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Research Article

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Very Low Density and Biodiversity of Seabird and Marine Mammal at-sea Distribution in the Amundsen Sea, 2010

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Abstract
Our long-term study on the quantitative at-sea distribution of the upper trophic levels - seabirds and marine mammals - in polar ecosystems aims at quantifying the factors influencing their distribution as well as detecting possible spatial and temporal changes, with special attention to hydrography and global climate changes. During the ANT- XXVI/3 expedition of icebreaking RV Polarstern in February-March 2010, a total of 8,270 seabirds belonging to 15 identified species were recorded in the Amundsen Sea during 1,070 half-hour transect counts, with a mean of eight birds per count. The most numerous species were by far Antarctic petrel, Adélie penguin and snow petrel, which together accounted for more than 80% of all individuals of these species recorded. Substantial hotspots of seabirds perched on three icebergs, representing 44% of all observations: 85% of the Antarctic petrels and 40% of the snow petrels [1]. Without taking into account these data, the mean seabird number becomes five individuals per count, representing the lowest value registered in Antarctic seas. The most numerous pinniped was crabeater seal contributing 98% of the total of 2,350 individuals of four pinniped species [2]. Among cetaceans, the most abundant species were Antarctic Minke whale and fin whale (60% and 25% of the total of 170 individuals, four species). The maps allow for a visual comparison that is sufficient for the purposes of this article, reflecting the influence of hydrological features such as water masses and fronts, pack ice and ice edge, free drifting icebergs.

Keywords: Seabird and Marine Mammal At-Sea Distribution, Amundsen Sea

Introduction
Seabird and marine mammal distributions in the Amundsen Sea are poorly studied: the only previous study was that by Ainley et al. in 1994 [3-5]. We had the opportunity to participate in an expedition in the Amundsen Sea Embayment and Pine Island Bay in February-March 2010. The aims of the PolE team are to complete, with the addition of the Amundsen Sea, our long-term study of the environmental factors explaining the distribution at sea of the higher trophic levels in polar marine ecosystems. Included is a broader goal to detect possible temporal and spatial variations.

Materials and Methods
Marine bird and mammal distribution was studied during the ANT-XXVI/3 expedition of icebreaking RV *Polarstern* in the Amundsen Sea, West Antarctica. Data collected during the first North-South transect from Christchurch, New Zealand, through the Ross Gyre have already been published [6]. In this article, we report on the second West-East transect in the Amundsen Sea Embayment (ASE) and mainly Pine Island Bay (PIB) from 12 February to 27 March 2010, i.e. *partim* > 68°S, > 109°W (Figure. 1) corresponding to Antarctic Surface Water south of the Sub-Antarctic Front. We evaluated ice cover, expressed as per-cent coverage within a radius of ~500 m around the ship. Ice conditions are shown in Figure. 2 and hydrographical data (water temperature and salinity) in Figure. 3 were collected as mean values for each count [7]. Transect counts were conducted from the bridge (18 m above sea level) without width limitation during 30-min periods, on a continuous basis when the ship was underway, when daylight and visibility conditions allowed. More details on our counting method are described in previous articles of this team [8-11]. These counts from ship were complemented by 24 helicopter flights between 12 February and 25 March, providing a full coverage of PIB: speed

80 knots, height 100 feet, lasting 2.5 hour each, mean values. This article presents basic data without correction for diurnal haul-out/diving periods, nor for calculation such as density: they can thus be considered minimal estimations.

