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THE ABUNDANCE OF NARWHAL (*Monodon monoceros* L.) IN ADMIRALTY INLET, NORTHWEST TERRITORIES, CANADA, AND IMPLICATIONS OF BEHAVIOR FOR SURVEY ESTIMATES

by

LARRY P. DUECK

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
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ABSTRACT

The diving behavior of narwhal (Monodon monoceros) in Admiralty Inlet, Northwest Territories was investigated using scan and focal-animal sampling techniques in order to determine the proportion of narwhal out-of-sight during aerial photographic surveys. Observations were conducted between late June and early July in 1983 to 1985 from shore and ice-based sites and during helicopter flights. Three categories of behavior were used: directional movement, surface activity, and deep dives. Directional movement was most frequently observed during pre-breakup, early-breakup, and open water periods, followed by surface activities and deep dives. During late-breakup, surface activities were most frequent. The behavior of narwhal was highly variable as indicated by significant differences in the frequency of all three behavioral categories between periods of breakup, observation sites, times of day, and tide categories.

There was no significant difference in mean surface time between pre-breakup, late-breakup and open water periods ($\bar{x}$=121 sec, S.D.=118 sec, n=236), although surface time during early-breakup ($\bar{x}$=182 sec, S.D.=269 sec, n=159) was significantly greater than all other periods. There was no significant difference in mean deep dive time between pre-breakup and early-breakup periods ($\bar{x}$=195 sec, S.D.=165 sec, n=25) but no deep dives were timed during late-breakup and only one (195 sec) was timed during the open water period. There were significant differences in both mean surface time and deep dive between observation sites for the early-breakup period, possibly reflecting the constraints of movement through different ice conditions.

The estimated proportion of narwhal visible, based on mean surface and deep dive durations was 38% for pre-breakup, late-breakup and open water periods and 48% for early-breakup. The range in proportion of animals visible based on 95% confidence intervals of surface and deep dive times was 0.29 to 0.52 for pre-breakup, late-breakup and open water periods and 0.34 to 0.64 for early-breakup.

The abundance of narwhal in Admiralty Inlet during the open water period in 1983-1985 was investigated with aerial photography using a systematic transect sampling design. The estimated number of narwhal visible at the surface was 2306 (95% C.I. of 1244-4277) in 1983, 5220 (95% C.I. of 3104-8780) in 1984, and 5619 (95% C.I. of 2819-11,200) in 1985. Important areas of distribution appeared to be the west side of Admiralty Inlet between Strathcona Sound and Yeoman Island and the mouths of Adams and Strathcona Sound. The increase in estimates each year corresponded with earlier breakup of ice in Lancaster Sound although differences in survey coverage may be partially responsible for observed differences in estimated numbers. Based on the estimated proportion of narwhal visible during the open water period, a correction factor of 1.9 to 3.4 is indicated, suggesting that estimated numbers should be at least doubled to account for animals out-of-sight. Caution in the use of this factor is recommended however, because of the potential biases involved in behavioral observations.

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TABLE OF CONTENTS

LIST OF TABLES

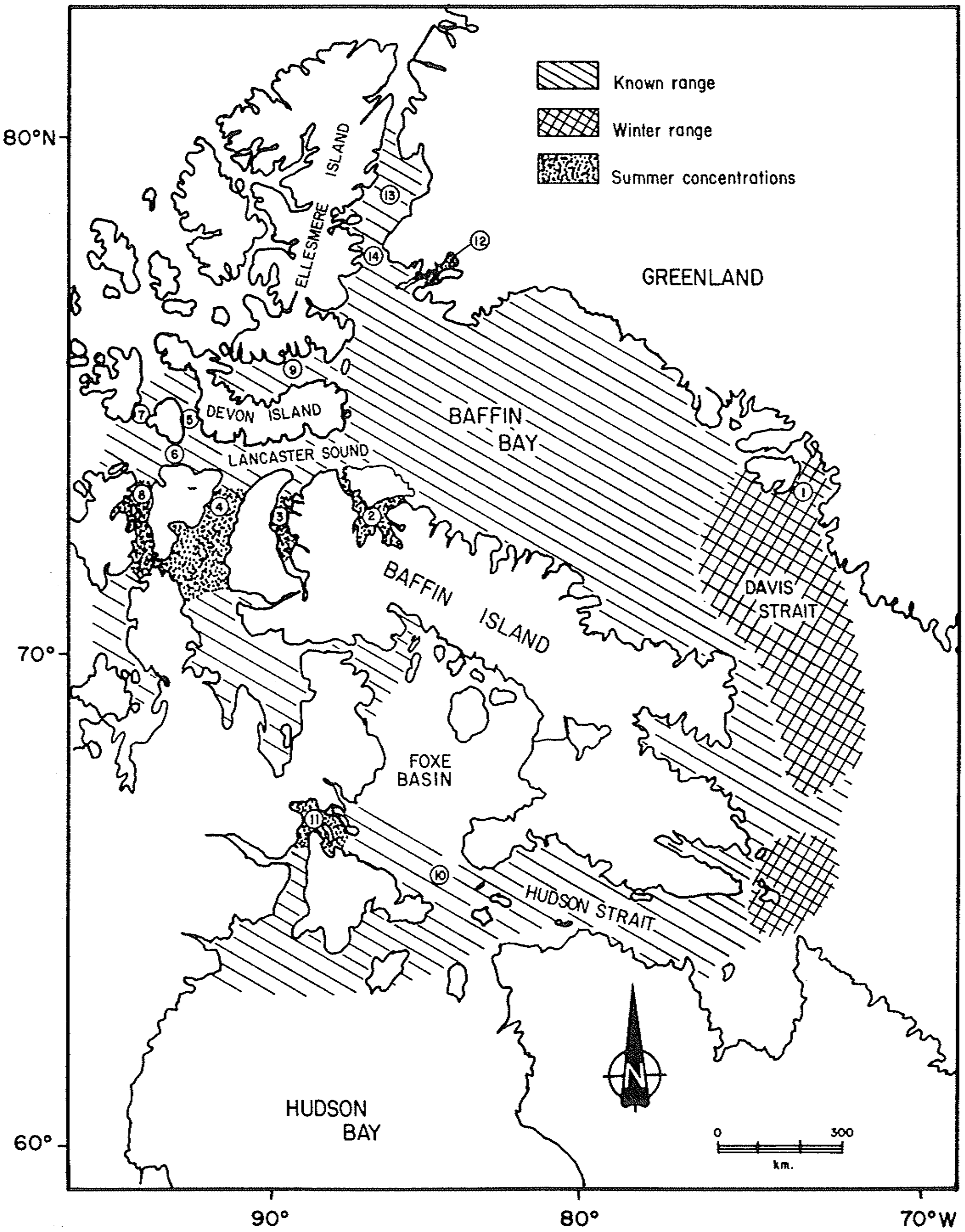
LIST OF FIGURES

CHAPTER I: GENERAL INTRODUCTION

The narwhal (Monodon monoceros L.) is the most northerly distributed cetacean in the world, inhabiting the seas of the eastern Canadian arctic (Strong 1988, Mansfield et al. 1975), west Greenland (Born 1986, Vibe 1950) east Greenland (Pederson 1931), and the Eurasian arctic (Tomilin 1957). It is a migratory species, excluded from the more northern portions of its range by the presence of ice during the winter. The distribution of narwhal is discontinuous and narwhal west of Greenland are thought to have little contact with those to the east (Mitchell and Reeves 1981). Narwhal that inhabit the waters west of Greenland appear to be further subdivided, at least in summer, into three main groups: one that enters Lancaster Sound and summers in adjacent fjords, one in the Inglefield Bredning area of northwest Greenland, and one in northern Hudson Bay and southern Foxe Basin (Fig. 1). Although conclusive evidence for discreteness of these groups has not been obtained, they have been tentatively identified as distinct stocks for management purposes (Strong 1988) and are hereafter referred to as such. Estimates of the abundance of the Lancaster Sound stock, considered the largest component of the Canadian/Greenlandic population, range from 10,000 to 30,000 (Mansfield et al. 1975, Davis et al. 1978, Smith et al. 1985).

There are three reasons for reassessment of the abundance of narwhal: 1) habitat encroachment by industry, 2) the harvest of narwhal by Inuit, and 3) uncertainty regarding the reliability of previous estimates of narwhal abundance. In terms of habitat encroachment, the

Figure 1. Distribution of narwhal in Canadian and Greenlandic waters (after Kemper 1980, Strong 1988). 1) Disko Bay, 2) Eclipse Sound, 3) Admiralty Inlet, 4) Prince Regent Inlet, 5) Wellington Channel, 6) Barrow Strait, 7) McDougal Sound, 8) Peel Sound, 9) Jones Sound, 10) Foxe Channel, 11) Repulse Bay/Frozen Strait, 12) Inglefield Bredning, 13) Kane Basin, 14) Smith Sound.


Known range
Winter range
Summer concentrations
GREENLAND
ELLESMERE ISLAND
DEVON ISLAND
LANCASTER SOUND
BAFFIN BAY
BAFFIN ISLAND
DAVIS STRAIT
FOXE BASIN
HUDSON STRAIT
HUDSON BAY
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
⑪
⑫
⑬
⑭
N
0
300
km.
80°N
70°
60°
90°
80°
70°W

Lancaster Sound stock inhabits an area important both for potential hydrocarbon development and as a potential traffic corridor for transportation of hydrocarbons from western reserves to eastern markets. The effect of drilling activities or large-scale vessel traffic on narwhal is largely unknown and a reasonable measure of narwhal abundance is important in order to determine the impact of such activities as they increase.

The narwhal is an important resource for the Inuit of the eastern Canadian Arctic and west Greenland (Bisset 1970, Kapel 1977). The narwhal harvest in Canada is restricted by a quota system, permitting a specific number of animals to be harvested per year by each community. However, the quota is based strictly on historical take rather than biological assessment of sustainable yield (Strong 1988) and the impact of the hunt is largely unknown. Loss rates (animals killed but not secured by hunters) may add significantly to the number of narwhal actually killed each year (Finley _et_ _al_. 1980, Weaver and Walker 1988).

The uncertainty regarding previous estimates of narwhal abundance arises from the wide range and apparent contradictions in previous studies. The highest estimates of the Lancaster Sound stock, made during the spring migration, were 20,000-30,000 (Davis _et_ _al_. 1978, Koski 1980a). However, other estimates of narwhal abundance have been considerably lower (10,000 Mansfield _et_ _al_. 1975, 13,200-18,000 Smith _et_ _al_. 1985) and estimates for summer ranges in particular have failed to account for the estimates obtained during spring migration. The differences in estimates are likely due to a number of problems associated with differences in weather, survey techniques, and the variable distribution and behavior of narwhal. Visual aerial surveys are particularly prone to observer biases, making comparison between surveys difficult. A proportion of narwhal are also missed because the observer failed to see animals at the surface, was unable to count animals accurately in the time available, or the animals were submerged when the aircraft flew over. No previous surveys of narwhal have attempted to account for missed animals.

Aerial photography is becoming increasingly common as a means of assessing wildlife populations because it reduces observer biases associated with visual surveys by allowing a more detailed examination of sample area (Heyland 1972). Aerial photography is also able to record animals beneath the water surface, in the visible portion of the water column because of its directly vertical orientation while visual observers are generally restricted to views at some angle to the water surface, allowing poor visibility into the water column. However, the behavior of narwhal is not limited to the visible portion of the water column and aerial photography is still subject to missing some animals which are below the visible zone when the photograph is taken.

The purpose of this study was to assess the abundance of narwhal in Admiralty Inlet, a portion of the summer range of the narwhal, using aerial photography as the census medium. The study consisted of two components. The first was an examination of the behavior of narwhal with particular reference to their diving behavior and time spent out of sight. The results of this work and the implications for using this data to correct survey estimates for the proportion of animals not visible are reported in Chapter II. The second component, reported in

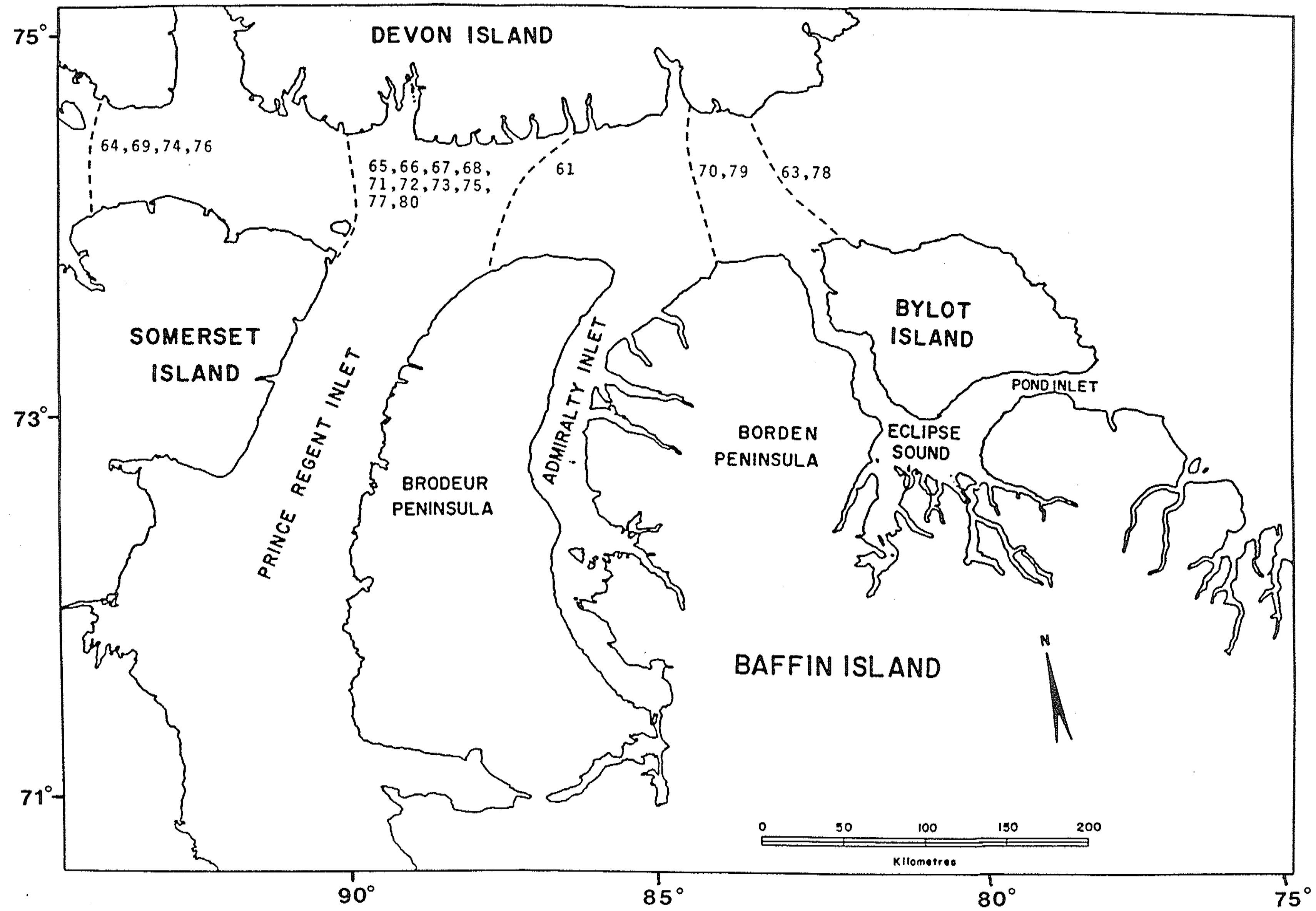
Chapter III, was an examination of the results of aerial photographic surveys conducted in Admiralty Inlet in 1983-85. These are discussed with regard to estimates of visible animals, variation between years and comparisons to previous survey estimates for the area and correction for deep diving whales.

Study Area and General Ice Conditions

Admiralty Inlet, one of the largest fiords in the world, is located between the Brodeur and Borden Peninsulas of northern Baffin Island and opens into Lancaster Sound to the north (Fig. 2). It is 12-50 km wide and 260 km long with several smaller inlets extending off the east side. Water depths drop quickly along most coastal areas of the inlet. In central Admiralty Inlet, depths range from 230 to 750 m (Canadian Hydrographic Service 1981). Circulation patterns are poorly known. In northern Admiralty Inlet, surface currents appear to follow a general counter-clockwise motion, the predominantly eastward moving water mass in southern Lancaster enters Admiralty Inlet on the west side and leaves on the east.

