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Long-term study of at-sea distribution of seabirds and marine mammals in the Scotia Sea, Antarctica

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Abstract The Scotia Sea is one of the most biologically rich regions of Antarctica, and it hosts a large community of upper trophic-level predators. Long-term at-sea monitoring provides valuable information on the Antarctic marine ecosystem and relationships among top predators. This paper presents the results of at-sea monitoring of seabirds and cetaceans over five consecutive summer seasons (2010—2014) in the Scotia Sea, Antarctica. A total of 11 656 flying birds belonging to 24 species were recorded in 884 ten-minute counts. Six Procellariiformes species were abundant: Black-browed Albatross, Cape Petrel, Southern Fulmar, Antarctic Prion, Wilson's Storm-petrel, and Black-bellied Storm-petrel. Only three of these species accounted for 82% of the total abundance: Antarctic Prion (40%), Southern Fulmar (22%), and Cape Petrel (20%). A total of 678 baleen whales belonging to five species were recorded along a sampling effort of 2 351 nautical miles: Humpback, Sei, Southern Right, Fin, and Minke whales, which had different abundances during the study. The Fin Whale had the highest mean encounter rate for the 5 years (0.29 whales per nautical mile), followed by the Humpback Whale (0.09 whales per nautical mile). Annual dissimilarity in abundance of both seabirds and cetaceans occurred in conjunction with changes in the sea surface temperature and ice cover, showing the dependence of top predators on environmental changes. The largest aggregations of all top predators (seabirds and cetaceans) were recorded in two regions, west and south of the South Orkney Islands, suggesting important prey availability (especially krill) in those areas.

Keywords **seabirds, cetaceans, Scotia Sea, Antarctica**

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1 Introduction

The Scotia Sea is one of the most biologically rich regions of the Southern Ocean and southern Atlantic Ocean, with a high biomass of phytoplankton and zooplankton[1–2]. The most important current in the Scotia Sea is the Antarctic Circumpolar Current (ACC), which flows west to east and transports nutrients throughout the Southern Ocean[3]. The Scotia Sea is one of the most studied regions of the Southern Ocean, and monitoring of the distribution of top predators provides valuable information on how species interact with each other and with the environment. Importantly, long-term studies provide additional information about the evolution of communities over time and space.

There have been many multiyear investigations conducted in the Scotia Sea, with a focus on climate[4–5], plankton[6], changes in ice cover[7], or bird populations and communities[8–11]. Taking into account the importance and unique features of this oceanic area, in 2009 the Commission

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for the Conservation of Antarctic Marine Living Resources (CCAMLR) created the South Orkney Islands (SOI) Marine Protected Area (MPA) on the southern edge of the Weddell–Scotia Confluence. Since summer 2010, the Argentine Antarctic Program has conducted a long-term study of the at-sea distribution of seabirds and cetaceans in the Scotia Sea. The aim of this study was to monitor the distribution of top predators in the Scotia Sea and to investigate changes in their distribution over time and space based on at-sea surveys conducted during summer from 2010 to 2014.

2 Methods

2.1 Study site

The surveys were carried out onboard the R/V Puerto Deseado between January and March each year from 2010 to 2014. The surveys were conducted between 58°00′–64°00′S and 40°00′–49°00′W and the study area included the SOI MPA, which is part of CCAMLR Domain 1 (Western Peninsula and South Scotia Arc: Figure 1).

2.2 Survey methods and analysis

Visual observations of seabirds and cetaceans were made from the ship's bridge (15 m above sea level) and the outdoor bridge wings, which together provided a visual field of 360°. Sighting surveys were conducted daily during daylight hours by two experienced observers who worked individually in staggered shifts of 4 h. Photographs were taken with a digital camera equipped with a 50× zoom lens to assist in the subsequent identification of species by comparison with catalogs and personal photograph files. Seabirds and cetaceans were sighted with the naked eye then species identification was made using 16×50 binoculars. Sea ice cover (% concentration; from observer estimation) and sea surface temperature (SST; °C at a depth of 3 m recorded by a Sea-Bird Electronics 21 thermosalinograph every 30 s) were updated at the beginning of each 10-min count. Analysis of variance (ANOVA) was used to detect significant differences in SST among seasons. Because the R/V Puerto Deseado was also carrying researchers undertaking oceanographic studies, the ship's tracks differed each season.

