Environmental
Studies
Research
Funds

134 Study of Summer and Fall Movements and Dive Behaviour of Beaufort Sea Belugas, using Satellite Telemetry: 1992 – 1995

Canadä

March 1997

ENVIRONMENTAL STUDIES RESEARCH FUNDS

REPORT NO. 134

MARCH 1997

Study of Summer and Fall Movements and Dive Behaviour of Beaufort Sea Belugas, using Satellite Telemetry: 1992-1995.

P.R. Richard[1], A.R. Martin[2], and J.R. Orr[1]

[1]Fisheries & Oceans,
Resource Management Division
FWI, 501 University Crescent,
Winnipeg, MB, R3T 2N6

[2]Sea Mammal Research Unit
c/o British Antarctic Survey
High Cross Madingley Road
Cambridge CB3 0ET
United Kingdom

Scientific Advisor: Pierre R. Richard

The correct citation for this report is:

Richard, P.R., A.R. Martin and J.R. Orr. 1997.
Study of Summer and Fall Movements and Dive Behaviour of Beaufort Sea Belugas, using Satellite Telemetry: 1992-1995.
Environmental Studies Research Funds No. 134. Calgary. xx p.

The Environmental Studies Research Funds are financed from special levies on the oil and gas industry and administered by the National Energy Board for the Minister of Energy, Mines and Resources, and by the Northern Affairs Program for the Minister of Indian Affairs and Northern Development.

Published under the auspices of the
Environmental Studies Research Funds
ISBN 0-92162-39-9

TABLE OF CONTENTS

List of Tables ii

List of Figures ii

Acknowledgements iii

Executive Summary iv

Résumé v

1.0 INTRODUCTION 1

1.1 Background 1
1.2 Study questions and hypotheses 2

2.0 METHODS 5

2.1 Study area 5
2.2 Local consultation 5
2.3 Capture Methods 5
2.4 Tagging procedure 7
2.5 Tag description and data acquisition 7

3.0 RESULTS AND DISCUSSION 13

3.1 Field work 13
3.2 Transmitter longevity 13
3.3 Habitat use 15
3.4 Fall migration and stock identity 19
3.5 Sources of bias in aerial surveys 21

4.0 CONCLUSIONS 25

5.0 REFERENCES 27

6.0 APPENDIX I 29

7.0 APPENDIX II 34

LIST OF TABLES

Table 2.1: Description of the tag duty cycles 10

Table 3.1: Details on live-captured belugas in the Mackenzie Delta, 1993 and 1995....... 14

LIST OF FIGURES

Figure 2.1: Study area and placenames 6

Figure 2.2: A- Hoop net capture, July 1993; B- Seine net capture, July 1995 8

Figure 2.3: A- Double-tube tag design and attachment used in 1993 and some of the 1995 tags; 9
B- Single-tube tag design and attachment used on 12 of the 1995 tags 9

Figure 3.1: Individual tracks of tagged belugas A-1993; B- 1995. Circles are best daily position near 7:00 AM local time (M=closed circles, F = open circles). Different weeks (Sat-Fri) are represented by alternating solid and broken lines. Tracks begin with a square and end with a triangle 16

Figure 3.2: Examples of: A- square-shaped dive, B- V-shaped dive.................... 18

Figure 3.3: Boundaries of the 1992 survey strata.................... 20

ACKNOWLEDGEMENTS

The project was funded by the Environmental Studies Research Funds (ESRF), the Fisheries Joint Management Committee (FJMC), the Department of Fisheries & Oceans (DFO), and the Sea Mammal Research Unit (SMRU).

We are indebted to the FJMC and the Hunter and Trappers Committees (HTC) of Inuvik, Tuktoyaktuk and Aklavik for their continued support and assistance in this project, in particular Robert Bell, Billy Day, Matt Stabler, Debbie Anderson, Joey Amos and Ella Jean Nogasak. The herding and live-capturing of belugas were successful because of the knowledge provided by Hugh Rogers, the late Henry Chicksi, Norman (Shepard) Felix, Ricky Joe, David Roland and Randy Pokiak (and his family), and their assistants Glen Angasuk, Chris Felix, Roy Kimiksana, Walter Selamio, Roy Ipana and John Roland. Garry Raddi, Larry Angasuk, Pat Kasook, Freddie Rogers and the late Narcisse Capot-Blanc skillfully navigated the capture boats. We are grateful to the Polar Continental Shelf Project (PCSP) for their aircraft and logistic support and we especially thank the base managers Claude Brunet and Jerry McEachern for their patience and understanding. Ollie Cox, Phil Lovell, Bernie McConnell and Colin Hunter (SMRU) are the technical wizards behind the satellite-linked tags and were very helpful in many ways to the project. Thanks also to Sylvain De Guise (Université du Québec à Montréal), David St. Aubin (Mystic Marinelife Aquarium), Clint Wright (Vancouver Aquarium), Jim Robinette and Dave Lonsdale (Schedd Aquarium), William Day, Tommy Chicksi and Neil Robinson (DFO), Marc Dufresne and François Roy (Institut national d'écotoxicologie du Saint-Laurent) and Harvey Johnson and Ron Beck (Lethbridge Community College) who volunteered their help in the field. We thank Patt Hall (DFO) for her participation in the 1994 field work, her support in handling the contract and liaison with Service ARGOS and the ARGOS Global Agreement. Thanks also to Gilly Banks and Mandy Lisle (SMRU) for their cheerful help on many matters. Finally, we thank Stuart Innes and Patt Hall for their comments on earlier drafts of the report.

EXECUTIVE SUMMARY

We conducted a study of Beaufort Sea belugas, involving tracking and recording dive behaviour using satellite-linked time-depth recorders between July 1992 and December 1995. The project took in total four years of field and lab work and analysis. This report describes the project's methods and highlights its most important results. More detailed scientific papers on various parts of the study will be published subsequently.

With the help of hunters from Inuvik, Tuktoyaktuk and Aklavik, fourteen males and six female belugas were live-captured using hoop nets and seine nets and "tagged" in the delta of the Mackenzie River, Northwest Territories, Canada. Satellite-linked time depth recorders and transmitters ("tags") were used to obtain detailed behavioural data to study migration routes to summer and winter concentration areas, to understand the effect of beluga movements and diving on population estimates based on aerial surveys, and to study habitat preferences and habitat use.

The amount of data obtained from each tag varied because some tags did not last long due to instrument failures or software problems but the data was sufficient to reach all of the goals of the study. The results showed unsuspected behaviour on the part of Beaufort sea belugas. Most male belugas moved to M'Clure Strait and Viscount Melville Sound soon after being tagged. Most females remained within the southern part of eastern Beaufort Sea and in Amundsen Gulf. Fall migration routes into Alaskan waters were obtained from three animals. One other beluga crossed the Arctic Ocean, ultimately reaching the East Siberian Sea, which suggests an alternate fall migration route for some animals, and that Beaufort Sea belugas can be subject to fall hunts in Alaska and Siberia. All animals made dives to depths of 400-600 m, some as deep as 1160 m. Our results suggest that 1992 Beaufort population estimates based on belugas seen at the surface may have been negatively-biased severely both by whale movements and diving behaviour. The results also put in question previous summaries of Beaufort Sea beluga ecology. Beaufort Sea belugas are not limited to shallow or ice-free waters in summer, and are capable of moving rapidly through heavy pack ice. In addition, our observations of repeated deep dives to the seabed, refute assumptions that belugas are mainly pelagic feeders.

RÉSUMÉ

Entre juillet 1992 et décembre 1995, nous avons effectué une étude de suivis télémétriques et d'enregistrements de plongées des bélugas de la mer de Beaufort. Ce projet a pris quatre ans de travail sur le terrain et de travail de laboratoire et d'analyse. Le rapport décrit les méthodes utilisées et met en évidence les résultats les plus importants. Des articles scientifiques portants sur les différentes parties de l'étude seront publiés par la suite.

Avec l'aide de chasseurs d'Inuvik, de Tuktoyaktuk et d'Aklavik, nous avons capturé dans le delta du fleuve Mackenzie quatorze mâles et six femelles bélugas avec des filets cerceaux et des seines. Nous les avons équipés d'instruments de mesures des plongées reliés à des balises-satellites. Ces instruments ont servi à obtenir de l'information détaillée sur le comportement de ces bélugas afin d'étudier leurs migrations vers les aires de concentration estivale et hivernale, de comprendre l'effet du comportement sur les estimations de population obtenus à partir d'inventaires aériens et d'étudier leur choix d'habitats et l'utilisation qu'ils en font.

La quantité de données obtenues a été assez variable car certains instruments ont souffert de bris et de problèmes de logiciels. Cependant, elle a été suffisante pour atteindre tous les buts de l'étude. Les résultats démontrent des comportements inattendus chez les bélugas de la mer de Beaufort. Peu de temps après avoir été relâchés, la plupart des mâles se sont acheminés vers les détroits de M'Clure et du Vicomte-Melville. La plupart des femelles sont restées dans la partie sud-est de la mer de Beaufort et dans le golfe d'Amundsen. On a pu observer la migration de trois bélugas vers les eaux Alaskiennes. Cependant, un quatrième béluga a traversé l'océan Arctique pour se rendre dans la mer de Sibérie orientale, ce qui laisse supposer un second chemin migratoire pour les bélugas de la mer de Beaufort. On pense donc que cette population pourrait subir une chasse automnale en Alaska et en Sibérie. Tous les bélugas ont effectué des plongées à des profondeurs de 400-600 m, certaines de 1160 m. Nos résultats laissent supposer que la population de la mer de Beaufort a été largement sous-estimée par les décomptes de bélugas en surface lors de l'inventaire aérien de 1992 à cause de leurs comportements migratoires et de leurs plongées. Enfin, nos résultats mettent en doute les généralisations faites dans le passé sur l'écologie des bélugas de la mer de Beaufort. Ces bélugas ne sont aucunement limités aux eaux peu profondes ou libres de glaces en été. Ils sont capables de migrations rapides à travers un pack dense. De plus, leurs plongées répétées sur des fonds à grandes profondeurs contredisent les hypothèses que ce sont principalement des prédateurs pélagiques.

1.0 INTRODUCTION

1.1 Background

The Environmental Studies Research Funds, the Fisheries Joint Management Committee, and the Department of Fisheries and Oceans sponsored a workshop concerning Beaufort Sea beluga (Duval 1993). One of the goals of the workshop was to define research priorities for research funding in the following years. Participants agreed that a study of beluga behaviour using satellite tagging was a research funding priority. They felt that such a project could address "outstanding issues of Beaufort Sea beluga management: movements of individuals through Canadian, Alaskan and Siberian waters; movements of individuals between provisional Alaskan stock boundaries; survey correction factors such as the proportion of time at surface in various habitats and at various seasons; and feeding inferences".

In the past, eastern Beaufort Sea beluga behaviour, range and migration routes were deduced from local knowledge, land-based observations and opportunistic or planned aerial surveys. Several of these studies were components of larger environmental studies for energy projects. Local knowledge is extensive in time but is limited by the range within which local people travel and know well. Land-based observations can also cover a long time frame but they are again limited by the range of observers, a few kilometers. Aerial surveys are not limited in range but rather in time. They are very expensive and therefore not often repeated. Consequently, aerial survey give only occasional snapshots of beluga distribution (usually only when they are concentrated) and give few cues on their behaviour and ecology. In all cases, we get only information on the geographic position of animals but belugas move in a three dimensional environment. A novel approach was needed to understand in greater detail the short-range and long-range movements of eastern Beaufort Sea belugas and their diving behaviour.

Biologists have used satellite-linked transmitters for over a decade to study land mammal behaviour (Harris et al. 1990) but attempts to use this tool on whales were not successful until the late 1980s owing to the efforts of a handful of private and public research laboratories. One of these labs, the Sea Mammal Research Unit, has provided the instruments that we used in this study. Satellite telemetry is expensive but it gives us an insight on beluga behaviour and ecology which would have been impossible to get otherwise.

Detailed behavioural data of Beaufort Sea belugas was needed specifically:

1) to study their migration routes between summer and winter concentration areas (for stock assessment);

2) to understand the effect of beluga movements and diving on population estimates based on aerial surveys (for stock assessment);

3) to study habitat preferences and habitat use (for habitat protection).

Eastern Beaufort Sea belugas were thought to summer only in the Mackenzie Delta and surrounding waters of the eastern Beaufort Sea and Amundsen Gulf before undergoing a migration through Alaskan waters to the Bering Sea where they are presumed to spend the winter (Fraker 1980). We used the results of this study to investigate the fall migration routes of Beaufort Sea belugas.

Aerial survey estimates are based on surface counts of belugas. Beluga movements and diving behaviour can bias the counts of a survey. The results of this study are used here to investigate different types of biases: biases due to movements out of surveyed areas and those due to movements within them, and biases due to diving behaviour.

To date, much emphasis in the study of belugas has been on the species' summer estuarine and coastal habits, including their feeding on anadromous and coastal-spawning fishes, such as capelin, herring, saffron cod, charr and whitefish (Doan and Douglas 1953, Sergeant 1973, Finley et al. 1987, Brodie 1989, Frost and Lowry 1990). Belugas have been said to prefer loose ice to heavy pack (Finley et al 1982; Mclaren and Davis 1982) and heavy ice has been hypothesized to act as a barrier to beluga movement across the central Arctic (Sergeant and Brodie 1975). The beluga is often contrasted with the narwhal which is known for its deep water, bottom-feeding and ice-loving habits (Mansfield et al. 1975, Mclaren and Davis 1982). We used the results of this study to characterize habitat use and preferences exhibited by Beaufort Sea belugas, to ensure that critical habitats are protected.

1.2 Study questions and hypotheses

To address these issues, we asked specific questions in the context of the data we expected our telemetry instruments to collect. We then used these questions to develop testable hypotheses as follows.

a) **stock identity:** (given the fall movements of belugas) Which communities or hunting camps of the Alaskan Beaufort Sea and Alaskan and Russian Chukchi Sea, Bering Sea or East Siberian Sea could potentially hunt belugas originating from the Canadian Beaufort Sea?

Hypothesis: Eastern Beaufort Sea belugas range to waters along the above mentioned coasts and therefore may come within the normal fall hunting range of Alaskan and Russian hunters.

b) **bias to survey estimates due to movements:** (given the July movements of beluga) How mobile are belugas during aerial surveys for population size estimation? This question was broken down into three questions:

1. Since the 1992 Beaufort beluga survey (Harwood *et al.* in press) was done in several blocks of daily effort, was the movement of beluga likely to cause shifts in concentrations along or against the direction of a multi-day survey thereby causing overestimates or underestimates of abundance?

Hypothesis: The average daily movements of individual belugas within the survey area in July are less than the distance between geometric centers of the 1992 Beaufort survey strata.

2. Was the movement of belugas within a stratum likely to cause shifts in concentrations along or against the direction of survey?

Hypothesis: The average speed of individual belugas within the survey area in July allow movements that are shorter than the distance between 1992 survey transects.

3. Could there be any movements outside the area to be surveyed?

Hypothesis: Movement of individual belugas are confined to the 1992 survey strata.

c) **bias to survey estimates due to diving behaviour :** (given the diving behaviour of beluga in the Canadian Beaufort in July) Are survey estimates large underestimates as assumed at the Vancouver workshop?

Hypothesis: The mean proportion of time beluga are visible to aerial observers differs from the 50% assumed in the Vancouver workshop's estimate of population size.

d) **habitat use:** (given the movements and diving behaviour of beluga in summer and fall) Which portions of the water column are being used by beluga in which areas of the Beaufort Sea and in what proportion of total time?

Hypothesis: Belugas spend most of their time diving in mid-water.

