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DISTRIBUTION OF RINGED SEALS IN THE SOUTHEAST BEAUFORT SEA DURING LATE SUMMER

by

LOIS ANNE HARWOOD ©

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled DISTRIBUTION OF RINGED SEALS IN THE SOUTHEAST BEAUFORT SEA DURING LATE SUMMER submitted by LOIS ANNE HARWOOD in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

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Date. 22 Sept/89 ....

ABSTRACT

The distribution and relative abundance of ringed seals (Phoca hispida) in the southeast Beaufort Sea were examined through systematic aerial surveys in August-September 1982, 1984-1986. Data collected when sea state was ≤2 on the Beaufort Scale and when there was no forward glare were analyzed. Distribution was examined at three scales, and compared with coincident information on bearded seals, bowhead whales and beluga whales. The relative abundance of ringed seals was variable, reaching a maximum in 1982 (42.2 seals/100 km^2), declining through 1984 (14.73/100 km^2) and 1985 (7.92/100 km^2), and increasing again in 1986 (19.35/100 km^2). Similar fluctuations in the abundance of ringed seals with coincident changes in seal reproductive success were reported in the mid-1970's (Stirling et al. 1982; Smith 1987).

In 1982, 1984 and 1986, ringed seals were clumped in groups, and groups were clumped in aggregations. Group size varied within and among years (range 1-21). In 1985, seals were seen only as individuals and pairs, and no aggregations were seen. The density of ringed seals in aggregation areas ranged from 121 to 326 seals/100 km^2. The size (350 to 2800 km^2), number (1 in 1984, 2 in 1982, 3 in 1986) and location of aggregations varied among years. Ringed seals tended to aggregate most frequently and in greatest numbers in waters offshore of the Tuktoyaktuk Peninsula, at the approximate location where the Bathurst polynya occurs in winter.

Areas where ringed seals aggregated were examined with in situ data on zooplankton collected during an oceanographic sampling program conducted concurrently with aerial surveys in 1986, and with information from four seals collected from an aggregation area in September 1986. Mean densities of euphausiids and copepods were significantly greater in seal aggregation areas than in non-aggregation areas. Areas where ringed seals aggregated overlapped with some areas where (feeding) bowhead whales aggregated. Aggregation areas are known to have oceanographic characteristics favourable for production of zooplankton in this region. Stomachs and intestines of four seals collected from one aggregation area along the Yukon coast were full and contained the same prey type (mysids). The presence and behaviour of seabirds at the aggregations suggested prey were locally abundant. Results suggest ringed seals aggregate in late summer and fall to feed on concentrated prey found in the aggregation areas.

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1. INTRODUCTION

The ringed seal (Phoca hispida) has a circumpolar distribution, and is the most abundant and widespread marine mammal in the Canadian Arctic. This phocid (true) seal is the smallest pinniped (Banfield 1977; King 1983). The Caspian seal (Phoca caspica) and Baikal seal (Phoca sibirica), both isolated following the last glaciation, are the closest relatives of the ringed seal (see review in Kelly 1988).

Dorsally the adult pelage is relatively coarse, brown or black in colour, and marked with irregular silver or cream coloured rings. Ventrally the pelage is silver or cream coloured, with black spots (Banfield 1977). Pups weigh 4 to 6 kg at birth (Smith 1987), and like harp seals, are born with soft white pelage (lanugo).

In the southeastern Beaufort Sea and Amundsen Gulf, adult asymptotic lengths of 131 cm (63.4 kg) for males and 127 cm (61.1 kg) for females (Smith 1987) are slightly greater than for southeast Baffin Island, Bering and Chukchi seas, Sea of Okhotsk, and the Alaskan Beaufort Sea (McLaren 1958; Fedoseev 1965; Lowry et al. 1982). There is considerable individual variation in adult body size and pelage patterns within populations, but whether this variation relates to stock discreteness or habitat is not known (Kelly 1988).

Historically, ringed seals were important to the cash economy and domestic harvests of the Inuit (e.g. Usher 1975). Anti-sealing campaigns in the late 1970's, together with an increase in the wage economy, reduced the demand for ringed seal pelts and meat. Inuvialuit from the communities of Sachs Harbour, Holman Island, Tuktoyaktuk and Paulatuk continue to hunt seals for food for their dogs; annual harvests of approximately 1000 are 20-30% of harvests in the 1960's (IRC 1989).

The ringed seal population in the Beaufort Sea is present year-round, although some animals may undertake both local and large scale movements, presumably in response to food availability or ice conditions (Smith 1987). During winter, breeding adults establish and maintain territories in stable landfast ice areas. Immature animals a. found at the periphery of the prime breeding areas where the fast ice is less stable.

Ovulation occurs in late May, just prior to the end of lactation, and implantation of the blastocyst the following September (Smith 1987). The mating system is probably polygynous, but not to the same extent as for terrestrial breeding phocids (Stirling 1983). Males maintain territories which include several females and their sub-territories of birth lair complexes (Smith 1987). In Amundsen Gulf, pups are born in mid-April, and lactation lasts six to eight weeks (Smith 1987).

Ringed seals haul-out on the landfast ice to moult during June. In the southeast Beaufort Sea and Amundsen Gulf, greatest densities of ringed seals during breeding and haul-out occur in Darnley and Franklin bays, Prince Albert Sound, and Minto Inlet, and between Nelson Head and Cape Parry, but they are also widely distributed throughout most areas where stable fast ice occurs (Smith and Stirling 1978; Stirling et al. 1982). Limited survey data suggest that after the haul-out period, ringed seals are widely distributed throughout the Beaufort region until late August (Norton and Harwood 1985).

Ringed seals are important in arctic marine ecosystems, both as consumers and prey. They feed from several trophic levels, and in some areas exhibit seasonal and age-related differences in the type and amount of prey selected (Chapskii 1940; Dunbar 1941; Nikolaev and Skalkin 1975; Lowry et al. 1980; Smith 1987). During winter, ringed seals presumably feed within or near their territories, and depend on abundant resources such as spawning cod (Lowry et al. 1980; Smith 1987). During spring haul-out, they apparently feed less extensively, but food intake increases again in late summer and fall (McLaren 1958; Lowry et al. 1980; Smith 1987).

Stirling et al. (1977; 1982) reported a major decline in the abundance of ringed and bearded seals in the eastern Beaufort Sea in spring 1975, and consequent effects on polar bears (Stirling et al. 1976). Extensive mortality, combined with reduced productivity or large-scale emigration, were possible explanations for the decline in the seal populations (Stirling et al. 1982). Smith (1987) found a major decrease in recruitment in the ringed seal population during the same period, and hypothesized this may have been related to food availability during fall and winter of 1973-1974 (a winter with particularly heavy ice conditions). Lowry et al. (1980) suggest annual changes in the relative abundance (Stirling et al. 1982) and condition (Smith 1987) of seals may be explained by annual changes in prey abundance. There appears to be an important relationship between the quality and quantity of food available during late summer and fall, and reproductive success, but the nature of this relationship and the processes that influence it have not yet been adequately investigated.

The distribution of ringed seals during late summer and fall differs from that seen at other times of the year. From late August through to freeze-up in October, ringed seals tend to occur in large, loose aggregations. These aggregations have been described by several authors for the Canadian Beaufort Sea and Amundsen Gulf (Smith 1973; Renaud and Davis 1981; Harwood and Ford 1983; McLaren and Davis 1985; Harwood and Borstad 1985; Smith 1987), the Alaskan Beaufort Sea (J. Richardson, D. Ljungblad, pers. comms.), the eastern Arctic (Ellis 1957; Finley and Johnston 1977), and the Sea of Okhotsk (Fedoseev 1965). The objective of my thesis is to examine the possible relationship between aggregations of ringed seals seen in late summer-early fall and extensive feeding by seals on concentrated food organisms found in these areas.

The first paper of my thesis (Chapter 2) describes and documents patterns of ringed seal distribution in the southeast Beaufort Sea during the open water period. Data were collected during aerial surveys over the southeast Beaufort Sea in late August and September 1982, 1984-1986. Distribution is examined at three scales, and compared with patterns of distribution observed at the same time for bearded seals (Erignathus barbatus), beluga whales (Delphinapterus leucas) and bowhead whales (Balaena mysticetus). The Chapter concludes with information specific to each ringed seal aggregation, such as relative abundance, seal behaviour, species associations, and the persistance and geographic extent of each aggregation.

The second paper (Chapter 2) in my thesis examines characteristics of the ringed seal aggregation areas. Emphasis is on August-September 1986 since in situ sampling of zooplankton and chlorophyll a was conducted concurrently with the aerial surveys in that year. Chapter 3 also includes information on stomach and gut contents, age and body condition of four ringed seals collected from an aggregation area in 1986.

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2. DISTRIBUTION OF RINGED SEALS AND OTHER MARINE MAMMALS IN THE SOUTHEAST BEAUFORT SEA DURING LATE SUMMER

2.1 INTRODUCTION

The ringed seal (Phoca hispida) is the most abundant and widespread marine mammal in the Canadian Arctic. Prior to 1974, information on the distribution of ringed seals in the southeast Beaufort Sea was limited to localized field studies (e.g. Smith 1973), and to unpublished observations and anecdotal accounts (see review in Harwood et al. 1986). Oil and gas exploration activities in the early 1970's led to systematic surveys of ringed seals during spring while seals were hauled out on the ice during their annual moult (Stirling et al. 1982; Kingsley 1986).

From late August through to freeze-up in October, ringed seals in the Beaufort Sea tend to occur in large, loose aggregations (e.g. Renaud and Davis 1981; Harwood and Ford 1983; Harwood and Borstad 1985; McLaren and Davis 1985). The main objective of this Chapter is to describe and document patterns of distribution of ringed seals in the southeast Beaufort Sea during the open water period, with emphasis on the areas of aggregation. The distribution of ringed seals is compared with distribution patterns observed coincidentally for bearded seals (Erignathus barbatus), beluga whales (Delphinapterus leucas) and bowhead whales (Balaena mysticetus), and trends in relative abundance of each species are discussed. Data were collected during systematic aerial surveys in the southeast Beaufort Sea, August-September 1982, 1984-1986.

The spatial distribution of a species is usually clumped at one or more scales (Taylor et al. 1978). Clumping can be either a response to environmental factors which are unevenly distributed, a behavioural tendency of a species to aggregate, or both. Several models have been developed to measure the degree of clumping of the distribution of a species (e.g. Elliott 1971; Kingsley 1989). While these do not provide explanations for observed distributions, they provide a means for describing them, and for making inter- and intra-specific comparisons. The scale at which one describes distribution is important, and scales should be selected so results are biologically meaningful (Elliott 1971).

Here I evaluate the distribution of marine mammals in the southeast Beaufort Sea during the open water period at three scales: group (how many individuals per group?), local (how are the groups distributed relative to each other?), and regional (is distribution homogeneous across the region?). The group scale is probably most influenced by interactions among individuals. The local scale may be influenced by small scale oceanographic features (e.g. local temperature gradients) which influence the local distribution of prey.

The regional scale is most influenced by large-scale oceanographic features characteristic of this region, such as regional ice patterns, the Mackenzie River plume, or areas where open water (polynyas) existed during the preceding winter. However, the influence of large- and small-scale oceanographic features, and seal behaviour, on distribution are undoubtedly complex. These influences are expected to vary among locations and temporally, and are not expected to be mutually exclusive.

Ringed seals occur in areas of the Beaufort Sea, Amundsen Gulf, and the Northwest Passage which coincide with existing or proposed oil and gas development activities. There is concern about the potential effects of exploration, production and transportation of hydrocarbons on ringed seal populations (e.g. FEARO (Federal Environmental Assessment Review Office) 1984; DIAND and DOE (Dept. of Indian Affairs and Northern Development, Dept. of Environment) 1984). Most of the surveys described in this Chapter were designed to provide baseline information on marine mammal distribution and relative abundance as part of the overall research effort, and as an initial step in assessing or predicting potential impacts of development on marine mammals during the open water period. This information is essential for such assessments, and for population management, particularly since the ecosystem appears prone to large-scale natural fluctuations (Stirling et al. 1982).

2.2 METHODS

STUDY AREA

The study area extends from the Alaska-Yukon border (141° W longitude) eastward to Cape Bathurst (128° W longitude), and from the 2 m isobath seaward to (1982), or 25 km beyond (1984, 1985, 1986), the 100 m isobath (edge of the continental shelf). Approximate surface area is 80,400 km^2, with an approximate east-west distance of 500 km (Figure 2-1). A wide and shallow continental shelf extends up to 130 km from shore, with maximum depths of 60-100 m. Beyond the edge of the continental shelf is the abyssal plain of the Canada Basin in the Arctic Ocean.

Ice is the dominant and a dynamic feature of the offshore Beaufort Sea. During winter there are three ice zones: the polar pack which circulates clockwise over the Canada Basin in the Arctic Ocean (Figure 2-2); the landfast ice which forms each year beginning in late September or October, is attached to shore, and is relatively smooth and stable; and the transition or shear zone which occurs at the interface of the pack and landfast ice, and is dynamic. During most winter months, there is a polynya (open water) located near Cape Bathurst and Cape Parry (Smith and Rigby 1981).

Break-up of the landfast ice usually begins in June. The process is affected by the volume, currents and temperatures associated with the Mackenzie River discharge, and by solar radiation, winds, and ocean currents (Dey 1980). Most of the ice melts, but some is blown offshore and consolidates with the polar pack. From July through September, there is an increase in the amount of open water. The overall amount and persistence of open water is highly variable, and depends on a number of factors, most notably wind direction (Thomson et al. 1986). Freeze-up begins in late September and early October, and is usually complete by November.

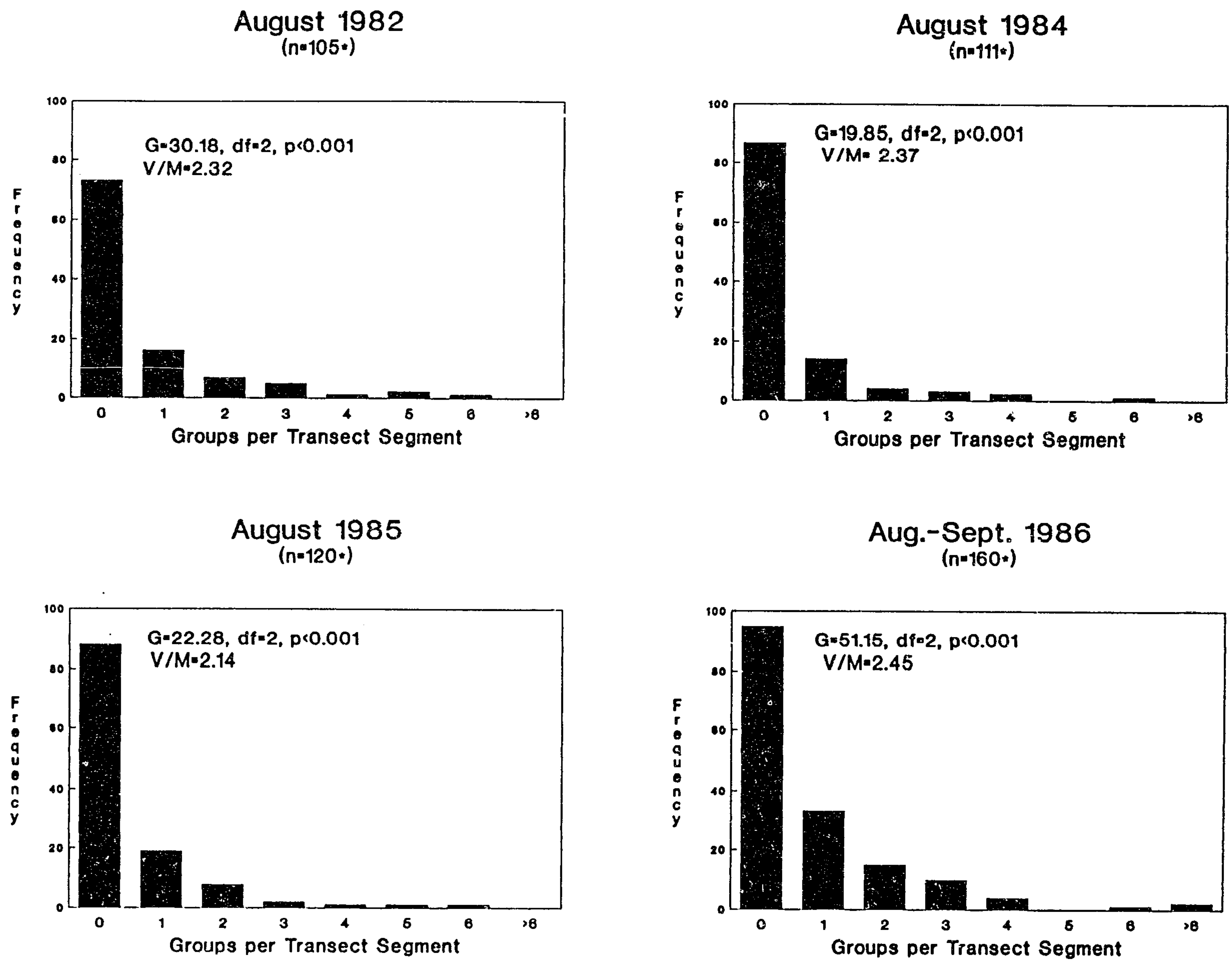

Figure 2-7. Frequency distribution of number of ringed seal groups per transect segment, southeast Beaufort Sea, late summer 1982, 1984-1986

Table 2-5

Group size and distance between groups for ringed seal aggregation areas in the SE Beaufort Sea, late summer, 1982, 1984 and 1986

Aggregation Area*	Range of observed group sizes	Mean group size (# of groups)	Range of distances between groups**	Mean distance between groups (km^2)
A	1-21	8.4 (11)	<0.1- 12.4	4.9
B	1-20	7.2 (27)	0.1 - 15.2	5.6
C	1-15	3.8 (15)	0.1 - 13.3	3.2
D	1-16	2.7 (15)	0.2 - 5.7	1.4
E	1-10	2.5 (6)	0.5 - 3.9	1.8
F	1-2	1.5 (6)	0.1 - 11.7	2.9

* areas indicated on Figures 2-8 to 2-11

** calculated from groups sighted on same or adjoining transect segments in the given aggregation our impression during the surveys that ringed seals were distributed as "groups of groups".