There is great annual variation in ice conditions in Admiralty Inlet, break-up being greatly influenced by the ice conditions in Lancaster Sound (Lindsay 1977, 1982, Marko 1982). Every winter an ice edge, referred to as the floe edge, develops across Lancaster Sound separating landfast ice to the west from mobile pack ice to the east. In severe ice years this ice edge is located near the mouth of Lancaster Sound (Fig. 2). In mild ice years this edge is located as far west as Barrow Strait. Lancaster Sound exhibits roughly a one month difference

Figure 2. Admiralty Inlet and surrounding area. The dashed lines indicate the approximate annual positions of the stable winter landfast ice edge in Lancaster Sound in 1961-80. Numbers to the right of each line refer to the year in which the floe edge was at this location (after Marko 1982).


DEVON ISLAND
64,69,74,76
65,66,67,68,
71,72,73,75,
77,80
61
70,79
63,78
SOMERSET
ISLAND
PRINCE REGENT INLET
ADMIRALTY INLET
BRODEUR
PENINSULA
BORDEN
PENINSULA
BYLOT
ISLAND
POND INLET
ECLIPSE
SOUND
BAFFIN ISLAND
N
0
50
100
150
200
Kilometres
75°
73°
71°
90°
85°
80°
75°

in timing of breakup between extremes of mild and severe ice years (Marko 1982).

Varying ice conditions were used to break up the study each summer into four periods. The "pre-breakup" period occurred prior to formation of major cracks in Admiralty Inlet. A floe edge across the mouth of the inlet separates landfast ice to the south from open water and pack ice in Lancaster Sound. In early July, narwhal are able to penetrate Admiralty Inlet along cracks which develop in Admiralty Inlet in roughly the same place each year. This was referred to as the "early breakup period". Breakup proceeds from north to south in northern Admiralty Inlet as large pans are flushed out by wind and current action. Ice in central and southern Admiralty Inlet and in the smaller adjacent inlets is broken down by solar radiation and ice movement. By mid to late-July, Admiralty Inlet is generally characterized by rubble ice to large pans of ice, loosely aggregated and with many areas of open water of varying size between ice pans. This was referred to as the "late-breakup period". The "open water period", characterized by less than 10% ice cover, generally starts in mid-July in mild years and up to a month later in heavy ice years (Lindsay 1977, 1982). However, substantial amounts of pack ice may enter Admiralty Inlet from Lancaster Sound throughout the summer as ice from the central Arctic islands is carried along the predominantly eastward current in Lancaster Sound. Consistent freezing conditions in late September cause formation of new ice in Admiralty Inlet, usually resulting in a cover of consolidated ice by the end of October.

CHAPTER II: NARWHAL BEHAVIOR IN ADMIRALTY INLET IN SUMMER AND ESTIMATES OF THE PROPORTION OF NARWHAL VISIBLE

INTRODUCTION

Whales spend a large proportion of time below the water surface, whether engaged in feeding, travel, or social activities. Much of this time may be spent in the visible portion of the water column, but they are essentially invisible to observers looking at acute angles to the water surface. Because of this, estimates of whale numbers are typically low. Attempts to correct for missed whales have been made for shipboard counts (Doi and Nakono 1982, Hiby 1982, Joyce 1982, Miyashita 1986) and visual aerial surveys (Davis *et al*. 1982).

For aerial photography, this problem is not as severe due to the advantage of a directly vertical orientation, allowing maximum visibility into the water column. The proportion of missed animals is thus restricted to animals diving below the visible portion of the water column.

Indications of the potential of narwhal to spend considerable time out of sight are based on several observations of their diving capabilities and evidence from their diet. They are found almost entirely over deep water and are capable of dives to over 350 m and lasting half an hour (Scoresby 1820, Silverman 1979, Finley and Gibb 1982). Tomilin (1957) considered the lack of teeth in narwhal an adaptation to feeding on pelagic cephalopods, and the diet of narwhal has been shown to include a number of pelagic as well as benthic species (Finley and Gibb 1982, Hay 1984).

No studies to date have specifically examined the diving behavior of narwhal to determine the proportion of time narwhal spend below the surface of the water searching for food or engaged in other activities. This information is essential to assess the reliability of survey estimates and to correct estimates for the proportion of narwhal below the visible portion of the water column. The purpose of this study was to investigate the behavior of narwhal and its variability in order to quantify the proportion of animals which would be visible to an aerial platform at any given time.

MATERIALS AND METHODS

Observation Platforms

Observations of narwhal behavior were made from seven ice-based sites, six shore-based sites, and 28 helicopter flights during July and August of 1983-1985 in Admiralty Inlet, N.W.T. (Table 1, Fig. 3). Ice-based observations were conducted at two locations along the floe edge during pre-breakup conditions and at 5 locations along cracks and loose pan ice south of the floe edge (referred to as Admiralty cracks) during the late-breakup period in July 1985. Narwhal were observed from Elwin Inlet and Cape Crauford shore-based sites during early-breakup conditions in July 1983 and July 1984 respectively. The remaining shore-based sites (Giants Castle, 1983; Turner Cliffs, 1984; Kakiak Point and South Point, 1985) were used during open water periods in August.

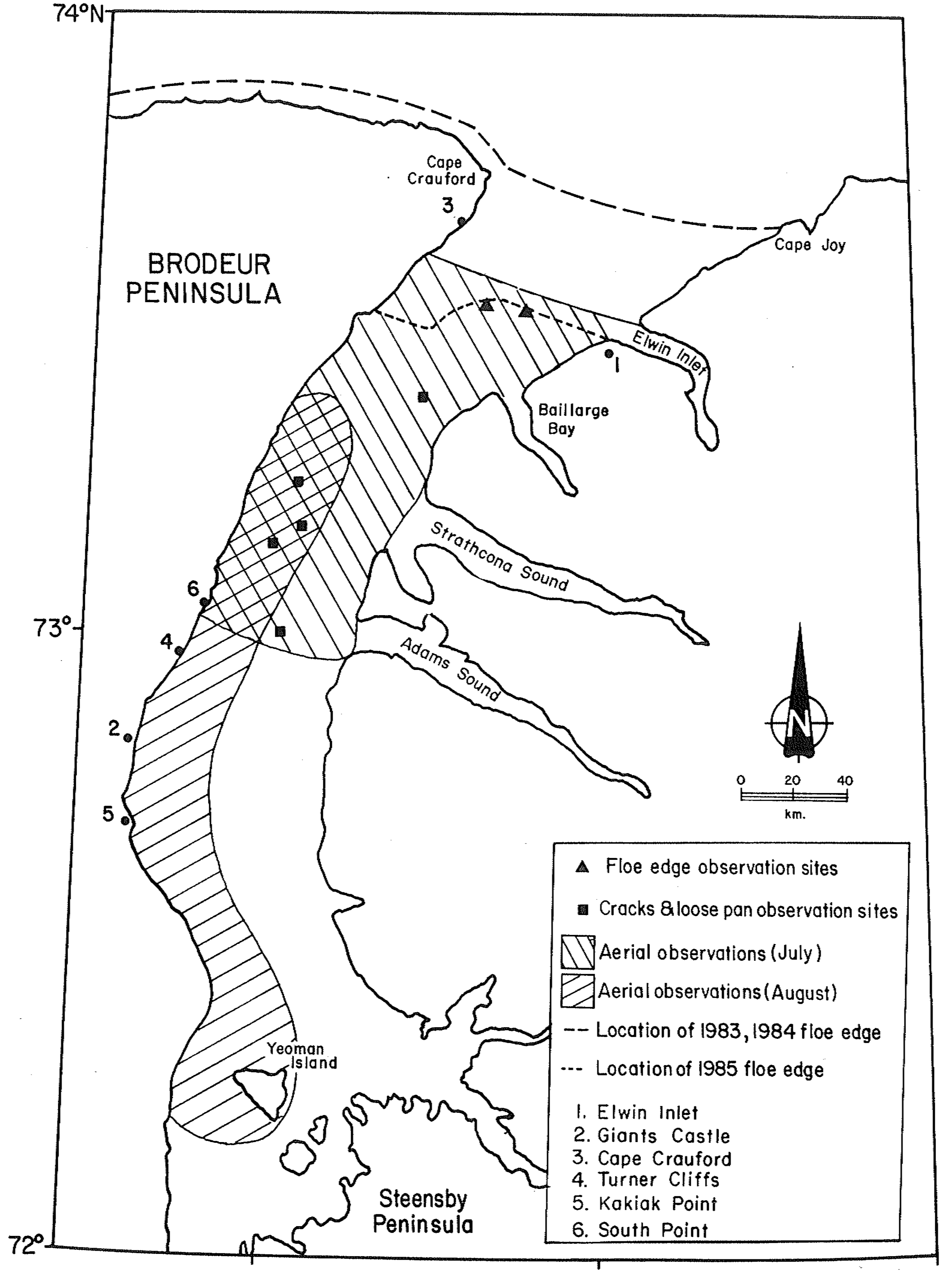
Narwhal were observed for 153.5 hours from static platforms and 38.7 hours during 28 helicopter flights (Table 1). Approximately 14% (n=57) of scan samples from static platforms were obtained during pre-breakup, 55% (n=419) during early-breakup (Elwin Inlet and Cape Crauford sites), 16% (n=66) during late-breakup (Admiralty Inlet cracks locations), and 15% (n=64) during the open water period (Giants Castle, Turner Cliffs, Kakiak Point and South Point). About 12% (n=45) of focal samples were obtained during pre-breakup, 38% (n=142) during early breakup, 38% (n=142) during late breakup, and the remaining 12% (n=46) during the open water period.

Table 1. Sampling effort for behavioral observations of narwhal summarized by observation platform.

Platform	Period	Observation site (see Figure 3)	Dates	Observation days	Observation hours	Number of scan samples	Number of focal samples	Mean duration of focal samples (seconds)
Static	Pre-breakup	Floe edge[a]	July 2-8, 1985	6	19.9	57	45	125
	Early-breakup	Elwin Inlet	July 9-30, 1983	11	66.0	208	87	182
		Cape Crauford	July 9-29, 1984	10	26.6	24	55	317
	Late-breakup	Admiralty cracks[a]	July 14,15, 19-22, 1985	6	21.8	66	142	133
	Open water	Giants Castle	August 3-15, 1983	2	2.7	9	5	62
		Turner Cliffs	August 10-11, 1984	3	4.0	9	9	174
		Kakiak Point	August 11-12, 1985	3	6.2	28	26	65
		South Point	August 16-24, 1985	4	6.3	18	6	151
Aerial	Pre-breakup	(see Figure 3)	July 3-8, 1985	2	3.8	3	-	-
		(see Figure 3)	July 13-22, 1985	7	14.0	12	-	-
	Open water	(see Figure 3)	August 8-27, 1984	7	10.3	7	-	-
			August 7-26, 1985	6	10.7	6	-	-

[a] Ice-based observations; all other sites, except those designated "helicopter", were land-based sites.

Figure 3. Locations of shore-based, ice-based, and aerial-based observations of narwhal behavior in Admiralty Inlet in 1983-1985.


74°N
73°
72°
86°
84°
82° W
BRODEUR PENINSULA
Cape Crauford
3
Cape Joy
Elwin Inlet
1
Baillarge Bay
Strathcona Sound
Adams Sound
6
4
2
5
Yeoman Island
Steensby Peninsula
N
0 20 40
km.
▲ Floe edge observation sites
■ Cracks & loose pan observation sites
Aerial observations (July)
Aerial observations (August)
Location of 1983, 1984 floe edge
Location of 1985 floe edge
1. Elwin Inlet
2. Giants Castle
3. Cape Crauford
4. Turner Cliffs
5. Kakiak Point
6. South Point

Narwhal Behavior and Data Recording

Narwhal behavior was divided into three general categories: 1) directional movement, 2) surface activity, and 3) deep dives (Table 2) based on work by Silverman (1979) and personal observations. Directional movement was defined as movement continuing in a consistent direction over several successive, short duration dives. Surface activity consisted of all activities of a non-directional nature at or near the surface. A deep dive was a dive beyond visible range.

Two types of behavioral sampling were used: scan sampling and focal animal sampling (Altmann 1974, Tyler 1979). Scan sampling was used from static and aerial platforms to score the instantaneous behavior of all visible animals over a short time and provide information on the relative frequency of behaviors. Group size, sex and age composition, orientation, and activity type were recorded. To determine the behavior of an animal, each individual or group visible in the sample area was observed for a period equal to approximately two interbreath intervals.

Scans were conducted throughout the entire day from shore and ice-based platforms whenever narwhal were visible in the area. Intervals between scan sessions (scan of all animals visible in the sample area) ranged from 15 min to one hour, depending on the number of animals present, but were most frequently conducted on an hourly basis.

Scan sampling of narwhal behavior was conducted from a Bell 206B Jet Ranger helicopter in August 1984 and July and August 1985. One person observed from the the left front seat and another from the right rear. Flights lasted 35 to 160 minutes and were flown at an altitude of

Table 2. Categories of narwhal behavior as observed in Admiralty Inlet in 1983-1985 (based on work by Silverman 1979 and personal observations).

Category	Activity	Description
Directional movement (DM)	Directional shallow dives	Continuous movement in a consistent geographic direction by means of repeated shallow dives, generally of short duration (most <20 seconds).
Surface activity (SA)	Back/head exposed	The animal floats at the surface with most of the back and/or head exposed. The animal may float passively or move slowly at the surface.
	Bobbing	The animal is oriented horizontally and repeatedly surfaces and sinks back down just below the surface, respiring and exposing part of its back, head and blowhole each time it surfaces (at least every three seconds).
	Circling	Similar to directional shallow dives except that movements are localized and the animal usually changes direction after each dive.
	Hanging	Relatively inactive behaviour in which the animal remains motionless or moves slowly just beneath the surface, surfacing occasionally to breath.
	Social interactions	All interactions between two or more individuals involving orientation or movement toward each other, physical display or contact, suckling of young by female.
Deep dives (DD)	Deep dives	The animal dives at a steep vertical angle to a depth beyond visibility range. The dive is preceded by a powerful downward thrust of the flukes, resulting in a high arching of the back and caudal peduncle. Occasionally the flukes are raised above the water surface before the animal leaves the surface.

210 m and a speed of about 90 knots (170 km/hr). Flights in July 1985 were conducted over floe edge and ice crack habitats during pre-breakup and late-breakup periods respectively, while those in August 1984 and August 1985 were over open water. Scans from the air were subject to helicopter availability. Each helicopter flight was considered as one scan session.

Focal animal sampling was conducted from static platforms between scan sessions. A focal animal sample consisted of a continuous record of behavior of an individual (alone or in a group) that lasted until the individual could not be distinguished from other individuals. Unique markings present on some animals helped to distinguish focal animals from other individuals in the same group. During focal animal sampling, the following data were recorded as fully as possible: group size and composition, orientation, time of occurrence at the start of each new activity, and description of activity. The time of occurrence of blows were also recorded but blows occurring while the animal remained at the surface were much less conspicuous and were rarely recorded.

Focal animal sampling from the air was attempted but discontinued to avoid exposure of animals to aircraft noise during continuous circling of the aircraft. In scan sampling from the helicopter, exposure to helicopter noise was limited to a single brief flyover. This exposure was considered to have minimal effect at the altitude and speed flown.

Data were recorded in field notebooks or on tape recorders and later transcribed in the lab. Spotting telescopes (20X), binoculars (8X and 10X), and a theodolite (20X) were used as visual aids from shore and ice-based platforms.

Data Analysis

The proportion of narwhal engaged in a particular behavioral category (uncorrected for animals out of sight) was calculated as the sum of animals in that category divided by the total number of animals observed:

$$P_i = \frac{\sum c_i}{\sum m_i} \qquad [1]$$

where P_i = the proportion of animals scored in the i^{th} behavior category;

c_i = the number of narwhal engaged in the i^{th} behavior category;

m = the total number of narwhal observed.

The frequency of narwhal observed in the three categories of behavior were examined using chi-square goodness of fit and contingency tables (Snedecor and Cochran 1967). Relative frequencies were compared between platforms, periods, observation sites, years, tide and time of day. To assess the effect of tide, four categories were chosen: low, rising, high, and falling. To assess the effect of time of day, four time periods were selected: early a.m. (00:00-06:00), late a.m. (06:00-12:00), early p.m. (12:00-18:00), and late p.m. (18:00-24:00). Low and high tides were defined as ±1 hours around the predicted tides provided in the Canadian Tide and Current Tables (Anon. 1983, 1984, 1985). Mean dive and surface times were compared using Games and Howell's modified Tukey method for multiple comparisons for pairwise contrasts (Keselman and Rogan 1978). The level of significance was set at 0.05 for all statistical tests.

