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Major hotspots detected along the Scotia Ridge in autumn for southern right whales *Eubalaena australis*, Antarctic fur seals *Arctocephalus gazella* and Antarctic prions *Pachyptila desolata*

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Abstract We investigated the role of hydrological features, such as water masses, fronts, eddies, and sea ice, in affecting the distribution of upper trophic level species in the Scotia Sea region during autumn. On board RV *Polarstern*, we performed 365 30-min strip transects recording seabirds and marine mammals along the North Scotia Ridge and the South Sandwich Trench in March—April 2013. Among the 7 identified cetacean species recorded, the humpback whale *Megaptera novaeangliae* was the most abundant baleen whale (40 individuals), and noteworthy were sightings of six southern right whales *Eubalaena australis*. Pinnipeds (3 species, 1650 individuals) were dominated by Antarctic fur seal *Arctocephalus gazella* (99%), and seabirds (36 species, 18900 individuals) by Antarctic prion *Pachyptila desolata* (~50%). The distribution of these top predators was highly patchy with the majority of observations concentrated in a few counts. This heterogeneity is likely a result of prey availability, and we discuss how hydrological features may have caused the patchiness.

Keywords **Scotia Sea, Scotia Ridge, Scotia Trench, seabirds & marine mammals, southern right whale, Antarctic fur seal, Antarctic prion**

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1 Introduction

The distribution of upper trophic level predators in the polar oceans reflects prey abundance and availability (e.g., zooplankton, krill, nekton, and small fish), in turn responding to lower trophic level processes. These top predators therefore constitute the best indicators to localize areas of high biological production [1-6].

In the Antarctic, biological studies mainly concern the Weddell, Ross and Bellingshausen seas[7-9]. Appreciable work has been conducted in the Scotia Sea as well, but not during autumn except in the Scotia-Weddell Confluence (about 50 papers resulting from AMERIEZ: Antarctic Marine Ecosystem Research in the Ice Edge Zone). Following the description of an important autumn aggregation around the South Shetland Islands[6], this paper reports on autumn observations of top predators in the Scotia Ridge in northern Scotia Sea.

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Water masses and fronts, pack ice and ice edge are well understood to be the main hydrological factors influencing the distribution of upper trophic level species (e.g., seabirds and marine mammals) in the ocean[10-18]. Bathymetry is often considered a factor in affecting species distribution and abundance due to its relationship with upwelling fronts and eddies[19-21]. Recent studies summarize the situation in the southern "ocean" in general[22] or for Antarctic Minke whale *Balaenoptera bonaerensis* in particular[20], or an aggregation of fin whales *B. physalus*, southern fulmars *Fulmarus glacoides* and grey-headed albatrosses *Thalassarche chrysostoma* around the South Shetland Islands[6].

Our study area covers the southwest sector of the Atlantic Ocean at the boundary of the Antarctic Circumpolar Current (ACC) and the Polar Front (PF), as reflected by signatures of water temperature (SST) and salinity. We progressed longitudinally between Patagonia and the Scotia Ridge, including the vicinity of South Georgia and South Sandwich Islands, and the South Sandwich Trench. During both the outward leg, originating from Punta Arenas, Chile, and inward leg, terminating at the Falkland Islands, we conducted surveys of marine birds and mammals during daylight hours attempting to relate the results to hydrological variables.

2 Material and methods

During the PS81 (ANT-XXIX/4) expedition of icebreaker RV *Polarstern* from Punta Arenas, Chile to the North Scotia Sea Ridge, South Georgia, and the South Sandwich Trench and back to the Falkland Islands from 22 March till 26 April 2013, three independent datasets were collected in order to establish the at-sea distribution of seabirds and marine mammals. The main dataset was collected from the port side of the bridge (hereafter "left", n = 365), another from the starboard side ("right", n = 282); in both cases, one observer either side tallied marine birds and mammals. A third data set was derived from helicopter flights in a few locations (lasting two hours each, height 300 feet, speed 80 knots; two to three observers; n = 8). The transect counts, from 18 m above sea level, were partitioned into 30 min segments, without width limitation on a continuous basis, light and visibility permitting (see description and discussion in[4-5]).

Sea surface temperature (SST) and salinity were continuously recorded using a thermo-salinometer at keel depth (–10 m). Ice cover was evaluated from the bridge and expressed as per-cent coverage within an approximated range of 500 m around the ship.