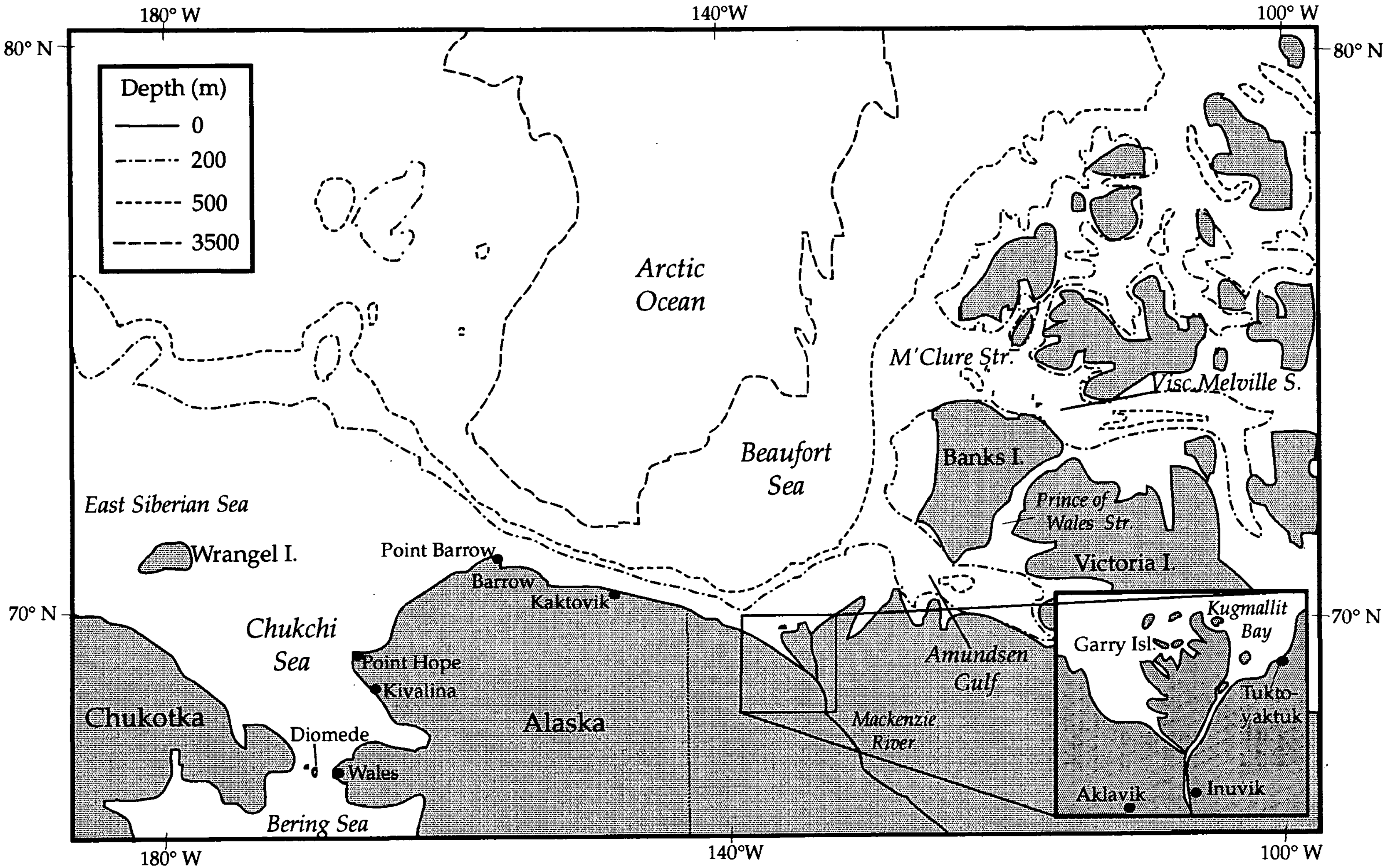


Figure 2.1: Study area and placenames.

2.0 METHODS

2.1 Study area

We captured belugas in the delta of the Mackenzie River, Northwest Territories, Canada (Fig. 2.1). The tagged belugas defined the study area by their movements through the Mackenzie Delta and out into the eastern and western Beaufort Sea, the western portion of the Canadian Arctic archipelago, the Chukchi Sea, the Arctic Ocean, and the east Siberian Sea.

The Mackenzie Delta is a shallow estuary (max. depth ≤ 20 m). The neighbouring Amundsen Gulf, M'Clure Strait and Viscount Melville Sound are comparatively deep bodies of water (max. depths ≤ 600 m). The Beaufort Sea is composed of a shallow continental shelf (≤ 200 m) and of a shelf break, 100 to 150 km from the coast, where the bottom drops to the 3000-4000 m depths of the Arctic Ocean (Fig. 2.1). The Chukchi Sea and east Siberian Sea are also shallow seas but the shelf there is much wider, reaching 600 to 700 km from the coastline.

Thick permanent pack ice (≥ 9/10) covers the Arctic Ocean and the seaward portion of the Beaufort Sea (Appendices. I-II). The coastal waters of the Beaufort Sea, Amundsen Gulf and M'Clure Strait are partially covered with ice and gradually lose it during the months of July and August. Viscount Melville Sound is also partially open by mid-August. By mid-September, both M'Clure Strait and Viscount Melville Sound are covered with new ice. The coastal waters of the Beaufort Sea and the whole of Amundsen Gulf remain open well into November.

2.2 Local consultation

Before each field season, we consulted representatives of Inuvik, Tuktoyaktuk and Aklavik Hunters and Trappers Committees (HTCs). We described the objectives of the study, proposed capture methods and discussed local participation, potential capture sites and timing of the field work. The Inuvik and Tuktoyaktuk HTCs chose people to assist in the live-captures. There was continued discussion between field staff and the herding crews. We shared opinions about beluga behaviour, capture methods, capture sites and other topics and we made decisions by consensus. While at the hunting camps, field staff discussed the project with hunters present.

2.3 Capture methods

Methods of capture were modified slightly with locations and year, reflecting our increasing experience. In general, we first located whales from land or from boats. Belugas deemed suitable for tagging were slowly herded into shallow waters (≤ 2 m) by the herding crews composed of 4-11 widely separated boats remaining 50-70 m behind the whales. As the whales came closer to the shallows, boats moved in closer to reduce their chances of escape. Once in the shallows, the capture boats would break away from the herding boats and position themselves alongside the whale in order to net it. We used two types of nets: a 1.2 m diameter metal hoop with a pursing 1 m net and a 150 m 30 cm mesh dark-green net with lead and float lines.

The hoopnet method requires a minimum of three people and one inflatable boat. One person places the hoop net around the head of the whale as it surfaces. The others assist in restraining the netted beluga and secure it with a tail rope (Fig. 2.2A). The beluga usually stops struggling within a few minutes. In the second method, the surrounding seine net is deployed by circling the boat at high speed around the target belugas and corralling them inside. Capture boats circle around the net opening to ensure that whales do not escape escaped from the rear. Belugas hit the net and are quickly surrounded by the other boats. We restrain them with a hoop net and tail rope as above (Fig. 2.2B) to ensure that they do not get excessively tangled and are able to breathe.

2.4 Tagging procedure

Once secured, we measured and determined the sex of each animal and took a small skin biopsy for genetic studies. We fitted them with a flipper identification band (Orr and Hiatt-Saif 1992), and in 1995, a licensed veterinarian took blood samples to assess their physiological state and health of each beluga at the time of capture. We then attached a satellite transmitter to the dorsal ridge, secured by two straps of flexible belt material laid transversely on each side of the whale (Fig. 3). Each strap was held in place with four 6 mm diameter nylon pins, inserted into the dorsal ridge and out through the strap on the other side and held in place by nylon nuts and washers. The handling time for each animal, including attachment of transmitters, averaged 40 min.

The dorsal ridge of belugas consists of a ridge of skin, connective tissue and blubber that has few nerve endings or blood vessels. Dorsally attached transmitters cause no visible discomfort to the whale during attachment and, according to post-release observations which span several weeks, do not appear to affect subsequent behavior. The pins slowly migrate caudo-dorsally through the tissue over the months, eventually allowing release of the whole package.

2.5 Tag description and data acquisition

During this study, we used two types of transmitter housings. Both employed anodised aircraft–grade aluminum tubing to protect the instrumentation and batteries from the effects of water leakage and pressure. The earlier design, used in 1993 and 1995, had two tubes linked together with a bridge (Fig. 2.3A). The later model used also in 1995 had a single, slightly longer tube to reduce drag (Fig. 2.3B). In both designs, metal end–caps fitted with 'O' rings sealed the tubes and the whole unit was pressure–resistant to 2000 m (6,600 ft).

All transmitters were of the same basic structure, consisting of a housing, sensors to collect information, an antenna, lithium batteries, circuitry to produce the signal itself, and a micro–processor programmed to control the sensors, collect and compress data, and trigger the transmitter at each surfacing.

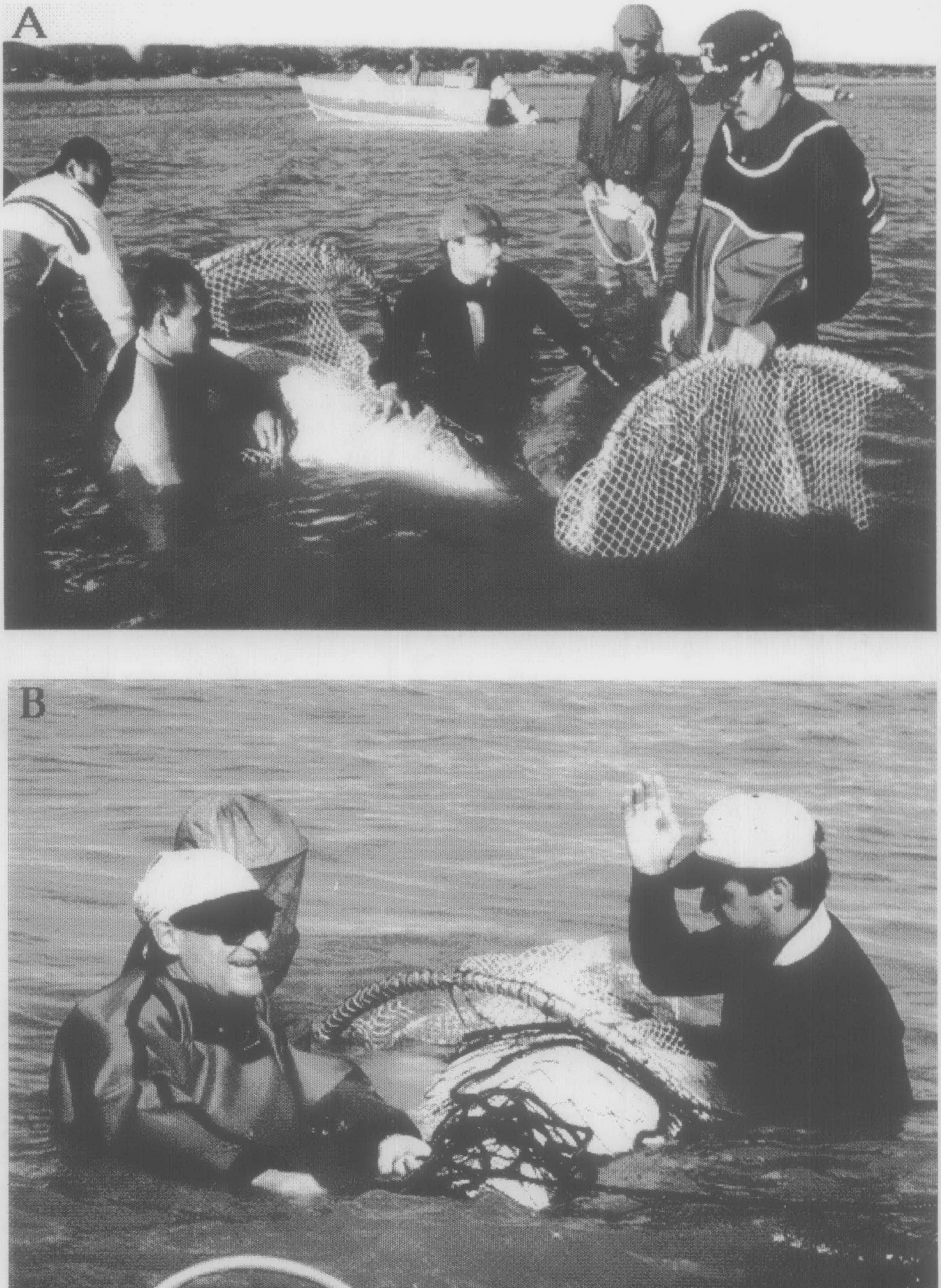


Figure 2.2: A-Hoop net capture, July 1993; B-Seine net capture, July 1995.

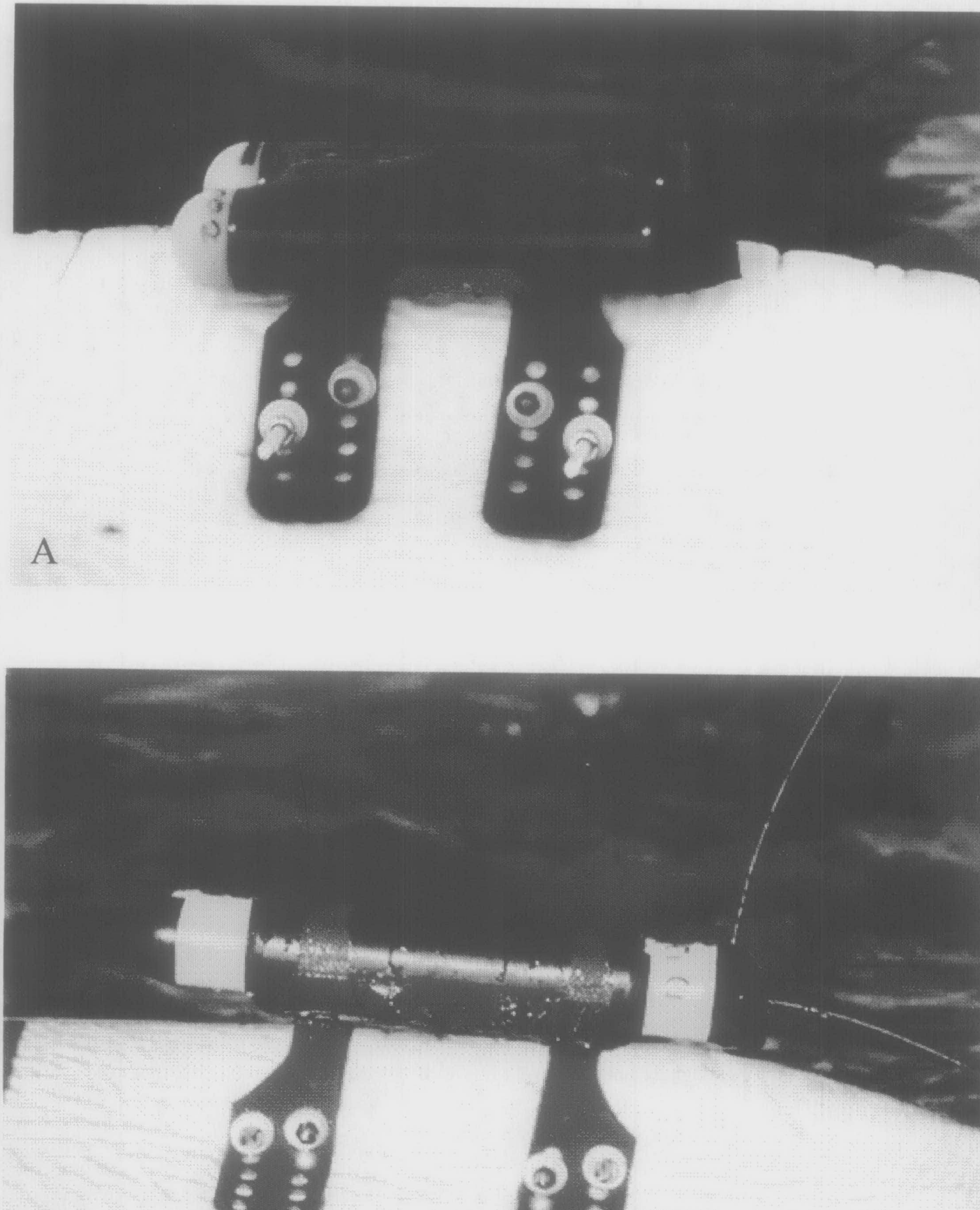


Figure 2.3: **A**- Double-tube tag design and attachment used in 1993 and some of the 1995 tags; **B**- Single-tube tag design and attachment used on 12 of the 1995 tags.

In 1993, to save battery power loss, we programmed the tags to work on a duty cycle (Table 2.1). The tags worked full time for the first two week period to gather as much dive data as possible, then they progressively dropped in activity as time elapsed. With such a schedule, we used the most power initially when the probability that the tags were working was highest. We used less power in later months, when there was a greater chance of tag loss or damage.

In 1995, we experimented with two methods of conserving battery power. We programmed eight tags to collect data when the belugas were most likely to be within the delta. The tags were programmed to work full time in the first 30 days, then to move to a one-day-on/one-day-off cycle until their batteries were exhausted. The eight remaining tags gave priority to collecting data over the longest possible period of time by gradually decreasing the proportion of time spent switched on.

Table 2.1: Description of the tag duty cycles

Duty cycle	Continuous duty	days of reduced duty	Activity
1	first 15 days	16-21 days 62-91 days	12 hr on - 30 hr off 24 hr on-144 hr off
2	none	all	variable < 24 hr
3	first 30 days	subsequent days	1 day on- 1 day off

The tags started transmitting data every time the belugas surfaced and exposed the instrument's antenna, repeating their transmissions every 40 sec. If a NOAA satellite was overhead at the time, tag positions were calculated by Service ARGOS when three or more transmissions were received by the satellite. The position's latitude and longitude are calculated from the difference in signal frequency between repeated signals while the satellite was passing overhead a transmitter (Anonymous 1996).

