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ORIGINAL PAPER

Movements of narwhals (*Monodon monoceros*) from Admiralty Inlet monitored by satellite telemetry

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Abstract Twenty-one narwhals tagged in 2003 and 2004 in Admiralty Inlet showed a different summer distributional pattern than previous narwhal-tracking studies from Somerset Island, Eclipse Sound and Melville Bay. The migration of the narwhals tracked from Admiralty Inlet moved out through Lancaster Sound 15 days earlier ($P < 0.0001$) than the narwhals summering around Eclipse Sound, whereas the Admiralty Inlet narwhals reached the mouths of Eclipse Sound 18 days later ($P < 0.0001$) than the Eclipse Sound summering population. The winter range of the Admiralty Inlet narwhals overlapped with the winter range of narwhals from Melville Bay and Eclipse Sound in central southern Baffin Bay and Northern Davis Strait, but not with the winter range of narwhals from Somerset Island that wintered further north. Distribution size of range, and population size did not appear to be related. An example of considerable year to year variation between area of summer and winter distribution in the 2 years was believed to be related to the sample size and number of pods of whales tagged, rather than to differences in sex or age classes.

Keywords Narwhal · Telemetry · Admiralty Inlet · Baffin Bay · Davis Strait · Migration

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Introduction

The narwhal (*Monodon monoceros*) is an Arctic odontocete that measures up to 5 m in lengh. Males have an ivory tusk that erupts from the upper left jaw (Hay and Mansfield 1989). The narwhal lacks a dorsal fin, but has a low irregular dorsal ridge along the posterior half of its back (Hay and Mansfield 1989). Narwhals occur in inshore areas of northeastern Canada and Greenland during the open-water season from July to September (Born et al. 1994; Dietz et al. 1994; Richard et al. 1994). The narwhal is also found on the east coast of Greenland and further east into the European Polar Basin, with most observations close to Svalbard and Franz Josef Land (Dietz et al. 1994). In the autumn, narwhals leave inshore areas of northeastern Canada and Greenland and make long-distance movements to their wintering grounds (Dietz and Heide-Jørgensen 1995; Dietz et al. 2001; Heide-Jørgensen et al. 2002, 2003a, b) which are covered with dense pack ice from November to July (Koski and Davis, 1994; Laidre et al. 2004b).

Narwhals are hunted in both Canada and Greenland, and therefore knowledge of stock discreteness or relatedness is important to provide advice on the management of these hunts. Understanding the degree of exchange between populations is also important in the design of comparative studies of contaminant loads in narwhals (Dietz et al. 2004). Finally the migration route and timing of their migration are of importance for impact assessments of human activities, such as shipping, commercial fishing and development of non-renewable resources (e.g. offshore oil and gas).

Although gross patterns of seasonal migrations have been inferred from statistics on Inuit catches of narwhals and from aerial surveys at different seasons (e.g. Born et al. 1994; Koski and Davis 1994; Richard et al. 1994), satellite tracking methods have provided considerable detailed knowledge about narwhal seasonal range, migratory patterns and seasonal ecology (Martin et al. 1994; Dietz and Heide-Jørgensen 1995; Heide-Jørgensen and Dietz 1995; Dietz et al. 2001; Heide-Jørgensen et al. 2001, 2002, 2003a, b; Laidre et al. 2002, 2003, 2004a, b; Lydersen et al. 2007). Nevertheless, there is still much to learn from tagging as well as from other approaches. Little is known about the genetic exchange relative to the movements during the breeding season. A study of the population structure based on mtDNA revealed low nucleotide diversity, but significant levels of heterogeneity were detected between a number of combinations of three West Greenlandic sampling areas and a combined group from eastern Canada and northwestern Greenland (Palsbøll et al. 1997). The sample size from Canada was, however, too small ($N = 29$) to show conclusively any population structure. In areas where it has proven difficult to capture and tag narwhals (e.g. the Inglefield Bredning and Uummannaq area in Northwest Greenland), a combination of more indirect methods (genetics, contaminant and stable isotope analyses) has been used to elucidate stock connections (Palsbøll et al. 1997; Dietz et al. 2004).

The objectives of this study were to: (1) assess the degree of site tenacity of Admiralty Inlet narwhals during the open-water season, (2) to determine the migration routes and wintering range of this population, and (3) to examine the level of overlap in the winter range with the winter range of narwhals from other summer aggregations.

Materials and methods

The tagging area

The whales were tagged at Kakiak Point (72°41′00″N–86°41′20″W) in Admiralty Inlet, Baffin Island, Nunavut, Canada, a fjord which is approximately 250-km long and up to 35-km wide, with maximum depths of up to 700 m. The fjord is bordered by high (≥500 m) steep-sided cliffs of the Brodeur Peninsula Plateau to the west and Borden Peninsula to the east, but also by promontories of low bluffs or raised beaches with shores of sand and gravel. This fjord is a well-known narwhal summering area, where these whales are regularly hunted by Inuit of the hamlet of Arctic Bay/Ikpiarjuk.

According to local hunters, the fast ice usually clears the fjord at the end of July, although some years pack ice can remain throughout the summer. Little ice was present in the vicinity of Kakiak Point from 11 to 22 August of 2003 and 2004.

Local hunters hold Kakiak Point as one of the best spots in Admiralty Inlet to hunt narwhals because of the tendency of these whales to approach the coastline at that point. It also proved to be an excellent location for live-capture operations. In addition to narwhals, bowhead whales (*Balaena mysticetus*) and ringed seals (*Phoca hispida*) were regularly observed close to the campsite in both years.