Transect segments with observed densities of ≥100 ringed seals/100 km^2, defined as aggregations at this scale, are listed on Table 2-6. No transect segments from 1985 surveys met this criterion. Of the 689 transect segments surveyed under optimum conditions (all surveys), 30 (4.4%) were designated as aggregations, and 23 of these were from the synoptic regional surveys. There were no cases of the same transect segment (e.g. the same specific location) with a density of ≥100 seals /100 km^2 in more than one year (Table 2-6), although there were two instances of the same transect segment having an aggregation on two different surveys in the same year.

Seabirds were seen in close association (usually circling directly overhead, and in groups of up to approximately 50 birds) with ringed seals in some, but not all, aggregations (Table 2-6). Of the 30 transect segments with seal aggregations, seabirds were observed with seals on 11 of these. The occurrence of seabirds and ringed seals together in aggregation areas may reflect utilization of the same prey, or perhaps kleptoparasitism as noted by Smith (1987) in Prince Albert Sound.

Ringed seal groups were seen in circular or linear formations along 23 of the 30 transect segments within aggregations, but not elsewhere. Seals in circular groups were usually noted as oriented toward the center of the circle. This behaviour may be indicative of cooperative feeding, or serve some other social function.

Table 2-6

Transect segments with ringed seal densities $\geq$100 seals/100 km^2 (aggregations)

Survey/ Year	Aggreg. Area[1]	Transect Segment #	# Seals	Assoc. with Birds	Circles
Aug. 1982	A	64d	14	-	+
	A	79c	9	-	+
	A	94c	10	-	+
	A	80b	33	-	+
	A	95a	26	-	+
	B	26d	13	-	+
	B	41c	38	-	+
	B	27a	37	+	+
	B	27d	19	+	+
	B	42c	26	+	+
	B	42d	30	+	+
	B	57c	11	-	-
	B	12b	8	+	+
Sept.1982*	A	66b	8	-	-
	A	66c	20	-	+
	B	12b	22	-	+
Aug. 1984	C	40a	8	+	+
	C	54d	8	+	-
	C	55a	20	+	+
	C	55b	21	+	+
Aug.-Sept. 1986	D	41b	13	+	-
	D	39a	9	-	+
	D	39c	18	-	-
	E	69a	16	-	+
	E	54a	13	+	+
	E	68c*	7	+	-
	E	53d*	5	+	+
	E	54b*	7	+	+
	F	108c	9	-	-
Aug. 21 1986*	E	69b	10	-	-
	E	84a	11	-	-
	E	69a	10	-	+
Oct. 3*	F	109b	9	-	-

1 corresponds to approximate locations of "A,B,C,D,E,F" symbols on Figures 2-8 through 2-11, plotted from synoptic regional surveys

\- absent, + present

* based on local, reconnaissance, or regional surveys with incomplete coverage; synoptic regional surveys in bold

* did not meet abundance criterion but had birds and/or circles, and aggregations on adjacent transect segments

Regional Scale

From zero to 55 ringed seals were seen per transect. Clump factor ratios (Table 2-7) for 1982, 1984 and 1986, all greater than unity, indicate clumping between transects (e.g. by longitude), and a non-homogeneous distribution across the region in those years. The clump factor ratio for 1985 (1.02) suggests a homogeneous or slightly clumped distribution. Variance to mean ratios and indices of dispersion suggest clumping in all years at this scale, although to a much greater extent in 1982, 1984 and 1986 than in 1985 (Table 2-4).

The density contour maps illustrate patterns of distribution both along and between transects (e.g. by longitude and latitude), and also show that from a regional perspective, ringed seals aggregated in 1982, 1984 and 1986, but not in 1985. The contour maps indicate the approximate geographic location where most of the sightings were made (i.e. where the groups were clumped), and these are termed aggregation areas.

Ringed Seal Aggregations

On the density contour maps (Figures 2-8 to 2-11), the six areas of aggregation at the regional scale are indicated as "A" to "F". Each of the 23 transect segments with aggregations at the local scale was located within one of these larger aggregations depicted at the regional scale (Table 2-6).

The number and location of areas where ringed seals aggregated were not consistent among years (Table 2-8), but there were some general similarities with respect to geographic location. The extent

Table 2-7

Error coefficients of variation (E), clump factors (C), clump factor ratios, mean density (#/100 km^2), 95% confidence interval (C.I.), and standard error (SE) for ringed seals in the SE Beaufort Sea during late summer 1982, 1984-86

Survey	km^2 surveyed	# transects	# on-trans. seals	E_1	E_2	C_1	C_2	C_1/C_2	mean density	C.I.	SE
Aug. 1982	731	16	307	0.2441	0.1835	18.30	10.34	1.77	42.20	(40.10-43.95)	1.93
Aug. 1984	665	14	98	0.5121	0.4706	25.70	21.70	1.18	14.73	(12.88-16.58)	1.85
Aug. 1985	757	25	60	0.2026	0.2007	2.46	2.42	1.02	7.92	(7.26- 8.58)	0.32
Aug-Sept. 1986	1085	22	210	0.2218	0.1532	10.33	4.93	2.09	19.35	(18.04-20.66)	0.63

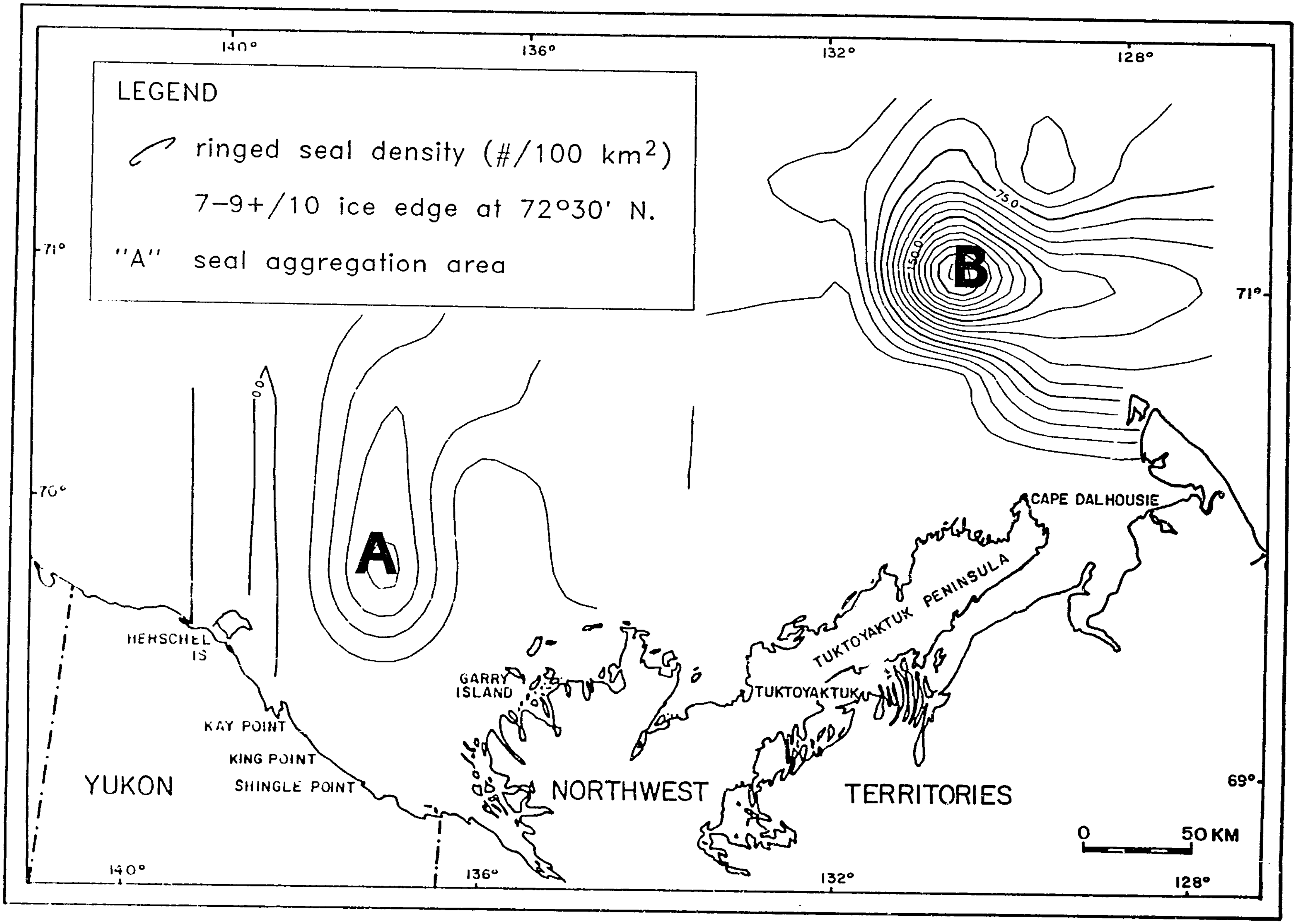

Figure 2-8. Distribution of ringed seals in the southeast Beaufort Sea, August 18-24, 1982

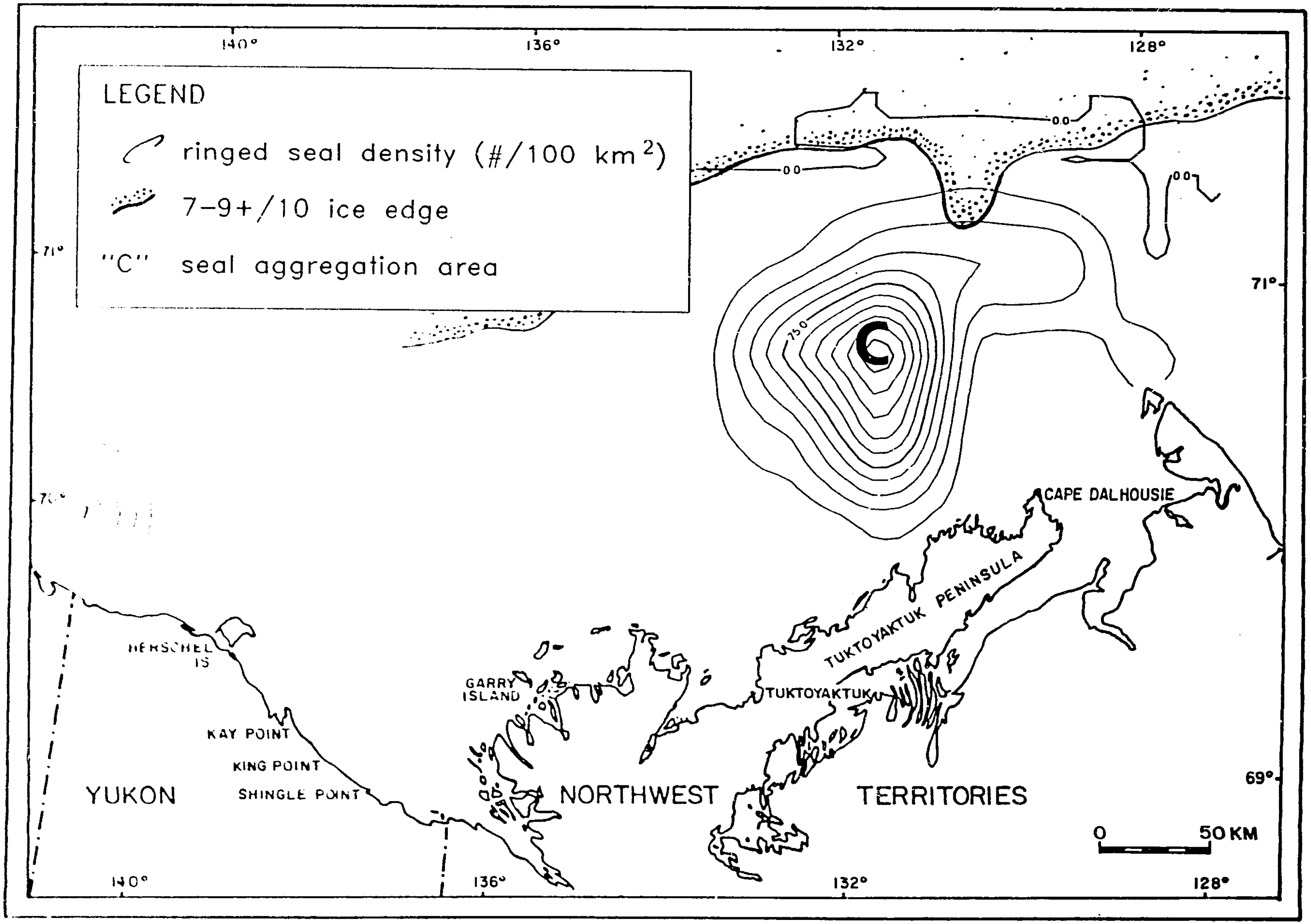

Figure 2-9. Distribution of ringed seals in the southeast Beaufort Sea, August 18-27, 1984

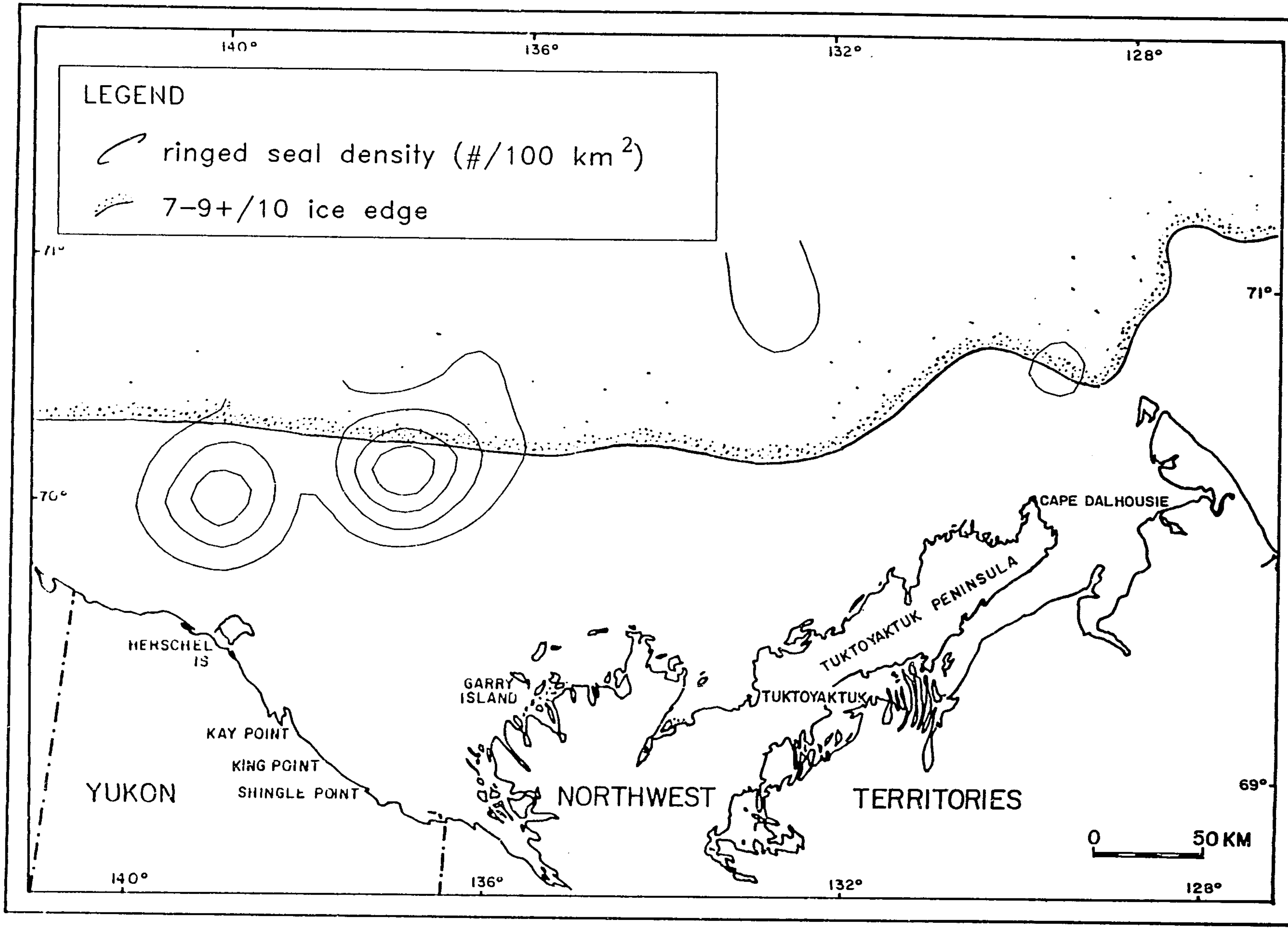

Figure 2-10. Distribution of ringed seals in the southeast Beaufort Sea, August 18-24, 1985