An estimate of P, the proportion of animals visible at any one time based on focal observations of surface and deep dive times, was obtained with the following equation (Eberhardt _et_ _al_. 1979):

$$P = \frac{s}{s + u} \qquad [2]$$

where s = the mean duration of all surface activities;

u = the mean duration of the time spent out of sight on deep dives.

RESULTS

Scan Samples

In scans from static platforms, the behavior of 7450 narwhal was sampled during pre-breakup, early-breakup, late-breakup and open water periods. In scans from aerial platforms, the behavior of 4650 narwhal was sampled during pre-breakup, late-breakup and open water periods. The frequency of observed behaviors (Table 3) differed significantly between aerial and static platforms (pre-breakup χ^2=16.7, d.f.=2, p<0.005; late-breakup χ^2=399.5, d.f.=2, p<0.005; open water χ^2=22.1, d.f.=2, p<0.005) and consequently, analyses were done separately for each platform.

For all periods except late-breakup, directional movement was the most frequently observed behavior, followed by surface activity and deep dives. These differences were significant for both static and aerial platforms, for χ^2 comparisons of all three behavior categories (static: pre-breakup χ^2=652, early-breakup χ^2=2334, open water χ^2=825; aerial: pre-breakup χ^2=378, open water χ^2=363; all p<0.005, d.f.=2) as well as for pair-wise χ^2 comparisons (Table 3). For observations from static platforms during the late-breakup period, surface activity was most frequently observed (χ^2=395, d.f.=2, p<0.005), with no significant difference in observed frequency between directional movement and deep dives (χ^2=0.18, d.f.=1, p>0.75). For aerial observations during the late-breakup period, surface activity was also most frequently observed, followed by directional movement and then deep dives (Table 3).

There was an overall difference in the frequency of observed behaviors between periods for both static (χ^2=805, d.f.=6, p<0.005) and

Table 3. Observed frequencies of behavior for static and aerial platforms for pre-breakup, early-breakup, late-breakup and open water periods, and results of χ^2 multiple and pairwise comparisons of row and column frequencies.

	Static Platforms					Aerial Platforms				
		Behavior (%)					Behavior (%)			
Period[a]	n	Directional movement (M)	Surface activity (S)	Deep Dives (D)	χ^2 comparison[b]	n	Directional movement (M)	Surface activity (S)	Deep Dives (D)	χ^2 comparison[b]
Pre-breakup (P)	826	73.3	24.0	2.7	MSD	448	77.0	17.2	5.8	MSD
Early-breakup (E)	4653	62.8	32.2	5.0	MSD		-	-	-	
Late-breakup (L)	821	17.4	66.0	16.6	$\mathrm{S}\underline{\mathrm{MD}}$	1292	46.0	50.5	3.5	SMD
Open water (O)	1150	70.5	27.3	2.2	MSD	809	64.9	34.4	0.7	MSD
χ^2 comparison[b]		$\underline{\mathrm{PO}}\mathrm{EL}$	$\mathrm{LE}\underline{\mathrm{OP}}$	$\mathrm{LE}\underline{\mathrm{PO}}$			POL	LOP	PLO	

[a] Letters in brackets correspond to variable abbreviations used in comparisons.

[b] Underlined categories indicate no significant differences found at * = 0.05; expected values for row comparisons were based on equal frequencies in each cell; expected values for column comparisons were based on cell frequencies proportional to total numbers observed for that period.

aerial platforms (χ^2=300, d.f.=4, p<0.005). For static platforms, the differences were attributable to differing levels of all three behaviors between early-breakup, late-breakup and the remaining two periods (Table 3). Directional movement was observed most frequently during pre-breakup and open water periods, followed by early-breakup and lastly by late-breakup. In contrast, both surface activity and deep dives were observed most frequently during late-breakup, followed by early-breakup, and lastly, by pre-breakup and open water periods (Table 3).

For aerial platforms, differences were attributable to varying levels of behavior in all three periods (Table 3). Directional movement was observed most frequently during pre-breakup, followed in descending order by open water and late-breakup. Surface activity was observed most frequently during late-breakup, followed in descending order by open water and pre-breakup. Finally, deep dives were observed most frequently during pre-breakup, followed in descending order by late-breakup and open water.

There were also differences in the frequency of observed behavior between sites for early-breakup (χ^2=13.0, d.f.=2, p<0.005) and open water periods (χ^2=52.5, d.f.=6, p<0.005). Directional movement was observed significantly more frequently at the Elwin Inlet site than at Cape Crauford, surface activity significantly less frequently, and no difference in deep dives. For the open water period (Table 4), there was no significant difference in frequency of directional movement between Giants Castle, South Point, and Kakiak Point, but directional movement was observed significantly more at these sites

Table 4. Observed frequencies of behavior for shore-based sites used during the open water period and results of χ^2 multiple and pairwise comparisons of column frequencies.

Observation site	n	Behaviour (%)		
		Directional movement	Surface activity	Deep dives
Giants Castle	125	86.3	10.3	3.4
Turner Cliffs	41	49.4	47	3.6
Kakiak Point	417	67.3	31.6	1.1
South Point	228	74.5	22.2	3.3
X^2 comparison[a]		GSKT	TKSG	TGSK

[a] Abbreviations used in comparisons correspond to the first letter of each site; underlined categories indicate no significant differences found at $\alpha = 0.05$; expected values for column comparisons were based on cell frequencies proportional to total numbers observed for that site.

than at Turner Cliffs. The frequency of surface activity was greatest at Turner Cliffs, followed in descending order by Kakiak Point, South Point, and Giants Castle. There was no significant difference in frequency of deep dives between Turner Cliffs, Giants Castle, and South Point, but deep dives were observed significantly more frequently at these sites than at Kakiak Point. Differences in observed behavior between sites may be partially attributable to differences between years. However, no significant difference in behavior was observed for aerial observations in the open water period.

A comparison of the distribution of activity types across time of day (Table 5) and tide categories (Table 6) for the Elwin Inlet site, the only static-based site with sufficient data to include in this analysis, indicated significant differences in behavior between categories for both variables (time of day χ^2=62.0, d.f.=6, p<0.005; tide χ^2=24.5, d.f.=6, p<0.005). Differences between time of day categories were attributable to less directional movement and more surface activity during late p.m. (18:00-24:00) than during other times while deep dives occurred more frequently during early p.m. (12:00-18:00) than at other times (Table 5). The difference between tides was attributable to greater levels of surface activity during low and rising tides compared to high and falling tides (Table 6).

Surface and Out-of-Sight Times

The duration of 375 focal-animal observations ranged from 4 sec to 32 min 55 sec (Table 1; $\bar{x}$=166 sec, S.D.=240 sec), resulting in records of 395 surface times (directional movement + surface activity) and 25

Table 5. Observed frequencies of behavior for the Elwin Inlet site by time of day categories, and results of X^2 multiple and pairwise comparisons of column frequencies.

Time[a]	n	Behaviour (%)		
		Directional movement	Surface activity	Deep dives
Early am (A) (0:00-6:00)	933	66.0	29.8	4.2
Late am (B) (6:00-12:00)	1356	66.9	29.1	4.0
Early pm (C) (12:00-18:00)	1018	64.6	28.0	7.4
Late pm (D) (18:00-24:00)	1188	55.6	39.6	4.8
X^2 comparison[b]		$\underline{\text{BAC}}\text{D}$	$\text{D}\underline{\text{ABC}}$	$\text{C}\underline{\text{DBA}}$

[a] Letters in brackets correspond to abbreviations used in X^2 comparisons.

[b] Underlined categories indicate no significant differences found at $\alpha = 0.05$; expected values for column comparisons were based on cell frequencies proportional to total numbers observed for that site.

Table 6. Observed frequencies of narwhal behavior for the Elwin Inlet site by tide categories, and results of χ^2 multiple and pairwise comparisons of column frequencies.

		Behaviour (%)		
Tide	n	Directional movement	Surface activity	Deep dives
Low	640	58.6	37.5	3.9
Rising	1246	60.7	34.5	4.8
High	1009	65.2	29.1	5.7
Falling	1600	66.0	28.9	5.1
X^2 comparison[a]		$\underline{\text{FHRL}}$	$\underline{\text{LR}}$ $\underline{\text{HF}}$	$\underline{\text{HFRL}}$

[a] Abbreviations used in comparisons correspond to first letter of each tide category; underlined categories indicate no significant difference was found at $\alpha = 0.05$; expected values for column comparisons were based on cell frequencies proportional to total numbers observed for that tide.

deep dives. In about 95% (n=355) of focal observations, only surface sequences (directional movement or surface activity) were timed. Observed surface time ranged from 4 sec to 14 min 55 sec ($\bar{x}$=145 sec, S.D.=195 sec, n=395). There was no significant difference in mean surface time between pre-breakup, late-breakup and open water periods ($\bar{x}$=121 sec, S.D.=118 sec, n=236), although surface time during early-breakup ($\bar{x}$=182 sec, S.D.=269 sec, n=159) was significantly greater than all other periods (modified Tukey method for pairwise contrasts, $p<0.05$). This difference was largely attributable to observations at Cape Crauford where the mean surface time was 253 sec (S.D.=354, n=60). The mean surface time at Cape Crauford was significantly greater than that for Elwin Inlet, indicating differences between sites for the same period of breakup. However there was no significant difference in surface time between any sites during the open water period ($\bar{x}$=93 sec, S.D.=141 sec, n=46; modified Tukey method for pairwise contrasts, $p>0.05$).

Observed deep dive time ranged from 35 sec to 13 min ($\bar{x}$=195 sec, S.D.=165 sec, n=25). There was no significant difference between pre-breakup and early-breakup periods (modified Tukey method for pairwise contrasts, $p>0.05$), but no deep dives were timed during late-breakup and only one (195 sec) was timed during the open water period. The mean deep dive time at Cape Crauford ($\bar{x}$=377 sec, S.D.=228 sec, n=6) was significantly greater than that for Elwin Inlet ($\bar{x}$=199 sec, S.D.=90 sec, n=15; modified Tukey method for pairwise contrasts, $p<0.05$).

Proportion of Animals Visible

Using mean surface and deep dive times from focal observations, two estimates of the proportion of narwhal visible were calculated (equation [2]). For pre-breakup, late-breakup and open water periods, in which mean surface time was 121 sec, the estimated proportion of narwhal visible was 0.38, while for early-breakup, in which mean surface time was 182 sec, the proportion visible was 0.48. The overall mean deep dive time for all periods, 195 sec, was used in both estimates.

The range in proportion of animals visible based on 95% confidence intervals of surface and deep dive times was 0.29 to 0.52 for pre-breakup, late-breakup and open water periods and 0.34 to 0.64 for early-breakup.

DISCUSSION

Activity Patterns of Narwhal

Finley and Gibb (1982) suggested that ice edges in spring act as barriers to summering areas rather than primarily as feeding areas. If so, directional movements might be expected to be high as narwhal attempt to gain access to summering areas and then decline after reaching those areas. Qualitative remarks in previous studies of the behavior of narwhal in the Pond Inlet and Eclipse Sound region indicate that directional movement predominates prior to and during breakup as narwhal move along the floe edge and into ice-covered fiords through ice cracks and enlarged seal holes (Silverman 1979, Finley and Gibb 1982) while non-directed movements and social interactions increase steadily from low initial levels in June, to peak levels during the open water period in August and September (Silverman 1979, Fallis *et al*. 1983). Narwhal are reported to deep dive frequently beneath the ice edge prior to breakup, which is thought to be associated with feeding activity (Silverman 1979, Finley and Gibb 1982, Hay 1984). Stomach samples indicate that little feeding takes place during the open water season (Mansfield *et al*. 1975, Finley and Gibb 1982, Hay 1984), suggesting that deep dives may also occur infrequently during this period.

Observations of narwhal behavior in Admiralty Inlet in July and August 1983-1985, indicated that narwhal did engage primarily in directional movement early in the season (pre and early-breakup). Surface activity and deep dives, occurring at relatively low initial levels, increased over the two subsequent periods as narwhal gained access to Admiralty Inlet, such that surface activity predominated during late-breakup, followed by directional movement and deep dives. In contrast to findings in the Eclipse Sound fiord complex (Silverman 1979), narwhal were observed to return to high levels of directional movement during the open water period. This apparent discrepancy may represent differences between locations in terms of the components of the population inhabiting these areas and subsequent differences in behavior. Differences in factors which affect movements, such as prey availability and distribution may also be responsible for the observed differences.

In this study, killer whales (*Orcinus orca*) may also have affected movements during the open water period. Killer whales are one of the few natural predators of narwhal (Steltner *et al*. 1984, Campbell *et al*. 1988). Killer whales were sighted on two occasions in the study area in 1985, and in both cases narwhal were engaged almost exclusively in directional movement very close to shore. It was not known to what extent killer whales may have affected behavior during other observations in the open water period.

Observations also demonstrated variability in narwhal behavior between sites, time of day, and tides. Some of the differences in frequency of behavior types between sites appeared to reflect the physical constraints of animal movement through particular ice conditions. At Elwin Inlet and Cape Crauford, the majority of observations were of narwhal moving along cracks. Deep dives were directed beneath ice-covered areas to get to other cracks or areas of open water. At Elwin Inlet, distances between and along cracks in which narwhal were observed, were shorter than those at Cape Crauford. Because of the longer time needed for deep dives below ice-covered areas at Cape Crauford, greater frequency of observed surface activity and longer surface time may reflect the time required to recover from deep dives.

Variability in the behavior of narwhal as a function of tidal cycles has been observed previously during the open water period (Vibe 1950, Silverman 1979), although the significance of this was not known. In this study, changes in behavior related to tidal cycle during the early-breakup period may reflect the effect of shifting ice causing cracks to open or close. Surface activity was greater during low and rising tides than high or falling, although the general trend of ice conditions, whether slacking off or closing up, was not analysed in relation to tide.

Evidence for diurnal behavior rhythms, or differences in behavior over time, have been documented for other species and may be a function of a number of variables including solar or lunar cycles, competition between species, or behavior of prey (Klinowska 1986). Narwhal in Admiralty Inlet engaged in more directional movement and less surface activity during morning periods (6:00-12:00) than at other times of day, and more deep dives during the afternoon (12:00-18:00). The significance of these temporal differences in behavior are not clear. If directional movement and deep dives are related to searching for prey and foraging, then temporal differences may indicate that prey are more available or easier to find during the day (6:00-18:00) than at night

(18:00-6:00) and may reflect distributional differences of prey with time of day.

Proportion of Animals Visible

In order to correct survey estimates for the proportion of narwhal out of sight, the probability of sighting an animal at the surface must be determined. Eberhardt (1978) describes the approach to this problem based on the observed surface and dive times of individuals. Assuming that all animals at the surface within the sample area can be seen, the probability that an animal will be counted is

$$P = \frac{s}{s + u} + \frac{t}{s + u} = \frac{s + t}{s + u} \qquad [3]$$

where s is the surface time, u is the diving time, and t is the sample time ($t<u$). The first component represents the probability that the animal will be at the surface when the sample area first comes within sight, while the second component represents the probability submerged animals will surface while the sample area is in sight. For instantaneous samples, such as in aerial photography, t approaches zero, so that P is simply $s/(s + u)$.

Sergeant (1973), observing beluga (<u>Delphinapterus leucus</u>) in highly turbid waters, estimated that they were visible about one-third of the time. Bowhead (<u>Baleana mysticetus</u>) have been estimated to be at the surface 15-23% of the time (Davis <u>et al</u>. 1982).

In this study, the proportion of narwhal visible based on mean surface and deep dive time was 0.38 for pre-breakup, late-breakup and open water periods, and 0.48 for early-breakup. These estimates include the time spent in the visible portion of the water column. However, because both surface and deep dive times were highly variable, the range of proportion visible was large. Based on 95% confidence intervals of surface and deep dive times, the range of proportion visible was 0.34-0.64 for early breakup and 0.29-0.52 for other periods. This large variability may be attributable to differences in behavior between periods of breakup, tides, and times of day as suggested by scan samples. The assumption that s (mean surface time) and u (mean deep dive time) provide a sufficiently representative measure of surface and submerged times may not be valid if s and u are highly variable (Eberhardt 1978, Eberhardt et al. 1979). Potential differences in observability of focal animals related to group size, distance offshore, age or sex of the individual further confound the use of s and u in calculating proportion of animals visible.

Surface and deep dive times were likely biased toward shorter durations, since very few focal animals were observed for more than one surface or deep dive sequence. Both mean surface and deep dive time at different sites were highly correlated with mean observation duration (r=0.97 and r=0.90, respectively) suggesting that observed surface and deep dive times may have been a function of the ability to recognize individuals. In many focal-animal observations, the observation began with animals at the surface and missed an unknown initial portion of the surface time, indicating that surface times may have been more biased than deep dive times. Shortened surface times would tend to lower estimates of the proportion of narwhal visible.