Live-capture methods

Narwhals were captured in nets set close to the surface and perpendicular to the shoreline. Due to the large number of narwhals in the area, only one net section, 50-m long, was set approximately 50 m from shore. The net was black and 10 m deep with 40 × 40 cm mesh sizes. They were kept afloat with 40-cm white buoys along the top line. Larger (100 cm) white buoys marked both ends of the net. It was anchored to a large stone on the beach and several heavy stones on the bottom at the seaward end. The net was under constant surveillance day and night and the presence of narwhals anywhere close to the net triggered increased preparedness in the capture team. Soon after whales became entangled, two inflatable boats were paddled out to the captured animals. Both nets and narwhals were raised to the surface to ensure that the animals could breathe comfortably. Whales were then dragged to shore after releasing the net from the seaward anchor and secured by a tail rope. The net was cut off the whales and a hoop net was placed around its head to control it, unless it had a large tusk to hold on to. Both methods were used to keep the blowhole out of the water. Transmitters were attached to the back ($n = 21$) and, in some cases, also on the tusk ($n = 3$) of the animals. After instrumentation, the animals were pushed to deeper water and released. Average handling time was 30 minutes.

Instrumentation of narwhals

Thirteen narwhals were caught between 10 and 23 August 2003, and eight narwhals were caught between 10 and 23 August 2004. The sex, standard length, tusk length (for males) and fluke width were recorded and they were instrumented with backpack transmitters of type SPOT2 ($n = 7$), SPOT3 ($n = 6$) or SPOT4 ($n = 8$) (Table 1). All backpack transmitters were produced by Wildlife Computers (Redmond, WA, USA). Three of the animals were also instrumented with tusk tags (ST-10: Telonics Inc.; housing: Wildlife Computers). With their larger batteries (6 lithium C cells), tusk tags were programmed to provide 500 transmissions every day, while the backpack tags which had smaller batteries (2 AAA lithium batteries) were programmed to transmit 200 transmissions every third day. Further details on weight and size of transmitters and attachment methods are available from Dietz et al. (2001) and Heide-Jørgensen et al. (2003a). Data from the transmitters

Table 1 Information on 21 narwhals instrumented with satellite-linked transmitters in Admiralty Inlet in August 2003 and 2004

Admiralty tagging #/group	PTT ID No.	Sex	Length (cm)	Fluke width (cm)	Tusk length (cm)	Tag type	PTT ID	Tagging date (YeMoDa)	Date of last transmission	Duration (days)	Length of tracking (km)
1/A	3960	Female	416	?	–	Backpack	SPOT3	2003.08.16	2003.12.29	135	8,147
2/B	37236	Male	411	?	43	Backpack	SPOT2	2003.08.16	2003.10.31	76	3,279
3/C	3961	Female	385	91	–	Backpack	SPOT3	2003.08.16	2004.03.13	210	12,955
4/D	7928	Male	335	82	55	Backpack	SPOT3	2003.08.18	2004.04.11	237	13,118
5/D	37234	Male	442	112	174	Backpack	SPOT2	2003.08.18	2003.12.28	132	4,226
	3965					Tusk tag	ST-10	2003.08.18	2003.11.04	78	6,108
6/D	37235	Male	448	104	193	Backpack	SPOT2	2003.08.18	2003.12.22	126	4,885
	3962					Tusk tag	ST-10	2003.08.18	2003.10.18	61	4,545
7/E	7931	Male	349	90	68	Backpack	SPOT3	2003.08.19	2004.01.25	159	10,215
8/F	20165	Male	483	119	190	Backpack	SPOT3	2003.08.20	2003.09.14	25	520
	20157					Tusk tag	ST-10	2003.08.20	2003.09.13	24	2,357
9/F	37283	Male	434	107	184	Backpack	SPOT2	2003.08.20	2003.10.10	51	1,345
10/G	37282	Female	373	87	–	Backpack	SPOT2	2003.08.21	2003.10.01	41	1,828
11/G	21794	Female	367	89	–	Backpack	SPOT3	2003.08.21	2003.11.10	81	3,091
12/H	7927	Male	365	85	70	Backpack	SPOT2	2003.08.21	2003.12.13	114	4,049
13/I	3964	Female	380	88	–	Backpack	SPOT2	2003.08.21	2004.09.15	25	1,136
14/J	37232	Male	392	100	202	Backpack	SPOT4	2004.08.11	2004.09.16	36	1,670
15/K	37233	Male	415	105	165	Backpack	SPOT4	2004.08.13	2004.11.27	106	4,059
16/K	37286	Male	408	110	140	Backpack	SPOT4	2004.08.13	2005.05.20	280	7,506
17/L	37288	Female	365	82	–	Backpack	SPOT4	2004.08.14	2005.08.06	357	11,470
18/M	21803	Female	388	100	–	Backpack	SPOT4	2004.08.14	2004.09.06	23	192
19/N	27262	Female	410	95	–	Backpack	SPOT4	2004.08.22	2004.12.29	129	2,877
20/N	37228	Female	390	91	–	Backpack	SPOT4	2004.08.22	2005.03.08	198	5,733
21/N	37277	Female	390	91	–	Backpack	SPOT4	2004.08.22	2005.02.02	164	3,770
All										3234	119081

were relayed via the ARGOS DCLS system (Service Argos Inc. 1989; Harris et al. 1990).

Data collection and analysis

Data on location and transmitter status were collected via the Argos Location Service Plus system (Toulouse, France; Harris et al. 1990). The SAS program Argos_Filter (V6.0) (David Douglas, USGS, Alaska Science Center, Alaska, USA; http://alaska.usgs.gov/science/biology/spatial/douglas.html) was used to filter locations that passed plausibility criteria. The criteria used were a minimum angle threshold of 5° between movement vectors of consecutive locations and a maximum speed of 10 km/h calculated from distance travelled and time span between locations. Locations of quality class 3 were always retained. In addition the program calculated distances travelled and migration speeds. Excel 97 (SR2) and StatView (V5.0.1) were used for statistical analysis and graphs. Maps of narwhal movements were generated using ArcMap (V8.3). Bathymetric contours based on 1° resolution data were obtained from the International Bathymetry Chart of the Arctic Ocean (IBCAO, Jakobsson et al. 2000). ESRI ArcView (V3.2) with ArcView's Animal Movement (V2.0) (Hooge and Eichenlaub 2000) and Spatial Analyst extensions was used to generate tracklines and kernel home-range estimates. Single daily locations with the highest (best) location class were selected, using the PICKDAY = 1 function of the Argos_Filter. The Animal Movement extension was then used to generate 95% kernel home range contours with this subset. The purpose of this selection was to reduce problems associated with temporal auto-correlation. Average home range for both years was calculated using combined 2003 and 2004 daily "best" locations. Land was not subtracted in the home range calculations to make the calculated figures methodologically comparable between summer and winter situation.