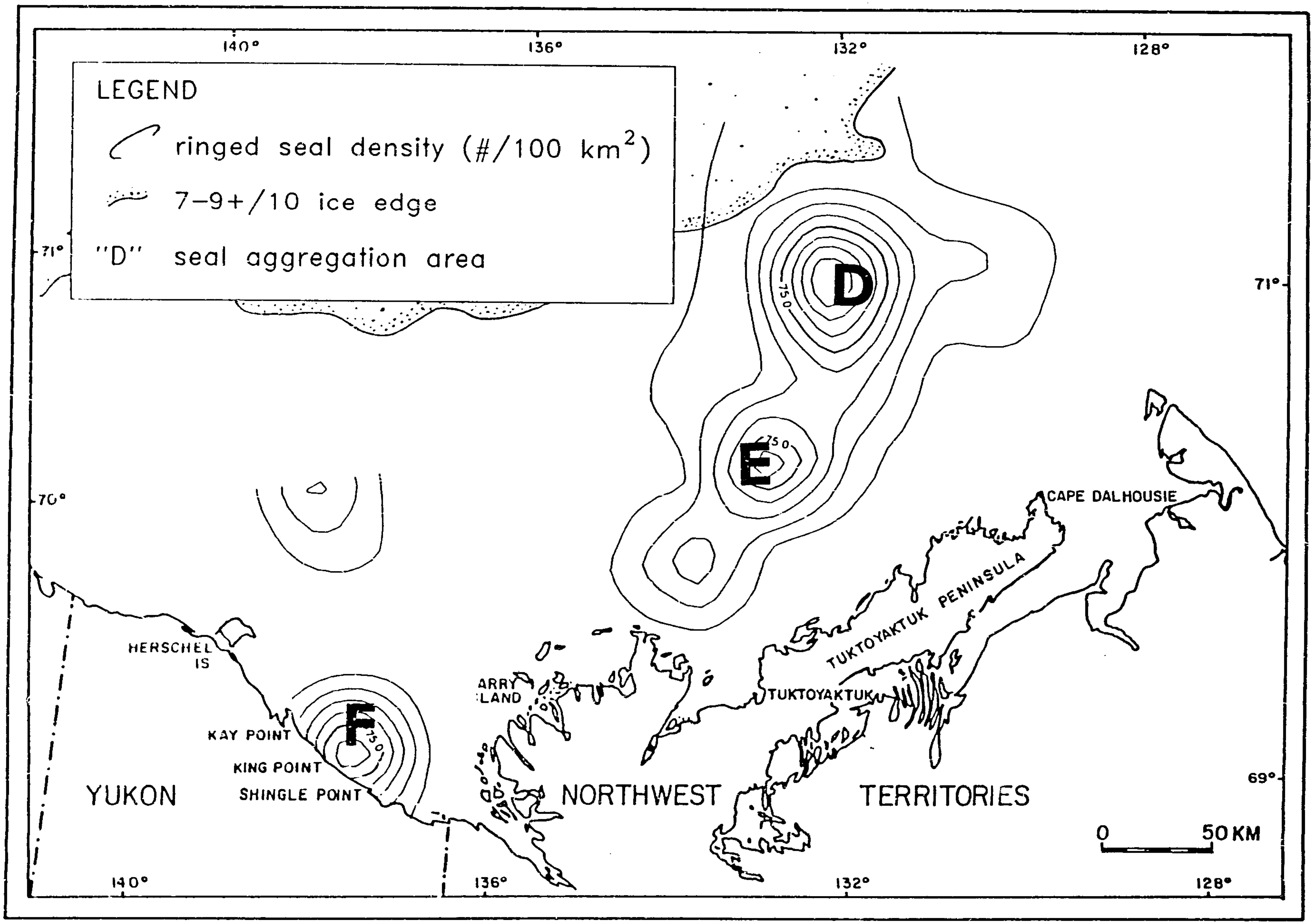

Figure 2-11. Distribution of ringed seals in the southeast Beaufort Sea, Aug. 31- Sept. 10, 1986

Table 2-8

Information on ringed seal aggregations in the
SE Beaufort Sea during late summer, 1982, 1984 and 1986

Aggreg. Area[1]	Geographic Location	Year	# transect segments [area km^2][3]	No. of seals	No. of groups	# seals/ 100 km^2	Abund. Index	% of Sight.[4]	First & Last Obser.	Assoc. Birds[5] (%)	Assoc. Bowhead
A	Shelf Break N of Shingle	1982	5 [1800] (2)	92 (28)	11 (7)	248 (189)	4400	30	Aug. 19 (Sept. 13)	0	no no
B	N of Cape Dalhousie	1982	8 [2800] (1)	182 (22)	27 (3)	307 (326)	8700	59	Aug. 24 (Sept. 12)	63	yes yes
C	NW of Cape Dalhousie	1984	4 [1400]	57	15	192	2700	58	Aug. 22 Aug. 22	100	no
D	NW of Cape Dalhousie	1986	3 [1060]	40 ?	15	180	1900	19	Aug. 31 (Sept. 23)	33	yes yes
E	Tuktoyaktuk Pen. Shelf	1986	(3) 2[6] [1800]	(31) 29	(15) 6	(278) 129	2300	23	(Aug. 21) Sept. 10	57	no no
F	Yukon Coast	1986	1 [350] (1)	9 (9)	6 (6)	121 49*	400	4	Sept. 7 (Oct. 3)	0	yes yes

( ) - based on local or non-synoptic regional surveys
* - based on reconnaisance format surveysiawv
1 Reference to Figures 2-8 to 2-11
3 number transect segments with densities $\geq$100 seals/100 km^2; area= # segments x 353 km^2 per segment
4 Calculated for regional, synoptic surveys only
5 % of transect segments in aggregation which had birds associated with seals
6 three additional transect segments with densities 67-94 seals/100 km^2

of the aggregations, extrapolated from the number of transect segments in each aggregation, varied from approximately 350 km^2 in nearshore waters off the Yukon coast (August 1986), to 2800 km^2 north of Cape Dalhousie (August 1982).

More seals were seen in aggregations in August 1982 (89% of sightings) than in either August 1984 (58%) or August-Sept. 1986 (46%) (Table 2-8). Abundance indices for ringed seals in the six aggregations varied from 400 (Yukon coast 1986) to 8700 (north of Cape Dalhousie, 1982). Densities in aggregations ranged from 121 to 326 seals/100 km^2, whereas over the region as a whole, densities ranged from 7.9 to 42.2 seals/100 km_2 (Table 2-3). Seals were sighted in smaller numbers in neighbouring transect segments (not included in Table 2-8), considered to be at the periphery of the aggregation areas, but not at densities $\geq$100 seals/100 km^2.

Ringed seals aggregated 50-100 km north and northwest of Cape Dalhousie ("B" in August-September 1982, "C" in August 1984, and "D" in August-September 1986), 20-70 km north of the Tuktoyaktuk Peninsula on over the continental shelf ("E" in August-September 1986), and along the Yukon coast between Kay and Shingle points ("F" in September-October 1986). A fourth area, located 90-110 km north of Shingle Point at the edge of the continental shelf had relatively high ringed seal densities in 1985 and 1986 (e.g. maximum of 41 seals/100 km^2 on September 5, 1986), but did not meet the criteria used here for an aggregation. This area is approximately 50 km north of aggregation "A" seen in August 1982.

Seal aggregations "D" (surveyed August 31, 1986) and "E" (August 21 and September 10, 1986) may have been part of the same (larger) aggregation. A subsequent survey of aggregation "D" on September 23 was hampered by weather, although the number and location of sightings made under relatively rough seas suggested that certainly whales and possibly seals were still concentrated there at that time.

Portions of the two ringed seal aggregations seen in late August 1982 were resurveyed three weeks later, and in 1986, portions of the three areas of seal aggregation were surveyed at least once more after their initial observation. Assuming seals remained in the area for the period separating the surveys, it appears the aggregations persisted for a period of several weeks (as opposed to days). Four of the six aggregations were surveyed again 19 to 26 days after their first observation, and in each case, observed seal densities indicated an aggregation (as defined here) was still present.

Other Marine Mammals

Bearded Seals

Under optimum survey conditions, bearded seals could be distinguished from ringed seals on the basis of size and colour, and, occasionally by their behaviour and/or observation of the 'square flipper'. They were much less common than ringed seals. The ratio of ringed:bearded seal sightings ranged from 17:1 (1982) to 49:1 (1984).

Bearded seals were seen in groups of one, two and three (Table 2-4: Figure A2-1). The number of bearded seal groups seen per transect segment ranged from zero to two (Figure A2-2). In August 1982 (the only survey with a sufficient sample size), the V/M ratio (1.02) and index of dispersion (I_d=12.32, df=12, p>0.25) suggest no differences in the size of bearded seal groups. However, in August 1982, there were apparent differences in the distribution of groups among transect segments (I_d=130.00, df=104, p<0.05, Table 2-4).

The number of bearded seals per transect ranged from zero to five. The clump factor ratio (1.17), V/M ratio (2.10) and index of dispersion (I_d=31.31, df=15, p<0.01) suggest that bearded seals were clumped at the regional scale in 1982 (Tables 2-8 and 2-9). This is attributed to sighting 14 of the 18 seals in 1982 in the same general area (offshore of the Tuktoyaktuk Peninsula, approximately 50-100 km north of Cape Dalhousie) (Figure 2-12; Figure A2-3). This area appears a preferred habitat for bearded seals, since most of the bearded seal sightings (32 of 39) were made here.

Bowhead Whales

Bowhead whales were observed in groups ranging from one to five (Figure A2-4). Variance to mean ratios and indices of dispersion suggest a random distribution of bowheads into groups in each year except 1986 (Table 2-4; Figure A2-4). There were no statistical differences in the frequency distribution of bowhead group sizes among years (G=19.22, df=12, p>0.05).

The number of bowhead groups observed per transect segment ranged from zero to five (Figure A2-5). Variance to mean ratios and indices of dispersion suggest the distribution of groups among transect segments was non-random in all years (Table 2-4). As for ringed and

Table 2-9

Error coefficients of variation (E), clump factors (C), clump factor ratios, mean density (#/100 km^2), 95% confidence interval (C.I.), and standard error (SE) for bearded seals, bowhead whales and beluga whales in the SE Beaufort Sea during late summer 1982, 1984-86

Survey	km^2 surveyed	# transects	# on-trans. sightings	E_1	E_2	C_1	C_2	C_1/C_2	mean density	C.I.	SE
Bearded Seals											
Aug. 1982	731	16	18	0.3393	0.3141	2.07	1.78	1.17	2.46	(2.04- 2.87)	0.19
Aug. 1984	665	14	2*	0.6686	0.7393	-	-	-	0.30	(0.17- 0.43)	0.06
Aug. 1985	757	25	2*	0.7048	0.7220	-	-	-	0.26	(0.18- 0.34)	0.04
Aug-Sept. 1986	1085	22	8*	0.5143	0.4768	-	-	-	0.74	(0.58- 0.90)	0.07
Bowhead Whales											
Aug. 1982	2923	16	43	0.3042	0.2294	3.98	2.26	1.76	1.47	(1.29- 1.65)	0.08
Aug. 1984	3326	14	8*	0.4094	0.3780	-	-	-	0.24	(0.19- 0.29)	0.02
Aug. 1985	3784	25	28	0.4691	0.2877	6.16	2.32	2.66	0.74	(0.65- 0.83)	0.04
Aug-Sept. 1986	5425	22	32	0.4172	0.3538	5.57	4.00	1.39	0.59	(0.50- 0.68)	0.04
Beluga Whales											
Aug. 1982	2923	16	82	0.6585	0.6933	35.56	39.42	0.90	2.81	(1.77- 3.85)	0.49
Aug. 1984	3326	14	47	0.4308	0.5093	8.72	12.19	0.72	1.41	(0.99- 1.82)	0.19
Aug. 1985	3784	25	74	0.2732	0.2601	5.52	5.01	1.10	1.96	(1.75- 2.17)	0.10
Aug-Sept. 1986	5425	22	11*	0.6703	0.6394	-	-	-	0.20	(0.14- 0.26)	0.03

* sample size too small for C_1/C_2 to be meaningful

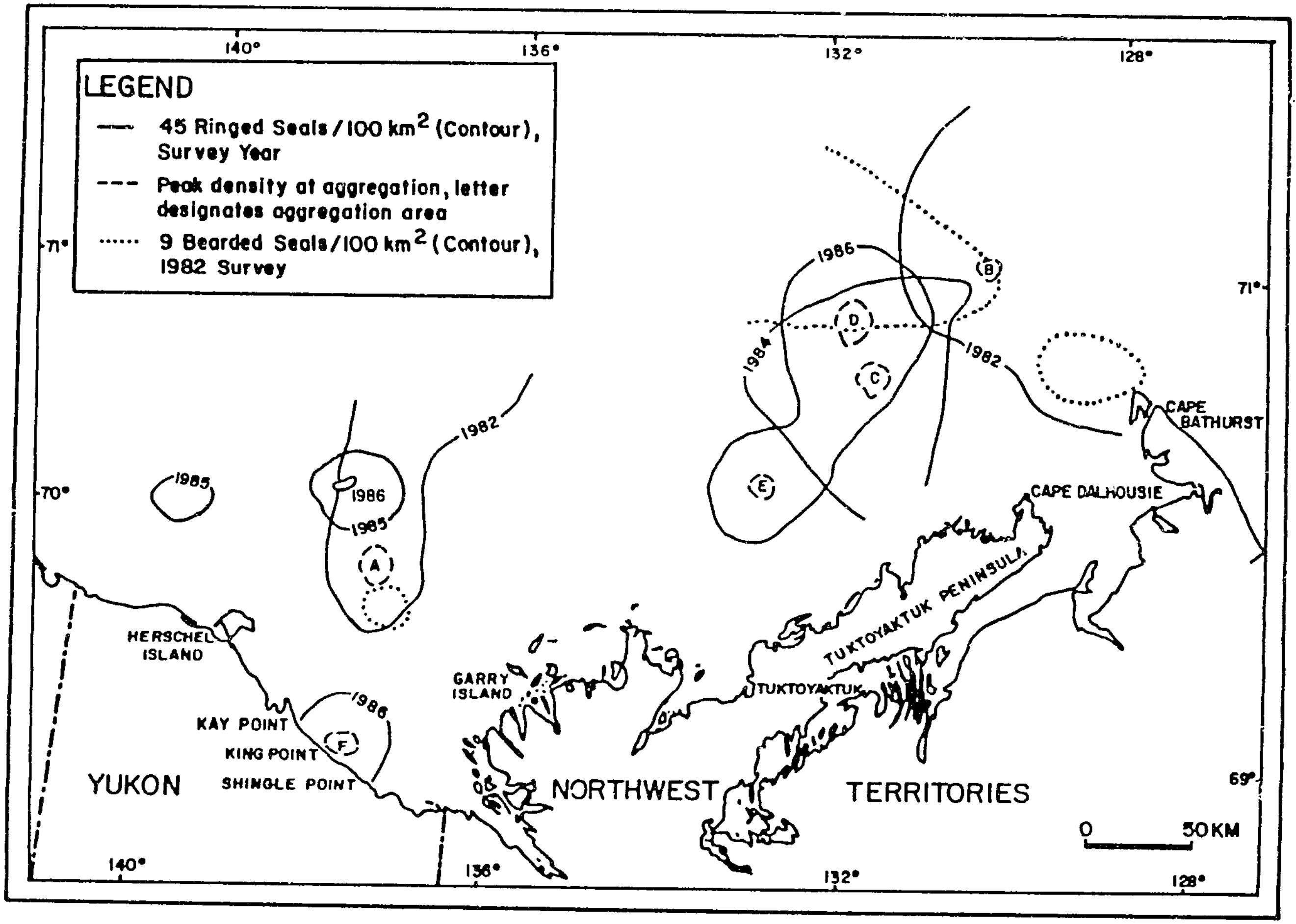

Figure 2-12. Approximate locations where ringed seals and bearded seals aggregated in the southeast Beaufort Sea during late summer, 1982, 1984-1986

bearded seals, the non-random distribution at this scale reflects that most transect segments had no sightings (Figure A2-5).

