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Summer and Autumn Movements of Belugas of the Eastern Beaufort Sea Stock

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ABSTRACT. Beluga whales of the eastern Beaufort Sea stock were tagged with satellite-linked time-depth recorders and tracked during summer and autumn in 1993, 1995, and 1997. Whales occupied the Mackenzie estuary intermittently and for only a few days at a time. They spent much of their time offshore, near or beyond the shelf break and in the polar pack ice of the estuary, or in Amundsen Gulf, M'Clure Strait, and Viscount Melville Sound. The movements of tagged belugas into the polar pack and into passages of the Canadian Arctic Archipelago suggest that aerial surveys conducted in the southeastern Beaufort Sea and Amundsen Gulf may have substantially underestimated the size of the eastern Beaufort Sea stock. Ranges of male and female belugas were somewhat segregated in two of the three years of study. In late July of 1993 and 1995, most males were located in Viscount Melville Sound, while females were primarily in Amundsen Gulf. Movement patterns of males tagged in late July in 1997 were different from those of males tagged in early July in 1993 and 1995. In September, belugas migrated westward along the continental shelf and farther offshore in the Alaskan Beaufort Sea. The tracks from 1997 show that the western Chukchi Sea is an autumn migratory destination and that at least some belugas continued their migration south towards the Bering Strait in November. Some conclusions from this study about beluga ecology challenge conventional wisdom, in that estuarine occupation appears to be short-lived, belugas travel long distances in summer to areas hundreds of kilometres from the Mackenzie Delta, and they do not avoid dense pack ice in summer and autumn.

Key words: beluga, *Delphinapterus leucas,* Beaufort Sea, Chukchi Sea, satellite-linked tracking, autumn migration, survey biases

RÉSUMÉ. Durant l'été et l'automne 1993, 1995 et 1997, on a effectué des suivis télémétriques par satellite de bélugas du stock de la mer de Beaufort orientale. Ces cétacés ont occupé l'estuaire du fleuve Mackenzie de façon intermittente, n'y restant que quelques jours à chaque fois. Ils ont passé la plupart de leur temps au large de l'estuaire, près de la pente continentale et plus au large dans la banquise polaire, ainsi que dans le golfe d'Amundsen et dans les détroits de M'Clure et du Vicomte de Melville. Leurs déplacements dans la banquise polaire et dans les passages de l'archipel Arctique laissent supposer que les inventaires aériens réalisés dans le sud-est de la mer de Beaufort et le golfe d'Amundsen auraient sous-estimé considérablement la taille du stock de la mer de Beaufort. On a observé une certaine ségrégation dans la répartition des mâles et des femelles dans deux des trois années de l'étude. À la fin de juillet 1993 et 1995, la plupart des mâles se trouvaient dans le détroit du Vicomte de Melville alors que les femelles étaient principalement dans le golfe d'Amundsen. Les déplacements des mâles équipés fin juillet 1997 différaient de ceux des mâles équipés début juillet 1993 et 1995. En septembre, ces animaux ont effectué leur migration vers l'ouest soit en suivant le plateau continental soit plus au large dans la mer de Beaufort alaskienne. Les suivis de 1997 ont démontré que l'ouest de la mer des Tchouktches est une destination migratoire automnale et qu'en novembre au moins quelques-uns des bélugas continuaient leur migration cap sud vers le détroit de Béring. Certaines conclusions tirées de cette étude mettent en doute les idées reçues concernant l'écologie du béluga. Le temps d'occupation de l'estuaire semble plus court que ce que l'on pensait et les bélugas effectuent de longs déplacements en été, atteignant des zones situées à plusieurs centaines de kilomètres du delta du Mackenzie. De plus, les bélugas n'évitent pas la banquise de glace dense en été ou en automne.

Mots clés: béluga, *Delphinapterus leucas,* mer de Beaufort, mer des Tchouktches, suivis télémétriques par satellite, migration automnale, biais d'inventaire

INTRODUCTION

Belugas *(Delphinapterus leucas)* belonging to the eastern Beaufort Sea stock have been thought to summer only in the Mackenzie Delta and surrounding waters of the eastern Beaufort Sea and Amundsen Gulf (Harwood et al., 1996) before migrating in autumn through Alaskan waters to the Bering Sea (Clarke et al., 1993), where presumably they spend the winter (Fraker, 1980). Much emphasis has been placed on this species' summer estuarine and coastal habits, including its feeding on anadromous and coastal-spawning prey, such as capelin, herring, saffron cod, charr, and whitefish (Doan and Douglas, 1953; Sergeant, 1973; Finley et al., 1987; Brodie, 1989; Frost and Lowry, 1990). Aerial survey observations had suggested that belugas preferred loose ice and avoided heavy pack ice (Finley et al., 1982; McLaren and Davis, 1982), which was thought to act as a barrier to beluga movement across

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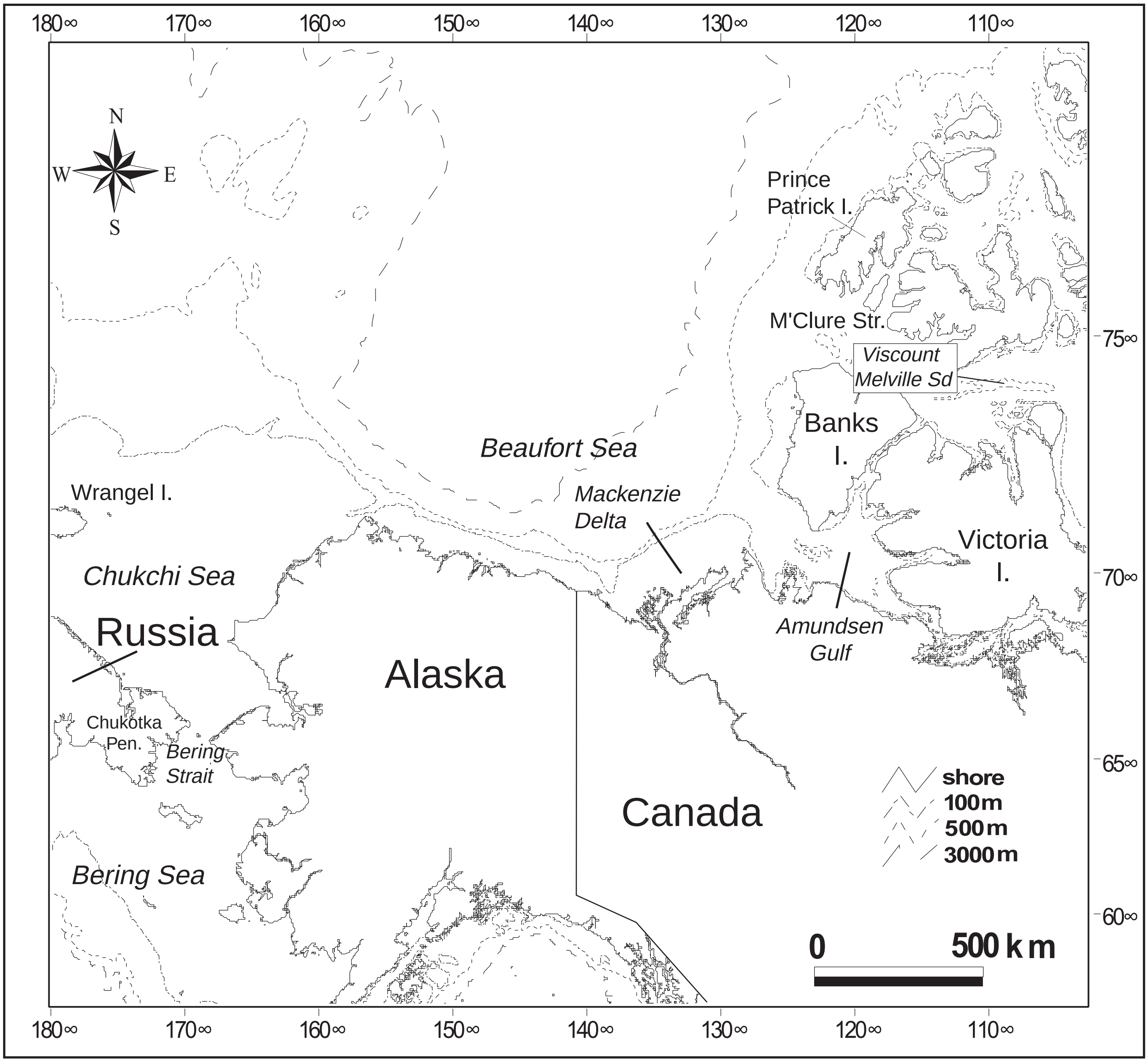

FIG. 1. Study area.

