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Habitat selection by marine mammals in the marginal ice zone

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Abstract: As part of the multi-disciplinary project, Antarctic Marine Ecosystem Research at the Ice Edge Zone (AMERIEZ), habitat selection by marine mammals was investigated within the marginal ice zone in relation to measured ice variables and other environmental factors. Data were collected on three cruises to the southern Scotia and northern Weddell seas during spring 1983, autumn 1986, and winter 1988. During winter, Antarctic fur seals were significantly associated with drift, pancake, brash ice, icebergs, and areas of uneven floe distribution, all characteristic of the marginal ice zone. Fur seals were seen in open water close to the ice edge during autumn, but during spring, as the pack ice began to retreat rapidly, animals were seen more often away from the ice. Minke whales were also associated with pancake and new ice but were seen further into the pack ice during both winter and autumn. The largest groups of minke whales during winter were observed with a large krill swarm in new ice. Crabeater seal was exclusively a species of the deep pack ice during all seasons and was associated with ice cover of 7–8 oktas and evenly distributed ice floes.

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Key Words: Antarctic fur seal, crabeater seal, minke whale, marginal ice zone, pack ice edge.

Introduction

A broad integrated approach to the relationship between higher vertebrates and the marine environment is important for the Antarctic and other communities. Most observations of higher vertebrates in the Antarctic are made in one habitat type, such as open water or the pack ice (e.g. Gilbert & Erickson 1977, Butterworth & Best 1982). Rarely has there been an effort to bridge more than one marine habitat simultaneously due to the conflicting constraints that ice and open water place on ship operations. The project, Antarctic Marine Ecosystem Research at the Ice Edge Zone (AMERIEZ), is a large multi-disciplinary investigation of the seasonal dynamics of the marginal ice zone including operations within the ice and the open water (Ainley & Sullivan 1984, Sullivan & Ainley 1987, Ainley & Sullivan 1989). Our component of the project was to investigate habitat choice, as defined by ice characteristics and other environmental variables, by higher vertebrates and any seasonal changes that occurred (Fraser & Ainley 1986). We initially hypothesized that (1) the ice edge was a region that separated two distinctive communities of vertebrates and that (2) the abundance of organisms should increase at the ice edge due to enhanced production (Smith & Nelson 1985). The objective of this paper is to report the relationship between marine mammals and the environmental variables that affected their occurrence patterns in the vicinity of the pack ice edge.

Methods

Three cruises were made on research vessels in the northern Weddell and southern Scotia seas, between 57° and 63° S and 35° and 54° W, during November (spring) 1983, March (autumn) 1986, and July–August (winter) 1988 as part of AMERIEZ (Fig. 1). This area is known as the Scotia/Weddell Confluence. Cruise tracks were designed to gain a synoptic picture of oceanographic features; hydrostations were spaced at 15 km intervals. Further details can be found in Ainley & Sullivan (1984), Sullivan & Ainley (1987), and Ainley & Sullivan (1989).

Strip transects were conducted with a 300 m strip width for pinnipeds and an 800 m strip width for cetaceans (Ainley *et al.* 1984, Ainley 1985). Strip widths were periodically checked using radar and a range finder. All mammals were counted in the strip, from the side of the ship with the least glare, whenever the ship was moving at speeds greater than 6 knots. In 1983, censuses were conducted for 30 min every hour. In 1986 and 1988, censuses were also conducted at intervals of 30 min, sometimes consecutively. Observations were made by two observers, scanning simultaneously, from the bridge or bridge wings, 10–15 m above sea level. Environmental variables were measured at the start of each 30 min period. If ice conditions changed dramatically, the census period was terminated prematurely and another begun.

