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Occurrence, Habitat Use, and Behavior of Seabirds, Marine Mammals, and Arctic Cod at the Pond Inlet Ice Edge

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ABSTRACT. In 1979, 17 species of birds were seen during studies near the Pond Inlet ice edge. Northern fulmars (*Fulmarus glacialis*), black-legged kittiwakes (*Rissa tridactyla*), thick-billed murres (*Uria lomvia*), and black guillemots (*Cepphus grylle*) all avoided the ice edge when bordered with heavy pack ice and all but kittiwake used the ice edge primarily for feeding. Guillemots and fulmars occurred in highest numbers in water along rough and moderately rough landfast ice; murres and kittiwakes showed no preference for such areas or for the other habitat surveyed (smooth landfast ice).

Narwhals (*Monodon monoceros*), white whales (*Delphinapterus leucas*), and ringed seals (*Phoca hispida*) were the only marine mammals common at the ice edge. Whales repeatedly dived under the edge — probably feeding, searching for open water west of the ice edge, or both. Densities of seals near the ice edge were higher than elsewhere on landfast ice.

Divers observed arctic cod (*Boreogadus saida*) close to the undersurface of landfast ice. Fish offshore were generally smaller, younger, and smaller-at-age than those inshore. Offshore, arctic cod were more numerous in areas with a rough under-ice surface than under smooth ice. Cod concentrated in crevices within rough under-ice surfaces. Inshore, cod were captured from ice cracks over shallow water.

I conclude that vertebrates occur at ice edges for one or more of several reasons. Ringed seals and arctic cod live in close association with landfast ice; they probably occur near ice edges simply because landfast ice is present there. Ice edges seem to be primarily barriers against the further movements of whales toward summering locations. Finally, for murres and some other birds, ice edges seem to be favored feeding locations (relative to open sea conditions) due to greater access to preferred foods.

Key words: arctic seabirds, ringed seal, narwhal, arctic cod, ice edges, Pond Inlet, habitat use, behavior, arctic waters, Lancaster Sound, Baffin Bay

RÉSUMÉ. En 1979, dix-sept (17) espèces d'oiseaux ont été aperçues durant des études à proximité du bord de la glace à Pond Inlet. Les fulmars boréaux (*Fulmarus glacialis*), les mouettes tridactyles (*Rissa tridactyla*), les marmettes de Brünnich (*Uria lomvia*) et les guillemots noirs (*Cepphus grylle*) évitaient tous le bord de la glace quand celui-ci était bordé par le pack épais et tous, sauf la mouette, utilisaient le bord de la glace pour se nourrir. Les guillemots et les fulmars apparaissaient en plus grand nombre dans l'eau longeant la banquise continue qui présentait une surface rugueuse ou modérée. Les marmettes et les mouettes n'ont démontré aucune préférence pour de telles zones ou pour d'autres habitats identifiés lors de la reconnaissance (banquise continue à surface unie).

Les narvals (*Monodon monoceros*), les bélugas (*Delphinapterus leucas*) et les phoques annelés (*Phoca hispida*) étaient les seuls mammifères marins à être fréquemment en bordure de la glace. Les baleines nageaient continuellement sous la bordure de la glace, soit pour se nourrir, soit pour chercher l'eau libre à l'ouest de la bordure de la glace ou pour les deux raisons. La densité des phoques à proximité du bord de la glace était plus élevée que n'importe où sur la banquise continue.

Les plongeurs ont observé la morue arctique (*Boreogadus saida*) directement sous la surface interne de la glace continue. Les poissons au large étaient généralement plus petits, plus jeunes, et plus petits au même âge que ceux à proximité du rivage. Au large, la morue arctique était plus nombreuse aux endroits où la glace présentait une surface interne irrégulière (de préférence à une surface interne régulière). La morue était concentrée dans les crevasses contenues sous les glaces présentant une surface interne irrégulière. A proximité du rivage, la morue était capturée dans les crevasses de la glace, en eaux peu profondes.

Les vertébrés sont présents en bordure de la glace pour une ou plusieurs raisons. Les phoques annelés et la morue arctique vivent en association directe avec la banquise continue, ils sont probablement présents à proximité du bord de la glace simplement parce que la banquise continue s'y trouve. Les bords de la glace semblent être des barrières surtout contre les mouvements subséquents des baleines vers les zones de migrations estivales. Finalement, pour les marmettes et certains autres oiseaux, les bords de la glace semblent être des zones favorites pour se nourrir (en relation avec l'eau libre) à cause de la facilité d'accès aux nourritures préferées.

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INTRODUCTION

Most marine areas in the Canadian High Arctic are covered either with solid (landfast) ice or consolidated pack ice during the winter months (Anonymous, 1970). Polar bears (*Ursus maritimus*) and ringed seals (*Phoca hispida*) are the only marine mammals that regularly overwinter in areas covered by landfast ice; several other species overwinter in areas where at least some open water is available in polynyas or at faults between landfast ice and extensive fields of heavy pack ice (Finley and Renaud, 1980; Stirling *et al.*, 1981). No seabirds overwinter in areas with solid ice cover; indeed, the black guillemot (*Cepphus grylle*) seems to be the only seabird capable of regularly overwintering in the High Arctic (Renaud and Bradstreet, 1980; Brown and Nettleship, 1981) and this alcid is largely restricted to dependable open water areas near faults and in some polynyas. These same high arctic areas are, however, used in summer by millions of breeding seabirds and tens of thousands of marine mammals (e.g., Brown *et al.*, 1975; Davis *et al.*, 1980). Thus the pattern and timing of ice breakup might affect the distributions of marine birds and mammals.

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In the eastern High Arctic, the pattern of ice breakup is similar from year-to-year although timing varies considerably (Lindsay, 1975; Marko, 1978). Generally, the channels of the archipelago become progressively more clear of ice from east to west as large rafts of ice deteriorate and break off from more solid landfast ice. This pattern of breakup results in the occurrence of interfaces, called ice edges, between the remaining landfast ice and water that is either open or only partially covered by pack ice. Concentrations of most seabird species that summer in the arctic (Bradstreet, 1979; McLaren, 1982) and some marine mammals (Finley *et al.*, 1980) occur along these ice edges.

The undersurface of the landfast ice supports a diverse assemblage of marine plants (Horner, 1977) and invertebrates (e.g., Barnard, 1959; George and Paul, 1970; Golikov and Averincev, 1977). The arctic cod (*Boreogadus saida*), a major food item for many marine birds and mammals, is also thought to be a component of this under-ice community (Andriashev, 1954; McAllister, 1975; Craig *et al.*, 1982). Bradstreet (1980) showed that in the Barrow Strait area, ice-associated fauna were of major importance in the diets of two alcids; this suggests that improved feeding situations may be one of the reasons why marine birds and mammals concentrate at ice edges.

This study was designed to document the occurrence, distribution, and habitat use of birds, mammals, and fish along the Pond Inlet ice edge in 1978 and 1979.

