses), 1 pinniped and 2 baleen whales. Species abundance hotspots reflected 2 major groupings—those with oceanic and coastal origins. We identified 15 richness hotspots, 9 of which were in proximity to the southern Antarctic Circumpolar Current front; the 6 others were associated with major breeding colonies and the location of 2 submarine canyon systems. Our approach integrates temporal and spatial variances over 14 individual surveys and provides useful reference points for identifying ecologically important areas, refining food web models and developing spatial management of and conservation strategies for marine ecosystems.

KEY WORDS: Abundance · Antarctic · Conservation · Hotspot · Persistence · Richness · Seabirds · Marine mammals · Marine spatial management

INTRODUCTION

Inhabiting the largest ecosystem on earth, seabirds and marine mammals are truly global organisms and sentinels of ocean ecosystem state (Tittensor et al. 2010, Sydeman et al. 2012). With conservation of seabirds and marine mammals becoming increasingly urgent, there is a need for the quantitative designation of hotspots—areas characterized by persistent, elevated abundance and species richness (Piatt et al. 2006, Sydeman et al. 2006, Davoren 2007, Santora et al. 2010, Nur et al. 2011, Suryan et al. 2012). Top predator hotspots can be identified either by tracking individuals and quantifying how much time they spend in each encountered habitat (Block et al. 2011), or alternatively, via shipboard surveys documenting the abundance and species richness of predators measured in each habitat (Yen et al. 2006, Santora et al. 2010, Nur et al. 2011, Suryan et al. 2012). However, persistence of hotspots is rarely quantified. Using a shipboard approach, we present information on the persistence of predator hotspots near the

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Antarctic Peninsula based on data collected during 14 shipboard surveys between 2003 and 2011. This is a region of rapid climate change (Meredith & King 2005) that has experienced serial depletion of marine mammals (Fraser et al. 1992, Ballance et al. 2006), and is becoming a growing ecotourism destination (Tin et al. 2008, Lynch et al. 2010) and a commercial krill fishery (Kawaguchi et al. 2006, Nicol et al. 2012). Therefore, we need to know where top predators and their prey are persistently concentrated to benefit marine spatial management and conservation (Reid et al. 2004, Santora et al. 2012a,b, Sigler et al. 2012).

The hotspot concept is useful in studies of highly mobile organisms such as seabirds and mammals, because the extreme variability characteristic of the distributions of marine organisms makes it highly unlikely that any single mapping would be truly representative. As a consequence, one needs repeated standardized surveys to determine those areas that persist in their attractiveness to top predators. However, the hotspot concept applied to top predators in marine ecosystems has received somewhat mixed definitions. According to Sydeman et al. (2006), marine hotspots are defined as 'sites of critical ecosystem linkages between trophic levels'. Piatt et al. (2006) defined hotspots as a 'relatively small area in which we expect to find animal aggregations repeatedly'. Davoren (2007) defined hotspots as 'areas where high abundance of species overlap in space and time'. Indeed, there have been many uses of the term hotspot, but the commonality of these definitions is some aspect of spatio-temporal persistence (Gende & Sigler 2006, Sigler et al. 2012, Suryan et al. 2012). We decided to quantify both abundance hotspots for individual species, and richness hotspots for the entire community. We calculated these from a suite of highly replicated shipboard surveys sampled over many years (Santora et al. 2010, 2012a). Using a grid-based approach, we define hotspots of species richness and abundance as locations with anomalies that exceed the mean for the entire study region by 1 standard deviation in a given survey, and define their frequency of occurrence by estimating the percentage of time a hotspot occurs over many surveys (Suryan et al. 2012).

Motivation for this study was based on the following: (1) the Antarctic Peninsula marine ecosystem has been impacted by human disturbances over the past 2 centuries (e.g. commercial whaling; krill fishing; Fraser et al. 1992, Trivelpiece et al. 2011, Nicol et al. 2012) and is experiencing rapid climate change (Meredith & King, 2005); (2) krill stocks have declined and gelatinous salps are increasing (Atkinson et al. 2004); (3) ecosystem-based management of the Southern Ocean krill fishery will benefit from the delineation of top predator hotspots so that overlap between fishing vessels and predators is minimized (Reid et al. 2004, Santora et al. 2010, 2012a) and; (4) the likelihood of seabirds and marine mammals exhibiting extremely dense aggregations at sea is high and leads to difficulties in modeling their spatial distribution that is not yet resolved (Oppel et al. 2012, Sigler et al. 2012). Our overarching objective was to quantify the location of persistent species richness and abundance hotspots. We applied a new variance-based metric to identify hotspots by accounting for their persistence (consistent or frequent occurrence) of anomalies through time (Suryan et al. 2012). We tested the hypothesis that the geospatial variability of species richness and abundance hotspots relates to distance from land and oceanographic boundaries.

METHODS

Study area

The US Antarctic Marine Living Resources (AMLR) program conducts surveys on a fixed grid along north-south transects with stations spaced at ~55 km intervals across a 150 000 km^2 area surrounding the South Shetland Islands at the northern tip of the Antarctic Peninsula (Fig. 1). The study area is located within the narrowest latitudinal stretch of the Southern Ocean (closest point between South America and Antarctica). The hydrography and circulation of this region is complex and variable and reflects inputs and mixing of waters from the Antarctic Circumpolar Current (ACC) within Drake Passage, the western portion of the Weddell gyre, and upstream regions along the western Antarctic Peninsula that enter through Gerlache Strait and western Bransfield Strait (Amos 2001, Thompson et al. 2009). The rugged bathymetry of the region (which includes the continental shelf around the islands, deep basins of Bransfield Strait, and the South Shetland Trench and Shackleton Fracture Zone ridge in Drake Passage) provides additional hydrographic and circulation variability (Orsi et al. 1995; Fig. 1). Physical oceanographic conditions around the South Shetland Islands exhibit a broad range of water mass characteristics because of the mixing of the ACC, Scotia Sea, Antarctic coastal current and the higher latitude waters of the Weddell Sea (Orsi et al. 1995, Amos 2001, Thompson et al. 2009). Relevant to this study, the southern Antarctic