Clearly, more extensive information on the deep dive and surface behavior of narwhal is required before a more precise estimate of the proportion of animals visible can be obtained. This may require a more sophisticated approach than that used in this study, perhaps involving time/depth recorders or radio-telemetry. In order to use behavioral information to correct survey estimates for unseen whales, the collected data must be sufficiently representative to assess variability of behavior over time and space, or be collected as close in time to surveys.

CHAPTER III: DISTRIBUTION AND ABUNDANCE OF NARWHAL IN ADMIRALTY INLET

INTRODUCTION

The highest estimate of narwhal abundance for the Lancaster Sound stock has been based on a combination of visual aerial surveys and shore-based counts of migrating animals during the spring (Davis et al. 1978). A major problem with this estimate is that surveys conducted during the summer period in different years have failed to validate even the lower range of this estimate (Koski and Davis 1979, 1980; Smith et al. 1985).

A variety of problems typically confound attempts to obtain reliable estimates of marine mammal populations. Marine mammals are typically difficult to census, because they are often widely distributed, far offshore, and difficult to see (Eberhardt et al. 1979). This is particularily true of the narwhal, as it is relatively inconspicuous due to its small size, dark coloration, lack of a dorsal fin, and wide offshore distrubution. Visual aerial survey results are also typically subject to a number of biases (Caughley 1974, 1977; Eberhardt et al. 1979). The degree of bias is affected by aircraft altitude and speed, observer differences, observer experience, definition of the transect width, variability in visibility across the transect, number of species being counted, weather, and behavior of the target species.

In this study, I estimated the abundance of narwhal in Admiralty Inlet using aerial photography to avoid biases related to visual observation during aerial censuses. Aerial photography offers several advantages in recording animal numbers: it allows accurate measurement of sample area; counting of animals is not limited by time; visibility is constant across the entire transect; and it provides a permanent record of the sample area, available for further investigation. In this chapter, I examine the results of aerial photographs taken during surveys conducted in Admiralty Inlet in August of 1983, 1984 and 1985 and estimate the numbers of narwhal based on these results.

MATERIALS AND METHODS

Survey Equipment and Procedures

All systematic aerial surveys for abundance were conducted with vertical, large format aerial photography as the sampling medium. The camera system was installed in the camera port in the floor of the midsection of a DeHavilland (DHC6) Twin Otter aircraft. Two types of camera systems were used: a Linhoff Aerotechnica in 1983 and a Wild RC-8 in 1984 and 1985. The two camera systems had different format sizes which resulted in different sampling area (Table 7). The Linhoff system was used with Ektagraphic 400 ASA positive film. The RC-8 was used with Kodak 2445 Aerocolor film. Both cameras were used with a shutter speed of 1/250 sec and an aperture of f5.6. A gyro-stabilizing base was used with the RC-8 to automatically level the camera unit just prior to exposing the frame, correcting for slight variations in aircraft tilt and roll. Both systems employed removable film backs and automated film advance. A programable interval timer governed sampling along each transect. Sample intervals were set such that there would be a slight gap between adjacent photo frames.

Navigation was accomplished by a combination of Global-500 Navigation System in 1983 and 1985 and Inertial Navigation System in 1984 and visual sightings of landmarks at the start and end points of transects.

The survey crew consisted of the pilot, navigator and camera operator. The navigator was responsible for operating the navigation equipment and directing the pilot on the desired flight path. The

Table 7. Specifications of aerial photographic equipment used during surveys of Admiralty Inlet in 1983 to 1985.

Year	Camera type	Film format size (cm)	Focal length of lens (mm)	Aircraft survey altitude (m)	Scale of image	Sample area of frame (km^2)	Approximate sample coverage[a] (%)
1983	Linhoff	9.5x12.1	90	488	1:5418	0.337 (0.52x0.66 km)	8.0
1984 and 1985	RC8	23x23	152.4	914	1:6000	1.904 (1.38x1.38 km)	16.8

[a] Sample coverage based on transect intervals of 4 nautical miles (7.4 km) and intervals between adjacent frames of 10% of frame length.

navigator informed the camera operator of the approach of start and end points of each transect, and documented sea state, sky conditions, aircraft speed and altitude, and camera function. The camera operator was responsible for setting the timing interval of the intervalometer; initiating, monitoring, and stopping camera function; changing film backs and film, and communicating camera performance to the navigator.

Systematic Survey Design

Two systematic surveys were conducted each year in mid-August, coinciding approximately with the overall median date of the open water season. These surveys were conducted in Admiralty Inlet north of 72°10'N (Fig. 4), in an area 170 km long by 25-50 km wide or about 6,000 km^2 of water surface area not including the smaller inlets on the east side of Admiralty Inlet. In 1985, the northern limit of the survey area was moved south to the latitude of Cape Joy (73°40'N) because few narwhal were counted further north in 1983 and 1984, substantiating local knowledge that few narwhal are seen north of Elwin Inlet in the open water season.

Surveys were designed using a systematic transect sampling method (Cochran 1977). All systematic transects were designed to be flown along lines of latitude. Each year, the northernmost transect was chosen at random from the four northernmost minutes of latitude in the study area. Subsequent transects were drawn at intervals of four minutes of latitude (7.4 km, Fig. 5). The number of transects actually completed in any single survey was less than the total number of transects defined. Film exposure requirements restricted available

Figure 4. Map of Admiralty Inlet, N.W.T. Shading designates the limits of the survey area for systematic surveys.

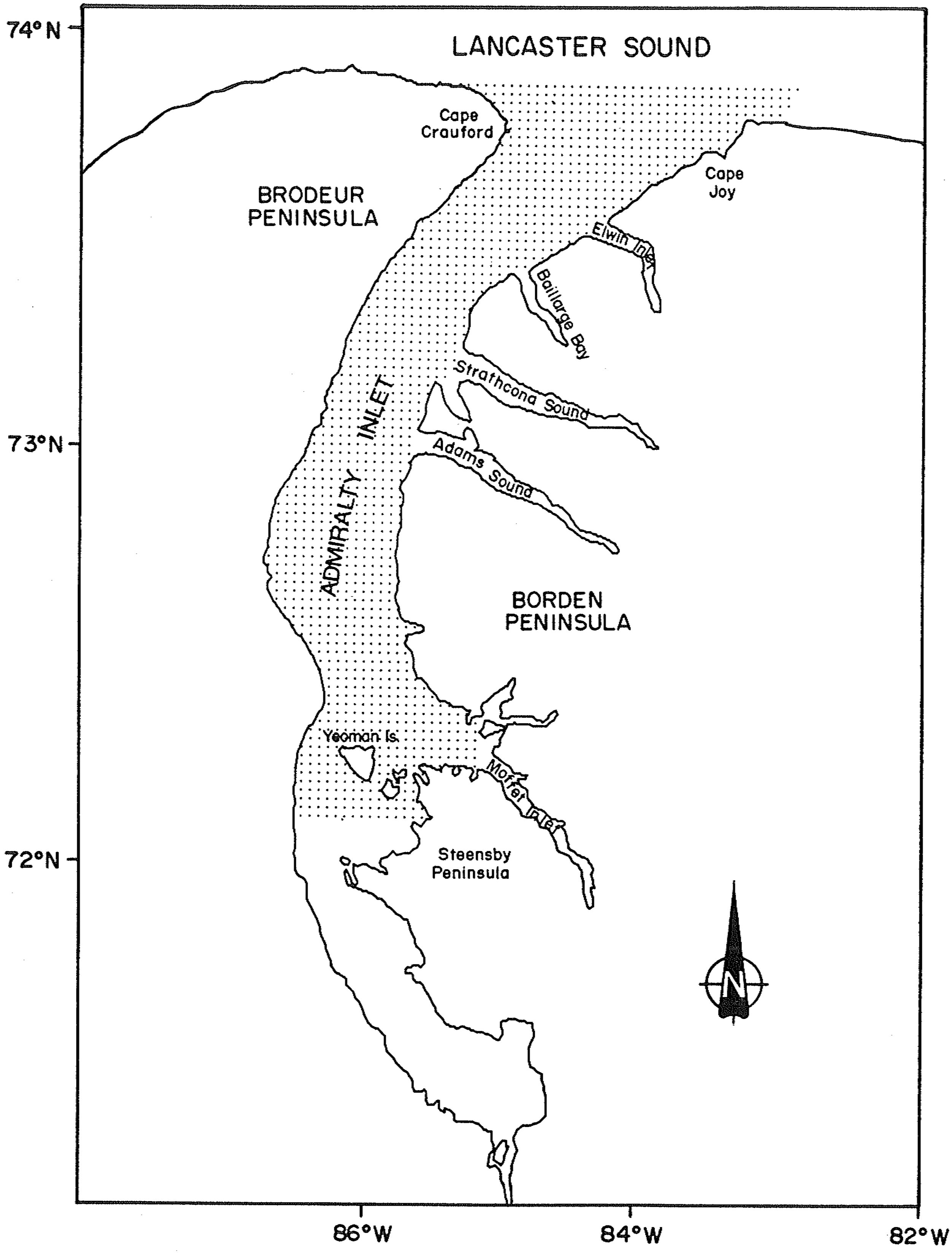
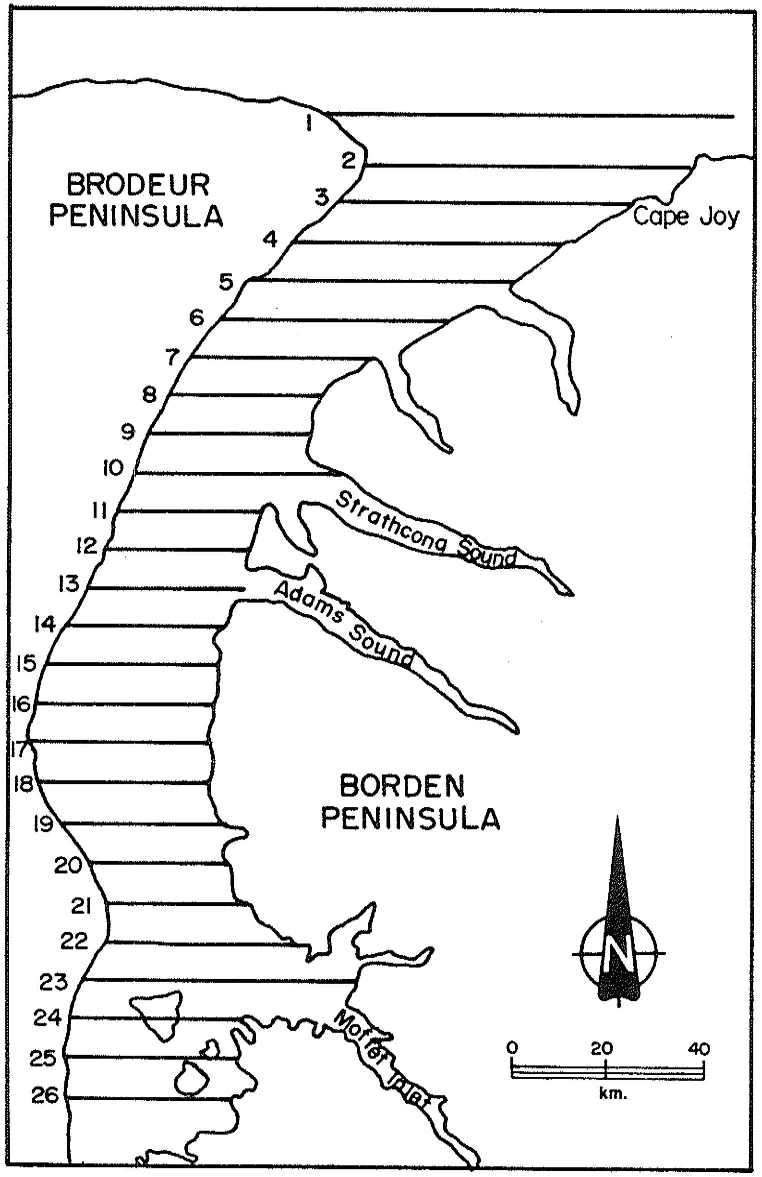

74° N
73° N
72° N
86° W
84° W
82° W
LANCASTER SOUND
Cape Crauford
Cape Joy
BRODEUR PENINSULA
Elwin Inlet
Baillarge Bay
Strathcona Sound
Adams Sound
ADMIRALTY INLET
BORDEN PENINSULA
Yeoman Is.
Moffet Inlet
Steensby Peninsula
N

Figure 5. Transect design for surveys conducted in Admiralty Inlet in a) 1983 and 1984, and b) 1985. Transect numbers are indicated on the left side.


BRODEUR PENINSULA
Cape Joy
Strathcona Sound
Adams Sound
BORDEN PENINSULA
Moffet Inlet
1
2
3
4
5
6
7
8
9
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21
22
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26
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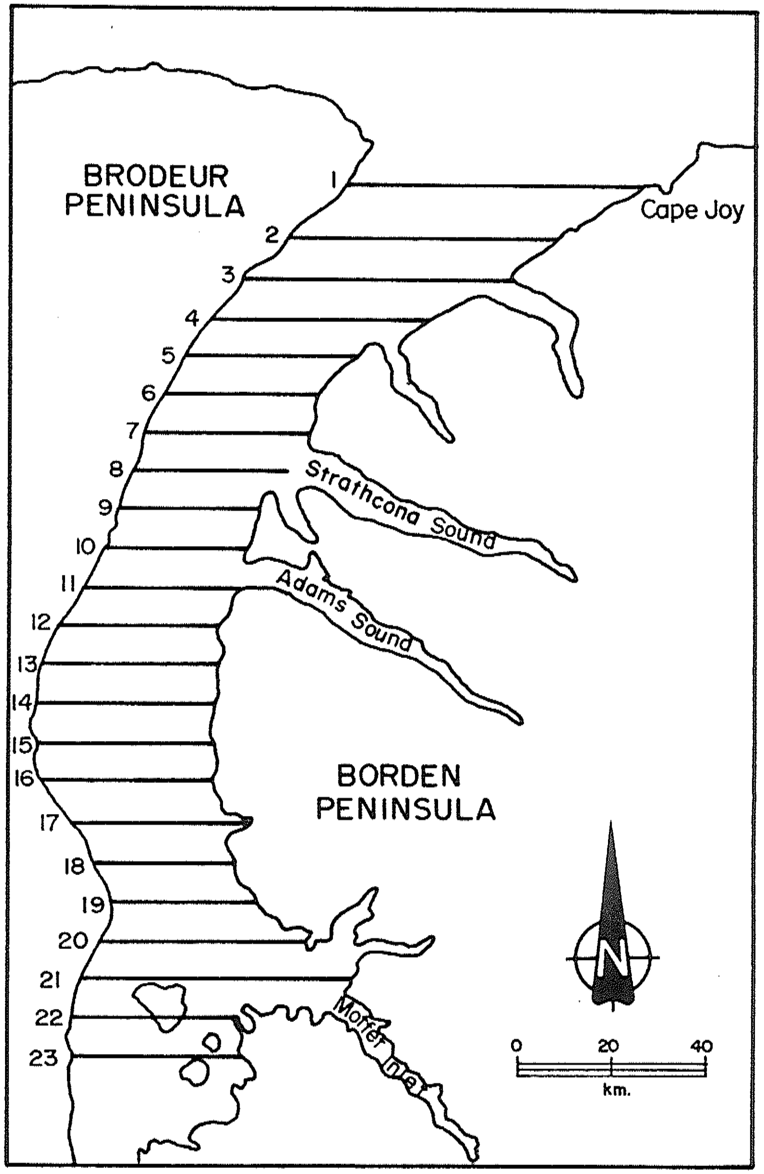
0
20
40
km.

a


BRODEUR PENINSULA
Cape Joy
Strathcona Sound
Adams Sound
BORDEN PENINSULA
Moffet Inlet
1
2
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13
14
15
16
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19
20
21
22
23
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0
20
40
km.

b

survey time to about ±2.5 hours around solar noon (time of peak sun height). Unsuitable weather conditions occasionally cut surveys short.

