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From Greenland to Canada in Ten Days: Tracks of Bowhead Whales, *Balaena mysticetus*, across Baffin Bay

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ABSTRACT. Five bowhead whales (*Balaena mysticetus*) were instrumented with satellite transmitters in northwestern Disko Bay, West Greenland, in May 2001. Best results were obtained when tags were deployed with a pole rather than a pneumatic gun. At least three of the tagged whales remained in the northwestern part of the bay for one to two weeks after tagging. A male and a female whale moved from Disko Bay to northern Canada. They left Disko Bay 11 days apart and took different routes across Baffin Bay to the southern part of the North Water polynya, just east of the entrance to Lancaster Sound. The whales crossed the central part of Baffin Bay relatively rapidly (travel time of 9–10 days, 3.1 and 4.5 km/h). Dive behaviour of one whale was monitored and showed changes in dive depths, dive rates, and surfacing times in different localities, indicating behavioural changes probably related to feeding. The whales were presumably feeding in both Disko Bay in May and in the southern part of the North Water (southeast of Bylot Island) in June. This study confirms whalers' observations that bowhead whales move between West Greenland and the east coast of Baffin Island.

Key words: bowhead whale, *Balaena mysticetus*, satellite telemetry, dive behavior, sea ice, Baffin Bay, Canada, Greenland

RÉSUMÉ. En mai 2001, cinq baleines boréales (*Balaena mysticetus*) ont été équipées d'émetteurs spatiaux dans le nord-ouest de la baie de Disko (Groenland occidental). Les meilleurs résultats ont été obtenus lorsque les marqueurs ont été apposés avec une perche plutôt qu'avec un fusil à air comprimé. Au moins trois des baleines marquées sont restées dans la partie nord-ouest de la baie pendant une à deux semaines après le marquage. Deux individus, un mâle et une femelle, se sont déplacés de la baie de Disko au nord du Canada. Ils ont quitté la baie à 11 jours d'écart et ont emprunté des trajets différents pour traverser la baie de Baffin et rejoindre la partie méridionale de la polynie de l'Eau du Nord, située juste à l'est de l'entrée du détroit de Lancaster. Les baleines ont traversé la partie centrale de la baie de Baffin assez vite (en 9 et 10 jours, soit 3,1 et 4,5 km/h). On a suivi le comportement de plongée d'une baleine, qui a montré des changements dans la profondeur des plongées, leur fréquence et le temps en surface à divers endroits, révélant des modifications du comportement probablement associées au nourrissage. On suppose que les baleines s'alimentaient dans la baie de Disko en mai aussi bien que dans la partie méridionale de l'Eau du Nord (au sud-est de l'île Bylot) en juin. Cette étude confirme les observations des baleiniers à l'effet que les baleines boréales se déplacent entre l'ouest du Groenland et la côte est de l'île de Baffin.

Mots clés: baleine boréale, *Balaena mysticetus*, télémétrie par satellite, comportement de plongée, glace marine, baie de Baffin, Canada, Groenland

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INTRODUCTION

The population of bowhead whales, *Balaena mysticetus*, in the Baffin Bay and Davis Strait area numbered at least 12 000 individuals in the 1800s (Woodby and Botkin, 1993). The population was severely depleted by commercial whalers before 1900 and is now considered to be between 250 and 350 whales (Finley, 1990; Zeh et al., 1993). Most of the information on the migration routes and former high-density areas in Canada and Greenland is based on observations from whalers in the 1800–1900s and Inuit hunters (e.g., Reeves et al., 1983; Ross, 1993; NWMB, 2000). The general hypothesis is that bowhead whales spend the winter distributed from the northeast coast of Labrador to the east

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coast of Baffin Island across to West Greenland. In the spring, the bowhead whales are found at the ice edge of Davis Strait and Hudson Strait, in localized areas in West Greenland, and along the east coast of Baffin Island. Whales from West Greenland are thought to cross Baffin Bay (at approximately 72˚ N) and reach Lancaster Sound between May and July, while the whales on the east coast of Baffin Island move north. During the summer, bowhead whales are widely distributed and enter many fjords and bays of the Canadian High Arctic. The fall migration begins in September and continues through October, when whales either move south along the east coast of Baffin Island or cross over to the West Greenland coast, appearing there in September and October (Reeves et al., 1983).

Over the past 20 years, scattered observations of bowhead whales have been reported from West Greenland, suggesting that bowhead whales still occupy their historic locations (Born and Heide-Jørgensen, 1983; Kapel, 1985; Reeves and Heide-Jørgensen, 1996; Heide-Jørgensen and Acquarone, 2002). The winter abundance of bowhead whales along West Greenland (derived from aerial surveys of belugas, *Delphinapterus leucas*) has been estimated to be at least "a few tens" of bowheads between 1981 and 1994 (Reeves and Heide-Jørgensen, 1996). This crude estimate was not corrected for whales that were submerged during the surveys, a phenomenon also known as availability bias. In 1998, Heide-Jørgensen and Acquarone (2002) produced an estimate of 233 bowheads (SE = 165) that included a correction for availability bias.

Studies of the migratory behaviour of bowhead whales in Baffin Bay are of interest for stock delineation, especially in the light of renewed hunting in Canada (Finley, 2001). The only direct evidence of a relationship between bowhead aggregations in eastern Canada and western Greenland is the photographic documentation of a whale in Isabella Bay, NE Baffin Island, in September 1986 being re-sighted near Disko Bay in April 1990 (Heide-Jørgensen and Finley, 1991). Bowhead whales inhabit areas with extensive ice cover and may be affected by habitat variability that results from climate change. Information on the plasticity of the migratory routes of bowhead whales provides insight on their vulnerability to changes in available habitats, and determination of migration routes also elucidates stock discreteness. The purposes of this study were to improve satellite tracking techniques for bowhead whales, to document the spring movements of bowhead whales from Disko Bay, West Greenland, and to investigate diving behaviour and habitat use over the course of the migration period.