The satellite also recorded every packet of data transmitted by the tags. The tags collected information about the diving and surfacing behaviour of each whale during the time that the transmitters were functioning. Nevertheless, because satellites were only within view for a small proportion of each day and because transmissions must be separated by at least 40 seconds, it was not possible to receive a complete and detailed record for any whale. To overcome this handicap, we programmed the transmitter to describe diving behaviour in three levels of resolution. We expected to receive enough data of each level to allow reconstruction of the complete timescale by interpolation.

The three levels of resolution were:

1- highest: A sequence of values representing the depth of the animal at fixed intervals (usually 1 minute or 2.5 min.). Each transmission could relay about 30 such values. The main use of this information was to find the profile of dives, which would allow us to infer their likely function.

2- medium: a summary of the characteristics of individual dives (maximum depth, duration and duration of the preceding inter–dive interval). Each transmission could relay the information for ten consecutive dives. This allowed us to relate a large number of dives to the depth of water in which they were made and thereby establish what period of time a whale needed to spend at the surface between dives of a particular length. The shape of the dive and its function can normally be found or inferred from the high resolution data.

3- low: Summary of the duration and maximum depth of all dives over a given period, together with the proportion of time spent in depth bands (e.g. 0–3 m, 3–6 m, 6–10 m etc.). Each transmission described the whale's behaviour over a two–hour period. Having established the type of diving being carried out in each locality using high and medium resolution data, the low resolution information allowed us to see how a day or week or month is allocated to each type of behaviour.

3.0 RESULTS AND DISCUSSION

Results are presented in the following order. First, we describe the live-captures and related field events. Secondly, we present the longevity of each tag and discuss factors influencing their respective performance. Third, in the section on habitat use, we give an overall description of the movements of tagged belugas, relate these movements to water depth and ice cover and describe the type of diving behaviour exhibited in each area. Next we describe the fall movements of the tags that transmitted into the fall period and discusses the implications in terms of stock identity. Lastly, we examine the potential biases of aerial survey estimates that are due to beluga movements and diving behaviour.

3.1 Field work

In July 1992, we scouted the waters of the Mackenzie Delta by boat and helicopter. We made a few attempts at herding whales to determine their basic reactions to the boat and investigated areas for future live-capture sites.

In July 1993, we caught four belugas, three near the northwest end of Garry Island and one in Kugmallit Bay (Table 3.1). Despite many attempts, we were unable to catch additional belugas.

In July 1994, all our attempts to capture belugas proved unsuccessful. The weather was poor that year and the whales seldom came close to the camp in Kugmallit Bay. So we moved the camp to Garry Island, where most of the whales were caught in the previous year. Bad weather continued to hamper our efforts and, even when the weather was good, few whales could be seen in the area or could be herded into the shallows.

In July 1995, we devised a new approach which involved a herding the belugas into water less than 2 m and corralling them in a seine net. This proved to be a very effective method of capturing belugas in the Mackenzie Delta. We captured 24 belugas of which we tagged 16 with transmitters and flipper bands (Table 3.1).

3.2 Transmitter longevity

The longevity of individual tags varied between 7 and 91 days, with most (15) tags transmitting for 30 days or more (Table 3.1). Three of the tags (M93-17006, F95-17006, F95-17008) stopped after a few days for unknown reasons. There is no evidence from the signal strength that loss of battery power was the cause. In 1995, all eight tags of the newer design failed to provide positions after 30 days when they switched from full time transmission to one day on - one day off (Table 3.1) because an ARGOS software problem caused tag data to be ignored by the receiving station's computer. The fact that those eight new tags all lasted 30 days suggests that they would have transmitted longer, had it not been for the ARGOS software problem.

Table 3.1: Details on live-captured belugas in the Mackenzie Delta, 1993 and 1995 (†see table 1; *longevity = days to last position)

Year-no.	Tag no.	Sex	Date capture	Length (m)	Location	Duty cycle†	longevity days*
93-1	17005	M	10-Jul	442	Garry Island	1	11
93-2	17006	M	10-Jul	424	" "	1	28
93-3	17009	F	11-Jul	302	" "	1	34
93-4	17002	M	19-Jul	457	Kugmallit Bay	1	91
95-1	17001	M	3-Jul	427	" "	2	85
95-2	17002	M	4-Jul	404	" "	2	49
95-3	17003	M	4-Jul	432	" "	2	23
95-4	17004	M	5-Jul	373	" "	2	34
95-5	17005	M	5-Jul	353	" "	2	42
95-6	17010	M	9-Jul	399	" "	3	30
95-7	17011	M	9-Jul	402	" "	3	30
95-8	17012	M	10-Jul	404	" "	3	30
95-9	5801	M	11-Jul	406	" "	3	30
95-10	17013	M	11-Jul	402	" "	3	30
95-11	N/A	M	12-Jul	402	" "		
95-12	N/A	M	12-Jul	353	" "		
95-13	17014	F	12-Jul	340	" "	3	30
95-14	N/A	M	12-Jul	221	" "		
95-15	8754	F	13-Jul	363	" "	3	30
95-16	N/A	M	13-Jul	216	" "		
95-17	17006	F	13-Jul	343	" "	2	7
95-18	5800	M	16-Jul	467	" "	3	30
95-19	N/A	M	16-Jul	419	" "		
95-20	N/A	M	16-Jul	406	" "		
95-21	N/A	M	16-Jul	N/A	" "		
95-22	17007	F	16-Jul	373	" "	2	81
95-23	17008	F	16-Jul	361	" "	2	9
95-24	N/A	M	16-Jul	180	" "		

3.3 Habitat use

3.3.1 Movements to different areas

The number of positions varied from day to day for each tagged beluga. Plotting them all gives a false impression that some areas are used more than others because, on some days, we got more positions than on others. To represent a truer image of the daily use of various areas, we plotted each animal's best daily position around 12:00 Greenwich Mean Time (GMT) or 7:00 AM local time.

Fig. 3.1A shows the tracks of the four belugas tagged in 1993. After release, all three 1993 males remained only a few days in the delta and traveled north farther and deeper into the Arctic Ocean than expected based on previous knowledge of their distribution. They reached latitudes ranging from 74°N to 78°N. One of the males (93-17005) then traveled east through M'Clure Strait to Viscount Melville Sound arriving on 27 July. It remained there for 36 days and later returned west through McClure Strait. It continued westward crossing Alaskan waters and its transmissions stopped north of Point Barrow on 9 October. In all, its track covered roughly 2600 km. A second male (93-17006) followed approximately the same northbound track as 93-17005 for about 400 km but its tag stopped transmitting after 10 days. The third male (93-17002), also traveled north but then turned northwest crossing the Arctic Ocean during the early part of August reaching as far north as 78° 43'N on 14 August. It later moved southwest into Russian waters ending transmissions north of Wrangel Island on 22 August, after having covered a distance of roughly 2000 km. The female (93-17009) moved east into Amundsen Gulf on 19 July and remaining there a week. It then returned to the delta where it spent the following week. On 1 August, it made its way back to Amundsen Gulf where its transmissions stopped on 7 August. It covered a total distance of about 1200 km.

Fig. 3.1B shows the tracks of the 16 belugas tagged in 1995. After about a week or less in the delta and surrounding waters, ten males traveled north following similar tracks to the 1993 males. Like male 93-17005 had done two years earlier, all ten moved east into M'Clure Strait and arrived at Viscount Melville Sound in late July. An eleventh male (95-17003) went to Viscount Melville Sound by way of Amundsen Gulf and Prince of Wales Strait. One female (95-17014) also moved north following a similar route to the male tracks but returned to the delta on 24 July after spending a few days above 75°N. The other four females and one male (95-17002) stayed in the delta and surrounding waters and in Amundsen Gulf. Of those four females. three were accompanied by yearlings.

An ARGOS software problem prevented data collection from six of those ten male tags after 30 days. The other four male tags (M95-17001, M95-17004, M95-17005, and M95-17012) remained in Viscount Melville Sound between 6 and 21 days. Three of them returned to the Beaufort Sea or the Mackenzie Delta, one through M'Clure Strait (M95-17001) and two through Prince of Wales Strait (M95-17004, M95-17005).

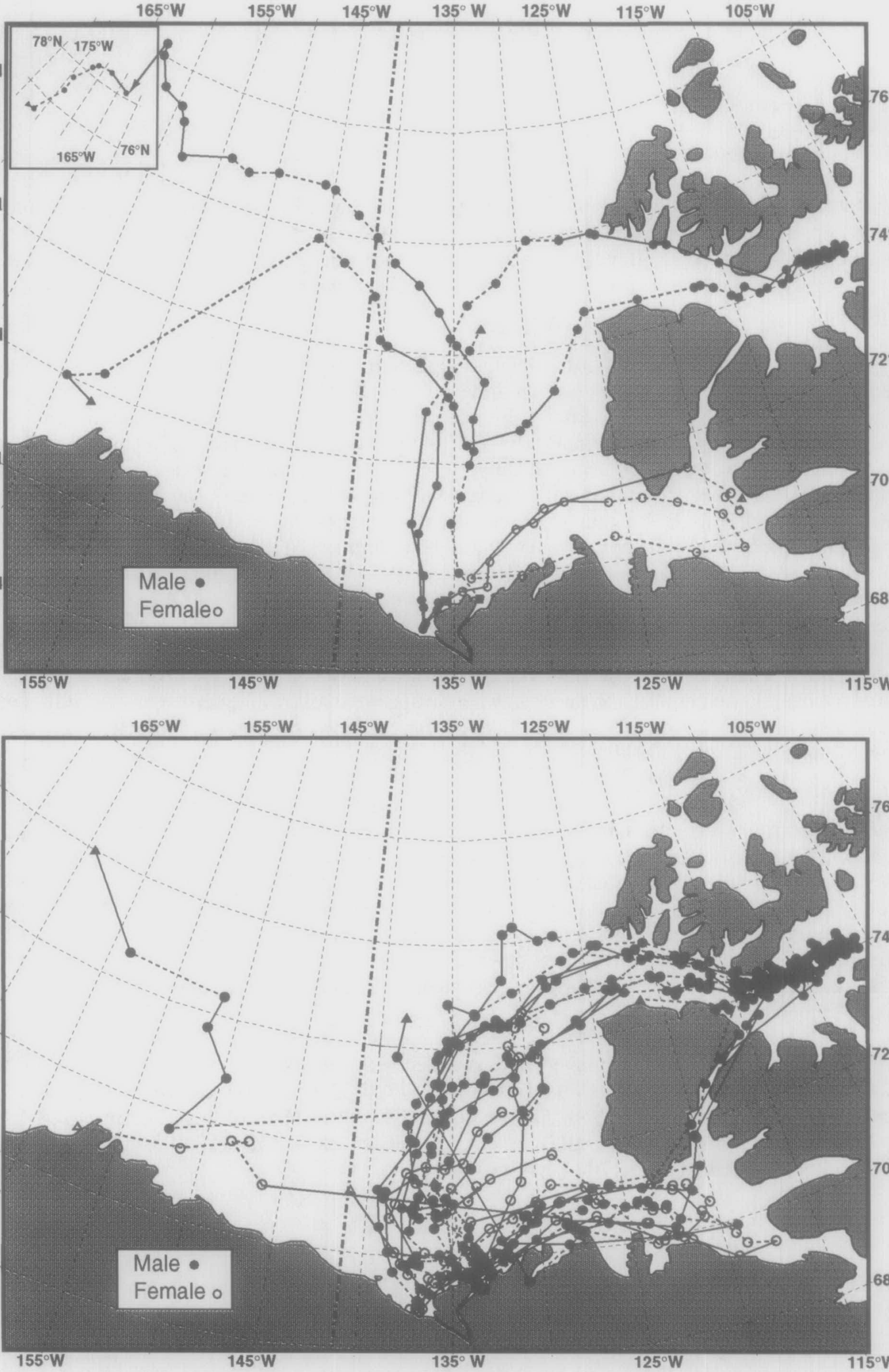


Figure 3.1: Individual tracks of tagged belugas A-1993; B- 1995. Circles are best daily position near 7:00 AM local time (M=closed circles, F = open circles). Different weeks (Sat-Fri) are represented by alternating solid and broken lines. Tracks begin with a square and end with a triangle.

The fourth one (M95-17012) moved out of Viscount Melville Sound into M'Clure Strait but transmissions ended there on 11 August.

Of the transmitters deployed on males, tag (M95-17001) lasted the longest. This whale traveled west to Alaskan waters and then northwest of Point Barrow, ending close to meridian 165°W on 27 September. Of the transmitters deployed on females, tag (F95-17007) was the longest. It also traveled east to Alaskan waters reaching Point Barrow on 23 September.

3.3.2 Movements relative to ice

All but one female stayed in the open water and loose pack of southeastern Beaufort and Amündsen Gulf. Thirteen of the 1993 and 1995 males and one 1995 female traveled through medium (6/10-8/10) and heavy (9/10+) ice in the offshore eastern Beaufort Sea pack. The males did so even when a more open passage to Viscount Melville Sound was available along the west coast of Banks Island (Appendix I: 20 July- 3 August 93; Appendix II: 11 July- 1 August 95). The males also crossed heavy ice (9/10+) in M'Clure Strait and Viscount Melville at the beginning of August.

The 1993 male that crossed the Arctic Ocean (M93-17002) westward to the Siberian Sea did so almost entirely in heavy pack ice (9/10+). Similarly, males 93-17005 and 95-17001 traveled in September through the heavy pack (9/10+) of the offshore Alaskan (western) Beaufort Sea (Appendix I: 28 September 93; Appendix II: 26 September 95).

3.3.3 Movements relative to depth

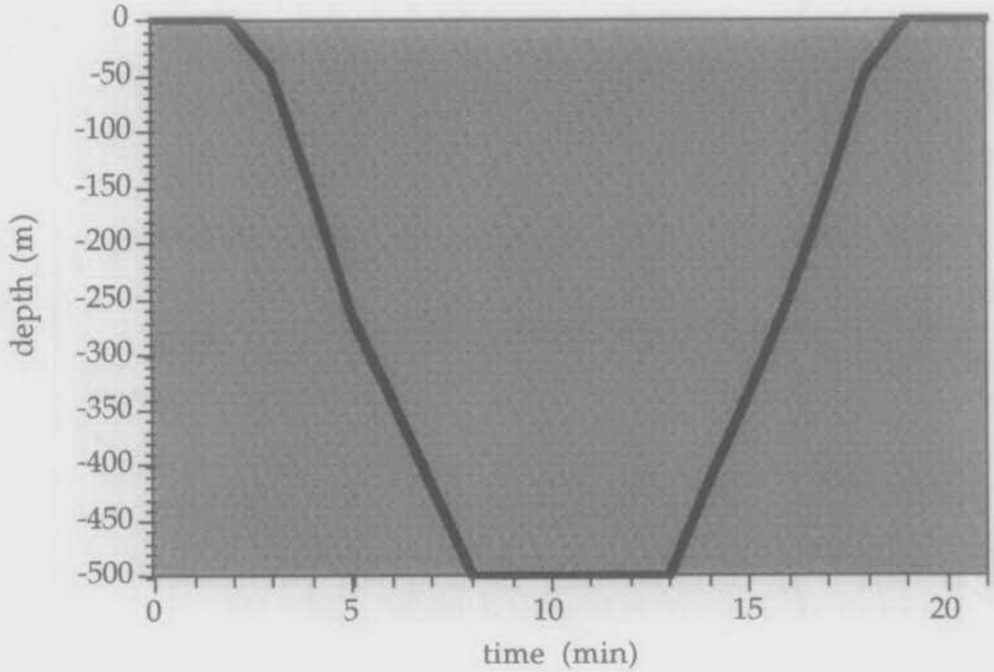
Many of the tagged belugas traveled through very deep waters beyond the shelf break (Fig. 3.1). Several tracks were over waters more than 2000 m deep and some were over waters 3000-4000 m deep. The eleven males that moved into the Arctic archipelago went to the same area of Viscount Melville Sound where there is deep trough of more than 500 m.

3.3.4 Diving behaviour

Because the behaviour of tagged belugas depended largely on water depth, we defined three categories of depth with which to describe their behaviour. Males and females behave similarly, but only males went out into very deep water (i.e. such that they could not reach the seabed).

<u>Shallow water.</u> We defined this as the area within the delta itself and the neighbouring coastal zone. Depths rarely exceed 15 m and tagged belugas spent little time here, staying only a few days after release (see above section on movements). In shallow water, dives of short duration (average < 30 sec) characterize their behaviour . It is not possible to say if feeding took place, but the short time spent there suggests that belugas found deeper water sites more attractive.