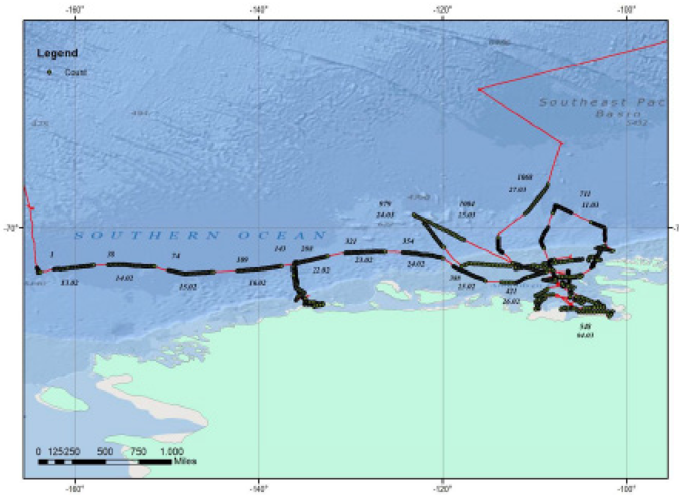


Figure 1: ARK-XXVI/3 expedition of RV *Polarstern*, February-March 2010: transect count numbers, positions and dates (dd.mm) (from AWI DShip database of Polarstern expeditions, https://dms.awi.de/, [7]).

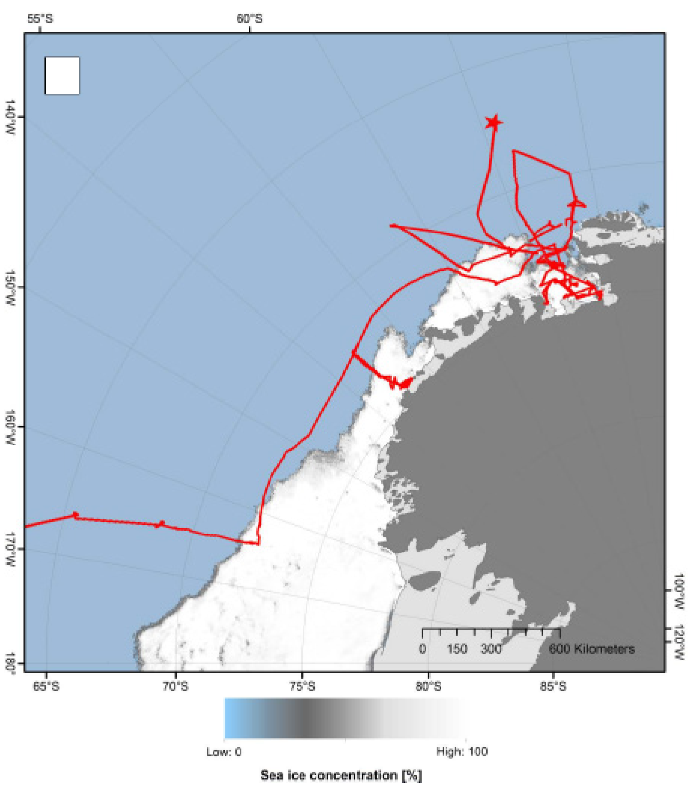


Figure 2: Ice coverage in the Amundsen Sea recorded during the expedition from satellite pictures on 23 March 2010: the route of *Polarstern* is indicated in red (University of Bremen, https://seaice.uni-bremen.de/sea-ice-concentration/)