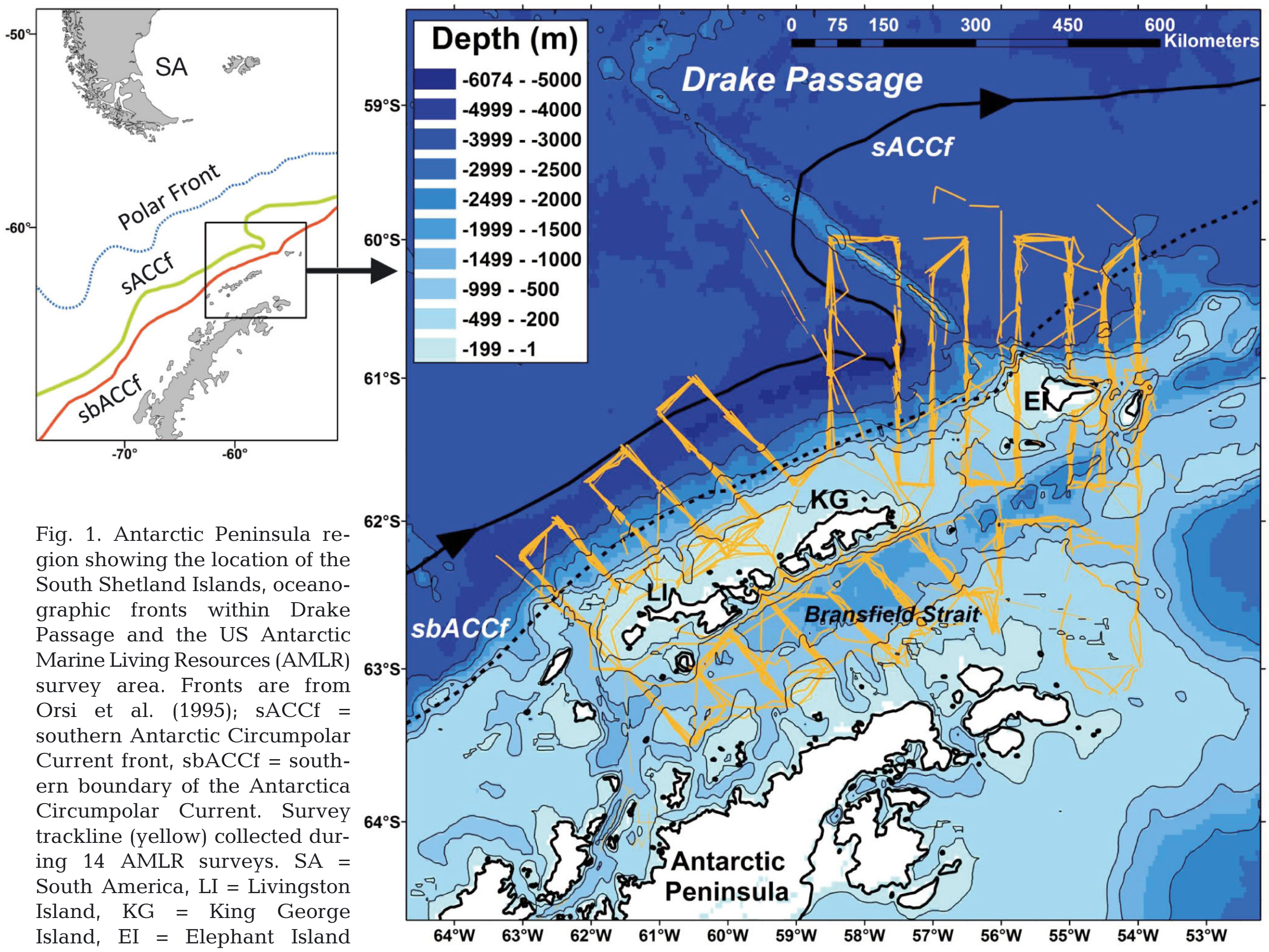

Fig. 1. Antarctic Peninsula region showing the location of the South Shetland Islands, oceanographic fronts within Drake Passage and the US Antarctic Marine Living Resources (AMLR) survey area. Fronts are from Orsi et al. (1995); sACCf = southern Antarctic Circumpolar Current front, sbACCf = southern boundary of the Antarctica Circumpolar Current. Survey trackline (yellow) collected during 14 AMLR surveys. SA = South America, LI = Livingston Island, KG = King George Island, EI = Elephant Island

Circumpolar Current front (sACCf) and its southern boundary (sbACCf) (Fig. 1) is an ecologically important oceanographic frontal zone for whales and krill (Tynan 1998, Atkinson et al. 2008).

During January–March 2003 to 2011, we conducted 14 surveys to map the distribution and relative abundance of seabirds, pinnipeds and cetaceans (Table 1, Fig. 1). Our coverage of transects was replicated annually and within the summer season; occasionally there were 2 surveys per year (Table 1, Fig. 1). The grid design enabled sampling of a variety of habitats, including the extensive insular shelf systems around the archipelago, submarine canyons, shelf-break regions, deep basins of Bransfield Strait and the oceanic waters of southern Drake Passage; see Fig. 2 for a summary of survey effort

Table 1. Summary of survey effort for predator observations conducted on 14 Antarctic Marine Living Resource (AMLR) program surveys. Only survey effort that falls within the 54 regularly sampled grid cells is presented

Year	Survey	Days	Survey dates	Survey hours	Distance (km)
2003	1	16	16 January – 28 January	129.27	2394.1
	2	16	10 February – 25 February	113.73	2106.7
2004	1	17	13 January – 31 January	126.60	2344.6
2005	1	15	15 January – 30 January	121.02	2241.3
	2	16	22 February – 9 March	107.03	1982.2
2006	1	16	16 January – 31 January	114.07	2112.6
2007	1	18	8 January – 26 January	148.10	2742.8
2008	1	23	13 January – 5 February	154.47	2860.8
	2	17	16 February – 5 March	128.93	2387.8
2009	1	18	12 January – 29 January	165.12	3058.0
2010	1	13	25 January – 9 February	84.88	1571.9
	2	14	19 February – 6 March	90.30	1666.8
2011	1	21	14 January – 4 February	188.22	3481.7
	2	15	17 February – 5 March	98.48	1823.8

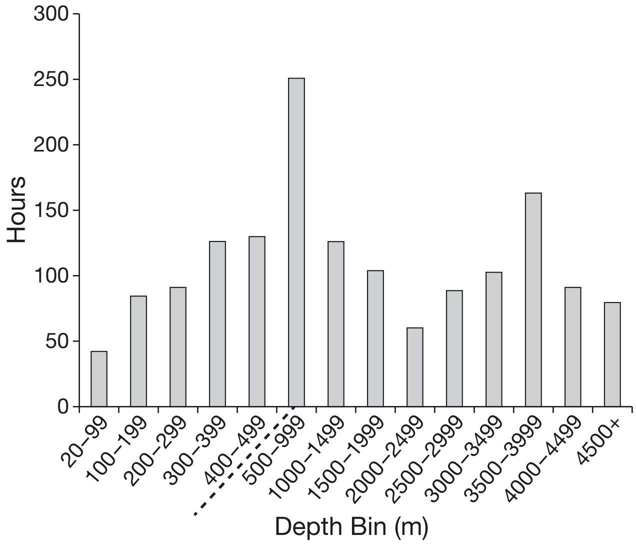

Fig. 2. Summary of survey effort in relation to bathymetry; dashed line indicates change from 100 m to 500 m depth bin size, due to sampling of shelf-break and slope regions

according to different sea depth bins. Previously, a subset of this dataset was used to identify the location and spatial association of baleen whale and krill demographic hotspots (Santora et al. 2010). Moreover, the grid design has permitted the description of habitat use for poorly known cetaceans (Santora & Brown 2010, Santora 2012) as well as modeling mesoscale structure and spatial organization of krill hotspots (Santora et al. 2012a).

Predator surveys

Sighting data on predator abundance and distribution were continuously collected during daylight hours between sampling stations along fixed transects (Fig. 1). Additional survey methods are described in Santora et al. (2009, 2010) and Santora & Reiss (2011). Ship speed during transits was generally 10 knots (~18.6 km h^{-1}), and observers used hand-held binoculars to scan for predators from a height of ~13 m above sea level. Each sighting was assigned a time and a spatial position from the ship's global positioning system. Sea surface state (Beaufort scale) and visibility (e.g. fog, glare) were continuously monitored and effort during unfavorable conditions (e.g. Beaufort >5, heavy fog) was excluded prior to analysis. Counts of seabirds were made within a 90° arc from 300 m ahead of the ship to one side while underway (Camphuysen & Garthe 2004). Ship-following birds were recorded when first encountered and ignored thereafter. Surveys of whales were conducted using standard line transects by trained observers each year. All recorded cetacean sightings were observed in a 180° arc forward of the vessel and up to 3 km away. For each whale sighting, a best-estimate spatial position, bearing and a perpendicular distance estimate to the ship's trackline were logged (Buckland et al. 1993). Observations of seals were collected in a 180° arc forward of the vessel and included position and group size (Santora 2013). True to all shipboard surveys of air-breathing marine animals, there is an inherent issue of detectability associated with the animal's behavior and sea state conditions (Southwell et al. 2008). Although line-transect (distance) sampling was not used to estimate absolute marine mammal density, sightings were collected consistently across all 14 surveys to estimate a standardized relative abundance index.

We selected the 16 most numerous and frequently sighted top predator species for quantifying abundance hotspots (Table 2, Appendix 1; Hunt et al. 1990). Three species of marine mammals (2 baleen whales, 1 pinniped) and 13 species of seabirds were selected based on their overall abundance, representing a variety of different foraging behaviors and life histories. All of the species examined in this study feed on small zooplankton and nekton (e.g. krill, copepods, mesopelagic fish, squid), but differ in their feeding behavior due to locomotion and body size (Croxall & Prince 1980, Laws 1985). Baleen whales predominantly feed on krill and exploit dense patches of krill throughout the water column (Laws 1977). Penguins and pinnipeds are pursuit diving predators and select a variety of krill and fish species (Croxall & Prince 1980, Reid et al. 2006). The flying seabirds examined in this study are restricted to feeding near the sub-surface and select a variety of prey (Croxall & Prince 1980). For comparative purposes, we focused on 2 species each of baleen whales (*Balaenopteridae*), penguins (*Spheniscidae*), albatross (*Diomedeidae*), storm petrels (*Hydrobatidae*) and 6 species of petrels (*Procellaridae*). Because of the difficulty identifying prions (*Pachyptila* spp.) at sea, counts of unidentified prion, Antarctic prion (*P. desolata*) and thin-billed prion (*P. belcheri*) were pooled into 'prion species'. Our analysis of species richness hotspots were based on all species observed (Appendix 1).