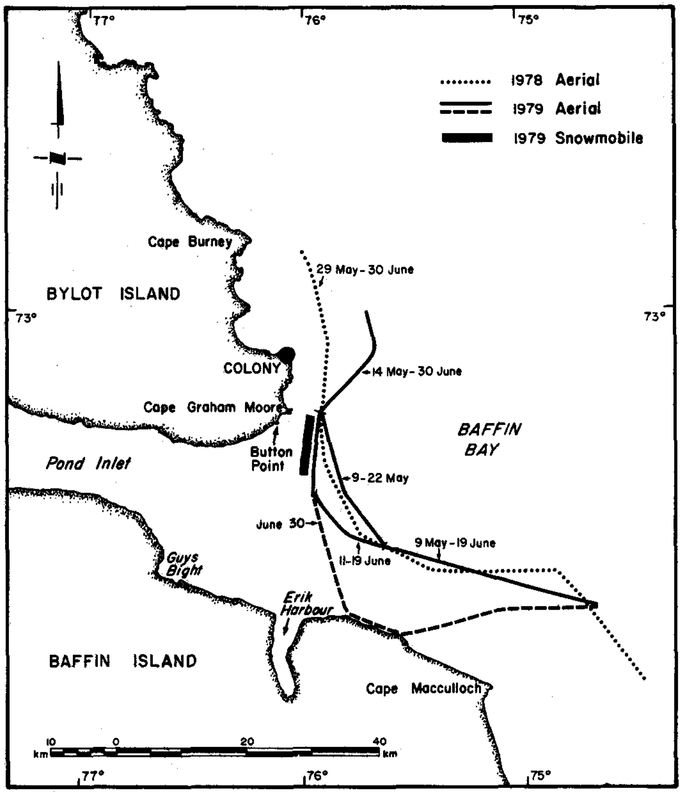

FIG. 1. Survey routes along the Pond Inlet ice edge in 1978 and 1979. Large solid circle north of Cape Graham Moore indicates colony where about 6000 kittiwakes and ~40 000 murres breed (Brown *et al.*, 1975).

METHODS

Marine birds and mammals were investigated by aerial surveys and ice-based studies. Aerial surveys of the Pond Inlet ice edge (Fig. 1) were undertaken in 1978 and 1979; techniques are described in McLaren (1982). Survey results presented herein are from the late May to late June period.

In 1979, a route for counting birds and marine mammals from snowmobiles was established along a portion of the ice edge near Bylot Island (Fig. 1). This route was surveyed daily from 15 June to 3 July. The initial route was 8.2 km long, but due to deteriorating ice conditions some parts of the route could not be covered after 19 June. Daily coverage was 3.4-8.2 km (total 123.8 km). All snowmobile surveys were conducted between 0900 and 1300 h E.D.T. by one or two observers.

The snowmobile route was divided into segments of 200 m. For each segment, observers recorded habitat and the numbers and behaviors of all birds and mammals seen on the ice or in the water. Flying birds were not considered. Habitat variables included the type of landfast ice (surface smooth, moderate, or rough) and the percentage cover by pack ice on the sea within an estimated 100 m of the ice edge (Fig. 2). Birds and mammals seen less and more than 100 m seaward from the ice edge were recorded separately. Only animals within the estimated 100 m are considered below because low angles hindered observations beyond this distance (also, along ice edges most birds occur near the ice/water interface (Bradstreet, 1979)).

Flight movement by birds in 1979 was documented separately during 79 five-minute watches conducted at spaced intervals during snowmobile surveys. During watches the observer was located at the ice edge (facing east). Birds flying left (generally north) or right (generally south) within about 100 m of the ice edge were counted and identified. Forty-five additional watches were conducted on 15 (n = 24), 18(12), 24(4), and 26(5) June between 1550 and 1827 h. Feeding and other behavior by birds and mammals was recorded whenever encountered.

Fish associated with the undersurface of offshore landfast ice in 1979 were observed by SCUBA-equipped divers during studies of ice biota (Cross, 1982) and collected by divers and fish traps under the ice. The traps had 1-m^3 collection boxes and four 9 x 1 m wings of 2-cm mesh netting (stretched). The upper portions of the wings and box were buoyed and the lower portions were weighted. The traps were set through holes in offshore landfast ice and positioned against the ice undersurface. Up to four traps were operated from 16 June to 2 July (total 50 trap-days). All fish caught were cod (Gadidae). From 20 to 30 June 1979, 107 cod were also speared from ice cracks over shallow inshore water. An additional 36 cod were speared near shore in 1978. All cod were weighed and measured

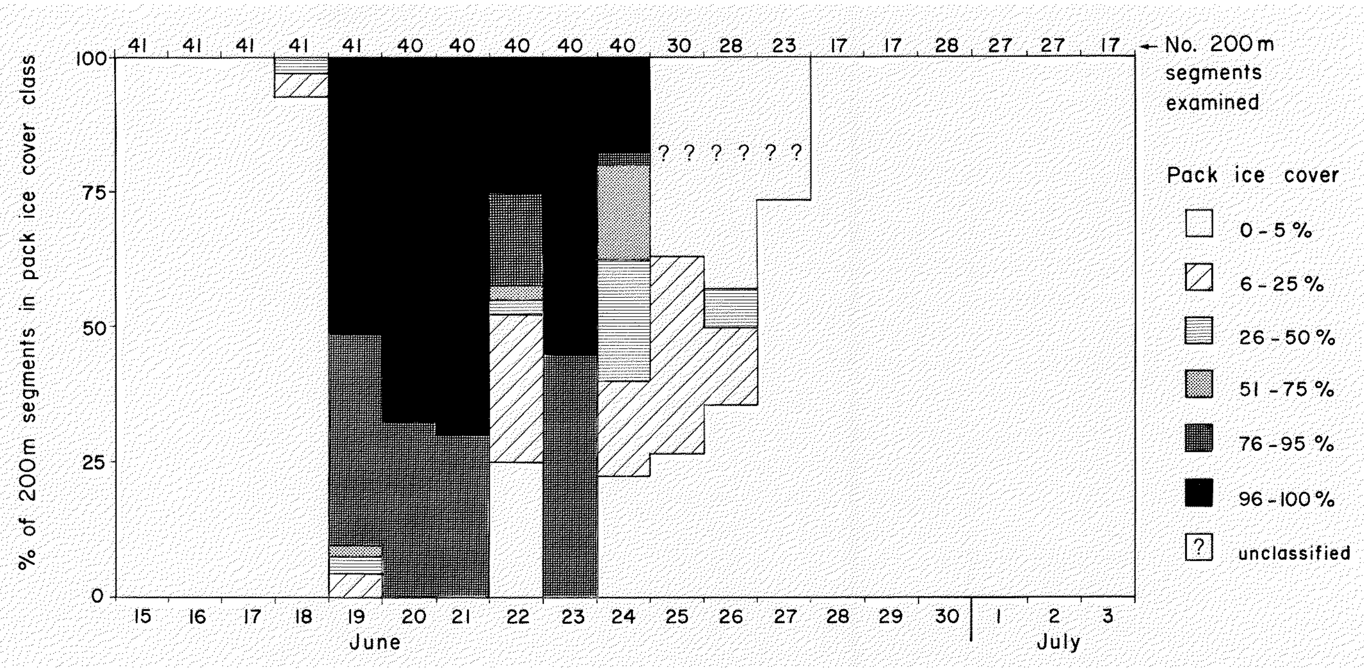

FIG. 2. Phenology of pack ice conditions seaward of the snowmobile survey route at Pond Inlet, 15 June - 3 July 1979. The top row of figures gives the number of 200 m segments examined on each date.

(fork length) in the field and frozen. In the laboratory, the otoliths were removed, measured, and their ages determined. A subsample of cod (four of age one year — fork length range 52-70 mm; 15 of age two years — range 85-108 mm; 7 of age three years — range 98-121 mm) were all identified as *Boreogadus saida* based on gill raker counts of 35 to 45. I assume that all fish collected during this study were *B. saida*.

RESULTS

Occurrence of Birds at the Ice Edge

Snowmobile and aerial surveys of the Pond Inlet ice edge in 1979 (Table 1) showed that murres, fulmars, and kittiwakes, in that order, were the most abundant species. Aerial surveys in 1978 had given similar results, although fulmars were less abundant than kittiwakes that year. These three species and black guillemot are treated in detail below. In 1979, 13 other bird species were recorded during snowmobile surveys along the Pond Inlet ice edge. Of these, only glaucous. Thayer's, and ivory gulls were seen during more than half of the daily snowmobile surveys.