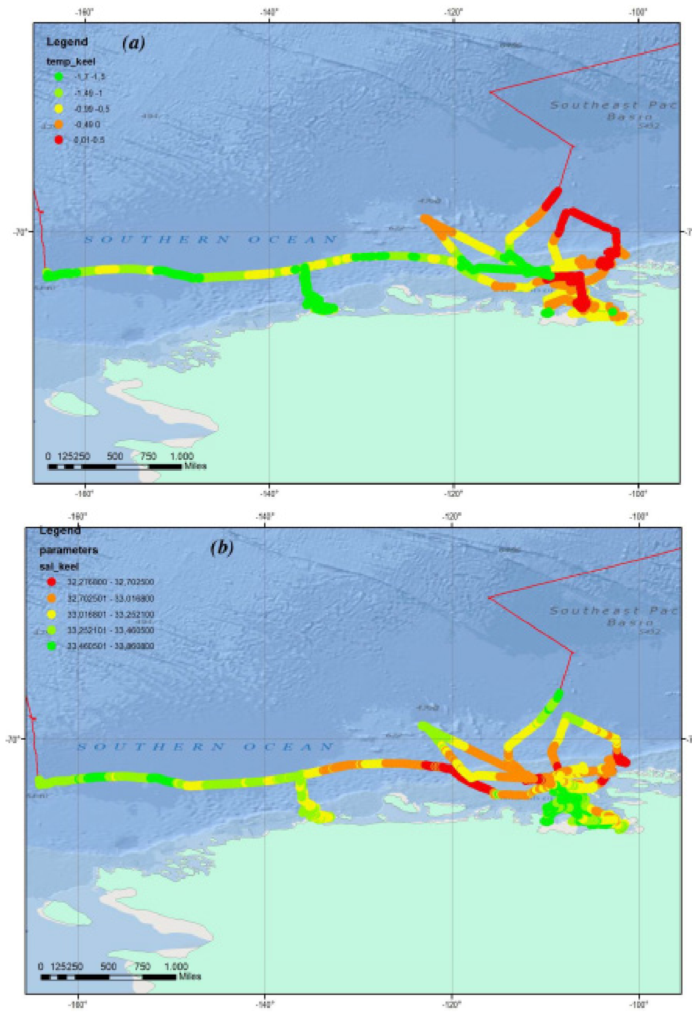


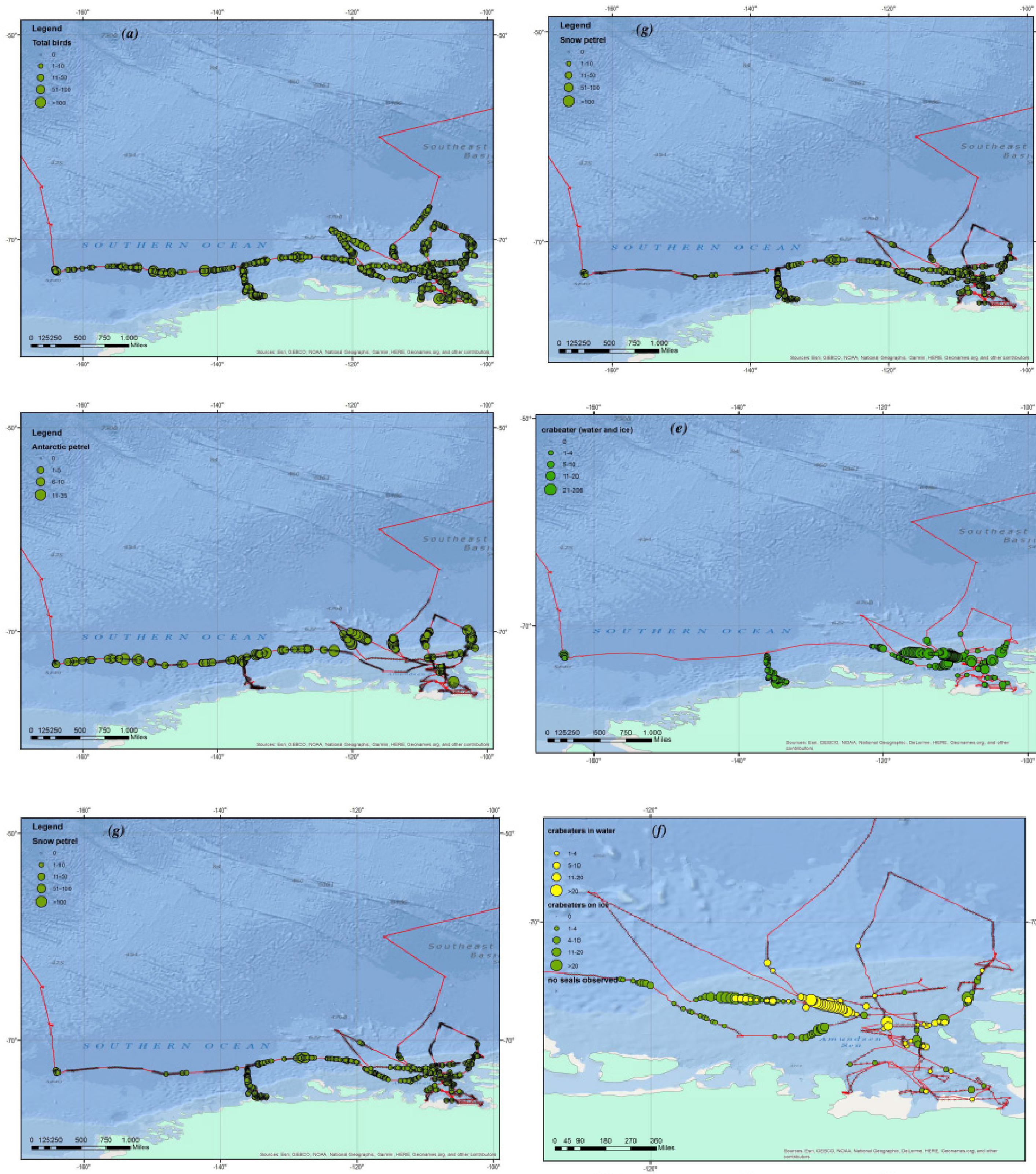
Figure 3: Hydrographic data collected on board *Polarstern*: water temperature SST **(a)** and salinity **(b)**(from AWI DShip database of Polarstern expeditions, https://dms.awi.de/, [7]).