2.2.1 Seabirds

The seabird observations were conducted in 10-min strip

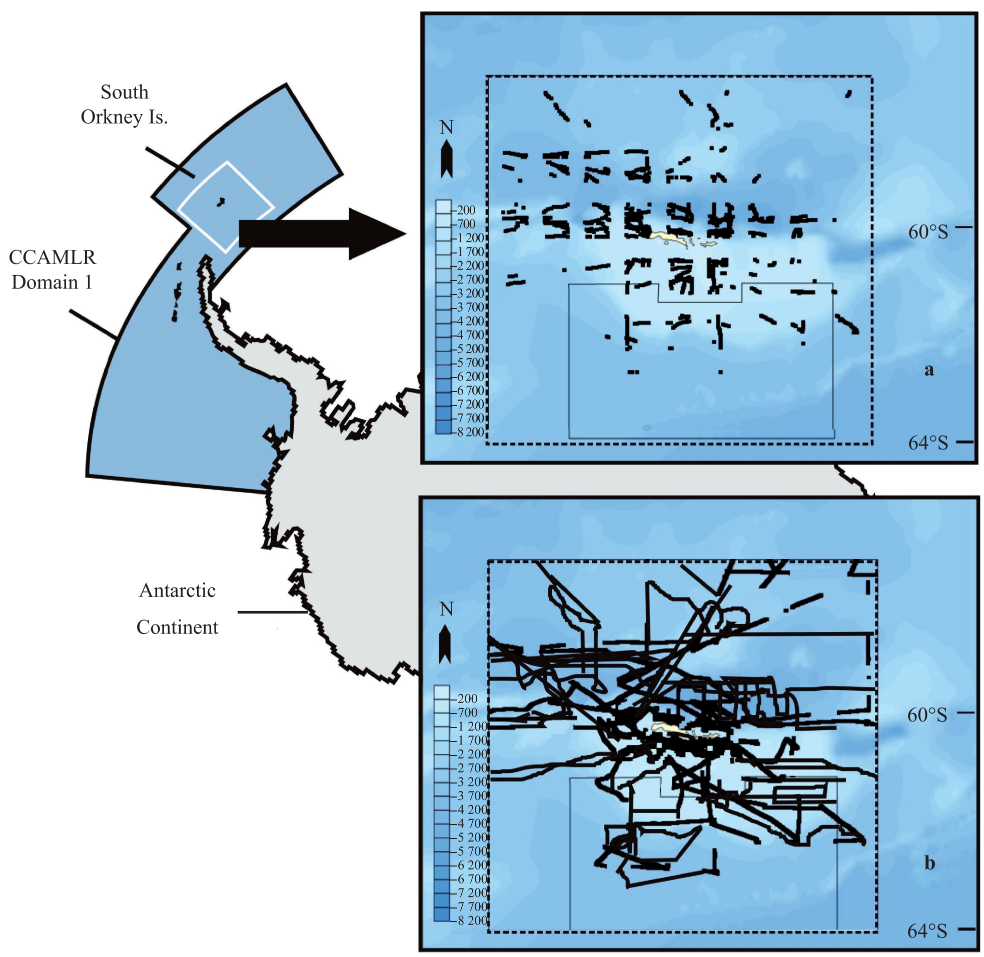

Figure 1 Study site and survey effort in summer 2010–2014. **a**, Survey effort for seabirds. Each dot indicates one 10-min count (n = 884). **b**, Approximate survey transects for cetaceans (solid lines) corresponding to 2 351 nm. Dotted line indicates the study area; solid line indicates the approximate boundary of the South Orkney Islands Marine Protected Area. The color bar indicates bathymetry (m).

transects during daylight. For seabirds, one sampling unit was a 10-min count followed by a 10-min break, for a total of three sampling units per hour. The number of follower birds (birds following the ship from the stern) was updated at the beginning of each hour of observation. Only counts made when the ship was moving at ⩾5 knots were included in the analysis. Six Procellariiformes species that were dominant during the five summer seasons were included for analysis: the Black-browed Albatross *Thalassarche melanophris*, Cape Petrel *Daption capense*, Southern Fulmar *fulmarus glacialoides*, Wilson's Storm-petrel *Oceanites oceanicus*, Black-bellied Storm-petrel *Fregetta tropica*, and Antarctic Prion *Pachyptila desolata*. The species abundance was not normally distributed and a high percentage of sampling units showed 0 individuals for some or all species. For this reason, the average abundance of seabird species was calculated using nonparametric regression with bootstrap confidence intervals[12]. Three habitat types were defined for seabirds according to the distance between the sighting location and the land: neritic, 0–30 nautical miles (n mile) in >70% of sightings; pelagic, >30 n mile from land in >70% of sightings; and neritic–pelagic, a similar number of sightings in both neritic and pelagic habitats. Penguins were excluded from the study because they are difficult to observe at sea.

2.2.2 Cetaceans

Five species of baleen whales were observed: the Southern Right Whale *Eubalaena australis*, Antarctic Minke Whale *Balaenoptera bonaerensis*, Sei Whale *B. borealis*, Fin Whale *B. physalus*, and Humpback Whale *Megaptera novaeangliae*. Cetacean observations were conducted in parallel with seabird observations, but without a 10-min break between sampling units. Unlike seabird observations, cetacean observations continued even when the ship was carrying out oceanographic sampling. Therefore, the cetacean survey was conducted over approximately 2 351 n mile compared with 1 176 n mile for the seabird survey. Cetaceans were identified to the lowest possible taxonomic level. When identification was not possible, the species were recorded as unidentified. To study cetacean distribution, the geographic areas where species aggregations were sighted were taken into account. The cetacean encounter rates were estimated for each of the five survey seasons[13].