Results from this study were compared and contrasted to previous tracking studies of narwhals including summer and winter home ranges, migration routes and distances. The previous studies include narwhals tagged in Melville

Bay, Greenland (1993: $n = 5$; 1994: $n = 4$), and from Canada in Eclipse Sound (1997: $n = 5$; 1998: $n = 5$; 1999: $n = 7$) and around Somerset Island (2000: $n = 10$; 2001: $n = 7$) (Dietz and Heide-Jørgensen 1995; Heide-Jørgensen and Dietz 1995; Dietz et al. 2001; Heide-Jørgensen et al. 2002; 2003).

Results

Duration of transmitter uplinks

The duration of the tags' uplinks ranged between 23 and 257 days. Average and maximum longevity increased in the latest produced transmitter model: ST-10 (mean = 54; range 24–78; $n = 3$), SPOT2 (mean = 81; range 25–132; $n = 7$), SPOT3 (mean = 141; range 25–237; $n = 6$) and SPOT4 (mean = 162; range 23–357; $n = 8$). Summer range was defined as release dates in (Table 1) to 10 September, the overall average date that tagged whales started to move in a directed manner out of Admiralty Inlet and the other compared summer populations (Dietz and Heide-Jørgensen 1995; Dietz et al. 2001; Heide-Jørgensen et al. 2002, 2003). Data on summer range for Admiratly Inlet was available for 13 narwhals in 2003 and 8 narwhals in 2004. Winter range was defined as 15 November to 25 April. This was based on the overall average date when all the whales had terminated their fall migration and switched from directed travel to more local movements. Nine Admiralty Inlet narwhals transmitted through the winter period in 2003–2004 and six in 2004–2005.

Movements

In summer of 2003, the tagged whales ranged over most of Admiralty Inlet (Figs. 1a, 2a), but in 2004 they concentrated in the central portion of the inlet (Figs. 1b, 2a). The estimated summer home range of the whales tagged in 2003 was therefore 4.8 times larger than the corresponding summer range in 2004 (Table 3; Fig. 2a). A similar pattern was observed on the wintering ground in southern Baffin Bay and northern Davis Strait. The winter home range of the whales tagged in 2003 was 6.7 times larger than the winter range for the 2004 deployment (Table 3). Four narwhals tagged of the 2003 sample went much further south than any of the narwhals tagged in 2004. One of the 2003 whales (#7928) reached latitude 63.0°N in February 2004 (Figs. 1a, 2b), while the southernmost winter latitude reached by a 2004 whale (#37228 in October 2004) was approximately 65.7°N, that is 300 km further north (Figs. 1a, 2b). The 2003 deployment was a larger sample size (13 animals in 9 groups: A–I) compared to the one in 2004 (eight animals in five groups: J–N). This could explain the differences in their ranges (Table 1). The winter home range of the whales tagged in 2003 was 21.3 times larger than the corresponding summer home range. Similarly, the following year, the winter range was 15.4 times larger than the summer distribution.

Seasonal distribution against latitude

A plot of latitude against Julian day (JDay) provides a summary of the seasonal movement patterns of narwhals in 2003 and 2004 (Fig. 3). Movement out of Admiralty Inlet (i.e. to latitudes north of 73.8°N) took place between 14 September and 11 October (JDay: 254–284). Most of the tagged whales used the southern coastline on their eastward migration out of Lancaster Sound. Their southbound movement along the east coast of Baffin Island took place between 29 September and 10 November (JDay: 272–314) and most of the narwhals migrated beyond the 500 m isobath (Figs. 1a, 1b). The tagged narwhals arrived at their wintering ground between approximately 17 October and 15 November (JDay: 290–319, Fig. 3). At first glance, there was no obvious pattern in winter latitudinal distribution between animals of different sex or age class, nor did it appear to be related to the timing of their departure from Admiralty Inlet. The first narwhal to leave Admiralty Inlet was an adult female (#3961; Fig. 3, red line) whose migration ended with an average winter latitude around 68°N, whereas the last departing animal was a juvenile male (#7928; Fig. 3, orange line) which moved to the southernmost latitude (63°N) reached by any of the tagged narwhals.

The two animals with transmitters functioning the longest (#37288 and 37286) started their northbound spring return migration around 25 April (JDay: 115) and continued transmitting for 2 months, until approximately 25 June (JDay: 176). This northward migration occurred in heavy pack ice. These whales took a less direct route than the autumn migration in open water and the duration of their migration took approximately three times as long.

Comparative results from double-tagged whales

Three males were equipped with both a backpack and a tusk transmitter. The tusk tags provided locations for 24–78 days (mean: 54 days), while backpack tags provided locations for 25–132 days (mean: 94 days) (Table 2). In two cases, tusk tags lasted only 48–59% (Mean: 53.5%) of the time from which positions were obtained from the backpack transmitters. It is unknown why the tusk tags failed earlier, but likely explanations are either that the tags came loose or that their electronics or antenna were damaged by contact with the seabed. Underwater footage has revealed that, when submerged, narwhals swim upside down and fairly close to the bottom (Dietz et al. 2007). In the third

