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Marine Birds in the Marginal Ice Zone of the Barents Sea in Late Winter and Spring

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ABSTRACT. We recorded the distribution and abundance of marine birds in the northern Barents Sea from 27 February to 8 March 1987 and from 20 to 31 May 1988. Birds were more abundant in waters associated with pack ice than in open water away from pack ice. Within the pack ice, thick-billed murres (*Uria lomvia*) were the most commonly encountered birds in both periods. Murre densities in the pack ice north of the zone proximate to the ice edge were positively correlated with distance from the ice edge. Large leads were more frequently occupied by murres than small leads, and had larger numbers of birds present. In spring, we found more birds along a well-defined ice edge than were present either in open water or in leads in the pack ice within 5 nautical miles of the ice edge. Transects along the ice edge revealed little correlation in abundance between species, or within species when coverage was repeated during the same day. We conclude that the birds showed considerable specificity of habitat choice within the habitat divisions that we recognized and that avian patches were of short duration. We need information on the distribution, abundance and movements of prey patches if we are to understand the changing distribution patterns of the birds.

Key words: marine birds, northern fulmar, *Fulmarus glacialis,* black-legged kittiwake, *Rissa tridactyla,* thick-billed murre, *Uria lomvia,* dovekie, *Alle alle,* marginal ice zone, Barents Sea

RÉSUMÉ. Du 27 février au 8 mars 1987 et du 20 au 31 mai 1988, on a procédé à un relevé de la distribution et de l'abondance des oiseaux marins dans la partie septentrionale de la mer de Barents. Les oiseaux étaient plus abondants dans les eaux associées à la banquise que dans l'eau libre située loin de la banquise. La marmette de Brünnich (*Uria lomvia*) est l'oiseau que l'on retrouvait le plus souvent dans le périmètre de la banquise au cours des deux périodes de l'étude. La densité de marmettes sur la banquise, au nord de la zone proche de la lisière de glace, était corrélée de façon positive avec l'éloignement de la lisière de glace. Les grands chenaux étaient plus fréquemment occupés par les brunettes que les petits chenaux, et les oiseaux y étaient présents en plus grand nombre. Au printemps, on trouvait plus d'oiseaux le long d'une lisière de glace bien définie qu'on en trouvait soit dans l'eau libre, soit dans des chenaux présents dans la banquise à moins de cinq milles marins de la lisière de glace. Des transects longeant la lisière de glace n'ont révélé qu'une faible corrélation entre l'abondance des diverses espèces, ou au sein d'une même espèce lorsque le relevé était répété au cours de la même journée. On en conclut que les oiseaux manifestaient une grande spécificité dans le choix de leur habitat au sein des divisions de l'habitat établies par nous et que les regroupements aviens étaient de courte durée. Si l'on veut comprendre l'évolution des schémas de distribution des oiseaux, on doit avoir plus de renseignements sur la distribution, l'abondance et les mouvements des regroupements de proies.

Mots clés: oiseaux marins, fulmar boréal, *Fulmarus glacialis*, mouette tridactyle, *Rissa tridactyla*, marmette de Brünnich, *Uria lomvia*, mergule nain, *Alle alle*, zone de glace marginale, mer de Barents

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INTRODUCTION

In polar marine ecosystems, marginal ice zones support high levels of productivity in spring (Schandelmeier and Alexander, 1981; Smith, 1987; Smith et al., 1990). Marine birds in both the Arctic and Antarctic frequent these regions of transition between near-continuous ice cover and open water (c.f. Hunt, 1991), and several species groups have distributions that are largely restricted to the marginal ice zone (Hunt and Nettleship, 1988). We present observations of marine birds made during two multidisciplinary cruises to the Barents Sea (Syvertsen, 1987; Lønne, 1988). During the time available to us, we focused on identifying the characteristics of the habitats used by thick-billed murres (*Uria lomvia*) within the ice pack, and on examining the distribution and abundance of birds along the ice edge and in the adjacent ice and open-water habitats.

In the Arctic, much of the early work on avian use of the marginal ice zone examined avian ecology along the edge of the fast ice in the Canadian High Arctic (Bradstreet, 1979, 1988; McLaren, 1982). This work focused on trophic relationships and the use of sympagic (under-ice) fauna by birds and other predators (Bradstreet, 1980, 1982; Bradstreet and Cross, 1982), as has recent work in the northernmost Barents Sea (Gulliksen, 1984; Lønne and

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Gulliksen, 1989, 1991a,b). Other workers in the Beaufort and Bering Seas (McRoy et al., 1971; Divoky, 1977, 1981) and northern Barents Sea (Mehlum, 1989, 1990) have emphasized spatial patterns of abundance within the marginal ice zone as well as trophic relations. For the Bering Sea, Divoky (1981) described how birds initially aggregate at the ice edge, and later, as the ice pack begins to disintegrate, move to widening leads throughout the pack as they seek access to food near colony sites that will be occupied during the ice-free summer nesting season.

In the Antarctic, most studies have focused on the distribution of avian biomass in the marginal ice zone of the ice pack (Ainley and Jacobs, 1981; Fraser and Ainley, 1986; Ainley et al., 1992). Although much of this work has focused on trophic relations and on a food web tied to the pelagic community rather than to sympagic fauna, Ainley and co-workers have also stressed the importance of the ice-edge zone as a region in which avian biomass is concentrated (e.g., Ainley and Jacobs, 1981). In contrast, Veit and Hunt (1991) found that, although seabirds frequently concentrate at Antarctic ice edges, these concentrations do not occur more frequently than expected by chance. Some differences in evaluating the importance to birds of the transitional zone between open water and ice may have been due to the patchy distribution of birds along this zone. Such patchiness would create sampling problems when only one or a few transects perpendicular to the ice edge were used to determine its importance to marine birds. Therefore, in this study we were interested not only in the abundance of birds in the open water, ice edge and pack ice zones, but also in the variability of their numbers along the ice edge.

