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Summer Distribution of Marine Birds in the Western Beaufort Sea

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ABSTRACT. Proposed expansion of oil and gas development into offshore waters of the Beaufort Sea has raised concerns that marine birds could be affected by disturbance and oil spills. We conducted aerial surveys to determine the composition and distribution of avian species in the western Beaufort Sea. We sampled marine waters up to 100 km from shore, between Cape Halkett and Brownlow Point in June, July, and August of 1999 and 2000 and between Point Barrow and Demarcation Point in July 2001. Approximately 90% of the birds we observed were sea ducks, predominantly long-tailed ducks (*Clangula hyemalis*), king eiders (*Somateria spectabilis*), and scoters (*Melanitta* spp.). Densities of most species decreased with distance from shore, although king eider densities were higher in deeper, offshore waters. Densities of long-tailed ducks increased in nearshore coastal lagoons at the onset of post-breeding moult, and densities of eiders increased offshore during their peak moult migration. In general, bird densities were highest in areas with less than 30% ice cover, although high densities of king eiders occurred in areas with 30%–60% ice cover. Our results suggest species-specific uses of the Beaufort Sea in summer for moulting, migration, brood rearing, and foraging. The vulnerability of marine birds to potential oil spills and disturbance will depend on the location of facilities, timing of events, and ice conditions.

Key words: aerial surveys, Alaska, Beaufort Sea, distribution, eiders, *Somateria* spp., ice, long-tailed duck, *Clangula hyemalis*, marine birds, oil, sea ducks

RÉSUMÉ. Un projet d’expansion de l’exploitation pétrolière et gazière dans les eaux du large de la mer de Beaufort a soulevé des questions au sujet des retombées éventuelles pour les oiseaux marins suite aux perturbations et à des déversements d’hydrocarbures. On a effectué des relevés aériens pour analyser la composition et la répartition des espèces aviaires dans la mer de Beaufort occidentale. On a échantillonné les eaux marines jusqu’à une distance de 100 km du rivage, en juin, juillet et août de 1999 et de 2000, entre Cape Halkett et Brownlow Point et, en juillet 2001, entre Point Barrow et Demarcation Point. Environ 90 % des oiseaux observés étaient des canards de mer, surtout des hareldes kakawis (*Clangula hyemalis*), des eiders à tête grise (*Somateria spectabilis*) et des macreuses (*Melanitta* spp). Les densités de la plupart des espèces diminuaient en s’éloignant du rivage, encore que celles de l’eider à tête grise étaient plus élevées dans les eaux plus profondes du large. Les densités de la harelde kakawi augmentaient dans les lagunes côtières à proximité du rivage au début de la mue post-reproductrice, et celles de l’eider augmentaient au large au plus fort de la migration de mue. En général, les densités d’oiseaux étaient plus fortes dans les zones où il y avait moins de 30 % de manteau glaciel, encore que de fortes densités de l’eider à tête grise se trouvaient dans les zones ayant de 30 à 60 % de manteau glaciel. Nos résultats suggèrent qu’en été les espèces utilisent la mer de Beaufort d’une façon qui leur est propre pour la mue, la migration, l’élevage des couvées et le nourrissage. La vulnérabilité des oiseaux marins face à d’éventuels déversements d’hydrocarbures et perturbations va dépendre de l’emplacement des installations, du moment où se produiront les événements et de l’état des glaces.

Mots clés: relevés aériens, Alaska, mer de Beaufort, répartition, eiders, *Somateria* spp, glace, harelde kakawi, *Clangula hyemalis*, oiseaux marins, pétrole, canards de mer

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INTRODUCTION

Recent expansion of oil and gas development into the western Beaufort Sea has raised concern that wildlife may be at increased risk of disturbance and oil spills (U.S. Army Corps of Engineers, 1999). Proposed oil and gas development in 3.95 million ha of submerged lands in the Beaufort Sea (USDOI MMS, 2002) would likely affect wildlife. The Beaufort Sea provides moulting habitat (Schamel, 1978; Johnson and Richardson, 1982), migratory pathways (Richardson and Johnson, 1981; Johnson and Richardson, 1982; Petersen et al., 1999; Dickson et al., 2001), brood-rearing habitat (Schamel, 1977), and food resources (Griffiths and Dillinger, 1981; Johnson and Richardson, 1982; Divoky, 1984b) for hundreds of thousands of marine birds each year (Johnson and Herter,

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1989). Wildlife of particular concern are king eiders (*Somateria spectabilis*) and common eiders (*Somateria mollissima*), whose regional populations declined by more than 50% between 1976 and 1996 (Suydam et al., 2000); spectacled eiders (*Somateria fischeri*), a threatened species that declined by 96% in Alaska between the 1970s and early 1990s (Stehn et al., 1993); and long-tailed ducks (*Clangula hyemalis*), which may also be declining in Alaska (Goudie et al., 1994; Mallek et al., 2002). The probability that these and other marine bird populations will be affected by development is dependent, in part, on their temporal and spatial distribution relative to existing and future offshore industrial activities. Therefore, we sought to document locations and timing of marine bird concentrations in the western Beaufort Sea.

While distributions of marine birds in nearshore areas of the western Beaufort Sea have been described (Johnson and Richardson, 1982), offshore distribution in summer is poorly documented. Frame (1973) described seabirds (Laridae and Alcidae) during an oceanographic cruise in late summer, but did not provide density estimates. Divoky (1984a, b) used ship-based surveys to compare avian biomass of different regions of the western Beaufort Sea in August and September, though he did not include birds within 300 m of land or long-tailed ducks and loons in waters more than 20 m deep. Harrison (1977) conducted aerial surveys over offshore waters of the Beaufort Sea, but since transects were widely spaced (75 km in most areas), he provided only a general description of marine bird distribution. Searing et al. (1975) conducted aerial reconnaissance surveys for marine birds in the Canadian Beaufort, yet did not describe densities or distribution. Timing and routes of bird migration in the Beaufort Sea were described using radar (Richardson and Johnson, 1981; Johnson and Richardson, 1982), but offshore distribution was not well documented. Recently, satellite telemetry was used to describe the migratory routes of eiders through the Beaufort Sea (Petersen et al., 1999; Dickson et al., 2001; Petersen and Flint, 2002); however, information of this type is lacking for most species, and the eiders may not be representative of all birds that use the Beaufort Sea in summer.

Distribution of marine birds is controlled, in part, by ice cover on the sea surface (Stirling, 1980). While extensive ice cover may limit access to food, moderate ice cover may benefit some species by reducing wave action, increasing roost sites, and promoting production of invertebrate food resources (Routh, 1949; Divoky, 1979; Bradstreet, 1988; Stirling, 1997). Other studies have shown that ice conditions influence survival, routing, and staging of spring migrants in the Beaufort Sea (Barry, 1968; Richardson and Johnson, 1981; McLaren and Alliston, 1985), but little is known about the relation of ice and marine bird distribution in midsummer.

In this study, we used systematic aerial surveys to document distribution of marine birds in the western Beaufort Sea in relation to stage of summer, region, and water depth. In addition, we describe the relation of ice cover and bird density in late July, when failed breeders, nonbreeders, migrants, moulting birds, and foraging birds were present in the region. To our knowledge, these are the only systematic aerial survey data from the western Beaufort Sea that permit comparison of temporal and spatial differences in marine bird distribution along depth and ice-cover gradients in summer.

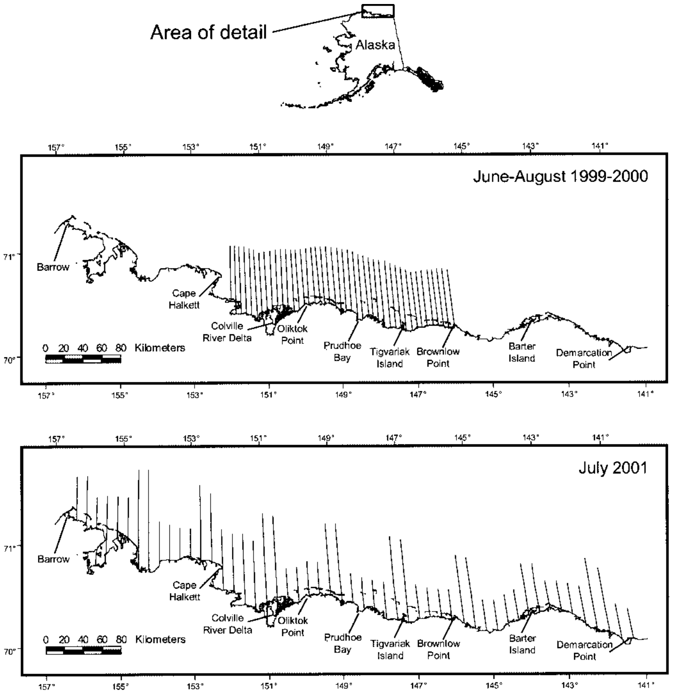

FIG. 1. Study area, showing aerial transects flown in 1999–2000 and 2001.

METHODS

The continental shelf in the western Beaufort Sea is relatively narrow, extending 40–100 km from shore (Gatto, 1980; Norton and Weller, 1984). In this region, ice covers the sea surface during eight to nine months of the year (Johnson and Herter, 1989; Parkinson, 2000). The Colville River flows into the Beaufort Sea, bisecting the Alaskan coastline with a large delta. The large volume of fresh water flowing into the sea from this and other river deltas generally produces the first areas of open marine water in spring. The nearshore environment in the western Beaufort Sea is characterized by shallow bays and lagoons formed by barrier islands and shoals (Norton and Weller, 1984).

We designed systematic transects to survey marine birds in the western Beaufort Sea in summer from 1999 to 2001. The number and length of transects varied between years. In 1999 we flew 36 transects between Cape Halkett and Bullen Point (12 km east of Tigvariak Island) during the last week of June, July, and August. In 2000, we expanded our sampling area eastward to include Brownlow

TABLE 1. Area surveyed (km^2) in the western Beaufort Sea in June, July, and August of 1999 and 2000.