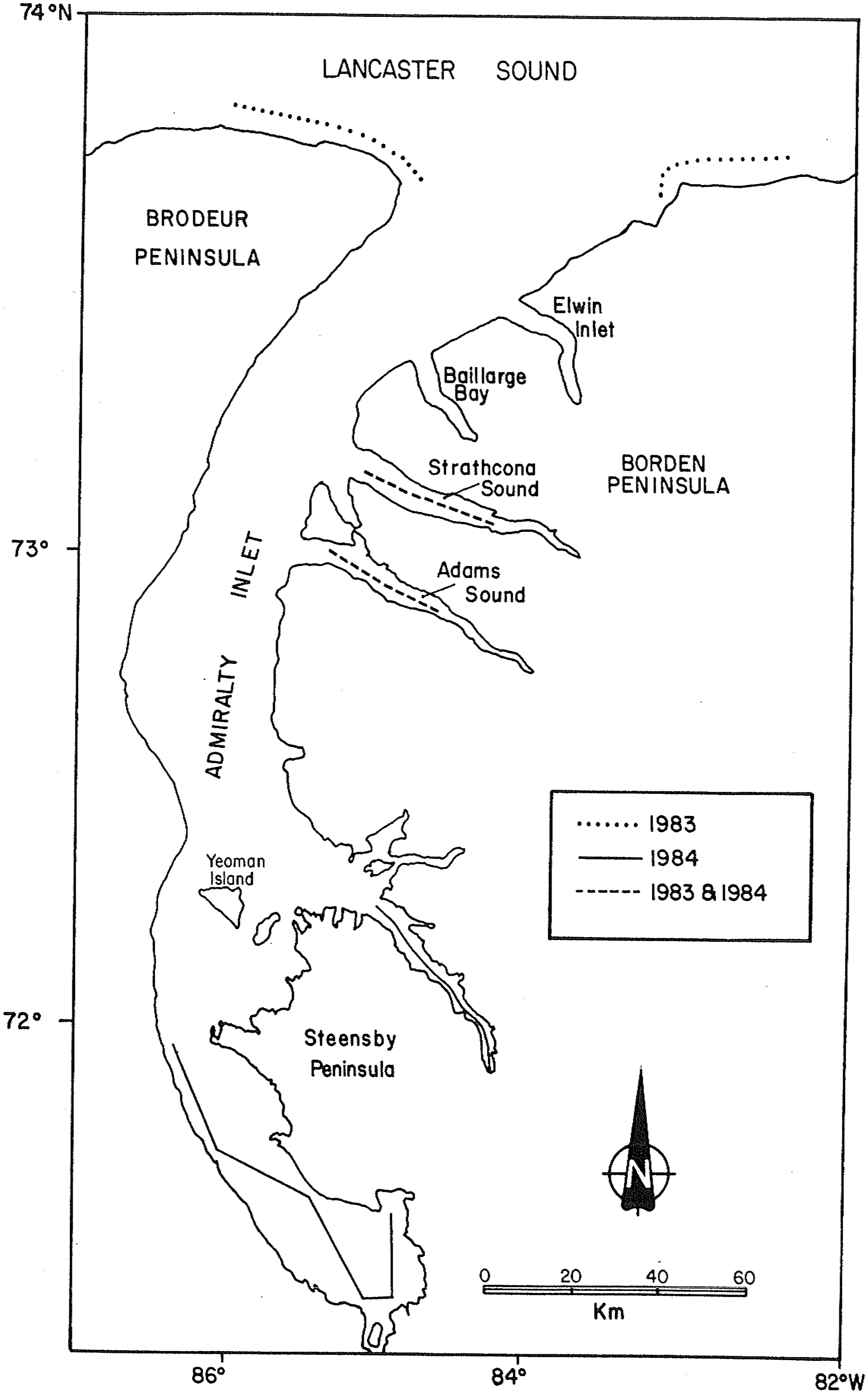
Non-systematic Surveys

Non-systematic surveys were conducted in 1983 and 1984 to assess distribution of narwhal in outlying areas. These surveys included: 1) a coastal reconnaissance survey at the mouth of Admiralty Inlet in 1983, 2) mid-inlet transects in Adams and Strathcona Sounds in 1983 and 1984 and Moffet Inlet 1984 and 3) nearshore and offshore transects in southern Admiralty Inlet in 1984 (Fig. 6). For non-systematic surveys in 1984, aerial photography was used and techniques were the same as those used during the systematic surveys. In 1983, visual techniques were used. Two positions on the port side and one on the starboard side of the aircraft were assigned randomly to three observers for each transect. Observers divided transects into two minute intervals and recorded numbers of whales and information on sea state, ice conditions, glare and fog into portable tape recorders. Visual transect width on each side of the aircraft was 840 m, defined by lining up markings on the window and wing struts.

Photo Interpretation

Images were examined directly from the processed film transparencies using a Richards large format film reading light table and variable power (0.7-3.0X) dissecting microscope. The microscope was set on a movable tracking system so that each frame could be examined in sections using a grid on a transparency. The width of each frame

Figure 6. Location of non-systematic surveys conducted in Admiralty Inlet in 1983 and 1984.


74°N
LANCASTER SOUND
BRODEUR PENINSULA
Elwin Inlet
Baillarge Bay
Strathcona Sound
BORDEN PENINSULA
73°
INLET
Adams Sound
ADMIRALTY
1983
1984
1983 & 1984
Yeoman Island
72°
Steensby Peninsula
N
0
20
40
60
Km
86°
84°
82°W

section was less than 2/3 the width of the viewing area of the microscope at low power.

The identity of narwhal was determined by shape, size, and color patterns. From a vertical platform at a scale of about 1:6000, a distinct image of a narwhal possessed the following general features: torpedo shaped with back and fluke region visible, a dark band along the mid-dorsal line of the back, and an apparent break between the main body and fluke region (Fig. 7). Features were less distinct for animals at depth, although most retained a characteristic color and torpedo shape. A combination of shape, color, and association with other narwhal was used as positive identification criteria and targets which lacked these were not counted. For each frame, the amount of land, fog, ice, and glare was recorded, as well as the sea state and presence of any film exposure anomolies. For each target on a frame, the number of animals, location on frame and orientation relative to the top of the frame were recorded. Ice cover was quantified by measuring the proportion (in tenths) of the frame covered by ice and recorded using the following categories: A (0/10), B (<1/10), C (1/10 to 3/10), D (4/10 to 6/10), E (7/10 to 9/10), and S (shore ice) (after Anon. 1979).

Figure 7. Reproduction of aerial photograph depicting narwhal enlarged 2.5 times.

Sample Area Calculation

The scale of the photographic images was determined by:

$$A = \frac{F}{H} \qquad [4]$$

where A = scale of the photographs;

F = focal length of the camera lens;

H = survey altitude of the aircraft.

The sampled area was then determined by extrapolating the frame dimensions for the scale of the photographs and subtracting proportions of the frame covered by land, fog, and glare:

$$X_i = \frac{W\ L}{A^2} \sum^{m_i} (1 - S_{ij} - V_{ij} - G_{ij}) \qquad [5]$$

where X_i = sample area of i^{th} transect;

W = format width of photo frame;

L = format length of photo frame;

m_i = number of frames on the i^{th} transect;

S_{ij} = proportion of j^{th} frame of i^{th} transect covered in land;

V_{ij} = proportion of j^{th} frame of i^{th} transect covered in fog;

G_{ij} = proportion of j^{th} frame of i^{th} transect covered in glare.

Abundance Analysis

The total number of narwhal on each transect was simply the total number of animals counted over all frames in the transect:

$$Y_i = \sum^{m_i} b_{ij} \qquad [6]$$

where Y_i = number of narwhal in sample area of i^{th} transect;

b_{ij} = number of narwhal counted on the j^{th} frame of the i^{th} transect, not including animals seen in the glare area.

Estimates of narwhal density were obtained by ratio estimation (Cochran 1977):

$$\hat{R} = \frac{\sum^{n_i} Y_i}{\sum^{n_i} X_i} \qquad [7]$$

where $\hat{R}$ = estimated survey density;

n_i = number of transects flown.

The error variance of $\hat{R}$ was calculated using a first order serial difference estimator (Kingsley and Smith 1981). This was based on the expectation that adjacent transects are likely to have densities more similar (autocorrelation) than transects further apart. This method is intended to provide estimates of variance which are more precise than standard methods if the distribution is autocorrelated (Kingsley and Smith 1981). The serial difference estimator for the standard error of a systematic survey is intended to give the same expectation as the standard procedure if the population is uncorrelated (Kingsley pers. comm.). The error variance of the estimated density, $S^2(\hat{R})$ was:

$$S^2(\hat{R}) = (1-f)\frac{\sum^{n-1}(d_i - d_{i+1})^2}{2(n-1)n\bar{X}^2} \qquad [8]$$

where f = sampling fraction, $\sum^{n_i} X_i/T$, where T = the total census area;

$d_i = Y_i - \hat{R}X_i$;

$\bar{X} = \sum^{n}(X_i/n)$.

Confidence limits for density were determined by (Smith et al. 1985):

$$\sqrt{R_L} = \left(\frac{-t\ S(\hat{R})}{\sqrt{\hat{R}}} \pm \sqrt{\frac{t^2\ S^2(\hat{R})}{\hat{R}} + 4\ \hat{R}}\right)\Big/2 \qquad [9]$$

where R_L = confidence limit for density, and

t = critical point in Students t distribution.

Estimates of total visible population were simply obtained by extrapolating density estimates and confidence limits of density estimates over the census area.

A measure of narwhal clumping (c) was obtained by:

$$c = \sum^{n} Y_i \quad \frac{S^2}{\hat{R}^2}$$

This clumping factor measures the tendency of narwhal to be seen in the same area.

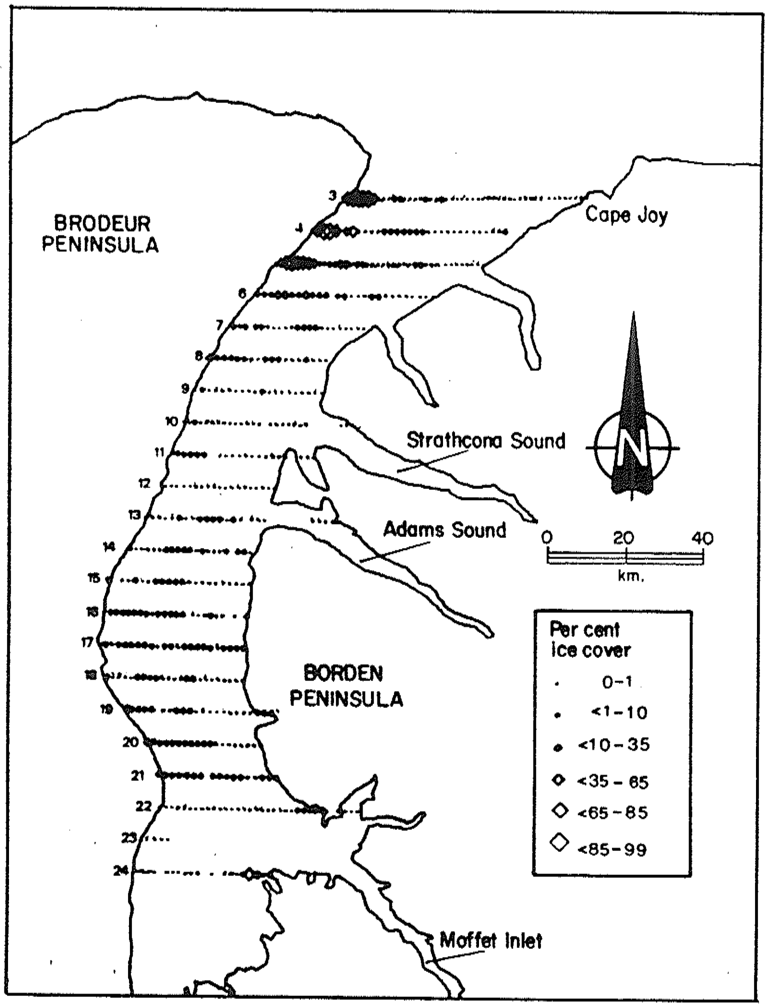
RESULTS

Ice Conditions Encountered During Aerial Surveys

In 1983, break-up was later than usual. The floe edge of Lancaster Sound, typically located at the entrance to Barrow Strait in mid-May (Marko 1982, Fig. 2) extended between eastern Devon Island and Borden Peninsula of Baffin Island as late as the first week of July. The ice remained relatively stable in Admiralty Inlet until late July. Considerable amounts of pack ice remained present until the first week of August because of north winds and moving ice in Lancaster Sound. Much of this was flushed out prior to the aerial surveys in mid-August, leaving about 12% of the study area covered in varying concentrations of ice (as estimated from aerial photographs; Fig. 8). About 10% of the area was covered in 1/10 to 3/10 ice, most of which was distributed over northern and western Admiralty Inlet. Ice concentrations of 4/10 or more covered less than 3% of the study area, most of which was found around Cape Crauford and the western shore in northern Admiralty Inlet.

The winter ice edge in Lancaster Sound was located west of Admiralty Inlet in 1984, allowing an earlier breakup of Admiralty Inlet to occur in that year. Lancaster Sound was generally open with variable amounts of moving pack ice present by early July. Open water in Admiralty Inlet was prevalent by the beginning of August. At the time of aerial surveys in mid-August, about 40% of the study area was covered with low (<1/10) concentrations of ice (mostly less than 0.5/10) and about 5% was covered in 1/10 to 3/10 ice, primarily

Figure 8. Ice distribution in Admiralty Inlet in 1983 as determined from aerial photographic surveys on a) 17 August and b) 18 August. Transect numbers are indicated on the left side.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km.
Per cent ice cover
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<1-10
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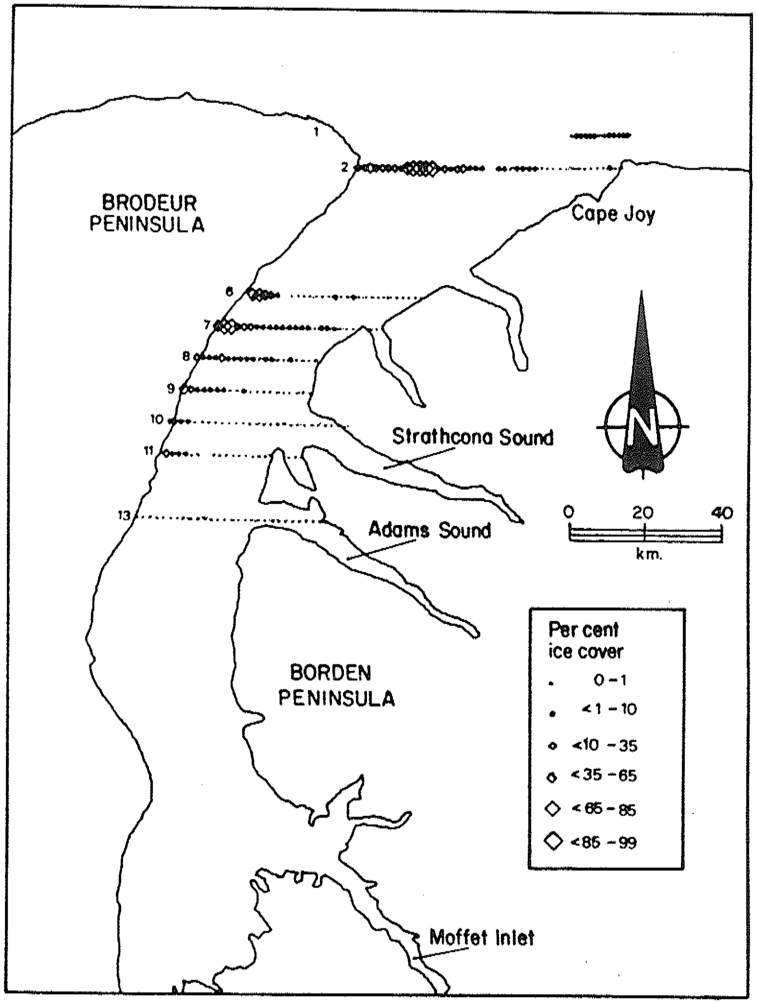
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km.
Per cent ice cover
0-1
<1-10
<10-35
<35-65
<65-85
<85-99

b

distributed in the central and northern portion of the study area (Fig. 9).

It was an exceptionally mild ice season in 1985. Breakup was similar to 1984 but occurring one to two weeks earlier. By mid-July, most of Admiralty Inlet consisted of loose, large ice pans and rubble ice. During the aerial surveys in mid-August, there was virtually no ice present (<1%).