Analysis

All shipboard trackline and predator sightings were combined in a geographic information system. The shipboard trackline was extensive and covered open

Table 2. Summary of species, total sightings (S), total individuals (Ind.) and individuals per unit effort (*IPUE*) observed at sea for 14 US Antarctic Marine Living Resources (AMLR) surveys (January – March, 2003 to 2011). SE = standard error, SD = standard deviation, CV = coefficient of variation, *Species that breed at the South Shetland Islands or Antarctic Peninsula

Common name	Scientific name	S	Ind.	*IPUE* (No. h^{-1} $cell^{-1}$ $survey^{-1}$) Mean	SE	SD	CV
Cape petrel*	*Daption capense*	8523	70703	42.85	6.56	22.75	0.53
Antarctic fulmar*	*Fulmarus glacialoides*	5955	34700	22.79	5.54	19.19	0.84
Black-browed albatross	*Thalassarche melanophrys*	2966	5003	3.51	0.84	2.92	0.83
Grey-headed albatross	*Thalassarche chrysostoma*	844	966	0.64	0.14	0.49	0.76
Southern giant petrel*	*Macronectes giganteus*	1628	2334	1.43	0.21	0.74	0.51
White-chinned petrel	*Procellaria aequinoctialis*	1468	2085	1.18	0.46	1.62	1.37
Blue petrel	*Halobaena caerulea*	1154	2159	1.04	0.34	1.19	1.15
Prion	*Pachyptila* spp.	2736	5108	2.11	0.71	2.45	1.16
Wilson's storm petrel*	*Oceanites oceanicus*	5169	7646	5.04	0.74	2.59	0.51
Black-bellied storm petrel*	*Fregetta tropica*	6046	8165	4.48	0.84	3.22	0.72
Chinstrap penguin*	*Pygoscelis antarctica*	4877	28066	17.09	2.12	7.35	0.43
Gentoo penguin*	*Pygoscelis papua*	275	1612	1.16	0.46	1.61	1.38
South polar skua*	*Catharacta maccormicki*	531	579	0.38	0.05	0.18	0.47
Humpback whale	*Megaptera novaeangliae*	767	1346	0.92	0.14	0.48	0.53
Fin whale	*Balaenoptera physalus*	543	1084	0.76	0.33	1.16	1.51
Antarctic fur seal*	*Arctocephalus gazella*	1517	2261	1.46	0.30	1.05	0.72

water (there was no pack ice present), bays, inlets and passages between islands. Survey effort was binned into 54 cells, each 0.5° latitude × 1° longitude in dimension (~2860 km^2). The ship's trackline (at 1 min intervals) was plotted to determine the number of hours sampled per cell and survey, as an index of effort (Table 1, Fig. 1). Only cells that were sampled during at least 7 surveys and for at least 1.5 h (~27.78 km) were used in subsequent analyses. Using these criteria, a total of 546 cells and 1684 h were sampled over 14 surveys for a mean ± SD of 38 ± 11 cells survey^{-1} and 3 ± 0.3 h cell^{-1} survey^{-1}, respectively (Table 1). This cell size has been used extensively in this region to examine net-based spatial distribution and abundance patterns of Antarctic krill (Atkinson et al. 2004, 2008), associations between hotspots of baleen whales and krill (Santora et al. 2010), and mesoscale structure of krill hotspots (Santora et al. 2012a).

A 3-step process, similar to that of Suryan et al. (2012), was used to quantify temporal and spatial variance and anomaly persistence of a cell's value of species per unit effort (*SPUE*) and individuals per unit effort (*IPUE*). This procedure integrates variability and anomaly persistence into a metric that, when mapped, produces a seascape of resolved peak species richness and abundance values (hotspots). First, for each survey, rates of *SPUE* and *IPUE* are calculated (1) by dividing the total number of species (out of 54 species; see Appendix 1) or individuals of a given species (Table 2) by the amount of hours surveyed per cell and then subtracting the survey mean and dividing by the survey standard deviation to normalize each survey (e.g. z-score; Table 2):

$$SPUE_{i,j} \text{ or } IPUE_{i,j,z} = [(N_{i,j}/E_{i,j}) - S_j x] \,/\, S_j sd \qquad (1)$$

where $N_{i,j}$ is the number of species sighted (or relative species abundance; z refers to the species under consideration in $IPUE_{i,j,z}$) in cell i during survey j, $E_{i,j}$ is the number of hours sampled per cell, $S_j x$ and $S_j sd$ are the survey mean and standard deviation of species richness and abundance in a given survey. Second, the grand mean and standard deviation of $SPUE_{i,j}$ and $IPUE_{i,j,z}$ is estimated for each cell over all surveys. Within a given survey, hotspots are cells with species richness or abundance anomalies that exceed the grand survey mean by >1 SD. Third, the percentage of time a cell displayed an anomaly >1 SD above the grand mean is tabulated. This threshold of >1 SD is a common measure for variance of anomalies in space-time series analysis and has previously been used to map persistence of remotely-sensed chlorophyll *a* (chl *a*) (Suryan et al. 2012) as well as krill and whale hotspots (Santora et al. 2010, 2012a). Cells with higher percentages reflect locations where species richness or species abundance is persistently higher than the baseline standardized anomaly. For mapping purposes, persistence is classified to permit comparison of hotspot spatial distribution patterns. Classes, based on percentage of surveys, are 0–15%, 15–30%, 30–45% and >45%.

Our first objective was to examine whether groups of species exhibit similar spatial persistence based on the distribution of their abundance hotspots. We used 2 complementary multivariate statistical procedures to address this objective regarding species abundance hotspots: hierarchical cluster analysis and principal component analysis (PCA; Legendre & Legendre 1998). Estimates of species hotspot persistence (per cell, based on percentage of surveys) were approximately normally distributed (Kolmogorov-Smirnov test, $p > 0.05$) and were inputted into PCA and cluster analysis as a Pearson correlation matrix. Meaningful principal components were determined by inspecting eigenvalues (e.g. Scree plot) and percent variance explained (Legendre & Legendre 1998). Cluster analysis (Ward's method with Euclidean distance metric and standard deviation scaling) was used to produce a dendrogram indicating groups of species sharing similar hotspot persistence.

Our second objective was to determine how the persistence of species richness and abundance hotspots varied relative to distance to land and the hydrographic boundaries. Tynan (1998) suggested that the southern boundary of the ACC front has ecological significance for whales throughout the Southern Ocean, and Bost et al. (2009) discussed how fronts are likely regions of elevated trophic transfer and therefore important foraging areas for both seabirds and mammals. Therefore, we tested the hypothesis that the persistence of species richness and abundance hotspots are spatially associated with the ACC front and its southern boundary, and inversely related to distance from land. To test this hypothesis, we correlated a cell's persistence value (percentage of surveys with an anomaly >1 SD) with distance to land and hydrographic features. We calculated the nearest distance (km) from each cell centroid to the position of the southern ACC front and its southern boundary (Orsi et al. 1995) and nearest land. For perspective, the mean distance from land across all cells is 112.2 ± 90.4 km, and the mean distance to the southern ACC front and its southern boundary is 222.9 ± 140.5 and 134.1 ± 100.8 km, respectively. We used a randomization procedure (bootstrap and Monte Carlo analysis; 10 000 randomizations) to calculate Spearman rank correlations and probabilities, with an emphasis on significant negative correlations as indicators of association (i.e. less distance between hotspot and feature).

RESULTS

Species richness hotspots

The mean (± SD) number of species sighted per cell was 12.1 ± 2.3 and ranged from 5.4 to 18.9 for all 14 surveys. All richness hotspots exhibited persistence values >50 %, indicating that species richness within these locations was generally high on nearly half of total surveys (Fig. 3). Species richness hotspots were located throughout the study area (n = 15), but were generally more common north of the South Shetland Islands in association with the southern ACC front and its southern boundary (Fig. 3). There were 3 richness hotspots associated with the location of 2 submarine canyon systems; cells C5 and C6 near Livingston Island and cell F7 in Bransfield Strait adjacent to the northwestern tip of the Antarctic Peninsula (see bathymetry in Fig. 1). There were 3 species richness hotspots (cells E5, F4 and F5) located to the east, north, and south of King George Island (Admiralty and Maxwell Bays). In addition, there were 2 adjacent richness hotspots at the southern edge of the study area near a confluence formed by the mixing of waters from Bransfield and Gerlache Straits (cells C8 and D8; Fig. 3).

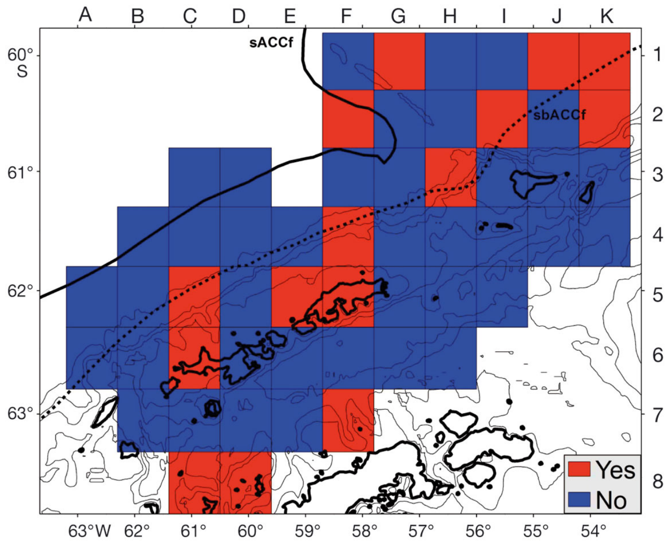

Fig. 3. Location of species richness hotspots. All richness hotspots were persistent for >50 % of all surveys; red square (Yes) indicates richness hotspots

Table 3. Principal component analysis (PCA) for the persistence of abundance for 16 species; eigenvalues and total variance for PCA factors