METHODS

Daily searches for whales were conducted from four small boats between 28 April and 7 May 2001 near the town of Qeqertarsuaq, Disko Island. The overall ice coverage in the western part of Disko Bay was about 10% during the field period, which was unusually light for this time of the year. Most of the ice consisted of broken pieces of fast ice that drifted with the current. When a whale was sighted, the boats moved towards the whale until it dove. While the whale was underwater, the four boats spread out to search for the next surfacing location. When the whale was re-sighted, the process was repeated again until the whale was surfacing in a predictable manner, which usually took less than half an hour. When a whale was first approached (within 4–5 m), a skin biopsy for genetic studies was taken using a crossbow.

Bowhead whales were instrumented with three different types of satellite-linked radio transmitters: ST15 and ST16 (Telonics, Mesa, Arizona) and SPOT1 tags (Wildlife Computers, Redmond, Washington). The ST16 was modified by Wildlife Computers to include binned information on dives. All transmitters were equipped with lithium thianyl batteries and were glued to a cup-shaped stainless steel base, mounted to a titanium spear (diameter 8 mm) with three barbs and a sharp pointed tip. The ST15 tags were deployed with the 'ARTS' (Air Rocket Transmitter System; see detailed description in Heide-Jørgensen et al., 2001a). The ST16 and SPOT1 tags were deployed with an 8 m fiberglass pole approximately 4–5 m from the whale. The tag was mounted on the tip of the pole, secured by a nylon line. The titanium spear was pushed through the skin and into the blubber using the pole to attach the tag. When the tag was implanted in the whale, the nylon line was cut by a sharp edge on the pole. It was important to position the satellite tag high on the whale's back to ensure it was above the water, so that the satellite could receive its transmissions. The tag delivery system was designed so that a biopsy of the whale skin was taken simultaneously (with a 10 mm hollow cylinder, 28 mm in length with internal barbs). Tags were deployed only when the whale was positioned alongside the boat 4–5 m away, and when the whale remained at the surface long enough for us to place the tag in a good position.

Compressed and summarized dive data were transmitted to the satellite for one whale (ID 24638). A dive was defined as submergence below 8 m, and the surface was defined as above 9 m, following sampling schemes also used for narwhals and belugas (Heide-Jørgensen et al., 2001b). The tag sampled depth every 10 seconds, accumulating information on depth of dives, duration of dives, and time spent at different depths across four six-hour periods each day. Time spent was coded in 10 duration classes (0–1, 1–3, 3–6, 6–9, 9–12, 12–15, 15–18, 18–21, 21–24, > 24 min), and depth in 14 depth classes (8–19, 20–35, 36–51, 52–99, 100–151, 152–199, 200–299, 300–399, 400–499, 500–599, 600–699, 700–799, 800–900, > 900 m). The maximum depth of dives for each 24-hour period was also determined. Dive data were examined for temporal variability. Vertical speeds were calculated from dive duration through depth classes of known length to 'destination depths' where the dives ended (see Heide-Jørgensen et al., 1998). Every fifteenth transmission

TABLE 1. Transmitters deployed on bowhead whales in Disko Bay during 3–7 May 2001. 'ARTS' is the Air Rocket Transmitter System described in Heide-Jørgensen et al. (2001a).

Whale ID No.	Sex	Tag Type / Duty Cycling / Method of Deployment	Date Tagged in May 2001	Length of Spear (cm)	Number of Good-quality Positions (LC 0-3)	Number of Poor-quality Positions (LC A and B)	Tag Longevity (days)
20158	Female	ST15 / 1 day on-3 off / ARTS	3	35	15	7	2
24638	Male	ST16 / none / pole	5	36	198	383	44
26712	Female	SPOT / none / pole	6	36	13	49	5
21800	Male	ST16 / 1 day on-1 off / pole	6	45	1	5	9
26716	Female	SPOT / none / pole	7	45	24	280	50

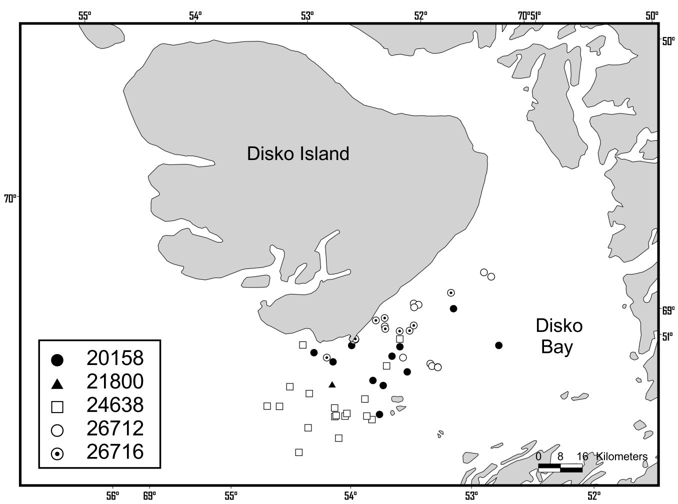

FIG. 1. Map of positions received for all bowhead whales (n = 5) tagged in Disko Bay in May 2001. Only positions with quality of 0 or better are reported.

provided readings of voltage and the cumulative number of transmissions.

Locations and dive data were collected using the Argos System (see Harris et al., 1990). Location qualities were provided by Service Argos and coded according to predicted accuracy. Location codes (LC) were B, A, and 0–3 in order of increasing accuracy of position. All location qualities were used to calculate an average daily position for each whale over the entire tracking period. The average positions were also used to calculate distance and speed over each 24-hour period and provide mean distances and speeds for selected periods during the movements of the whales.