The number of bowheads observed per transect ranged from zero to 12. Variance to mean ratios, indices of dispersion (Table 2-4), clump factors (Table 2-9), and contour maps (Figure 2-13, Figures A2-6 to A2-8) suggest clumping of bowheads in all surveys at the regional scale. Bowheads aggregated in the same geographic area (e.g. Yukon coast, interface of Mackenzie Plume with offshore, offshore Tuktoyaktuk Peninsula) in more than one year, but there was no one area where they aggregated in all years. Aggregations along the Yukon coast and at the interface, separated by 30-40 km, appear as one larger area on the contour maps for 1985 and 1986 (Figure 2-13).

Sample size was too small (n=9) in 1984 to do the distribution analyses because some of the areas where bowheads aggregated were surveyed under less than optimum conditions for seals (and thus considered unsampled here). However, in that year bowheads were aggregated along the Yukon coast, offshore of Cape Dalhousie, near Cape Bathurst and in southwest Franklin Bay (Harwood and Borstad 1985).

Beluga Whales

Beluga were seen in groups ranging from one to 20 (Figure A2-9). The frequency distribution of number of beluga per group did not fit a Poisson distribution in 1982 ($G=44.46$, $df=3$, $p<0.001$), 1984 ($G=10.40$, $df=2$, $p<0.01$) or 1985 ($G=9.46$, $df=2$, $p<0.01$), indicating a non-random

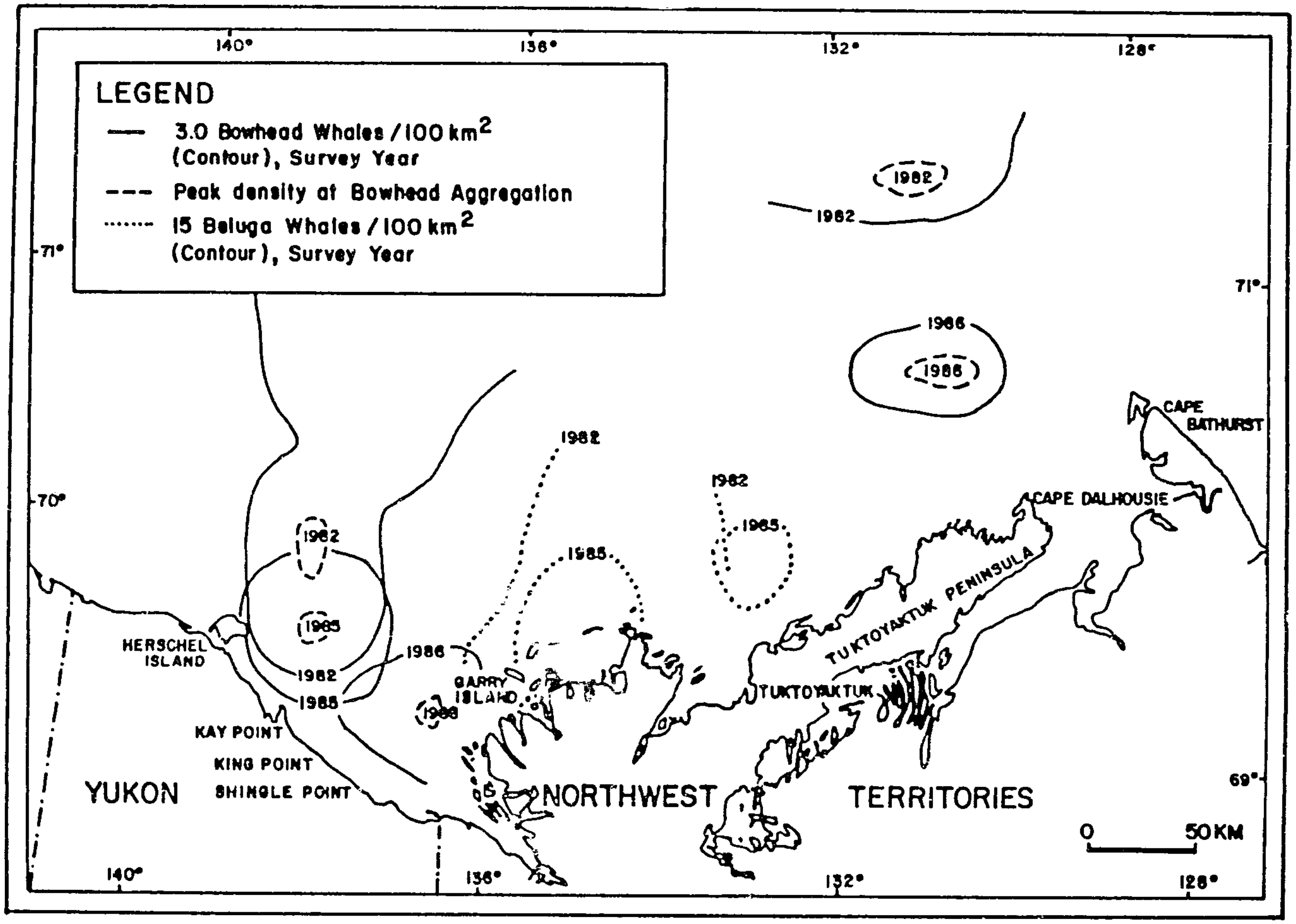

Figure 2-13. Approximate locations where bowhead whales and beluga whales aggregated in the southeast Beaufort Sea during late summer, 1982, 1984-1986

distribution of beluga group sizes. Variance to mean ratios and indices of dispersion (Table 2-4) suggest a clumped distribution of beluga at this scale only in 1982 and 1985. Between year differences ($G=87.07$, $df=21$, $p<0.001$) in distribution of group sizes were attributable to the 1982 survey (Table 2-4). In that year, one group of 20 and two groups of 10 were sighted; these were the only instances in all surveys of groups larger than six.

The number of groups of beluga per transect segment ranged from zero to six (Figure A2-10). Variance to mean ratios and indices of dispersion suggest clumping of groups along transect segments (Table 2-4). There were no apparent differences between years in the frequency distribution of number of groups per segment ($G=28.27$, $df=21$, $p>0.10$), suggesting the departure from a random distribution was of similar magnitude and direction in each year.

The number of beluga per transect ranged from zero to 53. Variance to mean ratios and indices of dispersion (Table 2-4) suggest clumping of beluga at the regional scale in all years, particularly in 1982 when the three large groups were seen. The clump factor ratios (Table 2-9) and contour maps (Figure 2-13, Figures A2-11 to A2-13) suggest beluga were clumped at the regional scale in August 1985, but not August 1982 or 1984.

In all surveys, the distribution of beluga was characterized by individuals or small groups (2-6 whales) widely distributed offshore, particularly north of the Mackenzie River estuary (Figure 2-13). As for ringed seals, beluga sightings tended to consist of 'groups of groups' as shown by results from the group and local scales. As shown on Figure 2-13, there were no large areas in the offshore that were attractive to beluga as was the case for bowhead whales and seals.

The return fall migration of beluga usually occurs in August, earlier than that of bowheads. The surveys were conducted during the fall migration period, and in the case of 1986 (August 31-September 10), probably after it. Thus all of the data collected on beluga reflect, and are probably strongly influenced by, migratory behaviour.

Overlap in the Distribution of Ringed Seals and Other Marine Mammals

By comparing the contour distribution maps (Figures 2-12 and 2-13), it is apparent that ringed seals, bowheads and bearded seals at times aggregated in the same general area. For example, bearded seals aggregated at the same general location as ringed seals in aggregation "B" in 1982. Bowheads occurred in the same general location as ringed seal aggregations "B", "D" and "F" in 1982 and 1986.

However, when the resolution is increased, it was apparent that the species were not aggregated along the same transect segments. There were negative correlations for all pair-wise comparison of species (Spearman ranked correlation, $p<0.0001$) along transect segments, except for ringed seals and bearded seals for which there was no correlation ($p=0.8145$).

2.4 DISCUSSION

SURVEY METHOD

When techniques are standardized and biases minimized, visual census remains the most appropriate and cost-effective method for Arctic marine mammal survey work (Smith et al. 1985; Kingsley et al. in prep). Systematic surveys are appropriate for a study such as this with objectives of mapping distribution and assessing relative abundance (Caughley 1977). The costs of positioning aircraft and fuel in such a large region necessitate use of a systematic (vs randomized) design (Robertson and Robertson 1985).

It is difficult to obtain representative distribution data through aerial census, particularly when the species being studied is small, widely distributed, and the study area is large. Counts have to be extrapolated to large unsurveyed areas. Sampling intensity is generally low, and dependent on size of study area and availability and range of survey aircraft (Caughley and Grigg 1981). Changing weather and ice conditions, and the potential for differential movements and surfacing behaviour of certain age classes complicate this further (Smith 1987). Not all animals in a given group are necessarily at the surface during a survey pass, and it is possible that animals in large groups are more readily detected than individuals.

Interpreted in the broad sense intended, the results of this study provide reasonable estimates of trends in marine mammal distribution and relative abundance since the most fundamental biases associated with open water surveys (Holt and Cologne 1987) were minimized. This was achieved by analyzing only data collected under optimum conditions, and through ensuring consistency with respect to observers, survey aircraft and survey parameters according to standardized criteria (Harwood et al. 1986; Norton et al. 1987).

Further (and costly) refinement of the method (e.g. examination of surfacing behaviour of various age classes) or further analysis (e.g. attempting to correct for differences among observers, variable survey conditions, etc.) would in most cases be impractical, and not expected to alter broad trends presented here. The method could be improved by flying three or four aircraft simultaneously during periods of optimum survey conditions, thereby reducing temporal and spatial gaps in survey coverage. Synoptic and complete coverage, under periods of calm conditions, is required for a consistent and meaningful comparison of distribution of a species within and among years.

Alternate survey altitudes are necessary for survey work in this region to accommodate changing weather patterns (Stirling et al. 1982; Kingsley 1986). Statistical differences in seal detectability attributable to changes in survey altitude and transect width were not detected in this study. Individual seals are generally not detectable at distances >400 m of the flight path under optimum (calm, no glare) conditions (Harwood and Ford 1983). Thus, the number of seals sighi by an observer searching a 1000m or 800m strip was expected to be lower than when a 400m wide strip was used, since half or more of the search time is expended over water where seals cannot be seen. However, search time (proportional to speed of the aircraft) expended over the inner 400m of the strip, when using a 800m or 1000m strip, was apparently sufficient to allow detection of seals with the same frequency as when observers just searched a 400m strip.

I attribute equal detectability at the different transect widths and altitudes used in this study to the fact that all of the data used for the analyses were collected under calm conditions. Under such conditions, seals create an obvious and easily detectable surface disturbance which is usually the first cue to their presence. If sea states are greater than 2 on the Beaufort Scale (whitecaps, waves), movement and disturbance cues are no longer available, and seals are virtually undetectable regardless of survey altitude, transect width, aircraft speed, etc. It is also possible that seals spend a large proportion of their time at the surface when conditions are calm, as has been suggested for cetaceans (Leatherwood et al. 1982), thereby increasing the length of time for detection.

ANALYSIS OF DISTRIBUTION BY SCALE

The number of marine mammals in a given group probably reflects interactions between individuals, possibly a combination of tolerance and benefits of cooperative feeding. The number per group may also be influenced by size or density of prey in a localized feeding area ("patch size").

While the group scale examines clumping into groups, the local scale examines clumping of the groups themselves. Factors that might influence the number of groups in a given area could include small-scale oceanographic features (e.g. localized temperature gradients) which influence the distribution and abundance of zooplankton patches (Omori and Hamner 1982; Hamner 1988). However, since ringed seals were clumped in the same geographic areas at both the local and regional scales, it appears that the local scale reflects factors operating at the regional scale (and is therefore another measure of it). For this reason, emphasis in this discussion is placed on the regional scale.

The regional scale depicts broad areas of the region in which groups were aggregated. This scale is influenced by large-scale oceanographic features, such as the Mackenzie River plume, ice, or where areas of open water (polynyas) occurred during the previous winter. These features produce conditions favourable for zooplankton (and probably also cod which feed on zooplankton) in this (Borstad 1985; Thomson et al. 1986; LGL 1988) and other regions (Mackas et al. 1980).

RINGED SEAL

The relative abundance of ringed seals during the open water period varied among years. Densities were highest in 1982, declined through 1984 and 1985, and increased again in 1986. Similar fluctuations in the abundance of ringed seals with coincident changes in seal reproductive success were reported in the mid-1970's (Stirling et al. 1982; Smith 1987), along with consequent effects on polar bears (Stirling et al. 1976; Kingsley 1979).

There is presumably more flexibility in group structuring during the open water period than during ice-covered periods because predators are absent. In the presence of predators, such as for ringed seals in winter and spring (Stirling 1977), and for harbour seals during haul-out (da Silva and Terhune 1988), group structuring is, at least in part, an anti-predator strategy.

Indeed there was a high degree of variability in group structuring in ringed seals during the open water period, both within and among years. Most groups with six or more seals were located in the aggregation areas, and all groups with 9 or more seals were in aggregation areas (by definition). It is possible that group size in the open water period increases along with patch size and availability of food items, as has been described for harbour seals (Harkonen 1987). It is possible that group size increases with abundance, as found by Kingsley (1989) for ringed seals during spring haul-out in the High Arctic.

During late summer of 1982, 1984, and 1986, ringed seal groups were clumped in aggregation areas. Aggregations have been reported for this region in late August of two other years (1980, 1983) when surveys were conducted (Renaud and Davis 1981; McLaren and Davis 1985). In this study, aggregations varied in size, location, geographic extent, and with respect to what other species occurred there at the same time. They appeared to persist for several weeks. Seabirds and bowhead whales were seen in association with ringed seals in some but not all aggregations. The possible importance of these aggregations to fall feeding is discussed in Chapter 3.

The distribution of ringed seals in the open water period was markedly different from that seen during ice-covered periods. The latter is influenced by ice conditions (Stirling et al. 1982; Kingsley 1986), and is usually characterized by relatively small, widely distributed groups and individuals. This probably relates to seasonal changes in the activities of the seals (from feeding to reproduction and then moulting), habitat (from open water to ice), and predation (from absence to presence of polar bears).

During winter and spring, adult seals occupy and defend territories, maintain breathing holes, are preyed upon by polar bears, reproduce (pup, mate, lactate), and finally, haul-out on the sea ice to moult (Smith and Hammill 1981; Stirling et al. 1982; Smith 1987). Predation by polar bears is believed to have been responsible, at least in part, for distribution patterns and small group sizes seen in winter and spring, the alert behaviour of basking seals, and other characteristics of the species such as pup colour, parturition sites and adult size (Stirling 1977). The only large groups (e.g. 50 seals) seen during spring haul-out surveys occur along the length of cracks, with each individual having an immediate escape route to the water.

In late summer and fall, polar bears retreat with the pack ice and predation ceases until freeze-up. In the absence of terrestrial predators, distribution and behaviour are expected to be influenced by other factors, such as food availability, since the negative influence of the predator would not prevail. Further, with reproduction and moulting activities complete, there would be time and energy available to ringed seals for extensive feeding.

OTHER MARINE MAMMALS

Like ringed seals, bearded seals are resident in the region and reproduce annually (Smith 1981). Bearded seals are benthic feeders (Mansfield 1967), and tend to occur most often over shallow depths where food is both abundant and accessible. The feeding habits of bearded seals in late summer and fall are different from that of ringed seals (e.g. Kosygin 1971; Finley and Evans 1982), but both are opportunistic.

Bearded seals occurred most often individually, as was also reported by McLaren and Davis (1985) for late summer surveys in this region in 1983. Group structuring in bearded seals was less variable among years than for the other species. Size and distribution of benthic prey species eaten by bearded seals differ from the pelagic ones used by bowheads and ringed seals, but little is known about this aspect. However, it seems that bearded seals most often forage individually at all times of the year.

Bearded seals were aggregated at the regional scale during August 1982; the aggregation in 1982, and most sightings of bearded seals in all surveys, were located in shallow waters (<50m) offshore of the Tuktoyaktuk Peninsula. Bearded seals were most common in this area in other open water surveys (e.g. McLaren and Davis 1985), and in spring surveys (Stirling et al. 1982; Kingsley 1986). Thus, bearded seals showed little change in distribution among seasons or years, consistent with the suggestion of Cleator (1987) that bearded seal stocks are relatively sedentary.

The western Arctic stock of bowhead whales winters in the Bering Sea, and undertakes an annual migration to summer feeding areas in the southeastern Beaufort Sea. The current estimate of bowhead stock size is 7800 (Zeh et al. 1988), which represents approximately 30-56% of the initial (pre-exploitation) stock size given by Breiwick et al. (1981). Bowheads are present in Canadian waters from May through to late September or October, or about 150 days. Feeding, the major activity of bowheads on their summer range, has been studied in both Canada (IGL 1988) and Alaska (Lowry et al. 1978; Richardson 1987).