Using the generalized boosted regression modelling technique[23], we tested the power of using seabird abundance as a predictor of the presence or absence of marine mammals: fur seals and whales. Due to low number of whale sightings, we combined whale sightings and converted abundance measurements to binary presences and absences. We performed three model runs: (1) oceanographic parameters (SST, distance to shore and bathymetry) and seabirds as predictors; (2) only oceanographic parameters as predictors, and (3) only seabird abundance as predictors. Cross-validation assessment of model accuracy was performed on random subsets of observations using the area under the receiver operating characteristic curve (AUC).

Basic results were included in the Biodiversity dataset: http://www.gbif.org/dataset/0e8b0e10-1680-4d71-ae93-f61bd7933b1d.

3 Results and discussion

During the 365 counts of the main dataset from the "left" side of the bridge, 129 cetaceans were encountered, belonging to seven species of which three were baleen whales *Mysticeti*: 41 humpback whales *Megaptera novaeangliae*, six fin whales *Balaenoptera physalus* and six southern right whales *Eubalaena australis* (which totalled 22† when adding tallies from helicopter flights; unidentified whales might belong to this species). Among pinnipeds, the vast majority were Antarctic fur seals *Arctocephalus gazella* (1635 out of 1650 individuals). Among seabirds, we counted 18900 individuals belonging to 36 identified species, not including the strictly coastal Patagonian ones. The most numerous species was Antarctic prion *Pachyptila desolata* with 9800 individuals (Table 1).

3.1 Count reliability

The result was a ratio of 1.3 for the five most abundant seabird species (min. 0.74, max. 1.73), 1.1 for the cetaceans (four species, 0.65 and 2.37) and 1.3 for the pinnipeds (two species, 1.84 and 4.81). We conclude that left and right datasets provided confidence in the reproducibility of our counting method.

3.2 Species occurrence patterns

The main water masses and fronts were recognised on the basis of SST (Figure 1) since salinity differences were very limited[24-27]. From North-West to South-East they were: Sub-Antarctic Surface Water (SASW), Antarctic Front (AF), Polar Front Water (PFW), Polar Front (PF) and Antarctic Surface Water (AASW) (Table 2). Many of the observed species distributions were limited by these hydrological features: chinstrap penguin *Pygoscelis antarctica*, southern fulmar *Fulmarus glacoides*, black-bellied storm-petrel *Fregetta tropica* and southern right whale were restricted to AASW; Antarctic prion and Antarctic fur seal to PFW; hourglass dolphin *Lagenorhynchus cruciger* and humpback whale to PFW and AASW; black-browed albatross *Thalassarche melanophrys* and white-chinned petrel *Procellaria aequinoctialis* to SASW and PFW; and South American fur seal *Arctocephalus australis* to SASW (Table 3, Figure 2). Areas of aggregation along the Scotia Ridge / Scotia Trench were comprised of Antarctic prions and Antarctic fur seals in six successive counts, southern right whales in four counts and humpback whales in five counts (Table 4).

†23 sightings, including one individual seen twice.

Table 1 Seabirds and marine mammals encountered along the North Scotia Ridge and South Sandwich Trench; total numbers recorded; *n* = number of half-an-hour transect counts on board Polarstern, and number of helicopter flights; mean per count: seabirds for total > 10, per hour respectively