Additionally, we examined the variability of the abundance of thick-billed murres with respect to habitat. Ainley et al. (1992) describe differences in the habitat preferences of a number of Antarctic bird species that use the marginal ice zone. Our cruises visited areas dominated by thick-billed murres, and we took the opportunity to examine aspects of the habitat that influenced their distribution within this Arctic marginal ice zone.

STUDY AREA

We conducted our study in the northwestern Barents Sea east of Svalbard (Fig. 1). To the north, this area is dominated by southward-flowing Arctic Water, which is separated by the polar front from Atlantic Water that enters the southern Barents Sea from the west (Loeng, 1991). During years with "normal" ice cover, maximum ice cover extends southeast to about 74°30′N. Ice cover in the study area consists primarily of 70 – 120 cm thick first-year ice (Vinje, 1985). Only rarely does multiyear ice originating in the Arctic Ocean penetrate to the waters near Hopen Island where we worked (Vinje, 1985), and during our two cruises, little multiyear ice was encountered. At the time of our 1988 cruise, southerly winds prevailed, and

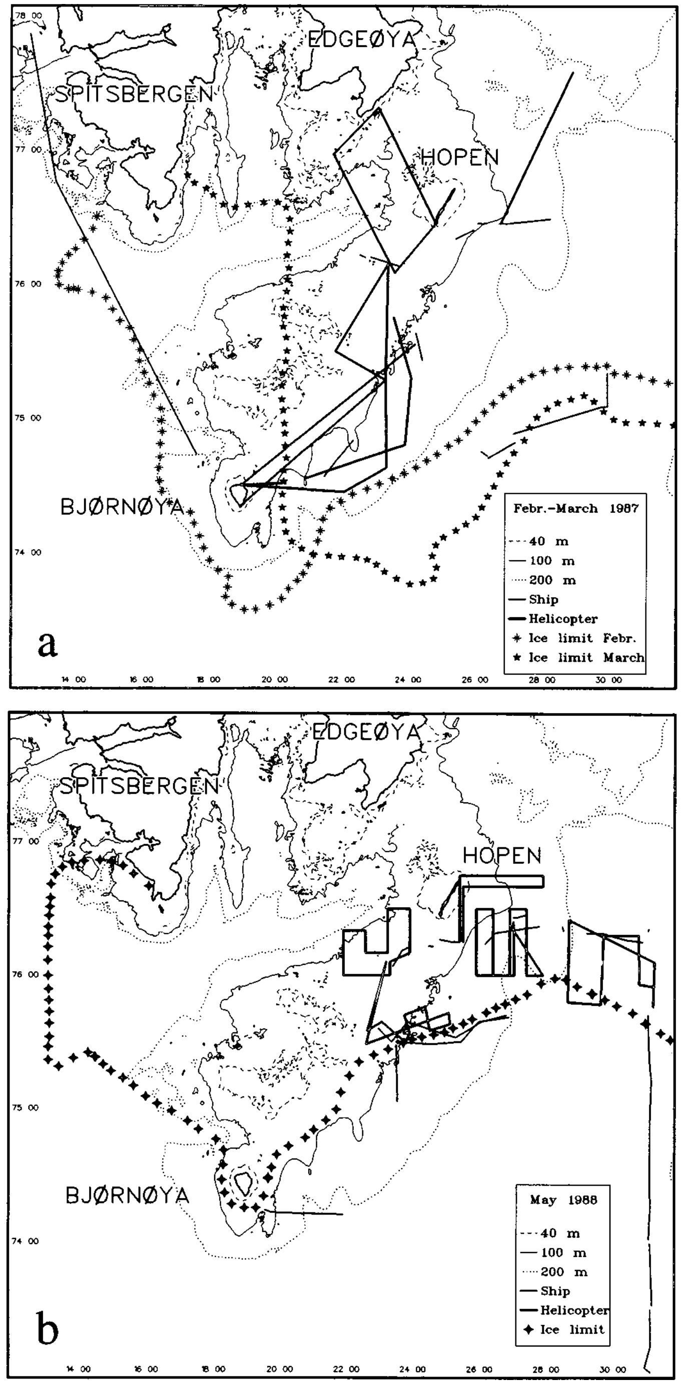

FIG. 1. a) Cruise track of the K/V *Nordkapp*, 20 February to 8 March, 1987; b) Cruise track of the K/V *Andenes*, 21 – 31 May, 1988.

there was a discrete ice edge separating ice-free water from the ice pack with 75 – 90% ice cover. The Barents Sea in the study area contains several shallow banks with water depths of as little as 17 – 45 m as well as deep submarine canyons. This variable bathymetry influences currents (Loeng, 1991) and may be responsible for affecting the location of leads, polynyas, and possibly the ice edge, although in this region most polynyas form on the lee side of islands (Vinje and Kvambekk, 1991).

The region in spring is dominated by a copepod-based food web, which supports large populations of arctic cod

(*Boreogadus saida*) and pelagic amphipods (e.g., *Parathemisto libellula*) (Sakshaug and Skjoldal, 1989). These species are found in the water column, and arctic cod frequently forage in leads and cavities under the ice (Lønne and Gulliksen, 1989). The region does not support a rich, autochthonous sympagic ice fauna, presumably because it is dominated by first-year ice (Lønne and Gulliksen, 1991a, b). However both the arctic cod and the *Parathemisto* feed on species that crop the under-ice algae.