Fulmars. In 1978 and especially 1979, fulmars were common at the Pond Inlet ice edge (Table 1, Fig. 3). In 1979 fulmars occurred along all three ice edge habitats surveyed by snowmobile but concentrated in areas where landfast ice was moderately rough (Table 2). Few fulmars occurred along the ice edge when pack ice cover was heavy (>50%, Table 3). Numbers of fulmars both on the water (Fig. 3) and flying along the ice edge (Table 4) were very variable and positively correlated ($P<0.02$).

Fulmars used two main feeding techniques. While swimming, fulmars pecked at the surface of the sea and took small zooplankters (Bradstreet and Cross, 1982). Fulmars also scavenged the carcasses of marine mammals taken by Inuit. Large numbers of fulmars quickly congregated around any floating carcass but fulmars never left the sea to scavenge carcasses on the landfast ice, no matter how close these carcasses were to the edge.

Kittiwakes. Most kittiwakes seen at Pond Inlet in 1979 were in flight. They were seen on the water during only seven of 19 daily snowmobile surveys (Table 1) but were seen in flight during watches on 17 of those 19 days (Table 4).

The feeding birds that were seen usually occurred in dispersed swimming flocks; these birds frequently pecked at the surface. Occasionally, single birds flying along the ice edge would plunge-dive into the sea and on one occasion a bird surfaced with a fish. Kittiwake flocks in flight were very rarely seen to stop and feed.

Murres. At Pond Inlet, spatial variability in numbers of murres along various portions of the ice edge was similar in 1978 and 1979 (Table 5, $P>0.1$). In 1979, large day-to-day variations in murre abundance were observed along the short route surveyed by snowmobile (Fig. 3). This variance appeared to be at least partly related to pack ice conditions. Virtually all murres used ice edge segments with <50% pack ice cover (Table 3). At Pond Inlet in 1979, densities of murres along smooth, moderate, and rough landfast ice were similar (Table 2).

Numbers of murres flying along the ice edge also varied from day to day (Table 4), and within day (Table 6). These flights could, perhaps, have little to do with use of the ice

TABLE 1. Numbers (per km) of birds and marine mammals seen along the offshore ice edge in Pond Inlet[a]

Area	Pond Inlet				
Survey Vehicle	Snowmobile			Twin Otter	
Species / Year	1979			1979	1978
	no./km	% on water	no. days seen	no./km	no./km
Northern fulmar *Fulmarus glacialis*	10.64	98	14	6.13	2.24
Brant *Branta bernicla*	0.01	100	1	0.01	0.07
Oldsquaw *Clangula hyemalis*	0.50	54	8	0.15	0.26
Common eider *Somateria mollissima*	0.16	19	3	0.06	0.11
King eider *S. spectabilis*	0.09	89	2	0.17	0.90
Purple sandpiper *Calidris maritima*	0.02	0	1	—	—
Red phalarope *Phalaropus fulicarius*	0.01	100	1	—	—
Pomarine jaeger *Stercorarius pomarinus*	0.01	0	1	<0.01	<0.01
Long-tailed jaeger *S. longicaudus*	0.04	0	2	<0.01	0.01
Glaucous gull *Larus hyperboreus*	1.72	21	12	0.60	1.50
Thayer's gull *L. thayerii*	0.44	0	11	0.10	0.03
Ivory gull *Pagophila eburnea*	1.00	4	10	0.15	0.05
Black-legged kittiwake *Rissa tridactyla*	2.17	76	7	2.96	8.53
Arctic tern *Sterna paradisaea*	0.08	0	1	0.02	—
Thick-billed murre *Uria lomvia*	28.54	98	16	95.86[b]	25.94
Dovekie *Alle alle*	—	—	—	—	0.05
Black guillemot *Cepphus grylle*	0.86	100	10	0.52	0.29
Common raven *Corvus corvax*	0.07	0	3	0.23	0.01
Polar bear *Ursus maritimus*	—	—	—	0.05	—
Harp seal *Phoca groenlandica*	—	—	—	0.09	0.02
Ringed seal *P. hispida*	0.35	97	12	0.03	0.01
Bearded seal *Erignathus barbatus*	0.02	100	2	—	—
Walrus *Odobenus rosmarus*	0.02	100	2	—	<0.01
White whale *Delphinapterus leucas*	0.17	100	3	0.19	0.36
Narwhal *Monodon monoceros*	0.98	100	7	0.15	0.14
Total survey length		124 km		282 km[b]	509 km
No. of surveys		19		4	5

[a]During snowmobile surveys, animals within 100 m seaward of the ice edge were considered; during aerial surveys, animals within 400 m were considered. Flying birds were considered during aerial but not snowmobile surveys. Aerial data from Pond Inlet *fide* P.L. McLaren (pers. comm.).
[b]Large numbers of murres were seen along the ice edge directly in front of the colony north of Cape Graham Moore during two surveys. When data from these transect segments are ignored, average murre densities were much lower (36.74 birds/km on 270 km of transects).

edge *per se* because the edge might have a 'leading-line' effect on murres flying toward the colony from offshore waters east and southeast of Pond Inlet. But this explanation seems unlikely. In 1979, observers at various ice edge locations frequently observed distant flocks of murres apparently returning directly to the colony from offshore areas. There was no discernible tendency for these murres to fly to the ice edge before turning toward the colony.

Murres occurred in the water along the ice edge in flocks of 1-100, but most flocks were small. Of 594 groups in the water, 76% consisted of five or fewer birds. Murres perched on landfast or pack ice occurred singly on three occasions and in groups of three, four and 30 at three other times. Murres appeared to use the ice edge primarily as feeding habitat. Murres in flocks tended to dive under the ice edge in quick succession rather than all at once. Durations of dives under rough and smooth landfast ice were not consistently different (Table 7). However, mean dive durations in 1979 were significantly less than in 1978. Mean ice thickness within 100 m of the ice edge was also less in 1979 (76 cm — Cross, 1982) than in 1978 (150-175 cm — K.J. Finley, pers. comm.).

Flight speeds of murres along the Pond Inlet ice edge were measured on 4 July 1978. Under absolutely calm conditions, the murres were flying closely along a straight section of the ice edge. Two observers timed the flight of single murres (n = 10) and flocks (n = 10) along a measured distance of 100 m. Mean speeds for individuals (58.2 ± 2.2 $km \cdot h^{-1}$) and flocks (57.8 ± 3.2) were not significantly different (Mann-Whitney $P > 0.1$) and 58 $km \cdot h^{-1}$ is thus a reasonable estimate of the flight speed of murres under calm conditions.