	Species	Platform *n* >	*Polarstern* (left)[a] Number 365	Mean / count	*Polarstern* (right)[a] Number 282	Mean / count	*Polarstern* Out of effort[b]	Helicopter (mammals) Number 8 flights	Mean / h	Remark
1	king penguin	*Aptenodytes patagonicus*	215	0.59	201	0.71		+		250
2	gentoo penguin	*Pygoscelis papua*	80	0.22	42	0.15				
3	chinstrap penguin	*Pygoscelis antarctica*	2852	7.81	1632	5.79		+		4000 on 10 icebergs
4	rockhopper penguin	*Eudyptes chrysocome*	5		7					
5	macaroni penguin	*Eudyptes chrysolophus*	66	0.18	42	0.15				
	penguin sp.		141	0.39	93	0.33				
6	southern royal albatross	*Diomedea [epomorpha] epomorpha*	14	0.04	14	0.05				
7	wandering albatross	*Diomedea [exulans] sp.*	184	0.50	175	0.62				
	wand/roy albatross	*Diomedea [exulans]/ [epomorpha] sp.*	25	0.07						
8	black-browed albatross	*Thalassarche [melanophrys] melanophrys*	732	2.01	977	3.46				
9	grey-headed albatross	*Thalassarche chrysostoma*	52	0.14	46	0.16				
10	sooty albatross	*Phoebetria fusca*	8		6					
11	light-mantled sooty albatross	*Phoebetria palpebrata*	30	0.08	32	0.11				
12	southern giant petrel	*Macronectes giganteus*	567	1.55	685	2.43				
13	northern giant petrel	*Macronectes halli*	40	0.11	63	0.22				
	giant petrel sp.	*Macronectes sp.*	38	0.10	84	0.30				
14	southern fulmar	*Fulmarus glacialoides*	709	1.94	831	2.95				
15	Cape petrel	*Daption capense*	360	0.99	450	1.60				
16	snow petrel	*Pagodroma [nivea] sp.*	9		11	0.04				
17	white-chinned petrel	*Procellaria aequinoctialis*	936	2.56	1189	4.22				
18	Kerguelen petrel	*Pterodroma brevirostris*	123	0.34	136	0.48				
19	great-winged petrel	*Pterodroma [macroptera] macroptera*	1		1					
20	soft-plumaged petrel	*Pterodroma mollis*	345	0.95	379	1.34				
21	Atlantic petrel	*Pterodroma incerta*	2		2					
22	grey petrel	*Procellaria cinerea*	6		4					
23	blue petrel	*Halobaena caerulea*	278	0.76	325	1.15				
24	Antarctic prion	*Pachyptila desolata*	9769	26.76	7487	26.55				Mainly South Georgia
25	slender-billed prion	*Pachyptila belcheri*	9		2					
26	fairy prion	*Pachyptila turtur*	106	0.29	42	0.15				
	prion sp.	*Pachyptila sp.*	1253	3.43	742	2.63				
27	sooty shearwaterr	*Puffinus griseus*	67	0.18	142	0.50				
28	great shearwater	*Puffinus gravis*	19	0.05	28	0.10				
29	Wilson storm-petrel	*Oceanites oceanicus*	340	0.93	503	1.78				

(To be continued)

Continued

	Species	Platform *n* >	*Polarstern* (left)[a] Number 365	Mean / count	*Polarstern* (right)[a] Number 282	Mean / count	*Polarstern* Out of effort[b]	Helicopter (mammals) Number 8 flights	Mean / h	Remark
30	grey-backed storm-petrel	*Oceanites nereis*	31	0.08	24	0.09				
31	black-bellied storm-petrel	*Fregetta tropica*	787	2.16	859	3.05				
	storm-petrel sp.		24	0.07	2	0.01				
32	common diving-petrel	*Pelecanoides urinatrix*			33	0.12				
	South Georgian diving-petrel	*Pelecanoides georgicus*								One wrecked on board
	diving-petrel sp.	*Pelecanoides sp.*	369	1.01	376	1.33				
	South Georgian shag	*Phalacrocorax [atriceps] georgianus*	19	0.05	13	0.05				
	snowy sheathbill	*Chionis alba*	1		1					Falkland Isl
33	Antarctic tern	*Sterna vittata*	111	0.30	117	0.41				
34	south polar skua	*Catharacta [skua] maccormicki*	1		1					
35	brown skua	*Catharacta [skua] antarctica*	15	0.04	11	0.04				
36	Arctic skua	*Stercorarius parasiticus*			1					
	phalarope sp.	*Phalaropus sp.*	1							Off S America
	total all birds		**20740**	**56.82**	**17811**	**63.16**				
	total selected birds[c]		**18870**	**51.70**	**16501**	**45.21**				
	Commerson's dolphin	*Cephalorhynchus commersonii*					+			Strait of Magellan
1	hourglass dolphin	*Lagenorhynchus cruciger*	76	0.21	60	0.21				
	dolphin sp.		20	0.05	16	0.06		1		
2	long-finned pilot whale	*Globicephala melas*			30	0.11				
3	killer whale	*Orcinus orca*			3	0.01				
4	sperm whale	*Physeter macrocephalus*			1			1		
5	southern bottlenosed whale	*Hyperoodon australis*						9		
6	southern right whale	*Eubalaena australis*	6	0.02	3	0.01	4	9	0.71	
7	humpback whale	*Megaptera novaeangliae*	41	0.11	41	0.15	2	33	2.36	
8	fin whale	*Balaenoptera physalus*	6	0.02	11	0.04	3	14	1.00	
	large whale sp.		35	0.10	37	0.13				
	total all cetaceans		**184**	**0.50**	**152**	**0.54**				
	total selected cetaceans[c]		**129**	**0.35**	**149**	**0.53**				
1	south American fur seal	*Arctocephalus australis*	14	0.04	52	0.18				Off S America
2	Antarctic fur seal	*Arctocephalus gazella*	1634	4.48	2317	8.22				South Georgia
	seal sp.		511	1.40						
3	southern elephant seal	*Mirounga leonina*	2	0.01	6	0.02				
	total all pinnipeds		**2281**	**6.25**	**2402**	**8.08**				
	total selected pinnipeds[c]		**1650**	**4.52**	**2375**	**8.42**				