Canada's central Arctic (Sergeant and Brodie, 1975). Beluga coastal habits have been contrasted with those of the narwhal, a species known to prefer deep water, feed on or near the seafloor, and frequent areas of heavy pack ice (Mansfield et al., 1975; McLaren and Davis, 1982).

These descriptions of beluga behaviour, range, and migration routes were deduced from local knowledge, land-based observations, and aerial surveys. However, data gathered using these techniques are often limited either spatially or temporally, and in all cases information is obtained only at the surface. Belugas move in a three-dimensional environment, and most of their activity is underwater. A novel approach was needed to understand in greater detail their short-range and long-range movements and their diving behaviour.

In 1992, the Environmental Studies Research Funds, the Fisheries Joint Management Committee, and the Department of Fisheries and Oceans sponsored a workshop to determine research priorities for eastern Beaufort Sea belugas. Workshop participants agreed that a study of beluga behaviour using satellite-linked recorders could address "outstanding issues of Beaufort Sea beluga management: movements of individuals through Canadian, Alaskan and Siberian waters; movements of individuals between provisional Alaskan stock boundaries; survey correction factors such as the proportion of time at surface in various habitats and at various seasons; and feeding inferences" (Duval, 1993:19). Specifically, the study was designed to answer these questions:

1) What proportion of their time do belugas spend in different portions of the Beaufort Sea, Chukchi Sea, and East Siberian Sea?
2) What can be learned about survey biases, such as incomplete range coverage, changes in distribution during the survey period, and availability of belugas in the eastern Beaufort Sea to observers?
3) What autumn migration routes are used by belugas in the Beaufort Sea, Chukchi Sea, Bering Sea, and East Siberian Sea?
4) How do summer and autumn distribution patterns relate to water depth and pack ice distribution?

This paper reports on the location and movement aspects of the study. Barber et al. (2001) combine data from the Canadian eastern Arctic (Richard et al., 2001) to address the relationships between beluga distribution and seafloor depth and ice coverage.

MATERIALS AND METHODS

Study Area

Satellite tagging of belugas took place in the delta of the Mackenzie River, Northwest Territories, Canada. The movement patterns of successfully tagged belugas were used to define the study area, which included the Mackenzie Delta, the Beaufort Sea, the western portion of the Canadian Arctic Archipelago, the Chukchi Sea, the Arctic Ocean, and the Bering Strait (Fig. 1). This area included portions of the continental shelf, slope, and abyssal physiographic provinces, all of which influenced seasonal ice coverage.

The Mackenzie Delta is a shallow estuary along the northwest coast of Canada that is defined by a maximum depth of 20 m. The Beaufort Sea is composed of a shallow continental shelf ranging in width from 50 to 150 km and is defined by the 100 m contour. The landward portions of the Beaufort Sea shelf consist of the Mackenzie Delta and Amundsen Gulf. Amundsen Gulf, M’Clure Strait, and Viscount Melville Sound are comparatively deep bodies of water (maximum depths = ca. 600 m). The Chukchi Sea consists of a relatively wide and shallow platform with water depth rarely exceeding 100 m. The abyssal plain of the Arctic Ocean, which comprises most of the study area, has water depths greater than 3000 m.

Thick, permanent ice (> 90%) covers the Arctic Ocean and the seaward portion of the Beaufort Sea (Markham, 1981). The coastal waters of the Beaufort Sea, Amundsen Gulf, and M’Clure Strait are partially covered with ice that gradually melts away during the months of July and August. Viscount Melville Sound is also partially ice-free by mid-August. By mid-September, both M’Clure Strait and Viscount Melville Sound are covered with new ice. The coastal waters of the Beaufort Sea and the whole of Amundsen Gulf remain open well into November.

Live-Capture and Tagging Methods

Belugas were first sighted from land or from boats. Those belugas deemed suitable for tagging were slowly herded into shallow waters (depth = 2.5 m) by crews in five to seven widely separated boats, which remained 50 – 100 m behind the whales. Belugas were captured either by placing a hoop net around the head and chest of an individual whale or by encircling whales within a large-mesh seine net (Orr et al., 2001). Once secured, the whales usually stopped struggling within a few minutes. We then determined their standard length and sex. We tagged only those animals that were longer than 3 m because the dorsal ridge, to which the satellite transmitter was attached, was not as prominent in smaller animals. The satellite transmitter was secured to the dorsal ridge by two straps of flexible belt material laid transversely on each side of the whale (Fig. 2). Each strap was held in place by nylon washers and nuts fitted on two nylon pins (6 mm in diameter) inserted into the dorsal ridge. An identification band was also fitted to one pectoral fin (Orr and Hiatt-Saif, 1992). The handling time, including attachment of transmitters, averaged 40 min.

The beluga’s dorsal ridge consists of skin, connective tissue, and blubber and has few nerve endings or blood vessels. Attachment of a transmitter to the dorsal ridge causes no visible discomfort to the whale during the procedure. Nor does it appear to affect the whale’s subsequent behaviour, according to our post-release observations of tagged belugas. In some cases, these observations continued for several weeks. The pins slowly migrate caudo-dorsally through the tissue, allowing release of the whole package within a few months. Two belugas tagged in Canada’s eastern Arctic were re-sighted after a year, and their dorsal ridges had healed very well (Orr et al., 1998).

During the study, we used four tag models (Fig. 2), each consisting of a housing, sensors to collect data, an antenna, lithium batteries, circuitry to produce the signal itself, and a microprocessor. The microprocessor was programmed to control the sensors, collect and compress data, and trigger the transmitter at each surfacing. The tags started transmitting data every time a beluga surfaced far enough to expose the tag’s antenna. Transmissions were repeated every 40 sec. If a NOAA satellite was overhead at the time, and if two or more transmissions were received by Service ARGOS, the geographic location of the transmitter was calculated from the Doppler shift between signals obtained during that satellite pass (ARGOS, 1999). At least four signals are required to estimate the accuracy of the location.

In 1993, to save battery power loss, the tags were programmed to work on a duty cycle (Table 1). The tags worked full-time for the first two weeks to gather as much dive data as possible, then progressively reduced their activity. In 1995, we experimented with two methods of conserving battery power. Eight tags were programmed to collect data when the belugas were most likely to be within