METHODS

Survey Design and Techniques

Observations were made from 20 February to 8 March 1987 on the Norwegian Coast Guard Cutter K/V *Nordkapp* (Fig. 1a) and from 20 to 31 May 1988 on the K/V *Andenes* (Fig. 1b) during two multidisciplinary Pro Mare cruises (Syvertsen, 1987; Lønne, 1988). Observations of marine birds were conducted from inside the bridge of these ships (eye height 18 m above sea level). We counted all birds within a 300 m arc from directly ahead of the ship to 90˚ on the side with best visibility and entered records directly into a microcomputer (Tasker et al., 1984; Updegraff and Hunt, 1985). Counts were made continuously whenever the ship was under way and conditions permitted. For our analyses, we included all birds seen, except in the cases of thick-billed murres and dovekies (*Alle alle*), for which only birds sitting on the water were included. In open water, we counted birds when the vessel was traveling at its cruising speed of 15 kn, although occasionally speed varied between 10 and 23 kn. In ice, progress was much slower, and we made counts whenever the vessel was moving (speed varied up to 5 kn).

Although we generally did not have control of the ship's track, we did obtain use of a Lynx helicopter for bird surveys (Fig. 1). When in the helicopter, we flew at a speed of 90 knots at an altitude of 60 – 70 m, and two observers each surveyed a strip 100 m wide on each side of the aircraft from the back seat. Strip width was estimated by comparison with objects of known length (e.g., the ship), and was only approximate. Data were recorded into a tape recorder for subsequent transcription and encoding. The ability to see diving birds was compromised by the lack of forward visibility; thus these counts provide only an index of avian numbers.

To quantify avian use of the ice-edge zone in 1987, we conducted shipboard surveys of transects between Tromsø, Norway, and the ice edge, i.e., the segment from 75˚N to the ice edge at approximately 75˚40′N. In 1988, we surveyed a pair of transects along the ice edge on our final day in the study area. We commenced this survey at 75˚30′N, 23˚14′E and went east for 95 km. After a wait of one hour to allow the birds to return to the areas we had disturbed, we returned along the ice edge to our starting point. In addition, early in the 1988 cruise, we designed a helicopter survey that examined three transects perpendicular to the ice edge. Each of these three transects included 5 nautical miles over ice and 5 nautical miles over open water. During the passages between lines, we surveyed bird densities over open water and those over pack ice to provide additional comparisons with bird densities at the adjacent ice edge. A total of 18 nautical miles (33 km) were surveyed over open water, pack ice, and along the ice edge in this aspect of the study.

To relate murre usage of leads to lead area, during both our shipboard and helicopter-supported observations of the pack-ice zone in 1988, we estimated the length and breadth of each lead and the number of thick-billed murres present on the water. Subsequently, we determined for each observation the water depth, distance to colony, and distance to the ice edge, using nautical charts and concurrent ice surveys.

Statistical Analyses

Before performing any hypothesis-testing analyses, we examined our shipboard survey data from along the ice edge for autocorrelations to determine the length of statistically independent sampling units. We used the Statgraphics® (STSC, 1986) program for both integrated periodograms and autocorrelation analysis. The integrated periodogram analysis included both the 75% and 95% Kolmogrov-Smirnov bounds for a uniform distribution of bounds. On the basis of these analyses, we selected as our sampling units segments 3 nautical miles (5.5 km) long. This distance corresponded to a two-minute duration during the helicopter surveys. For the short helicopter surveys in the vicinity of the ice edge, we display our data in 1.5 nautical miles (2.8 km) units to provide finer resolution of the spatial variation in bird abundance.

We used a linear model to determine correlation coefficients between the abundance of thick-billed murres in the leads within the pack ice and the variables that we hypothesized may have influenced the suitability of various regions within the pack. To determine if leads of different sizes were more likely than chance to have murres present or to support different numbers of murres, we categorized leads into six size classes from $\leq$ 100 to > 1000 m^2. For presence/absence data, we used observations from both the helicopter and the ship. To compare the numbers of birds that were using different-sized leads, we used only data obtained on the ship, because these were more likely to be accurate counts. We tested for statistical differences using a contingency table and a chi-square test in Statgraphics.

Data collected during the brief helicopter surveys of the ice-edge zone were not analyzed statistically. In both the transects parallel to the ice edge over open water and those over ice, the differences in bird densities were dramatic, and the lack of independence of sampling units made formal statistical analysis problematic. A similar problem applied to the three transects perpendicular to the ice edge.

TABLE 1. Mean densities of marine birds and mammals (number per km²) in pack ice and open water more than 0.5 nautical miles from the ice edge.

February/March 1987

	Open Water		Pack ice			
Behavior	Flying	On Water	Flying	On water	Flying	On water or on ice
(observation platform)	(ship)	(ship)	(ship)	(ship)	(helicopter)	(helicopter)
Species	n=262[1]	n=262	n=150	n=150	n=714	n=714
Ivory gull	0.0	0.0	0.5	0.0	0.0	< 0.1
Black-legged kittiwake	0.4	0.0	0.4	0.0	< 0.1	0.0
Thick-billed murre	0.8	0.3	250.0	48.1	13.4	65.6
Dovekie	< 0.1	0.7	0.0	0.0	0.0	0.0