		1999			2000		
Depth	Zone	June	July	August	June	July	August
> 10 m	Halkett to Oliktok	251.8	209.9	228.8	246.5	246.9	245.5
	Oliktok to Prudhoe	196.3	154.3	194.8	207.2	182.3	180.0
	Prudhoe to Tigvariak	84.9	141.9	159.4	162.8	93.5	161.9
	Tigvariak to Brownlow	47.1	37.3	36.3	184.4	88.0	169.5
< 10 m	Halkett to Oliktok	115.5	115.5	115.5	115.5	115.5	115.5
	Oliktok to Prudhoe	33.0	33.0	33.0	33.0	33.0	33.0
	Prudhoe to Tigvariak	83.4	84.2	84.2	84.2	84.2	84.2
	Tigvariak to Brownlow	12.6	12.6	12.6	31.8	31.8	31.8

Point, adding seven transects (Fig. 1). Transects in 1999 and 2000 were approximately 60 km in length and spaced 5.4 km apart. Persistent fog on some transects prevented us from surveying the northern extent of all transects during every flight; thus, the aerial extent of coverage varied between surveys (Table 1). In 2001, we broadened the study area to sample marine waters to the shelf-break between Barrow and Demarcation Point (Fig. 1). We flew 52 transects spaced 10 km apart during the last week of July, in a repeating pattern of four short transects followed by two long transects. Table 2 shows area covered in each zone and depth. Short transects spanned from shore to 30 km offshore, or to the northern extent of the 20 m isobath, whichever was greater. Long transects spanned from shore to the 115 m isobath at the shelf break.

We constrained our survey to areas within the continental shelf for several reasons. Our primary interest was to determine bird distribution in areas likely to overlap with resource development. Currently, oil and gas development seaward of the continental shelf is unlikely (USDOI MMS, 2002). In addition, we limited our sampling to areas where we expected to encounter birds. We inferred that most birds would occur within our survey area from satellite telemetry studies (Petersen et al., 1999; Dickson et al., 2000) and from the knowledge that productivity of phytoplankton is higher over continental shelves (Stirling, 1997).

In all years, we used a twin-engine Aero Commander aircraft outfitted with bubble windows as a survey platform. Pilots maintained a ground speed of 180 km/hr and altitude of 45 m above sea level (asl). To increase efficiency, we increased ground speed to 200 km/hr and altitude to 90 m asl in areas of total ice cover. We conducted surveys when winds were less than 35 km/hr and wave height was less than 1 m. Pilots used a computerized moving map program to navigate along fixed electronic transects for precise replication. As two observers recorded bird sightings within 200 m of either side of the aircraft, the voice inputs into the onboard computer system interfaced with a Global Positioning System (GPS). This method provided position coordinates for each bird observation. Following each survey, the transcribed voice recordings were double-checked for accuracy and subjected to a customized computer check program. Next, we used ArcInfo scripts to create GIS coverages for distribution maps. To reduce measurement error, observers were trained in flock estimation using simulation software (Hodges, 1993). Observers used clinometers and radar altimeters to estimate transect width.

TABLE 2. Area surveyed (km^2) in the western Beaufort Sea, July 2001.

Depth	Zone	Area (km^2)
> 20 m	Barrow to Oliktok	150.3
	Oliktok to Brownlow	114.5
	Brownlow to Demarcation	219.6
10–20 m	Barrow to Oliktok	224
	Oliktok to Brownlow	82.3
	Brownlow to Demarcation	46.9
< 10 m	Barrow to Oliktok	167.1
	Oliktok to Brownlow	75.3
	Brownlow to Demarcation	29.1

We assumed that eider hens were the same species as the drakes accompanying them. By early August, however, most drakes had departed the survey area, making identification of hens difficult. Thus, we limit species-specific eider results to June and July, and report *Somateria* eiders (*S. mollissima*, *S. spectabilis*, *S. fischeri*, and unidentified eider spp.) for June, July, and August. We combined all scoters for analysis because of difficulty in distinguishing species from the air.

For summary purposes, we divided the study area into zones. In 1999 and 2000, we delineated eight zones, defined by two depth classes (< 10 m and > 10 m) within four areas. Area boundaries in 1999 and 2000 were Cape Halkett, Oliktok Point, the west dock at Prudhoe Bay, Tigvariak Island, and Brownlow Point. We calculated density as the number of birds per km^2. We restricted our density calculations to birds on the water, with the exception of glaucous gulls (*Larus hyperboreus*), which were seen almost exclusively in flight. We used analysis of variance to compare bird densities among zones and months. We identified a significant change in seasonal distribution by measuring the interaction between month and zone. Bird density did not vary among years ($p > 0.05$ in t-tests of all species); thus, we pooled data from 1999 and 2000. In 2001, we sampled farther offshore, allowing us to divide the study area into nine zones defined by three depth

TABLE 3. Numbers and percent composition of bird taxa observed during summer aerial surveys in the western Beaufort Sea (1999–2001).

Common Name	Scientific Name	Total Count	Percent of Total
Yellow-billed loon	*Gavia adamsii*	34	0.12
Pacific loon	*Gavia pacifica*	406	1.48
Red-throated loon	*Gavia stellata*	106	0.39
Shearwater spp.	*Puffinus* spp.	37	0.13
Tundra swan	*Cygnus columbianus*	21	0.08
Greater white-fronted goose	*Anser albifrons*	155	0.56
Lesser snow goose	*Chen caerulescens caerulescens*	25	0.09
Canada goose	*Branta canadensis*	28	0.10
Pacific black brant	*Branta bernicla nigricans*	85	0.31
Northern pintail	*Anas acuta*	173	0.63
Scaup spp.	*Aythya* spp.	237	0.86
Common eider	*Somateria mollissima*	1047	3.80
King eider	*Somateria spectabilis*	8034	29.20
Spectacled eider	*Somateria fischeri*	163	0.59
Steller's eider	*Polysticta stelleri*	3	0.01
Unidentified eider spp.	*Somateria* spp.	632	2.30
Black scoter	*Melanitta nigra*	46	0.17
White-winged scoter	*Melanitta fusca*	204	0.74
Surf scoter	*Melanitta perspicillata*	1434	5.21
Unidentified scoter spp.	*Melanitta* spp.	620	2.25
Long-tailed duck	*Clangula hyemalis*	12 330	44.81
Red-breasted merganser	*Mergus serrator*	33	0.12
Shorebird spp.	*Charadriidae* and *Scolopacidae* spp.	249	0.90
Jaeger spp.	*Stercorarius* spp.	90	0.33
Glaucous gull	*Larus hyperboreus*	1116	4.06
Sabine's gull	*Xema sabini*	53	0.19
Black-legged kittiwake	*Rissa tridactyla*	22	0.08
Arctic tern	*Sterna paradisaea*	128	0.47
Black guillemot	*Cepphus grylle*	3	0.01
Auklet spp.	*Aethia* spp.	3	0.01
Total		27 517	100.00

classes (< 10 m, 10–20 m, and > 20 m) within three areas bounded by Barrow, Oliktok Point, Brownlow Point, and Demarcation Point. We compared bird distribution in 2001 among these zones with analysis of variance. Sample units were the segment of a transect within a zone, resulting in 72 segments per month in 1999, 86 segments per month in 2000, and 152 segments in 2001 (July survey only).

To measure the relation between bird density and ice cover, we used data collected in July 2001. For this analysis, we subdivided transects into 5 km segments and calculated bird density within each unit. Units were then assigned to one of three ice categories according to percent cover recorded during surveys (low: 0–30%; moderate: 31–60%; and high: 61–100%). We used analysis of variance to detect differences in bird density among ice categories. We included distance from shore as a covariate in these analyses to control for possible interactions between ice cover and nearshore breakup.

Prior to statistical tests, we subjected density data to log transformation to reduce skewness (Johnson and Gazey, 1992). Significant differences were identified at the alpha = 0.05 level.

RESULTS

We observed a total of 27 517 birds belonging to 30 taxa during surveys in the western Beaufort Sea in 1999, 2000, and 2001 (Table 3). Long-tailed ducks comprised the largest proportion of birds (44.8%), followed by eiders (35.9%), scoters (8.4%), glaucous gulls (4.1%), and loons (*Gavia* spp.; 2.0%). Together, these taxa comprised over 95% of the avifauna in the survey area.

Densities of marine birds in the western Beaufort Sea showed significant temporal and spatial variability. Below we report the geographic distribution of long-tailed ducks, eiders, scoters, glaucous gulls, and Pacific loons (*Gavia pacifica*) with respect to month and ice cover. We also report incidental sightings of other taxa (Table 3).

Long-Tailed Duck

1999 and 2000: The long-tailed duck was the most abundant marine bird observed during offshore surveys in 1999 and 2000. Densities of long-tailed ducks increased after the onset of post-breeding moult in July and remained high through August ($F_{2,449} = 23.80$, $p < 0.001$; Table 4). When we controlled for summer month, densities of long-tailed ducks were significantly higher in zones with shallow water (< 10 m) than in those with deep water (> 10 m; $F_{7,449} = 21.42$, $p < 0.001$; Table 4; Fig. 2). While densities were higher in shallow zones in all months, the difference was significantly more pronounced in July and August, when long-tailed ducks were undergoing a post-breeding moult (interaction between month and zone: $F_{14,449} = 4.534$, $p < 0.001$). In July, the shallow zone between Tigvariak Island and Brownlow Point

TABLE 4. Mean density (birds/km^2), by species, month, and depth, for the four zones surveyed in 1999 and 2000 (SE in parentheses). Density estimates are back-transformed from log transformation.