3 Results

3.1 Seabirds

Between 2010 and 2014, 884 10-min counts were carried out and 1 176 n mile were surveyed (Figure 1a). Ice cover and SST differed between the five survey seasons (Table 1, Figure 2). The highest SST was recorded in 2011 and was coincident with the total absence of sea ice. However, the low SST values recorded in 2010 and 2014 were not coincident with the highest ice concentrations. A total of 11 656 flying seabirds belonging to 24 species were observed but 82% of the seabirds were represented by only three species: the Antarctic Prion (40.2%), Southern Fulmar (21.8%), and Cape Petrel (20.2%) (Tables 2 and 3). Antarctic Prions were the dominant species in three of the five survey seasons (Table 2), both in the SOI MPA and the rest of the study area. Distribution around the SOI varied among seabird species but the highest concentrations were recorded to the west, south, and east of the SOI (Figure 3). For example, the highest concentration of Southern Fulmars was west of the islands. The aggregations of Southern Fulmars were the largest among all observed species, with an estimated 800 individuals sighted in a single count 26 n mile offshore on 27 February 2010. Smaller aggregations of Southern Fulmars were recorded in the same area in 2011 and 2012, 36 n mile and 31 n mile offshore, respectively. Antarctic Prions were observed in large numbers west of the SOI along with Southern Fulmars. Other major aggregations of Antarctic Prions and other species were observed east and south of the SOI.

3.2 Cetaceans

A total of 678 cetaceans including five species of baleen whales were observed along a total survey transect of 2 351 n mile (Figure 1b): 324 Fin Whales (48%), 103 Humpback Whales (15%), 22 Antarctic Minke Whales (3%), 9 Sei Whales (1.4%), 6 Southern Right Whales (0.9%), and 214 unidentified cetaceans (31.5%). Cetacean abundances were highly variable between survey seasons (Table 2), but Fin and Humpback whales were the most abundant in all five years. The highest mean encounter rate in all five summers was with Fin Whales (0.29 whales per n mile), followed by unidentified whales (0.19 whales per n mile), Humpback Whales (0.09 Whales per n mile), Minke Whales (0.02 whales per n mile), and Sei Whales (0.01 whales per n mile). The average encounter rate for all cetaceans throughout the study area was 0.61 whales per n mile. Fin and Humpback whales showed different distributions (Figure 4a). Fin Whales were more abundant west of the SOI far from the ice fields, whereas Humpback Whales were most abundant in the south of the survey area, among the sea ice. On 3 March 2014 while heading south of the SOI MPA, a marked increase in SST was recorded on a 25 n mile transect, from 0.4°C at 06:00 h to 1.4°C at 19:00 h. During this 13-h period, 18 Humpback and 39 Fin whales (plus six Southern Right and seven unidentified whales) were sighted (Figure 5), representing 22% of the Humpback Whales and 23% of the Fin Whales encountered during the summer of 2014. There were no concentrations of seabirds associated with the whale sightings on that day. The observed whales were solitary, in pairs, in single species groups, and in mixed groups. Most of the sightings were for solitary individuals (29.73%), pairs (27.03%), and single species groups of 3–5 individuals (19.46%) (Table 4). Humpback and Fin whales were mostly sighted in pairs.