Results

A total of 8,270 seabirds belonging to 15 species were tallied during 1,070 half-hour transect counts in the Amundsen Sea Embayement (ASE) and Pine Island Bay(PIB), corresponding to 6,000 km at a speed of 6.5 knots (this low mean speed was due to both ice breaking and seismic activities). This represents a mean value of eight birds per count period. The most numerous species were 3,340 Antarctic petrels *Thalassoica antarctica* (mean of 3.1 per count), 1,770 Adélie penguins *Pygoscelis adeliae* (1.65 per count) and 1,280 snow petrels *Pagodroma nivea* (1.2 per count), together representing 80% of the total. Large numbers of seabirds were concentrated on three medium-sized tabular icebergs, between 68°S and 73°S, 160°W and 109°W, that occurred close enough to the ship that we could distinguish species. They represented 44% of the recorded seabird individuals: 85% of the Antarctic petrels, 40% of the snow petrels, and 33% of the Cape petrels *Daption capense*, as well as a few Adélie penguins [1]. When these hotspots are excluded from the calculations, the mean number of seabirds became five birds per count. Among pinnipeds we recorded 2,470, of four species; 2,350 crabeater seals *Lobodon carciniphagus* (2.2 per count), of which half were hauled-out on ice floes and half were swimming pods of juveniles accompanied by one or two adults [11]. Cetaceans tallied were 133 Antarctic Minke whales *Balaenoptera bonaerensis* (0.10 per count) and 19 fin whales *B. physalus*, representing together 85% of the total of 170 of four species (Table 1).

Table 1: Seabirds and marine mammals recorded during RV *Polarstern* expedition ANT-XXVI/3 in the Amundsen Sea, partim> 68°S, > 109°W; n = number of 30min transect counts; N = total number of individuals; mean per count (> 0.01)