		Halkett-Oliktok		Oliktok-Prudhoe		Prudhoe-Tigvariak		Tigvariak-Brownlow	
Species	Month	Deep[1]	Shallow[2]	Deep	Shallow	Deep	Shallow	Deep	Shallow
Long-tailed duck									
	June	0.00 (0.00)	0.14 (0.07)	0.05 (0.05)	0.56 (0.16)	0.03 (0.01)	0.32 (0.14)	0.12 (0.08)	0.28 (0.14)
	July	0.04 (0.02)	1.02 (0.20)	0.17 (0.14)	1.39 (0.22)	0.01 (0.01)	2.80 (0.40)	0.04 (0.04)	11.22 (0.61)
	August	0.35 (0.12)	2.06 (0.23)	0.18 (0.05)	2.34 (0.28)	0.12 (0.05)	1.32 (0.28)	0.06 (0.04)	4.50 (0.75)
King eider									
	June	0.06 (0.04)	0.09 (0.07)	0.00 (0.00)	0.12 (0.06)	0.03 (0.03)	0.12 (0.06)	0.00 (0.00)	0.25 (0.21)
	July	2.99 (0.22)	0.46 (0.16)	0.71 (0.20)	0.14 (0.14)	0.71 (0.27)	0.16 (0.13)	0.00 (0.00)	0.06 (0.06
	August	—	—	—	—	—	—	—	—
Common eider									
	June	0.00 (0.00)	0.36 (0.17)	0.00 (0.00)	0.38 (0.18)	0.05 (0.05)	0.43 (0.08)	0.11 (0.10)	0.47 (0.22)
	July	0.02 (0.01)	0.01 (0.01)	0.09 (0.06)	0.44 (0.18)	0.00 (0.00)	0.36 (0.11)	0.13 (0.13)	0.38 (0.23)
	August	—	—	—	—	—	—	—	—
Spectacled eider									
	June	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	July	0.12 (0.08)	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	August	—	—	—	—	—	—	—	—
Eider spp.[3]									
	June	0.06 (0.04)	0.43 (0.18)	0.00 (0.00)	0.47 (0.19)	0.06 (0.06)	0.53 (0.10)	0.11 (0.100)	0.63 (0.29)
	July	3.52 (0.21)	0.47 (0.16)	0.79 (0.20)	0.64 (0.22)	0.71 (0.27)	0.55 (0.16)	0.13 (0.13)	0.40 (0.24)
	August	0.63 (0.15)	0.31 (0.12)	0.09 (0.05)	0.09 (0.05)	0.10 (0.04)	0.09 (0.03)	0.12 (0.07)	0.54 (0.23)
Scoter spp.									
	June	0.00 (0.00)	0.13 (0.06)	0.00 (0.00)	0.03 (0.03)	0.02 (0.01)	0.23 (0.12)	0.00 (0.00)	0.02 (0.02)
	July	0.04 (0.03)	0.39 (0.13)	0.10 (0.10)	0.26 (0.12)	0.01 (0.01)	0.07 (0.04)	0.04 (0.04)	0.00 (0.00)
	August	0.00 (0.00)	0.03 (0.02)	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	0.08 (0.06)	0.00 (0.00)
Glaucous gull									
	June	0.01 (0.01)	0.43 (0.06)	0.01 (0.01)	0.64 (0.14)	0.00 (0.00)	0.71 (0.16)	0.00 (0.00)	0.50 (0.14)
	July	0.04 (0.01)	0.16 (0.04)	0.04 (0.02)	0.30 (0.08)	0.03 (0.01)	0.43 (0.13)	0.02 (0.01)	0.31 (0.11)
	August	0.02 (0.01)	0.25 (0.06)	0.02 (0.01)	0.70 (0.15)	0.00 (0.00)	0.24 (0.05)	0.00 (0.00)	0.16 (0.08)
Pacific loon									
	June	0.00 (0.00)	0.08 (0.03)	0.02 (0.01)	0.21 (0.07)	0.03 (0.01)	0.07 (0.03)	0.05 (0.02)	0.02 (0.02)
	July	0.05 (0.01)	0.14 (0.03)	0.03 (0.01)	0.03 (0.03)	0.05 (0.02)	0.09 (0.03)	0.03 (0.02)	0.02 (0.02)
	August	0.05 (0.02)	0.13 (0.03)	0.02 (0.01)	0.11 (0.04)	0.02 (0.01)	0.03 (0.02)	0.01 (0.01)	0.04 (0.03)

[1] More than 10 m deep.

[2] Less than 10 m deep.

[3] Identified and unidentified eiders.

hosted the highest densities of long-tailed ducks. In June, long-tailed ducks were seen offshore in small open-water areas, primarily in the eastern study area, whereas in August, they were more widespread.

2001: Long-tailed ducks were the most abundant bird observed in the expanded survey area in July 2001. Long-tailed duck densities varied significantly among zones ($F_{8,143}$ = 15.54, $p < 0.001$; Table 5), with highest densities in shallow water (Fig. 2). High densities were seen in lagoons between Oliktok Point and Brownlow Point, but these estimates were not significantly higher than those in other shallow-water zones.

Distribution of long-tailed ducks varied with ice cover. Long-tailed duck densities were significantly higher in areas with low ice cover (< 31%) than in areas with moderate (31–60%) and high (> 60%) ice cover ($F_{2,614}$ = 40.348, $p < 0.001$; Table 6).

All Eiders

1999 and 2000: Eiders were abundant in the study area. Densities were highest during post-breeding moult migration in July ($F_{2,449}$ = 12.32, $p < 0.001$; Table 4). Eiders were not evenly distributed throughout the survey area ($F_{7,449}$ = 4.609, $p < 0.001$; Table 4; Fig. 3), and distribution changed significantly between June and July ($F_{14,449}$ = 4.155, $p < 0.001$. For example, densities were higher in shallow-water vs. deepwater zones in June, whereas in July and August, eiders were concentrated in deep water between Cape Halkett and Oliktok Point. In August, densities were also high in shallow water between Tigvariak Island and Brownlow Point (Table 4).

2001: Eiders were abundant in the 2001 survey but were not distributed evenly through the survey area ($F_{8,143}$ = 11.124, $p < 0.001$). Highest densities were seen in shallow and mid-depth water between Barrow and Oliktok Point (Table 5; Fig. 3). While most eiders were west of Oliktok Point, smaller flocks were seen in the central and eastern portions of the study area close to barrier islands or the mainland shoreline. Eider density varied with ice cover: densities were higher in areas of low and moderate ice cover than in areas of high ice cover ($F_{2,614}$ = 15.645, $p < 0.001$; Table 6).

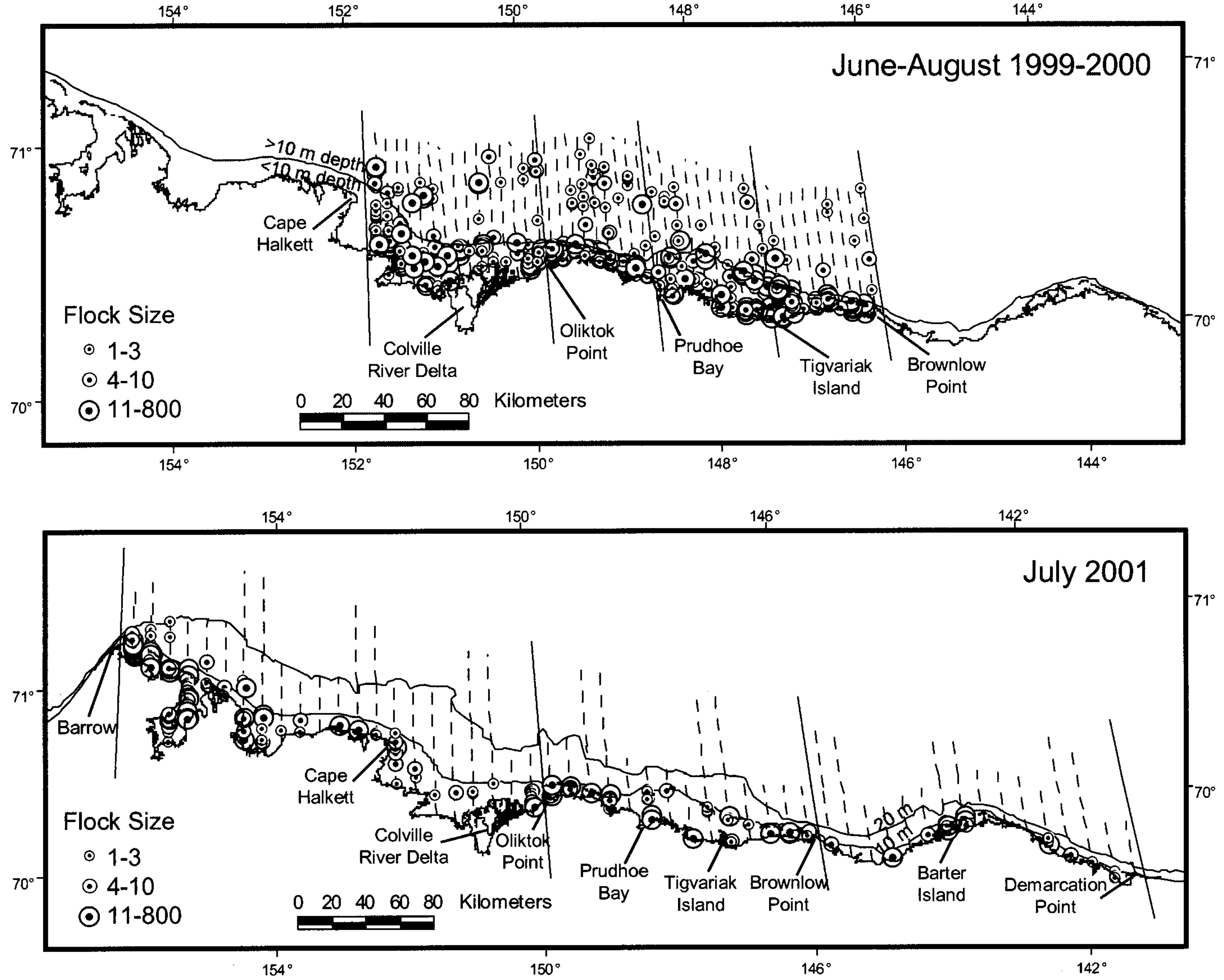

FIG. 2. Long-tailed duck flock locations in June, July, and August (1999 and 2000) and July 2001. Solid lines indicate zone boundaries; dashed lines indicate transects.

King Eider

1999 and 2000: King eiders were abundant in the western Beaufort Sea in 1999 and 2000, second only to long-tailed ducks. Densities of king eiders throughout the study area were significantly lower in June than in July ($F_{1,299} = 20.368$, $p < 0.001$; Table 4). After controlling for month, densities were significantly higher in the western deepwater zone between Cape Halkett and Oliktok Point than in other zones ($F_{7,299} = 6.108$, $p < 0.001$; Table 4; Fig. 4).

2001: King eiders were abundant in 2001 as well. Densities of this species were relatively low throughout the study area except in the mid-depth zone between Barrow and Oliktok Point (Fig. 4). There, king eiders concentrated in large flocks and comprised the largest proportion of avifauna.