Censuses were not made when visibility was less than

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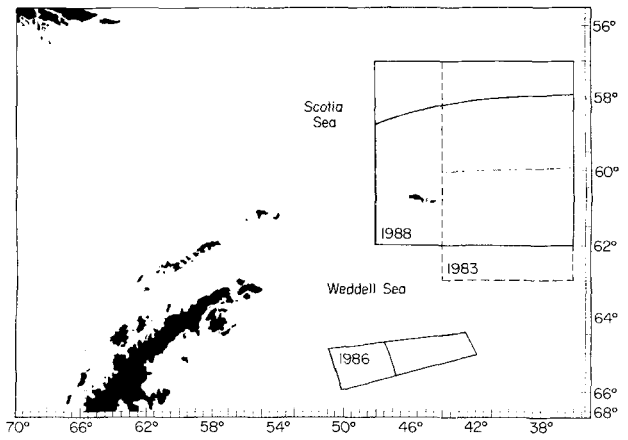


Fig. 1. Outlines of the AMERIEZ study areas for the three cruises made during spring 1983, autumn 1986, and winter 1988. Lines midway in each study box demarcate the ice edge with pack ice being to the south (1983, 1988) or west (1986). All latitudes are south latitudes and all longitudes are west longitudes.

800 m nor when, in open water, winds exceeded 25 knots. In 1983, 1986, and 1988, 39.4%, 53.7% and 51.1%, respectively, of the censuses were made in winds less than 15 knots.

To facilitate comparisons with the 1983 data, a transect in 1986 and 1988 was defined to be the area traversed in 30 min. Average area surveyed per 30 min transect using a 300 m strip width was 2.8 km^2 in 1983, and 2.4 km^2 in 1986 and 1988.

We divided the censuses into ice and open water sets. When a group of animals was seen, we recorded number of animals and, where possible, age and sex composition. We tested for differences in group sizes in the ice versus the open water with the median test and an alpha level of 0.05 (Conover 1980).

The following environmental variables were recorded at the beginning of each half hour of censusing: depth to ocean floor (m), sea surface temperature (°C), salinity (ppt), distance to ice edge (measured relative to the ice edge in km: negative distances for transects in the pack ice and positive distances for transects in open water), ice cover (oktas), ice pattern (even or uneven distribution of floes), ice type (pack ice, icebergs, shore ice, fast ice, drift ice, new ice) and ice form (small floes, brash ice, pancake ice, ice of land origin).

In order to compare areas where a species was seen and where a species was not seen, the 30 min. transects were used. Since continuous-time transects broken into 30 min. segments are not independent, we divided the 1986 and 1988 data into two sets. The first set consisted of all censuses made on the hour, and the second consisted of all censuses made on the half hour. The average distance between censuses was 9 km in 1983, and 8 km in 1986 and 1988. Identical analyses were made on the two data sets, and both test P-values had to be less than an α of 0.05 for significance to be achieved. The test with the largest P-value is reported here.

For the nominal ice variables, we tested the null hypothesis that the distribution of the variable where a species occurred was the same as the distribution of the variable where a species did not occur using a χ^2 test with adjusted standardized residuals (Haberman 1978). For the other variables, we tested the null hypothesis that the medians of the environmental variable where a species was seen and was not seen were the same with a Mann-Whitney U test corrected for ties (Conover 1980) ($\alpha = 0.05$). The statistical package used was SPSS-PC+ (Norusis 1988).

Results

Autumn 1986

Total area surveyed was 741 km^2 (based on a 300 m strip width); 90% of the area was in open water and 10% was in the ice. The most common mammalian species seen were minke whale (*Balaenoptera acutorostrata* Lacépède) (31 groups), Antarctic fur seal (*Arctocephalus gazella* Peters) (27 groups), and crabeater seal (*Lobodon carcinophagus* Hombron and Jacquinot) (42 groups). Leopard seals (*Hydrurga leptonyx* Blainville) were rarely seen (7 groups).

Except for one group of 18, minke whales were generally seen in small groups (median = 2 whales per group, $\bar{x} = 2.6$ whales per group, se = 0.5, $n = 31$ groups) whether in the open water ($n = 23$ groups) or in the ice ($n = 8$ groups) ($T = 0.72$, $P > 0.50$). The whales were seen significantly more often in new ice ($\chi^2 = 14.9$, df = 4, $P = 0.005$) and pancake ice ($\chi^2 = 11.9$, df = 4, $P = 0.02$), as well as in areas of cooler waters ($\bar{x} = -1.03$ °C, se = 0.15, $n = 23$) compared to areas where it was not seen ($\bar{x} = -0.72$ °C, se = 0.05, $n = 217$) ($Z = 2.45$, $P = 0.01$) (Table I).