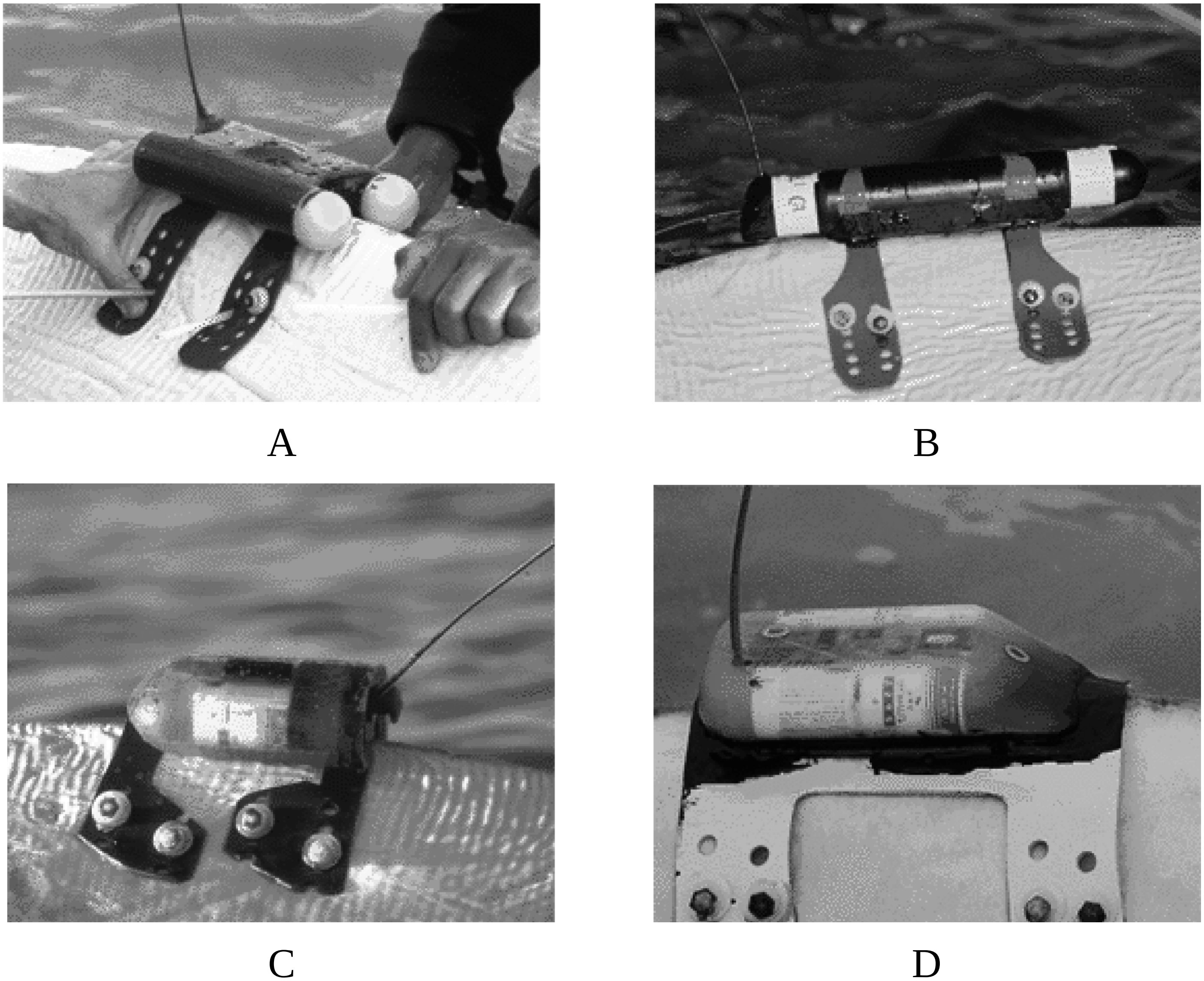

FIG. 2. Satellite-linked time-depth recorders installed on Mackenzie Delta belugas in July 1993, 1995, and 1997: A) SMRU-1, B) SMRU-2, C) SMRU-3, D) WCST-10. See Table 2 for details on dates and animals instrumented.

the delta. This meant that the tags needed to work full-time during the first 30 days, and then move to a one-day-on/one-day-off cycle until their batteries were exhausted. The eight remaining tags gave priority to collecting data over the longest possible period by gradually decreasing the proportion of time spent switched on. Finally, in 1997, the tags were put on a continuous activity schedule.

Analytical Methods

When sufficient signals are received during a satellite pass, the ARGOS DCLS estimates the position of the tag and assesses the estimate's precision (ARGOS, 1996). Service ARGOS provides an index of location fix quality, termed *location class* (LC).

Distances between consecutive fixes were calculated using great circle arcs on a spherical model of the globe of 6371.11 km diameter (Maling, 1989, 1993). We used good-quality locations (LC 1 – 3, "guaranteed" by ARGOS to have estimated errors of 1 km or less) to determine the range of swimming speeds of belugas over a range of elapsed times. Swimming speed was estimated using the great circle distance and the elapsed time between consecutive locations. Individual tracks of belugas were derived from all location classes but smoothed by removing outliers, using a filter based on good-quality fixes. We filtered low-quality locations (LC < 1) using a graded filter made from the range of swim speeds calculated from the good-quality locations. A low-quality location was kept if the swimming speed calculated at the preceding location was 10 km/hr or less, or 20 km/hr or less if the second location was estimated within two hours. Location and movement tracks were plotted using a polar stereographic projection.

TABLE 1. Description of the tag duty cycles programmed for beluga whale tagging studies conducted in July 1993, 1995, and 1997 in the eastern Beaufort Sea, Canada.

Duty Cycle	Continuous Duty	Days of Reduced Duty	Activity
1	first 15 days	16–21 days	24 hr on–144 hr off
		62–91 days	12 hr on–30 hr off
2	none	all	variable < 24 hr
3	first 30 days	subsequent days	1 day on–1 day off

There are two sources of bias in the estimation of swimming speeds: a) for short time intervals (less than 0.5 hr), swimming speed estimates can be strongly biased downward or upward by errors in location; b) for intervals over 2 hr, estimates of swimming speed are biased downward when movements are not straight lines between the locations used to calculate travel distance. To reduce these biases in analyses, we calculated swimming speeds only for intervals between locations that were more than 0.5 hr and less than 2 hr apart. An exception was made for whales following migratory routes where single-direction movements would likely occur over time spans longer than 2 hr.

RESULTS AND DISCUSSION

Animals Instrumented and Tag Longevity

A total of 30 belugas were instrumented in the three years of captures. Between 10 and 19 July 1993, we caught and instrumented 4 belugas: 3 near the northwest end of Garry Island (2 males and 1 female) and 1 male in Kugmallit Bay (Table 2). Despite many attempts, we were unable to catch additional belugas that year or the following year. In July 1995, the seine net allowed us to capture 24 belugas, of which we instrumented 11 males and 5 females (Table 2). We captured and tagged 10 belugas, 7 males and 3 females, between 26 July and 1 August 1997 (Table 2). In all years, females were seen less often and, when seen, were harder to catch than males, presumably because they were protective of their calves. As a result, we captured more males than females. We also preferred to have more males in the sample: in previous trials, males, who tend to have a thicker dorsal ridge, had retained tags longer than females. This was particularly important since we were trying to monitor the autumn movements.

The longevity of individual tags varied from 1 to 129 days, with 24 tags transmitting for 30 days or more. Of these, 11 tags transmitted for 60 days or more (Table 2). Several of the tags stopped after one or a few days for unknown reasons. There is no evidence from the signal strength that loss of battery power was the cause. In 1995, transmissions ceased after 30 days for the eight tags of the newer design.

Tag longevity improved from year to year, presumably because of improvements in tag housing. Excluding a tag lost after one day in 1997 and the 30-day tags of 1995, median tag longevities for 1993, 1995, and 1997 were 31, 38, and 81 days, respectively. The longest tag durations were recorded on a mature male (120 days) and a mature female (129 days) in 1997.

Reception loss probably occurs when belugas are traveling in ice and surface only infrequently, or when belugas are in small ice cracks where the ice thickness acts as a barrier to transmission. This may explain why data from some tags became sporadic for several days or weeks. Reception loss probably also occurred when tags started to detach from the dorsal ridge and their antennas were no longer upright. This may explain why locations became progressively fewer toward the end of the tag's life.

Distribution of Males in Summer and Autumn, 1993–95

In 1993 and 1995, male belugas remained in the Mackenzie estuary for only a few days (average = 4, range 1–10) after their release. Most of these males (11 of 14) then traveled north into the permanent pack ice of the Beaufort Sea and Arctic Ocean much farther than expected from previous knowledge of their distribution (Figs. 3A and 4A). They reached latitudes ranging from 74˚N to 78˚N within 5–13 days of being tagged (average = 10 days). They then traveled east through M'Clure Strait, moving towards Viscount Melville Sound. Eight of these males arrived in Viscount Melville Sound between 25 and 31 July. Another male (95-17003) made its way to Viscount Melville by way of Amundsen Gulf and Prince of Wales Strait, arriving there on 28 July. In Viscount Melville Sound, these males stayed almost exclusively over a trench more than 500 m deep in the middle of the sound, into which they dove repeatedly for many days (A. Martin, unpubl. data). Five of them transmitted long enough to allow us to record their departure from Viscount Melville Sound. Their stay in the Sound varied between 5 and 30 days (average = 13 days). Four of the five remaining males returned westward through M'Clure Strait, leaving between 2 and 28 August (median = 10 August). The fifth animal (95-17004) left on 5 August and moved south through Prince of Wales Strait. Tags stopped transmitting in late August, while the whales were in the Beaufort Sea, for all animals except one male (93-17001). This male remained offshore as he began his westward migration into Alaskan waters.

The twelfth male (93-17006) followed approximately the same northbound track as the others for about 400 km, but his tag stopped transmitting after 10 days. The remaining two males did very different things. One of them (95-17002) stayed in the delta and surrounding waters and made two trips to Amundsen Gulf. There he followed a clockwise pattern, moving eastward through the center or north portion of the gulf and westward through its south portion. The other (93-17002) also traveled north, but turned northwest and crossed the Arctic Ocean during early August, reaching as far north as 78˚42′N on 14 August. He later moved southwestward into Russian

TABLE 2. Tag parameters and capture data collected on beluga whales satellite-tagged in the Mackenzie Delta in 1993, 1995, and 1997.