King eider densities varied among zones and ice categories. Mean distance offshore was 16.5 km, with 81% of king eiders occurring more than 10 km from shore. With the exception of a single flock between Oliktok Point and Brownlow Point, king eiders were found only to the west of Oliktok Point (Fig. 4). Densities of king eiders were significantly higher in the shallow and mid-depth zones between Barrow and Oliktok Point than in other zones in the study area ($F_{8,143} = 10.078$, $p < 0.001$; Table 5). King eiders were not present in mid-depth and deep waters to the east, despite large areas of open water there. King eider distribution was unique in that densities were high in both low and moderate ice cover ($F_{2,614} = 11.267$, $p < 0.001$; Table 6), whereas densities of other species were high in low ice cover only.

Common Eider

1999 and 2000: Common eiders were seen frequently in 1999 and 2000. Unlike those of other species, densities of

TABLE 5. Mean density (birds/km^2), by species and depth, for the three zones surveyed in July 2001 (SE in parentheses). Density estimates are back-transformed from log transformation.

	Barrow-Oliktok			Oliktok-Brownlow			Brownlow-Demarcation		
Species	Deep[1]	Mid[2]	Shallow[3]	Deep	Mid	Shallow	Deep	Mid	Shallow
Long-tailed duck	0.05 (0.05)	0.20 (0.09)	3.36 (0.34)	0.00 (0.00)	0.00 (0.00)	7.00 (0.44)	0.00 (0.00)	0.04 (0.03)	2.35 (0.40)
King eider	0.06 (0.06)	2.67 (0.30)	1.07 (0.27)	0.00 (0.00)	0.00 (0.00)	0.12 (0.12)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Common eider	0.00 (0.00)	0.07 (0.05)	0.31 (0.12)	0.00 (0.00)	0.01 (0.01)	0.23 (0.13)	0.00 (0.00)	0.00 (0.00)	0.30 (0.21)
Spectacled eider	0.00 (0.00)	0.01 (0.01)	0.05 (0.04)	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Eider spp.[4]	0.06 (0.06)	3.25 (0.29)	2.07 (0.28)	0.00 (0.00)	0.15 (0.08)	0.48 (0.16)	0.00 (0.00)	0.00 (0.00)	0.37 (0.22)
Scoter spp.	0.00 (0.00)	0.00 (0.00)	0.48 (0.19)	0.00 (0.00)	0.02 (0.02)	0.67 (0.26)	0.03 (0.03)	0.00 (0.00)	0.00 (0.00)
Glaucous gull	0.04 (0.02)	0.08 (0.03)	0.25 (0.06)	0.01 (0.01)	0.04 (0.03)	0.49 (0.16)	0.08 (0.04)	0.06 (0.04)	0.98 (0.25)
Pacific loon	0.01 (0.00)	0.08 (0.02)	0.30 (0.05)	0.00 (0.00)	0.08 (0.03)	0.37 (0.08)	0.01 (0.01)	0.08 (0.04)	0.11 (0.06)

[1] More than 20 m deep.

[2] 10–20 m deep.

[3] Less than 10 m deep.

[4] Identified and unidentified eiders.

common eiders did not vary significantly among summer months ($F_{1,299} = 0.513$, $p = 0.475$), but densities did vary among zones of the study area (Table 4). In general, common eiders were concentrated in the shallow-water zones, with the highest densities between Oliktok Point and Prudhoe Bay and between Tigvariak Island and Brownlow Point (Fig. 5). In these areas, common eider pairs, flocks, and broods were concentrated close to barrier islands. Lower densities of common eiders were observed seaward of the barrier islands up to 50 km from shore.

2001: As in previous years, common eiders were concentrated in shallow waters in 2001 (Fig. 5). While there was a tendency for common eiders to occur close to shore, we did not detect significant differences in densities among zones ($F_{8,143} = 1.951$, $p = 0.057$; Table 5). In shallow-water zones, common eiders were generally distributed near barrier islands and within nearshore coves and lagoons.

Ice cover influenced common eider distribution. Common eider densities were significantly higher in areas of low ice cover than in areas with moderate or high ice cover ($F_{2,614} = 6.316$, $p = 0.002$; Table 6).

Spectacled Eider

1999 and 2000: Spectacled eiders were uncommon in the 1999 and 2000 surveys. We observed a total of five flocks (144 individuals) in July 2000. These flocks were all located within the deepwater zone between Cape Halkett and Oliktok Point (Table 4; Fig. 6). Given their sparse distribution, we did not detect significant differences in density between months ($F_{1,299} = 1.104$, $p = 0.315$) or zones ($F_{7,299} = 1.364$, $p = 0.220$). All spectacled eiders, however, were seen offshore from the Colville River Delta, suggesting that the area may be an important staging location for the species.

2001: Spectacled eider density was low in 2001 (Table 5). We observed 15 individuals in shallow and mid-depth waters between Prudhoe Bay and Barrow (Fig. 6). We detected no significant differences in density among zones ($F_{8,143} = 0.992$, $p = 0.445$) or among ice-cover categories ($F_{2,614} = 1.209$, $p = 0.299$; Table 6).

TABLE 6. Mean density (birds/km^2) by species of birds observed in three ice-cover categories in July 2001 (SE in parentheses). Density estimates are back-transformed from log transformation.

Species	Ice cover		
	Low (<31%)	Moderate (31%–60%)	High (> 60%)
Long-tailed duck	0.89 (0.08)	0.04 (0.02)	0.01 (0.01)
King eider	0.27 (0.05)	0.36 (0.09)	0.02 (0.01)
Common eider	0.07 (0.02)	0.01 (0.01)	0.00 (0.00)
Spectacled eider	0.01 (0.01)	0.01 (0.01)	0.00 (0.00)
Eider spp.[1]	0.41 (0.06)	0.44 (0.09)	0.02 (0.02)
Scoter spp.	0.13 (0.03)	0.01 (0.01)	0.00 (0.00)
Glaucous gull	0.17 (0.02)	0.04 (0.02)	0.03 (0.01)
Pacific loon	0.14 (0.02)	0.04 (0.01)	0.01 (0.01)

[1] Identified and unidentified eiders.

Scoters

1999 and 2000: Scoters were common in the survey area in 1999 and 2000. We observed surf scoters (*Melanitta perspicillata*), black scoters (*M. nigra*), and white-winged scoters (*M. fusca*) during surveys. Of these, surf scoters were the most common, representing 88% of the scoters that we identified to species. Because of the high proportion of unidentified scoters (27%), we combined all scoters for analysis. Density of scoters was significantly higher in July than in other months ($F_{2,499} = 4.197$, $p = 0.016$; Table 4). Scoter density also varied among zones ($F_{7,499} = 3.079$, $p = 0.004$), but a high degree of overlap in confidence intervals precluded detection of significant differences between most zones. In general, shallow water between Cape Halkett and Oliktok Point was important in all months, particularly in July when densities were highest (Fig. 7). In June, shallow water between Prudhoe Bay and

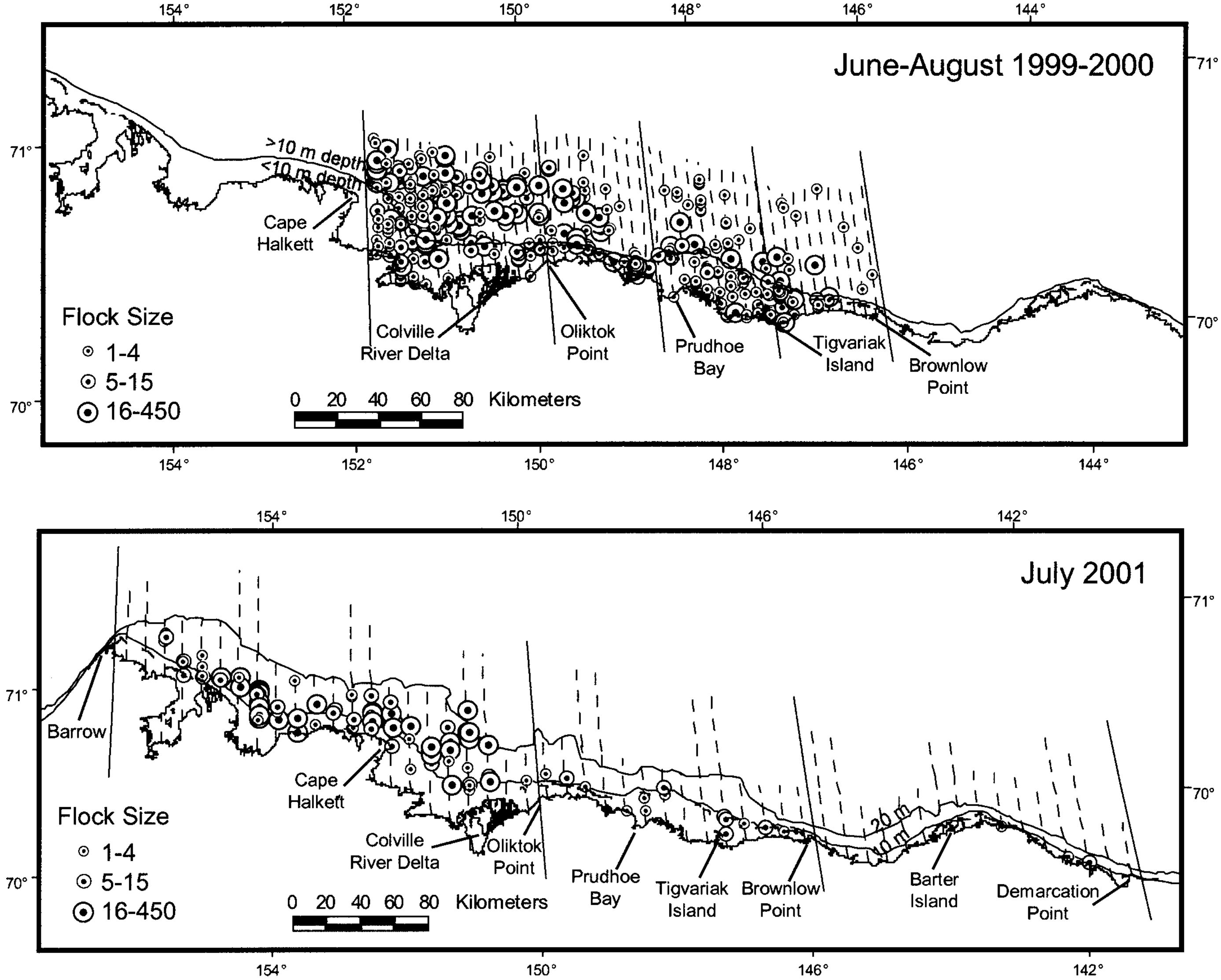

FIG. 3. Eider flock locations in June, July, and August (1999 and 2000) and July 2001. All *Somateria* spp. combined. Solid lines indicate zone boundaries; dashed lines indicate transects.