Fur seals, almost all male on the basis of size, generally occurred in small groups or as solitary animals ($\bar{x} = 1.9$ animals/group, se = 0.2, median = 1 animal per group, $n = 27$ groups); group size did not vary between open water ($n = 20$ groups) and the ice ($n = 7$ groups) ($T = 0.10$, $P > 0.50$). All the fur seals were seen on ice floes during the open water censuses (not so during other seasons, see below). When the ship was in ice, 85% of the groups were seen on the ice and 15% were in the water.

Fur seals were not associated with any ice variable (all tests, $P > 0.10$) though when seen in the ice, animals tended to occur in brash ice (Table I). The species was seen in areas significantly closer to the ice edge ($\bar{x} = 63.4$ km, se = 30.6, $n = 19$) ($Z = -2.9$, $P = 0.004$) and in more shallow waters ($\bar{x} = 2899.3$ m, se = 172.0, $n = 19$) ($Z = -3.1$, $P = 0.002$) compared to areas where not seen (ice edge: $\bar{x} = 201.3$ km, se = 14.6, $n = 211$; ocean depth: $\bar{x} = 3729.3$ m, se = 69.9, $n = 211$).

Crabeater seals were seen in small groups (median = 2 seals per group, $\bar{x} = 2.5$ seals per group, se = 0.4, $n = 42$

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groups) with similar group size in open water ($n = 14$ groups) and in ice ($n = 28$ groups) ($T = 0.21, P > 0.50$). When the ship was in open water, 78.6% of the seals were seen on ice floes; 21.4% in the water. When the ship was in ice, 92.8% of the seals were seen hauled out on ice floes with 7.1% in the water.

Crabeater seals were associated with heavy ice cover ($\chi^2 = 13.1$, df = 3, $P = 0.004$) and pack ice ($\chi^2 = 11.1$, df = 4, $P = 0.03$) characterized by ice floes ($\chi^2 = 19.2$, df = 5, $P = 0.002$) with a regular pattern ($\chi^2 = 7.9$, df = 2, $P = 0.02$) (Table I). This species was seen further into the pack ice ($\bar{x}$ = -26.3 km, se= 14.2, $n = 19$) ($Z = -4.2, P < 0.001$) and in areas of more shallow oceanic depths ($\bar{x} = 2948.5$ m, se = 82.0, $n = 19$) ($Z = -2.8$, $P = 0.004$) and cooler temperatures ($\bar{x} = 1.56$ °C, se = 0.06, $n = 19$) ($Z = -4.2$, $P < 0.001$) compared to areas where it was not seen (ice edge: $\bar{x} = 210.8$ km, se = 14.3, $n = 209$; ocean depth: $\bar{x} = 3725.0$ m, se = 71.3; temperature: $\bar{x}$ -0.68 °C, se = 0.05).

Winter 1988

Total area surveyed was 581 km² (based on a 300 m strip width); 54% of the area was in open water and 46% was in ice. The most common species seen were Antarctic fur seal (76 groups seen), minke whale (21 groups), and crabeater seal (19 groups). Leopard seals were rarely seen (6 groups).

Fur seals were observed in small groups or as solitary animals ($\bar{x} = 3.3$ animals/group, se = 0.7, median = 1 animal per group, $n = 76$ groups); although groups larger than 10 animals were occasionally seen (size: 14–35, $n = 5$ groups). This species was seen in the same size groups in open water ($n = 56$ groups) as in ice ($n = 20$ groups) ($T = 0.03, P > 0.50$). On the basis of size, almost all individuals were male. When the ship was in open water, all of the fur seals were seen in the water. When the ship was in ice, 32.7% of the fur seals were seen in the water while 67.2% were seen on ice floes.