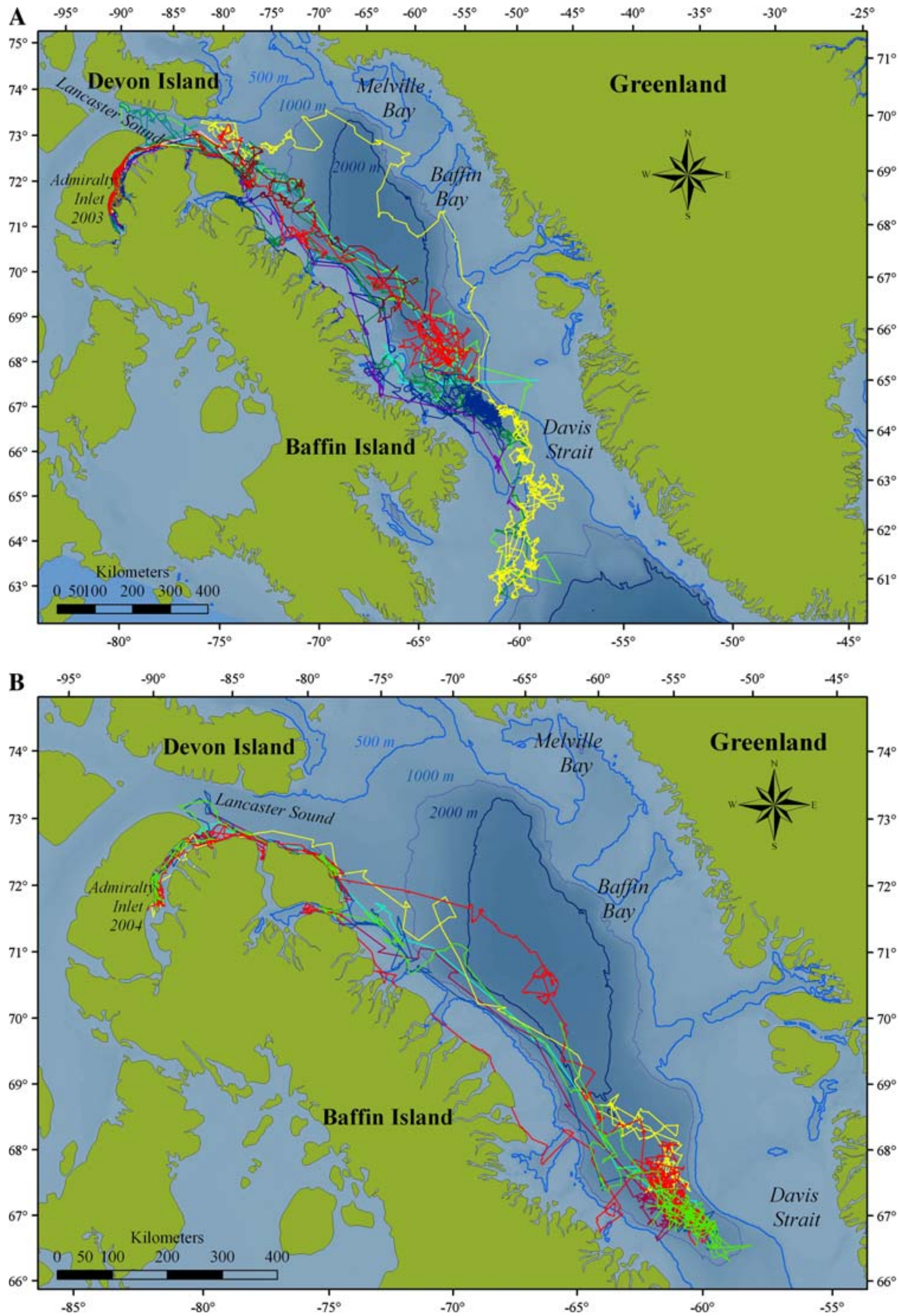

Fig. 1 **a** Tracklines from 13 narwhals tagged in August 2003 in Admiralty Inlet, Canada. Of these, nine transmitters lasted beyond 15 November where the whales reached their wintering ground in southern Baffin Bay and northern Davis Strait. The transmitters lasted from 25 to 237 days. **b** Tracklines from eight narwhals tagged in Admiralty Inlet in 2004. Of these six transmitters lasted beyond 15 November, where the whales reached their wintering ground in southern Baffin Bay and northern Davis Strait. The transmitters lasted from 23 to 357 days. See Table 1 for further information

case (#20165/20157), both tusk and backpack transmitters only lasted for a short period of time (24 and 25 days, respectively).

The backpack transmitters were programmed to transmit only 200 uplinks every third day, while tusk tags provided 500 uplinks every day. Therefore, the backpack transmitters gave only 22.6% (range 12.5–32.9%) of the number of uplinks obtained from the tusk tags over the same period of time. The reduced number of uplinks likewise resulted in shorter travel distances calculated from the backpack transmitters being only 33.1% (range 22.1–43.1) of the distances calculated from the tusk tag data (Table 2). If we correct for this bias (using the inverse of 33.1%), the narwhal equipped with backpack tag #37288 which migrated an estimated 11,470 km distance of the 357 days, could in fact have moved 34,653 km or more during that period, which, for the sake of comparison, is a good portion of the circumference of the earth (40,075 km).