PCA factor	Eigenvalue	% Total variance
1	5.24	32.72
2	2.39	14.91
3	1.54	9.60
4	1.42	8.89
5	1.04	6.47
6	0.89	5.57

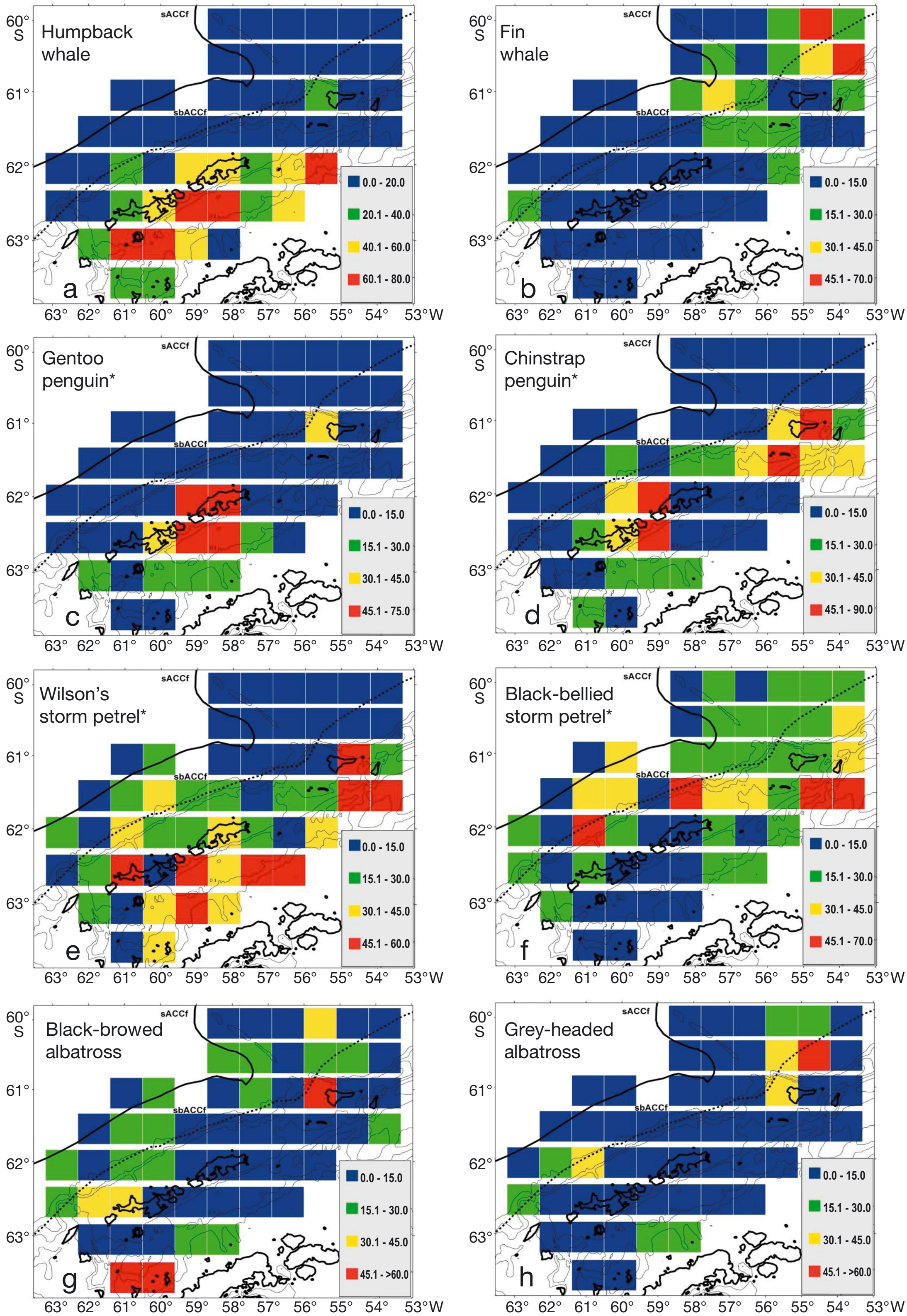

Fig. 4. Classified persistent abundance hotspots (percentage of time cell anomaly exceeds 1 standard deviation above the mean) of (a) humpback whale, (b) fin whale, (c) gentoo penguin, (d) chinstrap penguin, (e) Wilson's storm petrel, (f) black-bellied storm petrel, (g) black-browed albatross, (h) grey-headed albatross, (i) cape petrel, (j) Antarctic fulmar, (k) Antarctic fur seal, (l) south polar skua, (m) blue petrel, (n) prions (o) white-chinned petrel and (p) southern giant petrel. *Species breeds in study region and therefore some hotspot locations may represent land-based breeding colonies

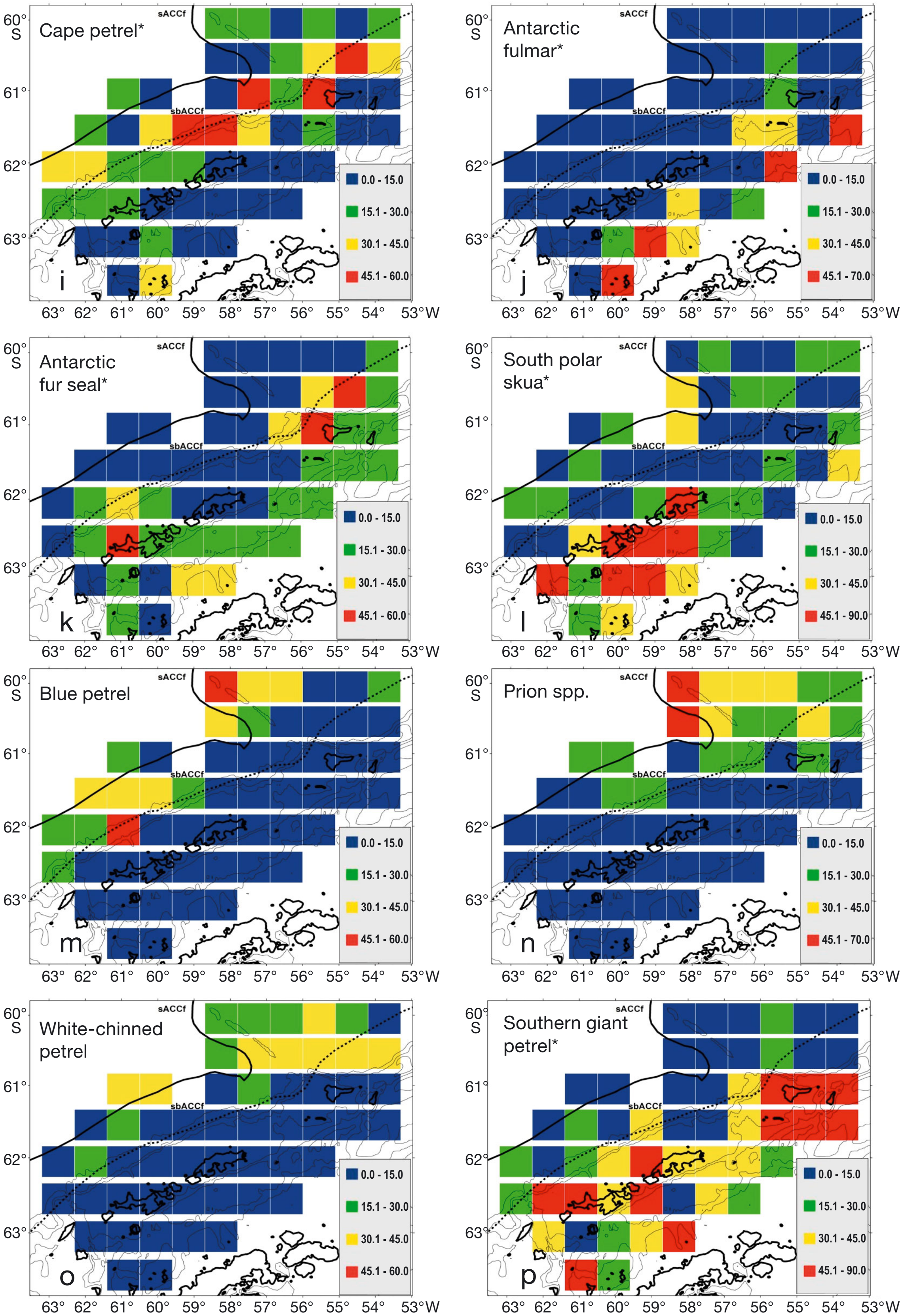

Fig. 4 (continued)

Species abundance hotspots

We identified abundance hotspots as those areas that consistently displayed abundance anomalies exceeding 1 standard deviation above the long term spatial mean >45 % of the times surveyed. We identified abundance hotspots for 16 top predators and generally showed 2 areas of concentration related to coastal and oceanic habitats (Figs. 4a–p & 5). Cluster analysis and PCA of species abundance hotspots revealed 2 groupings that reflect their preferred foraging habitats and for some species, probable land-based breeding locations (Table 3, Fig. 5). There is an 'Oceanic Drake Passage' group, including fin whale, black-bellied storm petrel, prions, white-chinned petrel, blue petrel, Antarctic fur seal, grey-headed albatross, cape petrel and black-browed albatross; and a 'Coastal Bransfield Strait' group, including humpback whale, gentoo penguin, chinstrap penguin, south polar skua, Antarctic fulmar, Wilson's storm petrel and southern giant petrel (Fig. 5). In addition, cell loadings of PC1 and PC2 dichotomized by positive and negative values illustrate this apparent spatial segregation (Fig. 6).