The species was seen significantly less often in open water (27.5%) and more often in ice cover of less than 6 oktas, specifically in oktas 1 and 5 ($\chi^2 = 15.9$, df = 3, $P = 0.001$), in areas with uneven floe distribution ($\chi^2 = 15.8$, df = 2, $P < 0.001$), in drift ice and near icebergs ($\chi^2 = 21.3$, df = 4, $P < 0.001$), and in pancake and brash ice ($\chi^2 = 23.8$, df = 4, $P < 0.001$) (Table II). Fur seals were seen significantly closer to the ice edge ($\bar{x}$ = -2.2 km, se = 5.1, $n = 40$) ($Z = -2.4$, $P = 0.015$) and in cooler waters ($\bar{x}$ = -1.05 °C, se = 0.11, $n = 40$) ($Z = -1.9$, $P = 0.06$) compared to areas where animals were not seen (ice edge: $\bar{x}$ = 19.1 km, se = 4.2, $n = 205$; temperature: $\bar{x}$ = -0.33 °C, se = 0.11, $n = 205$).

Nearly all (90.5%) minke whale sightings occurred within the pack ice. The whales were seen in small groups (median = 2 whales per group, $\bar{x} = 8$ whales per group, se = 3.2, $n = 21$ groups) although three large groups (15, 25, and 65 whales per group) were seen near areas where densities of krill were observed hydro-acoustically (K. Daly & M. Macauly, personal communication 1989).

Table I. Percentage of sightings of Antarctic fur seals, minke whales, and crabeater seals for ice cover, pattern, type, and form for transects where animals were seen and not seen during autumn 1986. n = number of 30 min. transects, * = categories where the value in the seen category is significantly higher ($\alpha = 0.05$) than the not seen category using residual analysis

	Antarctic fur seal		minke whale		crabeater seal	
Variable	seen n=221	not seen n=19	seen n=217	not seen n=23	seen n=221	not seen n=19
cover:						
open water	48.9	52.6	49.8	43.5	51.1	26.3
1-3 okta	30.3	21.1	28.1	43.5	30.3	21.1
4-6 okta	4.1	0	4.1	0	3.2	10.5
7-8 okta	16.7	26.3	18.0	13.0	15.4	42.1*
pattern:						
open water	48.9	52.6	49.8	43.5	51.1	26.3
even	17.6	10.5	15.7	30.4	15.8	31.6*
uneven	33.5	36.8	34.6	26.1	33.0	42.1
type:						
open water	45.0	52.6	49.8	43.5	51.1	26.3
new ice	3.6	0	1.8	17.4*	3.6	0
pack ice	23.1	21.1	23.5	17.4	20.4	52.6*
drift ice	23.1	26.3	23.5	21.7	23.5	21.1
icebergs	1.4	0	1.4	0	1.4	0
form:						
open water	48.9	52.6	49.8	43.5	51.1	26.3
ice of land origin	12.2	0	11.1	13.0	12.2	0
pancake ice	4.1	0	1.8	21.7*	4.1	0
brash	6.3	21.1	8.3	0	7.7	5.3
small and medium floes	27.1	26.3	27.6	21.7	23.5	68.4*
fast ice	1.4	0	1.4	0	1.4	0

Minke whales were seen significantly more often in ice cover of 7–8 oktas ($\chi^2 = 13.5$, df = 3, $P = 0.004$), in areas with even floe distribution ($\chi^2 = 12.4$, df = 2, $P = 0.002$), in new ice ($\chi^2 = 14.7$, df = 4, $P = 0.005$), and in pancake ice ($\chi^2 = 22.3$, df = 4, $P < 0.001$) (Table II). The species was seen in areas of cooler waters ($\bar{x}$ = -1.59 °C, se = 0.16, $n = 15$) and further into the pack ice ($\bar{x}$ = -41.7 km, se = 8.4, $n = 15$) ($Z = 3.6$, $P < 0.001$) compared to areas where it was not seen (ice edge: $\bar{x} = 18.9$ km, se = 3.8, $n = 230$; temperature: $\bar{x}$ = -0.38 °C, se = 0.10, $n = 230$).

All sightings of crabeater seals occurred within the pack ice. The species was seen in small groups (median = 2 seals per group, $\bar{x} = 3.8$ seals per group, se = 1.3, $n = 19$ groups) although two large groups were seen (12 and 25 seals per group). When observed, 36.8% of the groups were in the water; 63.2% were hauled out on ice floes.