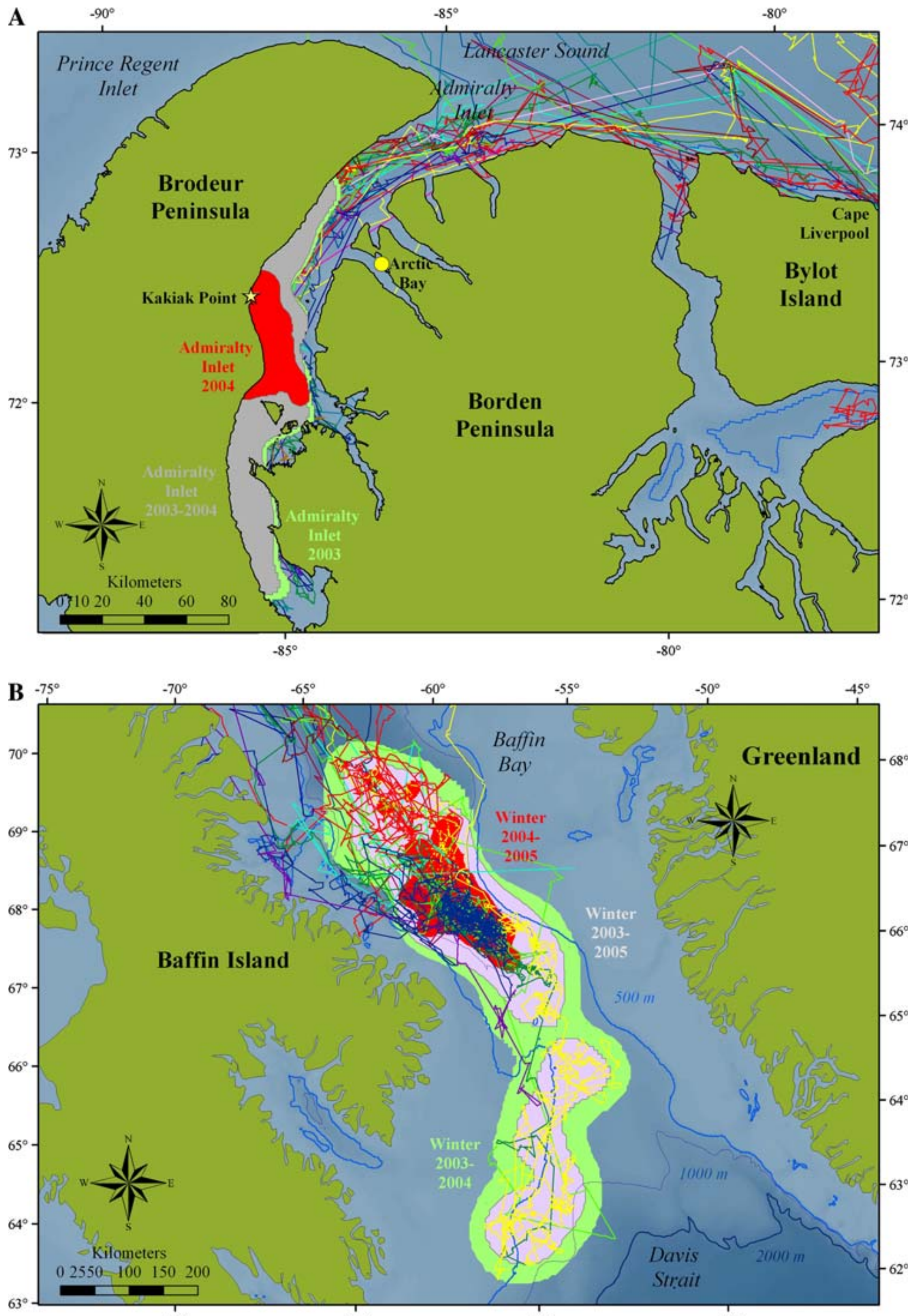

Fig. 2 **a** Close up of Admiralty Inlet with tracklines and 95% kernel home range polygons calculated for 21 narwhals tagged in August 2003 and 2004 The polygons shows the summer range of distribution of 2003 (*light green*) and 2004 (*red*) separately as well as the average of both years (*grey*). Summer was defined from tagging data in August to 15 September. **b** Tracklines for the 15 narwhals that were tracked to their wintering grounds in 2003 and 2004. The 95% kernel home range shows the winter range of the instrumented whales in 2003–2004 (*light green*) and 2004–2005 (*red*) separately as well as the average of both years (*grey*)

Year round tracking

An adult female (#37288) provided locations for almost an entire year (357 days). This animal spent the winter at latitudes between 68° and 69°N (Fig. 3). It entered Lancaster Sound on 25 June and moved westward towards the mouth of Admiralty Inlet reaching just north of Elwin Inlet (73°35′45″N, 84°01′55″W) by 13 July 2005. The female did not enter Admiralty Inlet, most likely because the fast ice had not left the fjord at that time and it was not possible to move south into the Inlet. It later turned eastward moving along the north coast of Borden Peninsula towards the mouth of Navy Board Inlet on 16 July 2005. The narwhal continued further east along the north coast of Bylot Island and finally turned back west towards Lancaster Sound on 28 July. Contact with this animal was lost on 6 August, when it was still near the mouth of Lancaster Sound, east of Cape Liverpool, Bylot Island (73°41′20″N, 78°27′06″W).

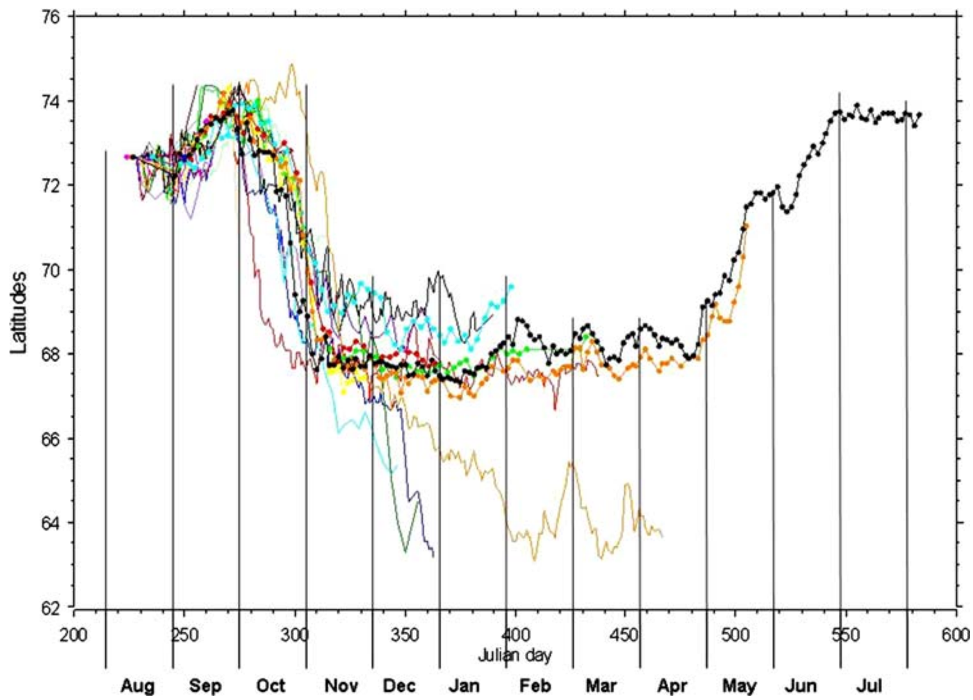

Fig. 3 The seasonal movements depicted as latitudinal presence as a function of Julian day of the 21 narwhals tagged in Admiralty Inlet in August 2003 and 2004. Julian days <220 are depicted as Julian Day +365 to obtain graphic continuity from the tagging date in August over the autumn and the following year