We found that closely related species, such as gentoo and chinstrap penguins and black-browed and grey-headed albatrosses, aggregated together in the same hotspots (Fig 4c,d,g,h). By contrast, other

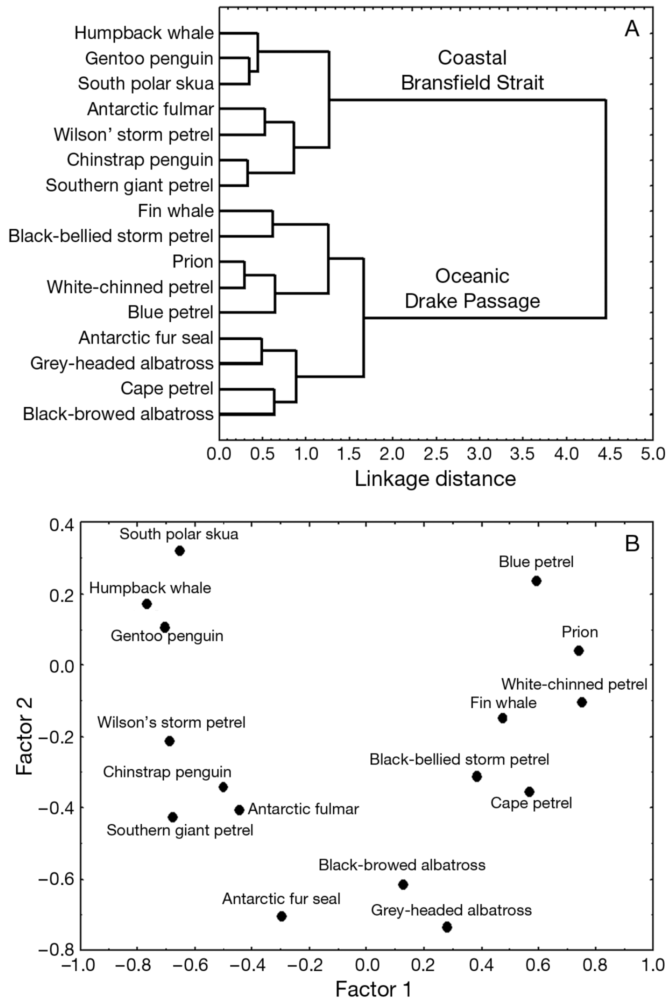

Fig. 5. Species assemblages defined based on their persistence of abundance as determined by (A) hierarchical cluster analysis and (B) ordination of factors from principal component analysis

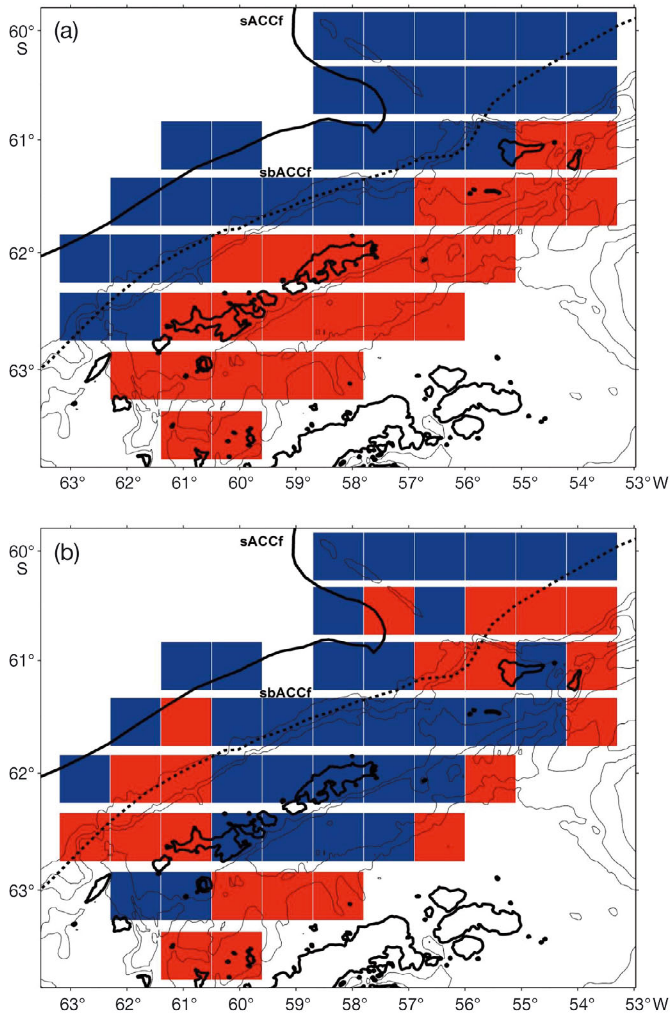

Fig. 6. Plot of principal component analysis (PCA) factor loadings per cell (grouped by positive [red] and negative [blue] values) for (a) PC1, illustrating species assemblages based on abundance hotspots and showing a separation of the 'Oceanic Drake Passage' from 'Coastal Bransfield Strait' (see Fig. 1) and (b) PC2, showing regionally specific areas to the spatial persistence of top-predators due to island locations and unique circulation or water mixing/retention

species pairs appeared to segregate into different hotspots. This apparent segregation seemed to be based on oceanographic habitats. For example, hotspots of humpback whales and Wilson's storm petrels were concentrated within Bransfield Strait, whereas hotspots of fin whales and black-bellied storm petrels were concentrated in southern Drake Passage (Fig. 4a,b,e,f). The closely related and similarly sized cape petrel and Antarctic fulmar are frequently observed in aggregations numbering in the thousands, yet their hotspot locations were separated according to oceanic and coastal origins. Abundance hotspots of cape petrels occurred mainly within the southern ACC frontal zone (Fig. 4i), whereas abundance hotspots of Antarctic fulmars were chiefly in southern Bransfield Strait (Fig. 4j).

We found that some species exhibited more hotspots than other species (Fig. 7). For example, black-bellied storm petrels, southern giant petrels, Antarctic fur seals and humpback whales showed more hotspots, while species such as grey-headed albatross, gentoo and chinstrap penguins, and Antarctic fulmar had fewer (Fig. 7). The medium and high persistence species abundance hotspots (yellow and red cells) were summed across all 16 species per cell to reveal the importance of a cell (Fig. 8). Several cells proved attractive to multiple species. For example, the cell that includes the western half of Elephant Island (I3) includes hotspots for 6 species (grey-headed albatross, black-browed albatross, cape petrel, fur seal, southern giant petrel, gentoo and chinstrap penguins) and the one that includes the eastern portion of Livingston Island (C6) includes hotspots for 6 species (humpback whale, gentoo and chinstrap penguins, Wilson's storm petrel, south polar skua and southern giant petrel). The highest concentration of neighboring cells with multiple species abundance hotspots (cells D6, E6–7, and F5–7) are located in Bransfield Strait.

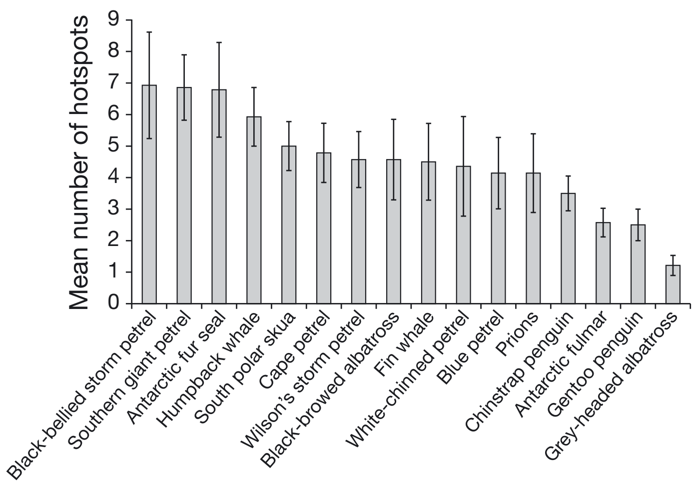

Fig. 7. Mean number (±SD) of species abundance hotspots over 14 surveys. Species are sorted relative to frequency of hotspots