Guillemots. At Pond Inlet, guillemots tended to concentrate in areas adjacent to rough landfast ice (Table 2) and,

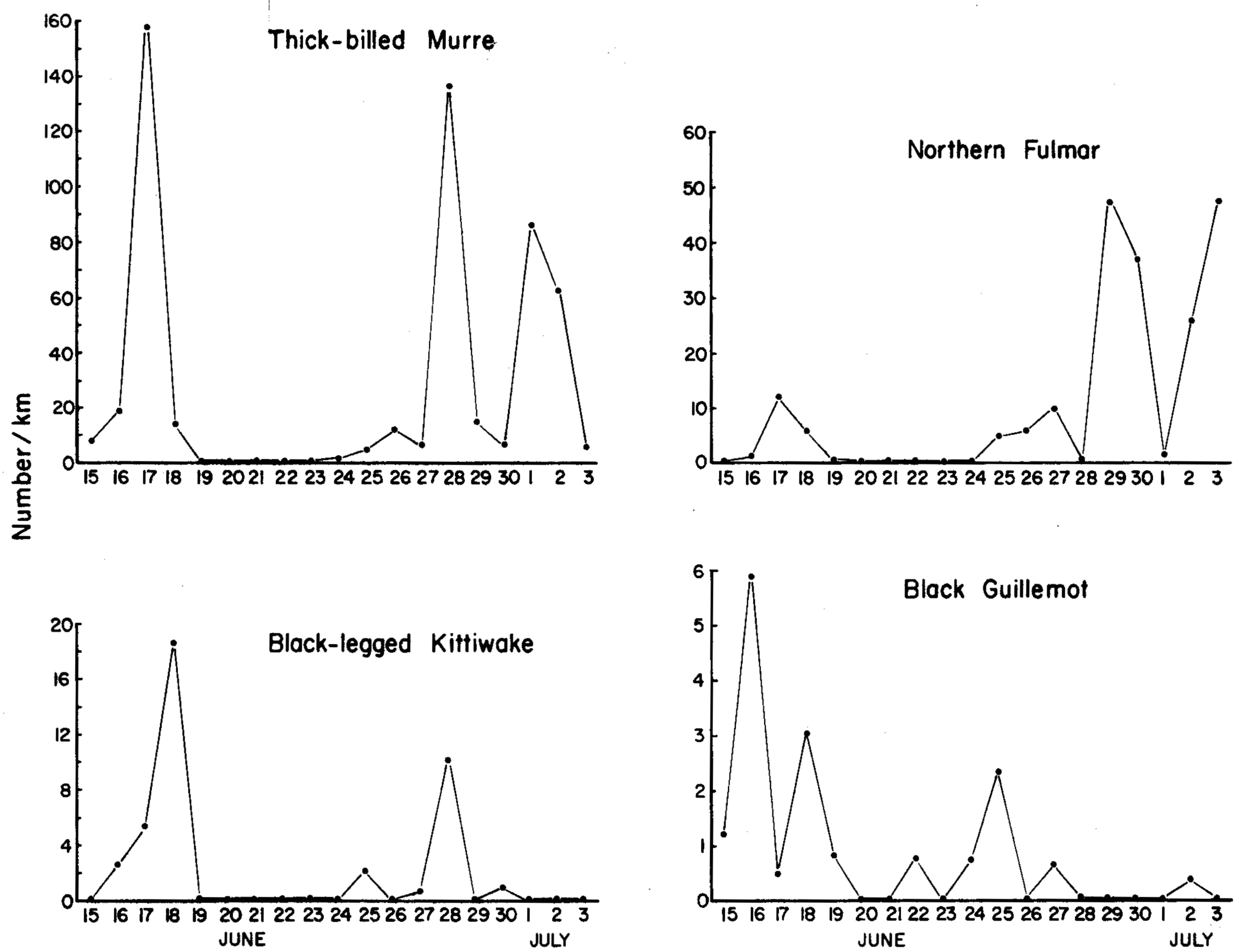

FIG. 3. Numbers (per km) of four seabirds seen during daily snowmobile surveys of the Pond Inlet ice edge. Vertical axes vary in scale.

TABLE 2. Numbers of birds/km on the water in relation to ice edge habitat during nineteen snowmobile surveys of the Pond Inlet ice edge, 15 June - 3 July 1979

	Ice Edge Habitat[a]				
Species	Smooth	Moderate	Rough	Chi square[b]	P
Northern fulmar	10.3	12.1	3.3	9.82	<0.01
Black-legged kittiwake	0.9	4.6	2.2	1.77	>0.1
Thick-billed murre	43.6	32.7	32.6	0.48	>0.1
Black guillemot	0.5	1.7	3.4	35.12	<0.001
No. segments	206	127	35		
% of segments	56	35	10		

[a]Data obtained along 368 200-m segments of ice edge with ≤50% pack ice cover and summed over duration of study. Data from an additional 31 segments in which habitat type was not recorded or not clearly identifiable, are not considered.

[b]Chi square values are determined from the distributions of groups of birds relative to the distributions of the various habitat types. Moderate and rough habitat categories pooled in calculating the chi square value for kittiwakes.

TABLE 3. Numbers of birds/km on the water in relation to pack ice cover during nineteen snowmobile surveys of the Pond Inlet ice edge, 15 June - 3 July 1979

	Pack ice cover[a]				
Species	≤50%	>50%	Un-classified	Chi square[b]	P
Northern fulmar	11.1	0.0	9.8	121	<<0.001
Black-legged kittiwake	2.3	0.0	2.4	—	—
Thick-billed murre	39.1	<0.1	3.1	298	<<0.001
Black guillemot	1.4	0.3	0.3	17	<0.001
No. segments	399	191	29		
% of segments	64	31	4		

[a]Data obtained along 619 200-m segments of ice edge and summed over duration of study.

[b]Chi square values are determined from the distributions of groups of birds relative to the distributions of the various categories of pack ice cover.

TABLE 4. Numbers of birds (per 5-min) flying north or south past a point location along the Pond Inlet ice edge[a]

Date	Northern fulmar	Black-legged kittiwake	Thick-billed murre	Black guillemot	n^b
1978					
16 June	0.6[c]	1.6	5.8	0.7	30
17 June	5.2	4.6	11.2	0	30
18 June	5.0	2.3	8.9	0.2	90
19 June	7.6	3.0	49.2	0.1	30
21 June	0.3	0	2.2	0.2	30
30 June	1.9	0.2	2.0	0.9	30
4 July	1.1	0	47.1	0.1	30
5 July	2.1	0.7	8.2	0.8	30
1979					
15 June	3.8 ± 4.1[d]	0 ± 0	4.6 ± 9.7	0 ± 0	5
16 June	8.0 ± 6.3	6.4 ± 7.3	6.6 ± 7.2	1.4 ± 1.7	5
17 June	10.2 ± 2.5	4.6 ± 5.4	41.8 ± 36.3	1.2 ± 1.3	5
18 June	11.0 ± 6.4	11.0 ± 9.4	40.4 ± 43.0	0.8 ± 1.8	5
19 June	5.8 ± 6.2	28.0 ± 17.8	0.2 ± 0.5	0.2 ± 0.5	5
20 June	0 ± 0	2.3 ± 4.0	26.7 ± 38.7	0 ± 0	3
21 June	0 ± 0	0.8 ± 1.8	0 ± 0	0 ± 0	5
22 June	48.0 ± 26.1	13.8 ± 14.5	2.6 ± 5.8	0.6 ± 1.3	5
23 June	1.0 ± 2.2	0.6 ± 1.3	0 ± 0	0 ± 0	5
24 June	0.2 ± 0.5	0.4 ± 0.9	4.8 ± 6.7	0.2 ± 0.5	5
25 June	5.8 ± 2.7	4.0 ± 3.7	29.6 ± 25.9	2.2 ± 1.9	5
26 June	29.0 ± 14.5	6.5 ± 3.8	136.0 ± 13.6	1.5 ± 1.7	4
27 June	52.3 ± 15.6	4.0 ± 4.4	89.0 ± 57.7	3.3. ± 4.9	3
28 June	81.5 ± 43.1	0 ± 0	94.5 ± 10.6	3.0 ± 4.2	2
29 June	133.5 ± 103.9	0.5 ± 0.7	78.5 ± 5.0	1.5 ± 2.1	2
30 June	12.3 ± 13.7	6.0 ± 3.9	178.0 ± 61.4	1.3 ± 1.0	4
1 July	2.0 ± 0.8	1.3 ± 1.5	16.5 ± 11.5	2.3 ± 2.1	4
2 July	3.5 ± 5.7	3.0 ± 2.9	64.5 ± 25.1	0 ± 0	4
3 July	26.7 ± 1.2	4.0 ± 6.1	178.7 ± 50.2	1.3 ± 2.3	3
r_s^e	0.55	0.14	0.49	-0.08	
P	<0.02	>0.10	<0.05	>0.10	

[a]Only birds within 100 m seaward of the ice edge are included.