Table 2 Information for comparable periods from three narwhals instrumented with both backpack and tusk tag transmitters in Admiralty Inlet in August 2003

PTT ID No.	Tag type	Trms per day	Duty cycle	Duration (days)	Days with trms	Length of tracking (km)	Number of accepted positions	BP dist as % of TT dist	BP pos as % of TT loc
37234	Backpack	200	3rd day	78	26	2,089	173	34.2	22.3
3965	Tusk tag	500	Daily	78	78	6,108	776		
37235	Backpack	200	3rd day	62	21	1,958	194	43.1	32.9
3962	Tusk tag	500	Daily	61	61	4,545	589		
20165	Backpack	200	3rd day	25	9	520	59	22.1	12.5
20157	Tusk tag	500	Daily	24	8	2,357	473		
								33.1	22.6

BP backpack, *TT* tusk tag, *trms* transmissions, *dist* distance, *loc* locations

The transmitter did not last long enough to determine if the animal ever returned to Admiralty Inlet.

Discussion

Comparison with other tagged populations

During summer months, the home range of tagged whales from Admiralty Inlet did not overlap with any home ranges of the 9 Melville Bay narwhals tagged in 1993–1994, the 17 Eclipse Sound narwhals tagged in 1997–1999, or the 17 Somerset Island narwhals tagged in 2000–2001) (Fig. 4a, b; Dietz and Heide-Jørgensen 1995; Dietz et al. 2001; Heide-Jørgensen et al. 2002, 2003). The winter distribution of three of those four population samples overlapped. Based on their estimated winter home ranges, Admiralty Inlet, Eclipse Sound and Melville Bay tagged narwhals showed varying degrees of overlap in their wintering grounds as well as differences in home range size. Somerset Island narwhals, however, wintered further north than tagged animals from the three other populations. All three population's tagged animals stayed south of the 2,000-m abyss in central Baffin Bay and showed affinity for the slopes in southern Baffin Bay and northern Davis Strait over depths of about 500–1,000 m. The southern range of the distribution of Admiralty Inlet whales tagged in 2003 extended more than 300 km further south than any previously tracked winter locations.

The movement of tagged narwhals out of Admiralty Inlet was observed on average over 15 days earlier ($P < 0.0001$; T test) (Mean: 28 September, 95% CL:

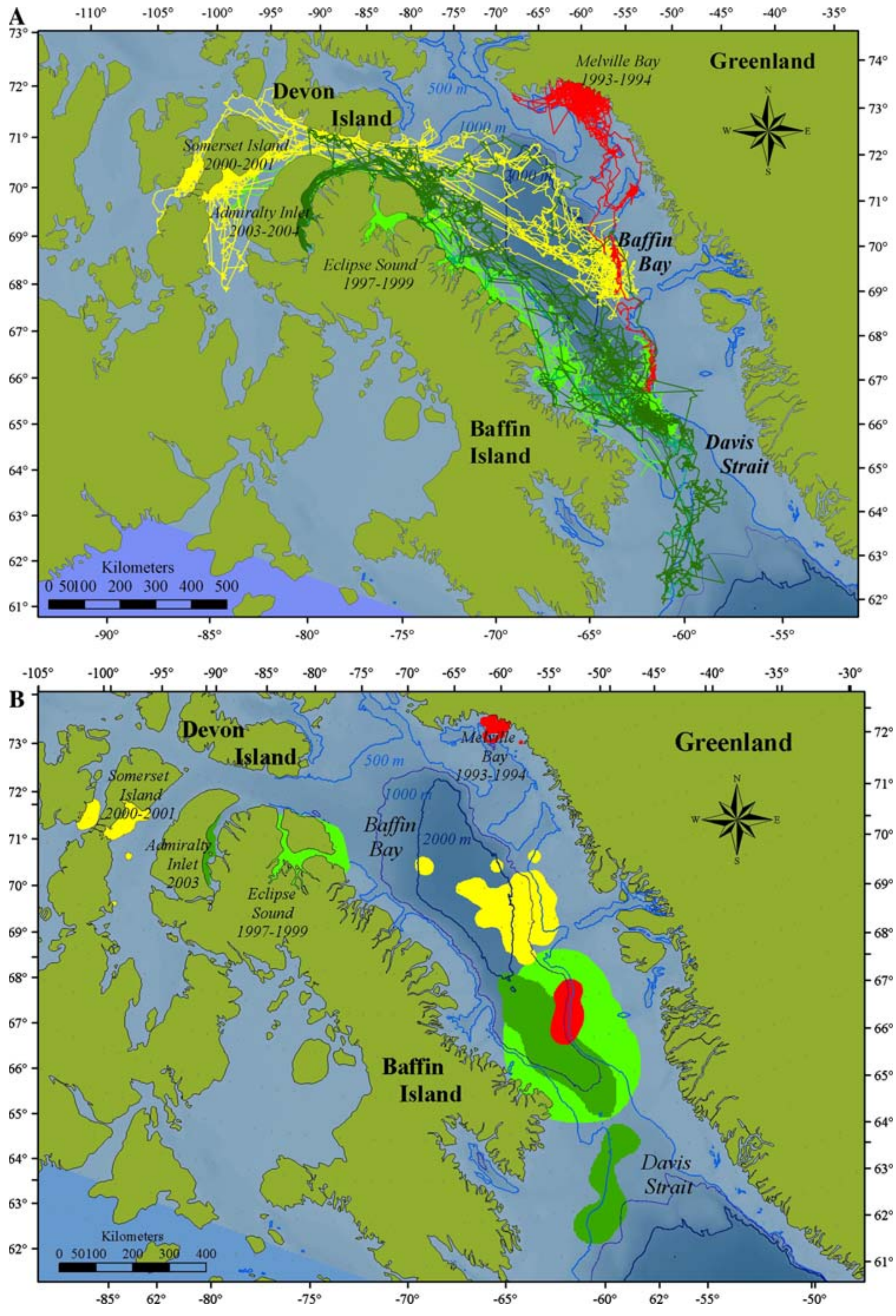

Fig. 4 **a** Tracklines; **b** kernel home range polygons for the narwhals tagged in 2003 and 2004 in Admiralty Inlet compared with previous tagging published by Dietz and Heide-Jørgensen (1995), Dietz et al. (2001), Heide-Jørgensen et al. (2002, 2003). *Dark green*, *yellow*, *light green* and *red* indicates narwhals tagged in Admiralty Inlet, Somerset Island, Eclipse Sound and Melville Bay, respectively