Crabeater seals were associated with heavy ice cover ($\chi^2 = 16.0$, df = 2, $P = 0.001$), an even ice pattern ($\chi^2 = 11.2$, df = 2, $P = 0.004$) (Table II), in pack ice ($\chi^2 = 16.9$, df = 4, $P = 0.002$) and on ice floes ($\chi^2 = 13.1$, df = 4, $P = 0.01$).

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Table II. Percentage of sightings of Antarctic fur seals, minke whales, and crabeater seals for ice cover, pattern, type, and form for transects where animals were seen and not seen during winter 1988. n = number of of 30 min. transects, * = categories where the value in the seen category is significantly higher ($\alpha = 0.05$) than the not seen category using residual analysis, and - = category not seen.

	Antarctic fur seal		minke whale		crabeater seal	
Variable	seen n=205	not seen n=40	seen n=99	not seen n=14	seen n=102	not seen n=11
cover:						
open water	60.5	27.5	-	-	-	-
1-3 okta	8.8	20.0*	27.3	14.3	28.4	0
4-6 okta	15.6	35.0*	42.4	28.6	42.2	27.3
7-8 okta	15.1	17.5	30.3	57.1*	29.4	72.7*
pattern:						
open water	42.4	2.5	3.0	0	2.9	0
even	20.5	30.0	36.4	64.3*	35.3	81.8*
uneven	37.1	67.5*	60.6	35.7	61.8	18.2
type:						
open water	42.4	2.5	3.0	0	2.9	0
new ice	11.2	15.0	22.2	50.0*	25.5	27.3
pack ice	22.9	35.0	53.5	42.9	50.0	72.7*
drift ice	19.0	32.5*	21.2	7.1	21.6	0
icebergs	4.4	15.0*	-	-	-	-
form:						
open water	42.4	2.5	3.0	0	2.9	0
ice of land origin	6.3	15.0	-	-	-	-
pancake ice	5.9	25.0*	16.2	42.9*	18.6	27.3
brash	19.5	37.5*	27.3	0	26.5	0
small floes	12.2	17.5	28.3	28.6	28.4	27.3
medium and large floes	13.7	2.5	25.3	28.6	23.5	45.5*

Crabeater seals were seen further into the pack ice ($\bar{x}$ = -37.6 km, se= 5.4, n = 11) (Z = -3.1, P = 0.002) and in areas of cooler waters ($\bar{x}$ = -1.56 °C, se = 0.16, n = 11) (Z = -3.2, P = 0.001) compared to areas where seals were not seen (ice edge: $\bar{x}$ = 18.1 km, se = 3.7, n = 234; temperature: $\bar{x}$ = -0.40 °C, se = 0.10, n = 234).

Spring 1983

Total area surveyed was 579 km^2 (based on a 300 m strip width); 96% of the area was in open water and 4% in the ice. A presentation of tabular data is not given because few mammal species were seen. The most common species seen were Antarctic fur seal (17 groups seen) and crabeater seal (11 groups), followed by minke whale (6 groups) and leopard seal (4 groups).

All sightings of fur seals occurred in open water, and on the basis of size, most individuals were males. Fur seals were primarily solitary (88% of sightings were of solitary animals, n = 17 groups). When seen, 17.6% of the fur seals were hauled out on ice floes; 82.3% were in the water. Fur seals were seen in areas of deeper waters ($\bar{x}$ = 3335 m, se = 266, n = 12) (Z = -2.2, P = 0.03) compared to areas where animals were not seen ($\bar{x}$ = 2643 m, se = 81, n = 122).

Discussion

During winter, the three abundant marine mammal species in our study area were clearly associated with ice. Antarctic fur seals were seen mainly along the pack ice edge. Fur seal associations with ice cover of 1 and 5 oktas probably reflected the dynamic aspects of the zone as the ice edge alternately advanced and retreated due to freezing (5 oktas) or thawing (1 okta) events. In either case, fur seals occurred mainly in brash and pancake ice where floes were distributed unevenly, conditions characteristic of the marginal ice zone. During autumn, fur seals were seen close to the ice edge, mainly in open water. This may have been due to the fact that in 1986 the marginal ice zone was extremely narrow, and ice floes were closely spaced only a few kilometres into the pack (Sullivan & Ainley 1987).