Notes: [a] counting from backboard and portside of the bridge respectively; [b] not included in calculations; [c] after exclusion of unidentified and strictly selected coastal species

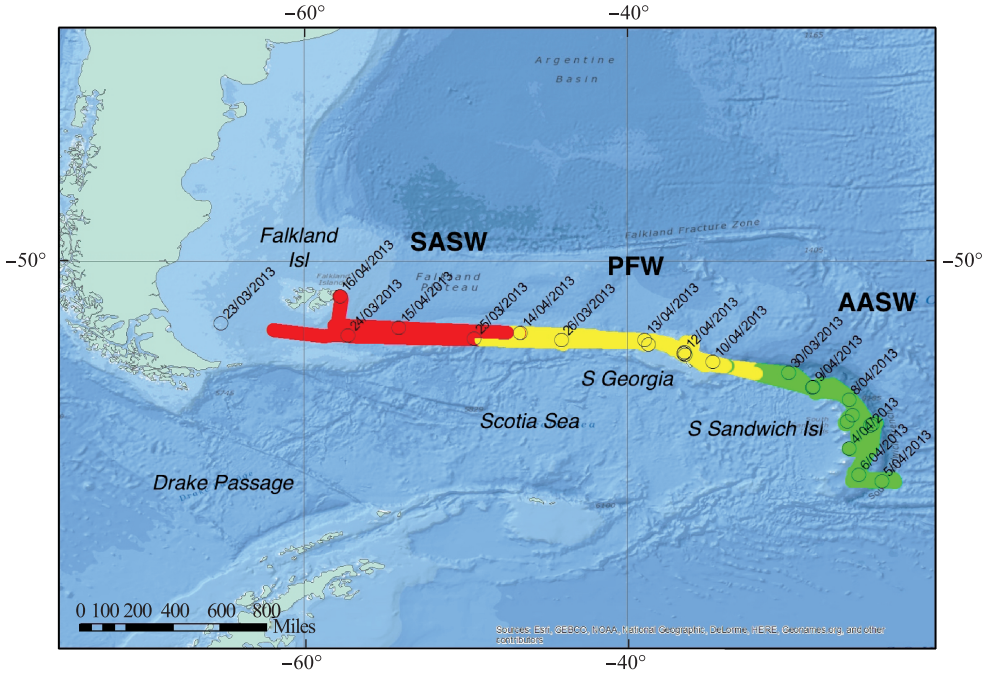

Figure 1 Near-surface water temperature (SST, °C) registered on board RV *Polarstern* along the North Scotia Ridge and the South Sandwich Trench, March – April 2013; noon position; main water masses and fronts: Sub-Antarctic Surface Water (SASW, SST > 5°C, red); Antarctic Front (AF); Polar Front Water (PFW, 1.7°C < SST < 4.8°C, yellow); Polar Front (PF); and Antarctic Surface Water (AASW, SST < 1.7°C, green).

Table 2 Main water masses and fronts detected along the North Scotia Ridge and South Sandwich Trench, and their SST and salinity values

	Position	SST/°C	Salinity
Sub-Antarctic Surface Water (SASW)		6.45 (4.96–7.15)	33.98 (33.87–34.02)
Antarctic Front (AF)	53.6°S, 49.1°W		
Polar Front Water (PFW)		3.06 (1.76–4.79)	33.76 (33.15–33.89)
Polar Front (PF)	55°S, 32°W		
Antarctic Surface Water (AASW)		0.47 (−0.17–1.70)	33.81 (33.70–33.93)

Table 3 Seabirds and marine mammals encountered along the North Scotia Ridge and South Sandwich Trench, grouped per water mass; main seabird species (total > 500); *n* = number of counts from the bridge (left); *N*: total number; mean: per count