[b]n in 1978 is number of minutes watched. n in 1979 is no. of 5-min watches.

[c]Values are no./5-min.

[d]Values are mean no./5-min ± SD.

[e]Spearman correlation values are between mean no. per 5-min watch and no./km observed during corresponding survey by snowmobile in 1979 (Fig. 3).

like fulmars and murres, avoided areas with heavy pack ice cover (Table 3). There was no significant correlation between the numbers of guillemots seen during flight counts (Table 4) and concurrent snowmobile surveys (Fig. 3).

Black guillemots observed on the water were in groups of 1-10, with singles predominating (66% of 68 groups). In contrast to results for murres, mean dive times of guillemots were significantly greater in 1979 (83 ± 12 s, $n = 4$) than in 1978 (41 ± 32 s, $n = 5$; $t = 2.52$; $P < 0.05$). When data from 1978 and 1979 were combined, durations of dives under smooth ice were similar for murres ($\overline{X} = 87$ s) and guillemots ($\overline{X} = 67$ s; $t = 1.49$; $P > 0.1$). Flight speeds of two guillemots under calm conditions (51 and 53 km·h^{-1}) were somewhat less than the mean for murres (58 km·h^{-1}).

Occurrence of Marine Mammals at the Ice Edge

All marine mammals sighted during daily snowmobile surveys (Table 1) were in the water with the exception of a single ringed seal hauled out on an ice pan. Narwhals and ringed seals were the only species observed in areas of heavy pack ice cover and then only rarely. Narwhals, white whales, and ringed seals — the only species seen in any numbers — were all sighted along smooth, moderate, and rough landfast ice.

Narwhal. The narwhal was the most common marine mammal seen during snowmobile surveys (Table 1, Fig. 4). The major movement of narwhals to the Pond Inlet ice edge occurred during late July in 1978 (Finley *et al.*, 1980) and from 15-22 July in 1979 (Finley and Miller, 1982). Information on numbers and behavior was recorded for 28 observations involving 1-62 animals (includes all sightings made during the study). Groups, which were defined as discrete, cohesive units occurring alone or within dispersed herds, varied in size from one to seven animals. Adult males, adult females, and juveniles were all present, but only 25% of the 192 animals were identified to sex and

TABLE 5. Murre densities as determined by aerial surveys along the Pond Inlet ice edge

Year	Date	No. of 2-min survey segments	Mean no. murres/segment	Standard deviation	Coefficient of variation (%)
1978	29 May - 2 June	18	51.6	147.8	286
	8 - 10 June	18	7.0	18.2	260
	12 - 15 June	18	28.0	53.0	189
	19 - 21 June	16	94.6	119.3	126
	26 - 30 June	20	459.5	612.8	133
1979	21 -22 May	13	26.4	61.4	233
	10 - 11 June	12	635.5	1400.5	220
	19 June	13	119.8	206.9	173
	30 June	8	865.5	1453.0	168

Mann-Whitney *U* comparison of coefficients of variation
Pond Inlet, 1978 *vs.* 1979: $U = 10$; $P>0.1$.

TABLE 6. Flight movement of murres past a point location along the Pond Inlet ice edge at two times of day

Date	Time of day (h) 0900-1300	1550-1827	Mann-Whitney *P*
15 June	4.6 ± 9.7 (5)[a]	5.9 ± 4.4 (24)	0.1
18 June	40.4 ±43.0 (5)	155.6 ± 59.3 (12)	0.002
24 June	4.8 ± 6.7 (5)	52.5 ±38.9 (4)	0.02
26 June	136.0 ± 13.6 (4)	99.6 ± 51.1 (5)	0.6

[a]Values are mean no. ± SD (no. of 5-min watches).

TABLE 7. Dive times of murres under smooth and rough landfast ice along the Pond Inlet ice edge in 1978 and 1979

Year/ice type	Duration of dive(s) Mean ± SD (range)	*n*	*t*	*P*
1978 smooth	115 ± 47.3 (53-192)	8		
rough	167 ± 0.7 (166-167)	2	—	—
1979 smooth	82 ± 27.5 (20-120)	41		
rough	73 ± 21.4 (30-160)	34	1.74	0.08
1978 all	137 ± 42.0 (53-192)	15		
1979 all	74 ± 28.9 (15-160)	93	5.63	<0.001

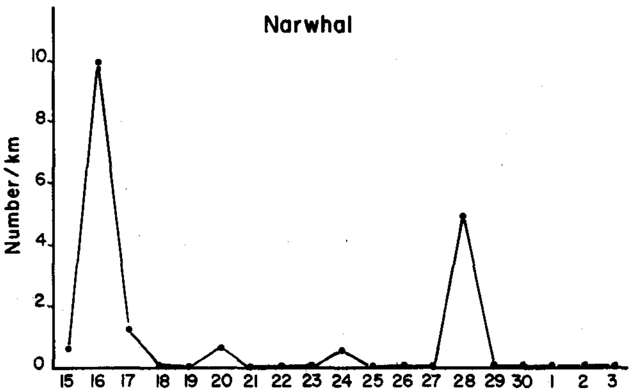

FIG. 4. Number (per km) of narwhals seen on daily snowmobile surveys of the Pond Inlet ice edge.

age. Most narwhals (76%) were within 30 m of the ice edge when observed. Activities at the ice edge included directed movement (37 N, 1 NE, 10 S, 1 SE), back-and-forth movement, loafing, and diving under the ice edge. The significance of the last activity is unclear — it may have involved feeding, searching for open cracks and leads west of the ice edge (Finley *et al.*, 1980), or both. Diving under the edge was noted during eight of 28 observations and involved at least 31 animals. Durations of five dives were noted — an adult male and an unidentified individual for 110 s; an adult female and juvenile for about 120 s; a juvenile for 155 s; two adults and three juveniles for 244 s; and an adult female for 420+ s. On two occasions, juveniles were left waiting at the ice edge while other group members dove.

White Whale. In 1979, behavioral information was recorded during ten observations involving 1-16 white whales. Sizes of discrete groups ranged from one to eight. At least 49 white whales were seen from 18 June to 7 July, including 14 adults, 13 gray juveniles, two brown juveniles, 12 unclassified juveniles, and eight animals of unknown age. Activities at the ice edge included directed movement (10 N, 29 S), back-and-forth movement, and diving under the edge. The function of diving under the edge is unclear. It was noted during two of ten observations and involved at least seven animals. Only one dive was timed; a brown juvenile dived from 10 m out, headed directly toward the ice edge, and resurfaced after 345 s.

Ringed Seal. Ringed seals were seen during 12 of 19 snowmobile surveys (0.35 km^{-1}) but were not commonly seen during aerial surveys of the Pond Inlet ice edge (Table 1), probably because ringed seals in the water are difficult to see from aircraft. During the 22 May-10 July 1978 period, ringed seal densities were significantly higher on landfast ice within 24 km of the ice edge (0.95-1.41 km^{-2}) than in landfast ice areas beyond this distance (0.37-0.38 km^{-2}; $P < 0.01$). At the ice edge, ringed seals in the water were usually alone ($n = 29$) but one group of three was seen.