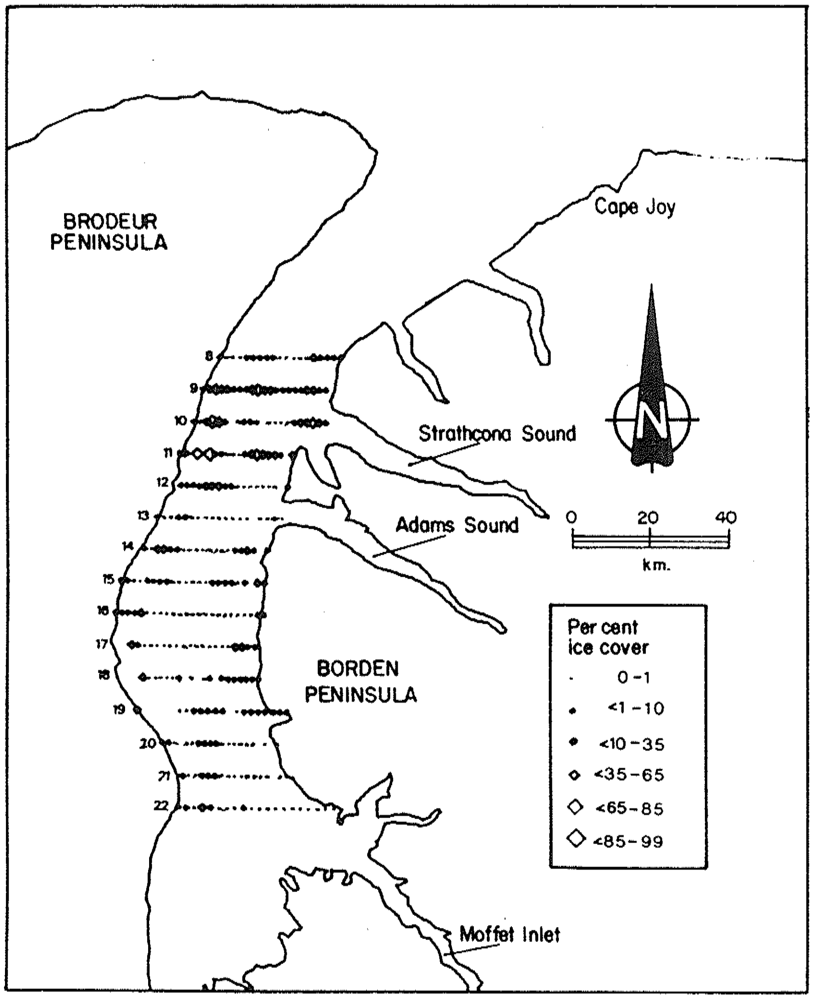
Survey Results

In all surveys where glare was present on photographs the number of whales in glare areas was significantly less than expected (Table 8). Glare-covered portions of frames were subsequently omitted from all abundance and other density related analyses but included in distribution maps.

Six systematic (two each year) and 4 non-systematic surveys were conducted from 1983 to 1985 (Table 9). The initial goal was to survey the entire study area each year but this was achieved only in 1984 when one of the surveys was flown at half the designed coverage (at intervals of 8 minutes of latitude or 14.8 km). Survey results are presented separately and represent only the area under survey for that day because of potential movement of narwhal between surveys.

Examination of narwhal numbers in relation to ice cover for 1983 and 1984 surveys indicated that narwhal were found more frequently in ice concentrations of less than 1/10 than other ice cover categories for the August 18, 1983 and August 23, 1984 surveys (Table 10). For the

Figure 9. Ice distribution in Admiralty Inlet in 1984 as determined from aerial photographic surveys on a) August 21, and b) August 23. Transect numbers are indicated on the left side.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Per cent ice cover
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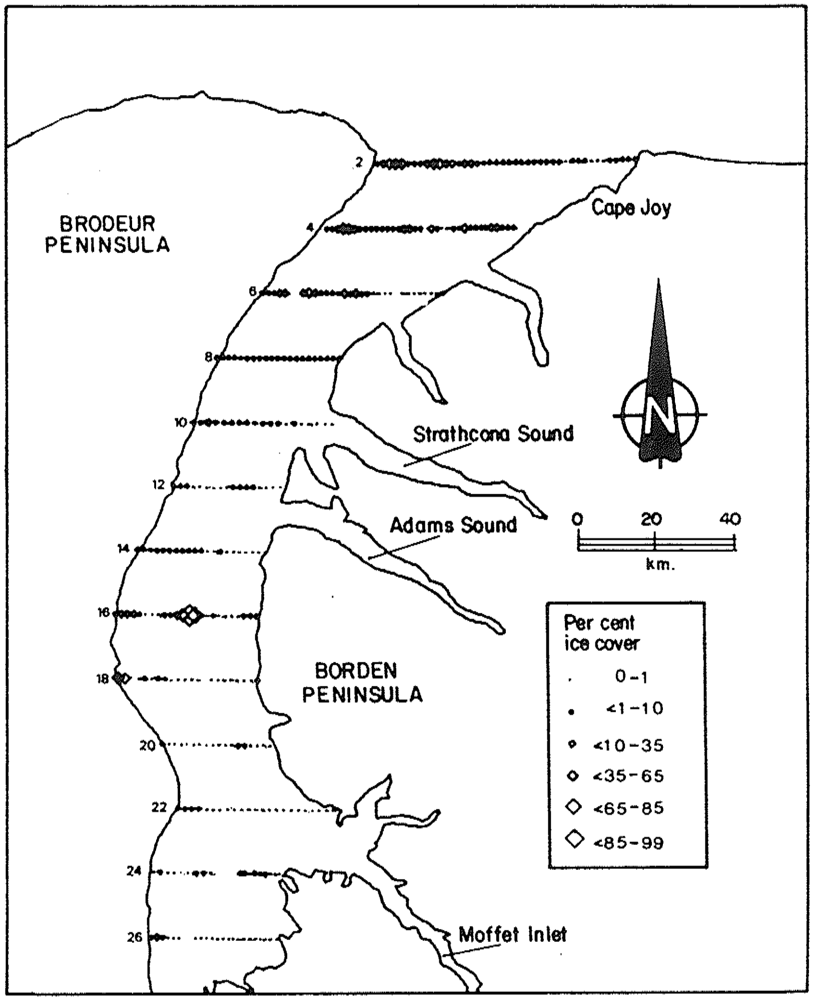
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Per cent ice cover
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<1-10
<10-35
<35-65
<65-85
<85-99

b

Table 8. Results of chi-square analyses comparing the observed versus expected numbers of narwhal in glare portions of aerial photographs.

Survey	Region of frame	Area (sq. km)	Number of narwhal	Chi-square Statistic
August 17/83	Non-glare	402.2	159	25.8
	Glare	75.8	2	
August 21/84	Non-glare	490.0	341	11.8
	Glare	32.3	6	
August 23/84	Non-glare	540.6	469	8.7
	Glare	23.5	7	

Table 9. Summary of transects flown, sample area and total counts of narwhal for aerial photographic surveys flown in Admiralty Inlet in 1983-1985.

Year	Date	Survey type	Survey region	Figure	Sample area (sq. km)[a]	Total number of narwhal counted
1983	August 17	Systematic	Transects 3-24	10	518	161
	August 18	Systematic	Transects 1-2 Transects 6-11,13	11	55 167	3 212
		Non-systematic	Coastline at Admiralty mouth Adams & Strathcona Sounds	6	151[b] 70[b]	0 0
1984	August 21	Systematic	Transects 8-22	13	523	347
	August 22	Non-systematic	Admiralty S. of Yeoman Is. Moffet Inlet. Adams & Strathcona Sounds	6	200 65	0 0
	August 23	Systematic	Transects 2-26[c]	14	564	476
1985	August 13	Systematic	Transects 12-23	15	464	531
	August 14	Systematic	Transects 4-21	16	677	872

[a] not including areas covered by land or fog
[b] visual survey; area based on transect width of 0.84 km on each side of aircraft
[c] survey flown at reduced (half) coverage sampling even number transects

Table 10. Chi-square (goodness of fit) analysis of numbers of narwhal observed in relation to ice cover as determined from systematic aerial photographic surveys in Admiralty Inlet. Ice types were pooled as necessary to achieve minimum expected of 5 in each ice class category.

Survey	Ice Categories Compared[a]	Degrees of Freedom	Chi-square Value[b]	P
August 17/83	A, others	1	0.05	>0.90
August 18/83	A,B, others	2	9.7	<0.01
August 21/83	A,B,S, others	3	6.9	>0.10
August 23/83	A,B, others	2	54.8	<0.005

[a] Ice categories: A=0/10, B=<1/10, C=1/10-3/10, D=4/10-6/10, E=7/10-9/10, S=shore ice.

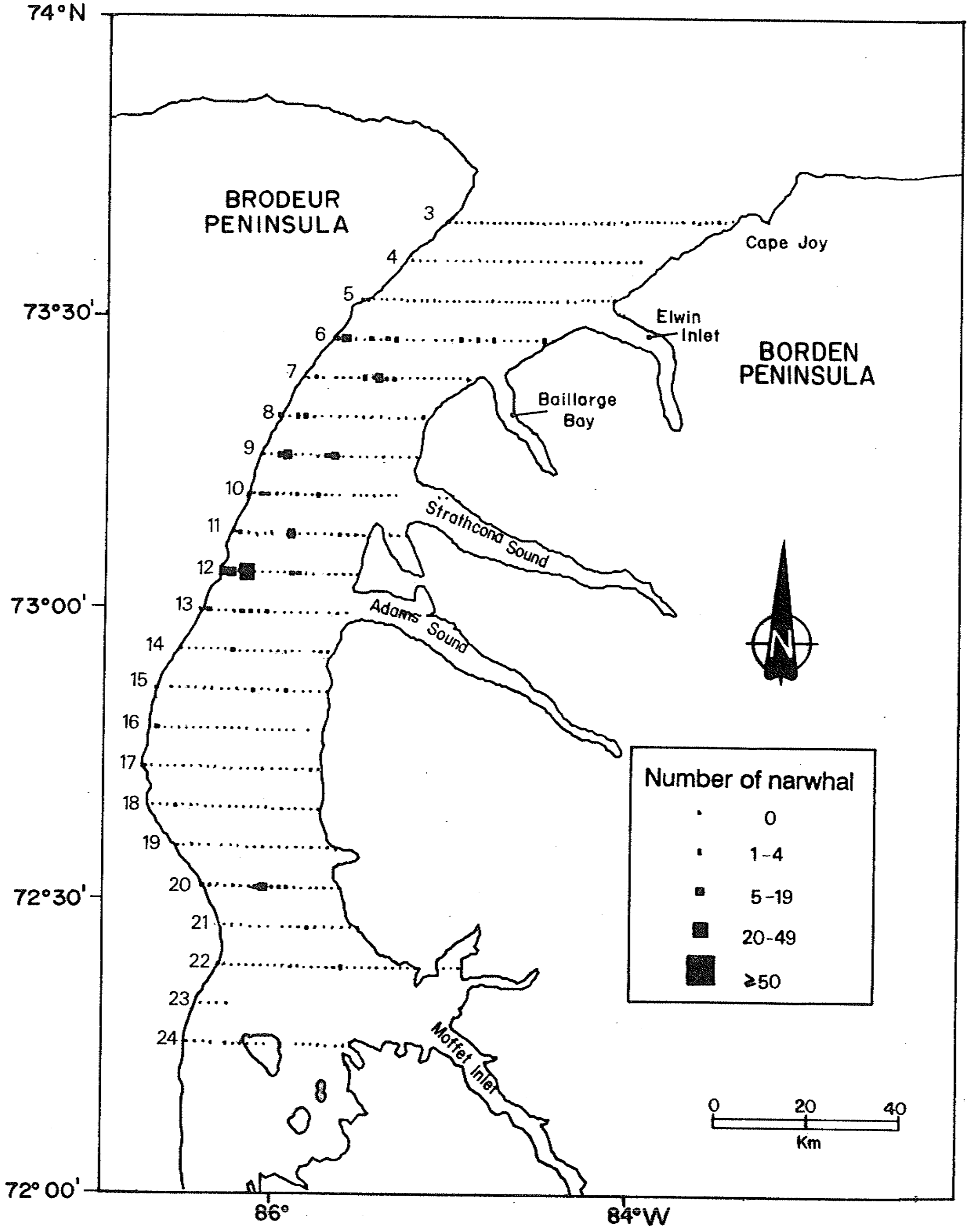
August 17, 1983 and August 21, 1984 surveys, narwhal were distributed evenly across ice class categories.

In 1983 systematic surveys were flown on 17 and 18 August and a number of non-systematic transects on August 18 (Table 9). The first systematic survey, consisting of all but the most southern transect and the two most northern transects, was flown during rough sea state conditions (Beaufort scale 3 or more) which was reflected in low observed densities and estimates of total numbers (Table 11). Most narwhal were seen between Elwin Inlet and Adams Sound (transects 6-12) in the western portion of the inlet (Fig. 10).

On the August 18 1983 systematic survey, 223 km^2 were sampled in two segments: 56 km^2 over the two most northern transects and 167 km^2 over 7 of the transects surveyed the previous day (Fig. 11). The most northern transect was only partially photographed due to technical problems. Sea state conditions were favorable throughout the entire survey, less than or equal to Beaufort 2. Only three narwhal were counted on photographs in the northern segment and none was seen during constant surviellance by visual observers in the non-photographed portion of the transect. In the southern segment, narwhal were more widely dispersed across the inlet than on August 17. A particularly large concentration was observed on transect 13 near the mouth of Adams Sound (Fig. 11). The estimate of total numbers for August 18 represented only the southern segment of the two surveyed areas, less than one third the total study area and thus the estimate is likely low.

Four transects were sampled during non-systematic surveys on August 18: two near-coastal transects on either side of the mouth of

Figure 10. Narwhal distribution during systematic aerial photographic surveys in Admiralty Inlet for August 17, 1983.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19
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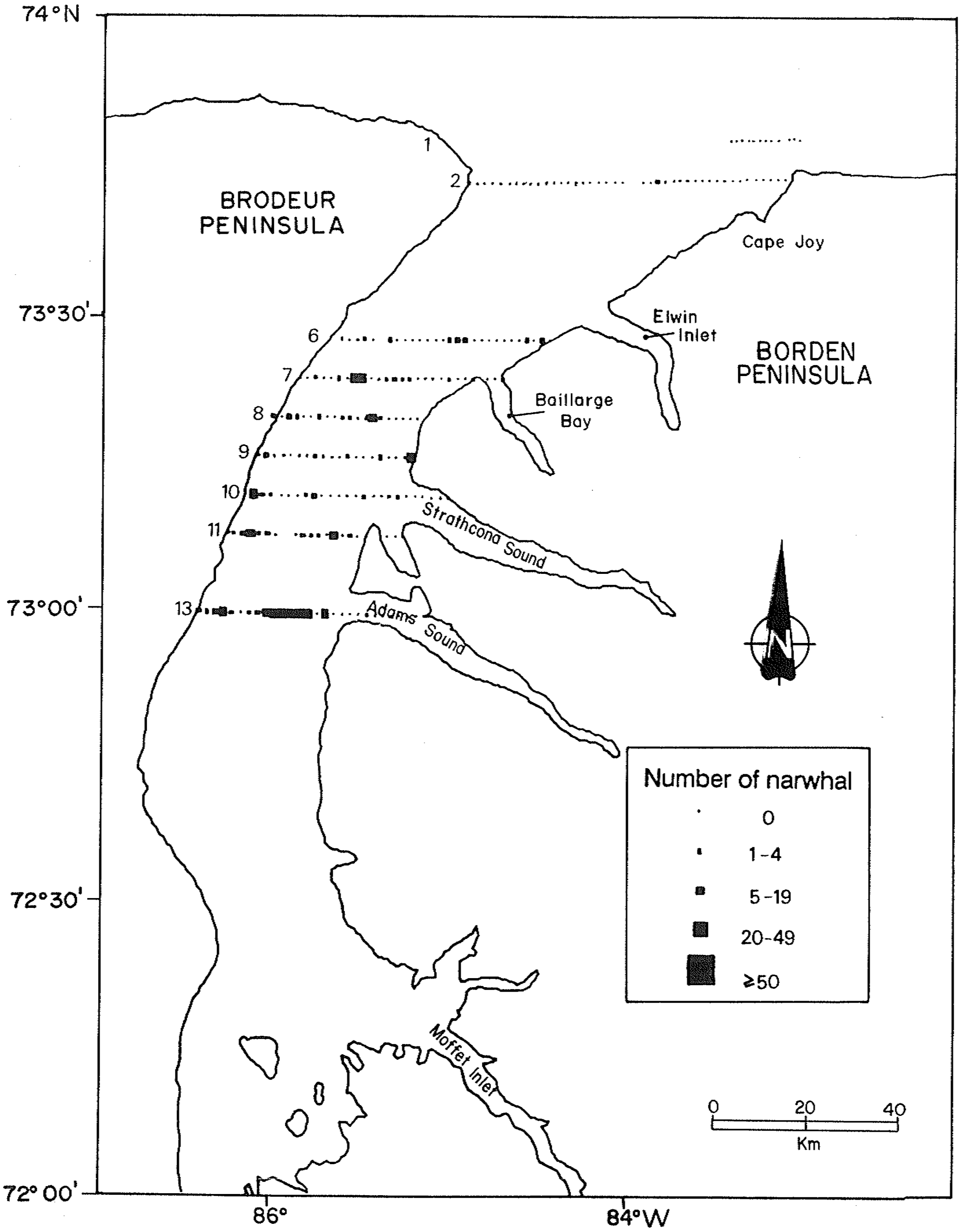
22
23
24
N
Number of narwhal
0
1-4
5-19
20-49
≥50
0
20
40
Km