DNA was extracted from the skin samples using DNeasy tissue extraction kits (QIAGEN). The sex of each animal sampled was then determined using a polymerase chain reaction (PCR)-based method that amplifies a portion of the X-chromosome and a portion of the Y-chromosome (if present) (Bérubé and Palsbøll, 1996). Animals were scored as female if there was only a single amplification product corresponding to the X-chromosome fragment and male if there were two products, one from the X-chromosome and one from the Y-chromosome.

Standard descriptive statistical analyses of the dive data were conducted and the level of significance was determined at $p = 0.05$. Since the dive data were categorized and summarized over six-hour periods, independence between samples was assumed, and ANOVA and ANCOVA were used to determine the effects of periods and day on the diving activity.

RESULTS

From 29 April through 8 May 2001, bowhead whales were observed in the northwestern part of Disko Bay daily (or whenever weather conditions permitted searches). All sightings consisted of single whales. Skin biopsies were collected from 15 whales, including all those that were tagged. Molecular sex identification of the samples revealed that 8 of the 15 were females.

Movements

Five bowheads, all estimated to be 12–15 m long (Table 1), were tagged with transmitters during this period. Tags provided locations for a minimum two days. The tagged whales appeared to prefer the northwestern part of Disko Bay (Fig. 1). Tags deployed on two whales (ID nos. 24638 and 26716) transmitted data for 44 and 50 days, and results from those tags are presented in detail here.

On 3 May 2001, an ST16 tag was implanted on a male whale (ID 24638) on the right side, 35 cm below the dorsal line and halfway down the long-axis. This whale (tagged at approximately 69˚12′ N, 53˚08′ W) left the Disko Bay area (69˚30′ N) on 10 May and headed northwest directly towards the east coast of Baffin Island (Fig. 2). Travelling a distance of 846 km, it reached an area only 100 km from Bylot Island, Canada, on 20 May, ten days after departing from Disko Bay (Table 2). Once this male crossed 73˚ W, it slowed down and moved to the southern margin of an area called the North Water polynya, east of Bylot Island. It made localized movements in this area (approximately 74˚ N, 75˚ W) from 30 May until 17 June, when transmissions stopped. Approximately 12 000 transmissions were obtained from this tag, which is about its maximum longevity, and the tag stopped transmitting because of declining voltage.

On 7 May 2001, a SPOT1 tag was implanted on a female whale (ID 26716) 20 cm below the dorsal line, halfway

TABLE 2. Total distance and mean rate of travel for whales 24638 and 26716 in three areas. Standard deviations are shown in parentheses. Since the two whales took different migratory paths, the arrival in the North Water was defined as crossing 73˚ N for 24638 and crossing 76˚ W for 26716.

Whale ID No.		Tagging to Departure from Disko Bay	Travel Across Baffin Bay	In the North Water	Average Speed and Total Distance
24638	Speed km/h	1.15 (0.8)	3.11 (1.6)	0.93 (0.7)	1.53 (1.4)
26716		0.87 (0.5)	4.53 (1.1)	2.41 (2.0)	1.96 (1.8)
24638	Distance km	120	846	622	1590
26716		287	1063	809	2159