A



B

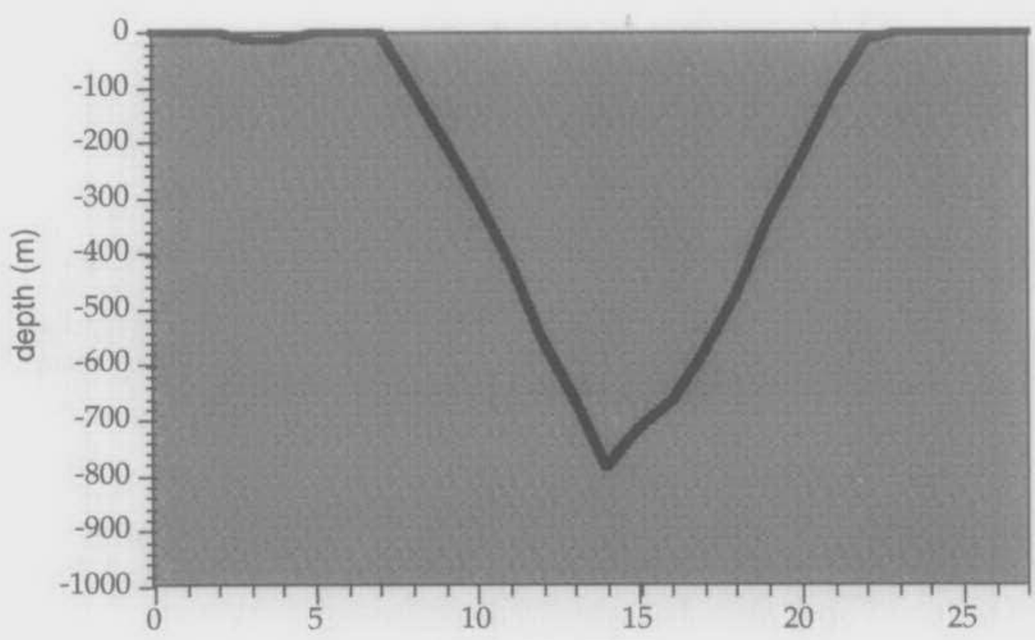


Figure 3.2: Examples of: A-square-shaped daive; B-V-shaped dive.

Medium–depth water. We defined this area as water ranging from 15–600 m deep. There, belugas are able to reach the seabed and spend at least a few minutes on the bottom. This area included all of the shelf areas on the southern and eastern sides of the Beaufort Sea as well as the channels within the Arctic archipelago (Fig. 2.1). This is where both males and females spent most of their time during the summer. Typical behaviour in medium-depth water consisted of square-profile dives of 10–20 min to the seabed, separated by periods of 5–8 min at or near the surface (Fig. 3.2A). Sometimes batches of these bottom dives were separated by long periods (up to several hours) near the surface. We assume that these long and deep dives allow foraging on the seabed.

Deep water. We defined this as water deeper than 600 m. Belugas can reach these depths, but their breathold capacity prevents them staying below this level for more than a few minutes. These depths are found only offshore in the central Beaufort (Fig. 2.1), where the seabed can be greater than 3000 m below the surface. Only males ventured into waters of this depth. There, belugas usually moved rapidly and seemed to be simply moving from one place to another. They spent much of their time in the top 50 m of the water column. Deep dives tended to be very deep and had a characteristic 'V' shape, indicating that the whale reached a maximum depth and then immediately headed to the surface (Fig. 3.2B). We did not see this type of dive elsewhere and its function is not known. It may be related to the heavy ice pack covering these deep waters and the requirement to find small breathing holes in heavy ice. The deepest (1160 m) and longest duration (25 min) dives recorded for belugas are of this type, made by male 95-5800 in July 1995. More typically, belugas reached depths of 700–900 m during dives lasting 15–20 min.

3.4 Fall migration and stock identity

Fraker (1980) hypothesized that the fall migration of Beaufort Sea belugas ran along the Alaskan coast of the western Beaufort Sea and south through the Chukchi Sea to their wintering area in the Bering Sea. Indeed, a recent review of fall aerial surveys (September-October 1982-1991) in the Alaskan Beaufort covering up to latitude 73°N reported many sightings of belugas (Clarke et al. 1993). We expected that our tagged animals would follow such a course. The tracks of three of the four belugas with the longest lasting transmitters overlap the coverage of Clarke et al. (1993) fall surveys. These belugas (M93-17005, M95-17001, F95-17007) left for Alaskan waters in the first two weeks of September and passed Point Barrow one or two weeks later (Fig. 3.1AB).

In contrast, earlier in August, male 93-17009 traveled through the Arctic Ocean and was last located in the East Siberian Sea. It is noteworthy that one of the above-mentioned animals (M93-17001) moved farther west into the Chukchi Sea (~165°W) and much farther north (>76°N) than the sightings described by Clarke et al. (1993). It may have been headed, like male 93-17009, for the east Siberian Sea where observers have seen hundreds of belugas during fall walrus surveys (J. Burns, Fairbanks, AK, pers. comm.). These large sightings raise the possibility that our two tagged males' westward movements are not exceptional and that many Beaufort Sea belugas transit through the east Siberian Sea in the fall before moving south.

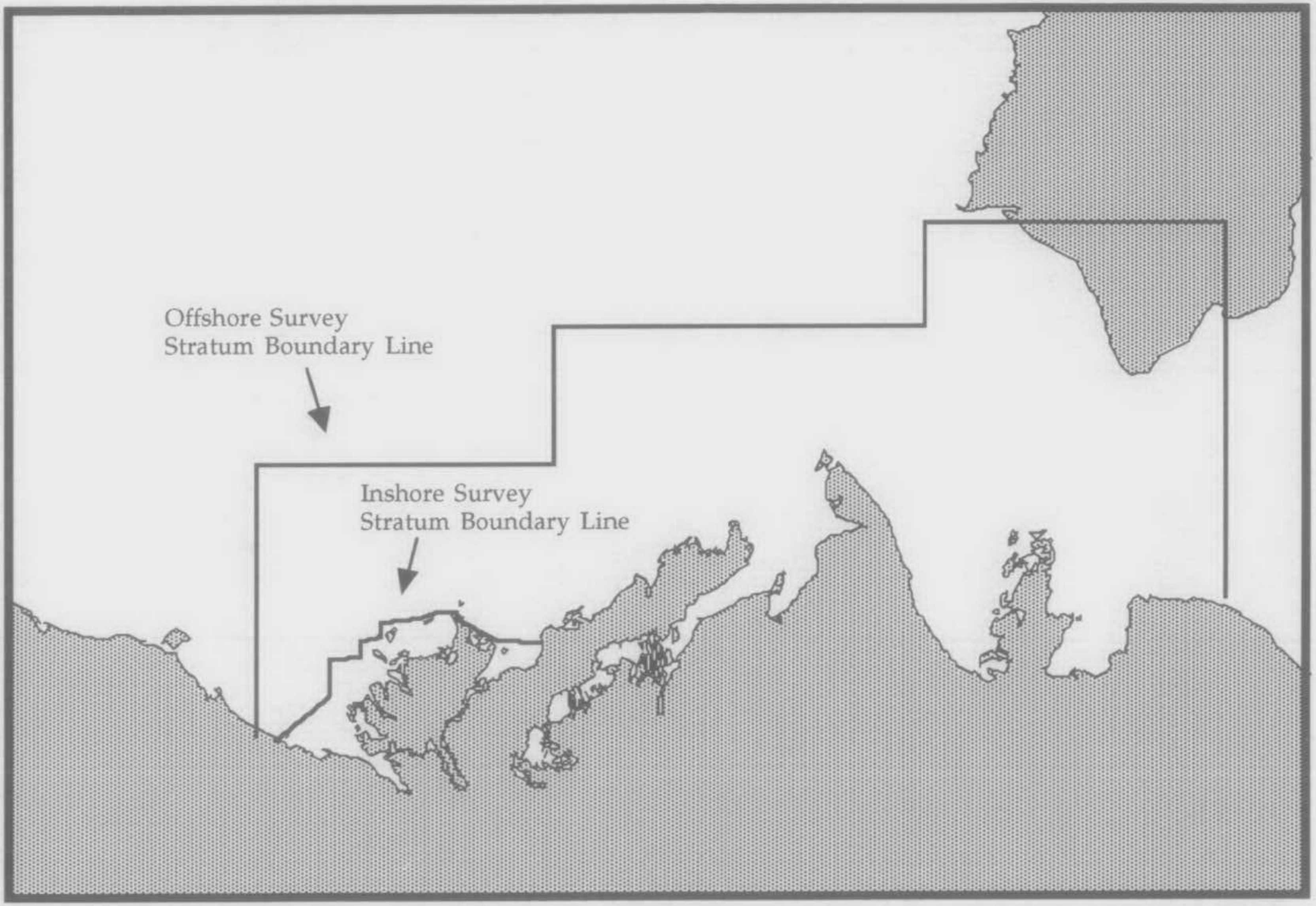


Figure 3.3: Boundaries of the 1992 survey strata.

If so, previous hypotheses on beluga movements gave only a partial picture of the fall migration routes of the Beaufort Sea stock.

In a recent review of the beluga harvest in Alaska, Frost and Suydam (1995) assumed that the spring catch north of the Bering Strait is largely composed of migrating Eastern Beaufort Sea belugas. They also suggested that some eastern Beaufort belugas are probably taken in summer and fall by several Alaskan villages (Kaktovik, Barrow, Diomede, Kivalina, Point Hope and Wales). They estimated that a total of 26-85 belugas may be taken from the Eastern Beaufort Sea beluga population every year. If many Beaufort Sea belugas transit through the Siberian Sea in the fall then the stock could also be hunted in Chukotka (Russia). The Russian catch is not well documented but is thought to be in the low tens (K. Frost, Alaska Dept. Fish & Game, Fairbanks, pers. comm.).

3.5 Sources of bias in aerial surveys

The last survey of the Eastern Beaufort Sea beluga stock dates to July 1992 (Harwood et al. 1996) and encompassed an area seaward from the coast to 70.5°N and 71°N, and between meridians 122°W and 138°W(Fig. 3.3). This survey area was based on available knowledge of Beaufort beluga summer concentrations (Norton and Harwood 1985) although the actual range of the population was suspected to be larger. Three sources of bias may have affected those survey estimates. First, if many belugas had left the area before the survey, the estimated population size was too low because the survey did not cover the entire range of the stock. Secondly, if belugas moved sufficiently fast enough in one direction to be counted twice during the survey, the estimate may be too high. Finally, belugas often dive below the surface for several minutes, causing an inevitable underestimate of population size since survey estimates are based on surface counts. To understand the effects of these potential biases more fully, we describe the behaviour of the belugas tagged in July 1993 and July 1995 and discuss the impact such behaviour might have had on the 1992 estimates of stock size.

3.5.1 Bias attributable to movements outside of the 1992 survey area

Five of the 20 tagged belugas (4 F, 1M) stayed within the survey area all or most of the days leading up to 26 July, the date the 1992 survey ended. Of those belugas, two left the survey area briefly for neighbouring areas in eastern Amundsen Gulf, returning a day or two later. The 1992 survey area therefore covered all but a small portion of the area used by these five belugas.

The information used to delimit that portion of the beluga's range for this survey was reasonably accurate. Until now, there was little knowledge of beluga summer movements deep in the Arctic pack ice or east into the central Arctic archipelago. Opportunities to make observations there are few, because marine travel and aerial observations are severely limited by heavy ice conditions. We know of only one reference on belugas north of Banks Island in summer. Manning and MacPherson (1958) reported several herds of 50 to "several hundred" belugas were seen traveling west on 12 and 23 August 1952 along the north shore of Banks Island.

The importance of their observation is now clear, in light of our telemetry results. Fourteen of the twenty animals we tagged in 1993 and 1995 (12 M, 2F) left the survey area after less than a week (range= 2.5-6.3 days). One other male left after two weeks (15.4 days). The average residence time for these 15 animals was 4.6 days (range= 3-15). We don't know how long the animals were in the area before being tagged so we calculated the potential residence time assuming they all arrived in the Mackenzie Delta on the 3 July because this was the earliest capture date. The average potential residence time was 12.2 days, i.e. less than two weeks (range = 4-19 days). Based on this assumption, none of these 15 animals would have been in the survey strata on the dates of the 1992 survey (23-25 July).

The fact that 15 of 20 tagged animals left the survey area soon after release in early to mid-July of both years and that they traveled far north into the pack ice suggests that the 1992 survey, which ended near the edge of the dense pack, covered only a fraction of the entire July range of the stock and therefore under-estimated stock size. Ninety percent of the tagged males and one third of the females left the survey areas before the 23 July, the day the 1992 survey began. If the same ratios applied in 1992, the survey would only have estimated 40% of the total surfaced population.

On 16 August 1993, an aerial observer flying near the last recorded position of male 93-17005 in Viscount Melville Sound sighted 75-100 belugas (T.G. Smith, Eco-marine Corp., Garthby, QC, pers. comm.). These beluga sightings were 8 and 45 km from the four positions given by male 93-177005 in the same 24 hr period. This area was also used by 10 tagged males in August 1995. The occurrence of tagged males in two different years and the aerial sightings of close to a hundred belugas suggests that beluga movements into Viscount Melville Sound are not unusual. This area may in fact be used by thousands of belugas from the Beaufort Sea stock. We assume that they are Beaufort Sea belugas because of approximately fifty belugas tagged in the eastern Canadian Arctic in summer, none has ever moved into Viscount Melville Sound. All moved south into Peel Sound in late summer and later moved northeast into Lancaster Sound and Baffin Bay (Smith and Martin 1994, Richard, unpublished data).

3.5.2 Bias attributable to movements within the 1992 survey area

If beluga movements within the survey were highly directional, individual animals may have been counted more than once as the survey planes flew across each survey strata. Were used mean vector speeds (i.e. mean speed in a given direction) instead of travel distances for analyses since the elapsed times between positions used to calculate distances was variable. Mean direction varied among animals and, more importantly, mean vector speeds were fairly slow (< 3 km/hr) for most animals, indicating little directional movement within the survey strata.

Based on the 1992 survey design, we calculated the mean N-S speed for the estuarine strata, where most transects were oriented E-W, and the mean E-W speed for the offshore strata, where all transects were oriented N-S. In either case, vector speeds were generally small, averaging less than 1 km/hr (0.13-0.81 km/hr). At 1 km/hr, a beluga would have taken about 1.3 hr to cover half the distance between estuarine transects and at least 9 hr to cover half the distance between offshore transects. In contrast, flying at an average ground speed of 191 km/hr, a 1992 survey aircraft took 15-36 min to complete two estuarine transects (length 10-56 km) and 2.2-2.5 hr to complete two offshore transects (length 200-220 km).

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

3.5.3 Bias attributable to diving behaviour within the 1992 survey area

Aerial survey estimates of beluga populations based on counts of surfaced animals underestimate the total population size because some are beneath the surface when the observers are overhead.

The simplest way to look at the counting bias due to diving behaviour is to reduce the problem to one of calculating how much time belugas spend below a given threshold. This threshold is the depth from which a beluga cannot rise to the surface during the length of time an observer is overhead. In such a case, the probability of a diving beluga being missed by an observer is simply the average proportion of time belugas spend below that depth threshold. This is a minimum estimate of the bias since a beluga will not necessarily surface during the passage of the survey plane, even if it is above the threshold depth.

We chose a range of depth threshold from most conservative (25 m) to most optimistic (5 m) using assumptions on beluga ascent rate (Martin and Smith 1990) and on assumptions regarding the amount of time an object is in view of observers (which in turn depends on the observer's scanning behaviour and on aircraft speed). In the offshore strata where there is sufficient depth for these thresholds, the proportion of time tagged belugas spent below 5 m, 10 m and 25 m averaged respectively 37%, 23% and 17%. Under such circumstances, the probability that a survey observer missed a diving beluga in offshore strata would be at a minimum 17%-37%. While it is not possible to estimate the probabilities that observers missed belugas during the 1992 surveys, these extrapolations illustrate the potentially large counting bias due to diving behaviour.

Surfacing behaviour also affects the probability of detection of belugas. This varies between survey strata:

<u>Estuarine strata.</u> The estuarine strata of the 1992 survey covered the heavily silted waters of the Mackenzie Estuary where visual water penetration is nil, so the only animals visible are those actually at the surface. The median interval between recorded surfacings of tagged belugas varied between 23 and 49 sec in the inshore sector, and 75% were in the range 11–92 sec for most animals. These numbers are similar to those obtained by Frost and Lowry (1995) for belugas monitored by VHF radio tags in Bristol Bay, Alaska, and Cunningham Inlet, Somerset Island, NWT.