Tag No.	Make/Model	Sex	Length (cm)	Date Captured	Capture Location	Longevity (days)[1]	Duty Cycle[2]
93-17005	SMRU 1	M	442	10 July	Mackenzie Bay	11	1
93-17006	SMRU 1	M	424	10 July	Mackenzie Bay	28	1
93-17009	SMRU 1	F	302	11 July	Mackenzie Bay	34	1
93-17002	SMRU 1	M	457	19 July	Kugmallit Bay	91	1
95-17001	SMRU 1	M	427	03 July	Kugmallit Bay	85	2
95-17002	SMRU 1	M	404	04 July	Kugmallit Bay	49	2
95-17003	SMRU 1	M	432	04 July	Kugmallit Bay	23	2
95-17004	SMRU 1	M	373	05 July	Kugmallit Bay	34	2
95-17005	SMRU 1	M	353	05 July	Kugmallit Bay	42	2
95-17010	SMRU 2	M	399	09 July	Kugmallit Bay	30	3
95-17011	SMRU 2	M	402	09 July	Kugmallit Bay	30	3
95-17012	SMRU 2	M	404	10 July	Kugmallit Bay	30	3
95-5801	SMRU 2	M	406	11 July	Kugmallit Bay	30	3
95-17013	SMRU 2	M	402	11 July	Kugmallit Bay	30	3
95-17014	SMRU 2	F	340	12 July	Kugmallit Bay	30	3
95-8754	SMRU 2	F	363	13 July	Kugmallit Bay	30	3
95-17006	SMRU 1	F	343	13 July	Kugmallit Bay	7	2
95-5800	SMRU 2	M	467	16 July	Kugmallit Bay	30	3
95-17007	SMRU 1	F	373	16 July	Kugmallit Bay	81	2
95-17008	SMRU 1	F	361	16 July	Kugmallit Bay	9	2
97-2118	WC ST-10	F	374	26 July	Kugmallit Bay	129	-
97-8755	SMRU 3	M	400	29 July	Kugmallit Bay	81	-
97-8757	SMRU 3	M	379	29 July	Kugmallit Bay	68	-
97-25846	WC ST-10	M	374	29 July	Kugmallit Bay	85	-
97-8754	SMRU 3	M	405	31 July	Kugmallit Bay	90	-
97-8758	SMRU 3	M	421	31 July	Kugmallit Bay	120	-
97-10693	SMRU 2	M	395	31 July	Kugmallit Bay	73	-
97-25845	WC ST-10	M	426	31 July	Kugmallit Bay	1	-
97-8756	SMRU 3	F	362	01 August	Kugmallit Bay	56	-
97-10692	SMRU 2	F	338	01 August	Kugmallit Bay	65	-

[1] Longevity = days to last location.
[2] See Table 1.

waters, ending transmissions north of Wrangel Island on 22 August.

Until recently, little was known about summer movements of belugas from the Beaufort Sea deep into the Arctic pack ice, or east into the central Canadian Arctic Archipelago. Opportunities to make observations in those areas are few, because heavy ice conditions severely limit marine travel and aerial observations. We knew of only one reference to belugas located north of Banks Island in summer. Manning and MacPherson (1958) reported several herds of 50 to "several hundred" belugas traveling west along the north shore of Banks Island on 12 and 23 August 1952. In the light of our telemetry results, the significance of their observations is now clear. Following the movement of male 93-17005 into Viscount Melville Sound, a plane flew near his last recorded position. There, on 16 August 1993, an observer sighted a total of 75–100 belugas in two groups (T.G. Smith, Eco Marine Corp., Garthby, Quebec, pers. comm. 1993). These groups were seen 8 km and 45 km respectively from the four locations obtained for 93-17005 within the same 24 hr period.

The occurrence of tagged males in the summers of 1993 and 1995 and the above-mentioned sightings of close to a hundred belugas suggest that beluga movements into Viscount Melville Sound are not unusual. This area may in fact be used by thousands of male belugas from the Beaufort Sea stock. We assume that they are from the Beaufort Sea stock because none of the 35 belugas tagged in the eastern Canadian Arctic in the summer moved that far west (Smith and Martin, 1994; Richard et al., 2001): all moved south into Peel Sound in late summer and later moved northeast into Lancaster Sound and Baffin Bay. The westward movement of male 93-17002 towards the western Chukchi Sea was unanticipated and suggests that the summer range of male belugas from the eastern Beaufort Sea could span an even larger area.

Distribution of Females in Summer, 1993–95

The summer range of most tagged female belugas in 1993–95 was different from the range of most males (Figs. 3B and 4B). Like the males, the females did not stay in the Mackenzie Delta very long after release (average = 3 days, range = 2–6 days). But afterwards, four of the six females moved from the delta region to Amundsen Gulf, where they arrived between 16 July and 5 August (median = 28 July). In Amundsen Gulf, the females made a more or less clockwise loop (similar to that of male 95-17002) lasting 6–11 days (average = 8) before returning to the delta or to offshore waters north of the delta near the shelf

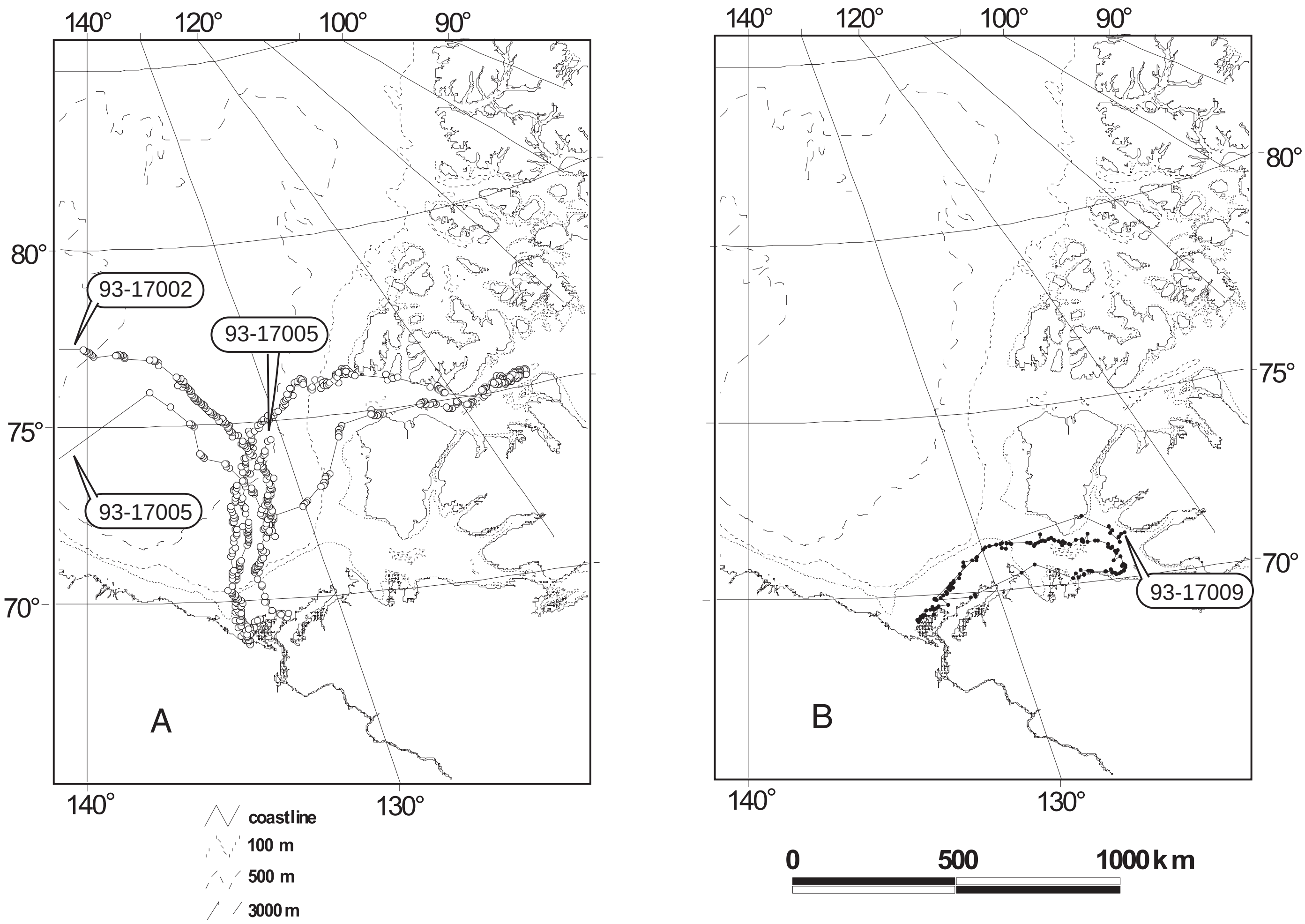

FIG. 3. Movements in Canadian waters of male (A) and female (B) belugas instrumented in early July 1993 in the Mackenzie Delta. A numbered callout box indicates the final location on map for each animal.

break. It is interesting to note that these movements ran in the same direction as the clockwise current gyre of Amundsen Gulf. One of these females (93-17009) returned to Amundsen Gulf a second time in early August for three days. A fifth female (95-17014), presumably with her yearling or two-year-old calf, moved north (like the males) soon after her release, but she returned south to the delta on 26 July after reaching 74˚46′N, 129˚59′W. Four of the six females were accompanied by young-of-the-year or one- to two-year-old calves (Tables 3 and 4).