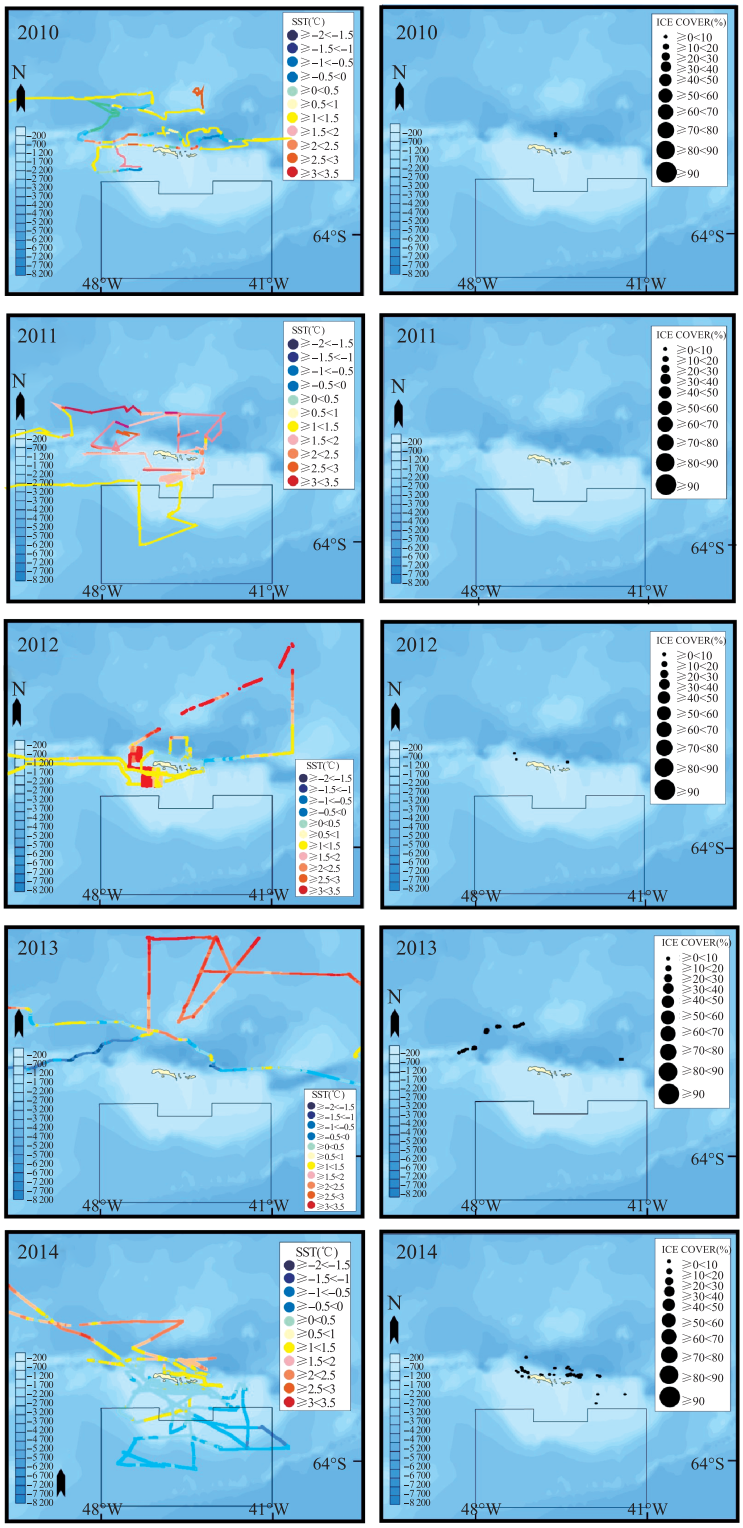

Figure 2 Ship's tracks, SST, and ice cover recorded during the surveys in summer 2010—2014.

Table 1 Comparison between sea surface temperature (SST) and ice cover for surveys during summer 2010—2014. Data are presented as means ± standard error. Lower-case letters indicate significance, *$P < 0.05$ among treatments (years)

	2010 (n = 107)	2011 (n = 207)	2012 (n = 192)	2013 (n = 80)	2014 (n = 298)	Statistic and significance (*P< 0.05)
SST	0.9 ± 0.1 a	1.9 ± 0.1 b	1.7 ± 0.1 c	1.6 ± 0.1 d	0.6 ± 0.1 e	F = 120.01*
Ice cover/%	0.1 ± 0.1 a	0	0.1 ± 0.1 ab	3.5 ± 0.9 c	0.7 ± 0.1 b	H = 18.27*

Table 2 Total numbers of seabirds and cetaceans recorded at sea during summer 2010—2014. n is the number of 10-min counts devoted to flying seabird sightings; MPAn is the number of counts made in the Marine Protected Area; n mile is the total nautical miles covered during the whale surveys. Numbers in parentheses indicate the relative densities of species (%)

	2010 n = 107 MPAn = 0 n mile = 283	2011 n = 207 MPAn = 26 n mile = 552	2012 n = 192 MPAn = 0 n mile = 511	2013 n = 80 MPAn = 0 n mile = 213	2014 n= 298 MPAn= 77 n mile= 792
Seabirds					
Wandering Albatross *Diomedea exulans*	0 (0)	10 (0.5)	3 (0.1)	1 (0.2)	3 (0.1)
Royal Albatross *Diomedea epomophora*	0 (0)	0 (0)	1 (0)	0 (0)	7 (0.2)
Grey-headed Albatross *Thalassarche chrysostoma*	2 (0.1)	7 (0.3)	25 (1.1)	6 (1.1)	39 (0.9)
Black-browed Albatross *Thalassarche melanophris*	13 (0.5)	64 (3)	125 (5.3)	15 (2.6)	165 (4)
Light-mantled Sooty Albatross *Phoebetria palpebrata*	2 (0.1)	28 (1.3)	3 (0.1)	3 (0.5)	26 (0.6)
Southern Giant Petrel *Macronectes giganteus*	43 (1.8)	47 (2.2)	55 (2.3)	15(2.6)	64 (1.5)
Northern Giant Petrel *Macronectes halli*	1 (0)	21 (1)	21 (0.9)	4 (0.7)	12 (0.3)
Cape Petrel *Daption capense*	376 (15.6)	710 (33.2)	240 (10.1)	292 (51.4)	735 (17.6)
Southern Fulmar *fulmarus glacialoides*	1096 (45.6)	350 (16.4)	879 (37)	69 (12.1)	150 (3.6)
Antarctic Petrel *Thalassoica antarctica*	0 (0)	0 (0)	0 (0)	4 (0.7)	2 (0)
White-chinned Petrel *Procellaria aequinoctialis*	5 (0.2)	70 (3.3)	52 (2.2)	18 (3.2)	141 (3.4)
Snow Petrel *Pagodroma nivea*	1 (0)	131 (6.1)	0 (0)	2 (0.4)	17 (0.4)
Antarctic Prion *Pachyptila desolata*	727 (30.3)	603 (28.2)	730 (30.7)	113(19.9)	2 520 (60.4)
Atlantic Petrel *Pterodroma incerta*	0 (0)	2 (0.1)	1 (0)	0 (0)	1 (0)
Soft-plumaged Petrel *Pterodroma mollis*	0 (0)	3 (0.1)	1 (0)	0 (0)	0 (0)
Kerguelen Petrel *Pterodroma* (*Aphodroma or Lugensa*) *brevirostris*	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)
Wilson's Storm-petrel *Oceanites oceanicus*	124 (5.2)	80 (3.7)	67 (2.8)	14 (2.5)	226 (5.4)
Black-bellied Storm-petrel *Fregetta tropica*	7 (0.3)	11 (0.5)	125 (5.3)	4 (0.7)	21 (0.5)
Skua *spp* (*)	5 (0.2)	2 (0.1)	45 (1.9)	0 (0)	33 (0.8)
Antarctic Tern *Sterna vittata*	0 (0)	0 (0)	0 (0)	8 (1.4)	6 (0.1)
Arctic Tern *Sterna paradisaea*	0 (0)	0 (0)	2 (0.1)	0 (0)	1 (0)
Antarctic Shag *Phalacrocorax bransfieldensis*	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Kelp Gull *Larus dominicanus*	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)
Cetaceans					
Southern Right whale *Eubalaena australis*	0 (0)	0 (0)	0 (0)	0 (0)	6 (1.6)
Antarctic Minke Whale *Balaenoptera bonaerensis*	22 (48.9)	0 (0)	0 (0)	0 (0)	0 (0)
Sei Whale *Balaenoptera borealis*	0 (0)	0 (0)	2 (1)	7 (17.5)	0 (0)
Fin Whale *Balaenoptera physalus*	3 (6.7)	0 (0)	136 (71.2)	17 (42.5)	168 (43.8)
Humpback Whale *Megaptera novaeangliae*	0 (0)	4 (22.2)	0 (0)	16 (40)	83 (21.6)
Unidentified whale	20 (44.4)	14 (77.8)	53 (27.7)	0 (0)	127 (33.1)