Species	*n*	1068		
	Ice (%)	5.7		
	SST (°C)	-0.83		
	Salinity	33.15		
	Depth (m)	2017		
	*Speed (knots)**	6.53		
	Species	N	Mean	Remark
Emperor penguin	*Aptenodytes forsteri*	236	0.22	
Adélie penguin	*Pygoscelis adeliae*	1766	1.65	Including 40 on an iceberg
Wandering albatross	*Diomedea [exulans]*	1		
Light-mantled albatross	*Phoebetria palpebrata*	18	0.02	
Southern giant petrel	*Macronectes giganticus*	346	0.32	
Southern fulmar	*Fulmarus glacialoides*	191	0.18	
Antarctic petrel	*Thalassoica antarctica*	3343	3.13	Including 2310 on icebergs
Snow petrel	*Pagodroma nivea*	1280	1.20	Including 550 on icebergs
Cape petrel	*Daption capense capense*	408	0.38	Including 35 close to an iceberg
Mottled petrel	*Pterodroma inexpectata*	41	0.04	
Blue petrel	*Halobaena caerulea*	56	0.05	
Blue petrel/ prion sp	*Halobaena/ Pachyptila sp.*	148	0.14	
Slender-billed prion	*Pachyptila belcheri*	30	0.03	
Black-bellied storm-petrel	*Fregatta tropica*	1		
South polar skua	*Catharacta [skua] maccormicki*	102	0.10	
Antarctic tern	*Sterna vittata*	303	0.28	Including 20 on icebergs
∑ birds		**8270**	**7.75**	Including 2900 on icebergs
∑ birds		**5370**	**5.03**	Excluding the icebergs hotspots
Number of identified species		15		
Leopard seal	*Hydrurga leptonis*	6		
Weddell seal	*Leptonychotes weddellii*	40	0.04	
Crabeater seal	*Lobodon carcinophagus*	2351	2.20	1205 on ice, 1053 in water
Ross seal	*Ommatophaga rossii*	3		
Pinniped sp	*Pinnipedia*	71	0.07	
∑ pinnipeds		**2468**	**2.31**	
Sperm whale	*Physeter macrocephalus*	2		
Antarctic Minke whale	*Balaenoptera bonaerensis*	133	0.12	
Dwarf Minke whale	*Balaenoptera [acurostrata] sp*	[2]		Out of effort
Fin whale	*Balaenoptera physalus*	19	0.02	
Humpback whale	*Megaptera novaeangliae*	9	0.01	
Whale sp		3		
∑ cetaceans		**170**	**0.16**	
* Low speed: ice breaking and / or seismic activities				


(a)
Legend
Total birds
0
1-10
11-50
51-100
>100
(g)
Legend
Snow petrel
0
1-10
11-50
51-100
>100
Legend
Antarctic petrel
0
1-5
6-10
11-35
(e)
crabeater (water and ice)
0
1-4
5-10
11-20
21-206
(g)
Legend
Snow petrel
0
1-10
11-50
51-100
>100
(f)
crabeaters in water
1-4
5-10
11-20
>20
crabeaters on ice
0
1-4
4-10
11-20
>20
no seals observed
SOUTHERN OCEAN
Southeast Basin
Miles

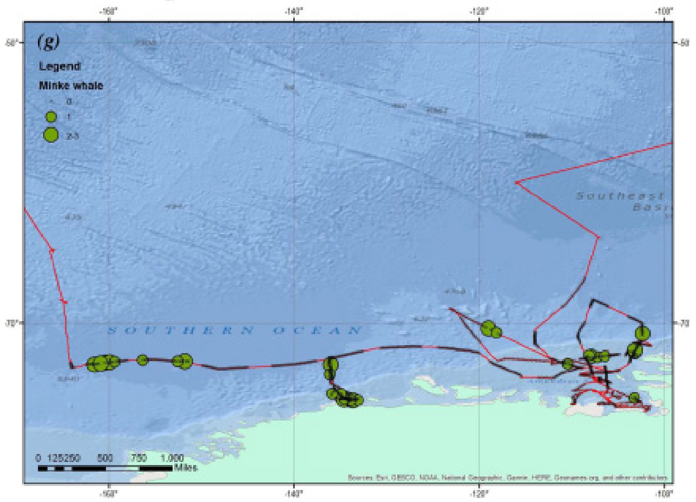


Figure 4: Quantitative distribution of the main top predator species encountered during *Polarstern* expedition ANT-XXVI/3 in the Amundsen Sea, partim> 68°S, > 109°W, number per 30min transect count: all birds (a), Adélie penguin *Pygoscelis adeliae* (b), Antarctic petrel *Thalassoica antarctica* (c), snow petrel *Pagodroma nivea* (d), crabeater seal *Lobodon carcinophagus*: all observations (e) & detailed zone in ASE & PIB: on ice (green) & in water (yellow) (f), Antarctic Minke whale *Balaenoptera bonaerensis* (g)

The distribution of Adélie penguin followed, as expected, the presence of pack ice, so that local densities in pack ice were actually much higher than the mean value cited here (Figure. 4a). Basically the same conclusion applies to snow petrel (Figure. 4d), crabeater seal more bound to close pack ice (Figures. 4e and f), and Antarctic Minke whale to the ice edge and the Outer Marginal Ice Zone OMIZ (Figure. 4g). In contrast, Antarctic petrel was more an open water species, especially close to the shelf edge (Figure. 4c).