The summer range of the females (and the one south-bound male, 95-17002) corresponds more closely to the range that was known before this study for Beaufort Sea belugas. Besides occupying the Mackenzie Delta, these belugas were known to range offshore of the delta, right up to the pack ice, and throughout Amundsen Gulf (Harwood et al., 1996). With few exceptions, the ranges of tagged females and males observed in 1993 and 1995 were well segregated after the animals left the delta. Such male-female segregation had not been documented previously.

Distribution of Males and Females in Late Summer, 1997

In 1997, belugas were tagged later in the season (Table 2). The pattern of male movements was strikingly different that year, as none of the males moved to Viscount Melville Sound. Eight of the whales (6 males, 2 females) remained a few days in the Mackenzie Delta (males averaged 5 days, range = 3–10 days; females = 1 and 2 days) before traveling east into Amundsen Gulf (Fig. 5A, B). Arriving there on 5–11 August (median = 6 August), these eight belugas made a clockwise loop of the gulf over a period of 6–16 days (average = 9). The ninth beluga, female 97-2118, went straight north into the pack ice, reaching 74˚N on 1 August and continuing north until she reached 77˚45′N, 300 km west of Prince Patrick Island. This female, in effect, reached the northernmost latitude of all belugas tagged during this study except male 93-17002. She moved south again from 20 to 30 August until she reached 74˚38′N. She then moved westward in September.

In 1997, six of the eight belugas (5 males, 1 female) that circumnavigated Amundsen Gulf returned to the Mackenzie

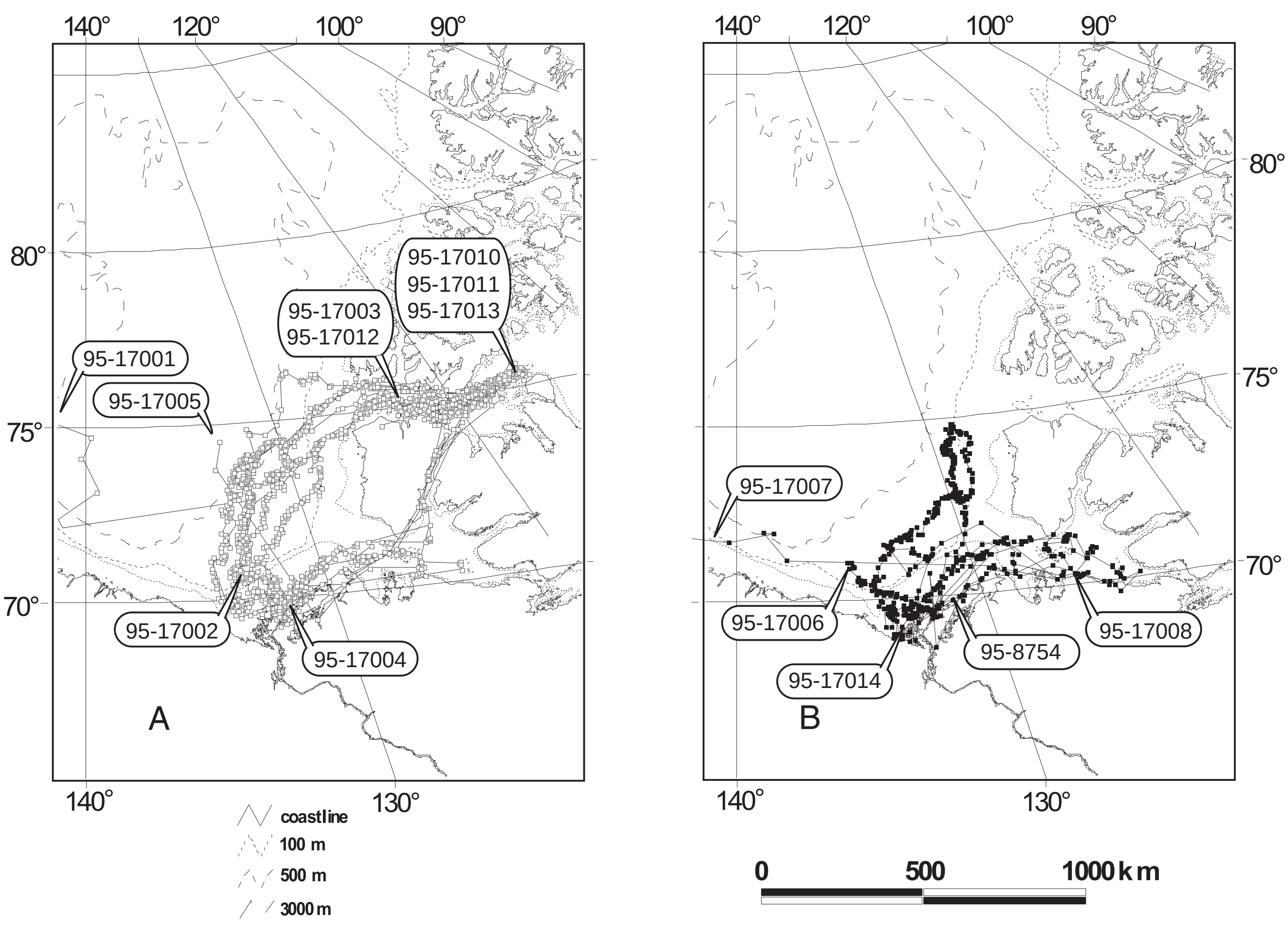

FIG. 4. Movements in Canadian waters of male (A) and female (B) belugas instrumented in early July 1995 in the Mackenzie Delta. A numbered callout box indicates the final location on map for each animal.

TABLE 3. Residence time in the 1992 aerial survey area of five belugas, tagged in the Mackenzie Delta in July 1993 and 1995, that did not leave the area during all or most of the time before 26 July, the day following the end date of the 1992 survey.

Tag No.	Sex	Length (cm)	With Calf	Date-Time Release (local)	Presence in Survey Area before 26 July
93-17009	F	302	–	11 July 1993 00:05	all days except 20–22 July
95-17002	M	404		4 July 1995 17:20	all days except 15 July
95-8754	F	363	217 cm[1]	13 July 1995 15:55	all days
95-17008	F	361	182 cm[2]	17 July 1995 00:15	all days
95-17007	F	373	–	16 July 1995 21:50	all days

[1] 1–2 yr old calf
[2] Newborn calf

Delta area between 12 and 24 August (median = 16 August). Of those six, the five males later went offshore to the shelf break (depths > 100 m) and the female (97-8756) returned to Amundsen Gulf. The two other belugas (male 97-8758 and female 97-10692) did not return to the delta; instead, they moved directly to the shelf break in late August. These 1997 whales seem to have followed movement patterns similar to those of females (and a few males) tagged in 1993 and 1995.

We have no clear explanation for the difference in movements between most of the males tagged in 1993–95 and those tagged in 1997. Whales tagged in 1997 may have been blocked by the heavy multi-year pack ice reported to have blocked M’Clure Strait in August, but inspection of the tracks shows that none of the tagged belugas actually approached M’Clure Strait (Fig. 5A, B). Furthermore, many animals in all three years traveled hundreds of kilometres into heavy pack ice (coverage of 90% or more).