Species		Zone[a] >	SASW		PFW		AASW	
		n >	84		128		104	
			N	Mean	*N*	Mean	*N*	Mean
chinstrap penguin	*Pygoscelis antarctica*				28	0.22	1992	19.15
black-browed albatross	*Thalassarche [melanophrys] melanophrys*		242	2.88	341	2.66	42	0.40
southern fulmar	*Fulmarus glacialoides*		1		1		527	5.07
white-chinned petrel	*Procellaria aequinoctialis*		203	2.42	663	5.18	5	
Antarctic prion	*Pachyptila desolata*		61	0.73	9499	74.21	132	1.27
black-bellied storm-petrel	*Fregetta tropica*		11	0.13	176	1.38	421	4.05
hourglass dophin	*Lagenorhynchus cruciger*		5		43	0.34	16	0.15
southern right whale	*Eubalaena australis*						6	
humpback whale	*Megaptera novaeangliae*				22	0.17	17	0.16
fin whale	*Balaenoptera physalus*				2		4	
south American fur seal	*Arctocephalus australis*		14	0.17				
Antarctic fur seal	*Arctocephalus gazella*				1596	12.47	38	0.37
southern elephant seal	*Mirounga leonina*				2			

Notes: [a] SASW: Sub-Antarctic Surface Water; PFW: Polar Front Water; AASW: Antarctic Surface Water