Tigvariak Island supported relatively high densities of scoters, whereas no scoters were seen there in August. In August, densities were highest in deepwater zones east of Oliktok Point and in shallow water west of Oliktok Point.

2001: Distribution of scoters in 2001 was similar to those of 1999 and 2000. Scoter density was significantly higher in shallow water between Barrow and Brownlow Point than in other zones ($F_{8,143}$ = 3.785, $p < 0.001$; Table 5). Within these areas, most scoters were concentrated west of Prudhoe Bay (Fig. 7). Scoters were relatively uncommon in water deeper than 10 m. Densities were significantly higher in areas of low ice cover than in areas of moderate or high ice cover ($F_{2,614}$ = 7.711, $p < 0.001$; Table 6).

Glaucous Gull

1999 and 2000: Glaucous gulls were less abundant than long-tailed ducks, eiders or scoters in 1999 and 2000. Unlike other birds observed during these surveys, glaucous gulls occurred in significantly higher densities in June than in July and August ($F_{2,449}$ = 3.397, $p = 0.034$; Table 4). Glaucous gulls were not equally distributed throughout the study area; rather, densities were consistently higher in shallow-water zones than in deep water ($F_{7,449}$ = 20.147, $p < 0.001$; Table 4; Fig. 8).

2001: In 2001, glaucous gulls were more uniformly distributed than in 1999 and 2000. Densities were higher in shallow water east of Oliktok Point than in other zones ($F_{8,143}$ = 6.085, $p < 0.001$; Table 5). While these nearshore areas were important, glaucous gulls were also seen in low densities at the northern extent of some transects, as far as 75 km from shore (Fig. 8). Despite the wide distribution of glaucous gulls, their densities were higher in areas with low ice cover than in areas with greater ice cover ($F_{2,614}$ = 14.743, $p < 0.001$; Table 6).

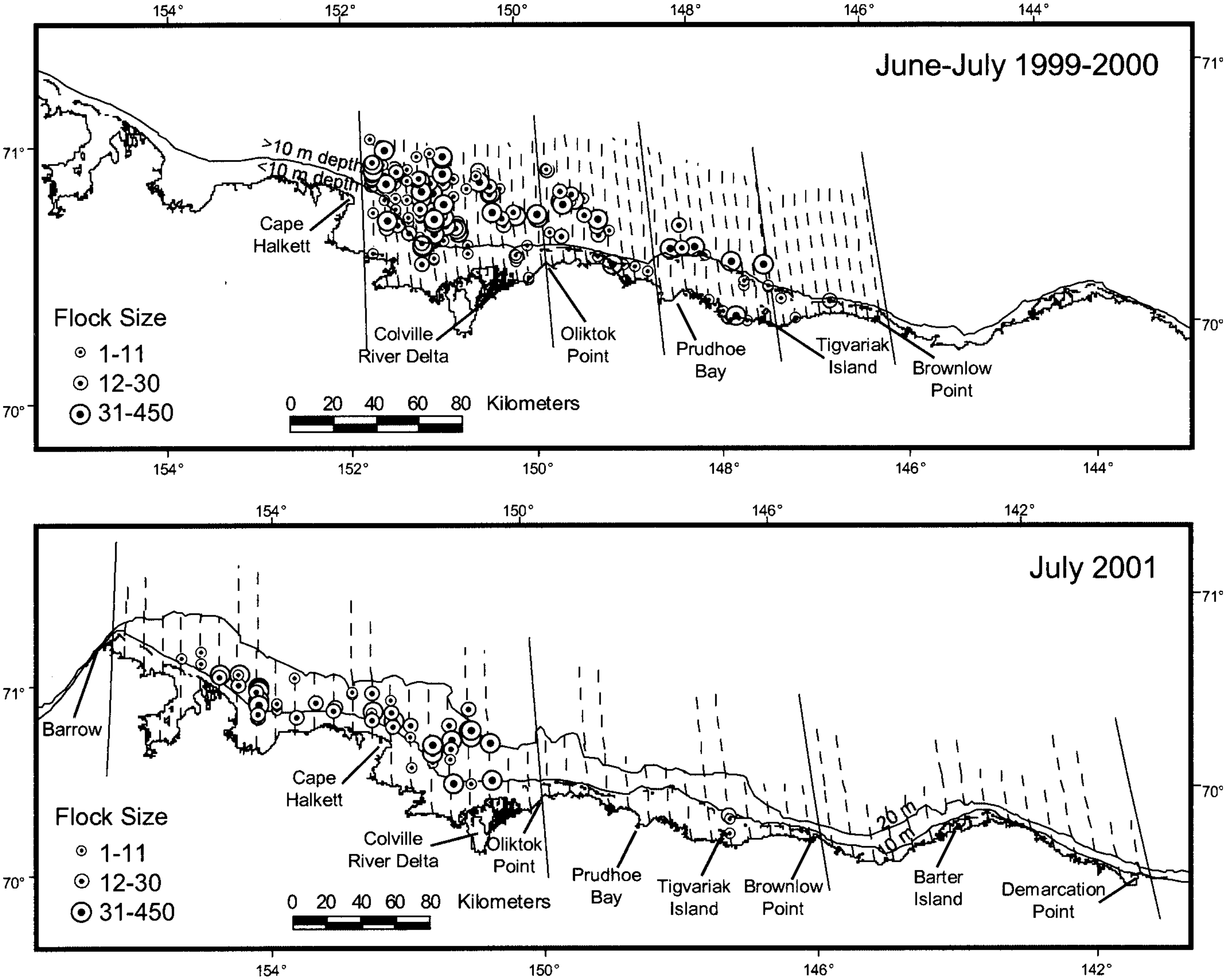

FIG. 4. King eider flock locations in June and July (1999 and 2000) and July 2001. Solid lines indicate zone boundaries; dashed lines indicate transects.

Pacific Loon

1999 and 2000: Pacific loons were ubiquitous in the survey area during 1999 and 2000. Although sightings were common, Pacific loons were generally seen as singles or in pairs rather than in flocks; thus, densities were relatively low compared to those of other marine birds. While density of Pacific loons did not vary through summer ($F_{2,449} = 0.225$, $p = 0.799$), it did vary among zones ($F_{7,449} = 7.022$, $p < 0.001$; Table 4; Fig. 9), with highest densities in shallow water between Cape Halkett and Prudhoe Bay. Distribution, however, changed significantly between months ($F_{14,449} = 2.282$, $p = 0.005$). For example, in both June and August, Pacific loon densities were high in all shallow zones, whereas in July, loons were concentrated specifically in shallow water west of Oliktok Point.

2001: Pacific loons were broadly distributed through the study area in 2001. While densities in most zones were comparable, shallow water between Barrow and Brownlow Point hosted the highest concentrations of Pacific loons ($F_{8,143} = 6.085$, $p < 0.001$; Table 5). Most Pacific loons were close to shore in shallow water, but we observed individuals and pairs up to 60 km from shore (Fig. 9). Like most other species, Pacific loons were concentrated in areas with low ice cover ($F_{2,614} = 27.096$, $p < 0.001$; Table 6).

Other Taxa

Eighteen additional taxa were seen during the survey (Table 3) in very low numbers that made comparisons among zones, months, and ice conditions difficult. Most red-throated loons (*Gavia stellata*) were observed in shallow water between Oliktok Point and Brownlow Point, but several were seen near the northern extent of transects, more than 50 km from shore. We recorded 34 yellow-billed loons (*Gavia adamsii*) in the study area between 1999 and 2001. Of these, most were in Harrison Bay between Cape Halkett and the Colville River Delta. Only three yellow-billed loons were detected beyond 10 m depth. We also observed small flocks of greater white-