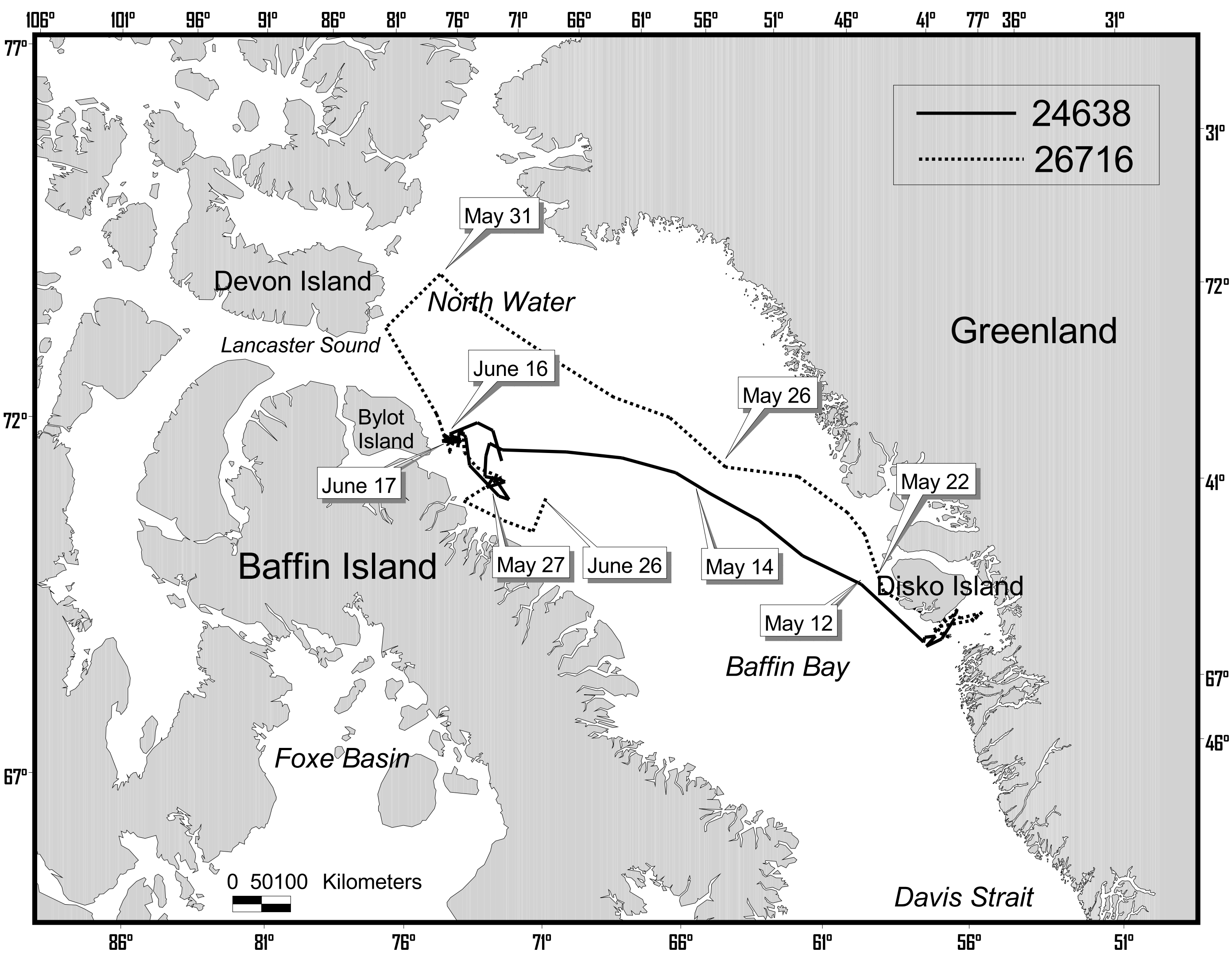

FIG. 2. Movements of two bowhead whales (24638, solid line; 26716, dashed line) from West Greenland to Canada in May–June 2001.

down the long axis. This whale (tagged at 69˚15′N, 53˚30′W) remained in Disko Bay for a longer period than the other whale and departed on 21 May (Fig. 2). It headed farther north closer to the Greenland coast and turned west towards Lancaster Sound at 72˚ N. It passed 73˚ W and reached an area off Devon Island in the central part of the North Water on 30 May, 10 days after departing from Greenland. From here it moved south, across the entrance to Lancaster Sound and frequented the same area as the other whale, an area approximately 100 km southeast of Bylot Island (Fig. 2). It continued moving south and spent approximately three days near Buchan Gulf. It then moved offshore (where there was a five-day period of no transmissions from the tag), and the final position was received on 26 June near the 500 m depth contour off the east coast of Baffin Island. This tag provided the expected 25000 transmissions before its battery voltage dropped, causing the tag to stop transmitting.