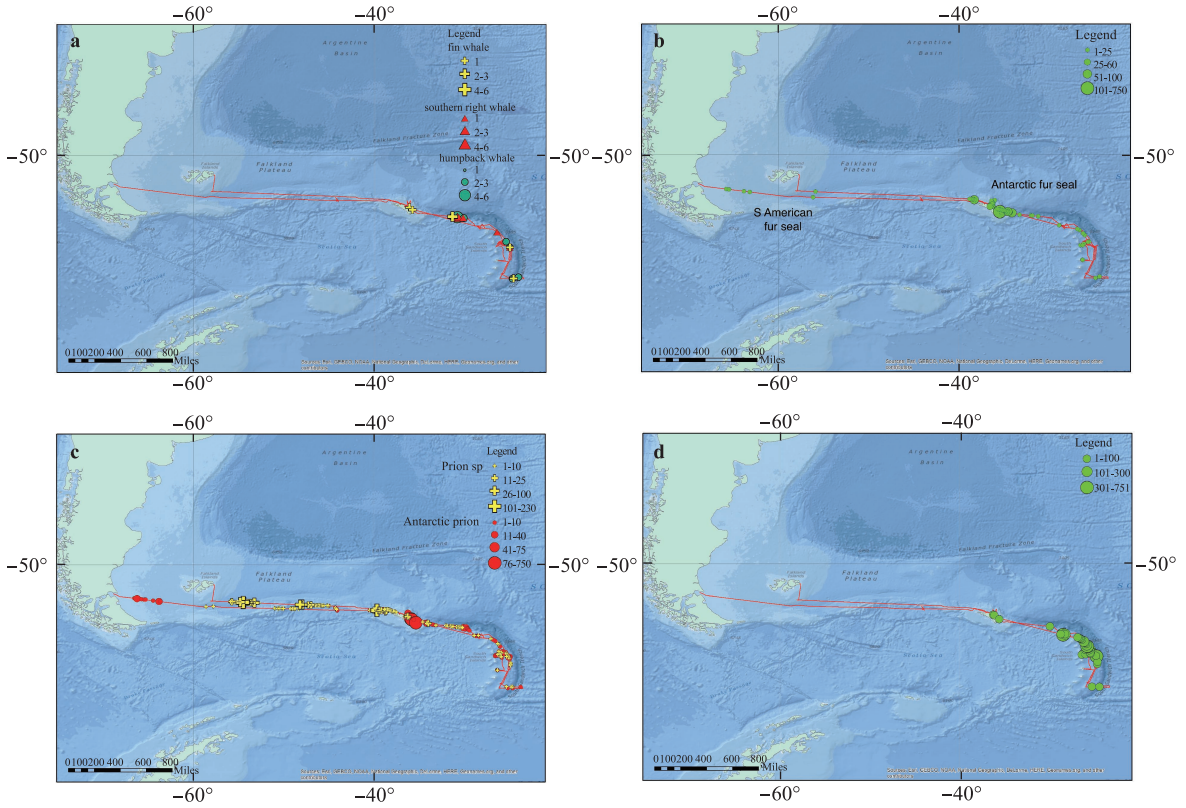

Figure 2 Distribution maps for the main species encountered on board RV *Polarstern* along the North Scotia Ridge and the South Sandwich Trench, March – April 2013 based on the "left" bridge dataset; number per transect count; species symbols and classes of abundance indicated on the map; large cetaceans: fin *Balaenoptera physalus*, southern right *Eubanaena australis* and humpback *Megaptera novaeangliae* whales (**a**); fur seal, mainly Antarctic *Arctocephalus gazella* (**b**); Antarctic prion *Pachyptila desolata*, red circles, and unidentified prion *Pachyptila sp.*, yellow crosses (**c**); chinstrap penguin *Pygoscelis antarctica* (**d**).

Table 4 Hotspot concentration of selected species close to South Georgia; number per count from the bridge (left)

Count	Date	Time	Lattitude /°S	Longitude /°W	Water temperature /°C	Depth /m	Species			
							Antarctic prion *Pachyptila desolata*	Antarctic fur seal *Arctocephalus gazella*	Southern right whale *Eubalaena australis*	Humpback whale *Megaptera novaeanglia*
130	29/03/13	13:30	54.33	36.04	2.93	5696	11	7	0	0
131	29/03/13	14:00	54.40	35.93	2.70	5514	60	9	0	0
132	29/03/13	14:30	54.46	35.82	2.71	5263	220	11	0	0
133	29/03/13	15:00	54.53	35.72	2.72	5311	600	23	0	0
134	29/03/13	15:30	54.59	35.61	2.74	5251	1700	9	0	0
135	29/03/13	16:00	54.66	35.50	2.79	6186	1500	55	0	0
136	29/03/13	16:30	54.71	35.39	2.73	6243	5000	750	0	14
137	29/03/13	17:00	54.77	35.26	2.72	6276	180	4	0	0
138	30/03/13	05:30	55.01	31.93	2.07	6474	0	16	0	8
	Antarctic Front									
139	30/03/13	06:00	55.02	31.77	1.70	5482	0	2	0	0
140	30/03/13	06:30	55.04	31.60	1.44	4306	0	0	0	0
141	30/03/13	07:00	55.05	31.44	1.37	4203	2	0	0	0
142	30/03/13	07:30	55.06	31.28	1.23	1189	0	0	0	2
143	30/03/13	08:00	55.07	31.12	1.20	1157	2	4	0	0
144	30/03/13	09:10	55.10	30.74	1.04	1345	5	0	2	4
145	30/03/13	09:40	55.12	30.58	1.05	3663	2	0	1	1
146	30/03/13	10:10	55.13	30.42	1.04	3721	7	0	0	0
147	30/03/13	10:40	55.14	30.25	1.02	4014	4	0	0	0
148	30/03/13	11:10	55.15	30.09	1.03	3925	2	0	1	0
Total							9295	890	4	29

Southern right whales were encountered from 29 March till 9 April, with most individuals being observed in five consecutive days (29 March to 2 April), *i.e.*, between 54.5°S and 58.5°S, 25°W and 35°W, East and South-East of South Georgia corresponding to Antarctic Water (Figure 1, Tables 4 and 5). Most individuals of the three species were actively feeding. The right whales were detected during the south-eastern journey, but not the return journey along the same route. Their position was clearly linked to the strong frontal system (SACCF) with an abrupt change in water temperature close to 3°C (Table 2, Figure 1). They were often seen at the edge of medium-sized icebergs and approached the ship when stationary. Attraction to ships by southern right whales has been noted in the past (*e.g.*, in December 1925 in South Georgia[28]). One individual seen during this expedition deserves special attention (Figure 3). This whale was photo-identified in October 1972 at Peninsula Valdès, Argentina as an adult and therefore must currently be at least 45 years old (see more detail in Reference [29]). A large concentration of humpback whales was also observed from a single helicopter flight (26 individuals at 59°S). Additional concentrations of Antarctic fur seals and Antarctic prions were detected in the same area. For these species this could correspond to the proximity to their main breeding colonies, and may reflect post-breeding aggregations (Table 4). Large numbers of chinstrap penguins were also observed on icebergs (more than 4000 on ten icebergs). Some chinstrap penguins were also seen swimming close to southern right whales, seemingly exploiting the same prey.