<u>Offshore strata.</u> In the offshore strata, survey observers could see a few meters below the surface when they were close to the track line, but nevertheless only counted animals that did break the surface. Median surfacing intervals in the offshore sectors were in the range 15–81 sec, with 75% usually between 11 and 68 sec.

It is difficult to translate these intersurfacing values into a probability of detection because the lengths of time that belugas were in the observers' fields-of-view were not measured during the 1992 survey. It was measured during a 1996 high Arctic beluga survey flown at 1000 ft and 200 km/hr, and the results for each sighting varied between a fraction of a second to about 14 sec (S. Innes, DFO Winnipeg, MB, pers. comm.). Frost and Lowry (1995) also estimated the time-in-view to be 7-10 sec in surveys of Alaskan belugas flown at 185-222 km/hr, and likely the observers in the 1992 Beaufort survey had fairly similar times-in-view. These values show that beluga intersurfacing intervals are generally longer than the time that belugas are visible to observers and consequently some belugas are inevitably missed when an observer's field of-view passes over their position.

4.0 CONCLUSIONS

The project successfully returned detailed information on the movements and behaviour of tagged belugas, information which is relevant to hunt management, habitat use and beluga ecology.

Based on tracking data and published sources, it appears likely that Beaufort Sea belugas migrate into Alaskan and Russian waters where they could be taken by hunters. The level of the combined catch in the two countries on the Beaufort Sea beluga stock may be several tens of animals each year but this remains to be confirmed.

On the other hand, we now know from the 1992 survey that the Beaufort Sea population is very large in proportion to the catches and it is probable that beluga movement and dive behaviour caused a large underestimate of that population size. During the 1992 survey, many belugas were likely below the surface while the survey plane was overhead, causing a large underestimate of total population size. Movements out of the survey area before the survey interval may also have been an important source of bias.

Some general conclusions about beluga ecology can be made from the results, conclusions which challenge conventional wisdom on beluga ecology. First, it appears that Beaufort Sea belugas dive regularly to the seabed and are capable of repeated deep dives down to hundreds of meters (some over 1000 m). Secondly, they are capable of long movements, hundreds of kilometers away from their early summer estuarine concentration. Estuarine occupation appears to be short lived, especially in males. This contradicts our perception of summering belugas as coastal, shallow water animals which are relatively sedentary in or near their estuarine habitat. Beaufort Sea belugas are also able to move through dense summer and fall pack ice, which contradicts the perception that belugas are limited in their movements by heavy ice and that they prefer areas of loose pack or open water.

5.0 REFERENCES

Anonymous. 1996. ARGOS User Manual. Service ARGOS, Inc. Landover MD, USA. 176 p.

Brodie, P.F. 1989. The white whale *Delphinapterus leucas* (Pallas, 1776) pages 119-144 in: Ridgway, S.H. and R. Harrison [ed]. Handbook of Marine Mammals, vol. 4: River Dolphins and Larger Toothed Whales. Academic Press. xix + 442 p.

Clarke, J.T., S.E. Moore, and M.M. Johnson. 1993. Observations on beluga fall migration in the Alaskan Beaufort Sea, 1982-87, and northeastern Chukchi Sea, 1982-91. Report Int. Whal. Commn. 43: 387-396.

Doan, K.H. and C.W. Douglas. 1953. Beluga of the Churchill region of Hudson Bay. Bulletin of the Fisheries Research Board of Canada Number 98: 27 pages.

Duval, W.S. 1993. Proceedings of a workshop on Beaufort Sea Beluga, Vancouver B.C., February 3-6, 1992. ix + 26 p.

Finley, K.J., G.W. Miller, M. Allard, R.A. Davis, and C.R. Evans. 1982. The belugas *(Delphinapterus leucas)* of Northern Québec: distribution, abundance, stock identity, catch history and management. Canadian Technical Report of Fisheries and Aquatic Sciences 1123: 57 p.

Finley, K.J., J.P. Hickie, and R.A. Davis. 1987. Status of the beluga, *Delphinapterus leucas,* in the Beaufort Sea. Canadian Field-Naturalist 101(2): 271-278.

Fraker, M.A. 1980. Status and harvest of the Mackenzie stock of white whales *(Delphinapterus leucas).* Rep. Int. Whal. Commn. 30: 451-458.

Frost, K.J. and L.F. Lowry. 1990. Distribution, abundance, and movements of beluga whales, *Delphinapterus leucas,* in coastal waters of western Alaska. pages 39-57 in: Smith, T.G., D.J. St. Aubin, and J.R. Geraci [ed]. Advances in research on the beluga whale, *Delphinapterus leucas,* Canadian Bulletin of Fisheries and Aquatic Sciences 224: 206 p.

Frost, K.J. and L.F. Lowry. 1995. Radiotag based correction factors for use in beluga whale population estimation. Working paper for Alaskan Beluga Whale Committee Scientific Workshop, Anchorage, AK, April 5-7, 1995. 12 p.

Frost, K.J. and R. Suydam. 1995. Harvests of beluga whales, *Delphinapterus leucas,.* in Alaska, 1987-1994. Working paper for Alaskan Beluga Whale Committee Scientific Workshop, Anchorage, AK, April 5-7, 1995. 12 p.

Harris, R.B., S.G. Fancy, D.C. Douglas, G.W. Garner, S.C. Amstrup, T.R. McCabe, and L.F. Pank. 1990. Tracking wildlife by satellite: current systems and performance. Fish and Wildlife Technical Report 30: 52 p.

Harwood, L.A., S. Innes, P. Norton, and M.C.S. Kingsley. 1996. Distribution and abundance of beluga whales in the Mackenzie estuary, southeast Beaufort Sea and West Amundsen Gulf during late July 1992. Can. J. Fish. Aquat. Sci. 53: 2262-2273.

Manning, T.H. and A.H. Macpherson. 1958. The mammals of Banks Island. Arctic Insitute of North America. Technical Paper 2: 74 p.

Mansfield, A.W., T.G. Smith, and B. Beck. 1975. The narwhal, *Monodon monoceros* , in eastern Canadian waters. Journal of the Fisheries Research Board of Canada 32: 1041-1046.

Martin, A.R. and T. G. Smith. 1990. Deep diving in Wild, Free-ranging Beluga Whales, *Delphinapterus leucas.* Can. J. Fish. Aquat. Sci. 49: 462-466.

McLaren, P.L., and R.A. Davis. 1982. Winter distribution of Arctic marine mammals in ice-covered waters of eastern North America. Unpublished report to the Offshore Labrador Biological Studies (OLABS) Program by LGL Environmental Research Associates Ltd. Toronto, xiii + 151 pages.

Norton, P. and L.A. Harwood. 1985. White whale use of the southeastern Beaufort Sea. Canadian Technical Report of Fisheries and Aquatic Sciences 1401: v + 46 p.

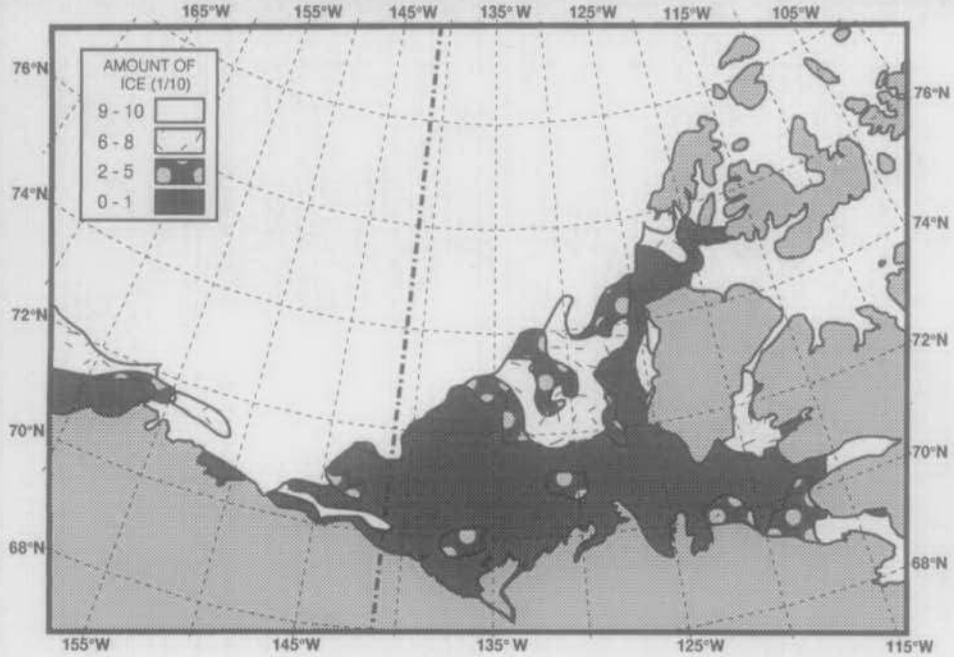
Orr, J.R. and M. Hiatt-Saif. 1992. A flipper band for individual identification of beluga whales *(Delphinapterus leucas).* Can. Fish. Aquat. Sci. 1856: iv + 9p.

Sergeant, D.E. 1973. Biology of white whales *(Delphinapterus leucas).* Journal of the Fisheries Research Board of Canada 30: 1065-1090.

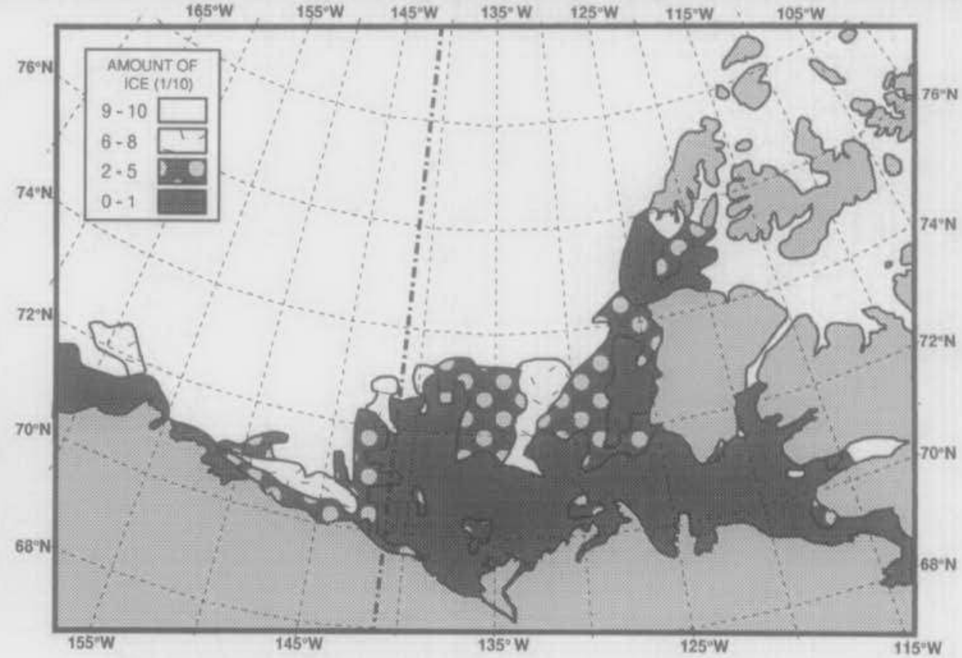
Sergeant, D.E. and P.F. Brodie. 1975. Indentity, abundance, and present status of populations of white whales, *(Delphinapterus leucas)* in North America. Journal of the Fisheries Research Board of Canada 32: 1047-1054.

Smith, T.G. and A.R. Martin. 1994. Distribution and movements of belugas, *Delphinapterus leucas*, in the Canadian High Arctic. Can. J. Fish. Aquat. Sci. 51: 1653-1663.

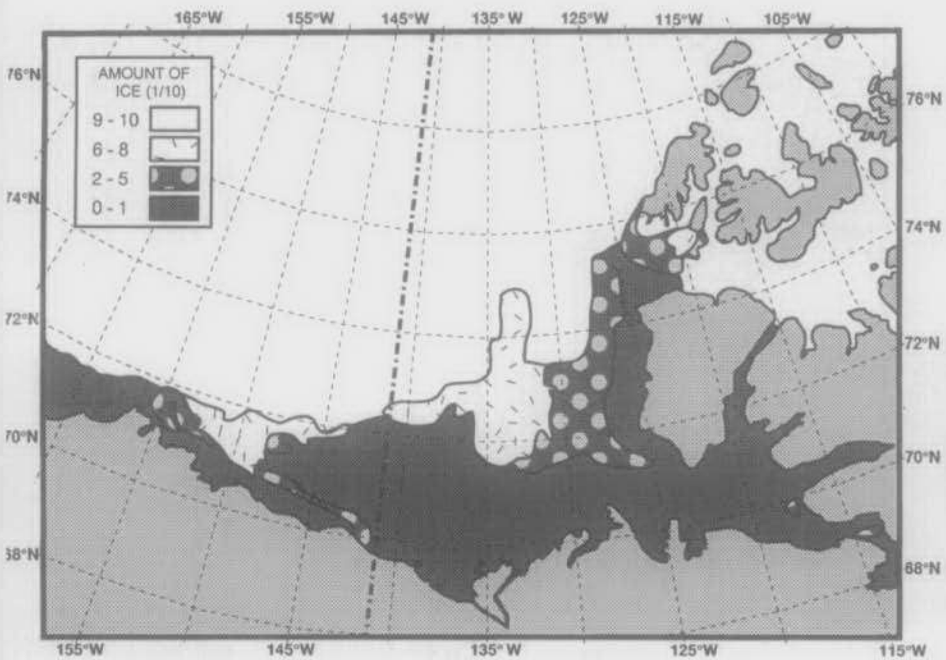
6.0 **<u>APPENDIX I</u>**: Ice conditions in the study area in July- October 1993 based on weekly ice composite charts, Environment Canada



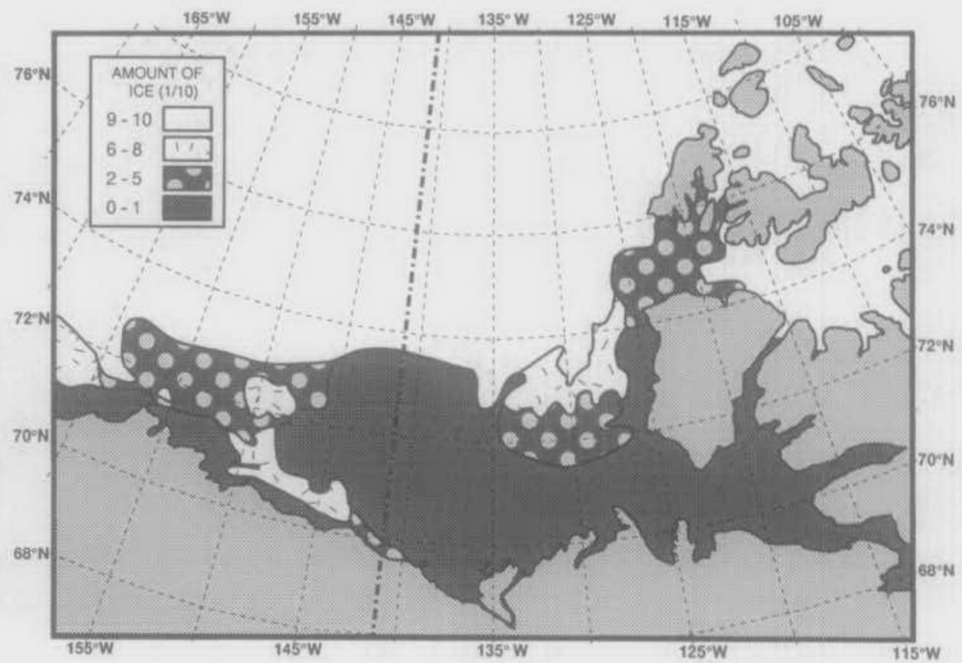
ICE CONDITIONS FOR THE WEEK OF JULY 13, 1993