May 1988

	Open water		Pack ice			
Species	n=247[1]	n=247	n=101	n=101	n=826	n=826
Ivory gull	0.0	0.0	0.3	< 0.1	< 0.1	0.0
	0.0[2]	0.0				
Black-legged kittiwake	1.0	< 0.1	2.6	0.2	< 0.1	< 0.1
	4.1[2]	0.7[2]				
Thick-billed murre	41.0	1.7	364.7	66.2	5.4	34.0
	10.9[2]	1.3[2]				
Dovekie	0.0	0.0	0.3	< 0.1	< 0.1	0.3
	0.2[2]	0.0[2]				

[1] Number of 3 nautical mile intervals sampled
[2] Data from open water north of 75° N

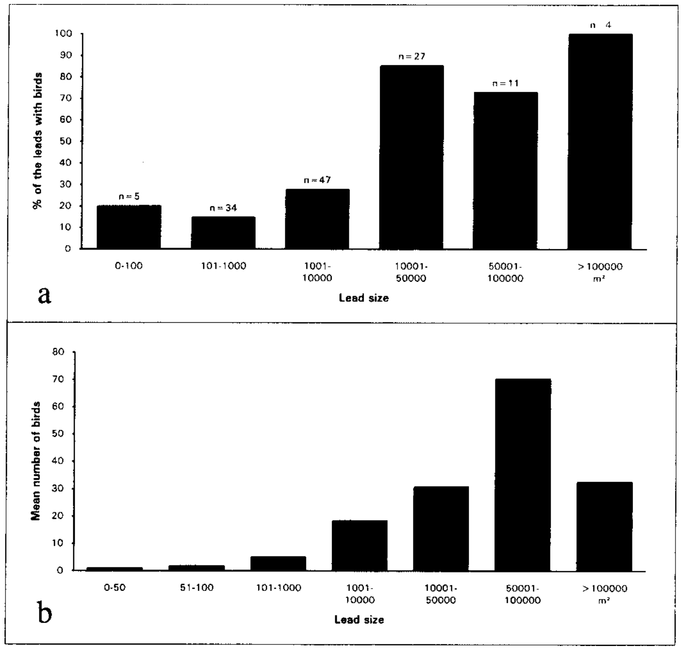

FIG. 2. a) The percent of leads of different sizes with thick-billed murres present, using data from both helicopter and shipboard surveys 21–31 May, 1988. $\chi^2 = 44.8$, df = 3, $p < 0.001$; b) The mean number of thick-billed murres present in leads of different sizes, as counted from the ship. $\chi^2 = 50.37$, df = 6, $p < 0.001$.

Our longer shipboard transect along the ice edge was useful for examining the extent of change in distribution of each species between the two passages along the ice edge, as well as for an assessment of autocorrelation. For the comparison of the stability of species' distributions as a function of survey segment length, we used Spearman rank correlations to examine the extent to which spatial variations in distribution changed between our two passages along the ice edge.

RESULTS

Comparisons of the densities of birds seen in the pack ice with those of birds seen in open water showed that there were more birds in the ice-covered waters than in open water (Table 1). This difference was similar on both the 1987 winter cruise and the 1988 spring cruise. The single species responsible for the difference was the thick-billed murre. Other bird species also tended to be more numerous in or over the ice (except dovekie in winter), but the differences were small and unlikely to be biologically meaningful. Thick-billed murres on the water in leads showed a preference for larger leads, both in winter and in spring (Fig. 2), when large leads were more likely to be occupied and to have larger numbers of birds present. In both winter and spring, the density of murres on the water was positively correlated with distance from the ice edge, although the coefficient of correlation was low (Table 2). Correlations between the density of thick-billed murres and overall ice cover, water depth, and distance to colony, except in spring, were not significant.

TABLE 2. Spearman rank correlations between the density of thick-billed murres on the water and aspects of the pack ice environment.

	Feb.–Mar. 1987 (n = 216)[1]	May–June 1988 (n = 435)
Category	Spearman P	Spearman P
Distance to ice edge	0.18[3]	0.18[4]
Distance to colony	-0.04	0.11[2]
Ice cover	-0.13	—
Water depth	-0.12	-0.08

[1] Sampling units were 3.0 nautical mile segments of observation track for the helicopter.
[2] $p < 0.05$
[3] $p < 0.01$
[4] $p < 0.001$

Helicopter surveys of paired sections of compact ice edge and pack ice, and compact ice edge and open water, showed more birds at the ice edge (Fig. 3). When counts were compared between pack ice and the ice edge, 90% of the birds observed on adjacent areas were at the ice edge, with thick-billed murres and northern fulmars (*Fulmarus glacialis*) dominating the ice-edge assemblage. For the sections of ice edge that were compared with open water, the ice edge supported more than 98% of the total birds seen. Again, thick-billed murres were the most numerous species at the ice edge, but dovekies and fulmars were also common. Data from the three transects perpendicular to the ice edge showed a similar pattern (Fig. 4). Most birds