Differences in group sizes among years were less pronounced in bowhead than in ringed seals, and were not statistically significant. This suggests that while group sizes of bowheads may vary, they do not do so to the same extent as for ringed seals. Actively feeding at this time of year, bowheads probably have less flexibility in group structuring because they are large and have large food (and thus patch size) requirements.

The distribution of bowhead whales during late summer 1982, 1984-1986 was clearly aggregated at the regional scale and, similar to ringed seals, the number of aggregations, and the location and intensity of aggregation varied among years. There was direct and indirect evidence that bowheads were feeding in the areas where they were aggregated (Harwood and Ford 1983; Harwood and Borstad 1985; Duval 1986; LGL 1988), and that prey were abundant in areas where they aggregated (LGL 1988).

The Mackenzie stock of beluga whales winters in the Bering Sea, migrates annually to summer areas in the Mackenzie River estuary and

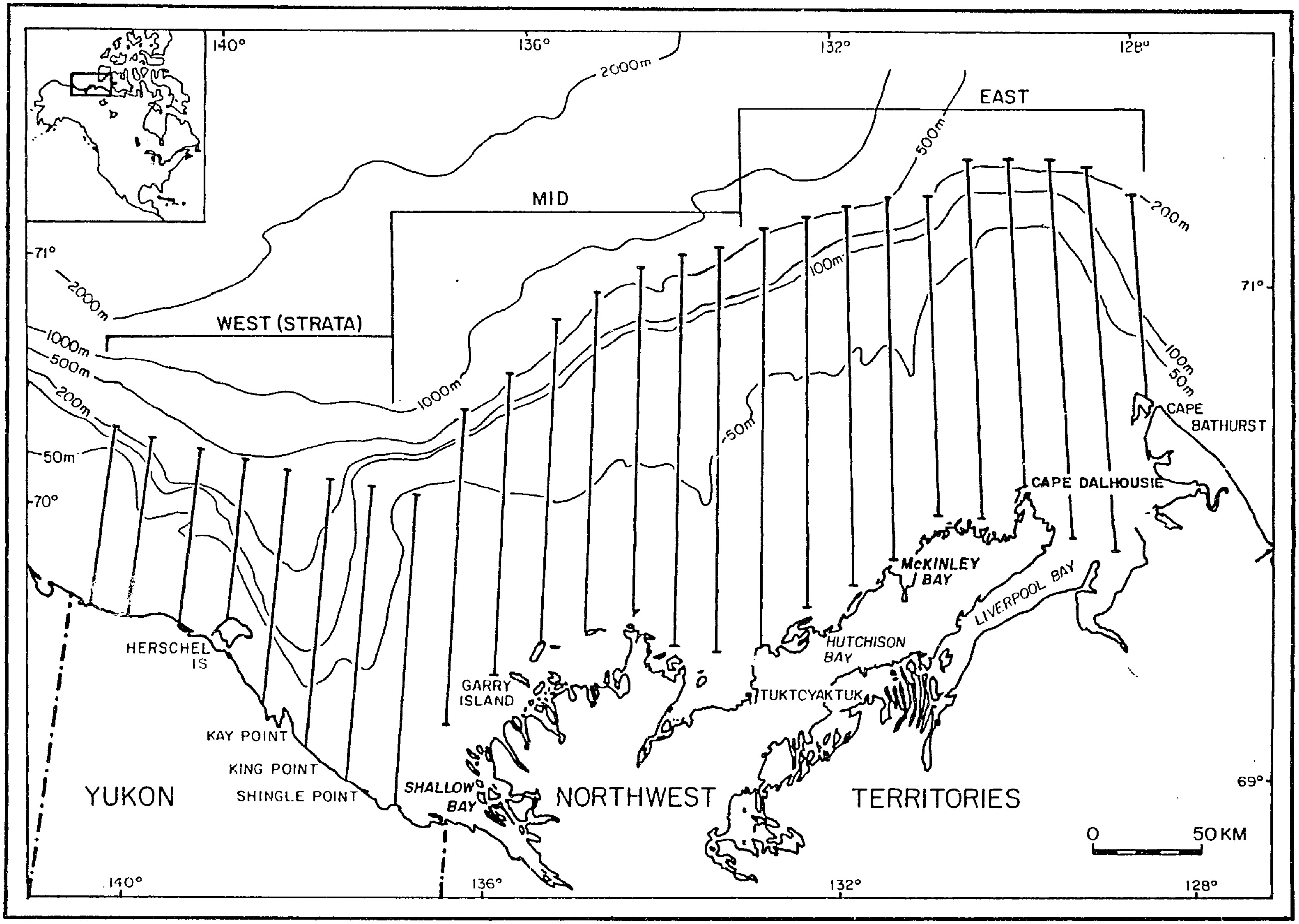

Figure 2-1. Bathymetry of the southeast Beaufort Sea and approximate location of survey transects and strata boundaries for aerial surveys August-September 1982, 1984-1986

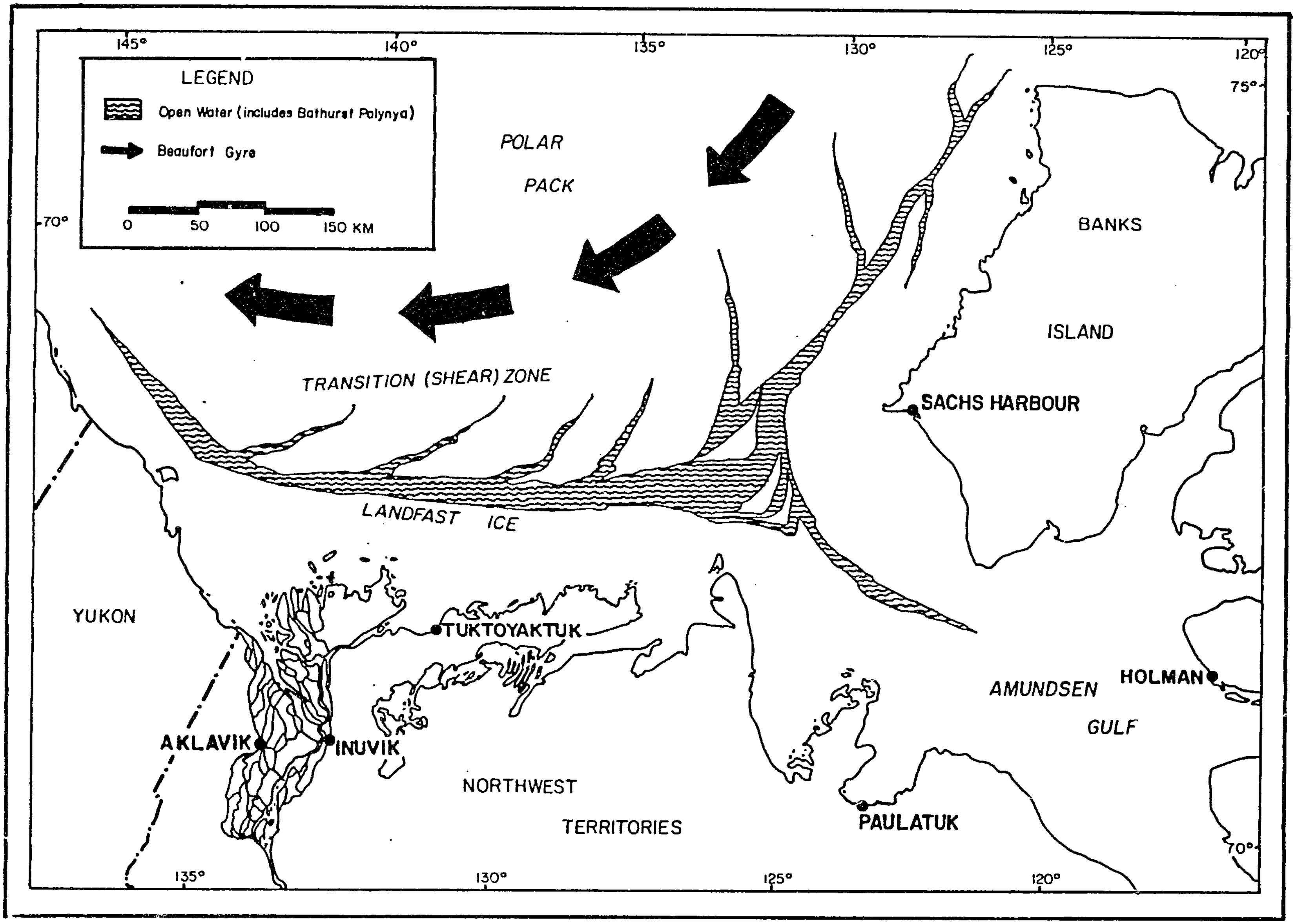

Figure 2-2. Approximate location of winter and spring ice zones in the southeast Beaufort Sea

AERIAL SURVEYS

Survey Timing and Location

Six regional systematic aerial surveys were conducted over the southeast Beaufort Sea during late August and September 1982, 1984, 1985, and 1986, and weather permitting, included coverage of transects shown on Figure 2-1 (Transect coordinates Appendix 1). Surveys were flown along standard and predetermined north-south transects following lines of longitude. At 70° N latitude, transects were spaced at intervals of 16 km (1982) or 20 km (1984-1986). Survey progression was west to east when weather permitted. Transects were truncated after flying for 30 km over consolidated ice.

The survey area was stratified to increase precision of abundance estimates (Caughley 1977). Strata boundaries were determined on the basis of major oceanographic features; strata are "west" -Yukon coastal and offshore waters (19,000 km^2), "mid" -Mackenzie River plume and adjacent offshore waters (26,000 km^2), and "east" -continental shelf off the Tuktoyaktuk Peninsula (35,000 km^2) (Figure 2-1).

Local systematic surveys (flown over a specific location) and a reconnaissance survey (flown along a coastline, not along transect lines) were flown in August-October 1986, over seal aggregation areas observed during the 1986 regional survey. Transect lines for the local surveys were established at equal intervals and spaced as a function of the size of the area to be surveyed and air charter time available (Appendix 1).

The first local survey was flown August 21, 1986, prior to the start of both the regional aerial survey and the oceanographic sampling program (Chapter 3). The survey was flown offshore of the Tuktoyaktuk Peninsula along four transect lines (110-185 km in length, spaced at intervals of 39, 42 and 55 km), three of which were the same as those sampled for zooplankton (Chapter 3). Four transects ranging from 70 to 90 km in length, spaced at intervals of 10 km, were flown north of Shingle Point over the Mackenzie River plume interface on September 5, 1986. Seven transects 60 km in length, spaced at intervals of 15 km, were flown September 23 approximately 50-100 km offshore of Cape Dalhousie between 132°50' and 129°25' W Longitude. One other survey of the same area (September 6, 1986) had to be cancelled due to unforecasted high sea states. A reconnaissance survey (325 linear km) was flown October 3, 1986 between Shingle Point and Herschel Island. West- and eastbound flights were positioned 3-4 km and 1 km from shore, respectively.

Survey Design and Procedures

All surveys were conducted from de Havilland Twin Otter aircraft based out of Tuktoyaktuk, NWT (1982) or Inuvik, NWT (1984, 1985, 1986). The aircraft had either a Global Navigation System (GNS-500) or Collins LRN-70 for navigation, a radar altimeter, a bubble window at the left search position, and an intercom for communication among observers and pilot.

Target survey speed was 200 km/h (108 knots), but varied ±15% due to wind effects. Survey altitude was either 152 m (500 ft) or 305 m (1000 ft), depending on objectives, cloud ceilings and survey conditions. Surveys were conducted when the sun was most directly overhead (1100 h to 1900 h) to minimize glare. Surveys were attempted when sea state was 5 or less on the Beaufort Scale of Wind Force, and when ceilings were greater than 152 m. These are considered minimum conditions for observing bowheads (Davis et al. 1982; Norton et al. 1987), the primary objective of most survey flights.

At least two experienced observers were present on each flight. Using a strip transect method (Caughley 1977), the designated search area was 800 m per side in 1982, and 1000 m per side in 1984, 1985, and on regional surveys in 1986. Localized (seal specific) surveys in 1986 used a strip width of 400 m per side, equivalent to that used in earlier seal surveys in this region (Stirling et al. 1982; Kingsley 1986). Transect width and spacing led to survey coverage of 2.1% for seals (1 observer, narrower strip) and 10% for whales (2 observers, wider strip).

Where possible, hand-held Suunto PM5/360S inclinometers were used to determine the lateral distance of sightings from the flight path, and in 1986, to mark the transect search area on the bubble window. The angle of depression from horizontal was measured when the animal was at a right angle to the aircraft, and the lateral distance from the aircraft calculated on the basis of this angle and survey altitude.

Observers recorded information on all marine mammals sighted on to audio cassette tapes, and later transcribed this to data sheets. A small number of seals (n=3 in 1982, n=7 in 1986) and polar bears (n=3 in 1984, n=1 in 1985) were observed on the ice surface, but these data were excluded from the analyses. Information recorded for each marine mammal sighting included wherever possible:

-species
-number of individuals
-number in group
-time of sighting
-location of sighting
-habitat characteristics
-distance between individuals, group organization
-behaviour
-movement, relative rate and direction
-presence of seabirds or other marine mammals

The geographic location of each sighting was recorded from the navigation system as distance from the end of the transect. Synchronized digital watches were used to record the start and end times for each transect, and the time of each sighting.

While surveying, a group of seals was defined as two or more individuals within close physical proximity (estimated five body lengths), and a group of whales as two or more whales within five body lengths, or, two or more whales moving in the same direction and at the same rate within about 500 m of each other (Harwood and Borstad 1985). A group of seals or whales or a solitary seal or whale constitute a 'sighting'.

Detailed records of survey conditions were kept throughout. We recorded sea state according to the Beaufort Scale of Wind Force, and ice in tenths (<1/10, 1-3/10, 4-6/10, 7-9+/10) according to WMO (1970) ice concentration categories. Other information recorded included water colour (against a 6-colour chart I prepared in 1984), and the locations of oceanographic fronts and industrial activities. These data are reported elsewhere (Harwood and Ford 1983; Harwood and Borstad 1985; Duval 1986; Ford et al. 1988).

DATA ANALYSIS

Survey Conditions

The effects of sea state and glare on detectability of other marine mammals have been well documented (e.g. Davis et al. 1982; Holt and Cologne 1987). Harwood and Ford (1983) found ringed seals were not consistently detectable when sea states exceed 2 on the Beaufort Scale of Wind Force (5 of 810 sightings made with sea states >2). Since minimum survey conditions set for the regional surveys (selected for detectability of bowheads) were not rigorous enough for reliable and consistent detection of seals, all survey condition notes were reviewed, and areas and times where conditions were not optimum were deleted (considered unsampled).

The criteria used for these optimum conditions for seal detectability were sea states of 0 (sea like a mirror), 1 (ripples but without crests), or 2 (small wavelets with glassy crests that do not break) on the Beaufort Scale of Wind Force, and no forward glare. Since all of the data used here were collected under optimum conditions (this occurred on 11,500 linear km, or 49% of the total transect distance), bias and error associated with survey conditions were minimized.

Of the six regional surveys, coverage during four of these was sufficiently complete and synoptic to determine broad trends in distribution and abundance of ringed seals. These four surveys, referred to as regional synoptic surveys, are used in all analyses and were conducted: August 18-24, 1982, August 18-27, 1984; August 18-24, 1985; August 31-September 10, 1986. Even these surveys had unsampled areas (gaps in spatial or temporal coverage) due to (1) occurrence of localized areas with less than optimum survey conditions, (2) truncation of transects due to ice, and (3) operation of two aircraft and using data from only one. While these interruptions in sampling are not expected to alter the broad trends discussed here, they do require that the data are interpreted accordingly (e.g. surveys delineate some but not all areas of aggregation, some but not all areas where marine mammals occurred at low densities, etc.).

Optimum condition portions of the other regional surveys (September 1982, September 1984, September 14, 1986) were insufficient for examination of regional distribution patterns, as were the 1986 localized and reconnaissance surveys, but are used to provide further information on seal aggregations.

Observer Variability and Seat Position

To maximize consistency both within and among years, I analyzed only data on seals that I collected myself. The same seat position, with a bubble window, was used in each year except 1985 (co-pilots' seat).

Data on whales collected by the two primary observers were used since each was trained and experienced, combinations of the same (four) observers were involved over all years, and the main objective for each was to observe whales. Although two aircraft were operated concurrently in 1984, only the data collected from the aircraft my regular partner and I were in has been used for analyses for that year.

Transect Width and Survey Altitude

Over the four years of the program, three different transect widths (400m, 800m, 1000m per side) and two different survey altitudes (152m, 305m) were used, which was unavoidable because of variation in objectives and weather conditions. Two tests were done to see if different survey altitudes and strip widths had a significant effect on seal detectability.