Occurrence of Arctic Cod

Cod sizes and ages. Cod captured offshore tended to be smaller and younger than those taken inshore. The mean fork length of cod taken offshore in 1979 (Fig. 5) was significantly less than that of cod taken inshore in either 1979 ($t = 5.51$, $df = 160$, $P<0.001$) or 1978 ($t = 3.50$, $df = 89$, $P<0.001$); lengths of cod taken inshore in the two years were not significantly different ($t = 1.71$, $df = 141$, $P>0.05$). Based on otolith readings, cod taken offshore also tended to be younger than those taken inshore in 1979 (Fig. 6; Kolmogorov-Smirnov $P<0.001$). Lengths at specific ages were also less offshore than inshore (Table 8). These comparisons suggest habitat-related differences in cod sizes and ages but the differences may have been due to sampling method artifacts. Although most cod captured under offshore ice were small (Fig. 6), a few large cod (probably 2+ years old) were seen there by divers but were not captured. Offshore, where two sampling methods were used, the ages of fish taken by divers (1.3 yr, $n = 17$) and by fish traps under the ice (1.9 yr, $n = 30$) were also significantly different (Mann-Whitney $z = 14.0$, $P<0.001$). Other information, however, suggests that the observed differences were real (see below).

Habitat of cod. Arctic cod are widely assumed to associate with the ice undersurface (Andriashev, 1954; McAllister, 1975); however, arctic cod can also occur near the bottom (Bohn and McElroy, 1976; Frost *et al.*, 1978) and in open water (Hognestad, 1968; Sangolt, 1979). This study provides new information about the microhabitat of arctic cod under landfast ice in spring.

Small ridges of rafted ice (usually <1 m high) were common on the surface at, and back from, the Pond Inlet ice edge in 1979. Under these small ridges, divers observed inverted ridges of much larger size (usually 5-10 m deep — Cross, 1982). The inverted ice ridges contained crevices and caverns of variable size and cod were most abundant in these spaces. Divers investigated four areas where under-ice pressure ridges were present, two areas where a few blocks of ice apparently had been broken off from the ice edge and forced under the remaining landfast ice, and six areas where the under-ice surface was smooth and regular.

At the four dive sites with pressure ridges (three near the ice edge, one far back from the edge under landfast ice), divers visually inspected the spaces in the upper 1-2 m along various lengths of the ridges. Cod were present at all four ridges; estimates of abundance were 15 fish in 30 m, 20 fish in 30 m, 15 fish in 10m, and five fish in 40m. The last estimate was for a ridge that had noticeably less internal space than the other under-ice ridges inspected. Cod

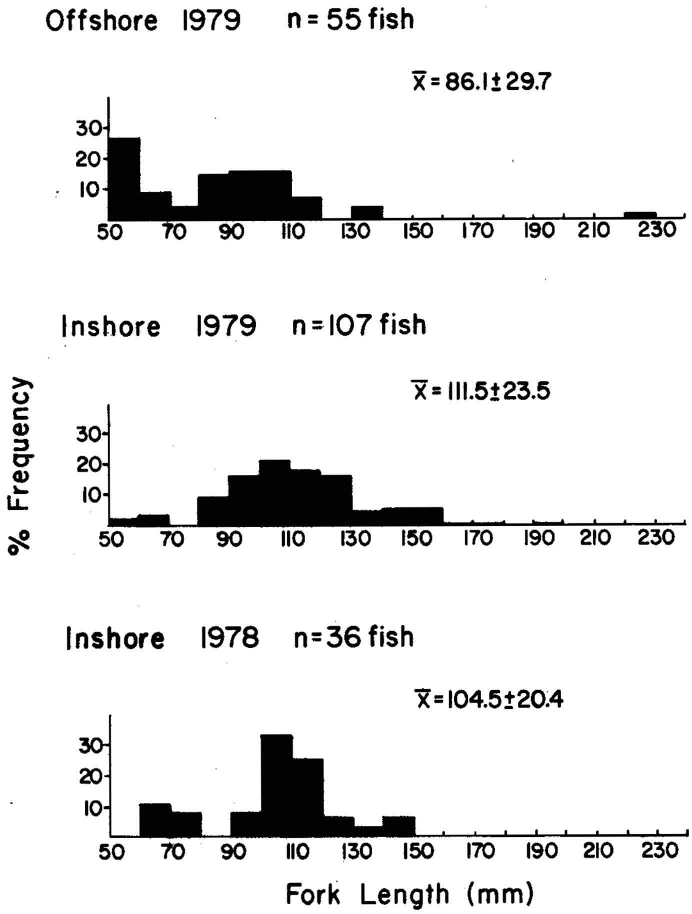

FIG. 5. Fork length-frequency distributions of arctic cod from offshore and inshore collections in Pond Inlet, 1978 and 1979.

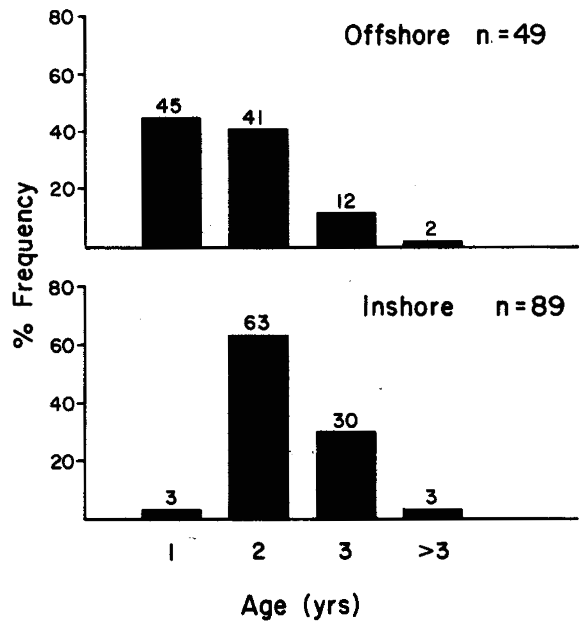

FIG. 6. Age-frequency distributions of arctic cod from offshore and inshore collections in Pond Inlet, 1979.

TABLE 8. Fork lengths of arctic cod of known age collected in 1979

Age (yrs)	Fork length ($\overline{X}$ ± SD (*n*)) in mm Offshore	Inshore	*t*	*P*	% difference
1	58.9 ± 5.1 (22)	61.3 ± 7.4 (3)	0.73	>0.1	3.9
2	94.8 ± 7.8 (20)	103.2 ± 12.5 (56)	3.49	<0.01	8.1
3	109.3 ± 7.1 (6)	131.4 ± 14.3 (27)	3.65	<0.01	16.8

observed near a ridge often escaped into spaces within the ridge when approached by divers. When divers attempted to capture cod from the internal spaces of a ridge, the fish sometimes would dart out of the ridge, swim near the undersurface of the landfast ice, and stop. On one occasion a fish first observed 10-15 m away from a ridge swam away (just under the undersurface of the ice) as if escaping. In addition to the fish captured, divers also saw larger cod (10+ cm long) in and near pressure ridges. At one location, a pressure ridge that was present in May had melted by July. Fish were present in the area during the May dive, but not observed in July.

Two large blocks of ice (tens of metres on a side) had been pushed under the ice edge at one dive site. In some places, spaces about 15-20 cm high occurred between these blocks and the undersurface of the landfast ice. Divers saw eight cod above one block and five cod above the other. The blocks were only partially inspected, so these are minimum estimates. At another location where several much smaller ice blocks had been pushed under the ice edge, no cod were found.

In contrast to the numbers of cod seen in or near the spaces in ridges and above large blocks of ice, divers saw very few cod under smooth landfast ice. Young-of-the-year cod were seen at three of six such locations, but only one older cod was seen. This fish dived when disturbed. Cod were caught in fish traps set under extensive areas of ice that were smooth on the surface and probably smooth on the undersurface (15 fish; 0.4 fish/trap-day), but the numbers there were lower than in traps set adjacent to areas with rough surface ice (20 fish; 1.3 fish/trap-day). Cod were occasionally seen from the surface in holes present in offshore landfast ice with a smooth upper surface. When approached, these cod generally either remained relatively motionless and were captured, or they dived and appeared to escape along the undersurface of the ice.