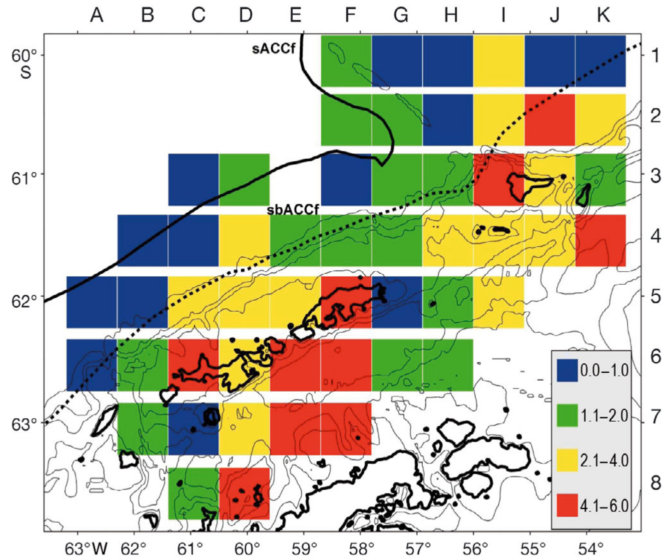

Fig. 8. Summary of the number of species (n = 16) abundance hotspots determined by summing the number of species hotspots per cell (see Fig. 4)

Oceanographic determinants of hotspots

The last application of the hotspot variance metric investigated the relationship between hotspot persistence and distance to land and 2 hydrographic boundaries (Table 4). Several species belonging to the 'Coastal Bransfield Strait' group (Fig. 5) exhibited significant associations (negative) between their spatial persistence and distance to land: humpback whale, Antarctic fur seal, Antarctic fulmar, chinstrap and gentoo penguins, southern giant petrel and south polar skua. None of these species displayed persistent hotspots that were associated with the position of hydrographic boundaries. On the other hand, species from the 'Oceanic Drake Passage' group displayed persistent hotspots that were closely associated with the position of the 2 hydrographic boundaries: fin whale, cape petrel, black-bellied storm petrel, prions, blue petrel, and white-chinned petrel. Interestingly, some species within this group exhibited higher correlation with one oceanographic boundary over the other, suggesting even further niche separation in the oceanic domain. For example, persistent hotspot of prions, blue petrel and white-chinned

Table 4. Spearman rank correlations for persistence of species abundance and richness relative to distance to land and the southern Antarctic Circumpolar Current front (sACCf) and the southern boundary (sbACCf). Bold values indicate significant association. *Significant negative association. Confidence limits (L95 % and U95 %) are based on a randomization test

Variable	Distance land			Distance sACCf			Distance sbACCf		
	Rho, p	L95 %, U95 %	R^2	Rho, p	L95 %, U95 %	R^2	Rho, p	L95 %, U95 %	R^2
Humpback whale	**−0.57, <0.01***	−0.36, −0.73	0.24	**0.59, <0.01**	0.38, 0.74	0.33	**0.51, <0.01**	0.28, 0.69	0.26
Fin whale	**0.30, 0.02**	0.04, 0.53	0.04	−0.16, 0.25	0.11, −0.41	0.007	**−0.33, 0.01***	−0.07, −0.55	0.11
Antarctic fur seal	**−0.48, <0.01***	−0.24, −0.66	0.25	**0.55, <0.01**	0.33, 0.71	0.21	0.02, 0.88	−0.25, 0.29	0
Cape petrel	0.24, 0.08	−0.03, 0.47	0.02	**−0.46, <0.01***	−0.22, −0.65	0.15	**−0.63, <0.01***	−0.43, −0.77	0.31
Antarctic fulmar	**−0.32, 0.02***	−0.06, −0.54	0.10	**0.49, <0.01**	0.26, 0.67	0.30	0.24, 0.08	−0.03, 0.48	0.20
Black-browed albatross	0.07, 0.62	−0.20, 0.33	0.004	−0.17, 0.22	0.10, −0.42	0.003	−0.11, 0.42	0.16, −0.37	0.003
Grey-headed albatross	0.13, 0.46	−0.17, 0.36	0.0002	0.12, 0.40	−0.16, 0.37	0.02	−0.11, 0.85	0.15, −0.37	0.02
Wilson's storm petrel	**−0.47, <0.01***	−0.23, −0.65	0.21	**0.46, <0.01**	0.22, 0.65	0.25	**0.37, <0.01**	0.12, 0.58	0.16
Black-bellied storm petrel	0.17, 0.21	−0.09, 0.42	0.007	−0.21, 0.13	0.06, −0.45	0.05	**−0.38, <0.01***	−0.12, −0.59	0.15
Prion spp.	**0.65, <0.01**	0.46, 0.78	0.54	**−0.50, <0.01***	−0.26, −0.68	0.22	**−0.30, 0.03***	−0.04, −0.53	0.03
Blue petrel	**0.68, <0.01**	0.49, 0.79	0.51	**−0.76, <0.01***	−0.62, −0.85	0.45	**−0.30, 0.03***	−0.04, −0.53	0.04
Chinstrap penguin	**−0.51, <0.01***	−0.27, −0.68	0.24	**0.28, 0.03**	0.02, 0.51	0.09	0.14, 0.32	−0.14, 0.39	0.005
Gentoo penguin	**−0.54, <0.01***	−0.32, −0.71	0.18	**0.48, <0.01**	0.25, 0.66	0.13	**0.32, 0.02**	0.06, 0.54	0.04
White-chinned petrel	**0.60, <0.01**	0.39, 0.75	0.38	**−0.57, <0.01***	−0.36, −0.73	0.26	**−0.29, 0.03***	−0.03, −0.52	0.07
Southern giant petrel	**−0.73, <0.01***	−0.58, −0.84	0.45	**0.52, <0.01**	0.29, 0.69	0.25	0.25, 0.07	−0.02, 0.48	0.04
South polar skua	**−0.27, 0.04***	−0.001, −0.51	0.07	**0.33, 0.01**	0.07, 0.55	0.15	**0.41, <0.01**	0.16, 0.61	0.17
Species richness	−0.09, 0.52	0.18, −0.35	0.003	0.07, 0.58	−0.19, 0.33	0.02	−0.12, 0.39	0.15, −0.37	0

petrel displayed higher correlation with the location of the southern ACC front than the southern boundary of the ACC front (Table 4, Fig. 4), whereas hotspots of fin whale, cape petrel and black-bellied storm petrel displayed higher association with the southern boundary. Species richness hotspots (Fig. 3) were not significantly associated with distance to land or hydrographic boundaries (Table 4), possibly indicating that persistence of these areas may be attributed to unique biological conditions and complex habitat heterogeneity.

DISCUSSION

Through years of replicated shipboard surveys and use of a variance-based hotspot metric, this study provides an atlas of persistent species richness and abundance hotspots. Unlike other recent efforts (Nur et al. 2011, Oppel et al. 2012), we used only actual observations and did not include estimated presence based on habitat models. That is, our quantification was based on places where we actually observed aggregations of seabirds and marine mammals, and we did not include those areas predicted to have aggregations on the basis of their habitat characteristics (which confuses what is observed and what is modeled). The quantification of hotspots is important from 2 different perspectives. First, identifying foraging hotspots is important for the conservation of top predators. Because marine ecosystems are highly variable, quantifying persistence of hotspots will benefit development of Marine Protected Areas to effectively conserve top predator species (Hyrenbach et al. 2000, Hooker & Gerber 2004, Hooker et al. 2011). For example, near the Antarctic Peninsula, knowledge of hotspot locations could be used to minimize conflict between top predators and humans; in particular, spatial allocation of krill fishing activity and vessel traffic patterns (Reid et al. 2004, Hill et al. 2009). Second, it is of interest from a perspective of foraging theory to identify how top predators find prey (Ainley et al. 1992, 2009, Veit 1999, Davoren et al. 2003, Silverman et al. 2004). If top predators memorize the locations of productive feeding areas, then areas we have identified as hotspots are likely to be among those locations memorized. How long individuals spend at such hotspots (Block et al. 2011) and the characteristics of prey aggregations, namely krill within hotspots (Santora et al. 2010, 2012a), remains to be quantified. In the future, blending shipboard surveys and satellite telemetry studies of top predators offers a promising way forward to accomplish estimates of population- and individual-level use of hotspots.

The novelty of the method we used is twofold. Most importantly, it was based on actual observations of species richness and abundance rather than modeled richness and abundance. The issue here is that top predators only aggregate in a small proportion of the habitats that are actually suitable to them, so that regression-style habitat models may overpredict hotspots. Part of the reason for this is that top predators are tracking highly mobile and patchy prey (Davoren et al. 2003). Second, the analysis was not contingent upon knowing any particular statistical distribution of top predator richness or abundance, and in that sense it was a nonparametric analysis. Also, most habitat models predict seabird and mammal abundance based on averages of satellite-based data (e.g. chl *a*, sea-surface temperature) that often lack the components that were likely attractive to the birds and mammals that were aggregated at the time of sampling (Block et al. 2011, Nur et al. 2011, Oppel et al. 2012). This study differs from others because top predator hotspots were defined based on their persistence; specifically accounting for the frequency of surveys that a particular location exhibited an anomaly richness or abundance value exceeding the long-term spatial mean by 1 SD. Using a similar approach, Suryan et al. (2012) defined persistence of remotely-sensed surface chl *a* areas (a widely used index of ocean productivity), revealing that the persistence metric explained more variance of seabird density than did mean chl *a*. This study builds on the work of Suryan et al. (2012), but differs because the persistence metric is applied directly to standardized rates of species richness and abundance of seabirds and marine mammals. We advocate the use of this method because it is straightforward and can be easily applied to shipboard surveys of top predators, their prey, and productivity.