The region was subdivided into 228 essentially square subareas or 'grid cells', after the method described by Robertson and Robertson (1985). Each grid cell is 18.5 km (10' latitude) by 19.1 km (30' longitude at 70^{o} N latitude), and has an approximate surface area of 353 km^2. Sampling units were 18.5 km transect segments within each grid cell.

A 3-way analysis of variance (SAS 1985) was run using ranks of ringed seal densities (calculated using an effective strip width of 400m) along transect segments as the dependent variable, and, transect width, altitude and year as the independent variables. This was done separately for each of the three strata. Second, the mean densities of ringed seals recorded by two observers were compared using a Mann-Whitney U statistic using data collected when both searched simultaneously on opposite sides of the aircraft, using transect widths of 1000m (left side) and 400 m (right side) at constant altitude (305 m). Survey coverage using this format was done for 68 transect segments under optimum survey conditions in August 1986.

Relative Abundance

Harwood and Ford (1983) made 74% of their ringed seal sightings (n=148 groups inclinometer readings taken) on the inner 400 m of the strip. Thus, an effective transect width of 400m was used for calculation of seal densities in all cases in this study, regardless of the width of the transect searched. Density of whales was calculated on the basis of search area (1.6 km in 1982, and 2 km in 1984, 1985, and 1986), since they are detected with equal frequency across transect strips up to 1 km wide (Davis et al. 1982; Harwood and Borstad 1985; Duval 1986; Ford et al. 1988).

To examine trends in abundance for each species, estimates of density and standard error were calculated for each year using the transect as the sampling unit. Mean regional density ($\hat{R}$) was calculated for each species and survey (equation 1), and variance (s_2^2) using equation (2) developed by Kingsley and Smith (1981) for systematic aerial survey data:

$$\hat{R} = \frac{\text{total number of on-transect sightings}}{\text{total area surveyed}}$$

$$= \frac{Y_i}{X_i} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$s_2^2 = \frac{\sum(d_i - d_{i+1})^2 \ (n)}{2 \ (n-1) \ (\sum X_i)^2} \qquad \text{where } d_i = Y_i - \hat{R}(X_i) \ldots\ldots\ldots\ldots (2)$$

Standard error (SE) was calculated $SE = s/\sqrt{n}$. T-tests for samples whose variances were unequal were used to evaluate differences in species density between years (Sokal and Rohlf 1981).

To provide indices of abundance for ringed seals, the mean density for each stratum and survey was calculated using the transect as the sampling unit and equation (1). These were multiplied by total area of the respective stratum, to obtain an index of strata abundance. These were summed over all strata for each year to provide an index of annual regional abundance. These must be interpreted as indices, since they do not account for surfaced seals missed by observers, or seals underwater during the survey pass.

Mean regional densities were multiplied by species-specific biomass factors. Factors for ringed seals (34 kg per seal), bowhead whales (26 metric tonnes per whale), and belugas (800 kg per whale) were as described by Frost and Lowry (1984). Cleator (1987) cites references that bearded seals weigh between 180 kg and 290 kg; the biomass factor for bearded seals used here is the mean (235 kg).

Distribution

Group and Local Scales

For analysis of distribution at the group and local scales, the frequency distribution of the number of seals per group ("group scale") and the number of groups per transect segment ("local scale") was evaluated. For these tests, solitary seals were defined as a group of one. The variance to mean (V/M) ratio was calculated at each scale since the ratio of these two parameters equals one for a Poisson (random) distribution. The index of dispersion ($I_d = V(n-1)/M$) was calculated (Southwood 1978) and compared to a chi-square distribution to determine significance of departures of the V/M from unity.

Frequency distributions were compared to a Poisson distribution, and a log-likelihood goodness-of-fit test (G-statistic) was used to evaluate the differences between the observed and expected frequencies (Sokal and Rohlf 1981). Given that a group was defined as including at least one seal, the randomness of allocation of additional seals to groups was analyzed by comparing the number of seals per group minus one, to a Poisson distribution with the same mean.

Classes with small expected values were pooled so that the combined expected value was ≥ 5, and a Williams correction for continuity was applied. The test was only done for surveys and species for which there were at least three classes (df=2 or more). For computational purposes, sums in each category were increased by one since the logarithm of zero is undefined.

Rejection of the null hypothesis indicates departure from a Poisson distribution, and thus a non-random distribution. Non-random distributions can be regular or clumped, readily revealed by plotting the frequency histogram, and examining the V/M ratio. A V/M ratio significantly greater than one indicates clumping.

Between year differences in the frequency distributions of number of seals per group and number of groups per segment were evaluated using a heterogeneity G test (Sokal and Rohlf 1981), under the hypothesis that the number of individuals in each group size category (or number of groups per transect segment) did not differ among years. Rejection of the null hypothesis indicates departure from uniformity, and a distribution that varied among the years tested. Where significance occurred, contributions to the G statistic were examined to determine which year (or years) was significantly different from the others.

To evaluate if ringed seals, bowhead whales, beluga whales and bearded seals occurred along the same transect segments, a Spearman's ranked correlation (SAS 1985) was used. Marine mammal densities along transect segments, for all surveys combined, were compared using only non-zero pairs.

Regional Scale

Marine mammal distribution at the regional scale was evaluated using clump factor ratios derived by Kingsley et al. (1985) to describe ringed seal distribution during spring in the High Arctic (1980-1981), and in the Beaufort Sea 1974-79 (Stirling et al. 1982), and for open water beluga and narwhal surveys in the High Arctic in 1974, 1977, 1980-82 (Smith <u>et</u> <u>al</u>. 1985). Distribution at this scale is depicted with contour density maps prepared for each survey year and species (e.g. Bonnell and Ford 1987).

Estimates of density and standard error were calculated for each species and year using the transect as the sampling unit. Mean regional density ($\hat{R}$), for each species and survey, were calculated using equation (1). Variance (s_k^2) for $\hat{R}$ was calculated two ways, using equation (2) given earlier, and equation (3):

$$s_1^2 = \frac{\sum d_i^2/n}{(n-1)(\sum X_i)^2}, \quad \text{where } d_i = Y_i - \hat{R}(X_i) \ldots (3)$$

(Cochrane 1963, cited in Kingsley and Smith 1981)

An estimate of survey precision is given by the error coefficient of variation (E_k):

$$E_k = S_k^2 \,/\, \hat{R}\,, \qquad \text{where } k= 1,2 \ldots\ldots (4)$$

The clump factors (C_k) are a measure of dispersion of seal and whale distribution, given by:

$$C_k = (E_k^2)\ (\textstyle\sum Y_i) \qquad \text{where } k= 1,2 \ldots\ldots (5)$$

C_2 is a measure of clumping between adjacent transects, and C_1 is a measure of clumping as it occurs over all transects. The clump factors (C_k) are weighted by a constant (E_k), which is the square of the precision of that method, either by adjacent transects (E_2) or over all transects (E_1). Thus, C_1 is the mean group size weighted by the precision of considering the variance over all transects, and C_2 is mean group size weighted by the precision of considering variance between adjacent transects.

The ratio of C_1/C_2 provides an indication of the homogeneity of distribution across all transects (e.g. by longitude). A ratio of 1 indicates homogeneity across the study area, a value greater than 1 indicates clumping, and a value less than 1 indicates a random distribution.

The density of seals and whales along transect segments were calculated using SAS (1985), and assumed to apply to the grid cell in which they were located. Linear interpolation of density values at grid cell centerpoints was used to produce and smooth contour lines depicting annual distribution of each species using Surface II (Sampson 1978) on mainframe computer at the University of Alberta.

Areas of concentration were first noted during examination of standard plots of transect lines and sighting locations. Contour intervals were set at fixed values for each given species, so that distribution could be compared visually among years. Contour interval levels used for the four species were: 15/100 km^2 for ringed seals, 3.0/100 km^2 for bearded seals, 1.2/100 km^2 for bowhead whales, and 5.0/100 km^2 for beluga whales.

The resulting plots show broad areas of concentration (the geographic location of areas with close contours), and also the degree of concentration (the closeness of contours). The maps are indicators of broad trends in distribution, and due to smoothing, should not be interpreted as exact; data used to calculate cell densities are relative, and do not represent actual seal or whale abundance. Peaks exceeding six times the contour interval values (90/100 km^2 for ringed seals, 18/100 km^2 for bearded seals, 7.2/100 km^2 for bowhead whales, and 30/100 km^2 for beluga) are defined as aggregations at this scale.

Ringed Seal Aggregations

Locations where seals (and whales) aggregated at the regional scale are depicted on the contour maps as peaks. Transect segments with $\geq$100 seals/100km^2, equivalent to sighting 8 or more seals within two minutes when surveying at 200 km/h, are defined as aggregations at the local scale. Transect segments with aggregations were plotted on the appropriate contour map, to compare the location of aggregations at both the local and regional scales.

For each survey, density ($\hat{R}_a$) of ringed seals in each aggregation was calculated using equation (6):

$$\hat{R}_a = \frac{\text{number of sightings*}}{\text{number of km}^2\text{ surveyed**}} \qquad \text{................(6)}$$

* summed over all transect segments in a given aggregation
** summed for all transect segments in that same aggregation

For synoptic regional surveys, $\hat{R}_a$ was extrapolated to unsurveyed areas of that aggregation to provide an index of relative abundance (I_a):

$$I_a = (\hat{R}_a) \times (\#\text{ transect segments}) \times (353\text{ km}^2) \qquad \text{...........(7)}$$

The percent of sightings in each aggregation was calculated by dividing the number of seals sighted in each aggregation by the number of seals sighted in the synoptic regional survey. Number of groups were tallied, and mean group size for each aggregation calculated. Geographic extent of each aggregation was estimated by multiplying the number of transect segments in the aggregation (e.g. those with densities of ≥100 seals/100 km^2) by 353 km^2 (area of one grid cell). Timing of the first and last surveys of an aggregation was used as a minimum estimate of the length of time that an aggregation persisted, but nothing is known about the distribution of seals before, after, or during the interval between, the surveys.

2.3. RESULTS

SUMMARY OF SURVEY EFFORT, SIGHTINGS, AND ICE CONDITIONS

Overall size of the study area (km^2), survey effort (km^2), and number of marine mammals sighted on portions of surveys which met the optimum condition criteria are given on Table 2-1. Total sightings were 884 ringed seals, 39 bearded seals, 171 bowhead whales and 248 beluga. Of these totals, 681 ringed seals, 30 bearded seals, 112 bowhead whales, and 214 beluga, were seen on the synoptic regional surveys which provided the basic data set.

Two tests revealed no significant effects of different survey altitudes and transect widths on seal detectability. Mean ringed seal densities recorded by two observers searching simultaneously (n= 68 transect segments) using transect widths of 1000m (left side) and 400m

Table 2-1

Summary of survey effort and on-transect marine mammal sightings in the SE Beaufort Sea during late summer 1982, 1984, 1985 and 1986

				Seals			Whales		
Survey Date	# transects *	# trans. segmts	km^2 size of area	km^2 surveyed for seals	#on-transect ringed seals	#on-transect bearded seals	km^2 surveyed for whales	#on-transect bowhead whales	#on-transect beluga whales
Regional Surveys**									
Aug.18-24, 1982	16	105	34,837	731	307	18	2923	43	82
Aug.18-27, 1984	14	111	34,882	732	98	2	3649	9	47
Aug.18-24, 1985	25	120	36,114	757	60	2	3784	28	74
Aug.31-Sep. 10,1986	22	160	51,718	1085	210	8	5425	32	11
Other Surveys***									
Sept.5-12, 1982	14	71	21,899	459	93	7	1837	9	12
Sept.6-17, 1984	9	34	9,340	198	1	1	990	7	7
Aug.21, 1986	2	13	4,242	64	47	1	137	4	10
Sept.5, 1986	4	19	6,359	133	11	0	667	7	5
Sept.14, 1986	10	54	16,842	353	38	0	1765	12	0
Sept.23, 1986	2	2	706	15	0	0	37	0	0
Oct. 3, 1986	Reconn. Flight	5	1,000	78	13	0	194	20	0

* whole or part of transect

** synoptic regional surveys (used for Distribution Analyses)

*** includes remaining regional surveys (insufficient coverage for distribution analyses) and localized surveys, and reconnaissance surveys (right side) were not significantly different (right observer, $\bar{X}$= 0.107 seals/km^2, sd=0.258; left observer, $\bar{X}$=0.069 seals/km^2, sd= 0.208; Mann-Whitney U, p>0.05). There also were no significant differences among ranks of ringed seal densities and transect width, survey altitude or year, for each of the three strata (Table 2-2). On the basis of these tests, I have pooled data collected using different transect widths and survey altitudes.

The relative abundance of ringed seals was variable among the four years of the study (Figure 2-3a), with a maximum in 1982, declining through 1984 and 1985, and increasing again in 1986. There were no two years in which ringed seal densities were similar (t-test for unequal variances, p<0.05). Like density, abundance indices for ringed seals varied among years (Figure 2-4). The year with the highest index was 1982 (41,200), and the year with the lowest was 1985 (6400).

As for ringed seals, mean observed densities of bowheads, bearded seals and beluga were greater in 1982 than in the other three years (Table 2-3). Trends in bearded seal abundance were the same as those for ringed seals, but this was not the case for bowhead or beluga. Pair-wise comparison of density for each species showed that the density of each species varied among years (t-tests for samples with unequal variances, p<0.05), except for densities of beluga which were similar (p>0.05) in 1982 and 1985.

In each survey, the density of ringed seals was considerably greater than that of the other marine mammals (Figure 2-3a). However, the biomass of ringed seals exceeded only that of bearded seals (2.5

Table 2-2

Comparison of ringed seal densities (seals/km^2) among altitude, transect width and year

Strata	Mean Ringed Seal Density ± s.d.	n (# trans segments)	Width		Altitude		Year		Interaction	
			F	P	F	P	F	P	F	P
West	0.0873 ± 0.2429	233	0.13	0.72(ns)	0.13	0.72(ns)	0.84	0.43	-	-
Mid	0.1338 ± 0.4767	193	0.18	0.67(ns)	0.01	0.92(ns)	0.32	0.73(ns)	0.14	0.94(ns)
East	0.3020 ± 0.7600	263	2.30	0.13(ns)	1.02	0.31(ns)	0.03	0.98(ns)	0.90	0.40(ns)

ns = $p>0.05$

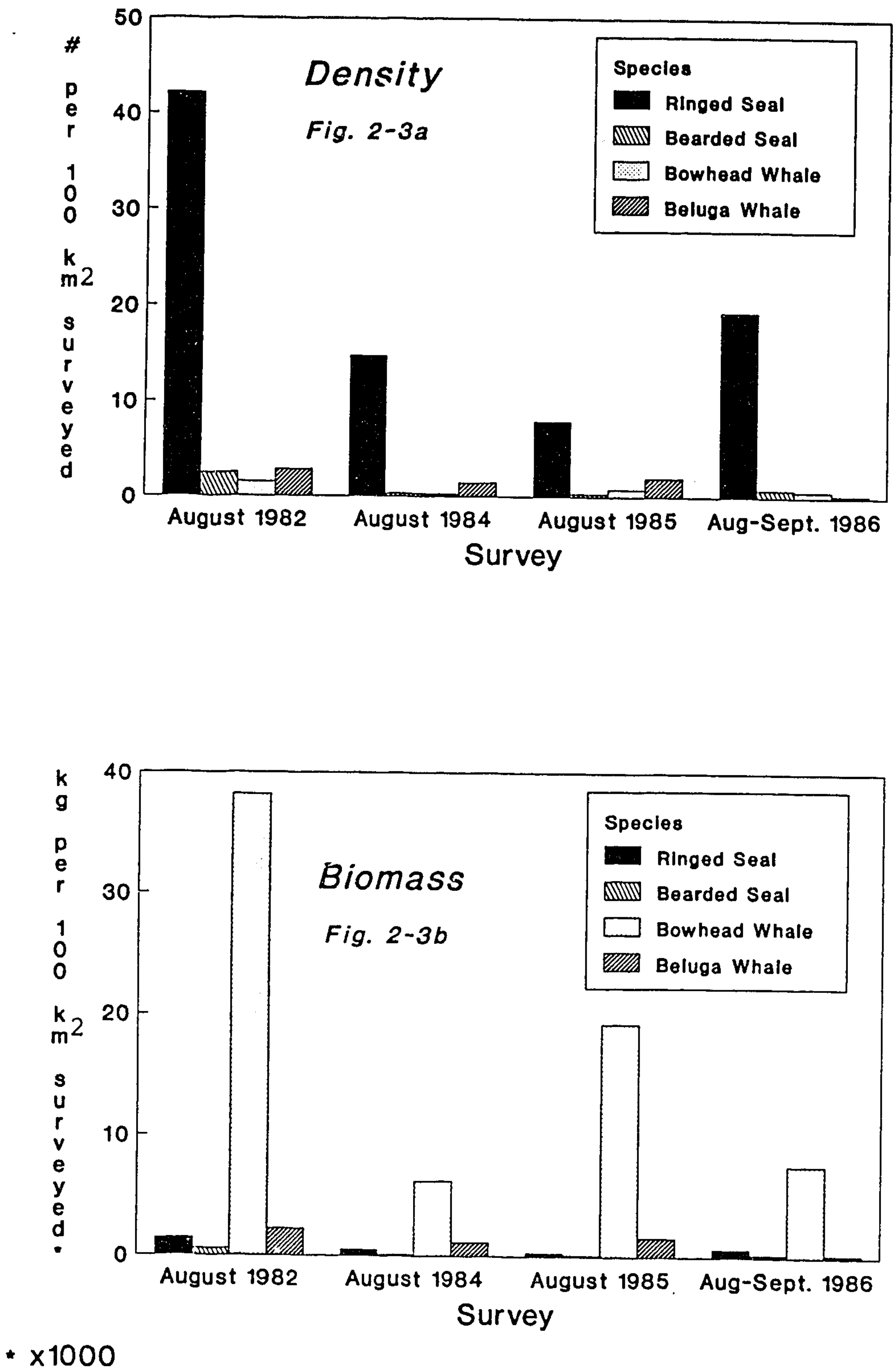

Figure 2-3. Observed densities and biomass of marine mammals in the southeast Beaufort Sea during late summer aerial surveys, 1982, 1984-1986