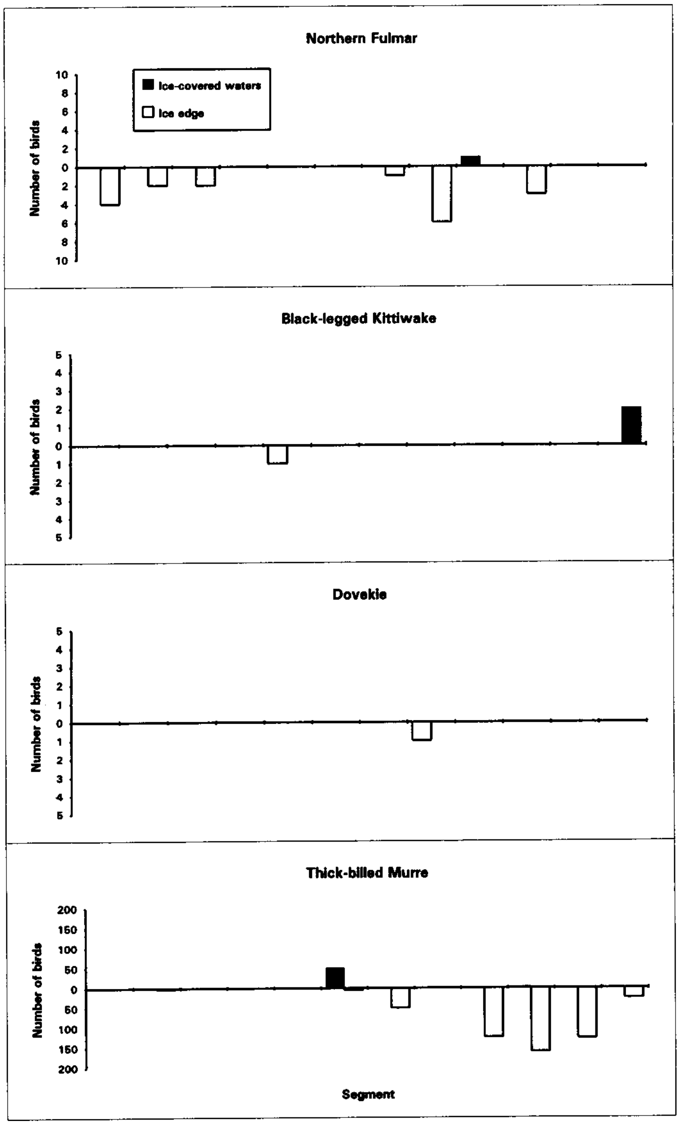

FIG. 3. a) A comparison of the number of birds of selected species using ice-filled waters vs. birds using the ice edge (ice/water interface) as observed from a helicopter flight along the ice edge. Each segment represents 1.5 nautical miles (2.8 km).

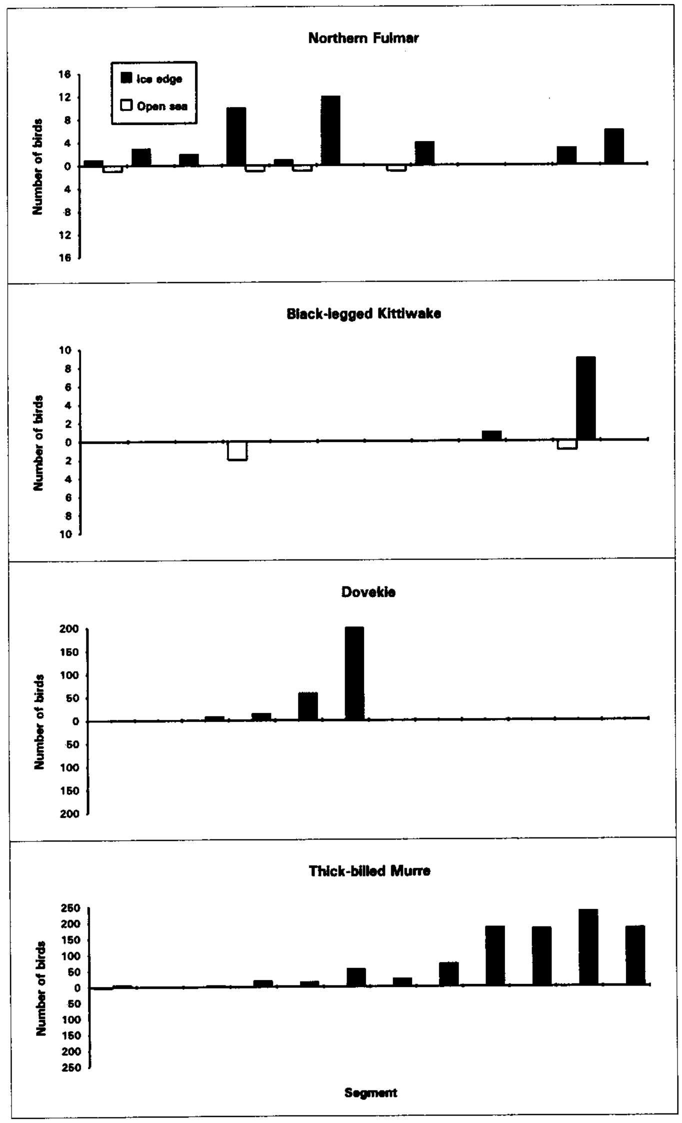

FIG. 3. b) A comparison of the number of birds of selected species using open water vs. birds using the ice edge, as observed from a helicopter flight along the ice edge. Segment length as in (a). Numbers of birds along the ice edge differ in (a) and (b) because separate surveys were used to compare bird use of open water and ice-covered water with use of the ice-edge habitat.

were seen immediately adjacent to the ice edge, with few more than 1.5 nautical miles away.

Both our shipboard (Fig. 5) and helicopter (Fig. 6) surveys along the ice edge in 1988 showed considerable patchiness in bird distribution. The coefficients of variation ranged between 1.0 and 1394.8 (for shipboard surveys) and were smallest for black-legged kittiwakes and greatest for thick-billed murres at a measurement interval of 3 nautical miles. Coefficients of variation were generally larger for the helicopter surveys, with a measurement interval of 1.5 nautical miles. In both surveys, northern fulmars, which were usually observed flying, had the most even distribution, whereas dovekies and thick-billed murres, both diving species, tended to be more patchily distributed.