25 September–1 October) than the average date when tagged narwhals from Eclipse Sound (Mean: 13 October, CL: 8–18 October) passed the mouth of Admiralty Inlet on their eastward movement out of Lancaster Sound (Dietz et al. 2001; Heide-Jørgensen et al. 2003). In addition, most of the Admiralty Inlet narwhals used the southern coastline of Lancaster Sound, while the Somerset Island narwhals mainly moved out through Lancaster Sound along the northern side of the sound, along Devon Island, in a similar manner to migrating belugas from around Somerset Island (Richard et al. 1998a, b, 2001; Heide-Jørgensen et al. 2003). This suggests that during their migration out of Lancaster Sound, contact between the two narwhale populations is rather unlikely.

The tagged Admiralty Inlet narwhals ($n = 17$) reached eastward of Eclipse Sound on average 18 days later

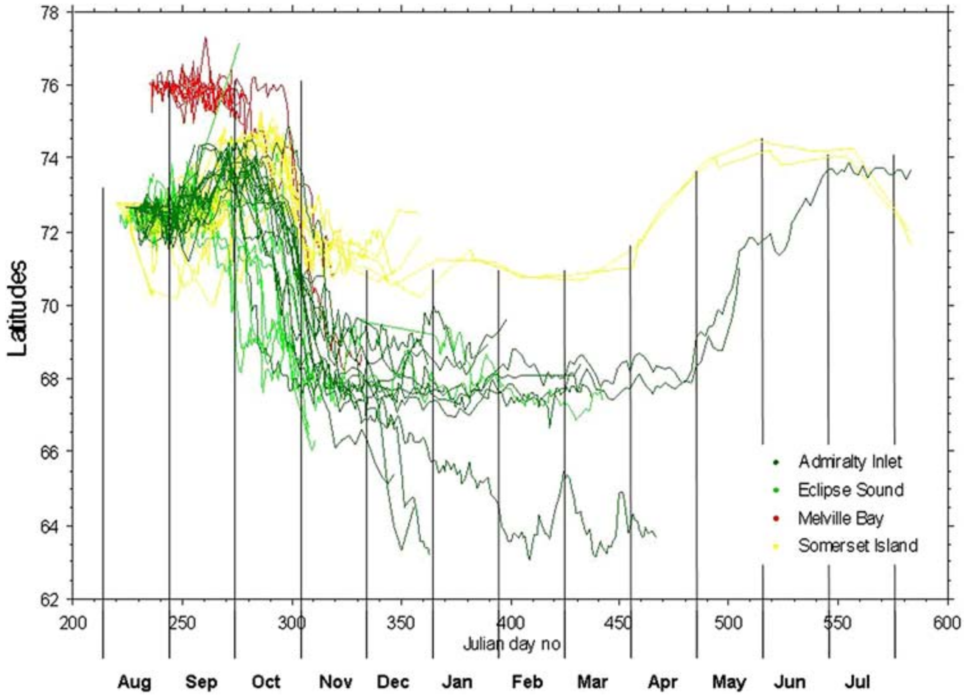

Fig. 5 The seasonal movements depicted as latitudinal presence and as a function of Julian day of the Admiralty Inlet narwhals compared to previously tagging conducted on the Melville Bay, Eclipse Sound and Somerset Island populations (Dietz and Heide-Jørgensen 1995; Dietz et al. 2001; Heide-Jørgensen et al. 2002, 2003). Julian days <220 are depicted as Julian day +365 days to obtain graphic continuity from the tagging date in August over the autumn and the following year

($P < 0.0001$; T test) in 2003 and 2004 (Mean: 12 October, CL: 8–15 October) than when the Eclipse Sound narwhals ($n = 11$) left their summering area in 1997, 1998 and 1999 (Mean: 24 September, CL: 15 September–3 October; Dietz et al. 2001; Heide-Jørgensen et al. 2002). This difference in timing could explain why Eclipse Sound narwhals had a longer migration, moving more closely along the coastline of eastern Baffin Island and sometimes (five out of nine monitored whales) entering fjords, while most of the Admiralty Inlet narwhals migrated 100 km or further offshore from the coastline on the 500 m depth contour or deeper water (Dietz et al. 2001; Heide-Jørgensen et al. 2002). The Somerset Island narwhals' southward migration took place even further offshore in Baffin Bay and ended farther north than tagged narwhals from the other areas. The Melville Bay narwhals started further east so their autumn migration was straight south, cutting through the eastern part of the Somerset Island narwhals wintering home range (Dietz and Heide-Jørgensen 1995; Laidre et al. 2003).

Two Somerset Island narwhals started their northward migration approximately a month earlier (late March) than the two Admiralty Inlet narwhals (late April; Fig. 5) and arrived in Lancaster Sound 1.5 month earlier (mid May) than the Admiralty Inlet narwhals (early July). When tagged Admiralty Inlet narwhals reached Lancaster Sound around the end of June, tagged Somerset Island narwhals had already moved 300 km westward into the sound. Even though based on a small sample size ($n = 3$), this migration pattern may suggests that the two narwhal populations, Admiralty Inlet and Somerset Island, may not enter into contact during their migration through Lancaster Sound. The Admiralty Inlet and Somerset Island narwhals therefore seem to be separated either in space or time making genetic exchange between these two stocks unlikely.