There is little previous information available on the pelagic distribution of Antarctic fur seals. During winter 1987, Fraser *et al.* (1989) found large groups of fur seals in marginal ice on the western side of the Antarctic peninsula and Ensor & Shaughnessy (1990) observed small groups of fur seals over a small rise in the shelf on the Kerguelen Plateau. Until now Antarctic fur seals have not been considered among the "ice seals" of the Antarctic (e.g. Siniff 1981), but clearly pack ice is important to the species. We hypothesize that fur seals are attracted to the marginal ice zone by the enhanced productivity of the food web community that occurs there (e.g. Smith & Nelson 1985), and that hauling out on ice floes in the marginal ice zone reduces the threat of predation. On two occasions we observed fur seals quickly hauling onto ice floes as killer whales (*Orcinus orca* Linnaeus) moved along the ice edge. Ice floes, particularly the larger ones, afford seals protection from predation (cf. Smith *et al.* 1981). The fact that most of the fur seals seen in the present study were males is consistent with the observation of Vergani & Coria (1989) who reported that males predominantly haul out at the nearby South Orkney Islands, which are within our study area (Fig. 1).

In all seasons of our study, minke whales were associated with new ice and pancake ice, which are characteristic of the marginal ice zone. During winter we had little chance to survey the interior pack ice, but in the 100 km wide marginal ice zone, we observed much freezing, thawing, and refreezing of surface waters (Ainley & Sullivan 1989). Thus, new ice was the most frequently encountered ice type. Ichii (1990) concluded that during the summer topographic features of the continental shelf, as well as sea ice, affected the distribution of this species. During the summer, Leatherwood *et al.* (1982) measured sea surface temperature and water depth and commented that the majority of minke whales were seen along the ice edge and not in open water. Naito (1982) found

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that minke whales during summer were most common near the ice, in areas of light ice cover, or in open water within the ice. Taylor (1957), finding a large group of minke whales trapped in sea ice off Graham Land in late autumn, suggested that the whales had been attracted to an unusual concentration of krill in the area. We hypothesize that, as in the case of Antarctic fur seals, the presence of minke whales was increased due to the enhanced productivity along the ice edge (see also Ichii 1990).

Mean group size reported here for minke whales in the pack ice during the winter is larger than any previously reported values. We did not close on the schools to confirm school size (Butterworth & Best 1982) so the means in our study are underestimates. Whether the whales were clumped for ecological rather than social reasons is not known. During summer, Naito (1982) found larger mean pod sizes in light ice conditions (5.3 whales per group) compared to open water (3.9 whales per group). Other studies (Butterworth & Best 1982, Leatherwood *et al.* 1982, Ainley 1985) found mean school size to be about two whales per group, as we found during autumn.

In contrast to the other species, crabeater seals occurred in the interior of the ice pack, a habitat characterized by dense ice cover and regular distribution of floes. Unlike fur seals, crabeater seals breed on the ice (Siniff 1981, Laws 1984), and require larger, more stable and dependable floes than are available in the marginal ice zone.

Few animals were seen during the spring cruise, which occurred during the breeding season, compared to the other cruises. Antarctic fur seals were again seen mainly in open water during the spring, but this time away from the ice edge, perhaps because with the start of the breeding season individuals would be moving toward land. In addition, the pack ice edge was beginning to retreat rapidly by several km d^{-1} (Ainley & Sullivan 1984) and the animals may not have followed the retreat closely. During the other seasons, the ice edge position stayed in the same general area.