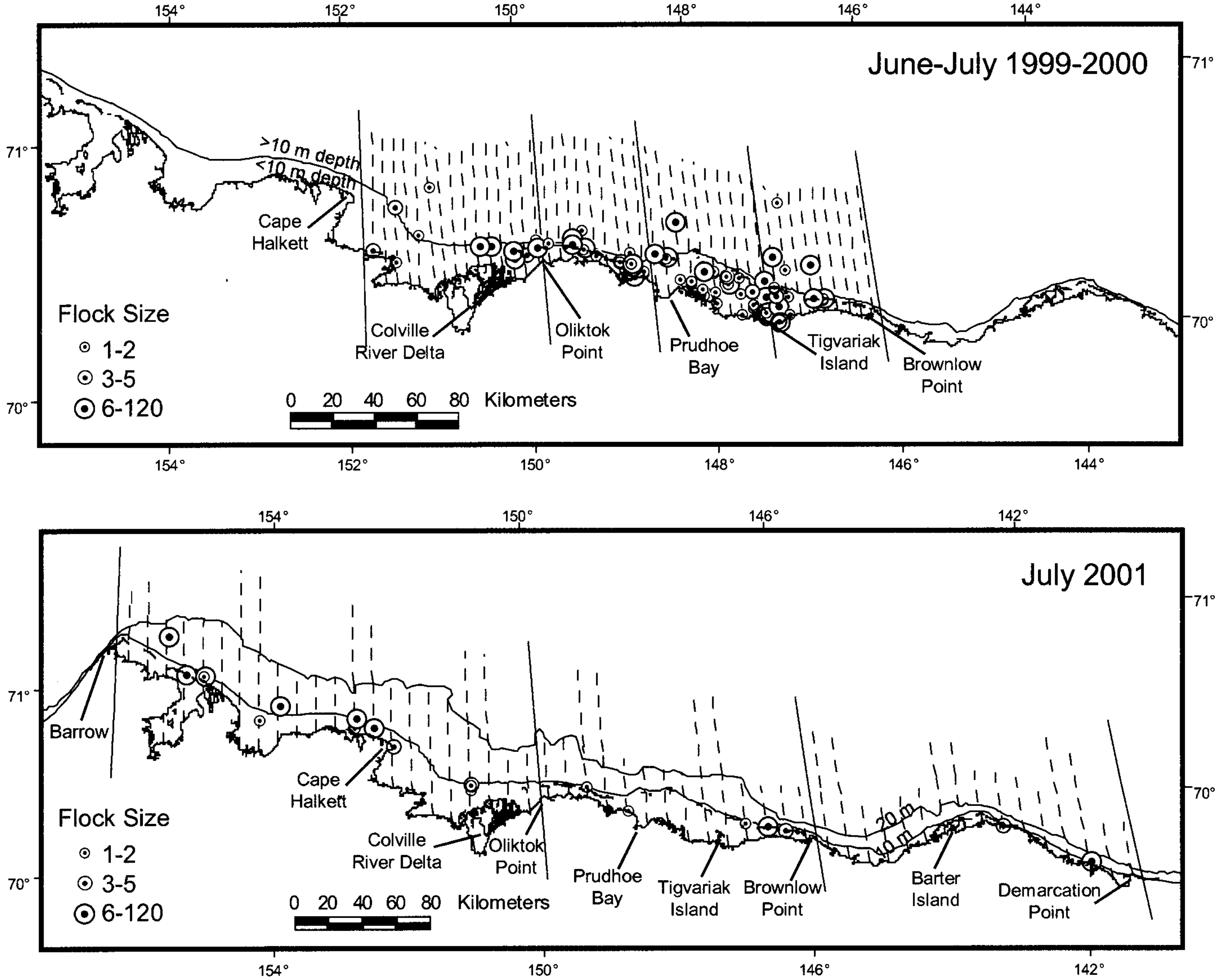

FIG. 5. Common eider flock locations in June and July (1999 and 2000) and July 2001. Solid lines indicate zone boundaries; dashed lines indicate transects.

fronted geese (*Anser albifrons*), lesser snow geese (*Chen caerulescens caerulescens*), Pacific black brant (*Branta bernicla nigricans*), and Canada geese (*B. canadensis*) along the coastline throughout the study area. Scaup (*Aythya* spp.) were seen close to shore west of Prudhoe Bay, with the highest concentrations near the outlet of the Colville River Delta and in large bays west of Cape Halkett. Low numbers of northern pintails (*Anas acuta*) and red-breasted mergansers (*Mergus serrator*) were also observed along the mainland coastline and the shorelines of barrier islands from Barrow to Demarcation Point. A flock of three Steller's eiders (*Polysticta stelleri*) was seen close to shore approximately 80 km southeast of Barrow. We observed flocks of unidentified shorebirds (Charadriidae or Scolopacidae spp.) along the mainland coastline and barrier islands from Cape Halkett to Brownlow Point. We also observed small groups of shearwaters (*Puffinus* spp.) foraging 25–55 km from shore between Oliktok Point and Brownlow Point in August 2000. Jaegers (*Stercorarius* spp.) were noted up to 75 km from shore throughout the entire span of the survey area. We observed small numbers of other seabirds in deep waters, including Sabine's gulls (*Xema sabini*), black-legged kittiwakes (*Rissa tridactyla*), Arctic terns (*Sterna paradisaea*), black guillemots (*Cepphus grylle*), and unidentified auklets (*Aethia* spp.).

DISCUSSION

Marine Bird Density and Distribution

We found that offshore densities varied along an east-west gradient, from species to species, with stage of summer, and in relation to ice cover. Nearshore areas appeared to be more important than offshore areas, largely because of the high abundance of long-tailed ducks that concentrate in nearshore lagoons to moult. In contrast, king eiders were found primarily in offshore waters more

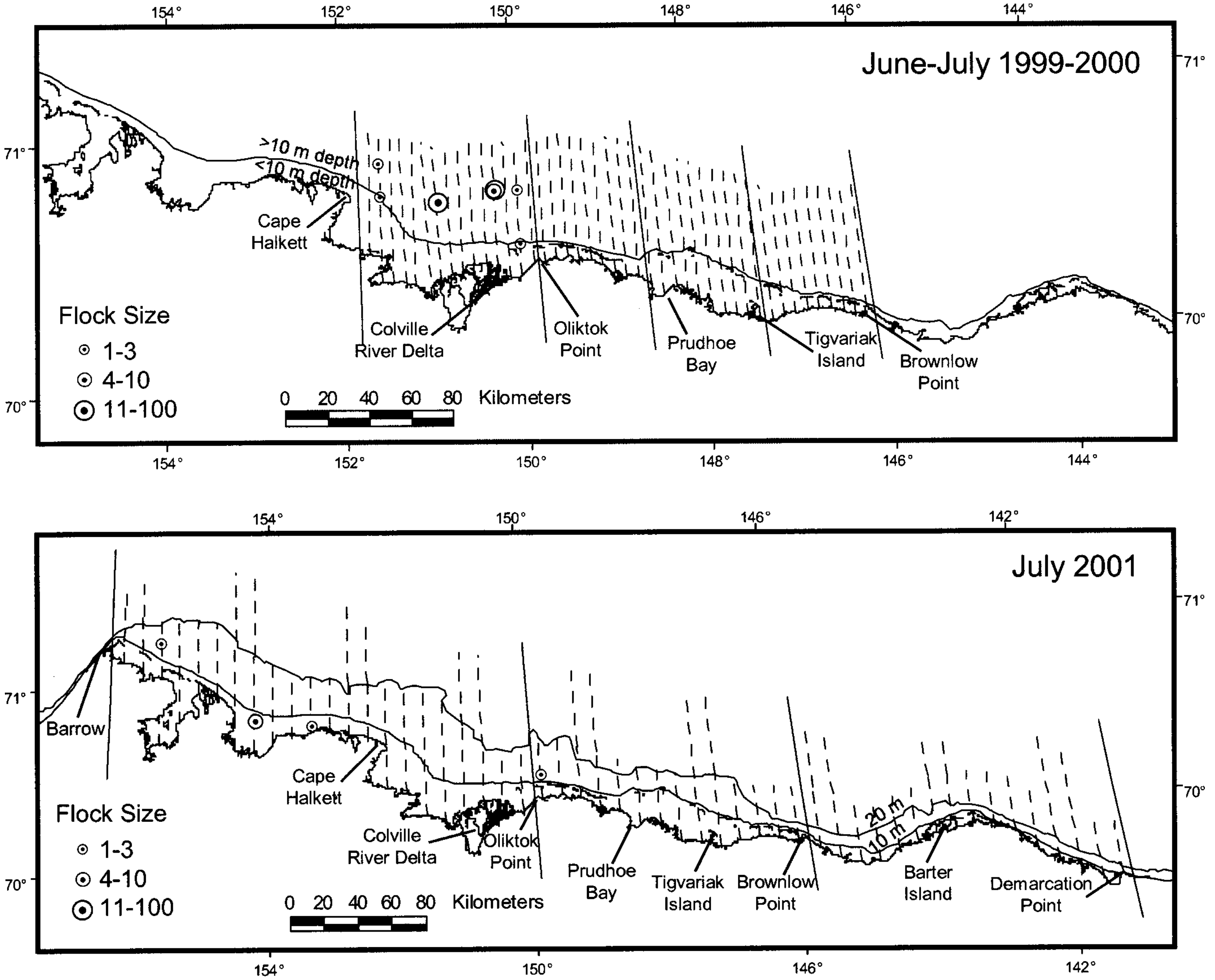

FIG. 6. Spectacled eider flock locations in June and July (1999 and 2000) and July 2001. Solid lines indicate zone boundaries; dashed lines indicate transects.

than 10 m deep west of Oliktok Point. Within this area, densities of king eiders were higher than those of long-tailed ducks. These spatial differences in species composition and density demonstrate that general conclusions about large geographic areas may misrepresent species-specific areas of importance.

Distribution patterns of birds observed in the Beaufort Sea appear to reflect the needs of individual species to moult, migrate, raise young, and forage. We observed an influx of long-tailed ducks into coastal lagoons in July, followed by dispersal to other areas in late August. This pattern is consistent with the explanation that nearshore coastal lagoons in the Beaufort Sea are important to moulting long-tailed ducks. Johnson and Richardson (1982) reported concentrations of up to 50 000 long-tailed ducks in nearshore waters between Oliktok Point and Prudhoe Bay in late July. These lagoons provide important habitat for moulting long-tailed ducks and scoters, providing abundant food availability, low risk of predation, and protection from wind, waves, and pack ice (Johnson and Richardson, 1982). Such characteristics can be critical to moulting birds when nutritional requirements and susceptibility to predation are high (Hohman et al., 1992). Offshore observations of long-tailed ducks in late June likely included late spring migrants or failed breeders en route to moulting grounds from breeding areas to the east. Our late-summer observations of long-tailed ducks are similar to those reported in ship-based studies that detected dispersal away from nearshore lagoons at the onset of fall migration (Divoky, 1984a).