*Includes the South Polar Skua (*Catharacta maccormicki*) and Subantarctic Skua (*C. antarctica lonnbergi*).

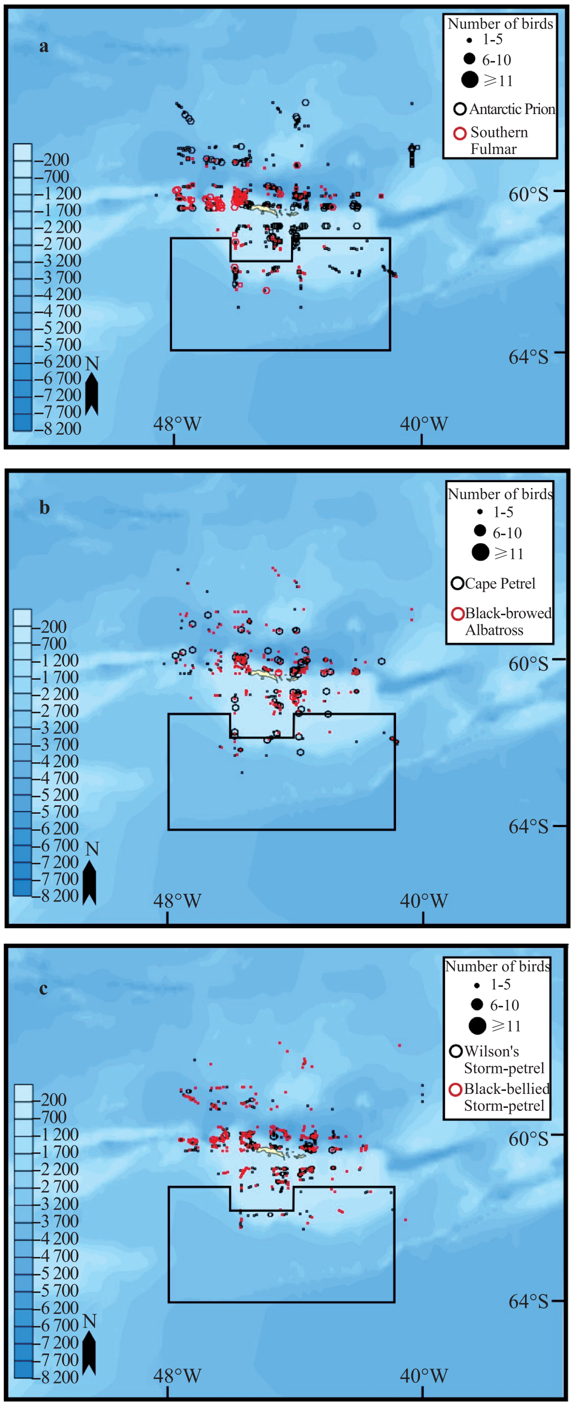

Figure 3 Spatial distribution and cumulative abundances for seabirds during the surveys in summer 2010—2014.