Figure 11. Narwhal distribution during systematic aerial photographic surveys in Admiralty Inlet for August 18, 1983.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Strathcona Sound
Adams Sound
Moffet Inlet
Number of narwhal
0
1-4
5-19
20-49
≥50
0
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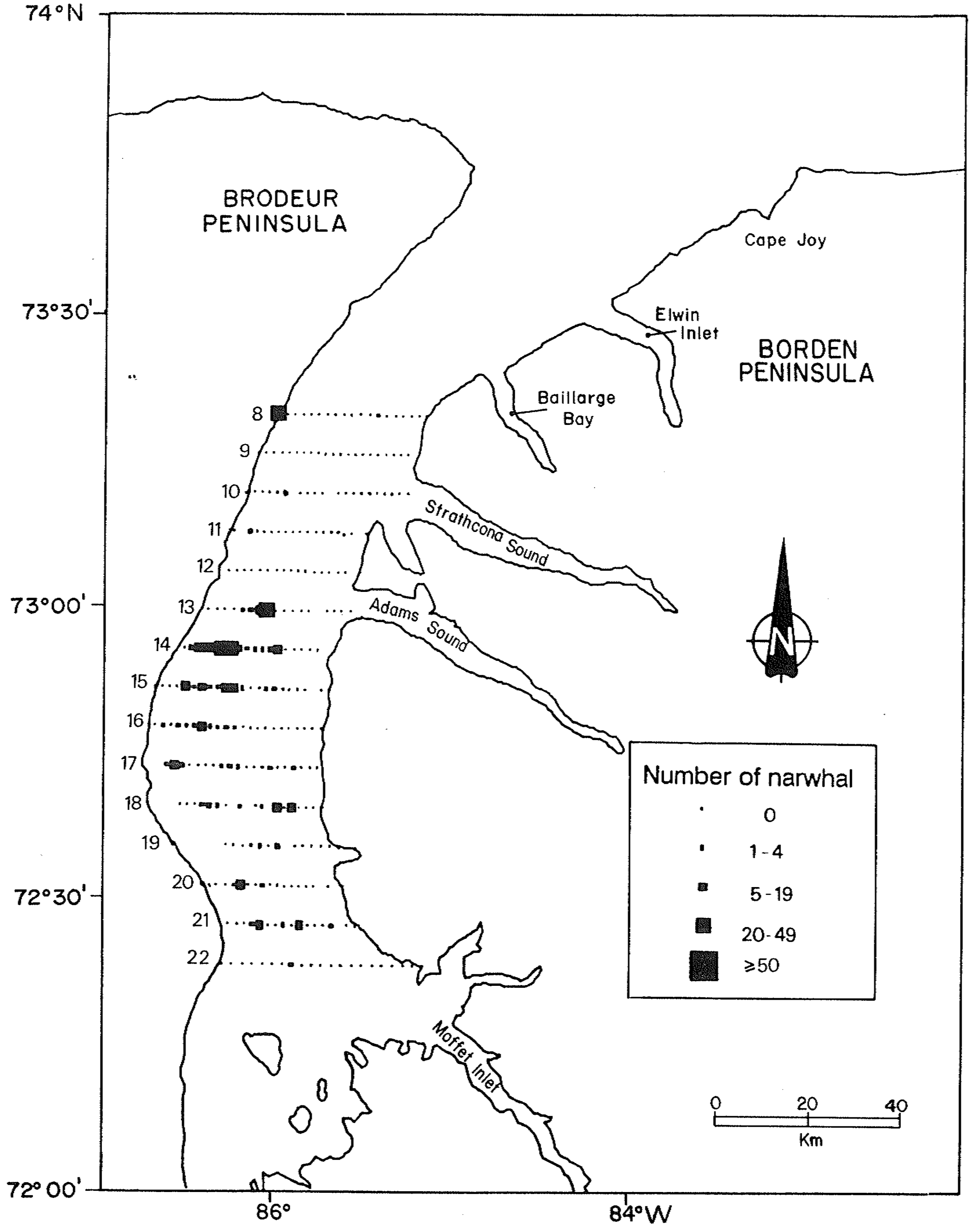
40
Km

Admiralty Inlet, and one transect each in Adams and Strathcona Sounds (Fig. 6). No animals were recorded on any of these transects.

In 1984, systematic surveys were flown on August 21 and 23 (Fig. 12 and 13) while non-systematic photographic transects (Fig. 6) were completed on the intervening day while sea state was unfavorable in the main census area. Sea state ranged from Beaufort 1 to 4 during both systematic surveys with greatest survey coverage obtained on August 23. On August 21, sea states of 3 and 4 occurred on the western portion of transects 15 and 16 and all of transects 20 to 22. The survey was therefore curtailed prior to obtaining representative coverage of the entire study area. Most narwhal were observed south of Adams Sound and in the western portion of the inlet (Fig. 12), particularly on transects 13-15. On August 23 1984, sea states of Beaufort 3 or more were encountered throughout all transects south of transect 18. Only even numbered transects were sampled during this survey because of limited aircraft time. This survey was the only one which effectively represented the entire census area and estimates of total numbers were corresondingly greater than those of the August 21 survey. Most narwhal were observed on transects 8-12 on August 23, with particularly high densities at the mouth of Strathcona Sound (Fig. 13). No narwhal were observed in Adams or Strathcona Sounds, Moffet Inlet or Admiralty Inlet south of Yeoman Island during the non-systematic reconnaissance surveys of August 22, 1984.

In 1985, systematic surveys were conducted on August 13 and 14. Sea states of Beaufort 3 and 4 were characteristic throughout most of the sampled area on August 13. For this reason only the southern half

Figure 12. Narwhal distribution during systematic aerial photographic surveys in Admiralty Inlet on August 21, 1984.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Number of narwhal
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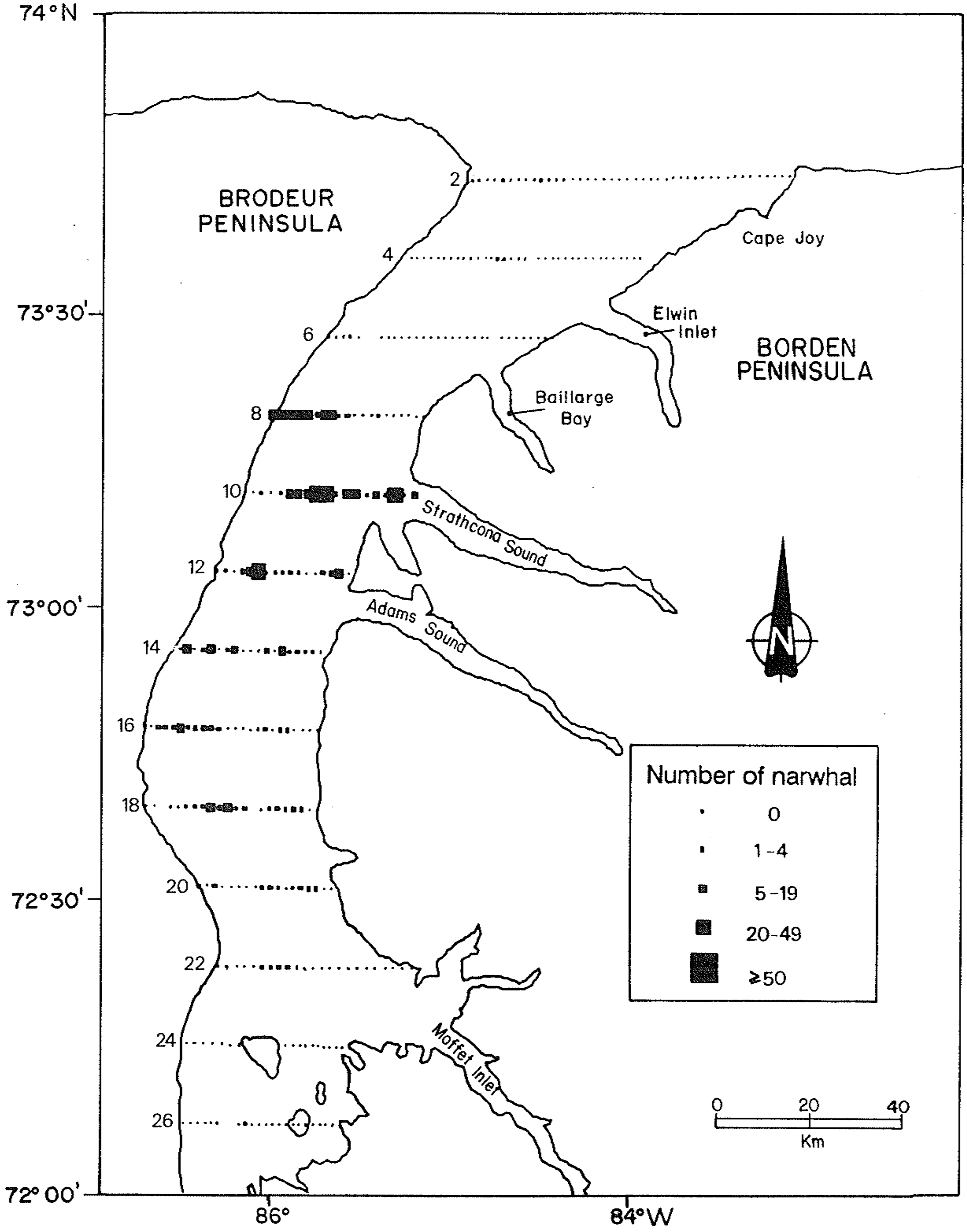
Km

Figure 13. Narwhal distribution during systematic aerial photographic surveys in Admiralty Inlet for August 23, 1984.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Number of narwhal
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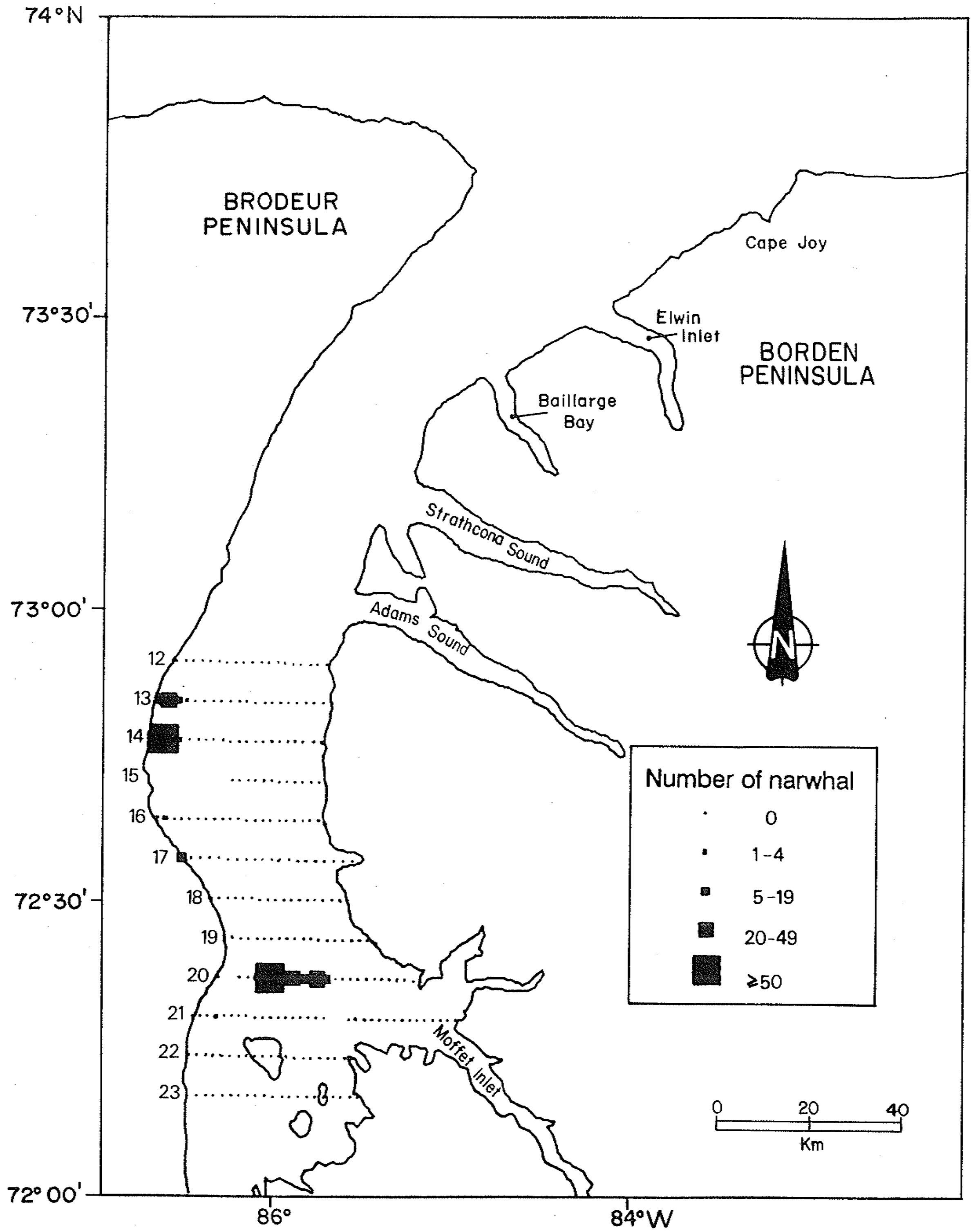
of Admiralty Inlet was surveyed (Fig. 14). Narwhal were observed in a few highly concentrated areas, one just north of Yeoman Island and two others along the western shore of the inlet on transect 13 and 14. These few concentrated areas resulted in high clumping factors and corresponding large confidence limits in estimates of total numbers (Table 11).

The August 14, 1985 survey was conducted with sea state conditions not exceeding Beaufort 2 and represented most of central and southern Admiralty Inlet (Fig. 15). The northern 3 and southern 2 transects (Fig. 5) were not sampled. Narwhal were highly concentrated in southern Admiralty Inlet along the western shore and just north of Yeoman Island. Clumping factors were high but not as high as the previous survey.