Inshore, the fish observed in cracks were usually either motionless or moving slowly. Only occasionally were cod in cracks seen to move rapidly and this usually occurred after an unsuccessful spearing attempt. More cod were seen in narrow cracks (less than about 6 cm wide) than in wider ones.

DISCUSSION

Marine Mammals

The importance of ice edges to marine mammals is equivocal. In this study, aerial surveys showed higher densities of ringed seals hauled out on landfast ice near the ice edge than on landfast ice farther inside Pond Inlet. Ice in offshore Baffin Bay was breaking up at this time, however, and the higher numbers of seals on landfast ice near the ice edge may have been due to an influx from offshore areas. A similar influx of ringed seals into an area with stable landfast ice was noted by Finley (1979) at Aston Bay, Somerset Island.

On the other hand, the lower densities of seals occurred in areas near the village of Pond Inlet where hunting may have been more intense (and seal densities subsequently lower) than in areas nearer the ice edge. At the ice edge, older ringed seals ate mostly arctic cod (Bradstreet and Cross, 1982), a prey closely associated with the undersurface of ice but not with the ice edge *per se*. Immature seals ate cod and *Parathemisto*, a pelagic amphipod (Bradstreet and Cross, 1982).

At times, white whales and narwhals congregate at the edges of landfast ice (Finley and Renaud, 1980; Finley *et al.*, 1980; Finley and Miller, 1982; this study). In winter, white whales may choose such areas in the High Arctic and elsewhere (Jonkel, 1969; Sergeant, 1973; Finley and Renaud, 1980) because such locations are where open water (required for breathing) can most dependably be found (Finley and Renaud, 1980). In spring, narwhals and white whales move to ice edges where they exhibit various behaviors, including feeding. At least narwhals feed heavily at this time (K.J. Finley and E. Gibb, pers. comm.), not only on arctic cod but also on deep-water fishes. The recorded dive times of narwhals and the presence of deepwater prey in their stomachs suggest that narwhals are not necessarily feeding on ice-associated prey. Arctic cod occur both under the ice in crevices and caverns that would be difficult for narwhals to exploit (this study) and in deeper water (Bohn and McElroy, 1976; Frost *et al.*, 1978).

Whales may congregate at ice edges in spring primarily because they act as barriers to further movements towards summering areas in the central Arctic. As soon as leads and cracks appear in the landfast ice at Pond Inlet (before breakup and clearance of the ice), narwhals penetrate these openings (Finley *et al.*, 1980; Finley and Miller, 1982). Similarly, Stirling *et al.* (1981) have noted that shoreleads are important spring migration routes for white whales.

Arctic Cod

Arctic cod were probably more abundant in areas where the under-ice surface was rough than in areas where it was smooth; this distributional difference is probably related to the better protection offered to cod in the rough under-ice areas. Cod captured offshore tended to be smaller (Fig. 5) and younger (Fig. 6) than those taken inshore. Further-more, 2- and 3-yr-old (but not 1-yr-old) cod were smaller-at-age in offshore than in inshore collections (Table 8). There may have been sampling-gear biases in this study but sizes of fish estimated from the lengths of cod otoliths found in murre stomachs in two study areas and three years (Bradstreet, 1980; Bradstreet and Cross, 1982) confirmed that arctic cod in offshore areas are smaller (and presumably younger) than those taken inshore (Table 9). Craig *et al.* (1982) working in inshore waters of the Beaufort Sea found that arctic cod taken there were 9-18 mm longer, at each age, than cod taken in offshore deep waters and suggested that warmer coastal waters might provide more favorable growing conditions than offshore areas.

TABLE 9. Mean lengths of arctic cod taken in offshore and inshore collections[a]

			Mean length of cod (mm)	
Year	Location	Technique	Offshore	Inshore
1976	Barrow Strait	murres	81	111
1978	Pond Inlet	murres	74	—
		spears	—	105
1979	Pond Inlet	murres	67	—
		traps and divers	86	—
		spears	—	112

[a]1976 data from Bradstreet (1980). 1978-79 murre data from Bradstreet and Cross (1982). Kruskal-Wallis tests indicated no differences in lengths among offshore collections or among inshore collections ($P > 0.05$). Fish in offshore collections were, however, significantly smaller than cod taken inshore ($P < 0.01$).

The 1-yr-old, ice-associated cod captured during this study were 0-yr, planktonic larvae in the summer of 1978, a year with heavy ice conditions in northern Baffin Bay (McLaren, 1982). Sekerak (1982) noted that larval cod were smaller-at-date and perhaps less numerous in the late summer of 1978 than in 1976, a year with more normal, and earlier, ice breakup. At the end of their first summer of life, these larval cod leave the water column and become associated with a substrate (Sekerak *et al.*, 1979). Many of them apparently associate with the ice undersurface as numbers of 1-yr-old cod were found in this habitat (especially offshore) during this study.

Divers failed to find any relationship between numbers of arctic cod and distance to the ice edge (Cross, 1982 and pers. comm.). Rather, microhabitat differences (smooth *vs.* rough under-ice surfaces) and distance to shore (inshore *vs.* offshore collections) apparently explain much of the variation in numbers, sizes, and ages of cod taken.

Marine Birds

Fulmars, kittiwakes, and guillemots. Fulmars were common at Pond Inlet (Table 1), but uncommon at ice edges in the Barrow Strait area in 1976 (0.28 km^{-1}; Bradstreet, unpubl. data). The Pond Inlet ice edge was probably the nearest area of extensive open water to the large colonies at Scott Inlet and Buchan Gulf, Baffin Island (see Brown *et al.*, 1975) but large areas of open water were near colonies in the Barrow Strait area in 1976. This may, in part, explain the relatively greater numbers at Pond Inlet; however, the attraction of offal from marine mammal carcasses (not generally available in Barrow Strait) may have also been important.

Extensive surveys of offshore and inshore areas in Barrow Strait in 1976 (Bradstreet, 1979) showed that kittiwake densities were much higher along coasts (28.1 km^{-1}) than along offshore ice edges (4.9 km^{-1}; Mann-Whitney $P<0.001$; Bradstreet, unpubl.). This preference for inshore habitats may, in part, explain the generally small numbers of kittiwakes seen along the offshore ice edge in Pond Inlet (Table 1). Few kittiwakes apparently feed along the Pond Inlet ice edge.

Compared to the large numbers of guillemots that breed in the Barrow Strait area (*cf.* Bradstreet, 1979), relatively few breed along coasts near the Pond Inlet ice edge (pers. obs.) and this probably accounts for the small number of guillemots seen along the Pond Inlet ice edge in 1978 and 1979 (Table 1) when compared to numbers seen in Wellington Channel in 1976 (Bradstreet, 1979). When present near breeding locations, ice edges are preferred feeding areas for guillemots (Bradstreet, 1979, 1980).