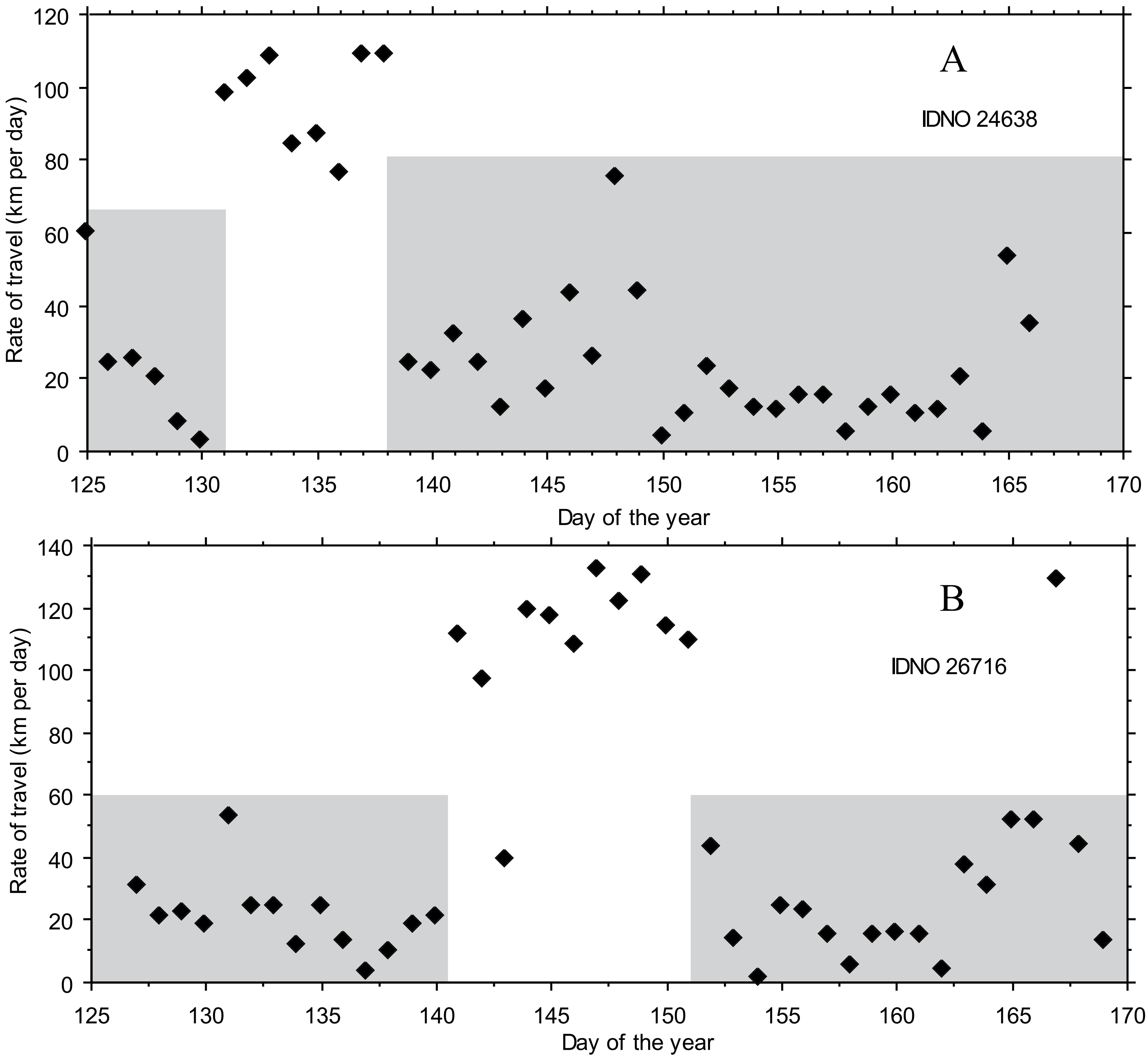

FIG. 3. Graphs of rate of travel (in km per day) relative to Julian day for (a) whale 24638 and (b) whale 26716. The shaded areas represent the whales' presence in Disko Bay after tagging (24638: 5–10 May, 26716: 7–21 May) and in the North Water-Southeast Bylot Island after crossing Baffin Bay (24638: 20–30 May, 26716: 22–30 May). The unshaded area represents the travel period across Baffin Bay (24638: 10–20 May, 26716: 31 May–26 June). Note the increase in travel rate as the whales moved west to Canada and the decrease in travel rate once they arrived in the North Water area.

The two whales were tagged approximately 10 km from each other in Disko Bay, and left Disko Bay 11 days apart. The whales took different routes with different timing across Baffin Bay. On the west side of Baffin Bay, the whales were approximately 350 km from each other on 31 May, with whale 26716 farther north on the east coast of Devon Island and whale 24638 at the southeastern corner of Bylot Island. Sixteen days later, the whales were less than 50 km from each other off the southeastern tip of Bylot Island.

The distance and speeds travelled by the two whales differed for both localized movements (in Disko Bay and the vicinity of Baffin Island) and long-distance travel (across Baffin Bay) (Table 2). Using average positions for each day, whale 24638 travelled a total of 1590 km during a 44-day tracking period, and whale 26716 travelled 2159 km during a 50-day tracking period. Average speed for the entire tracking period was calculated as 1.53 km/hr for whale 24638 and 1.96 km/hr for whale 26716.

Both whales maintained low speeds in Disko Bay and near Baffin Island, but increased their speeds when travelling across Baffin Bay. The rate of travel (based on average positions each day) demonstrated that whale 24638 travelled between 3 and 60 km per day when it was in Disko Bay and the vicinity of Baffin Island (Fig. 3a).

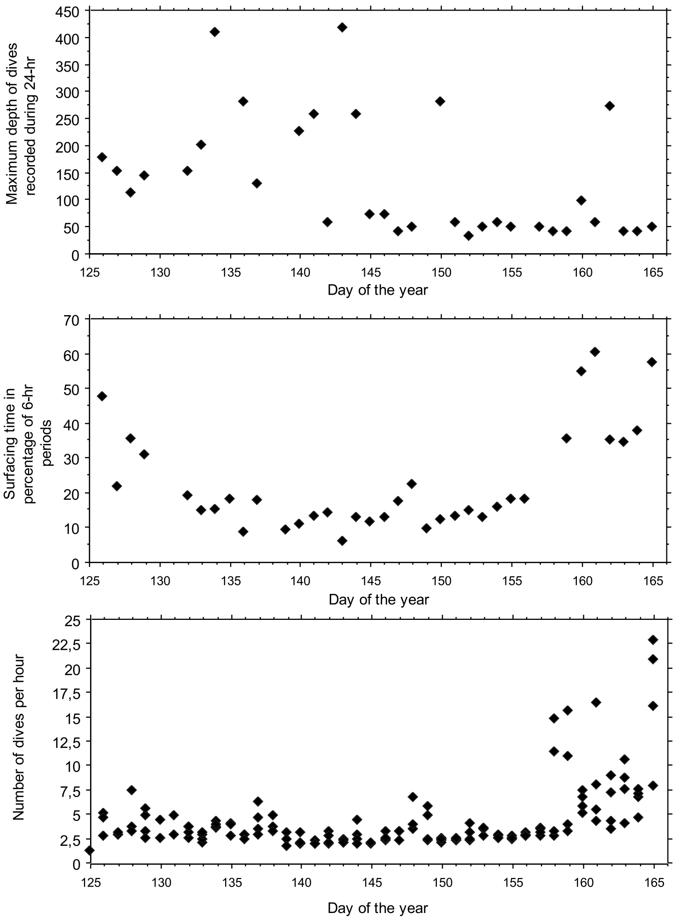

FIG. 4. Maximum daily dive depths (upper panel), surfacing time in percentage of 6-hour periods (middle panel), and dive rate in dives per hour (lower panel) for whale 24638.

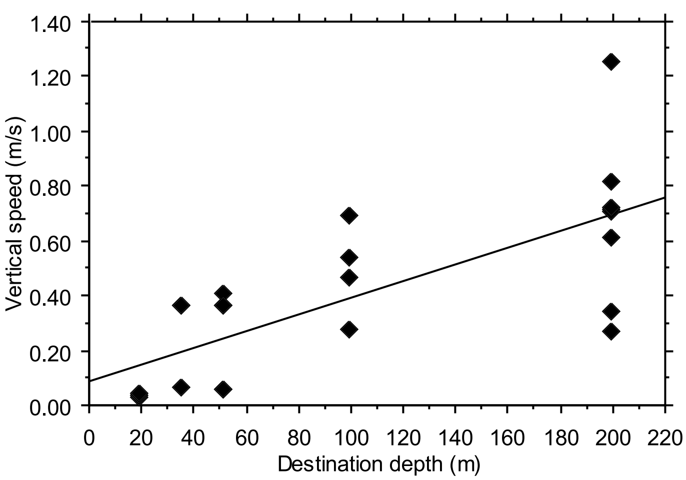

FIG. 5. Vertical speed by destination depth recorded for whale 24638 during the tracking period. The equation for the regression line is $y = 0.087 + 0.003 \times$ ($r^2 = 0.53$).