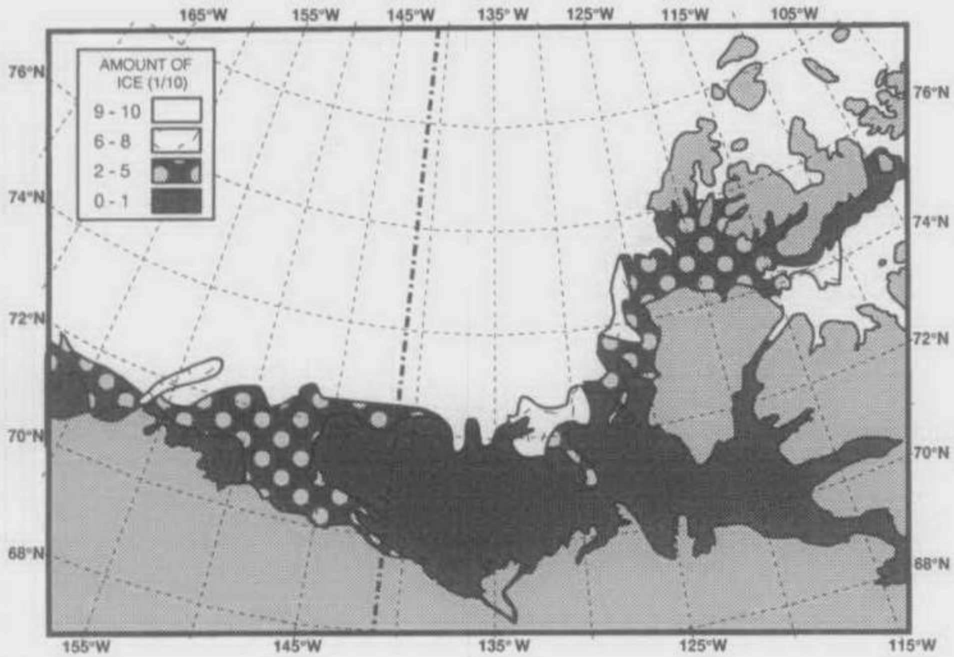
ICE CONDITIONS FOR THE WEEK OF JULY 20, 1993



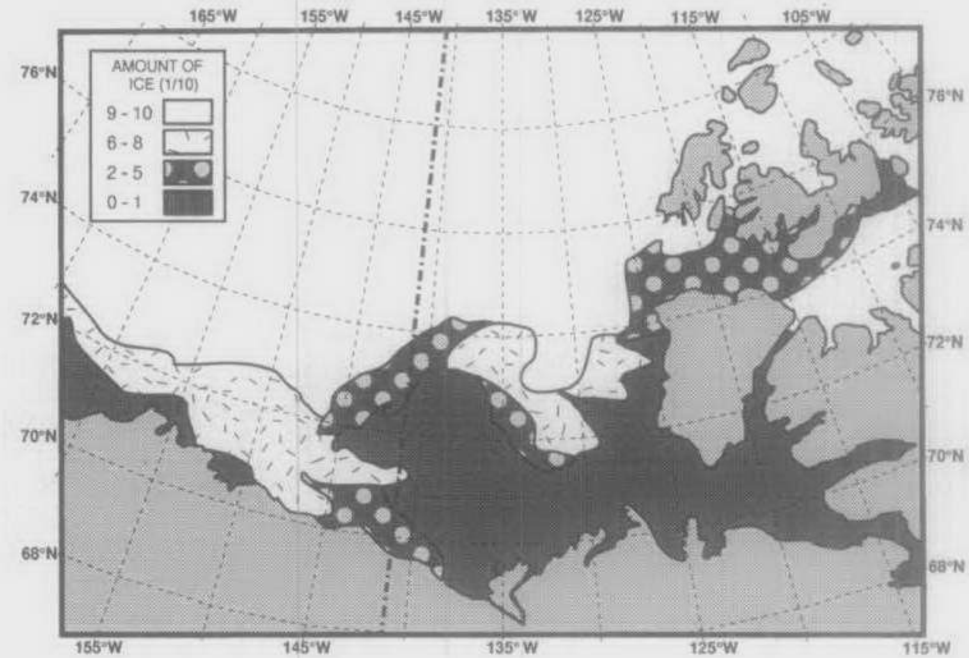
ICE CONDITIONS FOR THE WEEK OF JULY 27, 1993



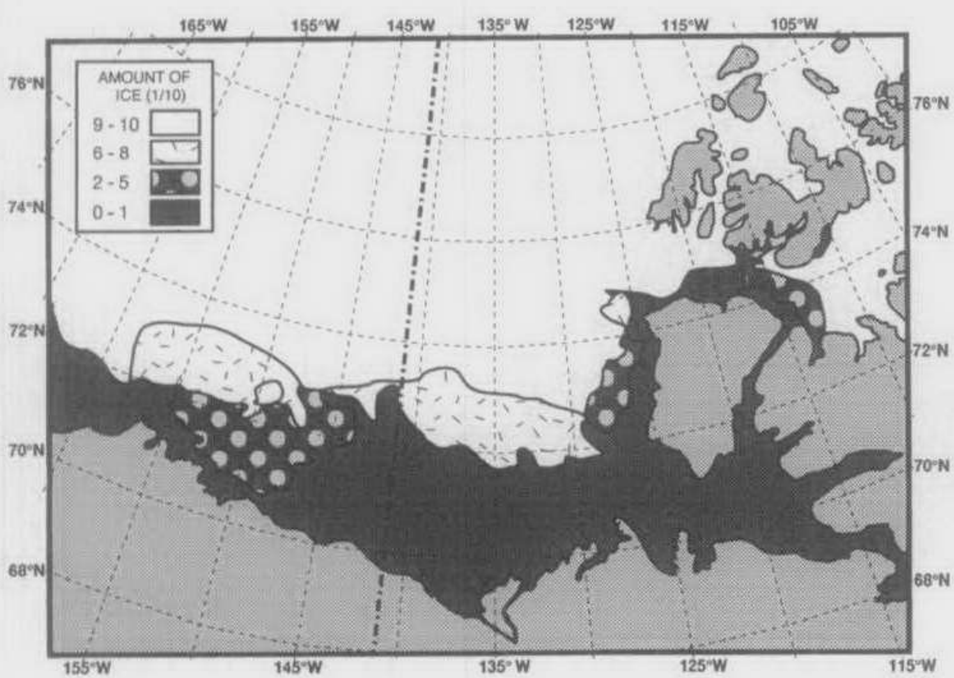
ICE CONDITIONS FOR THE WEEK OF AUGUST 3, 1993



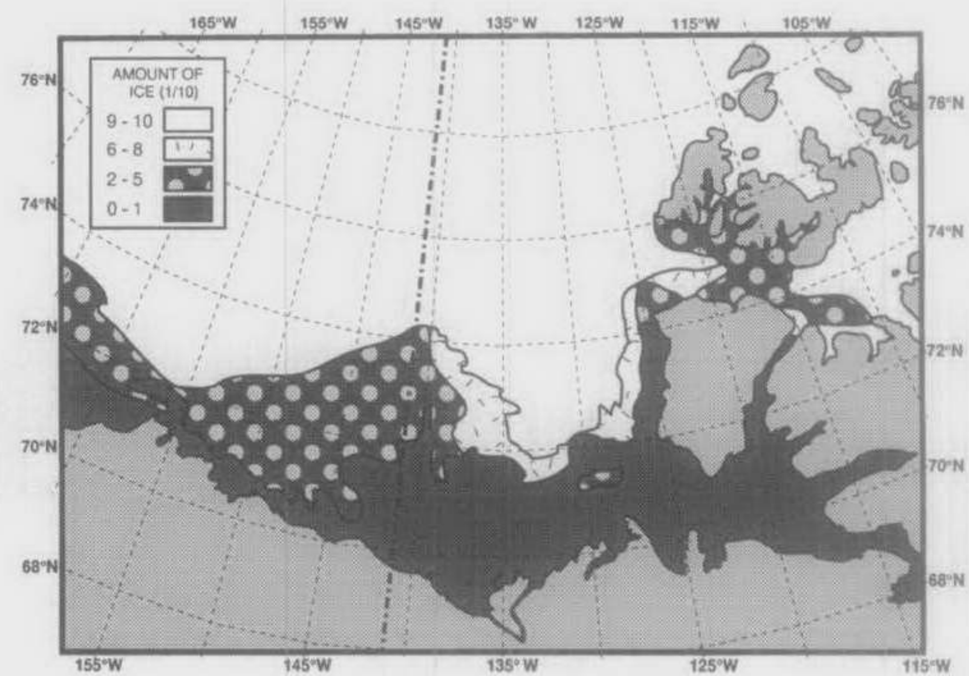
ICE CONDITIONS FOR THE WEEK OF AUGUST 10, 1993



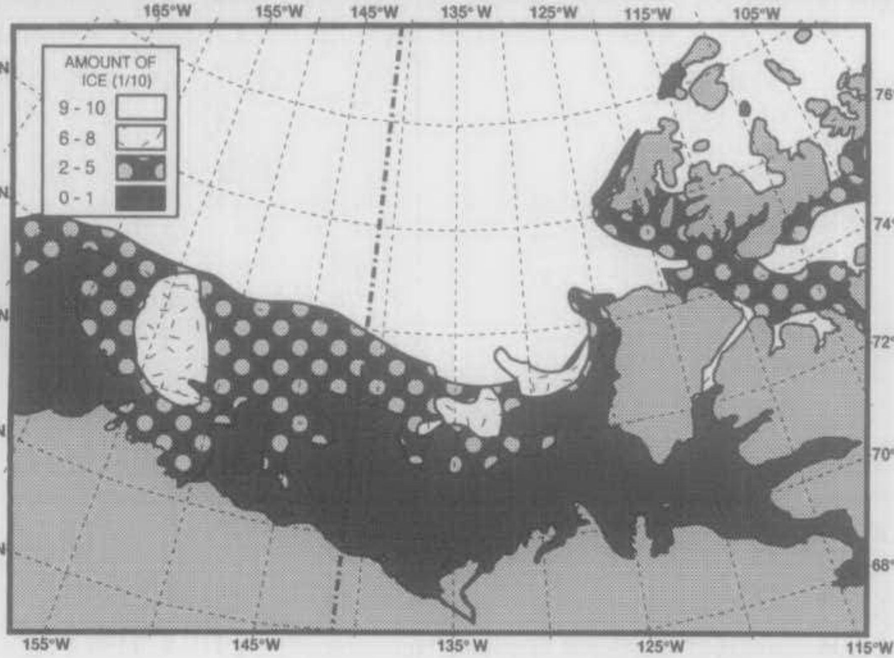
ICE CONDITIONS FOR THE WEEK OF AUGUST 17, 1993



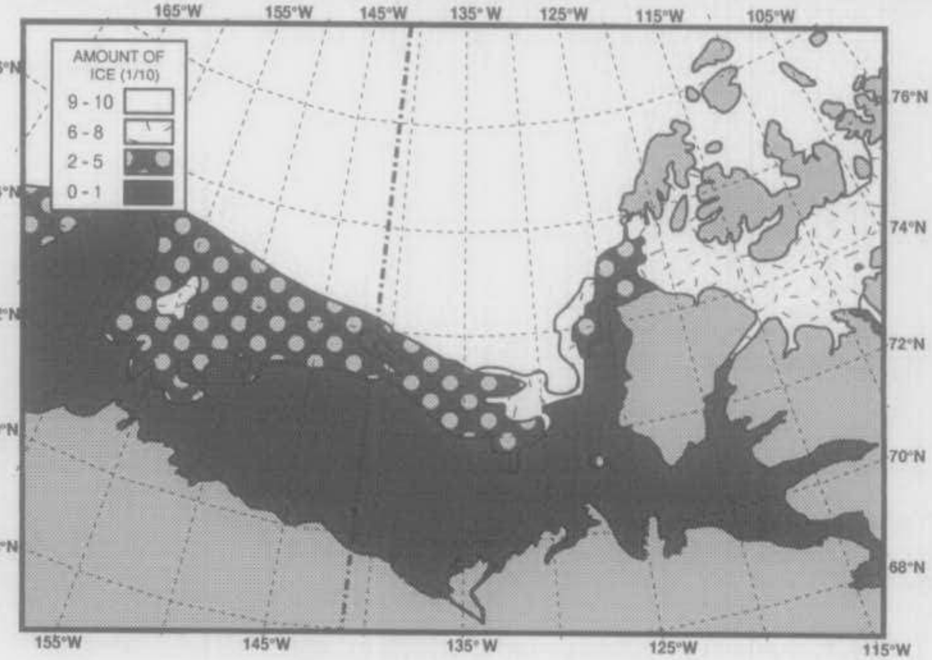
ICE CONDITIONS FOR THE WEEK OF AUGUST 24, 1993



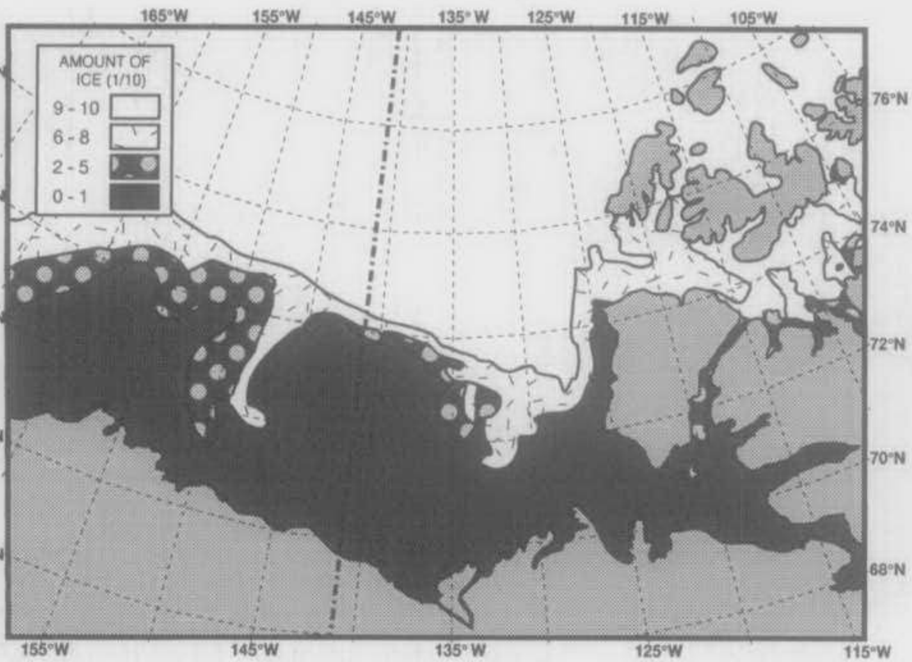
ICE CONDITIONS FOR THE WEEK OF AUGUST 31, 1993