Figure 3 Southern right whale *Eubalaena australis*, 6 April 2013, 58°S−27°W, close to an iceberg. Photo was taken by H. Robert. The same individual was photographed on 18 October 1972 at Peninsula Valdès (more detail in Reference [29]).

Table 5 Synopsis of the records of southern right whales *Eubaleana australis* along the N Scotia Ridge and the S Sandwich Trench, March–April 2013, from the different platforms; *n* = number of transect counts, of flights respectively

Date 2013 *n* >	Latitude /°S	Longitude /°W	*Polarstern* left 365	*Polarstern* right 282	*Polarstern* total*	*Polarstern* out of effort -	Helicopter 8	Remark
March 29	55.00	34.41					4	Mother + calf
March 30	55.06	31.28		1	1		-	
March 30	55.10	30.74	2	1	2			
March 30	55.12	30.58	1		1		-	
March 30	55.15	30.09	1		1			
April 1	57.33	25.19					4	2 close to iceberg
April 2	57.47	24.90	1		1			
April 2	57.47	24.90				2		
April 4	58.25	24.80				1		Close to stationary ship for hours
April 6	58.21	25.52					1	Close to iceberg
April 8	56.28	26.33	1		1			
April 9	55.77	28.32		1	1	1		
April 13	54	38					-	
April 14	52	45					-	
April 15	52	57					-	
Total			6	3	8	4	9	

Note: * Without cumulating left and right observations of the same count

3.3 Modelling: importance of hydrological variables in characterizing hotspots

When we modelled fur seal and whale occurrence along transects, bathymetry, distance to shore, and abundance of Antarctic prions were the most important predictor variables. When using only oceanographic data, depth and SST were the top two variables explaining the presence of whales, while distance to shore and bathymetry were the top two variables for fur seal. When we limited the predictors to only seabird abundance, Antarctic prion was the top predictor variable for both whales and fur seal, while southern fulmar and king penguin were the second most important variables (for whales and fur seal respectively). Models that included both oceanographic data and seabird abundance as predictors showed the top two predictors for whales to be bathymetry and abundance of Antarctic prion, and for fur seal to be distance to shore and abundance of blue petrel (Table 6). AUC values were lowest for the models using only seabird abundance (0.75 and 0.74 for whales and fur seal respectively). Models using only oceanographic data had AUC values of 0.85 and 0.84 for whales and fur seal respectively. The most accurate models were those that combined both seabird abundance data and oceanographic data (0.89 and 0.85 for whales and fur seal respectively; Table 6). Our models found that high concentrations of whales, fur seals and Antarctic (>150 birds) coincided when compared to presences and absences of both mammal groups. However, whales were commonly located in deeper waters (mean 4424 m), while fur seal were mostly present in shallower waters (mean 1268 m; Table 7).

Table 6 Top two predictor variables contributing to presences of whales and fur seal from generalized boosted regression models for models run using only oceanographic data, only seabird data, and oceanographic data combined with seabird data. Area under the receiver's operating characteristic curve (AUC) values are reported to assess model accuracy

	Whales			Fur seal		
	Oceans	Seabirds	Ocean + Seabirds	Oceans	Seabirds	Ocean + Seabirds
Top predictor	Bathymetry	Antarctic prion	Bathymetry	Distance to shore	Antarctic prion	Distance to shore
2nd best predictor	Sea surface temperature	Southern fulmar	Antarctic prion	Bathymetry	King penguin	Blue Petrel
AUC	0.85	0.75	0.89	0.84	0.74	0.85

Table 7 Means and standard deviations (in brackets) of the most important predictors for whales and fur seal (abundance of Antarctic prions and bathymetry) at locations where they were observed (Presences), and not observed (Absences)

	Whales		Fur seal	
	Presences	Absences	Presences	Absences
Abundance of Antarctic prion	27.7 birds (122)	2.85 birds (17.1)	17.3 birds (79.0)	1.2 birds (2.6)
Bathymetry	4424 m (1785)	2212 m (1509)	1268 m (1635)	2713 m (1495)

3.4 Discussion

Southern right whale observations can be considered significant with a total of 22 individuals (all platforms pooled), as the global population is estimated to be only 7500 individuals. The ocean around South Georgia represents their main summering ground, while breeding populations were estimated for Peninsula Valdès as 2600 (in 1997) and in South Africa as 3600 (in 2008)[30-32]. During the whaling era (1785–1913), the distribution of southern right whales was defined as 20°S and 57°S, mainly between 30°S and 50°S[33], with the area north-west of South Georgia recognised as important[34]. The majority of southern right wales, fur seals and prions as well as fin and humpback whales were concentrated in a very limited region (*i.e.*, a "hotspot" clearly delimited in space and time). Such aggregations can be considered reflecting high local concentration of their prey[1-6,35]. The position of the fronts and water masses can strongly vary on a small time scale, and thus influence seabird abundance[36]. This system also happens to influence large-scale krill transport possibly from the west of the Antarctic Peninsula to South Georgia[37].