When the whale was travelling across Baffin Bay, its speed increased to over 100 km per day. Whale 26716 displayed a similar pattern, maintaining low speeds within Disko Bay and the North Water and travelling at higher speeds across Baffin Bay (Fig. 3b).

Diving Behaviour

One whale (24638) provided dive data for the entire tracking period. The mean of the maximum dive depths in Disko Bay (where water depth > 300 m) was 146 m (n = 4). En route to Baffin Island (water depth > 2000 m), maximum dive depths increased to 235 m (n = 7). After the whale arrived at Bylot Island (depth > 500 m), maximum dive depths declined to 155 m (n = 8) and to 67 m (n = 15) after 1 June (Fig. 4). The deepest dive depth recorded during the entire tracking period was 416 m. The dive rate remained relatively constant from the tagging date to 5 June, with a mean of 3.0 dives/hr below 8 m (SD 1.1, range 1.2–7.3). However, after 5 June the dive rate increased to 7.9 dives/hr (SD 5.0, range 2.7–22.8) (see Fig. 4).

Fewer than 15% of the dives were deeper than 152 m. There was a significant shift in the number of dives to all depth categories with time (ANOVA). The number of dives shallower than 36 m increased significantly from May to June, whereas the number of dives to deeper depth categories declined during this period. The steep rise in dive rate (after 5 June) was related to increased diving activity in the 8–20 m depth category, although dives to the depth category between 20–36 m also contributed to the increase. Dives to depths between 100 and 200 m almost ceased after 15 May, with infrequent dives to these depths until 9 June.

Percent of time spent above 20 m was 65% in Disko Bay, 49% while traveling across Baffin Bay, and 54% during the stay off Bylot Island, increasing after 1 June to 81%. The average time spent above 20 m for the entire tracking period was 64%. In all three areas, the whale spent more than 90% of its time above 50 m depths.

In Disko Bay the surfacing time averaged 34% (SD 10.7, n = 4). En route to east Baffin Island this declined to 14% (SD 3.9, n = 9, $p = 0.0004$), and it remained low (13%) after the arrival at the area off Bylot Island (SD 4.4, n = 10, $p = 0.6568$). Surfacing time increased again after 1 June to 33% (SD 16.7, n = 13, $p = 0.0013$) (Fig. 4). The vertical speeds were significantly correlated with the destination depth of the dives and only once exceeded 1 m/s (Fig. 5).

There was no discernible difference between the four six-hour periods in dive rate, duration of dives, time spent at different depths, or the number of dives to different depths (ANOVA). Diurnal patterns of dive activities did not emerge over the two months of data collection (ANCOVA with day as covariate). Most dives lasted less than one minute, and the number of dives decreased as the duration categories increased (Fig. 6). Only 5% of the dives lasted more than 24 minutes.

DISCUSSION

Performance of Tags

Two of the five tags deployed on bowhead whales performed as expected, providing positions for up to 50 days

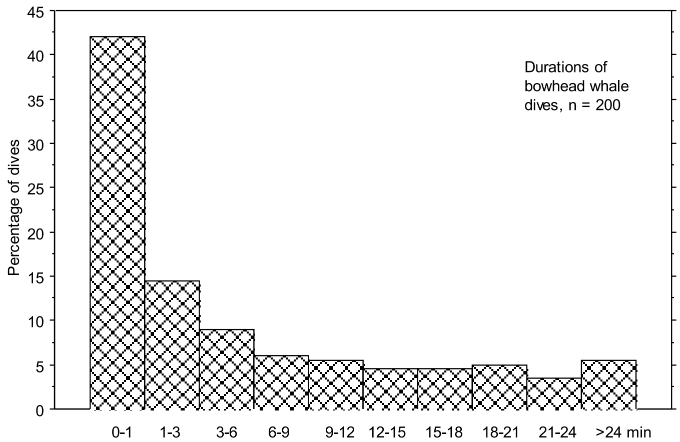

FIG. 6. Percentage of dives in different duration bins for whale 24638.

and ultimately draining their batteries. The reasons that some tags transmit longer than others are unclear. Failure is most likely related to poor implantation of the tag in the blubber, improper placement of the tag on the back of the whale (positioned too low for transmissions), or failure of the satellite tag itself. The tags deployed with the pole performed better than the tags deployed with the pneumatic gun (the 'ARTS'). During the instrumentation, both whales were close to the boats (< 10 m) and moving slowly, which facilitated the use of the pole. The use of the ARTS at short distances may harm the tags because of the impact upon implantation (i.e., the deceleration). The optimal tool for deploying satellite tags on baleen whales may depend on species, distance to the whale, and speed of the whale.

There have been no previous studies of satellite-monitored movements of tagged bowhead whales in Greenland, Baffin Bay, or Canada. In 1992, 12 juvenile (< 13 m body length) bowhead whales were satellite tagged in the Beaufort and Chukchi Seas and tracked for periods ranging from 3.1 to 32.5 days (Mate et al., 2000). The tagging procedure differed from the one reported here: whales were tagged in the open-water season in very shallow water (< 10 m depth) from a large vessel. Tags consisted of a cylinder with two 14 cm stainless steel rods, each with folding toggles, and tags were implanted using a crossbow. The tagging conducted in our study occurred in deep water (200 m) that was partially covered with ice. The whales were pursued from fast boats, and the tags were implanted using a pole. Tags in this study also differed in design, as only one rod was used to anchor the tags deep in blubber. These differences make it difficult to compare the technical performance of the two methods. The longest recorded track in Mate et al. (2000) was from one bowhead whale that moved 3886 km over the course of 33 days, with an overall speed of 5 km/h. The whale rapidly moved west from the Beaufort Sea to the western Chukchi Sea, only occasionally leaving the continental shelf.