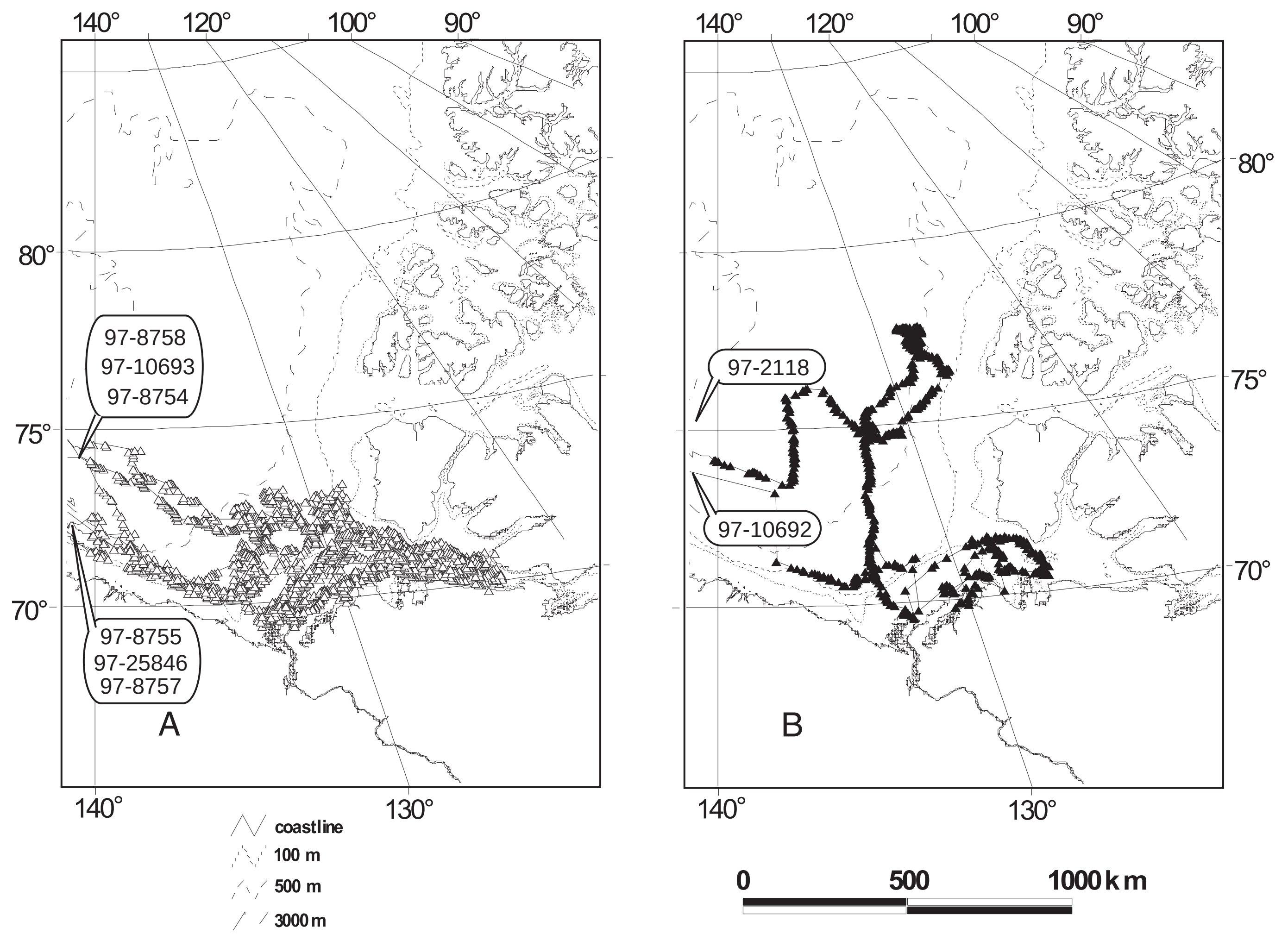

FIG. 5. Movements in Canadian waters of male (A) and female (B) belugas instrumented in late July 1997 in the Mackenzie Delta. A numbered callout box indicates the final location on map for each animal.

TABLE 4. Residence time in the 1992 survey area of 13 belugas, tagged in the Mackenzie Delta in July 1993 and 1995, that left the area before the dates of the 1992 survey.

Tag No.	Sex	Length (cm)	With Calf	Date-Time Release (local MST)	Exit Survey Area (local MST)	Residence (days)
93-17006	M	424	–	10 July 1993 13:30	15 July 1993 16:26	5.1
93-17002	M	459	–	19 July 1993 06:45	22 July 1993 00:52	2.8
95-17001	M	427	–	03 July 1995 19:10	06 July 1995 18:48	3.0
95-17003	M	432	–	04 July 1995 00:35	19 July 1995 11:22	15.4
95-17004	M	373	–	05 July 1995 17:10	10 July 1995 04:42	4.5
95-17005	M	353	–	05 July 1995 17:55	10 July 1995 09:43	4.7
95-17010	M	399	–	09 July 1995 01:37	13 July 1995 09:44	4.3
95-17011	M	401	–	09 July 1995 22:15	12 July 1995 12:40	2.6
95-17012	M	404	–	10 July 1995 04:18	16 July 1995 10:18	6.3
95-5801	M	406	–	11 July 1995 03:20	15 July 1995 05:26	4.1
95-17013	M	401	–	11 July 1995 04:00	14 July 1995 21:01	3.7
95-17014	F	340	223 cm[1]	12 July 1995 22:05	14 July 1995 20:59	2.0
95-17006	F	343	200 cm[1]	13 July 1995 17:30	18 July 1995 12:59	4.8
					Average Residence =	4.9

[1] 1–2 yr old calf

Another, more plausible explanation is that male belugas captured in the Mackenzie Delta in late July were less prone to venture into the Archipelago so late in the season. In previous years, males had arrived in Viscount Melville Sound in late July. Had the 1997 males tried to reach Viscount Melville Sound, they would have arrived about two weeks later, at a time when most males were starting to leave that area in 1993–95. Nevertheless, it is noteworthy that one male tagged in 1993 (93-17002) and another in 1995 (95-17002) did not go into the Archipelago, despite the fact that they were caught earlier in July (on 18 and 3 July, respectively) than the 1997 whales. It is possible that males that remain late in the season in the Mackenzie Delta may not go to Viscount Melville Sound at all; thus, if we had tagged later in 1993 and 1995, we might have had the same results as in 1997. There may therefore be other reasons, such as prey availability, that caused these males to remain in the southern Beaufort Sea and Amundsen Gulf in 1997.

Autumn Movements and Use of Alaskan and Chukotkan Waters

Twelve tags continued transmitting late enough in the season for the whales to have re-entered Alaskan waters on their westward autumn migration. Male 93-17002 left Canadian waters on 29 July and traveled northwest across the Arctic Ocean, reaching 78˚42′N, 166˚54′W on 14 August. He later moved southwest into Russian waters, ending transmissions north of Wrangel Island (75˚15′N, 177˚25′W) on 22 August. The remainder of the tagged belugas crossed into Alaskan waters later in September (median date = 7 September; range = 3–18 September; Table 5).

Several aerial surveys of the coastal shelf and slope waters of the western Beaufort Sea have been flown in the past to map the distribution of marine mammals in September. These surveys resulted in sightings of belugas in the Beaufort Sea, mainly on the outer portion of the shelf and the inner portion of the continental slope (Clarke et al., 1993; Treacy, 1998). None of our tagged animals ventured as far inshore as the coastal beluga survey sightings, but there was a fairly good overlap between the survey sightings made in the shelf break zone and five of our tracks (5 males, 1 female). Four of our tagged whales (3 males, 1 female) moved west along routes that were 170–400 km north of the survey sightings. Migration through Alaskan waters (west to 170˚W) lasted 8–19 days (average = 15 days; Table 5). Speed of migration calculated for animals that were moving in relatively straight paths ranged between 4.2 and 6.4 km/hr (mean = 5.1 km/hr).

Fraker (1980) hypothesized that the autumn migration of Beaufort Sea belugas ran along the Alaskan shelf and south through the eastern Chukchi Sea. In our tracking study, roughly half of the belugas that moved through Alaskan waters in 1993, 1995, and 1997 did so close to the shelf, but the rest traveled much farther north. Two of the belugas tagged in 1993 and 1995 moved west toward the western Chukchi Sea and the East Siberian Sea. As noted earlier, one of them (93-17002) arrived north of Wrangel Island on 20 August. In 1997, all of the tagged belugas reached the western Chukchi Sea (170˚W and westward) between 15 September and 9 October (median = 25 September).

Belugas whose tags continued transmitting through October remained in waters north and east of Wrangel Island until 18–28 October (median = 21 October). In the past, observers on walrus aerial surveys had noted sightings of hundreds of belugas in the western Chukchi and East Siberian seas at that time of year (J. Burns, Fairbanks, AK, pers. comm. 1993). Their observations lend support to the conclusion that movements of our tagged belugas are representative of a large segment of the Beaufort Sea summer population.

TABLE 5. Passage dates (GMT) of belugas satellite-tagged in July 1993, 1995, and 1997 in the Mackenzie Delta, Canada, during their westward migration in autumn.

Tag No.	Sex	Date West of 141˚W	Date West of 170˚W	Date South of 70˚N
93-17002	M	29 July	13 August	–
93-17005	M	14 September	–	–
95-17001	M	07 September	–	–
95-17007	F	18 September	–	–
97-2118	F	03 September	22 September	28 October
97-8754	M	04 September	24 September	18 October
97-8755	M	08 September	09 October	18 October
97-8757	M	08 September	20 September	–
97-8758	M	10 September	20 September	24 October
97-10692	F	05 September	19 September[1]	–
97-10693	M	07 September	15 September	–
97-25846	M	06 September	25 September[1]	21 October
Median[2]		07 September	21 September	21 October

[1] Extrapolated dates.
[2] 93-17002 was excluded from median calculations because it migrated earlier in summer.