Summer king eider distributions indicate that the Beaufort Sea provides an important post-breeding migratory pathway. Densities of king eiders were highest in late July, during the peak exodus of drakes from breeding grounds (Johnson and Herter, 1989). Like Harrison (1977), we found high densities of eiders in offshore waters west of Oliktok Point, where most birds occurred in waters more than 10 m deep and (on average) 16.5 km from the

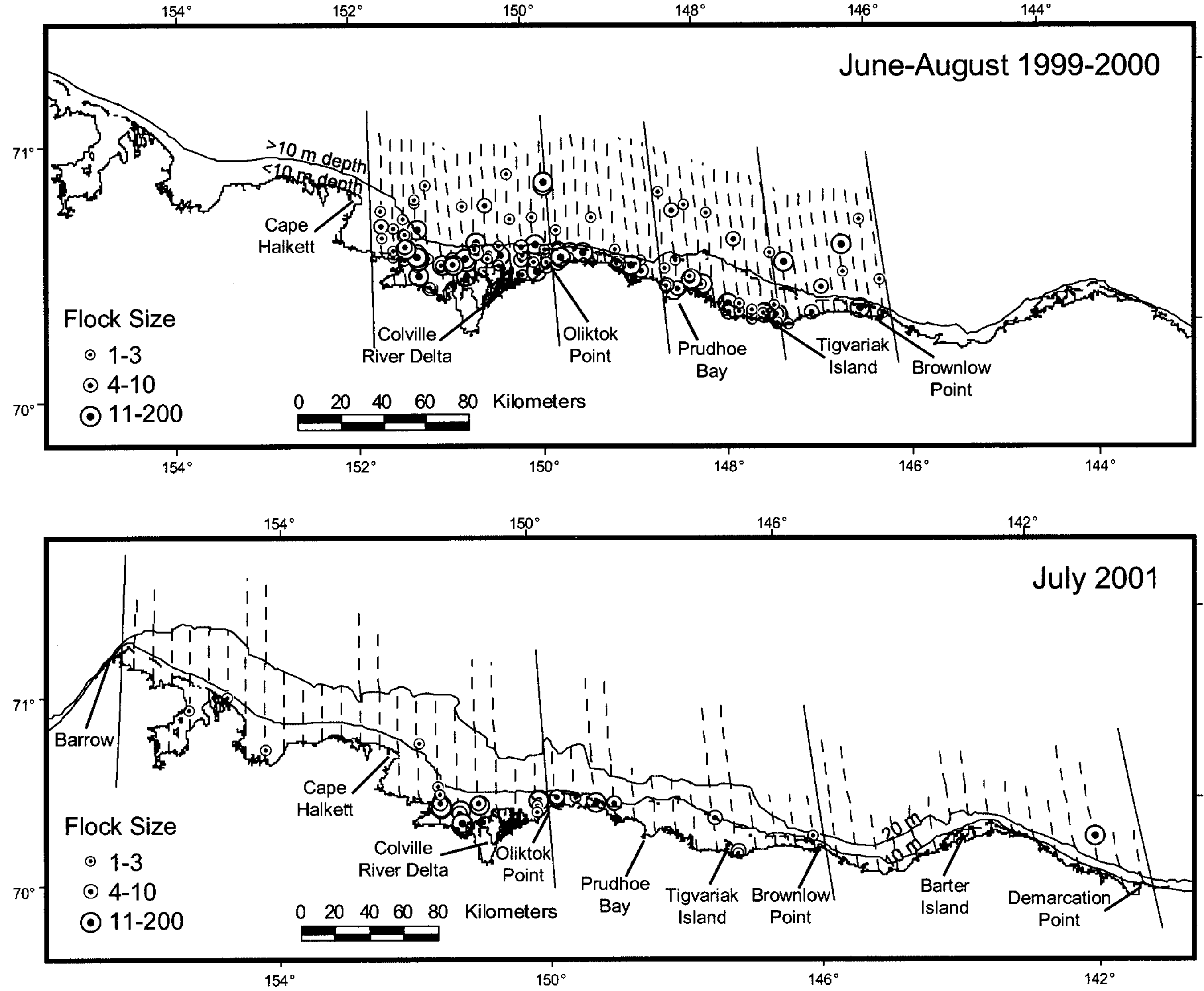

FIG. 7. Scoter flock locations in June, July, and August (1999 and 2000) and July 2001. All *Melanitta* spp. combined. Solid lines indicate zone boundaries; dashed lines indicate transects.

mainland. This finding largely corresponds with results from other studies of post-breeding king eiders migrating through the Beaufort Sea west of Oliktok Point (Dickson et al., 1998, 1999, 2000, 2001). A study of post-breeding spectacled eider migration showed that eiders used the Beaufort Sea between Oliktok Point and Barrow 3–25 km from shore (Petersen et al., 1999), while ship-based surveys identified the 20 m isobath as the primary corridor for migrating eiders (Divoky, 1984a). Johnson and Richardson (1982) found that eiders avoided nearshore waters during migration and moved west in a broad front. They predicted that eiders from Canada transit the Beaufort Sea far offshore and come closer to the Alaskan coast somewhere between Oliktok Point and Point Barrow. Our results support Johnson and Richardson's prediction, given the low densities of king eiders east of Prudhoe Bay and high densities west of Oliktok Point. However, preliminary results from satellite telemetry indicate that some post-breeding king eiders from Canada approach the Alaska coast east of Brownlow Point (4 of 10 satellite-marked king eiders located there; Dickson et al., 1998, 1999, 2000, 2001).

Common eiders use the Beaufort Sea to breed, migrate, and moult. Most common eiders were observed in shallow water near barrier islands where many breed (Schamel, 1977; Johnson, 2000; Flint et al., 2003). In these areas, we found that common eider densities did not vary significantly between summer months, suggesting that the eiders were local breeders rather than moult or fall migrants. Previous studies indicated that common eider broods depart barrier islands with adult hens in late June and remain in shallow waters nearby (Schamel, 1977). Recent satellite telemetry data showed that local breeding hens remained close to breeding sites in shallow waters through September (Petersen and Flint, 2002). Aerial survey crews observed common eider broods in barrier island lagoons between late July and early September (Fischer, unpubl. data). In this study, we observed hens with broods near

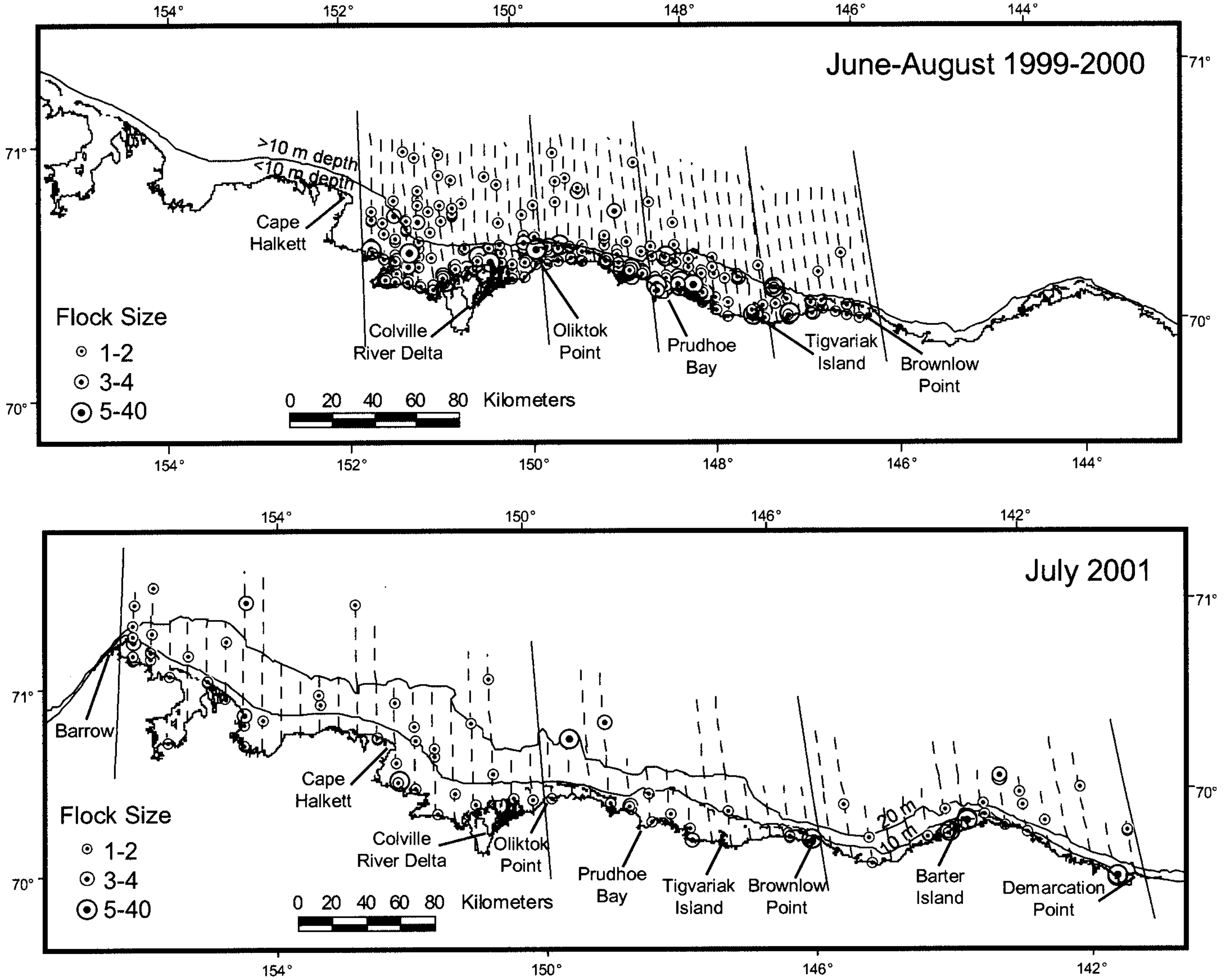

FIG. 8. Glaucous gull flock locations in June, July, and August (1999 and 2000) and July 2001. Solid lines indicate zone boundaries; dashed lines indicate transects.

barrier islands in late July. In addition to brood-rearing habitat, marine waters may also provide a corridor for migrating common eiders. Local breeding common eider drakes migrate from the Beaufort Sea in late July (Johnson, 2000). During this period, we observed flocks of common eiders up to 35 km from shore that may have been en route to moulting grounds. Finally, some common eiders may remain in the Beaufort Sea to moult (Johnson, 2000; Petersen and Flint, 2002), although we were unable to confirm this during aerial surveys.

Loons and gulls likely use the Beaufort Sea in summer to forage for themselves and provision their young. Previous studies have shown that loons forage within aquatic habitats and nearshore marine waters of the Beaufort Sea (Bergman and Derksen, 1977; Andres, 1993). Post-breeding red-throated and Pacific loons do not migrate or moult before September (Kessel, 1989; Barr et al., 2000); thus, it is unlikely that the loons we observed used the Beaufort Sea as moulting habitat or as a migratory pathway in summer. Alternatively, loons observed in marine waters may have been nonbreeding birds en route to wintering areas. Densities of loons did not vary among months, however, suggesting residency in the area throughout the summer. Glaucous gulls feed primarily on arctic cod in pelagic waters of the western Beaufort Sea (Divoky, 1984b). Our surveys were all completed before September, when this species typically begins its fall migration (Gilchrist, 2001); thus, the gulls we observed were likely individuals from local populations that breed on the mainland and on barrier islands and forage in the marine environment.