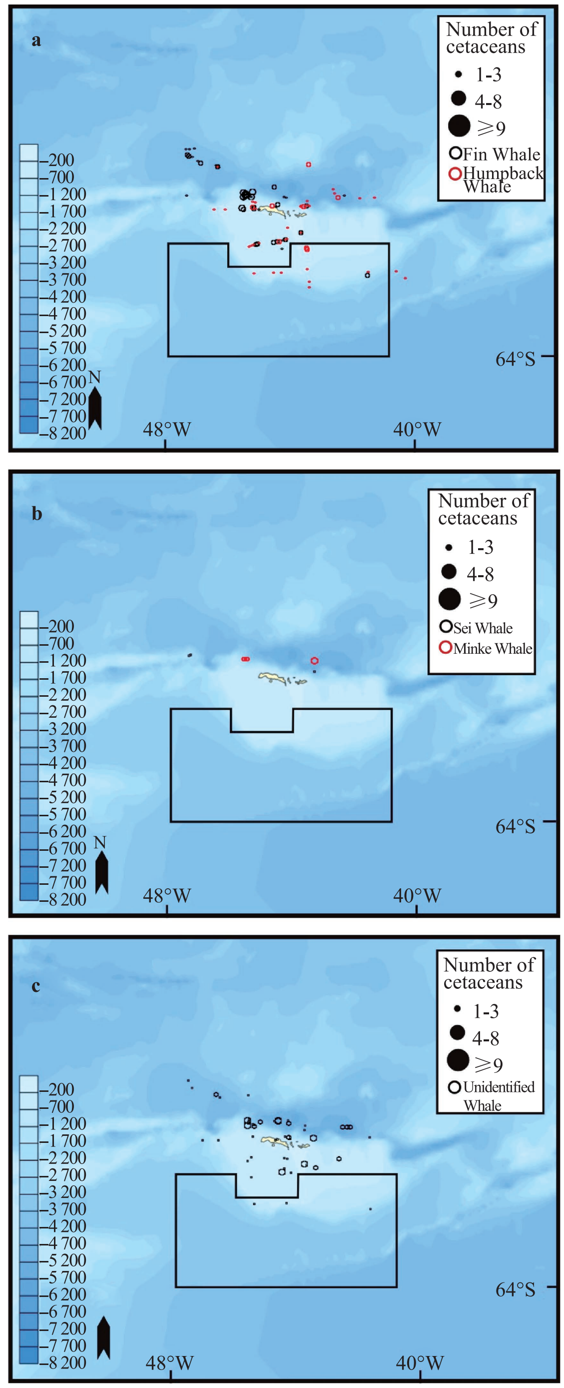

Figure 4 Spatial distribution and cumulative abundances for cetaceans during the surveys in summer 2010—2014.

4 Discussion

There are relatively few multiyear studies on the distribution of top predators in the Southern Ocean[14–19], and very few have surveyed seabirds and cetaceans simultaneously. The distribution of top predators such as seabirds and marine mammals depends on the presence, abundance, and availability of prey[19]. The study area is under the influence of the ACC, considered one of the most important Antarctic currents and responsible for transporting nutrients throughout the Southern Ocean[3]. Identified as Subarea 48.2 by CCAMLR, the Scotia Sea is one of the three areas of the Southern Ocean where the krill fishing effort is concentrated; the other two areas are Subarea 48.1 (South Shetland Islands and west of the Antarctic Peninsula) and Subarea 48.3 (South Georgia)[20]. The krill fishery has intensively targeted

Table 3 Mean abundances of six seabird species surveyed in the Scotia Sea in summer 2010—2014 with bootstrapped 95% confidence intervals (CL)

Species	2010 (*n* = 107)		2011 (*n* = 207)		2012 (*n* = 192)		2013 (*n* = 80)		2014 (*n* = 298)	
	Mean	CL	Mean	CL	Mean	CL	Mean	CL	Mean	CL
Black- browed Albatross	0.12	0.05−0.19	0.27	0.19−0.36	0.63	0.27−1.21	0.18	0.08−0.26	0.38	0.19−0.66
Cape Petrel	3.60	1.36−6.40	3.04	1.68−4.66	1.28	0.50−2.49	3.34	0.79−7.01	2.13	1.15−3.54
Southern Fulmar	10.20	1.37−25.80	1.38	0.34−3.20	4.46	1.52−8.37	0.79	0.22−1.50	0.34	0.16−0.54
Antarctic Prion	6.63	2.23−12.08	2.26	1.23−4.33	3.07	1.21−6.46	1.35	0.77−2.08	6.14	3.31−9.96
Wilson's Storm-petrel	1	0.58−1.52	0.91	0.69−1.12	0.82	0.45−1.33	0.60	0.33−0.9	0.78	0.59−0.97
Black-bellied Storm-petrel	1.18	0.70−1.69	2.26	1.23−4.33	0.34	0.24−0.45	0.17	0.06−0.27	0.42	0.32−0.54

Table 4 Cetacean observations in summer 2010—2014: solitary, in pairs, and in groups