Two tags, those of female 97-2118 and male 97-8758, continued to transmit into November. They indicated movements south along the coast and offshore of the Chukotka Peninsula (Fig. 6A, B). The male crossed the Bering Strait on 27 November, and his tag transmissions ended in the Bering Sea (65˚33′N, 170˚00′W) the next day. This lends some support to the hypothesis that the wintering area of Beaufort Sea belugas is the Bering Sea, as suggested by Fraker (1980). The female's transmissions ended on 1 December, while she was still in the Chukchi Sea (68˚23′N, 170˚20′W).

Potential Biases in Aerial Survey Estimates

The most recent survey of belugas in the Eastern Beaufort Sea stock took place in July 1992 (Harwood et al., 1996) and covered an area from the coast seaward to 70.5˚N and 71˚N, and between meridians 122˚W and 138˚W (Fig. 7). This survey area was based on available knowledge of beluga concentrations in summer (Harwood et al., 1996), although the total summer range of this population was suspected to be larger (Norton and Harwood, 1985).

Beluga movements could potentially cause two types of bias in aerial survey estimates. First, if many belugas left the area before the survey, the estimated population size would be too low because the survey would not have covered the entire range of the stock. Second, if belugas

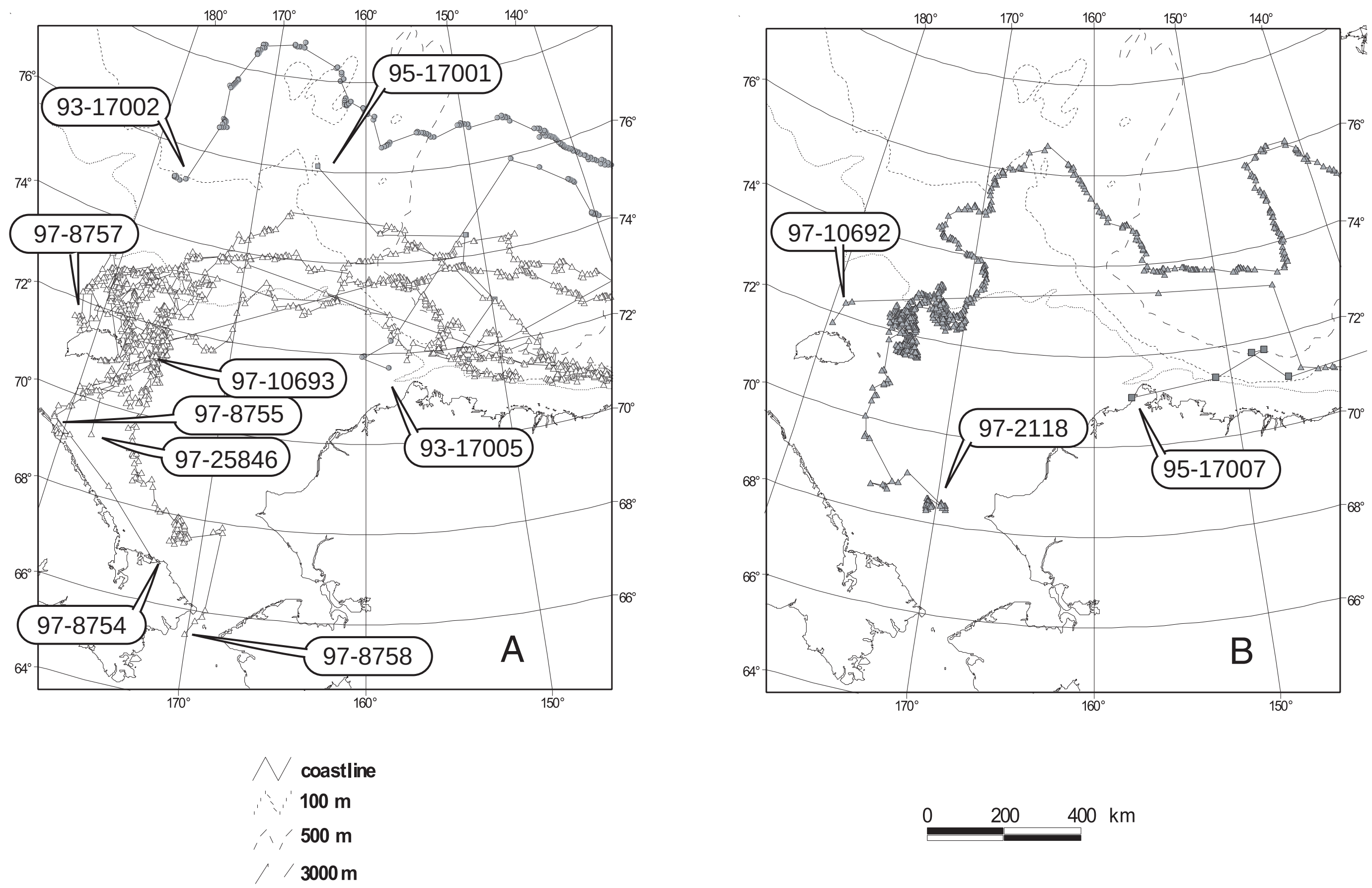

FIG. 6. Movements in Alaskan and Russian waters of male (A) and female (B) belugas instrumented in July 1993, 1995, and 1997 in the Mackenzie Delta (circles = 1993 locations; squares = 1995 locations; triangles = 1997 locations). A numbered callout box indicates the final location on map for each animal.

moved sufficiently fast in one direction to be counted twice during a survey flight, the estimate might be too high.

To understand the effects of these two types of bias more fully, we describe the movements of the belugas tagged in July 1993 and July 1995 and discuss the effect such movements might have had on the 1992 population size estimates.

Beluga Presence or Absence in the 1992 Aerial Survey Area

Five of the belugas (4 females, 1 male) tagged in July 1993 and July 1995 stayed within the survey area on all or most of the days leading up to 25 July (Table 3), the last date aerial surveys were conducted in 1992. Of those individuals, two left the survey area briefly for neighbouring areas in eastern Amundsen Gulf, returning a day or two later (Fig. 7). Therefore, the 1992 survey area covered all but a small portion of the area used by these five belugas. However, another 13 animals (11 males, 2 females) left the survey area before the 1992 survey dates (23–25 July) and did not return until later (Table 4). The tags of the remaining two whales stopped functioning before 23 July. The 13 animals moved north into the pack ice and, in the case of males, moved into the Canadian Arctic Archipelago (Fig. 7).

The fact that 13 of 18 tagged animals left the survey area soon after release in early to mid-July of both years and traveled far north into the pack ice suggests that the 1992 aerial survey, which ended near the edge of the dense pack ice, would have covered only a portion of the total area occupied by the stock. Therefore, the stock size may have been substantially underestimated. Ninety-two percent of the males and a third of the females tagged in 1993 and 1995 left the survey area before 23 July, the date that the 1992 survey began. If the same ratios applied in 1992, the survey would have estimated only 38% of the total population at the surface (8.3% of the males and 66.7% of the females), assuming a 1:1 male-to-female ratio. Of course, ratios based on the 1993–95 sample cannot be applied indiscriminately to the 1992 survey estimate. The percentage of “absent” belugas probably varies from year to year. Our example nevertheless illustrates the potential magnitude of this bias and its effect on the population estimate.