Effects of Ice Conditions

Ice conditions greatly influence distribution of marine birds in the Beaufort Sea (Norton and Weller, 1984) and are critical to survival of migrant birds there in spring (Barry, 1968; Stirling, 1980). Spring migration of most species occurs before the date when we initiated this study

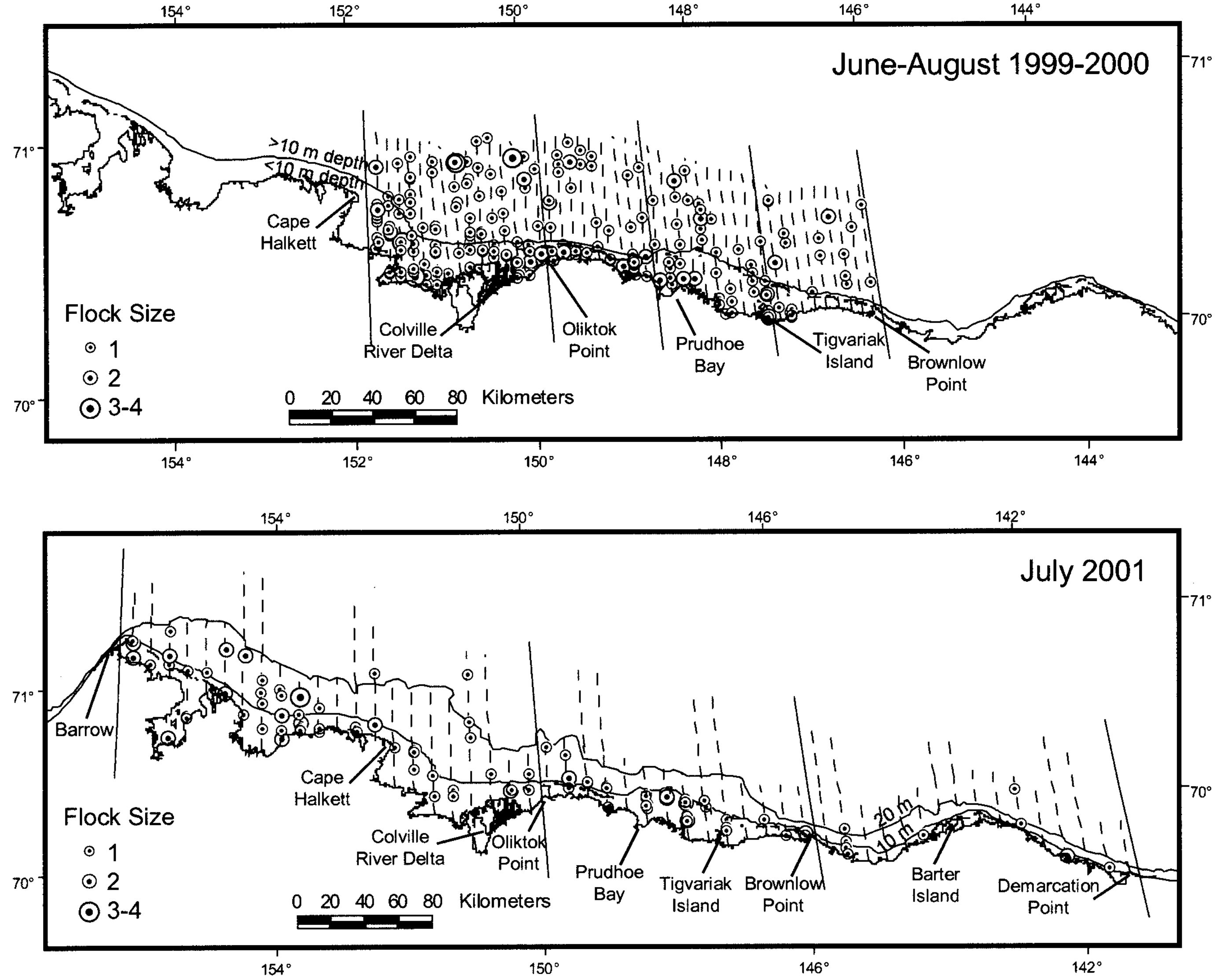

FIG. 9. Pacific loon flock locations in June, July, and August (1999 and 2000) and July 2001. Solid lines indicate zone boundaries; dashed lines indicate transects.

(Woodby and Divoky, 1982), but ice appeared to influence bird distribution into midsummer. In late July, ice conditions varied from open water to large areas of complete ice coverage. Extensive ice prevents marine birds from accessing food resources and is likely the reason we recorded low densities of marine birds in areas with over 60% ice cover. But while ice may limit access to food, moderate ice cover may benefit king eiders by providing protection from high winds and waves. Moderate ice cover reduces wave action, making it easier for birds to dive and rest on the surface (Stirling, 1997). Moreover, ice provides roosting sites for marine birds between feeding bouts, and it interacts with open water to encourage production of invertebrates (Routh, 1949; Divoky, 1979; Bradstreet, 1988; Stirling, 1997).

With the exception of king eiders, however, most marine birds were found in lagoons, where ice cover was minimal by midsummer. While moderate ice cover may offer benefits to marine birds, barrier island lagoons can satisfy the same functions. For example, barrier island lagoons have abundant food resources (Griffiths and Dillinger, 1981), offer protection from wind and high waves, and provide roosting sites (Johnson and Richardson, 1982). Ice can provide similar benefits, but distribution of ice is dependent on wind patterns, whereas barrier islands provide predictable habitat.

Limitations of Aerial Surveys

This project highlighted geographic areas, time periods, and conditions important to marine birds in the western Beaufort Sea; however, these results should be considered in the context of the limitations inherent in aerial surveys. First, in the interest of safety and visibility, we timed our surveys during periods of light or moderate winds. High winds from a favorable direction increase the rate of eider migration through the Beaufort Sea (Thompson and Person, 1963; Woodby and Divoky, 1982); thus, our results may highlight staging areas used by eiders during calm winds, rather than describing the variability in distribution that can occur over a range of wind conditions. Second, aerial surveys are not a useful tool to quantify birds in flight. Thus, with the exception of glaucous gulls, we did not include birds in flight in our density estimates. The likelihood of encountering individuals from an aerial platform is inversely related to the amount of time they are resident on the water surface; thus, we may have underestimated species that pass through the Beaufort Sea rapidly. Third, our results may have been biased by the clumped distribution of some sea ducks. For example, the fact that our aerial transects did not bisect Thetis and Egg Islands, where common eiders are known to nest at high densities (Schamel, 1978; Johnson, 2000), may have influenced the reported low densities in the shallow zone between Oliktok Point and Prudhoe Bay. Finally, our results may have been biased by species-specific differences in sightability. Correction factors are often applied in terrestrial habitats to compensate for such differences (Smith, 1995), but correction factors have not been developed to adjust for observations of marine birds in offshore waters. Although inter-specific density comparisons may be biased by differences in sightability among species, comparisons of densities of a single species among geographic zones are not.

Conservation and Management

Nearly four million hectares of submerged land between Barrow and Demarcation Point are being considered for oil and gas development (USDOI MMS, 2002). As development expands from onshore to offshore sites, potential for oil spills and disturbance in the marine environment will increase. Documentation of avian distribution may help minimize risks to marine birds by identifying important habitats and time periods. Information on spatial and temporal variation of bird concentrations can be used to aid selection of sites for industrial infrastructure, prioritize cleanup efforts in the case of an oil spill, and assess potential indirect impacts from proposed developments.

These results suggest that the vulnerability of marine birds to potential perturbations varies by species. In this study, sea ducks comprised nearly 90% of birds observed. In the event of an oil spill, sea ducks are more vulnerable to contact oil than surface-feeding species, such as glaucous gulls (Piatt et al., 1990). In general, marine birds would be more susceptible to contact oil if a spill occurred in nearshore areas, particularly within barrier island lagoons and near the Colville River Delta. Long-tailed ducks and common eiders concentrate in central barrier island lagoons between Oliktok Point and Brownlow Point. Within this area, long-tailed ducks were the most abundant species, with highest densities observed east of Tigvariak Island. While these two species were commonly seen in central barrier island lagoons, other protected shallow-water habitats attracted relatively high densities of long-tailed ducks, common eiders, Pacific loons, scoters, and glaucous gulls. Nearshore waters near the Colville River Delta were particularly important to long-tailed ducks, scoters, and loons.

In contrast to other marine birds, king eiders concentrated in mid-depth waters offshore of the Colville River Delta, where they may be particularly vulnerable to oil spills because of their large flock sizes, distance from shore, and presence in moderate ice-cover conditions. We observed flocks of up to 450 individuals (mean = 25, median = 8, n = 325); thus, a single event of spilled oil could affect many birds. Also, 81% of king eiders occurred more than 10 km from shore, where cleanup after an oil spill might be difficult. While spilled oil that contacts land can be cleaned up effectively, cleanup rates drop to 10–20% in open water (USDOI MMS, 2002; National Research Council, 2003). Moreover, most king eiders occurred in areas of broken ice conditions, where cleanup techniques have not been successful (USDOI MMS, 2002). In midsummer, 2001 we observed 75% of king eiders in areas with greater than 20% ice cover, suggesting that a failure to clean up spilled oil in broken ice conditions could have significant impacts on this species. Impacts would be particularly severe if oil persisted in areas of high use throughout the period of peak migration.

Additional marine bird surveys should be conducted in the Beaufort Sea to answer questions of management concern when specific oil and gas facilities are proposed. Given high spatial and temporal variability in bird distribution, precision of estimates may be improved if future survey designs use results from this study. Although nearshore habitats generally have higher densities of birds, an offshore component must be included in future surveys in order to quantify adequately the king eider populations that migrate through the Beaufort Sea. In addition, transects should not be constrained to lagoons between Oliktok Point and Brownlow Point, where many moulting sea ducks occur. While these lagoons are critical to large numbers of birds in summer, we found that other nearshore areas along the western Beaufort Sea coastline were also important to marine birds. Finally, efficiency of future surveys can be improved by reducing the latitudinal extent of transects to within 30 km of shore, where most marine birds occur.

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