Most whales and penguins were encountered around free-drifting icebergs. Their presence could be linked to higher local prey abundance (mainly krill *Euphausia sp.*), due to higher primary production under and close to free-drifting icebergs[38], the basic mechanism being that melt-water can cause a vertical upwelling transport for nutrients and therefore increase primary production, zooplankton and seabirds (synopsis in Reference [39]). Previous work has highlighted a similar association between crabeater seals *Lobodon carcinophagus* and icebergs[40]. Icebergs can also provide a certain protection against predators such as leopard seals *Hydrurga leptonyx* and/ or killer whales *Orcinus orca.*

Seasonal factors might be of importance for large cetacean aggregations, namely their seasonal migration towards the tropics in autumn, as well as for seabirds[41]. They could also be correlated to the movements of adult krill towards the shelf slope in autumn[42]. Two large groups

of humpbacks (~100 individuals) were observed on 22 January 2008 around 62°S, 0°E (*Polarstern* expedition PS71, HR). Another major autumn feeding ground for fin whales, southern fulmars and grey-headed albatrosses *Thalassarche chrysotoma* was detected around the South Shetland Islands[6]. A comparable high aggregation was observed in the Western Antarctic Peninsula in May 2009, with more than 300 humpback whales encountered in 65 km of transect, corresponding to an exceptionally large krill swarm[43].

Comparisons with other polar marine ecosystems based on data collected by the same team, same platform and same counting method allow us to express a kind of rough measurement for biodiversity based on number of species and individuals. In the Weddell Sea during the first leg of the EPOS 1‡ expedition, 31 seabird species were observed with a mean of 150 individuals per count[7]. In the South Shetland Islands area, 40 species were recorded for a mean of 340 individuals per count, and maximal value of 485 individuals[6]. In the South Georgia area, 37 species were represented with a mean of 50 per count (Table 1) and a maximal value of 1320 per count in seven counts close to the Antarctic Front (5000 in one count, Table 4). We consider that these data reflect a kind of low biodiversity index for the Antarctic marine areas characterized by small numbers of species and large number of individuals for some of them. Qualitative differences were detected as well, Antarctic prion being the most numerous species in this study, southern fulmar in the South Shetland, Antarctic petrel *Thalassoica antarctica* in the south-eastern Atlantic, and Adélie penguin *Pygoscelis adeliae* and Cape petrel *Daption capense* in the Weddell Sea.

This study further investigated how seabirds could be used to predict the occurrence of whales and fur seal. Models using just seabirds proved reasonable with AUC values that are greater than 0.74. Of importance here is that a model combining seabirds and oceanographic data provided much better results than either oceanographic data or seabird data alone. This provides evidence towards the use of seabird data to help project the distributions of marine mammals (and *vice versa*). Ecosystem-style modelling efforts, where all species are taken into account simultaneously, would likely improve the management situation in the Southern Ocean.

3.5 Conservation

The South Georgia and South Sandwich Island Marine Protected Area, established in 2012 and covering more than one million km^2, includes a large "no take zone" of 12 nmiles around each island. The objectives of the protected area already include the conservation of the environment, the restoration of native biodiversity, the sustainable management of fisheries to ensure minimal impact on non-target species and it underlines the need to encourage high quality scientific research[44]. Together with the seasonal closure of krill fishery, it was an essential step toward reducing potential competition between marine mammals, seabirds and krill, in an area previously known as a very important krill fishery[45]. Observations outlined in this paper stress again the international conservation importance of the South Sandwich Islands and South Georgia area for krill and top predators-seabirds and marine mammals especially southern right whale. An appropriate conservation strategy should ensure that krill fishery does not cause local reduction in krill abundance in key periods, *i.e.*, at least during the breeding and post-breeding seasons of top predators. This area therefore deserves more protection and management measures, with spatial and temporal extension of the protected zone. These measures should include restrictions in krill fisheries and of "scientific" whaling.

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