The total distance covered from helicopter during 24 flights was 7,600 km, i.e. a mean of 360 km per flight (range 135-460), entirely covering the PIB and thus not following exactly the same route as *Polarstern*. Main bird species were Adélie penguin with 2,270 individuals (mean of 103 per flight), followed by 255 snow petrels (12 per flight) and 65 Antarctic petrels (3 per flight). 24,112 crabeaters were tallied hauled-out on ice (1,100 per flight), with 100 only seen in the water; 25 Minke whales were also seen. The comparison with the data from our ship surveys (Table 2) shows a similar order of magnitude for Adélie penguin and crabeater hauled-out on ice but very different for the swimming pods and for other species, numbers recorded from ship being much higher.

Table 2: Seabirds and marine mammals encountered in the Amundsen Sea on board RV *Polarstern* and from helicopter, main species; n = number of 30min transect counts from ship; 24 helicopter flights, lasting 2.5 hours each

	Platform	*Polarstern*			Helicopter	
		1068 counts			7595 km	
		Total	Mean	Mean	Total	Mean
Species	*Species*		/ count	/ km		/ km
Adélie penguin	*Pygoscelis adeliae*	1766	1.65	0.27	2608	0.34
Antarctic petrel	*Thalassoica antarctica*	3343	3.13	0.52	65	0.009
Snow petrel	*Pagodroma nivea*	1280	1.20	0.20	254	0.033
Crabeater seal in water	*Lobodon carcinophagus*	1053	1.58	0.26	100	0.01
Crabeater seal on ice	*Lobodon carcinophagus*	947	1.42	0.24	24179	3.19
Crabeater seal total	*Lobodon carcinophagus*	2000	2.99	0.50	24299	3.20
Antarctic Minke whale	*Balaenoptera bonaerensis*	133	0.12	0.01	25	0.003

Moreover, a pod of seven killer whales *Orcinus orca* and one Minke whale, close to an iceberg surrounded by a lot of fresh blood, were tallied from another flight on 11 March, out of effort. The observation out of effort of two dwarf Minke whales *Balaenoptera* [*acurostrata*] *sp*. chased by a leopard seal *Hydrurga leptonyx* seems to reflect a predation attempt on 22 March, out of effort (70°30'S, 119°W): the two whales were trying to escape at maximal speed, closely followed by the seal.

Discussion

The ship-borne observations show numbers of species that are similar to those from a previous survey in the area: 15 seabirds, four pinnipeds and four cetaceans [3,5]. A few species dominated in numbers: three seabirds, one seal, and one whale. Moreover, numbers of individuals were very low as well, with mean values of eight seabirds (five if the large seabird hotspots on icebergs are excluded), two seals and 0.16 whale per 30 min count. This reflects a very low biodiversity, even compared with other polar marine ecosystems, both Arctic and Antarctic [12-14]. The vast majority of these species were bound to the ice edge corresponding to the continental slope and to the Outer Marginal Ice Zone (OMIZ). The presence of birds bound to open water ("water birds") e.g. Antarctic petrel, remains very limited (Figure. 4). As usual, such data can obviously not be expressed as mean values with standard deviations, since the distribution of data is far from normal.

The discrepancy between ship-borne and airborne observations might be due to different factors. We do not consider a lower detectability from a helicopter flying at 300 feet vs a slow moving vessel (8 knots). On the other hand, the presence of seabird individuals following the ship for long distances, not identified as such, might increase the number of observations from a ship. This might be the case of Antarctic petrel, with large breeding populations occurring in Marie Byrd Land (adjacent to the Amundsen Sea), i.e. two million breeding pairs and Mount Paterson (78°S, 154°W) with 10,000 pairs [15,16]. Moreover, in our case, helicopter flights did not follow exactly the same route as Polarstern, did not cover all ice bird hotspots, but on the contrary covered larger ice-covered zones. Many observations confirm this in areas exhibiting very low density in ships, such as the high Arctic Ocean or the North-East Passage off Siberia and Antarctic seas, while other studies showed that some seabird species avoid ships [17,18]. We did not do the corrections for potential ship-attracted birds, given that we chose to use an unlimited view scape.