Drivers of hotspots

We did not examine environmental predictors of hotspot occurrence, but rather focused on identifying their location and persistence so they could be examined in future studies combining information on oceanographic features and micronekton collectively to understand trophic transfer in marine environments (Santora et al. 2012b). Potential drivers of persistent top predator hotspots may include features such as abrupt topographies, hydrographic boundaries (Genin 2004), persistent chl *a* concentration (Suryan et al. 2012) and prey aggregations (Gende & Sigler 2006, Sigler et al. 2012). However, some environmental features are likely more persistent than others. For example, seamounts and submarine canyons are fixed locations, whereas locations of hydrographic fronts and prey aggregations may move (Hyrenbach et al. 2000, Morato et al. 2010). Future studies ought to apply dynamic habitat models to the hotspot persistence metric to determine what environmental predictors (e.g. bathymetry, sea surface temperature, ch *a* persistence) explain the spatial distribution and persistence of hotspots (Zydelis et al. 2011, Santora et al. 2012a, 2013). Importantly, hotspots identified in this study reflect summertime conditions when many species are using the area for breeding (e.g. penguins, fur seals) or replenishing energy reserves depleted during migration from wintering grounds (e.g. humpback and fin whales). The persistence of hotspots outside of the summer season remains unknown.

Although krill hotspots are an important predictor of baleen whale hotspots near the Antarctic Peninsula (Santora et al. 2010), future work should assess spatial relationships among krill and top predator hotspots and physical forces simultaneously (Hunt et al. 1998, Santora et al. 2012b, Sigler et al. 2012). Temporal and spatial scales of atmospheric and oceanographic process should be considered when weighing their predictive capabilities on the formation and persistence of biological hotspots (Palacios et al. 2006). For example, eddies are important sources of biological production that may contain high concentrations of chl *a* and krill (Kahru et al. 2007, Santora et al. 2012a,b), and likely affect spatial and temporal variation in top predator hotspots (Gende & Sigler 2006, Block et al. 2011). Bathymetry derived circulation patterns and coastal transport processes (e.g. Ekman transport) are likely important for understanding persistence and connectivity of top predator hotspots. Piñones et al. (2011) investigated transport pathways and residence times of water using a regional ocean modeling system (ROMS) to track simulated particles throughout the Antarctic Peninsula, revealing that biological hotspots were sites with the longest particle residence times (~30 d). If areas with long residence times contain predictable krill concentrations (Hofmann et al. 2004), then ROMS is an important tool for understanding mesoscale transport patterns of krill and connectivity among top predator hotspots among seasonal and inter-annual time scales (Santora et al. 2013).

Spatial organization of hotspots

Some areas clearly emerge as abundance hotspots because they are located close to large breeding colonies (AMLR 2007, Harris et al. 2011, Santora 2013). Others are nowhere near any known nesting locations (such as for the albatrosses and whales) and are therefore clearly attractive due to their potential food resources (e.g. submarine canyons north of Livingston Island; Santora & Reiss 2011). Our results indicate there are species abundance hotspots that are related to distance to land, in contrast to those related to the position of hydrographic boundaries. This gradient analysis is important for summarizing spatial organization of hotspots relative to the mesoscale structure of the marine environment (Santora et al. 2012a,b). For example, hotspots of fin whales, black-bellied storm petrels and cape petrels are associated with the southern boundary of the ACC, an ecologically important productivity zone throughout the Southern Ocean (Orsi et al. 1995, Tynan 1998). Species hotspots that were associated with the ACC were not associated with distance to land, indicating their affinity for oceanic waters. Distribution of hotspots of seabirds, such as blue petrel, prion species, and white-chinned petrel that do not breed in the study region but hail from colonies originating in sub-Antarctic latitudes, are not associated with islands and are concentrated in the oceanic domain (Hunt et al. 1990, Ainley et al. 1994). Exceptions to this are the black-browed and grey-headed albatross, which also breed on sub-Antarctic islands, and exhibit hotspots near Livingston and Elephant Islands. By contrast, species hotspots identified for chinstrap penguin, gentoo penguin, Antarctic fur seal, south polar skua, southern giant petrel and Wilson's storm petrel were closely associated with distance to land and may indicate probable breeding colony locations (Harris et al. 2011, Santora 2013).

Interestingly, all species richness hotspots displayed persistence values equal to or greater than 50% of the total time surveyed. This is in contrast to the species abundance hotspots identified, which showed a range of persistence values. In total, 15 species richness hotspots were identified, 9 of which occured near the southern Antarctic Circumpolar Current front, while others were located in proximity to the South Shetland Islands and the location of 2 submarine canyon systems. However, collectively the 15 species richness hotspots were not statistically associated with distance to the ACC or land. The consistently higher level of persistence exhibited by species richness hotspots may indicate there are likely unique physical and biological features specific to each of these locations, and therefore widely attractive to multiple top predator species. For example, krill hotspots located within the ACC, principally composed of large sexually mature krill, are distributed along the shelf-slope coinciding with moderate levels of eddy kinetic energy (Santora et al. 2010, 2012a); areas that attract diverse species groups including procellariid seabirds, toothed cetaceans and mesopelagic fishes (Appendix 1; Barrera-Oro 2002, Santora & Brown 2010, Santora 2012). Richness hotspots located near land may indicate higher numbers of species that either breed there, or are attracted to the complex bathymetric irregularities (such as submarine canyons) that foster predictable concentrations of krill (Santora & Reiss 2011); such bathymetric features are typical of the nearshore environment throughout the South Shetland Islands and Antarctic Peninsula region. Future studies should examine each species richness hotspot in greater detail, especially their scale-dependent responses to physical and biological drivers (Hurlbert & Jetz 2007) to determine if generalities can be made and applied throughout the Southern Ocean.

Hotspots and species interactions

Formation and maintenance of hotspots are also likely influenced by interactions such as competition and mutualism or facilitation (Reed & Dobson 1993, Camphuysen & Webb 1999, Ainley et al. 2006, 2009). Spatial segregation of species abundance hotspots may in fact indicate niche partitioning among species, and relate to difference in prey density and spatial organization (Piatt 1990, Piatt & Methven 1992, Santora et al. 2010, 2011). We found that several closely related species displayed strikingly different hotspot distribution patterns reflecting oceanic and coastal origins. For example, hotspots of humpback and fin whales — both major krill consumers requiring extremely dense krill patches — displayed virtually no spatial overlap (Santora et al. 2010, Sigler et al. 2012). Hotspots of similar sized cape petrel and Antarctic fulmar also exhibited non-overlapping hotspot patterns. Moreover, Wilson's and black-bellied storm petrel, 2 seemingly identical small petrel species, exhibited hotspots that overlapped very little. Additional characterization of physical and biological features of hotspots could be used to examine potential mechanisms of spatial segregation among sympatric species (Ainley et al. 2009, Santora et al. 2012b).

Species that benefit from one another (e.g. local enhancement; Grünbaum & Veit 2003) may exhibit higher levels of spatial persistence, having overlapping aggregations within profitable foraging areas. For example, albatross and petrels often aggregate together with pursuit-diving penguins and seals, which are able to exploit a larger portion of the water column, and whose foraging behavior may drive prey close to the surface in reach of the flying seabirds (Harrison et al. 1991, Silverman et al. 2004). Our results show that hotspots for black-browed and grey-headed albatrosses also contained fur seal hotspots, and were located near known major fur seal breeding colonies (e.g. Livingston and Seal Islets; cells C5–6 and H3–I2; Fig. 3). Thus, the location of fur seal colonies may be important to albatross conservation because of their facilitatory role in providing access to prey through the action of the seals. Moreover, the abundance hotspots described here may serve as a basis for examining potential competition among seabirds, seals and baleen whales, especially as whale populations continue to rebuild from commercial whaling (Fraser et al. 1992, Ainley et al. 2006, Trivelpiece et al. 2011). For example, hotspots of humpback whales were also closely associated with coastal areas, likely placing them in competition with neighboring seabird and seal colonies (Santora & Reiss 2011, Santora 2013). Such critically important interspecific interactions need to be taken into account in the implementation of effective conservation measures, as nonlinear impacts of the decline of a single predator can have disproportionate effects (Berec 2010).