In the present study, only whale 24638 provided a large number of good-quality positions (Table 1). Consequently, all position qualities were used, and an average daily position was calculated for both whales with long-term tracking records. A comparison of the trackline created from good-quality positions (LC 0–3) with the trackline created from average daily positions indicated that the poor-quality positions had only marginal influence on the bearing and length of the trackline.

Occurrence in Disko Bay

Eschricht and Reinhardt (1861) collected information on the time of departure (latest observations in spring) of bowhead whales from Qeqertarsuaq from 1780 to 1837. Their mean date for the last observations of whales in the Disko Bay area was 1 June, with a range from 26 April to 25 June. The two whales that were tracked in the present study left Disko Bay in mid-May, approximately 11 days apart. Information collected from local hunters before and after the field season confirmed that bowheads were present in the area at least from mid-April through 20 May. It appears that bowhead whales in Disko Bay may still maintain their historical patterns of distribution and movement, in spite of the severe reduction in numbers.

Bowhead whales feed on crustacean zooplankton, primarily large copepods of the genus *Calanus* and euphausiids (Brown, 1868; Lowry, 1993). In spring, the largest concentrations of copepods in Disko Bay are found in the upper 50 m of the water column (Madsen et al., 2001). The observed diving behaviour of the bowhead whale in Disko Bay and along the east coast of Baffin Island is consistent with preying on copepods in the upper part of the water column because the whale spent over 90% of its time above 50 m (water depth > 300 m in both areas). The biomass of copepods is known to reach a peak in Disko Bay in early June, when values of more than 100 mg C m^{-3} have been measured (Madsen et al., 2001). In the upper 50 m of the water column, 90% of this biomass estimate was composed of three *Calanus* species, *C. finmarchicus*, *C. glacialis* and *C. hyperboreus*. The bowhead whales tracked in this study apparently left the Disko Bay area prior to the peak availability of their preferred food species. Bowhead whales in Alaska have been reported to display similar behaviour, leaving the productive Bering Sea each year just before the spring bloom of copepods and migrating 3000 km to the less productive Beaufort Sea (Lowry, 1993). It is unclear why the bowhead whales leave Disko Bay and move to the North Water before the peak of the *Calanus* production in West Greenland.

Baffin Bay

This study demonstrates that bowhead whales are capable of navigating through the heavy pack ice in central Baffin Bay. Most likely the whales move north along the West Greenland coast until they find a suitable lead in the pack ice. These leads are known to intersect Baffin Bay from northwest to southeast (Environment Canada, 1990–2000). If whales find a lead heading northwest, they may be able to cross from Disko Bay to Lancaster Sound in a short time. Once whales cross the Baffin Bay pack ice, they can expect to find open water in the North Water polynya. It could not be determined which lead (or series of leads) the whales chose for moving across Baffin Bay. There were, however, areas of open water used by the whales at both ends of their movements, in Disko Bay and northeast of Baffin Island. The rate of travel did not appear to indicate that the bowhead whales were feeding in the ice-covered areas in Baffin Bay. While crossing Baffin Bay, the daily maximum dive depth for whale 24638 increased to an average of 235 m. While the dive rate remained constant (3 dives/hr), the surfacing time declined to approximately 14%. The increase observed in maximum dive depths is possibly related to navigation in the dense pack ice (i.e., using deeper depths to localize spots with open water) or low-frequency communication with other whales (low-frequency sounds are known to travel longer distances at deeper depths). Bowhead whales travelling under the ice may spend more time at deeper depths to avoid interacting with the ice (Krutzikowsky and Mate, 2000). The decrease in surfacing time indicates that the whale spent more time in water deeper than 8 m, in the layer between 8 and 50 m.

Average speeds for the two whales were similar for the course of the tracking period. Total distance was slightly lower for whale 24638 than for whale 26716. Whale 24638 may have taken a more direct course across Baffin Bay, which may have been related to available openings in the sea ice. One would assume that a whale would take the shortest distance between two feeding grounds for energetic reasons. Whale 26716, which took the longer route across Baffin Bay, had a higher average total speed than whale 24638 (1.96 km/h vs. 1.53 km/h), as well as a higher speed crossing Baffin Bay (4.53 km/h vs. 3.11 km/h).

The rapid rate of travel for both whales across the Baffin Bay pack ice does not agree with reports that bowhead whales occur in winter in central Davis Strait and southern Baffin Bay (see Brown, 1868; Southwell, 1898; Finley, 1990, 2001). Aerial surveys conducted in March 1981 and 1982 covered Davis Strait and most of Baffin Bay, but encountered bowheads only in the coastal areas off West Greenland and East Baffin Island (McLaren and Davis, 1981, 1983). Most likely bowhead whales occur in seasonal aggregations in coastal areas and traverse offshore areas only when moving/migrating to other concentration areas.

Occurrence in the North Water

Davis and Koski (1980), who surveyed the waters off northwest Baffin Island in spring 1976 and 1978, reported that bowhead whales first arrived at the eastern entrance to Lancaster Sound around 8–11 May. The migration from offshore areas towards Lancaster Sound lasted through 8 August and apparently peaked during 19–30 June in both years. The timing of the arrival of the two whales from Disko Bay seems to coincide well with these observations. In addition, Holst and Stirling (1999) reported 14 sightings of bowhead whales in the North Water, east of Devon Island, between 4 May and 13 June 1998, which coincides with the period when the whales from the present study were in this same area. The North Water polynya is known to be a highly productive area; it is capable of supporting a high degree of primary and secondary production early in the season and, consequently, a high abundance of marine mammals and sea birds (Stirling, 1997). It seems likely that the bowhead whales using the southern part of the North Water in spring are indeed whales from Disko Bay, as also proposed by Holst and Stirling (1999). This implies that the bowhead whales move quickly from one productive area (Disko Bay) to another highly productive area (the North Water) and take advantage of the early productivity blooms in the North Water polynya.