When assessing habitat preference, potential biases due to the sampling scheme must be considered in order to assess whether the patterns seen were real or artifacts of the sampling scheme. Potential biases in this study include (1) weather conditions affecting sightability, (2) behavioural changes of the species due to habitat differences, specifically dive times of the pinnipeds in open water, and (3) disparity among the three different years regardless of season. The observers in this study were experienced in observing animals in the marine environment. The second and third authors between them have made over 20 cruises in Antarctic waters, censusing animals according to the methods described. Thus the problems for inexperienced observers in sighting animals, described by Ohsumi & Kasamatsu (1981), was not a problem. Not seeing animals due to rough seas was also not a problem because we restricted our censuses to periods of calm weather when in open water. In the ice, rough seas do not occur.

Behavioural changes of the species due to habitat differences could be important if the changes are such that a majority of animals are not sighted. This would be the case if the pinniped species in our study had diving patterns like northern elephant seals (*Mirounga angustirostris* Gill) (DeLong & Stewart 1989) or southern elephant seals (*Mirounga leonina* Linnaeus) (Hindell *et al.* 1989), where the majority of time in the water is spent in long, deep dives. Antarctic fur seals have shorter dive times, ranging from 2–4 min, depending on depth of dive (Croxall *et al.* 1985, Fraser *et al.* 1989, Kooyman *et al.* 1986). Crabeater seals appear to have average dive times of 5 min (J. Bengtson, personal communication 1990). Therefore, observing these two pinniped species in open water does not appear to be a major problem.

The seasonal differences observed could be yearly differences because the three seasons were sampled in different years. If the pack ice edge influences the structure of communities (Ainley *et al.* 1986, Ainley *et al.* 1988), however, we predict that the patterns seen here will be found in future studies within the Scotia/Weddell Confluence region, regardless of year.

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References

AINLEY, D.G. 1985. Biomass of birds and mammals in the Ross Sea. *In* SIEGFRIED, W.R., CONDY, P.R., & LAWS, R.M., *eds. Antarctic nutrient cycles and food webs. Proceedings of the 4th SCAR Biology Symposium.* Berlin: Springer- Verlag, 498-575.

AINLEY, D.G. & SULLIVAN, C.W. 1984. AMERIEZ 1983: a summary of activities on board the R/V *Melville* and USCGC *Westwind*. *Antarctic Journal of the United States*, **19**(5), 100-103.

AINLEY, D.G. & SULLIVAN, C.W. 1989. A summary of a winter cruise in the Weddell and Scotia Seas on Polar Duke. *Antarctic Journal of the United States*, **24**(5), 144-147.

https://doi.org/10.1017/S0954102091000214 Published online by Cambridge University Press

AINLEY, D.G., FRASER, W.R. & DALY, K. 1988. Effects of pack ice on the composition of micronektonic communities in the Weddell Sea. *In* SAHRHAGE, D., *ed. Antarctic ocean and resources variability*. Berlin: Springer-Verlag, 140-146.

AINLEY, D.G., O'CONNOR, E.F. & BOEKELHEIDE, R.J. 1984. The Marine Ecology of Birds in the Ross Sea, Antarctica. *American Ornithologists' Union Monograph*, No. 32, 97 pp.

AINLEY, D.G., FRASER, W.R., SULLIVAN, C.W., TORRES, J.J., HOPKINS, T.L. & SMITH, W.O. 1986. Antarctic mesopelagic micronekton: evidence from seabirds that pack ice affects community structure. *Science*, **232**, 847-849.

BUTTERWORTH, D.S. & BEST, P.B. 1982. Report of the southern hemisphere minke whale assessment cruise, 1980/81. *Report to the International Whaling Commission*, **32**, 835-873.

CONOVER, W.J. 1980. *Practical nonparametric statistics, 2nd edition*. New York: John Wiley and Sons, 493 pp.

CROXALL, J.P., EVERSON, I., KOOYMAN, G.L., RICKETTS, C. & DAVIS, R.W. 1985. Fur seal behaviour in relation to vertical distribution of krill. *Journal of Animal Ecology*, **54**, 1-8.

DELONG, R.L. & STEWART, B.S. 1989. Diving patterns of northern elephant seal bulls. *Abstracts of the 8th Biennial Conference on the Biology of Marine Mammals*, p. 15.

ENSOR, P.H. 1990. Fur seals over the Kerguelen Plateau and elsewhere in the Southern Ocean. *Polar Biology*, **10**, 481- 483.