Year to year variability in range of distribution and migration

The 2003 sample of 13 narwhals tagged in Admiralty Inlet resulted in much larger summer home range compared to the 2004 sample of eight narwhals. Differences in the winter range of distribution could also be detected between 2 years as monitored by nine narwhals in the winter of 2003–2004 relative to six in the winter of 2004–2005. Differences in winter range of distribution can also be observed in tagging studies on other narwhal populations. It is therefore likely that the number of whales/pods tagged has an impact on the estimated home range and it is conceivable that it also affected our understanding of the routes and timing of migration.

The average size and age of the narwhals tagged in 2003 was larger than in 2004. Garde et al. (2007) found that the average length at physical maturity is 396 cm for females and 457 cm for males, respectively. Thus, females tagged in 2003 and 2004 and males tagged in 2004 are likely to all be adults, but three of 11 tagged males in 2003 (#7927, 7928 and 7931) measured between 335 and 365 cm and were probably sub-adults.

Nevertheless, the age or sex composition of the tagged whales does not clearly explain differences in home range between the 2 years. Juvenile males, adult males and adult

Table 3 Estimated 95% Kernel home range of narwhals at different seasons and from animals of different tagging locations and population estimates

Tagging location/year	Summer home range (km^2)	Winter home range (km^2)	Winter/summer home range	Population estimate	SE of estimate
Admiralty Inlet 2004/2004–2005	1,305	20,043	15.4	5,363[b]	2,688
Admiralty Inlet 2003/2003–2004	6,287	133,618	21.3	5,363[b]	2,688
Admiralty Inlet 2003–2004/2003–2005	5,503	82,411	15.0	5,363[b]	2,688
Somerset Island 2000–2001/2000–2002	15,399	44,183	2.9	45,358[a]	15,875
Eclipse Sound 1997–1999/1997–2000	57,702	131,772	2.3	20,216[b]	7,315
Melville Bay 1993–1994/1993–1995	4,586	14,747	3.2	4,676[c]	3,974

[a] Innes et al. (2002)

[b] DFO (unpublished)

[c] GINR (unpublished)

females all used the entire Admiralty Inlet home range in 2003. In winter, the four 2003 tagged whales that ranged farther south into Davis Strait were of mixed age–sex composition: an adult male, an adult female, and two juveniles. The two 2003 tagged juveniles (#7927 and 7928) wintered for the most part south of the 2004 winter range, while the third 2003 juvenile (#7931) spent the winter north of 68.2°N, in the northern part of the range. Only two adult animals, a 416-cm adult female (#3960) and a 448-cm adult male (#37235), both tagged in 2003, visited the area south of the 2004–2005 winter range. As only two adults out of six frequented this southern region during the winter 2003–2004, and none of the six adult narwhals monitored during the 2004–2005 winter went as far south, it is possible that this area is of lesser importance to Admiralty Inlet adult whales.

Comparison of home range size between narwhal populations and between seasons

The Admiralty Inlet animals had a smaller average winter home range than the Eclipse Sound animals, but the 2003 Admiralty Inlet home range was of comparable size (Table 3). Both of these home ranges were substantially larger than Somerset Island and Melville Bay winter home ranges. The Melville Bay tagged narwhals had the smallest home ranges both in summer and winter, although the data for winter only included two males for a short period of November and December 1993 and 1994. These home ranges do not seem to be related to the size of the population estimates. The Somerset Island population is estimated to number 45,358 narwhals while the other three populations are smaller in size (Table 3). For each population, the winter home range distribution of tagged narwhals was larger than the summer distribution, and in the case of Admiralty Inlet narwhals, that difference is particularly substantial (15 times). A likely explanation for this difference between summer and winter at least for three of the Canadian summering areas is that the fixed size of the fiords and bays they inhabit in summer limits their distribution while, in winter, their range is limited by suitable habitat in the large expanse of water of Baffin Bay and Davis Strait. Narwhals feed more during winter and may be competing for food (Greenland halibut, *Reinhardtius hippoglossoides*) and *Gonatus fabricii)* with other narwhal populations in Baffin Bay and Davis Strait, while in summer, they have a more limited food intake (Laidre and Heide-Jørgensen 2005). Finally, the dynamic pack ice in their winter range may force narwhals to move around more to find cracks in the ice to breathe. The overlap in winter range between several populations for several months suggests that there is some competition for available prey.

Year round tracking

One adult female narwhal almost provided locations for an entire year. On its return migration, this animal attempted to reach the entrance of Admiralty Inlet on July 12. However, the narwhal did not enter the fjord, probably because it was blocked by fast ice, and the transmitter did not last long enough to determine if the animal did in fact return later to Admiralty Inlet where it had been tagged the previous summer. Only two narwhals have previously been tracked longer than a year (Heide-Jørgensen et al. 2003). In that case, two narwhals instrumented in Creswell Bay, Somerset Island, in August 2000 returned to Peel Sound in August through September in the following year. Peel Sound is part of the summer home range of Somerset Island narwhals. These observations are suggestive of stock segregation and site fidelity in summer. Differences in migration routes and timing of migration noted above are also suggestive of stock segregation in the autumn and spring. In both cases, the sample sizes are small and the results could therefore be purely fortuitous.

More tracking data would be required to address this question.

Concluding remarks

This study provided information on the seasonal distribution of the Admiralty Inlet narwhal population, and added to a series of similar studies on neighboring narwhal populations. It suggests that this population's home range in summer is not likely to overlap with other narwhal populations in summer. In addition the autumn migration also seems to be separated in time and partly in space. The winter home range of the Admiralty Inlet narwhal population did not overlap with narwhals tagged around Somerset Island, but showed some overlap with narwhals from the Eclipse Sound and Melville Bay. One Admiralty Inlet animal's return migration together with previous long-term tracking of two Somerset Island narwhals provides some evidence of inter-annual site fidelity of narwhals to their summering areas. Consequently, these populations should be managed as separate stocks. This study has generated information on an additional summer population which together with previous information will be used in case-by-case advising and assessment to reduce potential conflicts with, e.g. oil and gas developments and fisheries.

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