Murres. At Pond Inlet, spatial variability in numbers of murres along the ice edge was similar in two years (Table 5) but greater than at the ice edge across Wellington Channel in 1976 (11 surveys between 1 June and 3 July; mean daily coefficient of variation = 136%; Mann-Whitney U between 1976 and 1978-79 data = 23; $P<0.02$; Bradstreet, 1979 and unpubl.). Also, at Pond Inlet there was considerable variation in day-to-day numbers of murres on the water (Fig. 3) and in flight (Table 5). Variance in numbers of birds on the water was related to an avoidance of areas with pack ice. Bradstreet (1979) found a similar avoidance of ice edges with bordering pack ice in Wellington Channel in 1975, but not in 1976 (when only small amounts of pack ice were present). A likely explanation for the variable flight activity can be developed from the fact that daily mean numbers of birds in flight and on the water were positively correlated in 1979 (Table 4). This suggests that the concentrations of murres observed during the snowmobile surveys may have been part of a larger-scale aggregation of birds along the ice edge. In such a situation, large numbers of birds in flight might be indicative of commuting between the colony and areas south of that portion of the ice edge surveyed by snowmobile. One example of this occurred on 27-28 June. Late on 27 June, large numbers of murres were flying south along the edge 10 km south of the area surveyed by snowmobile. Thousands of feeding murres were seen along the ice edge 5 km farther south. Few murres had been seen during the daily snowmobile census earlier in the day (Fig. 3), but on the morning of 28 June many murres were present at both locations. By the evening of the 28th, murre numbers had decreased substantially at the southern location, and on the morning of the 29th, murre numbers were again low along the route surveyed by snowmobile. It seems that feeding aggregations of murres along the ice edge formed and disappeared quickly. On two of four days when flying murres were counted both in the morning and afternoon, the numbers were significantly different (Table 6); these data also suggest occasional, rapid changes in bird activity along the ice edge.

If, as suggested, the occurrence of large numbers of murres in flight near the edge indicates the presence of a feeding aggregation somewhere along the ice edge, then the large day-to-day differences in flight activity (Table 4) reflect large temporal variability in the use of the Pond Inlet ice edge. Cases in which we saw many murres in flight but few along the area surveyed by snowmobile are probably attributable to the high spatial variability in densities of murres along the ice edge (Table 5). In summary, there was much temporal and spatial variability in use of the Pond Inlet ice edge by murres in spring. Murres were significantly more variable in their use of this ice edge than in their use of the Wellington Channel ice edge in 1976.

Murres are apparently attracted to ice edges at certain times and locations. Murres concentrated along offshore ice edges in Barrow Strait (three years — Bradstreet, 1979); and in Lancaster Sound, Jones Sound, and Pond Inlet (two years — McLaren, 1982; this study). In 1976, murres collected along offshore ice edges in Barrow Strait had eaten mainly ice-associated food taxa — arctic cod and amphipods — but had also eaten *Parathemisto,* which is pelagic (Bradstreet, 1980). In 1979 at Pond Inlet, two of these taxa (not *Parathemisto*) occurred in high densities under rough landfast ice (this study; Cross, 1982). But murres did not concentrate along the ice edge in areas with rough ice in 1979 (Table 2) and in that year murre diet was different than in 1976. In general, there was a marked reduction in the numbers and dry weights of arctic cod taken by murres from 1976 through 1978 to 1979, and a marked increase in the numbers and dry weights of *Parathemisto* (Bradstreet and Cross, 1982). This is apparently a case of murres switching from arctic cod to a lower-level food item, from locally-available under-ice biota back to a more broadly distributed pelagic form — *Parathemisto.*

Steele (1980) suggests that in marine food chains, lower-level food resources are of smaller average size, less concentrated, and thus less economical to exploit than higher-level food items. In each year of study Bradstreet and Cross (1982) found the mean lengths of *Parathemisto* taken by murres to be much smaller than the mean lengths of ingested arctic cod. *Parathemisto,* a planktonic amphipod, is not strongly associated with the undersurface of landfast ice (see Cross, 1982) nor does it concentrate in waters near the ice/water interface (Bradstreet, 1980). Ice-associated food taxa such as arctic cod and epontic amphipods are, on the other hand, mainly accessible at restricted areas adjacent to ice where these taxa are concentrated near a two-dimensional superstrate. The mean weights of the stomach contents of murres can be used as a measure of the relative economic return of feeding in the three years. In 1976 and 1978 when murres fed largely on arctic cod (96% and 86% of diet dry weight, respectively), mean weights of stomach contents were similar, and significantly greater than in 1979 when murres fed proportionately more on *Parathemisto* (50% of diet dry weight — Bradstreet and Cross, 1982). Thus, Steele's (1980) general model seems applicable to murres at ice edges.

In the sea, the large scale distribution of planktonic crustaceans is patchy (e.g. Mackas and Boyd, 1979) and largely controlled by water currents, not by the ability of these crustaceans to maintain position (*cf.* Steele, 1980). The combined effects of patchiness, planktonic nature, and lack of association with the ice edge mean that locations of *Parathemisto* concentrations useful to feeding murres are undoubtedly less predictable in time and space than are locations of arctic cod and under-ice amphipods. In years when sufficient under-ice fauna are not available and murres must turn to *Parathemisto* to satisfy food requirements, one would expect the use of ice edges to be more variable than in years when under-ice fauna are largely sufficient to meet most of the birds' energy requirements. This seems to have been the case at Pond Inlet in 1978 and 1979. Murres were significantly more variable in their use of the Pond Inlet ice edge in 1978-79 than they were in their use of the Wellington Channel ice edge in 1976. At Pond Inlet murres ate proportionately more *Parathemisto* and less ice-associated food than they did at Wellington Channel (Bradstreet and Cross, 1982). The sizes of *Parathemisto* taken by murres were large in 1978 (mean 29mm), compared to 1976 (21 mm) and murres apparently compensated for reduced numbers of cod by taking large numbers of large *Parathemisto*. In 1979, *Parathemisto* in murre stomachs were smaller (23 mm) than in 1978, and similar in size to those taken in 1976. Murres were apparently unable to compensate for the very low numbers of cod ingested even though they ate very large numbers of small *Parathemisto*. This resulted in the significant reduction of stomach content weights from 1978 to 1979.

The Pond Inlet study was conducted during the prelaying to early incubation period of the murre's nesting cycle and at this time individual murres can spend long periods (up to one day) away from the colony (Gaston and Nettleship, 1981). Flight speeds of murres (58 $km \cdot h^{-1}$) indicate that large potential feeding areas are accessible to murres. Apparently patchy, planktonic food resources can be exploited by murres at this time, whether such resources are along the ice edge or offshore.

The Importance of Arctic Cod

At ice edges the seabirds (fulmars, kittiwakes, murres, guillemots) and marine mammals (ringed seal, narwhal) whose diets have been investigated (Bradstreet, 1980; Bradstreet and Cross, 1981; Finley and Gibb, pers. comm.) all depend on arctic cod as a major component of their diets. Klumov (1937) regarded arctic cod as 'the biological pivot' in the lives of many northern marine vertebrates, 'an important intermediary link in the sea's food chain'. In this study, arctic cod were found to be closely associated with the undersurface of landfast ice in both offshore and inshore locations. At offshore ice edges, the diet of cod was dominated by copepods (primarily calanoids) and amphipods (primarily small *Parathemisto*); in turn, these zooplankters primarily ate diatoms (Bradstreet and Cross, 1982).

Thus, the system channels most of the energy flow from plants to high level consumers through a few key links, particularly arctic cod. If arctic cod are not plentiful, most of the birds and mammals studied can apparently turn to lower levels in the food chain for alternate food. This was demonstrated for murres, the most intensively studied species at ice edges, and deduced for most other species (not narwhals) from present knowledge of diet composition (Bradstreet and Cross, 1982).

Dunbar (1968, 1973) noted that systems in which energy is transferred through a few key links must be considered vulnerable because the disappearance of the key links will seriously affect dependent species. Natural oscillations in the numbers of arctic cod ingested by murres can apparently be large (not an uncommon situation in arctic animal populations — Dunbar, 1968); when cod numbers are low, murres and most of the other higher vertebrates studied can apparently turn to zooplankton as an alternate food source. This suggests that vertebrates are already well adapted to survive when arctic cod are not plentiful. However, the cost to consumers of turning to lower level food items must be remembered. With murres, for example, variation in the numbers of cod taken resulted at times in a significant reduction in the amount of food ingested. This suggests that any man-induced perturbation of the ice edge environment could have negative effects on murres, and perhaps on other species, if it made arctic cod less available than they are naturally.

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