	Number of individuals within group	%
Solitary		29.73
Pairs		27.03
Single species groups	3 to 5	19.46
	6 to 10	12.97
	11 to 15	3.78
	>15	1.08
Mixed groups	3 to 5	2.16
	6 to 10	2.16
	11 to 15	0.54
	>15	1.08

the area around the SOI since the 1980s, particularly to the north of the islands (outside the area of the present study) and to the west, along 1 000 m isobaths[7]. For example, in the 2012/2013 fishing season more than 20 000 tonnes of krill were caught west of the SOI[20] in the same area where the highest concentrations of seabirds and cetaceans were observed during the five survey seasons. The fact that abundant krill and large numbers of top predators are found west of the SOI suggest that this is an area where prey resources are concentrated and is targeted as a feeding area by seabirds and cetaceans during their seasonal migrations[21–25]. However, environmental changes can affect the distribution and density of resources at temporal and spatial scales, affecting the life cycles of top predators[10,21,25]. The amount, type, and extent of sea ice is particularly important[26-27] because it plays a crucial role in the recruitment of plankton, affecting the entire food web[24,28–30]. In warmer years without ice, fishing companies have reported a markedly reduced krill catch in the Scotia Sea as compared with colder years with high concentrations of sea ice[31].

In the present study all seabird species showed considerable variability in average abundance among the seasons. Based on the survey observations, these changes are associated with changes in ice cover, which affect prey abundance and availability. Krill are the primary prey resource for Cape Petrels, Southern Fulmars, Wilson's Storm -petrels, Black-bellied Storm-petrels, and Antarctic Prions. When krill are scarce, some species seek other more distant feeding areas or do not breed because they lack the energy required for reproduction. One study found that the breeding performance of Southern Fulmars tended to be lower in years with low sea ice concentration[10]. Other Procellariiformes species have adopted effective strategies to adapt to food shortages caused by extreme environmental conditions. Multiyear studies of the Antarctic Prion have shown that this species modifies its diet when prey is scarce, replacing krill with copepods and foraging in coastal areas rather than offshore[9]. By switching to feeding on copepods, Antarctic Prions are apparently able to maintain a comparable level of reproductive success, unlike most other krill-eating species that show diminished reproductive performance in years of reduced krill availability. This ability to switch to different foraging strategies may explain why the Antarctic Prion, despite showing some fluctuations in abundance, remained as the dominant species throughout the five survey seasons. The diet of the Black-browed Albatross is mainly based on squid and fish[32-33], and the species tends to forage in neritic areas[34]. The observations made during the present study confirmed a neritic distribution for the Black-browed Albatross (Figure 3b and Table 5). This species is a vagrant species not resident in the SOI and the Black-browed Albatrosses foraging around the SOI come from large colonies on South Georgia and its surrounding islands[36]. Therefore, variations in the abundance of the Black-browed Albatross probably reflect environmental changes near their colonies on South Georgia, where the species is also negatively impacted by interaction with the fisheries, more than they reflect changes around the SOI[34–36].

Like seabirds, the distribution of cetaceans reflects the abundance of their prey. Therefore, aggregations of cetaceans indicate areas of high biological productivity[25]. In the present study, the largest aggregations occurred west of the

Table 5 Habitats for each seabird species in summer 2010—2014

Species	Depth/m	Distance to nearest coast /(n mile)	Relative abundance/%	Habitat
Antarctic Prion	230—1 700	25—70	38.30	Neritic-pelagic
Southern Fulmar	900—2 000	90—100	20.35	Pelagic
Cape Petrel	560—2 500	90—120	18.69	Pelagic
Wilson's Storm-petrel	10—1 200	10—110	6.59	Neritic-pelagic
Black-bellied Storm-petrel	1 023—4 500	460—1 071	4.17	Pelagic
Black-browed Albatross	200—330	7—21	3.12	Neritic