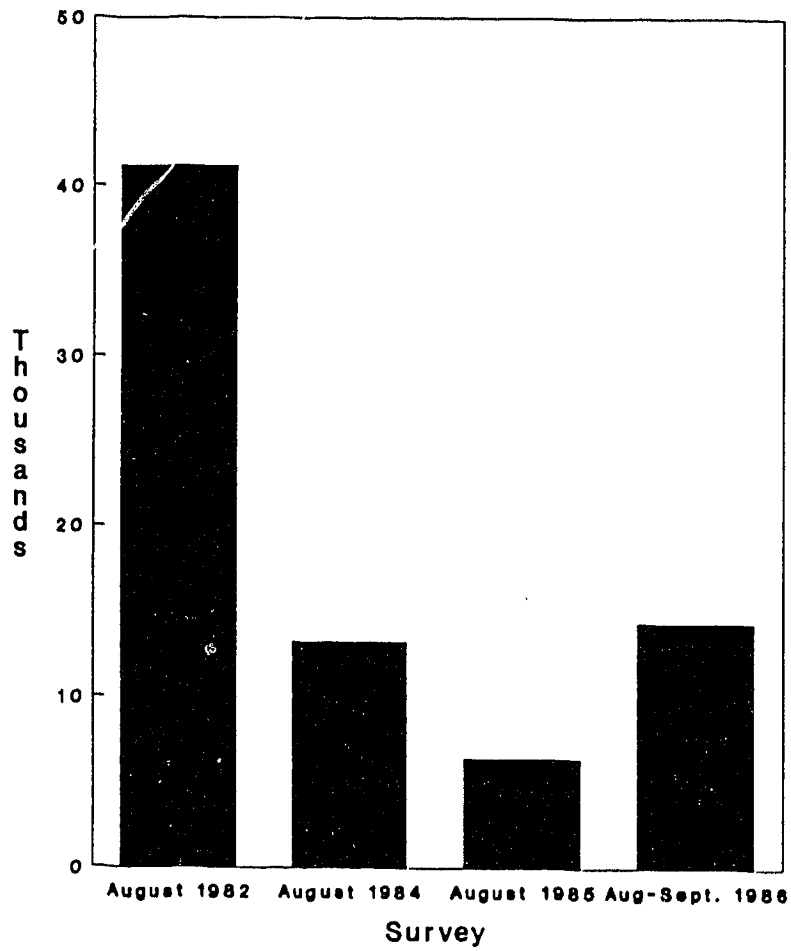

Figure 2-4. Indices of ringed seal abundance in the southeast Beaufort Sea, late summer 1982, 1984-1986

Table 2-3

Mean observed density of marine mammals in the SE Beaufort Sea during late summer 1982, 1984-1986

	Mean Density as #/100 km^2 (Standard Error)			
vey Dat	Ringed Seal	Bearded Seal	Bowhead Whale	Beluga Whale
18- 1982	42.20 (1.93)	2.46 (0.19)	1.47 (0.08)	2.81 (0.49)
g. 18- 27, 1984	14.73 (1.85)	0.30 (0.06)	0.24 (0.02)	1.41 (0.19)
Aug. 18- 24, 1985	7.92 (0.32)	0.26 (0.04)	0.74 (0.04)	1.96 (0.10)
Aug. 31- Sept. 10, 1986	19.35 (0.63)	0.74 (0.07)	0.59 (0.04)	0.20 (0.03)

times in 1982 to 7.1 times in 1984, see Figure 2-3b). The biomass of bowheads was greater than that of beluga (5 times in 1984 to 47 times in 1986). Ringed seals were 10 times (1985) to 61 times (1984) more abundant than bowhead whales, but the biomass of bowheads was 11 times (1986) to 71 times (1985) greater than that of ringed seals.

The location of the pack ice edge was variable among surveys. The years 1984 and 1986 were average ice years, with the $7\text{-}9^{+}/10$ pack ice edge north of the Tuktoyaktuk Peninsula at approximately 71° N latitude (100-150 km offshore). Most of the survey area was ice free, as was the case in 1982 where the edge of the pack was located even further north at 72°30' N latitude (300 km offshore). The pack ice edge in 1985 was 50-70 km from shore (between 70° and 70°20' N latitude) off the Tuktoyaktuk Peninsula, and about 100 km from shore off the Yukon coast.

DISTRIBUTION

Ringed Seal

Group Scale

Ringed seals were seen in groups of one to 21 (Figure 2-5). The frequency distribution of number of seals per group did not fit a Poisson distribution in 1982 (Figure 2-6, $G=343.24, df=6, p<0.001$), 1984 ($G=34.17$, $df=3$, $p<0.001$) or 1986 ($G=43.73$, $df=2$, $p<0.001$), suggesting a non-random allocation among the group size categories. Variance to mean ratios and indices of dispersion (Table 2-4) suggest these non-random distributions were clumped in 1982, 1984 and 1986, but not in 1985.

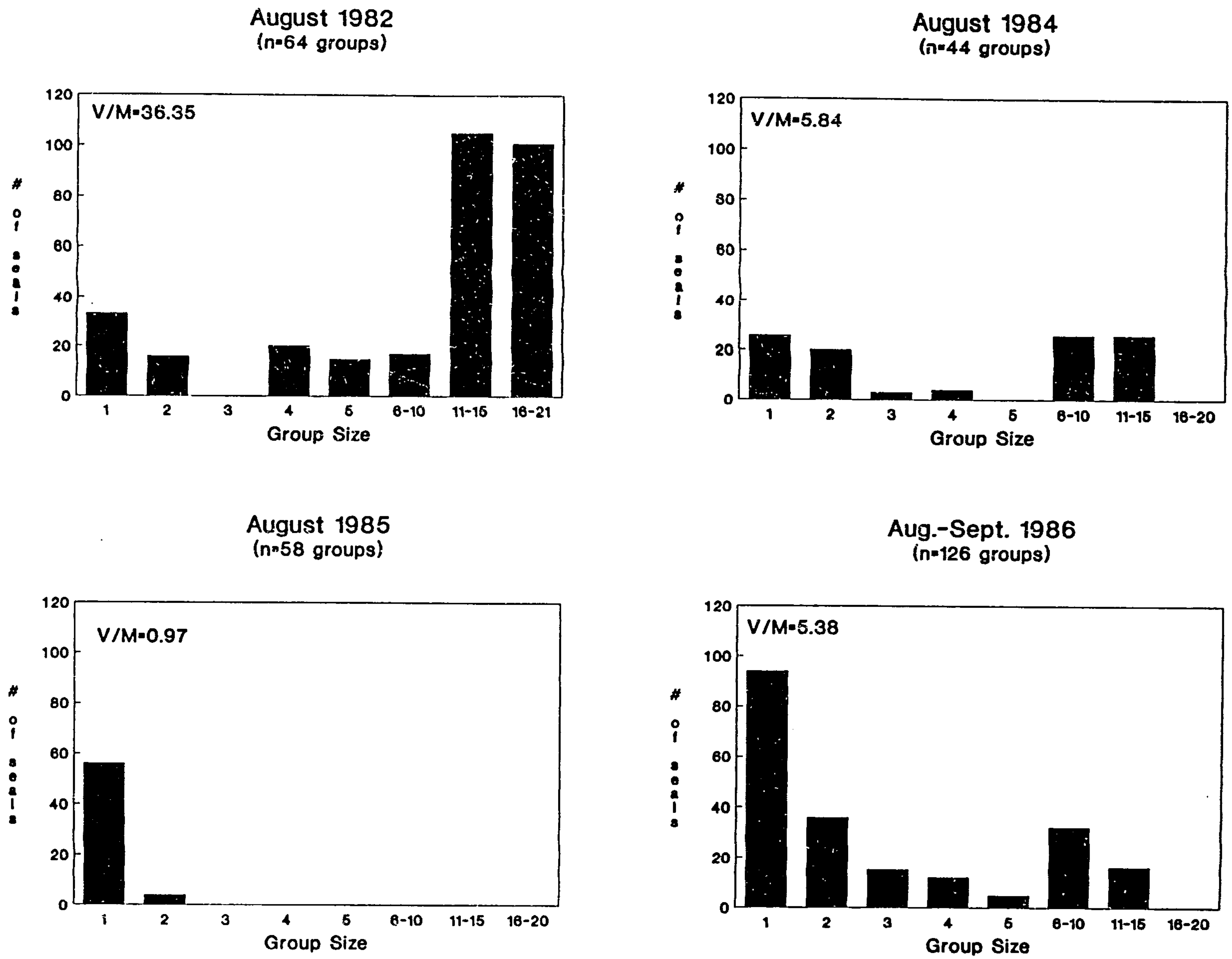

Figure 2-5. Distribution of number of ringed seals per group, southeast Beaufort Sea, late summer 1982, 1984-1986

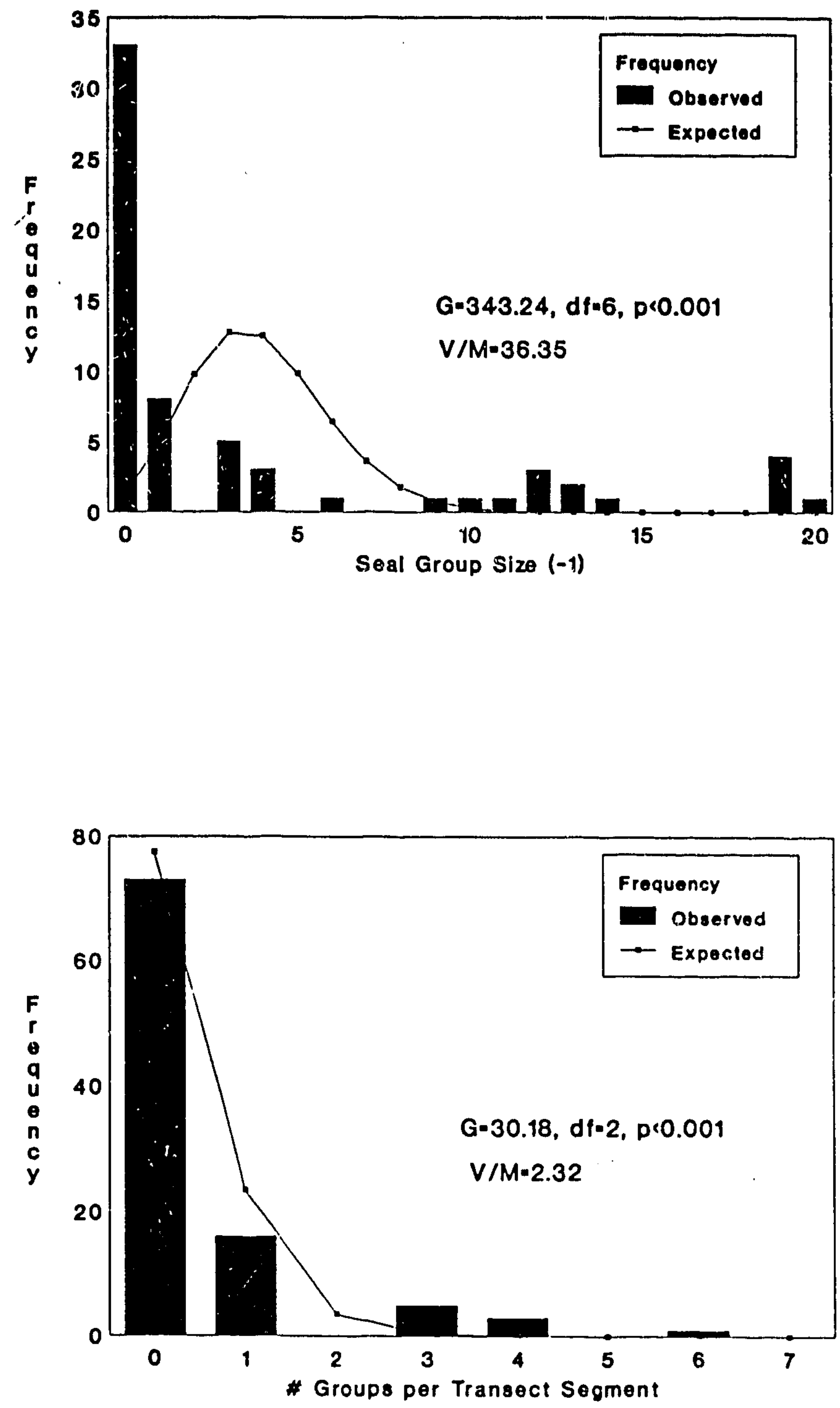

Figure 2-6. Comparison of frequency distributions of number of ringed seals per group and number of groups per transect segment with Poisson distributions with the same mean, southeast Beaufort Sea, late summer 1982

Table 2-4

Summary of distribution of marine mammals at three scales in the SE Beaufort Sea, late summer, 1982, 1984-1986

SCALE

SPECIES AND SURVEY	Group seals[whales] per group				Local groups per trans. seg.			Regional seals[whales] per trans.		
	Group Sizes	V/M	I_d	Different Among Yrs.?	V/M	I_d	Different Among Yrs.?	V/M	I_d	C_1/C_2
Ringed Seal										
1982	1-21	36.35	602.64*	G=408.95	2.32	241.55*	G=16.37	21.79	326.76*	1.77
1984	1-15	5.84	250.57*	df=21,	2.37	257.56*	df=30	27.55	358.17*	1.18
1985	1-2	0.97	57.00	p<0.001	2.14	253.20*	p>0.05	2.33	56.00*	1.02
1986	1-16	5.38	669.77*	(yes)[1]	2.45	386.90*	(no)	11.61	243.62*	2.09
Bearded Seal										
1982	1-3	1.02	12.32		1.18	130.00*	-	2.10	31.31*	1.17
1984	1	-	-		-	-		-	-	-
1985	1	-	-		-	-		-	-	-
1986	1-2	-	-		-	-		-	-	-
Bowhead Whale										
1982	1-3	1.40	46.25	G=19.22	1.87	195.40*	G=19.47	3.71	55.54*	1.76
1984	1-4	-	-	df=12	-	-	df=18	-	-	-
1985	1-2	0.60	11.40	p>0.05	3.13	364.00*	p>0.25	5.95	142.71*	2.66
1986	1-5	1.95	40.85*	(no)	2.68	420.21*	(no)	4.86	102.25*	1.39
Beluga Whale										
1982	1-20	8.93	233.19*	G=87.07	2.24	230.30*	G=28.27	30.75	460.81*	0.90
1984	1-5	1.31	35.29	df=21	1.97	210.40*	df=21	9.26	120.29*	0.72
1985	1-6	2.07	97.46*	p<0.001	2.68	318.32*	p>0.10	5.82	139.78*	1.10
1986	1-3	-	-	(yes)[2]	-	-	(no)	-	-	-

- sample size small (< 18 sightings)

1 no two years the same (p<0.001)

2 1982 different from other years (G=2.91, df=14, p>0.75 for 1984 and 1985 only)

* p<0.05

In 1982, there was a tendency for larger groups rather than singles or pairs, while in 1984, group sizes of one, two, and greater than six were prevalent. In 1985, no groups larger than two were seen. In 1986, most seals were seen as individuals, but there were also five groups with seven to 16 seals. These annual differences were statistically significant, since the number of ringed seals in each group size category was not the same between years ($G=408.95$, $df=21$, $p<0.001$), and no two years had a similar distribution among the group size categories.

Local Scale

From zero to 38 seals were seen on each transect segment (Figure 2-7). The frequency distributions of number of groups per transect segment, and departure of these from a Poisson (Figures 2-6 and 2-7), suggest a non-random distribution of groups in all years tested. The V/M ratios and indices of dispersion (Table 2-4) suggest the distribution of groups was clumped in all years. However, groups of ringed seals in 1985 consisted of only one (56) or two (2) seals. Between year differences in the frequency distributions of number of groups per transect were not apparent ($G=16.37$, $df=30$, $p>0.05$), suggesting that the magnitude and direction of clumping of groups along transect segments was consistent among years.