The whales' rapid transit across Baffin Bay makes it unlikely that they were feeding in the pack ice. However, it appears they may be feeding in the North Water polynya, since travel rate decreased and movements became more localized once they arrived there (Table 2, Figs. 4 and 5). Detailed quantitative information on copepod abundance in eastern Lancaster Sound in spring is not available. However, presumably the North Water polynya provides a spring bloom of copepods that is comparable to what is found in Disko Bay. After 1 June, when whale 24638 arrived in the North Water area, daily maximum dive depths decreased (to 67 m), surfacing time increased (to > 80%), and dive rate increased (to 7.9 dives/hr), behavioural changes that may indicate increased feeding. Sampling in eastern Lancaster Sound in July through October 1978 showed that copepods were most abundant between 0 and 50 m depth and declined with increasing depth (Buchanan and Sekerak, 1982). In August 1980, zooplankton were vertically distributed, with peak abundance just below the surface (< 5 m) and a higher abundance at 50–70 m depths in eastern Lancaster Sound (Longhurst et al., 1984). Copepods of the *Calanus* species were the most abundant zooplankton species in both studies.

Dive Behaviour

Krutzikowsky and Mate (2000) reported several dives of bowhead whales in the Beaufort and Chukchi Seas that lasted over 20 minutes, with few lasting more than 60 minutes. The maximum depth of the dives recorded for bowhead whales in Alaska was 352 m. Most dives went to depths above 100 m and most time was spent above 16 m. Despite their differences in bathymetry and seasonality, the two studies showed remarkably similar diving characteristics. The vertical speeds observed for the bowhead whale in this study were significantly lower than those reported for fin whales (*Balaenoptera physalus*) and blue whales (*Balaenoptera musculus*) (Croll et al., 2001).

Plasticity of Movement Patterns

Our observations of the dispersed distribution, solitary occurrence, and presumed solitary migration routes of whales from Disko Bay seem to confirm the reported solitary habits of bowhead whales in West Greenland during this period (cf. Reeves and Heide-Jørgensen, 1996; Heide-Jørgensen and Acquarone, 2002). However, despite the observations of solitary whales (which may be an effect of the past overexploitation of the stock), the whales may still maintain acoustic contact over large distances. The two other High Arctic cetaceans, the narwhal (*Monodon monoceros*) and the beluga, migrate to and from summer and wintering grounds in pods along specific corridors (Dietz et al., 2001; Richard et al., 2001; Heide-Jørgensen et al., 2002). The different routes chosen by the two bowhead whales, as well as the information on the phenology of their occurrence in West Greenland (i.e., variations in departure dates, Eschricht and Reinhardt, 1861) and the North Water (i.e., widespread solitary occurrence, Davis and Koski, 1980; Holst and Stirling, 1999), indicate that bowhead whales may have more plasticity in their migratory patterns than the two other Arctic cetaceans. This would increase the opportunities for widespread genetic exchange and may explain the relatively large genetic diversity among bowhead whales (Maiers et al., 1999). Of the three High Arctic cetaceans, narwhals show the lowest level of genetic diversity (Palsbøll et al., 1997) and the most restricted range of movements (cf. Dietz et al., 2001). Belugas fall between bowhead whales and narwhals in genetic variability (de March et al., 2002; Palsbøll et al., 2002), possibly reflecting their preference for open-water areas (the North Water and West Greenland), where they can sustain a wider range of movements (cf. Richard et al., 2001).

Evidently bowhead whales are dependent on the success of the marine production in focal areas of the North Water and Disko Bay. Although bowheads display characteristics that make them appear flexible in their choice of migratory corridors and the timing of migrations, climatic change could change the nature of the ice, ultimately affecting the distribution and characteristics of leads and polynyas. Reduced ice coverage in one or both of these areas may enhance plankton production and feeding opportunities of bowhead whales. However, the timing of the peak production will determine whether they can take advantage of that productivity.

Implications for Stock Identification

This study confirms the connection between bowhead whales in West Greenland and the east coast of Baffin Island. It appears the movements from one area to the other are accomplished over short time periods, without major stops en route, as proposed earlier by Eschricht and Reinhardt (1861), who based their conclusion on information from whalers that pursued bowheads during their spring migration to Baffin Bay (cf. Southwell, 1898). Prior to this study, the connection between bowheads in eastern Canada and West Greenland was established solely by a single whale photographed in Canada (NE Baffin Island) in late September and re-identified in Greenland in early April four years later (Heide-Jørgensen and Finley, 1991). The relationship between the bowhead whales found near the entrance to Lancaster Sound and those found in summer and autumn farther west in Lancaster Sound and tributaries remains unresolved. Bowhead whales in the eastern part of Lancaster Sound most likely come from Baffin Bay, as suggested by Eschricht and Reinhardt (1861) and by Davis and Koski (1980). However, the bowhead whales found in western Lancaster Sound and tributaries in summer may come either from the east coast of Baffin Island (from Disko Bay) or from Hudson Bay (through Fury and Hecla Strait). Clearly, more data and larger sample sizes are needed to identify the stocks of bowheads found in Canada in summer. Satellite tracking has proved to be a promising tool for studying stock identity and elucidating important information on movement patterns and habitat use of a species.

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