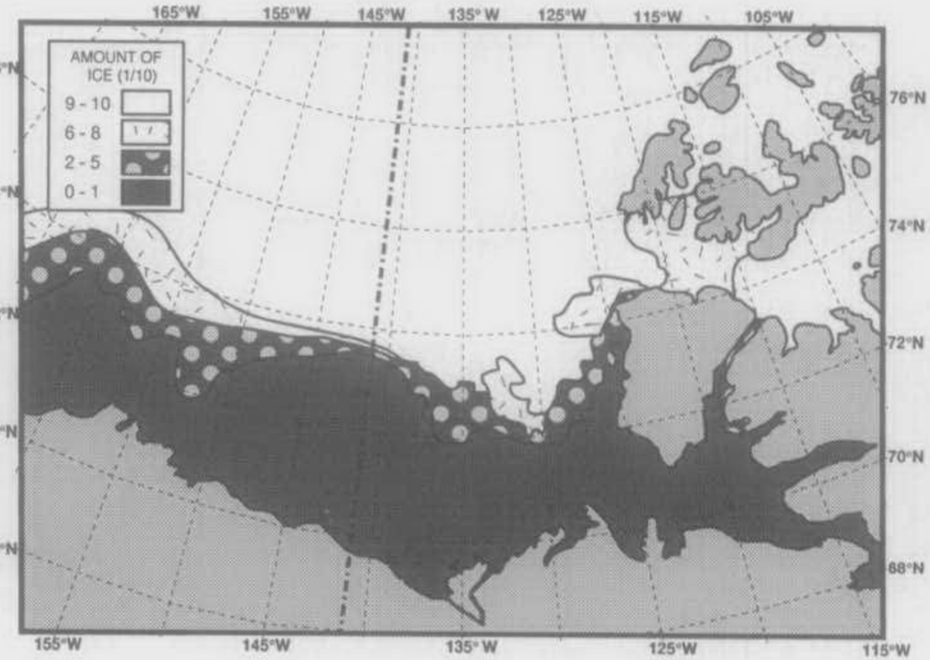
ICE CONDITIONS FOR THE WEEK OF SEPTEMBER 7, 1993



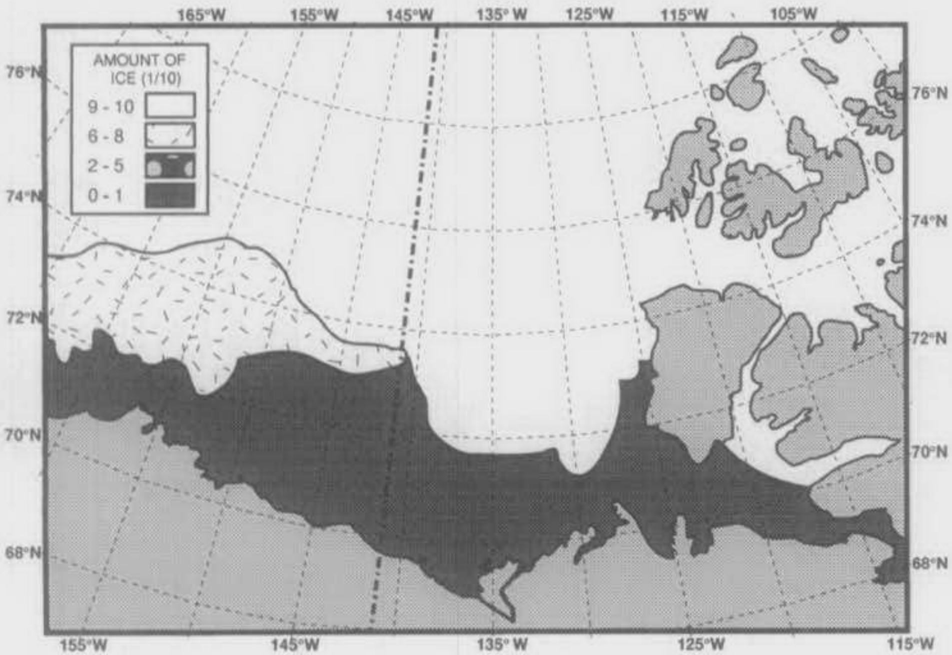
ICE CONDITIONS FOR THE WEEK OF SEPTEMBER 14, 1993



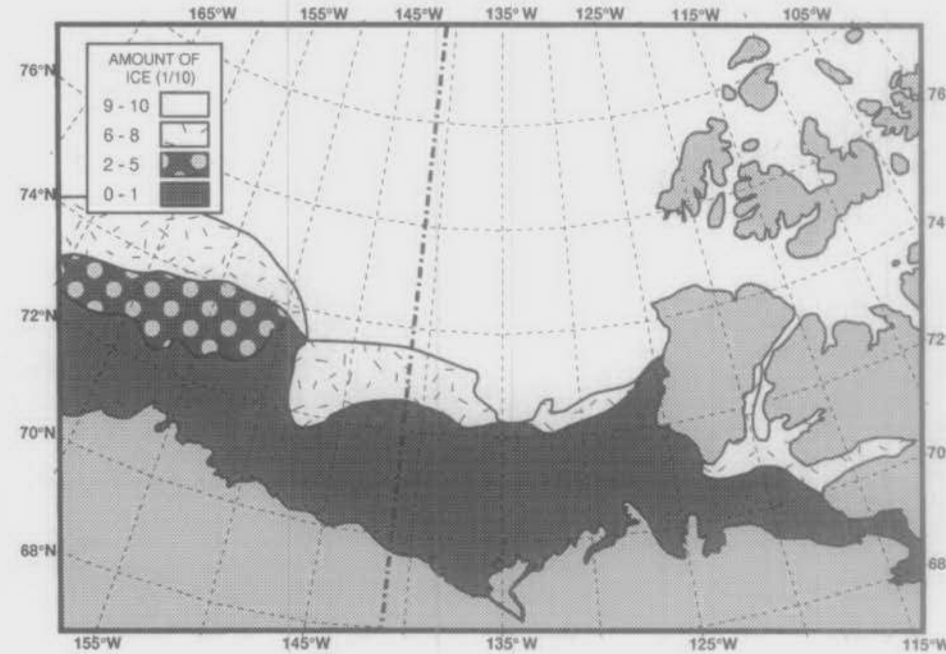
ICE CONDITIONS FOR THE WEEK OF SEPTEMBER 21, 1993



ICE CONDITIONS FOR THE WEEK OF SEPTEMBER 28, 1993

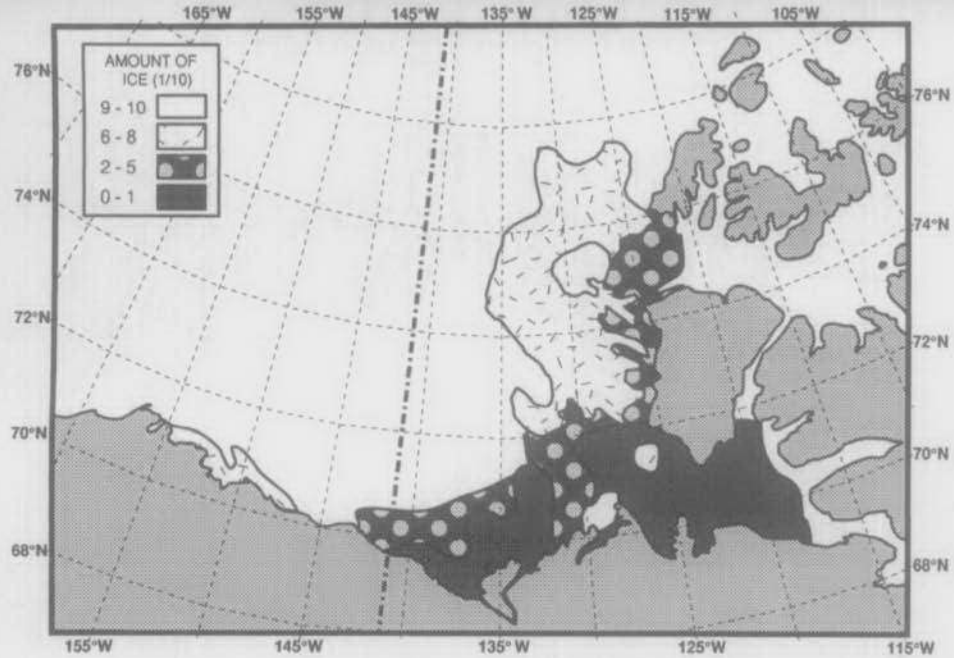


ICE CONDITIONS FOR THE WEEK OF OCTOBER 5, 1993

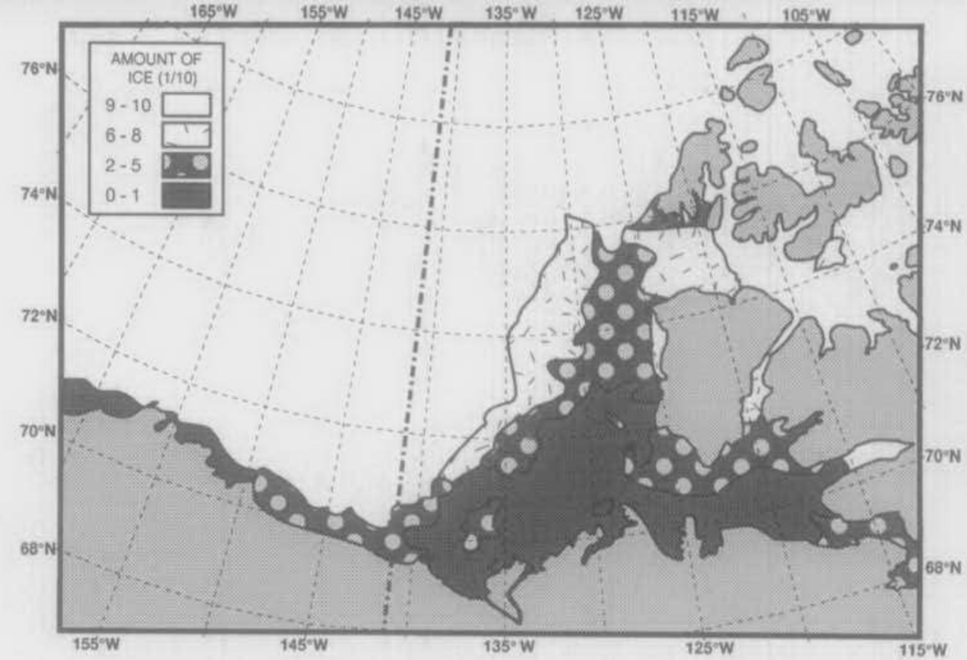


ICE CONDITIONS FOR THE WEEK OF OCTOBER 12, 1993

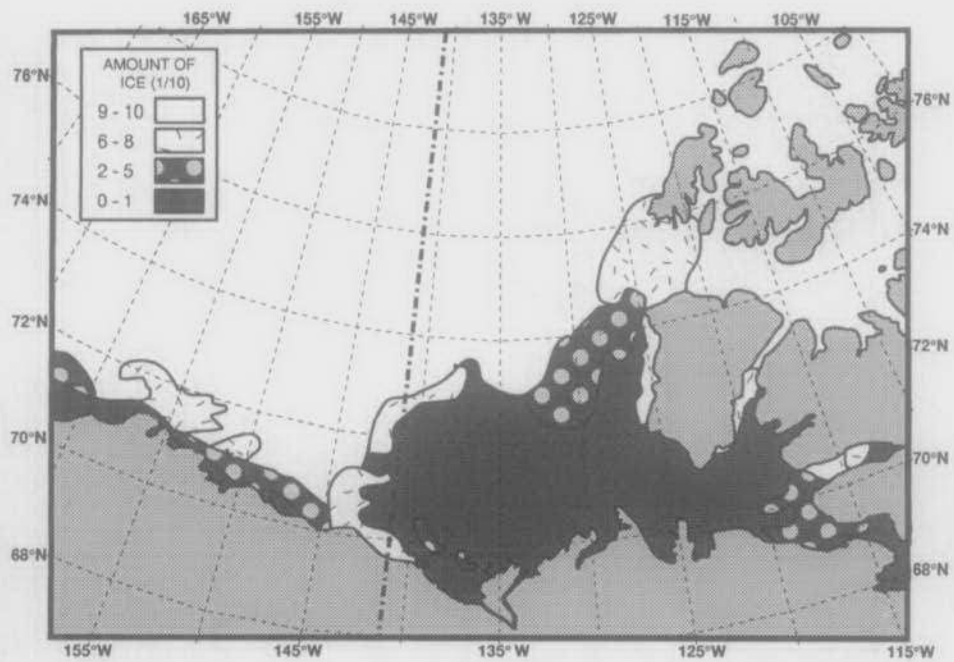
7.0 **APPENDIX II**: Ice conditions in the study area in July- October 1995 based on weekly ice composite charts, Environment Canada



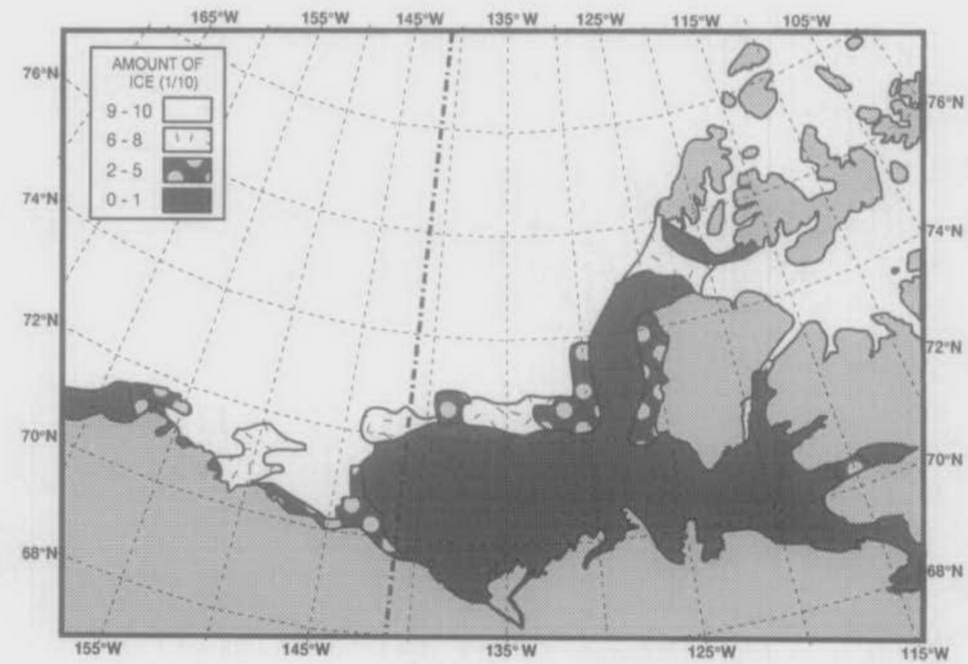
ICE CONDITIONS FOR THE WEEK OF JULY 4, 1995



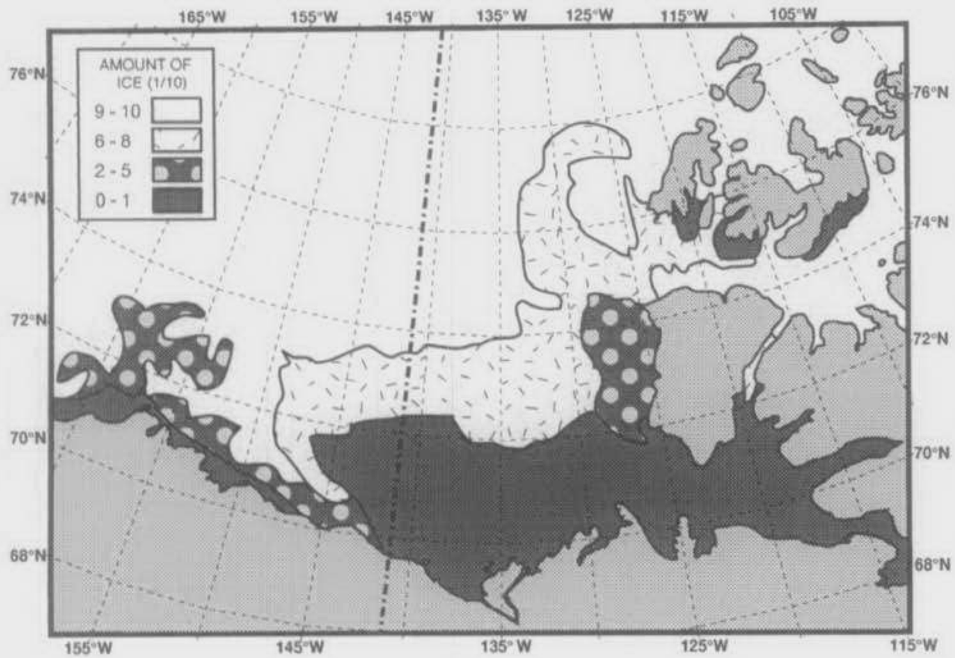
ICE CONDITIONS FOR THE WEEK OF JULY 11, 1995



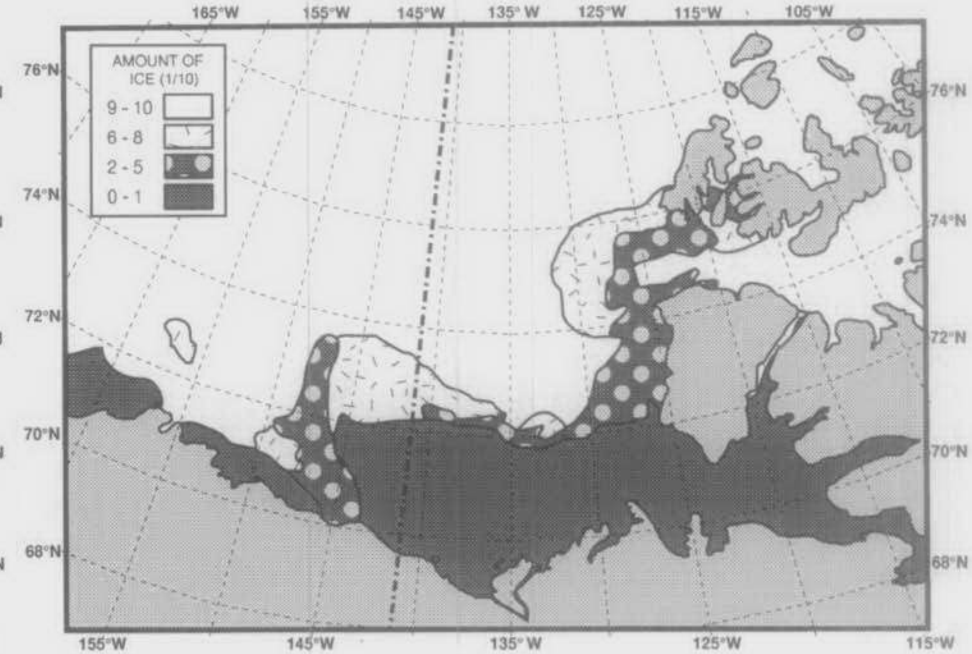
ICE CONDITIONS FOR THE WEEK OF JULY 18, 1995