The autocorrelation analysis of birds by species along the ice edge, with an initial sampling unit of 1.5 nautical miles, showed three species with statistically significant ($p < 0.05$) autocorrelations with a lag of 1 or 2 (Table 3). With an initial sampling unit of 3 nautical miles, dovekies on the westward run had statistically significant autocorrelations at a lag of 1, but not at greater lags. Using a sampling unit of 3 nautical miles, the integrated periodograms indicated random distributions of the data points ($p < 0.05$) for all species on both the eastward and westward transects along the ice edge.

When we compared the distributions of birds observed along the ice edge on our passages east and west, we found no statistically significant correlations in abundance (Table 4). Some of the temporal variability in distribution may have resulted from disturbance by the passing ship. However, the similarity of results for all species, many of which

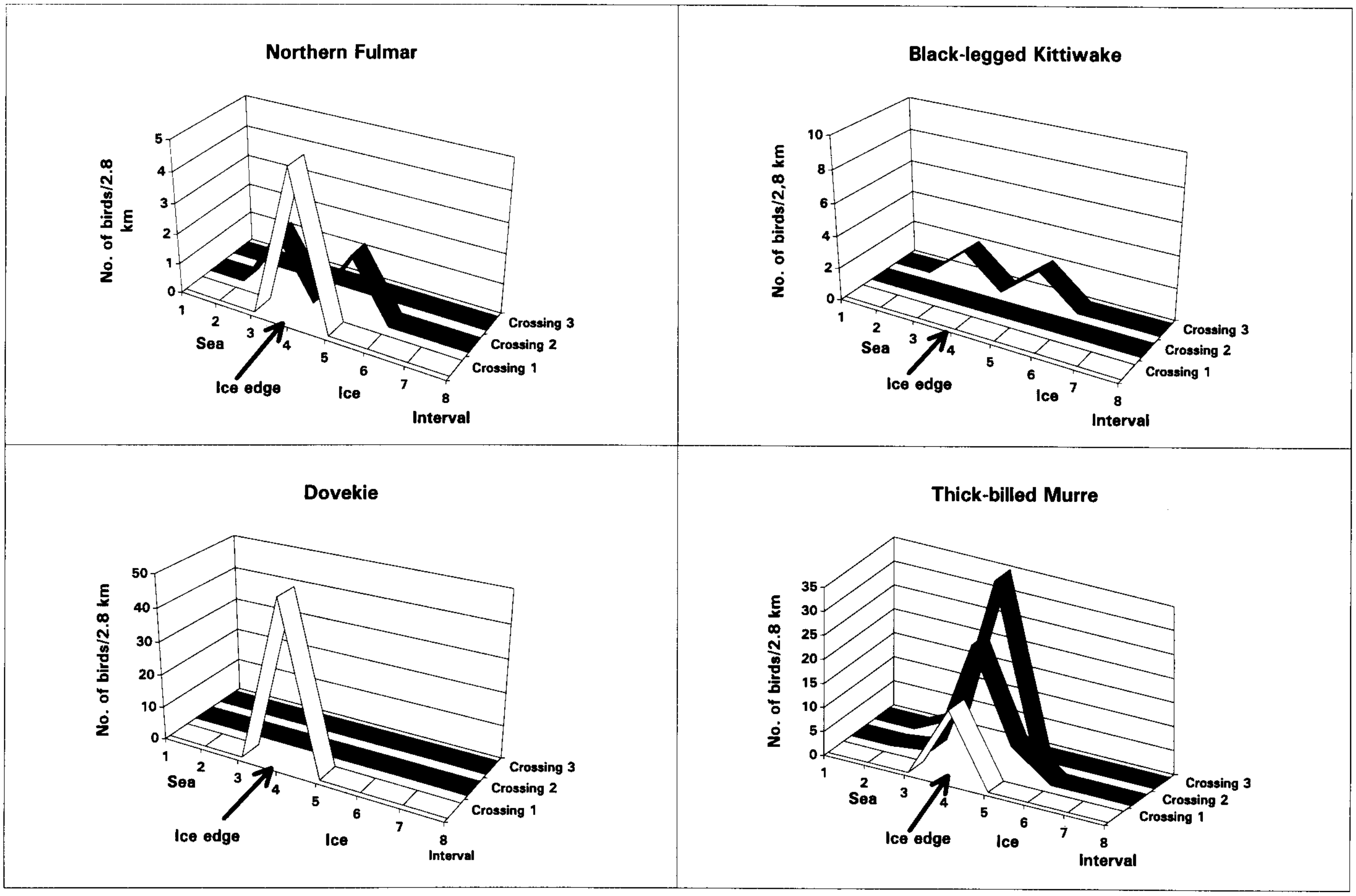

FIG. 4. Results of three crossings of the ice edge, 5 nautical miles (9.3 km) apart, by helicopter in May 1988.

appeared to ignore the ship, implied that there was a considerable temporal instability in the distributions of patches of birds foraging at the ice edge.

DISCUSSION

Marginal ice zones are often characterized by tongues of ice protruding into open water and a gradual or irregular transition between ice-covered areas and open water. When the pack ice is thus distributed by wind or currents, there is no clearly definable ice edge. When the wind blows from the open water toward the ice, the ice is compacted, and a discrete ice edge marks an abrupt transition from open water to ice-covered water. When there is a discrete ice edge, it is possible to examine avian usage of the edge zone as contrasted to the marginal ice zone. During our studies, the prevailing winds created a clearly defined ice edge.

Our results were similar to those of others (e.g., Bradstreet, 1979; Ainley and Jacobs, 1981; McLaren, 1982) in that we found greater numbers of birds associated with ice-filled waters than in open water away from the ice. However, it was not possible from our results to determine whether, at a population level, more birds were foraging in open water or in association with ice. Inbound to the ice at the eastern end of our study area in spring, we saw few birds; on the outbound transect in the west, densities of 14.4 birds km^{-2} persisted for 35 to 40 km south of the ice edge. The undersampling of the open water and the high variability in counts made extrapolations of total birds using the open water area unreliable.