FRASER, W.R. & AINLEY, D.G. 1986. Ice edges and seabird occurrence in Antarctica. *Bioscience*, **36**, 258-263.

FRASER, W.R., PITMAN, R.L. & AINLEY, D.G. 1989. Seabird and fur seal responses to vertically migrating winter krill swarms in Antarctica. *Polar Biology*, **10**, 37-41.

GILBERT, J.R. & ERICKSON, A.W. 1977. Distribution and abundance of seals in the pack ice of the Pacific sector of the Southern Ocean. *In* LLANO, G.A., *ed. Adaptations within Antarctic ecosystems. Proceedings of the 3rd SCAR Symposium on Antarctic Biology*. Washington DC.: Smithsonian Institution, 703-740.

HABERMAN, S.J. 1978. *Analysis of qualitative data, volume 1*. New York: Academic Press, 368 pp.

HINDELL, M.A., SLIP, D.J. & BURTON, J.R. 1989. Diving behaviour and foraging ranges of southern elephant seals (*Mirounga leonina*) from Macquarie Island. *Abstracts of the 8th Biennial Conference on the Biology of Marine Mammals*, p. 29.

ICHII, T. 1990. Distribution of Antarctic krill concentrations exploited by Japanese krill trawlers and minke whales. *Proceedings of the NIPR Symposium on Polar Biology*, **3**, 36-56.

KOOYMAN, G.L., DAVIS, R.W. & CROXALL, J.P. 1986. Diving behaviour of Antarctic fur seals. *In* GENTRY, R.L. & KOOYMAN, G.L., *eds. Fur seals maternal strategies on land and at sea*. Princeton: Princeton University Press, 117-125.

LAWS, R.M. 1984. Seals. *In* LAWS, R.M., *ed. Antarctic Ecology*, Vol. 2. New York: Academic Press, 621-715.

LEATHERWOOD, S., TODD, F.S. & THOMAS, J.A. 1982. Incidental records of cetaceans in southern seas January and February 1981. *Report to the International Whaling Commission*, **32**, 515-520.

NAITO, Y. 1982. Sighting records of minke whales in the pack ice and adjacent waters off the coast of Enderby Land. *Report to the International Whaling Commission*, **32**, 929- 993.

NORUSIS, M.J. 1988. *SPSS/PC+ V2.0 Base Manual*. Chicago: SPSS Inc., 606 pp.

OHSUMI, S. & KASAMATSU, F. 1981. Whale sighting efficiency of crew onboard of ocean research vessels in BIOMASS/FIBEX. International Whaling Commission Special Meeting on Southern Hemisphere minke whales, June 1981, *Paper* **SC/Jn81/MiS26.**

SMITH, T.G., SINIFF, D.B., REICHLE, R. & STONE, S. 1981. Coordinated behaviour of killer whales, *Orcinus orca*, hunting a crabeater seal, *Lobodon carcinophagus*. *Canadian Journal of Zoology*, **59**, 1185-1189.

SMITH, W.O. & NELSON, D.M. 1985. Phytoplankton bloom produced by a receding ice edge in the Ross Sea: spatial coherence with the density field. *Science*, **227**, 163-166.

SINIFF, D.B. 1981. Seal population dynamics and ecology. *Journal of the Royal Society of New Zealand*, **11**, 317-327.

SULLIVAN, C.W. & AINLEY, D.G. 1987. AMERIEZ 1986: A summary of activities on board the R/V *Melville* and USCGC *Glacier*. *Antarctic Journal of the United States*, **22**(5), 167-169.

TAYLOR, R.J.F. 1957. An unusual record of three species of whale being restricted to pools in Antarctic sea ice. *Proceedings of the Zoological Society of London*, **129**, 325- 331.

VERGANI, D.F. & CORIA, N.R. 1989. Increase in numbers of male fur seals *Arctocephalus gazella* during the summer autumn period at Mossman Peninsula (Laurie Island). *Polar Biology* **9**, 487-488.

https://doi.org/10.1017/S0954102091000214 Published online by Cambridge University Press