Figure 14. Narwhal distribution during systematic aerial photographic surveys in Admiralty Inlet on August 13, 1985.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Number of narwhal
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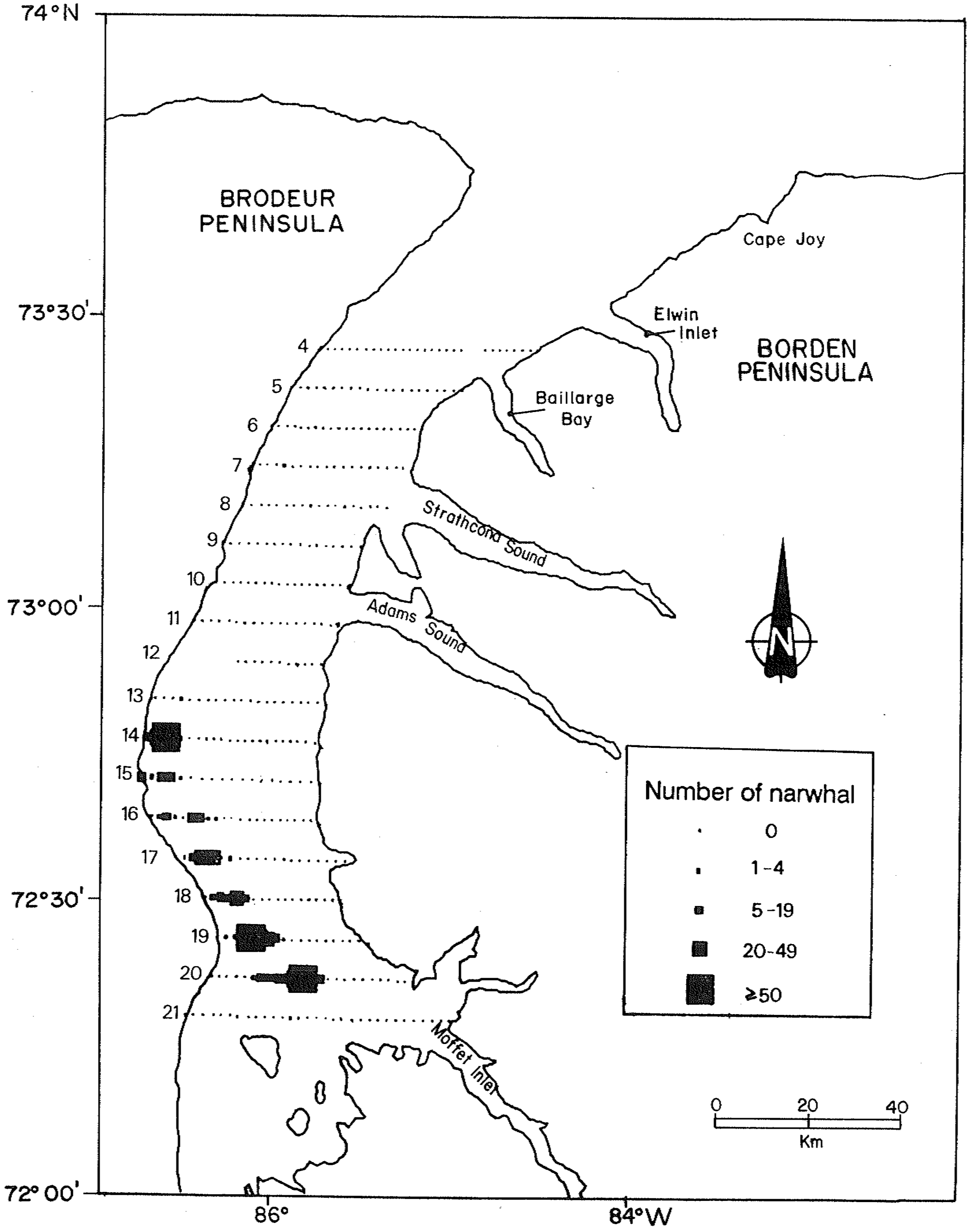
Km

Figure 15. Narwhal distribution during systematic aerial photographic surveys in Admiralty Inlet on August 14, 1985.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Number of narwhal
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≥50
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Table 11. Survey areas, sample areas, densities, estimates of total numbers, and clumping factors for systematic aerial surveys.

Date	Survey area (km^2)	Sample area[a] (km^2)	Effective sampling intensity	Number of narwhal in non-glare area	Density (number/km^2)	S.E.	Population estimate	Confidence limits (95%)	Clumping factor
August 17/83	5705	402.2	7.0%	159	0.40	0.11	2256	1,283-3,964	12.0
August 18/83[b]	1812	166.6[b]	9.2%	212	1.27	0.33	2306	1,244-4,277	13.9
August 21/84	3512	490.9	14.0%	341	0.76	0.17	2662	1,629-4,351	19.9
August 23/84	6017	540.6	9.0%	469	0.87	0.21	5220	3,104-8,780	27.3
August 13/85	3005	427.2	14.2%	531	1.24	0.81	3736	978-14,265	228.0
August 14/85	4342	673.5	15.5%	872	1.29	0.43	5619	2,819-11,200	96.9

[a] area of glare excluded from sample
[b] includes area represented by transects 6-11,13 only

DISCUSSION

Distribution of Narwhal

Narwhal enter Lancaster Sound from Baffin Bay as early as late May, depending on ice conditions, and are typically found in large aggregations in the vicinity of ice edges of Lancaster Sound and adjacent fjords in late June (Tuck 1957, Greendale and Brousseau-Greendale 1976, Johnson et al. 1976, Smith et al. 1985). As ice breakup progresses, narwhal enter the adjacent fjords and summer there until late September when they begin their return migration (Tuck 1957, Johnson et al. 1976).

Previous studies during the open water period have documented narwhal distribution throughout much of Admiralty Inlet, mainly between Elwin Inlet and Yeoman Island with highest densities most often observed south of Strathcona Sound (Koski and Davis 1979, Koski 1980b, Fallis et al. 1983). Large numbers have frequently been observed along the west side of the Inlet (Hay and McClung 1976, Koski 1980b, Fallis et al. 1983) and occasionally in Strathcona Sound, Adams Sound, and Moffet Inlet (Koski and Davis 1979, Fallis et al. 1983, Degerbol and Freuchen 1935).

Narwhal distribution during aerial surveys in this study was generally similar to previous studies. Narwhal were rarely observed north of Elwin Inlet or south of Yeoman Island. A trend for narwhal to be distributed primarily on the west side of the inlet was found in four out of six surveys in this study. There were marked changes in distribution between some surveys, indicating that narwhal distribution within Admiralty Inlet may be highly variable. However, there was no indication of large scale movements in or out of Admiralty Inlet during the survey period. Little use inlets on the east side of Admiralty Inlet was documented. Local residents of Arctic Bay indicate that narwhal are typically seen in Adams and Strathcona Sounds later in the season as narwhal begin to move out of Admiralty Inlet (Fallis *et al.* 1983) in general agreement with previous findings.

Several high narwhal concentration areas were documented in this study. One was the western portion of Admiralty Inlet south of Adams Sound and north of Yeoman Island. The other two were the areas west of Adams and Strathcona Sounds. The significance of these areas is not known. Oceanographic features which concentrate prey species and provide feeding opportunities (Gaskin 1982) may occur at these locations. For instance, the interaction of currents at the mouths of Adams and Strathcona Sound with that of Admiralty Inlet, in combination with the decrease in depth at these sites may result in eddies or upwellings.

The exceptionally high concentrations of narwhal on the western shore of Admiralty Inlet in 1985 was likely caused by the presence of killer whales. Local residents indicate that large nearshore aggregations of narwhal and harp seals (*Phoca groenlandica*) characteristically occur in association with killer whales, substantiated by two observations in this study during observations of narwhal behavior, on August 16 and 19, in 1985.

Previous studies have reported that distribution of narwhal was associated with ice cover (Finley 1976, Silverman 1976, Koski 1980b).

The association of narwhal with ice cover in this study was not strong, narwhal being equally distributed across ice types in two surveys and showing a slight preference for open water and <1/10 ice cover over higher ice cover in two other surveys. The total amount of ice cover was low in all surveys, consisting mostly of small pieces and distributed primarily in northern Admiralty Inlet. The association with ice may be limited to more continuous types of ice cover (Finley 1976. Silverman 1976).

Abundance Estimates

Previous estimates of narwhal in Admiralty Inlet based on visual aerial surveys have ranged from 1473 to 9683. Koski (1980b) obtained the lowest estimate in September 1979. That survey covered most of Admiralty Inlet but was conducted during rough sea state conditions and likely resulted in an underestimate. Koski and Davis (1979) estimated 7000 narwhal from a survey on 24 August 1978. Fallis _et al_. (1983) estimated 9683 narwhal in Admiralty Inlet for a survey of the southern half of Admiralty Inlet on 28 July 1975, but estimated only about 3000 narwhal during more extensive coverage on August 9 and 10. On 14 and 15 August 1976, Fallis _et al_. (1983) obtained estimates of 1600 and 1500 narwhal from surveys in the southern and northern segment of Admiralty Inlet respectively. Fallis _et al_. (1983) suggested that the estimate of 9683 narwhal obtained in their study was not an anomaly, based on the corroborative evidence of the Koski and Davis (1979) estimate, and suggest that Admiralty Inlet may be used by a substantial proportion of the Canadian Arctic narwhal population during the open water period.

Although not strictly comparable because of differences in survey timing, design and techniques, the extremes in reported estimates suggest there may be annual variability in the numbers of narwhal utilizing Admiralty Inlet.

Estimates of numbers obtained in his study fall nearly in the middle of the range of previous estimates (Fallis et al. 1983, Koski 1980b, Koski and Davis 1979). High clumping factors due to the distribution of narwhal over relatively few sampling frames resulted in large confidence limits, especially for 1985 surveys. Because of differing survey conditions and/or survey coverage obtained for different surevys, estimates of total numbers for each year are best represented by August 18 1983, August 23 1984, and August 14 1985. These estimates range from 2306 (1244-4277) in 1983, 5220 (3104-8780) in 1984, to 5619 (2819-11,200) in 1985. Both the 1984 and 1985 surveys represented most of the census area whereas the 1983 survey represented less than one third of the census area. If the estimate for 1983 is low due to the lower coverage, then the variability in estimated numbers between years is less than previous studies suggest.

There is no clear reason for annual variability in narwhal numbers from the existing data. Fallis et al. (1983) imply that the variation could be a function of survey timing. They found large discrepancies in estimates between 28 July 1975 and 9 and 11 August 1975 surveys. They suggested that narwhal had moved out of Admiralty Inlet between surveys. This study from 1983 to 1985 did not show movement or large presence of animals in the northern region of Admiralty Inlet in any surveys in August and Koski and Davis (1979) found large concentrations in

Admiralty Inlet well into late August. Movement out of Admiralty Inlet is generally thought to occur in late August and September (Bissett 1970, Johnson _et al_. 1976, Koski and Davis 1979, 1980).

Ice conditions in the spring may influence movements and distribution of narwhal entering Lancaster Sound (Koski and Davis 1980, Koski 1980b, Finley and Gibb 1982). An ice edge in Lancaster Sound east of Admiralty Inlet (Fig. 4) delays breakup in Admiralty Inlet by as much as several weeks (Lindsay 1977, 1982, Marko 1982). Koski (1980b) and Koski and Davis (1980) indicate that low numbers of narwhal recorded in 1979 may have been a result of persistent fast ice in Lancaster Sound disrupting normal distribution patterns. They cite atypically high numbers of narwhal in the same year summering in Eclipse Sound as well as in areas not previously recorded to support this hypothesis. Fallis _et al_. (1983) also indicated that their low estimate in 1976 corresponded to a late breakup whereas their high estimate in 1975 corresponded to an early breakup. In this study, a progression from a late breakup to an early breakup from 1983 to 1985 also corresponded with an increase in the estimate of total numbers of narwhal each year. However, the difference in survey coverage especially between 1983 and other years, is likely at least partially responsible for the difference in estimates between years.

Survey Precision and Accuracy

Aerial surveys have greatly improved estimates of narwhal over land-based counts, mainly by providing a measure of the offshore component of the population not previously available. However, as

Caughley (1974) indicates in reference to visual aerial surveys, aerial surveys are at best a rough method of estimating the size of a population and are characterized by problems both with precision and accuracy. Precision is largely a sampling problem in combination with the distribution of animals and is addressed primarily through increased survey coverage and appropriate survey design while survey accuracy is essentially a question of animal sightability and counting biases (Jolly 1969, Caughley 1974, 1977, Eberhardt et al. 1979).

In terms of survey precision, the financial costs associated with assessment of animals over extensive areas usually limit survey coverage and researchers are left with the task of designing good surveys. A randomized sample is generally considered to provide a less biased estimate of numbers (Cochran 1977) but systematic surveys are frequently used (Leatherwood 1979, Barham et al. 1980, Stirling et al. 1982, Smith et al. 1985) because they are more convenient to conduct and reduce the chance of aircraft disturbance affecting counts in adjacent transects since transects are never as close as would occur in a random sample (Eberhardt et al. 1979). Systematic surveys may be as, or more efficient than random ones if the distribution of animals is random or if there is a trend in distribution across the survey area (Kingsley and Smith 1981). Systematic surveys are less efficient if distribution is periodic in relation to the orientation and spacing of transects (Kingsley and Smith 1981), such as if whales are distributed along certain depth contours and sampled by transects parallel to these contours. There was no evidence to indicate a periodic distribution from north to south across the survey area in this study. Transects were oriented perpendicular to the main orientation of the study area so that any distributions associated with depth or distance from shore would not bias the analysis.

Estimates of standard error used for random samples are often also used in systematic surveys and underestimate the precision of density and population (overestimate the standard error) (Kingsley and Smith 1981). A low order serial difference estimator of the standard error was used in this study in an attempt to provide a more realistic estimate of the confidence limits of the population. The serial difference estimator is intended to provide greater precision when counts in adjacent transects are correlated and the same precision when uncorrelated (Kingsley and Smith 1981).

No attempts have been made to address the issue of survey accuracy in previous narwhal surveys. Consistent counting errors of animals at the surface during visual aerial surveys leading to inaccurate results could occur in two ways. First, when large numbers occur over a small area or unit of time, observers are forced to estimate numbers rather than directly count them. Second, if there are problems in defining or measuring the transect strip, observers may count animals which are off-transect or ignore animals which are on-transect.

Counting biases which result in undercounting of animals are considered the major problem of visual aerial surveys (Caughley 1974). Sightability of narwhal is affected by the characteristics of the habitat and the conspicuousness of the animal and determines the probability that an animal will be seen by the observer when it is in the sampling area (Caughley 1974). Narwhal are not particularly well suited for either visual surveys or aerial photography. They are dark colored as young and immature animals and do not contrast strongly with the dark background of the water. However, the water they frequent is usually very clear so there is little problem with turbidity. A certain number are missed because they are submerged beyond visibility.

Sources of bias have been examined in controlled surveys of kangaroos and sheep for which aircraft altitude, transect width, aircraft speed, and observer experience have been shown to significantly effect the counts of target species (Caughley et al. 1976). Except for observer effect, these factors affect counts mainly by changing the size of the area sampled or the time available to sample a given area. Fallis et al. (1983) indicate the problems involved in defining the transect width in a helicopter. Since no struts are available to line up markings on the strut with window markings, the transect width for helicopter surveys can only be roughly estimated with a single pair of markings on the window (Fallis et al. 1983, Smith et al. 1985). Sightability of animals is likely reduced with increased distance from the observer although the nature of the relationship, especially across a transect viewed at an angle from the aircraft, is not known (Caughley 1974, Eberhardt et al. 1979).

All previous studies indicated that a certain unknown proportion of submerged narwhal were missed because they were submerged beyond visibility of the observer. The aspect of animal behavior is a bias common to both visual and photographic aerial surveys. For visual surveys in which the sample area is viewed at an angle, the effect of submerged whales is particularly important because visibility into the water column is minimal so that animals submerged for even short periods could be missed. For aerial photographic surveys, narwhal which engage in deep dives below the visible region of the water column are not detected. The results of this study indicated that the proportion of animals out of sight is highly variable. The best estimate of the proportion of narwhal visible during aerial surveys was 0.38, based on the mean surface and deep dive times of observed narwhal. The 95% confidence limits of surface and deep dive times suggests the proportion visible falls somewhere in the range of 0.29 to 0.52, equivalent to a correction factor for surveys in this study ranging from 1.9 to 3.4.

In general, aerial photographic techniques avoid many of the problems associated with visual surveys. For at least some species, photography has been shown to result in higher counts of animals than visual techniques (Sinclair 1972, Bell _et_ _al_. 1973). Most of the biases in visual surveys are reduced or completely bypassed in photographic surveys, except for the bias imposed by behavior of the animal. Counting errors due to time constraints are eliminated, while photographs provide accurate measures of area, avoiding problems of variable sightability across the transect. Sightability of animals in glare areas of photographs may be reduced, but can corrected for by removing glare areas from the estimate. Because of the clarity of the water, submerged animals from this vertical platform should be less susceptible to being missed, except for those on deep dives or when water surface conditions are rough. Rough sea states were encountered during some surveys in this study and likely resulted in corresponding low counts and estimates of total numbers.

Conclusions

Estimates of the total number of narwhal visible in 1983, 1984, and 1985 are best represented by the results obtained for the second systematic survey conducted each year. Important areas of distribution during the mid open water period appear to be the west side of Admiralty Inlet north of Yeoman Island and south of Strathcona Sound and the areas near the mouths of Adams and Strathcona Sound. The results of behavioral observations of narwhal suggest that estimated numbers should be at least doubled to account for animals engaged in deep dives. Application of this correction factor provides estimates of total numbers in Admiralty Inlet of 4612 for 1983, 10,440 for 1984 and 11,244 for 1985. However, two problems suggest that caution should be used in applying this correction factor. First, potential biases in observations of narwhal indicate that the estimate of proportion visible may not be sufficiently representative to warrant use even of the lower range of the estimated correction factor. Second, the correction factor is based on an average measure of behavior and may not be representative of a specific point in time (or relatively short period) such as the aerial surveys. This study indicated that there were temporal, tidal, and location differences in behavior. Future work in correcting survey estimates for out-of-sight animals should take such variability in behavior into account.

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