Both the ice edge and leads within the ice pack were important foraging habitats for birds. There was, however, a shift between winter and spring in the ways these two habitats were used. In winter, murres in particular spent the night at the ice edge and foraged by day in the leads (Bakken, 1990). In spring, when it was light 24 hours per day, birds were present and foraging in the leads and at the ice edge at all hours. Although large flights of murres were seen, there was no clear temporal pattern in the direction of movement. Movements in spring may have included not only local shifts between foraging areas, but also movements to and from colony sites and migration to more northerly colonies.

Evening movements to the ice edge during winter may have been a means of escaping being trapped in freezing

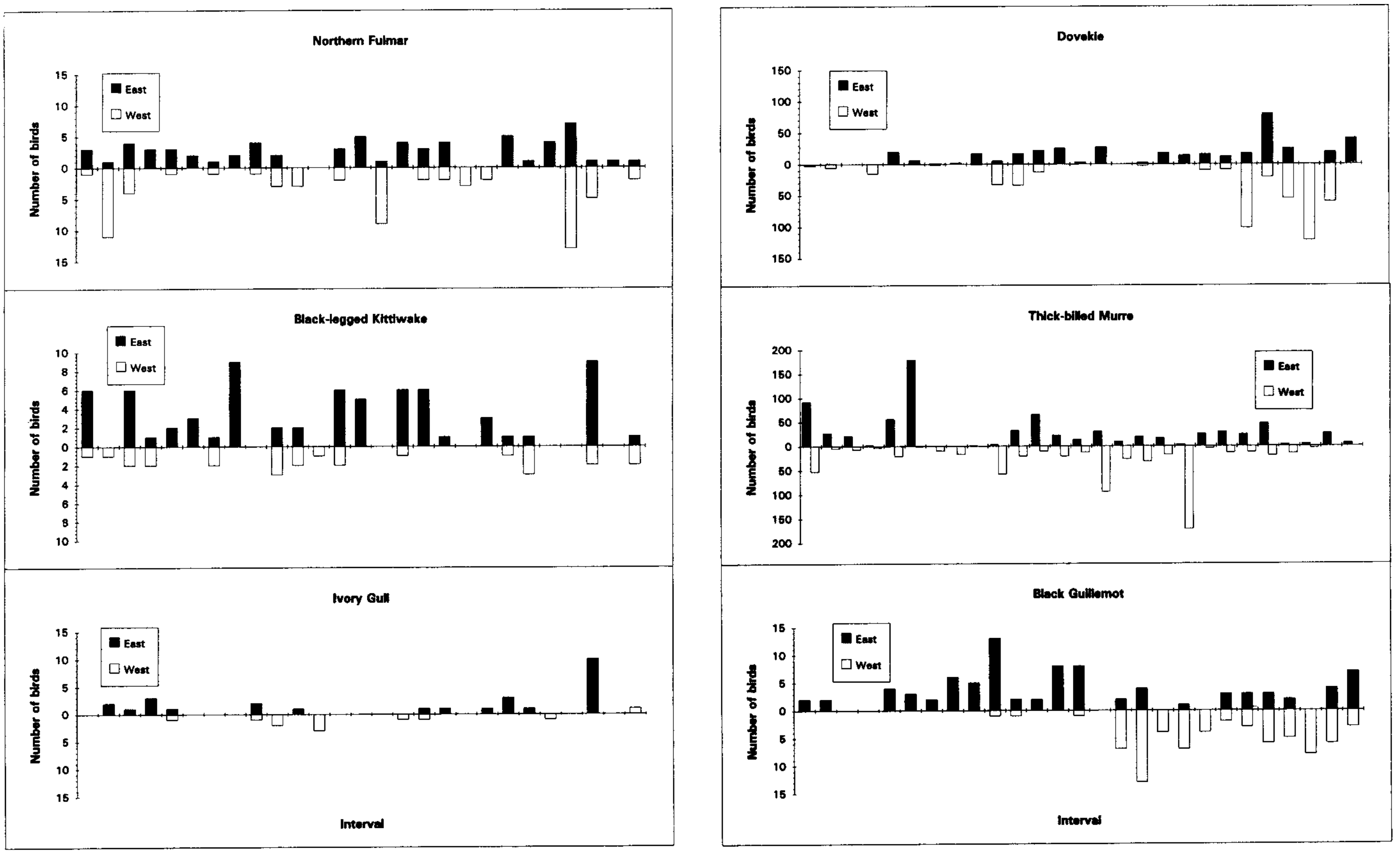

FIG. 5. Results of shipboard surveys along the ice edge. The west to east survey was run first; after an hour's wait, the return survey was begun. Each interval represents 2.8 km.

TABLE 3. Estimates of autocorrelation for lags of 1 at various bin sizes (nautical miles).

Species	Sampling methods	Bin size 1.5 n = 54	3.0 n = 27	6.0 n = 13	12.0 n = 6
Thick-billed murre:					
	ice edge E, boat	0.28[1]	0.07	-0.35	0.24
	ice edge W, boat	0.03	0.05	-0.04	0.16
	in pack, helicopter	ND[2]	-0.01	0.03	0.33[1]
Dovekie:					
	ice edge E, boat	0.41[1]	0.18	0.10	-0.02
	ice edge W, boat	0.49[1]	0.41[1]	0.34	-0.18
Black-legged kittiwake:					
	ice edge E, boat	-0.02	-0.32	-0.12	-0.27
	ice edge W, boat	-0.04	-0.05	-0.22	-0.32

[1] Estimated autocorrelation with $p \leq 0.05$

[2] ND = no data

TABLE 4. Spearman rank correlations (Rho) between the abundance of a species on two transects along the ice edge covering the same geographic area 1 to 9 hours apart. Note the effect of changing the length of observation segments (bin size). None of the correlations is significant at $p = 0.05$. See Figure 5.