Hotspot concentrations were noted in association with icebergs concerning 85% of Antarctic petrels, 40% of snow petrels, and 33% of cape petrels [1,19,20]. Such a phenomenon has been noted previously in 1994 [3]. It may be corresponding to the end of the breeding season, which is also beginning the annual moult and/ or as wintering strategy [21]. The importance of such hotspots has been seen, too, close to the Antarctic Peninsula [22]. Crabeater swimming pods of juvenile individuals accompanied by a few adults ("rookeries") swimming around icebergs represented half the total number recorded [2]. Free-drifting icebergs constitute sites of high biological production, from phyto- and zooplankton to birds, seals and whales, in this case three birds and crabeater seals [1,2,11,23-25]. Their influence includes areas of open water surrounding them for both seabirds and crabeater seal [1,2,25]. The same conclusion applies to other hotspots recorded by this team in both polar areas, concerning seabirds, cetaceans and seals [1,2,9,11,26]. They were tallied in late summer, and thus might reflect situations of pre-migratory/ movements gatherings following the breeding season. A single observation might correspond to a pre-nuptial migration: the presence of 18,500 chinstrap penguins – representing 90% of the total – walking on the ice towards their breeding sites in early summer in the Weddell Sea in 1988 [27].

A large-scale study on seabirds and whales was conducted in the same area in February 1994, simultaneous to one on pinnipeds, apparently the only one concerning seabirds until our study in 2010 [3,5, 27-30]. Our data basically confirm their main conclusions. Striking was the very low seabird density, near zero birds per km2 over the continental shelf. In the Amundsen Sea, dominant species seen in that earlier study were emperor *Aptenodytes foresteri* and Adélie penguins and snow petrel from 150° to 104°W, and locally blue petrels *Halobaena caerulea* and Antarctic prions *Pachyptila vittata* in open waters adjacent to the ice edge in the eastern section [3,5]. These differences in bird species abundance in the Amundsen Sea might be due to the important differences in ice coverage, very high in 1994 and extremely low in 2010. This could also explain the very high concentrations of crabeater seals hauled out on remaining ice in this 2010 study. Cetaceans seen in the earlier study were mainly 100 Minke whales (0.02 per half-hour), concentrated at fronts and ice edge [22,28]. Previous studies on the distribution of pack ice seals – mainly 1.7 million crabeaters - in the Ross and Amundsen seas already defined such distribution mechanisms: their density corresponded to 0.5/ km in small groups with a mean size of 1.6 individuals, basically corresponding to the breeding period [4].

Data collected by our team, using the same platform and same methodology, indicate much lower seabird numbers than in the other Antarctic seas with a mean value of eight per count (five when excluding the hotspots) belonging to 15 species. In the western Weddell Sea, 180 birds per count belonging to 30 species of which 73 were chinstrap penguins *Pygoscelis antarctica* (including the ones concentrated on icebergs), 70 Adélie penguins, 25 Cape petrels and four snow petrels. These four species represented 96% of the total [13,27]. The other Antarctic seas showed intermediate values, both in numbers of individuals as in numbers of species [31-33].

Conclusion

Our observations collected in February – March 2010 in the Amundsen Sea basically confirm the previous ones collected in February 1994. This concerns both the numbers of species as their distribution, especially the very low numbers in open water and the links of the other species with pack ice and ice edge. The very low number of bird species, their low abundance and the strong prevalence of a few of them, reflect a very low biodiversity and a low biological productivity, considering the abundance and distribution must reflect prey abundance. Differences in bird species composition between both studies might mainly be due to changes bound to post-breeding movements/ migration. Some species (e.g. Antarctic petrel) might be long-distance followers not detected as such on board: this might lead to a strong over-estimation of their numbers as well as to an important discrepancy between ship-borne and air - borne data.

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