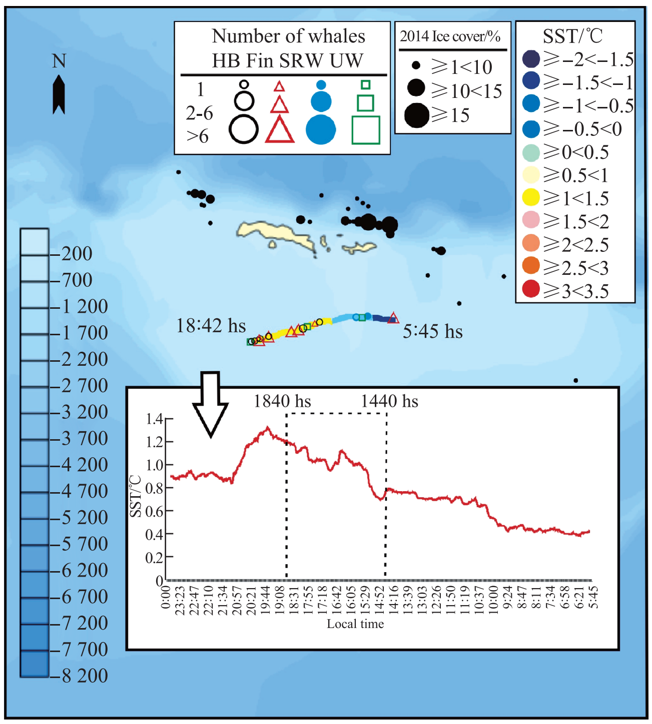

Figure 5 Whales sighted on the 3 March 2014 transect (colored line) south of the South Orkney Islands. The graph shows the changes in SST throughout the day and the dotted rectangle indicates when more than 60% of all cetaceans observed that day were sighted. HB, Humpback Whale; SRW, Southern Right Whale; UW, unidentified whales. Note that the SST continued to increase after 18:40 h but the observations had to be suspended because of darkness. 5:45 h and 18:42 h indicate the start and end times, respectively, of the transect made on 3 March 2014. The boundary of the South Orkney Islands Marine Protected Area was omitted for readability.

SOI and coincided spatially with the area where the highest concentrations of seabirds were observed. Whale sightings during the five survey years show similarities and differences with previous studies in the same area. In the present study, the highest average encounter rate was for the Fin Whale (0.29 whales per n mile), followed by the Humpback Whale (0.09 whales per n mile). Another study reported that the highest average encounter rate was for the Humpback Whale (0.073 whales per n mile) followed by the Fin Whale (0.053 whales per n mile)[13]. However, the values in that study were calculated over a single summer survey season. Nonetheless, both studies agree that Fin and Humpback whales were the most abundant whales in the Scotia Sea. The habitats of Fin and Humpback whales differed in the present study, in agreement with the findings of previous studies[13,22]. Fin Whales were more abundant west of the SOI in the absence of sea ice, whereas Humpback Whales were more abundant south of the islands among the sea ice and on the southern boundary of the ACC. The highest abundance of Humpback Whales occurred in the summers of 2013 and 2014, when the sea ice cover was the most extensive recorded during the 5-year survey period (Table 2, Figure 4), confirming the habitat preference for this species.

Fin and Humpback whales are sympatric species that coexist in the Scotia Sea, but with differences in their ecological niches that determine their spatial segregation. Fin Whales prefer a more pelagic habitat[22], have a broader trophic niche[36], and dive deeper[37] than Humpback Whales.

Therefore, Fin Whales tend to exploit somewhat different resources, avoiding direct competition with Humpback Whales[22]. This also explains why most of the Fin Whales observed during the present survey were sighted in deeper areas than Humpback Whales, and also explains why few interspecific associations were observed. A similar absence of interspecific competition among cetaceans has been reported in studies conducted in other Antarctic regions[38]. While most of the Fin Whales were observed northwest of the SOI, a considerable number were sighted at higher latitudes under particular oceanographic conditions. During a survey south of 61°S on 3 March 2014, an increase in SST from 0.4°C to 1.4°C was recorded in just over 12 h (Figure 5). As the SST increased (reaching similar temperatures to those recorded north of the SOI), a number of groups and pairs of Fin and Humpback Whales were observed, particularly of Fin Whales (39 individuals). This area of increased SST probably corresponded to the presence of eddies, hydrodynamic structures that concentrate or dilute plankton and suspended material through the physical process of accumulation, retention, and/or dispersion[39]. The biological implications of eddies in the Scotia Sea and Weddell–Scotia Confluence have been described in detail[40]. Cetaceans sighted on 3 March 2014, particularly Fin Whales, could have been attracted to these favorable feeding conditions, because this was the only sighting of this species south of 60°S.

Minke Whales were observed only in the summer of 2010, in contrast with previous studies that reported this species as the most abundant of all cetaceans[22,41]. As previously noted[13], Minke Whales are often under-recorded because they are small in size and have a blow that is easy to miss with increasing distances, under rough and windy conditions, and when visibility is poor. Most cetaceans were observed as solitary individuals (29.73%). However, 86% of all groups consisted of three to five individuals. The Fin Whale has the highest tendency to form single species groups. Large groups of Fin Whales have been previously observed feeding around the South Shetland Islands[24]. In the present study, 31.85% of all baleen whales observed could not be identified because of poor visibility. However, it is likely that most of these unidentified whales were Fin Whales because the largest aggregations occurred west of the SOI and tended to be observed in single species groups, similar to the observations of Fin Whales.

5 Conclusions

This is the first survey of seabirds and cetaceans conducted concurrently over five consecutive summers in the Scotia Sea. The feeding areas of seabirds and cetaceans overlap considerably, especially west and south of the SOI. Survey effort in the SOI MPA was limited, but was enough to suggest that the highest concentrations and activity of all trophic levels occur west of the SOI, in an unprotected area that is currently intensively fished. There were marked differences in the abundance of seabirds and cetaceans among the five survey years, suggesting annual variation in food stocks in some areas, but not to the west of the SOI where abundance, and therefore resources, appeared to be constant over the 5-year study period. The findings of the present study indicate that this area of the Southern Ocean is part of a changing environment with unknown resilience. In the future, ongoing multiyear studies integrating top predators and their prey are warranted to monitor the maritime areas around the SOI. These studies would provide a better understanding of the complexity and vulnerability of the Antarctic ecosystem.

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