Beluga Movement Patterns within the 1992 Aerial Study Area

The second source of movement bias can be studied by examining whale movements within the 1992 survey area. If beluga movements within a survey area are highly

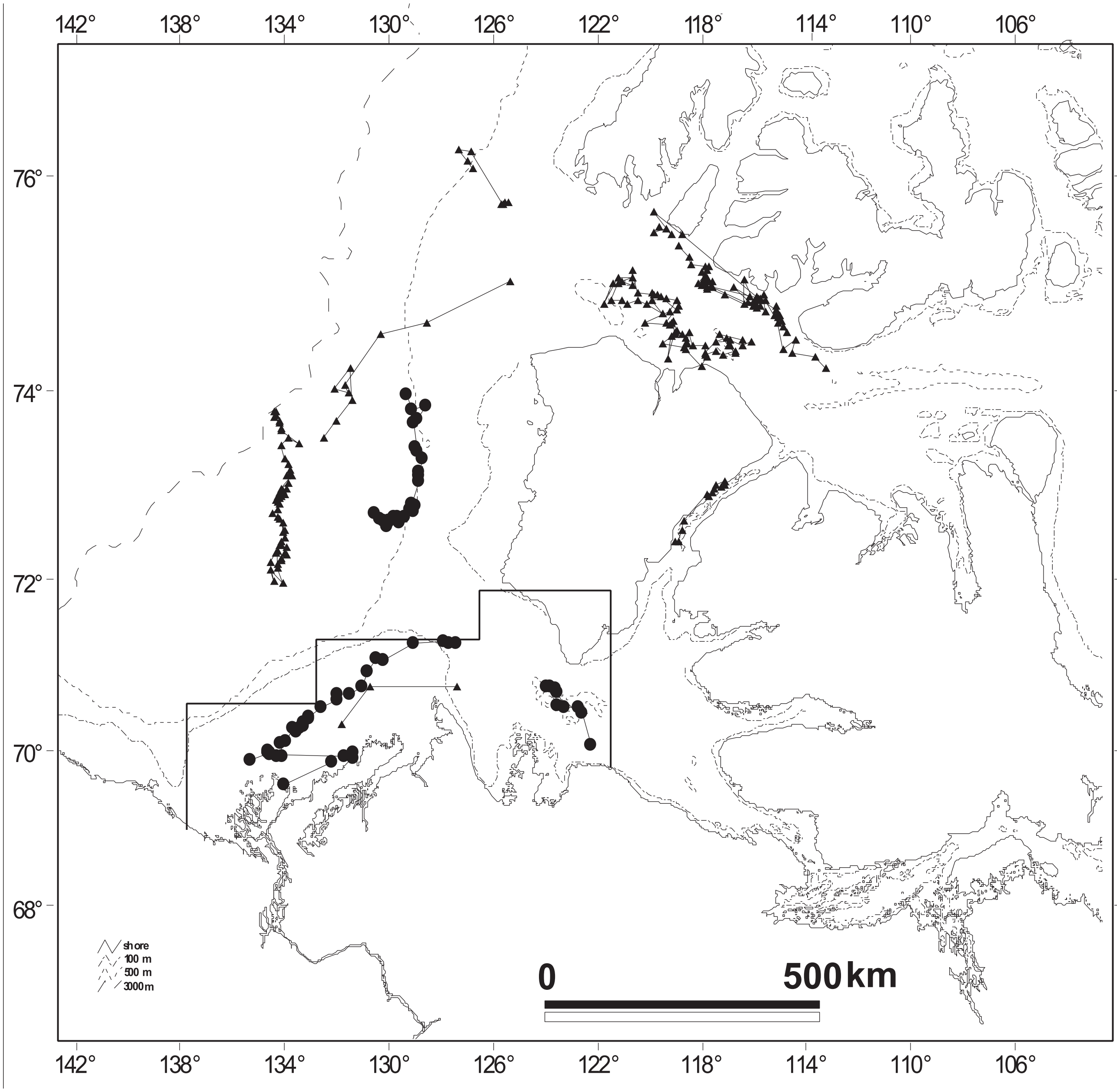

FIG. 7. Range of movements of belugas instrumented in 1993 and 1995 in the Mackenzie Delta compared to area surveyed by aircraft during 23–25 July 1992 (a solid black line encloses the survey area; triangles = males; circles = females).

directional, individual animals may be counted more than once as the survey plane flies across each survey stratum. For this analysis, we used the location data of all belugas tagged in 1993 and 1995 that occupied the survey area before and during the dates of the 1992 aerial survey. We also used their mean vector speeds (i.e., mean speed in a given direction) instead of travel distances for analyses, since the elapsed times between positions used to calculate distances were variable.

Mean direction varied among animals and, more importantly, mean vector speeds were fairly slow (less than 3 km/hr) for most animals, indicating little directional movement within a survey stratum (Table 6). On the basis of the 1992 survey design, we calculated the mean N-S speed for the estuarine strata, where most transects were oriented E-W, and the mean E-W speed for the offshore strata, where all transects were oriented N-S (Table 6). Vector speeds were generally small in both cases, averaging less than 1 km/hr (0.13–0.81 km/hr). At 1 km/hr, a beluga would have taken about 1.3 hr to cover half the distance between two estuarine transects and at least 9 hr to cover half the distance between two offshore transects. In contrast, flying at an average ground speed of 191 km/hr, a 1992 survey aircraft took 15–36 min to complete two estuarine transects (length 10–56 km) and 2.2–2.5 hr to complete two offshore transects (length 200–220 km).

Finally, if beluga movements were directional, and if belugas left a stratum surveyed one day for an adjacent

TABLE 6. Mean vector speeds and bearings of belugas satellite-tagged in 1993 and 1995 relative to strata boundaries established for aerial surveys conducted on 23–25 July 1992 in the Mackenzie Delta, Canada.

Beluga	N	Mean Speed (km/hr)	Mean Heading (360˚ bearing)	Mean N[+] S[-] Speed (km/hr)	Start Date	Stop Date	Period Sampled (days)
Estuarine Strata							
F 93-17009	15	0.60	43˚	0.44	11 July	13 July	1.59
F 95-17007	18	0.57	273˚	0.03	17 July	21 July	4.48
M 93-17002	6	0.57	324˚	0.47	19 July	20 July	1.19
M 93-17005	16	0.86	299˚	0.42	10 July	13 July	2.19
M 93-17006	14	0.14	232˚	-0.09	11 July	14 July	3.15
M 95-17010	14	1.06	227˚	-0.73	09 July	11 July	2.30
M 95-17012	12	1.36	330˚	1.17	10 July	11 July	1.36
M 95-5800	17	0.81	282˚	0.17	16 July	18 July	1.96
M 95-5801	21	0.89	216˚	-0.71	12 July	14 July	1.98
Average		0.76		0.13			
Offshore Strata				Mean E[+] W[-] Speed (km/hr)			
F 93-17009	59	0.51	88˚	0.51	13 July	26 July	13.42
F 95-17007	36	2.46	61˚	2.15	22 July	26 July	4.45
F 95-17014	14	4.05	289˚	-3.83	13 July	15 July	1.12
M 95-17010	10	1.39	285˚	-1.34	12 July	13 July	1.13
M 95-17012	8	0.45	281˚	-0.44	12 July	16 July	3.43
M 95-5800	31	2.34	266˚	-2.34	17 July	19 July	1.62
M 95-5801	10	0.45	237˚	-0.38	12 July	15 July	2.43
Average		1.66		-0.81			

stratum surveyed the next day, they could potentially be counted more than once. The mean N-S and E-W speeds measured on our tagged belugas, if applied to a 24 hr period, result in potential movements of about 24 km per day. By comparison, estuarine stratum centres of the 1992 survey were separated by at least 25 km and the offshore stratum centres, by at least 100 km. Consequently, if during the 1992 survey belugas behaved similarly to animals tagged in 1993 and 1995, their short-term movements within the survey strata would have had no effect on survey estimates.

CONCLUSIONS

Monitoring the movements of belugas in the Beaufort Sea has offered new insights on their behaviour in summer. Male and female ranges were somewhat segregated in two of the three years of study. Whales were shown to use the Mackenzie estuary intermittently and for only a few days at a time. They spent much of their time offshore of the estuary and in other areas to the east and north. In Amundsen Gulf, they often moved in a clockwise circuit, traveling eastward in the northern half or near the center of the gulf and westward in the southern half. In all three years, males and females traveled far into the permanent pack ice, and in 1993 and 1995, males also moved into the Canadian Arctic Archipelago, spending a week or longer in Viscount Melville Sound. These wide-ranging movements suggest that the 1992 aerial survey may have substantially underestimated the size of the eastern Beaufort Sea stock, in particular the number of males in the stock, since many of the animals tracked in 1993 and 1995 were hundreds of kilometres away from the survey area on the dates of the survey. On the other hand, there is no indication of short-term movement bias within the survey strata.

About half of the tagged animals (male and female) migrated far offshore of the Alaskan coastal shelf in September. The other tagged belugas migrated on the continental shelf or close to the continental slope. The 1997 tracks documented that the western Chukchi Sea is an autumn migratory destination and that at least some belugas continued their migration south toward the Bering Strait in November.

Some of our general conclusions about beluga ecology challenge conventional wisdom. Estuarine occupation appears to be short-lived, and belugas—especially males—travel long distances in the summer, reaching areas hundreds of kilometres away. This finding contradicts earlier perceptions of belugas as coastal, shallow-water animals that are relatively sedentary in or near estuaries in the summer. Belugas are also able to move through dense summer and autumn pack ice, again contradicting earlier perceptions of these whales as limited in their movements by heavy ice and preferring areas of loose pack ice or open water.

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