Species	Segment length (nautical miles) 3.0 n = 27	6.0 n = 13	13.0 n = 4
Northern fulmar	-0.18	0.17	0.40
Ivory gull	-0.07	-0.22	-0.74
Black-legged kittiwake	0.22	0.00	-0.40
Thick-billed murre	0.22	0.06	-0.20
Dovekie	0.08	0.21	0.40
Black guillemot	-0.08	-0.25	0.20
Seal (spp)	-0.04	0.19	0.60

and shifting leads at night (Hunt, 1991). In still air, murres are unable to take flight from small leads (Uspenski, 1958; Bakken, 1990). In spring, daylight was continuous, and there may have been less chance of murres being trapped unexpectedly. Even so, in spring murres showed a preference for large leads.

Murres seldom used leads near the ice edge, which may have reflected a preference for leads over shallower water, which were well north of the ice edge. The bottom in these shallows was well within the foraging range of diving murres (ca. 200 m) (Croll et al., 1992), and therefore murres using leads over these banks would have access to epibenthic prey inaccessible in deeper water. We hypothesize that leads near the ice edge may have been less favorable foraging sites because the ice was greatly disturbed and broken into smaller pieces by wave action, thereby disturbing or making less available prey associated with the sympagic community.

Depending upon where one crossed the ice edge, one would have a very different impression of its importance

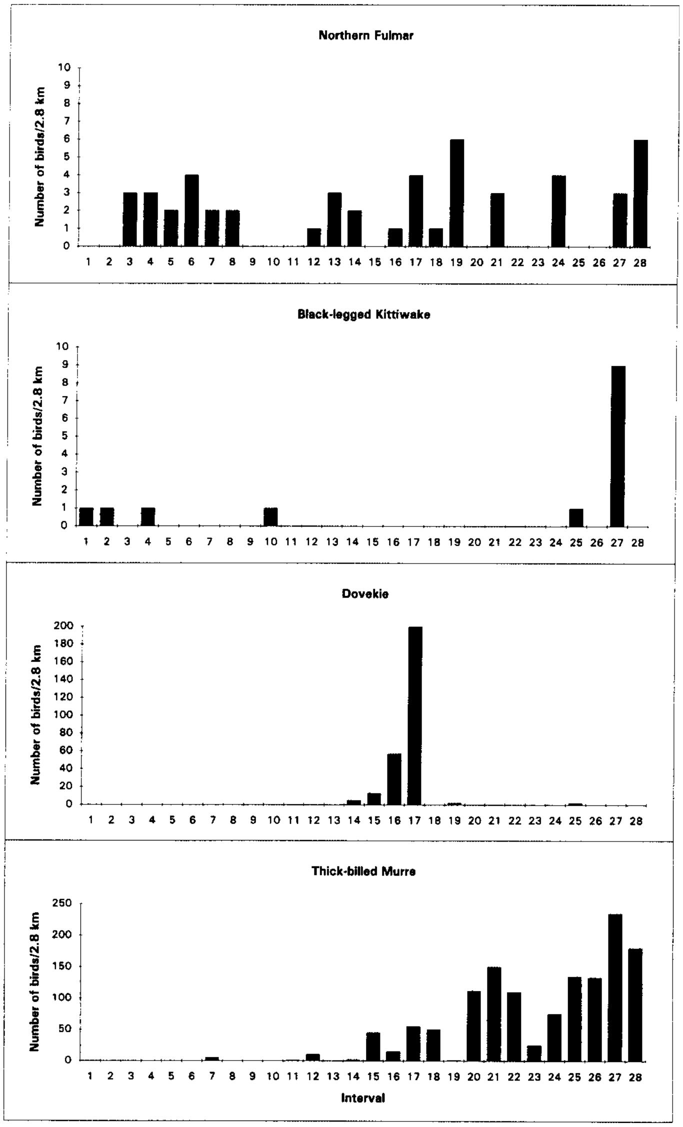

FIG. 6. Results of a helicopter survey along the ice edge in May 1988. Each interval represents 2.8 km.

to foraging birds. Our examination of variation in bird numbers along the ice edge showed that only 4 of 26 intervals of the shipboard survey had large numbers (≥ 50) of murres present, and that all but one of the intervals with ≥ 50 murres changed between the first and second transects. Likewise, during our helicopter survey, there was little uniformity in the distribution of birds along the ice edge.

There was also a remarkable lack of correlation between species along the ice edge. In both the shipboard and the helicopter surveys, only kittiwakes and fulmars on the shipboard survey had similar patterns, perhaps because both were evenly distributed in small numbers along the entire transect.

The diving species, murres and dovekies, had patchier distributions than surface-foraging species. The diving species may form patches at particularly rich foraging sites, as found elsewhere (Coyle et al., 1992; Hunt et al., 1992), but apparently these prey patches are of short duration; we found no statistically significant correlations in bird numbers between the eastward and westward shipboard ice-edge transits. The rapid redistribution of birds along the ice edge will make it difficult to obtain the measurements necessary for determining the factors responsible for the distributions observed. However, if we are to understand why birds assemble in certain places and what determines the duration of their stay, we must learn more about the distribution, abundance and behavior of prey species in the marginal ice zone.

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