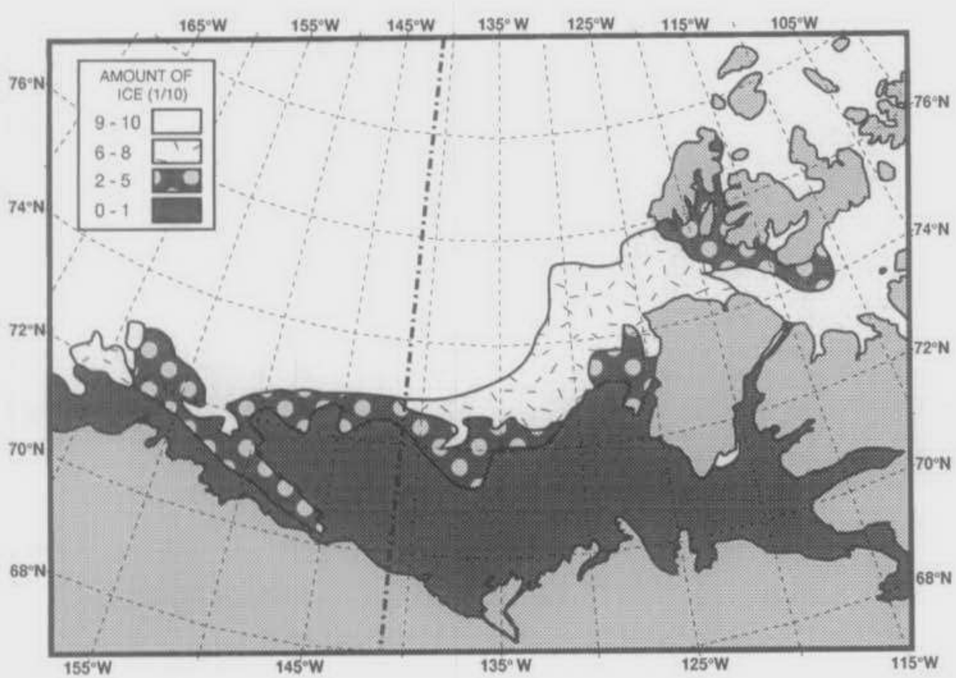
ICE CONDITIONS FOR THE WEEK OF JULY 25, 1995



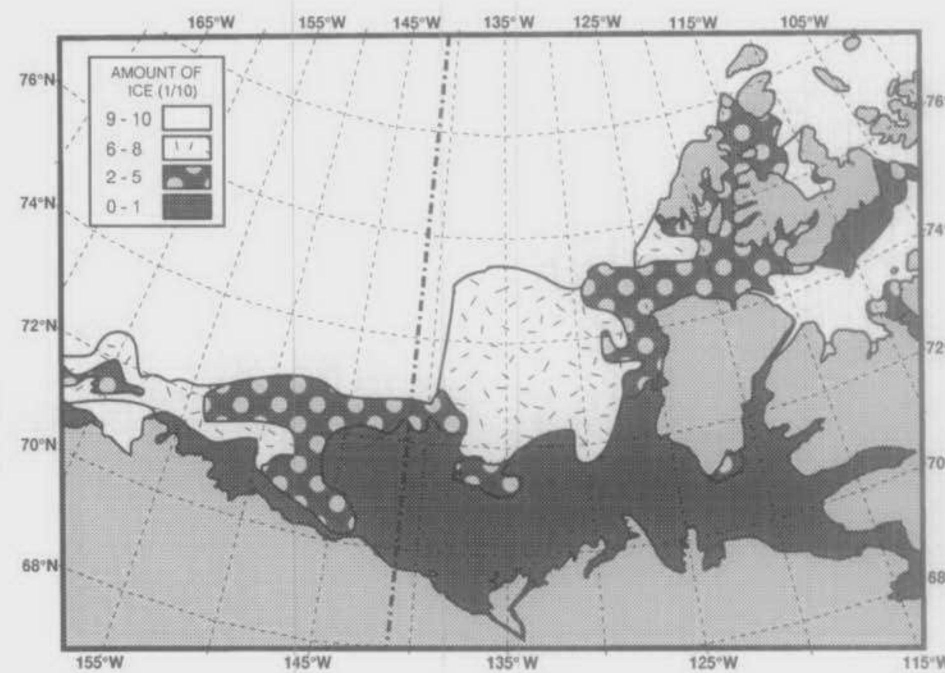
ICE CONDITIONS FOR THE WEEK OF AUGUST 1, 1995



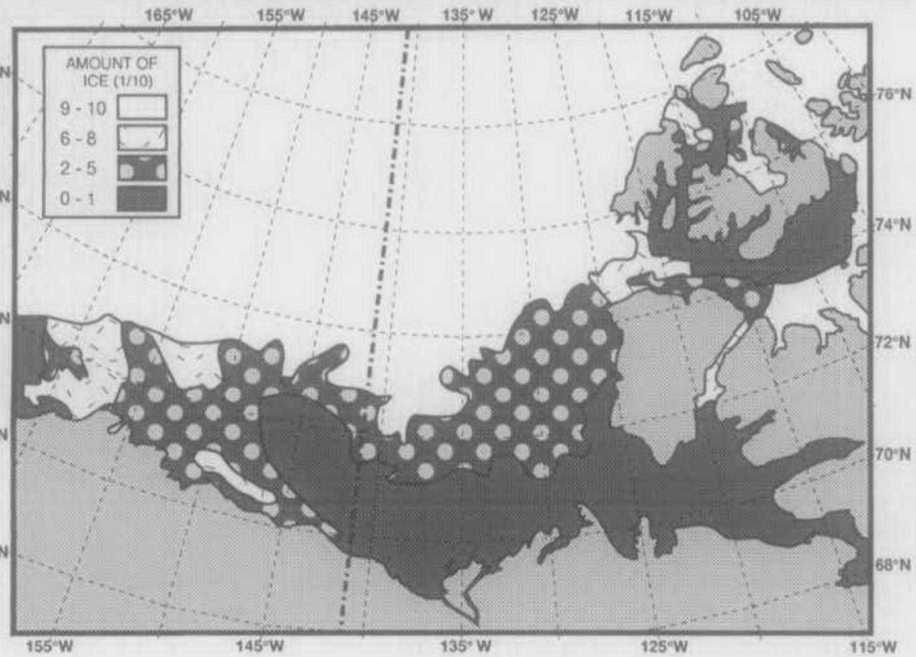
ICE CONDITIONS FOR THE WEEK OF AUGUST 8, 1995



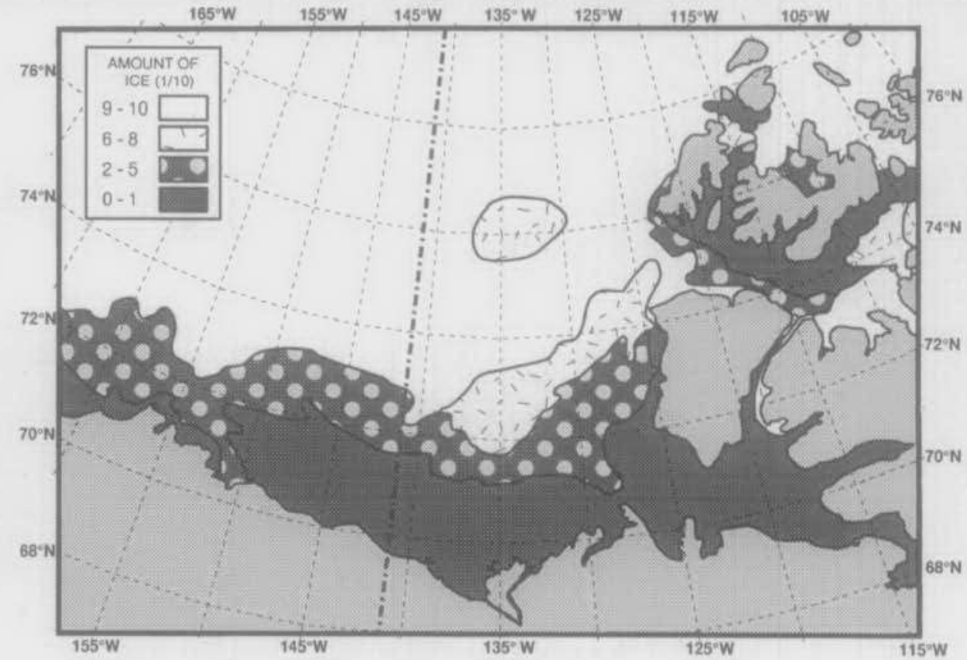
ICE CONDITIONS FOR THE WEEK OF AUGUST 15, 1995



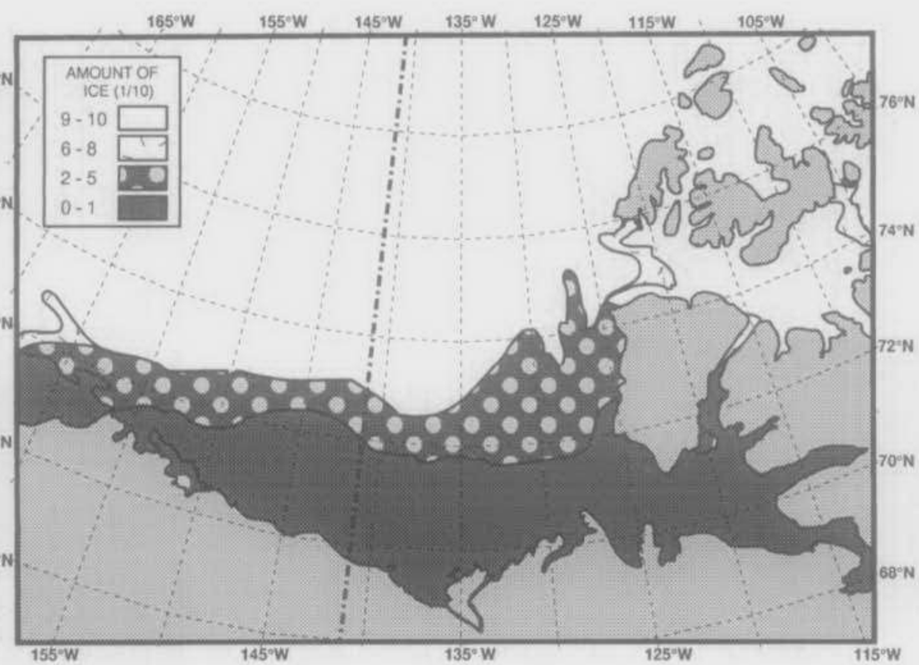
ICE CONDITIONS FOR THE WEEK OF AUGUST 22, 1995



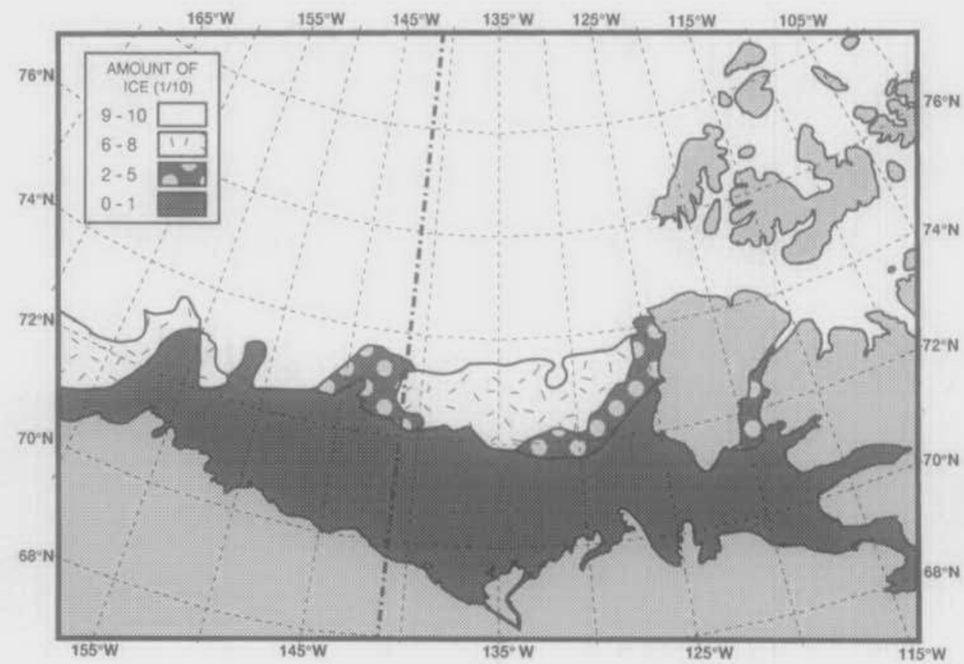
ICE CONDITIONS FOR THE WEEK OF AUGUST 29, 1995



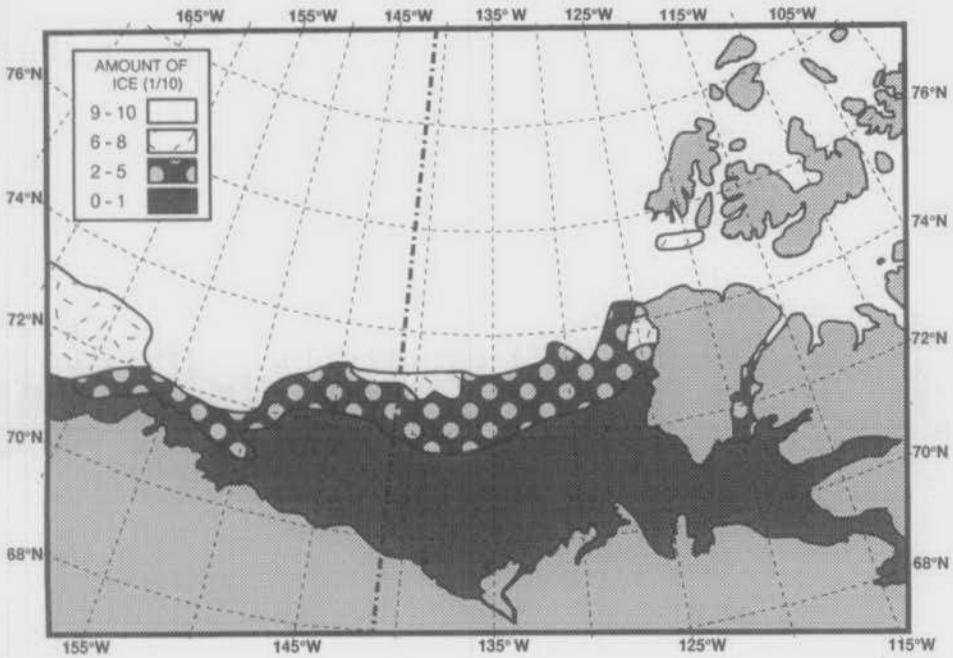
ICE CONDITIONS FOR THE WEEK OF SEPTEMBER 5, 1995



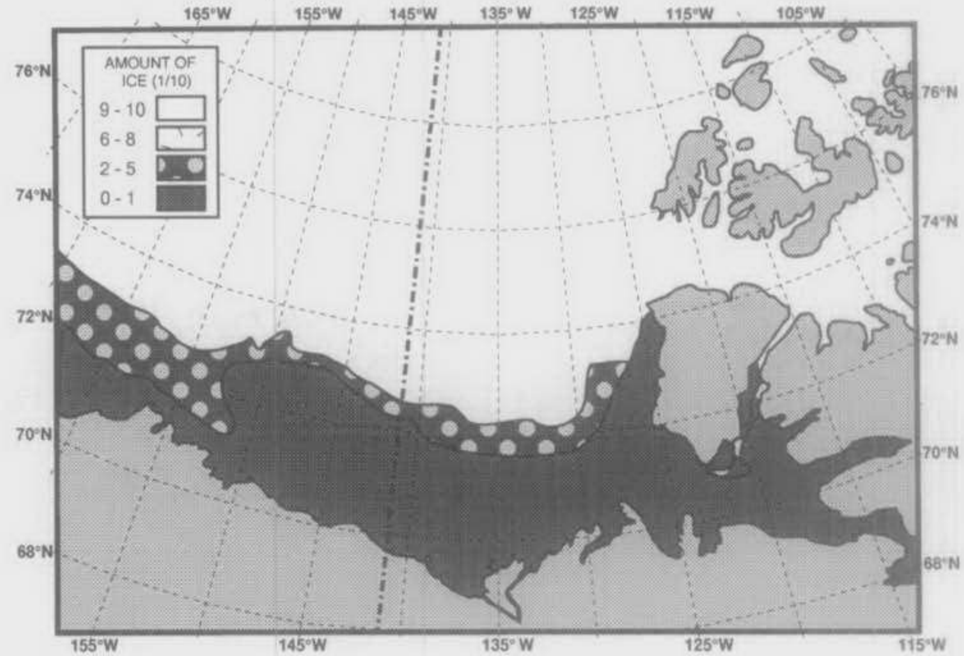
ICE CONDITIONS FOR THE WEEK OF SEPTEMBER 12, 1995



ICE CONDITIONS FOR THE WEEK OF SEPTEMBER 19, 1995



ICE CONDITIONS FOR THE WEEK OF SEPTEMBER 26, 1995



ICE CONDITIONS FOR THE WEEK OF OCTOBER 3, 1995