Implications for marine spatial management and conservation

The hotspot patterns presented in this study have implications for marine spatial management in the Southern Ocean. The majority of krill-predator and commercial fishing demand for krill in the Antarctic Peninsula region occurs within 150 to 200 km from land (Croll & Tershy 1998, Jones & Ramm 2004, Reid et al. 2004), coinciding with many of the hotspots identified in this study located near islands. Additionally, the commercial krill catch has increased in recent years, coinciding with new developments in fishing methods enabling nets to remain submerged for weeks and continuously pump krill to factory ships; some estimates suggest krill catches may be as high as 800 t per vessel per day (Nicol et al. 2012). To advance spatial management of krill and krill-predators the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) developed small-scale management units (SSMUs) to manage catch allocations of krill in small areas ensuring additional protection of important predator foraging areas where fishing vessels may pose potential competition (Constable et al. 2000, Hewitt et al. 2004, Hill et al. 2009). Near the Antarctic Peninsula region, there are 8 SSMUs whose boundaries were established in part due to the foraging range of land-based breeding penguins and seals. The SSMUs did not necessarily take into account the marine distribution of cetaceans, male fur seals, aerial seabirds (e.g. cape petrels, fulmars) and sub-Antarctic breeding seabirds that concentrate in the region. Moreover, potential overlap between krill-predators and fishing vessels was derived from a single shipboard survey spanning a week of survey effort near the Antarctic Peninsula (CCAMLR 2000 Survey; Reid et al. 2004). Due to the high level of temporal and spatial variance in the distribution of seabirds and marine mammals, using shipboard surveys to inform marine spatial management decisions for marine predators should require integration of multiple surveys replicated over many years to quantify mesoscale structure and oceanographic determinants of krill and predator hotspots (Santora et al. 2010, 2012a). Therefore, persistent top predator hotspots identified here should be compared to fluxes in krill abundance (Reiss et al. 2008), fishing pressure (Jones & Ramm 2004, Nicol et al. 2012), boundaries of existing SSMUs (Hewitt et al. 2004) as well as commercial shipping traffic patterns, which have steadily increased during the past few decades (i.e. tourist ships; Tin et al. 2008, Lynch et al. 2010).

The term hotspot is important for generating awareness and particular attention to species of conservation concern (Myers et al. 2000, Worm et al. 2003, Rodrigues et al. 2006). CCAMLR and BirdLife International are interested in the status of seabird and marine mammal predator populations of ecological and conservation value in the Antarctic Peninsula region. The frequency of occurrence and International Union for Conservation of Nature (IUCN; Rodrigues et al. 2006) status for all 54 taxa recorded during our surveys is presented in Appendix 1. In summary, there were 3 endangered species (hotspots identified for black-browed albatross and fin whale), 4 near threatened (hotspots identified for gentoo penguin) and 5 vulnerable (hotspots identified for grey-headed albatross and white-chinned petrel) species recorded during our surveys. Due to their frequency of occurrence and overall abundance, we were only able to apply the hotspot persistent metric to the 16 most common species inhabiting the study region, some of which may not be candidates for conservation. Species richness hotspots were identified based on sighting rates of all species, keeping in line with the classical concept of a biological hotspot (Myers et al. 2000, Hurlbert & Jetz 2007). Although some species were sighted less frequently than others

(Appendix 1), they collectively contributed to our identification of persistent species richness hotspots, indicating the ecology of these areas is likely unique. Therefore, the species richness hotspots we identified are obvious candidates for further evaluation of their vulnerability to anthropogenic disturbance and climate change. Future research ought to characterize and compare these richness hotspots in terms of their oceanography, habitat quality and the prey concentrations they may foster (Worm et al. 2003, Sydeman et al. 2006, Palacios et al. 2006).

In recognition of their vulnerability to human disturbances and climate change, an atlas of Important Bird Areas (IBA) based on breeding bird colonies in the Antarctic Peninsula region highlights many locations throughout South Shetland Island archipelago (Harris et al. 2011). Although identifying land-based IBA is valuable, it does not ensure protection of marine environments where seabirds concentrate their foraging effort and spend the majority of their time (Hooker & Gerber 2004, Hooker et al. 2011). Generally, foraging seabirds are found in proximity to their breeding colonies, suggesting an inverse function between their at sea abundance and distance to land (Croll & Tershy 1998). However, non-breeding species of seabirds are not tied to land for provisioning offspring, and some species traveling afar from breeding grounds to distant foraging grounds (e.g. albatross species in this study) indicate that land-based IBA alone will not ensure protection of habitats critical for sustaining seabird populations. The persistent hotspots presented in this study have important implications for designation of marine IBA and should be considered along with land-based IBA for developing Marine Protected Areas in the future. Therefore, future management, conservation and marine spatial planning near the Antarctic Peninsula should benefit from the baseline distribution of persistent multispecies hotspots quantified in this study.

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Appendix 1. Species observed during 14 US Antarctic Marine Living Resource (AMLR) surveys January – March, 2003–2011 (sorted alphabetically within frequency of surveys). Conservation status is provided by the International Union for Conservation of Nature (IUCN; www.iucnredlist.org); see Rodrigues et al. 2006 for details about the IUCN Red List

Name		Surveys observed	IUCN status
Antarctic fulmar	*Fulmarus glacialoides*	14	Least Concern
Antarctic fur seal	*Arctocephalus gazella*	14	Least Concern
Antarctic minke whale	*Balaenoptera bonaerensis*	14	Data Deficient
Antarctic prion	*Pachyptila desolata*	14	Least Concern
Antarctic tern	*Sterna vittata*	14	Least Concern
Black-browed albatross	*Thalassarche melanophrys*	14	Endangered
Black-bellied storm petrel	*Fregetta tropica*	14	Least Concern
Blue petrel	*Halobaena caerulea*	14	Least Concern
Brown skua	*Catharacta antarctica*	14	Least Concern
Cape petrel	*Daption capense*	14	Least Concern
Chinstrap penguin	*Pygoscelis antarctica*	14	Least Concern
Fin whale	*Balaenoptera physalus*	14	Endangered
Grey-headed albatross	*Thalassarche chrysostoma*	14	Vulnerable
Humpback whale	*Megaptera novaeangliae*	14	Least Concern
Light-mantled albatross	*Phoebetria palpebrata*	14	Near Threatened
Southern giant petrel	*Macronectes giganteus*	14	Least Concern
South polar skua	*Stercorarius maccormicki*	14	Least Concern
Wandering albatross	*Diomedea exulans*	14	Vulnerable
Wilson's storm petrel	*Oceanites oceanicus*	14	Least Concern
Gentoo penguin	*Pygoscelis papua*	13	Near Threatened
Northern giant petrel	*Macronectes halli*	13	Least Concern
White-chinned petrel	*Procellaria aequinoctialis*	13	Vulnerable
Soft-plumaged petrel	*Pterodroma mollis*	12	Least Concern
Kelp gull	*Larus dominicanus*	11	Least Concern
Southern bottlenose whale	*Hyperoodon planifrons*	11	Least Concern
Antarctic petrel	*Thalassoica antarctica*	10	Least Concern
Arctic tern	*Sterna paradisaea*	10	Least Concern
Macaroni penguin	*Eudyptes chrysolophus*	10	Vulnerable
Thin-billed prion	*Pachyptila belcheri*	10	Least Concern
Adelie penguin	*Pygoscelis adeliae*	9	Least Concern
Killer whale	*Orcinus orca*	9	Data Deficient
Snowy sheathbill	*Chionis albus*	8	Least Concern
Snow petrel	*Pagodroma nivea*	8	Least Concern
Antarctic shag	*Phalacrocorax bransfieldensis*	7	Not Evaluated
Common diving petrel	*Pelecanoides urinatrix*	7	Least Concern
Hourglass dolphin	*Lagenorhynchus cruciger*	7	Least Concern
Southern elephant seal	*Mirounga leonina*	7	Least Concern
Southern royal albatross	*Diomedea epomophora*	7	Vulnerable
Weddell seal	*Leptonychotes weddellii*	7	Least Concern
Leopard seal	*Hydrurga leptonyx*	6	Least Concern
Long-finned pilot whale	*Globicephala melas*	6	Data Deficient
Southern right whale	*Eubalaena australis*	5	Least Concern
Crabeater seal	*Lobodon carcinophaga*	4	Least Concern
Sooty shearwater	*Puffinus griseus*	4	Near Threatened
Kerguelen petrel	*Lugensa brevirostris*	3	Least Concern
White-headed petrel	*Pterodroma lessonii*	3	Least Concern
Parasitic jaeger	*Stercorarius parasiticus*	2	Least Concern
Emperor penguin	*Aptenodytes forsteri*	1	Least Concern
Fairy prion	*Pachyptila turtur*	1	Least Concern
Gray's beaked whale	*Mesoplodon grayi*	1	Data Deficient
King penguin	*Aptenodytes patagonicus*	1	Least Concern
Mottled petrel	*Pterodroma inexpectata*	1	Near Threatened
South Georgia diving petrel	*Pelecanoides georgicus*	1	Least Concern
Sooty albatross	*Phoebetria fusca*	1	Endangered

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