The distances between groups seen along the same or adjoining transect segments were relatively consistent among areas where the groups were clumped, ranging from <100 m to 15.2 km (Table 2-5); most groups were separated by 2 to 3 km. Together these analyses confirm

Beaufort Sea, and is estimated to contain 11,500 whales (Davis and Evans 1982; Finley et al. 1987). The feeding ecology of beluga is not well known, but prey items in summer probably include mainly fish and squid (Fraker et al. 1978).

The generally widely dispersed pattern of beluga during late summer contrasts with that seen in July when beluga concentrate (by the 1000's) in the Mackenzie Estuary. Densities in the Estuary reach 160/100 km^2 (Norton and Harwood 1986), while in the offshore during August 1982, 1984, and 1985, densities were within the range from 1.4-2.8/100 km^2.

In general, beluga were found in different locations than bowheads and seals (Figures 2-12 and 2-13). This reflects probable differences in the preferred prey of these species, and the migratory behaviour of beluga.

OVERLAP IN DISTRIBUTION OF MARINE MAMMALS

The overlap in seal and bowhead whale distributions in certain broad areas (Figures 2-12 and 2-13) indicates these areas were attractive to more than one species. However, at the transect segment level, it was apparent that they did not occur in the same localized areas, or at least not along the same 18.5 km transect segments. This may reflect use of different food resources which are separated in space, because of low inter-specific tolerances, or both.

Waters offshore of the Tuktoyaktuk Peninsula (particularly north and northwest of Cape Dalhousie), tended to have the largest and most frequent aggregations of ringed seals and bowhead whales. This was also the only area where bearded seals appeared to aggregate. This location corresponds to the approximate location of the Bathurst polynya, a particularly productive area in winter and spring (Smith and Rigby 1981).

Ringed seals also aggregated at location "E", while bowheads did not; both aggregated in this area in August-September 1980 (Renaud and Davis 1981). The edge of the continental shelf offshore of Shingle Point was important for seals in 1982 ("A") and to some extent in 1985 and 1986, while bowheads occurred in an adjacent but separate area in those same years. Yukon coastal waters were a preferred bowhead feeding area in 1984, 1985, and 1986, and for ringed seals at least in 1986. Each of these areas is known to have oceanographic characteristics which favour the production of zooplankton (Harwood and Borstad 1985; Thomson et al. 1986). Thus, the distribution of marine mammals seen in this study at the regional scale appears correlated to the distribution and abundance of prey. This is explored further in Chapter 3.

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3. CHARACTERISTICS OF RINGED SEAL AGGREGATION AREAS IN THE SOUTHEAST BEAUFORT DURING LATE SUMMER

3.1 INTRODUCTION

In late summer and fall, the energy requirements of ringed seals are substantial (to regain condition after reproduction and moulting, build reserves for coming winter), and feeding is extensive (Smith 1987). Lowry et al. (1980) hypothesized that ringed seals depend on concentrations of prey (cod, zooplankton) to meet annual energy requirements. During the open water period, ringed seals tended to form extensive aggregations in most years (1982, 1984, 1986). In this paper I examine the characteristics of ringed seal aggregations, and discuss their possible importance to fall feeding.

Ringed seals feed from several trophic levels and, in some areas, exhibit seasonal and age-related differences in the type and amount of prey selected (Chapskii 1940; Dunbar 1941; Nikolaev and Skalkin 1975; Lowry et al. 1980; Smith 1987). Since ringed seals feed opportunistically, their diet is expected to reflect geographic variability in the distribution and abundance of prey species. A variety of crustaceans (amphipods, isopods, decapods, euphausiids, and mysids), cods (particularly Arctic cod, Boreogadus saida), salmonids, sculpins, squid, lance, and wolfish have been reported in ringed seal diets (Chapskii 1940; Dunbar 1941; McLaren 1958; Fedoseev 1965; Nikolaev and Skalkin 1975; Smith 1977; Lowry et al. 1978, 1980; de Graaf et al. 1981; Bradstreet and Finley 1983; Gjertz and Lydersen 1986; Smith 1987).

Arctic cod is the primary prey of ringed seals in the Beaufort Sea and Amundsen Gulf when they feed under the ice (Lowry et al. 1980; Smith 1987). In comparison, from July through to October when open water prevails, adult and young of the year seals feed primarily on crustaceans (Smith 1987). In Amundsen Gulf, fish were slightly more prevalent than crustaceans in the stomach samples from adolescents during the same period (Smith 1987). The most common crustacean prey in seal stomachs (n=519) collected from the Beaufort Sea and Amundsen Gulf were hyperiid amphipods (Parathemisto libellula), euphausiids (Thysanoessa raschii), and mysids (Mysis oculata), although certain others (e.g. the isopod, Mesidotea entemon near Herschel Island) were important locally (Smith 1987). In the Alaskan Beaufort Sea, the open water diet also consists primarily of pelagic or benthic crustaceans (Lowry et al. 1980), but in that location, there was little difference among age classes for quantities and types of prey selected.

There is little available data on the distribution and abundance of ringed seal prey items in the southeast Beaufort Sea. Studies to date on zooplankton (Grainger 1965; 1975; Griffiths and Buchanan 1982; Dept. of Fisheries and Oceans, unpubl. data) and arctic cod (see review by Bradstreet et al. 1986) in the Beaufort Sea provide preliminary information on these aspects, but little is known about how environmental factors such as ice conditions influence prey distribution and abundance, either annually or seasonally.

Omori and Hamner (1982) describe the patchy distribution of zooplankton in tropical and subtropical oceans, and how this varies within and among species, and geographic locations. Patchiness is reportedly caused by responses to temperature and salinity gradients or discontinuities, water motion, light intensity, concentration of food, predators, complex social behaviour, and various combinations of these (Omori and Hamner 1982; Hamner 1988).

There have been several studies of relationships between whale distribution and oceanographic conditions in the Beaufort Sea (Fraker et al. 1979; Griffiths and Buchanan 1982; Borstad 1985; Richardson 1987; LGL 1988) and in other oceans (e.g. Nasu 1966; Best 1967; Gallardo et al. 1983; Murison and Gaskin 1989). These provide indirect evidence that oceanographic features are important in determining zooplankton distribution which in turn influences whale distribution. Similar studies of seals during the open water period in this or other regions have not been done.

Physical features in the southeast Beaufort Sea, such as complicated coastal morphology, steeply sloping bottom topography at the edge of the continental shelf and near Cape Bathurst, the large freshwater discharge of the Mackenzie River, and coastal upwelling driven by prevailing winds, are conducive to the formation of oceanographic fronts which concentrate zooplankton in this region (Borstad 1985; Thomson et al. 1986). The major determinant of the distribution of zooplankton in the southeast Beaufort Sea appears to be the Mackenzie River plume (LGL 1988). However, the nature and extent of the Plume is in turn determined by wind conditions, and the relationship is not simple (Borstad 1985; Thomson et al. 1986).

Information on the distribution of arctic cod in this region is limited as well (Bradstreet et al. 1986). There have been several fish sampling programs throughout coastal and to a lesser extent offshore areas of the Beaufort over the last decade, and adult cod were caught rarely, if at all, and never in large numbers (see review in Bradstreet et al. 1986). In contrast, young of the year Arctic cod were commonly sampled at stations in Mackenzie Bay, north of the Mackenzie Delta, and along the Yukon coast (Bradstreet et al. 1986; Dept. of Fisheries and Oceans, unpubl. data).

The distribution of ringed seals during late summer and fall differs from that seen at other times of the year. From late August through to freeze-up in October, ringed seals tend to occur in large, loose aggregations. These have been described by several other authors for the Canadian Beaufort Sea and Amundsen Gulf (Smith 1973; Harwood and Ford 1983; McLaren and Davis 1985; Harwood and Borstad 1985; Smith 1987), the Alaskan Beaufort Sea (J. Richardson, D. Ljungblad, pers. comms.), the eastern Arctic (Ellis 1957; Finley and Johnston 1977), and the Sea of Okhotsk (Fedoseev 1965). Smith (1987), describing aggregations seen by Renaud and Davis (1981) in the southeastern Beaufort Sea, suggested that the aggregations were either groups of older seals feeding and preparing to occupy winter habitats, or, young seals moving westward to the north slope of Alaska.

In this Chapter I examine the characteristics of ringed seal aggregation areas seen in the southeast Beaufort Sea during late summer 1982, 1984, and 1986 (Chapter 2). The concentration of chlorophyll a and mean density of zooplankton in ringed seal aggregation and non-aggregation areas are compared using data collected during an in situ oceanographic sampling program conducted concurrently with aerial surveys in 1986. Further characterization of an aggregation area is undertaken through examination of stomach and gut contents, body condition, and age of four ringed seals collected from within an aggregation area in 1986.

3.2 METHODS

The MV Arctic Ivik, a 68 m supply vessel, was operated along seven north-south transect lines offshore of the Tuktoyaktuk Peninsula (each 90 km in length), and five southwest-northeast transect lines offshore of the Yukon coast (each 65 km in length) during August 29-September 7, 1986. The charter was coordinated by Dept. of Indian and Northern Affairs Canada for a larger study examining characteristics of bowhead whale feeding areas. Three personnel from this project joined the Ivik cruise, primarily to collect ringed seals from within and outside of seal aggregation areas. The 1986 aerial surveys (Chapter 2) and Ivik-based portions of the study were coordinated, and personnel from each project contributed to the other.

OCEANOGRAPHIC SAMPLING

Oceanographic sampling from the Ivik involved 40 offshore and nearshore stations throughout the southeast Beaufort Sea region (Figure 3-1). All oceanographic and meteorological data collected on that cruise are reported in LGL (1988). Data from one major component of the zooplankton sampling program (zooplankton biomass through oblique tows) were obtained from LGL (1988), and along with chlorophyll a data

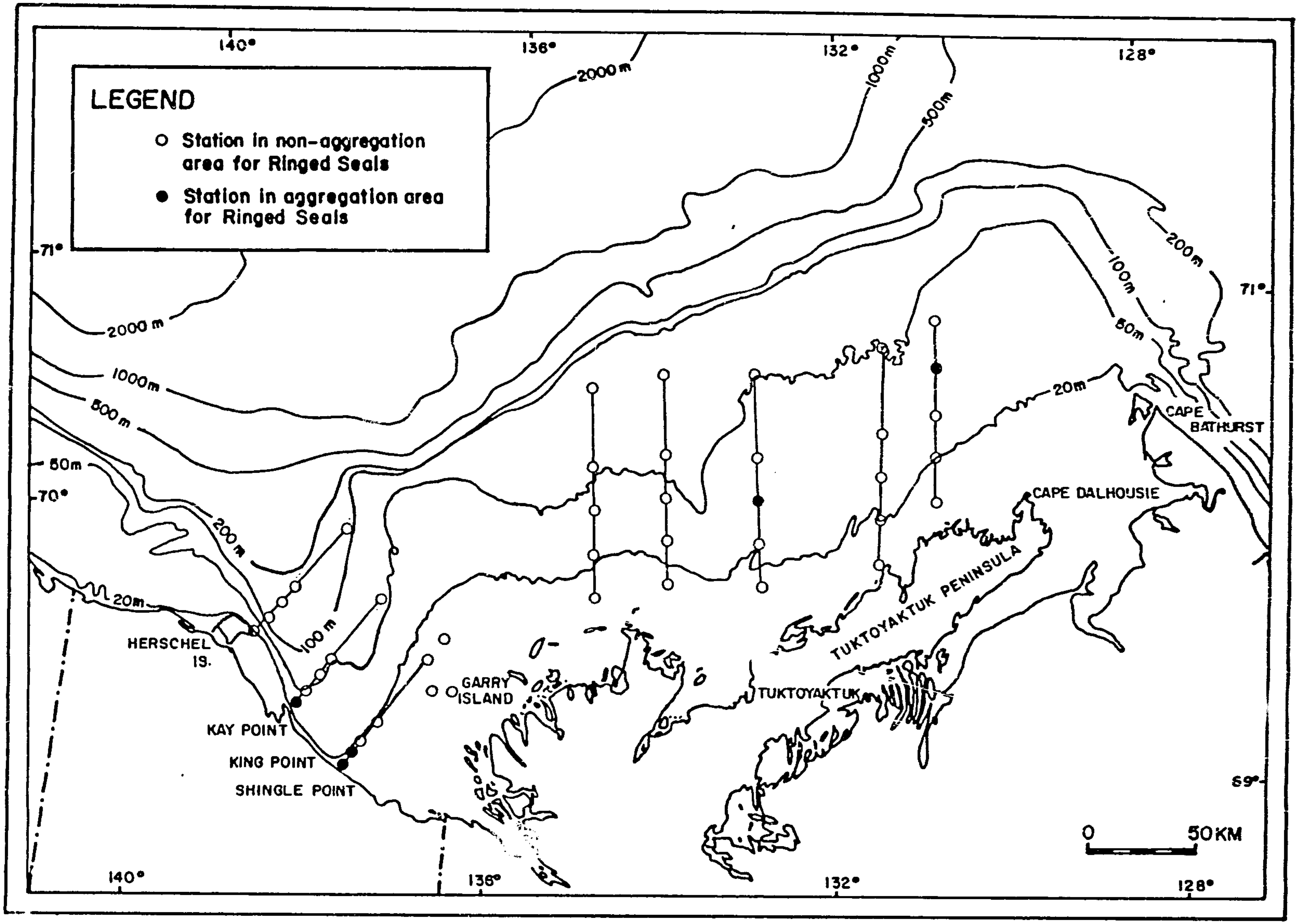

Figure 3-1. Stations sampled for zooplankton and chlorophyll a, southeast Beaufort Sea, Aug. 27 to Sept. 7, 1986

collected as part of this study, have been analyzed and interpreted in the context of ringed seal distribution.

The oblique tows (n=46) reported by LGL (1988) used a bongo frame fitted with nets 61 cm diameter. Mesh size was 0.5 mm, and tow speed was 1 m/s. In waters >50 m deep, tows were made in the upper 50 m. In waters <50m deep, tows were made to within 2-4 m of the seafloor, and conducted in a sawtooth pattern so that all tows continued for approximately the same duration. Nets were open on both ascent and descent. Identification of zooplankton samples is described in LGL (1988).

As part of this study, replicate 1 L water samples from the upper 1 m of the water column were collected at each of the 40 sampling stations. Depending on turbidity, volumes ranging from 100 ml to 1000 ml were filtered within 5 hours of collection through 4.25 cm Whatman GF/C glass fibre filters using a hand-pump vacuum. One ml $MgCO_3$ solution (10g/L) was added as the final 20 ml was filtered, and the filter paper then folded, and placed in a plastic petri dish with a tight fitting lid. Petri dishes were then wrapped in foil, labelled, and frozen.

Samples were transported frozen, and maintained at -40° C for 90 days before analysis. Chlorophyll a concentration in 95% ethanol extracts of the filtered phytoplankton material was measured using the colourmetric technique (Bergmann and Peters 1980), using a Bausch and Lomb Model 100 Spectrophotometer.

The region was subdivided into 228 essentially square subareas or 'grid cells' (Robertson and Robertson 1985), each 18.5 km (10' latitude) by 19.1 km (30' longitude at 70^{o} N latitude), and with an approximate surface area of 353 km^2. Sampling units for the data collected during aerial surveys were 18.5 km transect segments within each grid cell. Sampling units for the oceanographic data were the zooplankton and chlorophyll a sampling stations located within a grid cell. Wind data collected on the Ivik (LGL 1988) and by the Atmospheric Environment Service were reviewed, and grid cells with oceanographic sampling and aerial survey sampling separated in time by a period of major (>15 knots) winds were not considered further.

To examine differences in zooplankton density and surface chlorophyll concentration among seal aggregation and non-aggregation areas, a two-way analysis of variance was done using ranks of zooplankton density (separately for each taxonomic group), and chlorophyll concentration, as dependent variables (SAS 1985). To examine if the densities of zooplankton (by taxonomic group) or chlorophyll concentration were correlated with ringed seal densities, Spearman's ranked correlations were done (SAS 1985) among all grid cells with coincident data on seal density, and zooplankton density and chlorophyll a concentrations.

SEAL COLLECTIONS

Aerial surveys in 1986 (Chapter 2) were scheduled and positioned to provide current information on seal and whale distributions to the Ivik, so that seals could be collected from within and outside of aggregation areas. The vessel sampled zooplankton from three areas of ringed seal aggregation found in the surveys (September 3, aggregation "D"; August 30, aggregation "E"; September 5, aggregation "F"). Unfortunately, because of heavy seas it was only possible to launch the 5.5 m aluminum boat to collect seals in one location. Four seals were collected between 2000 and 2300 h September 5, 1986 from area "F" (Figure 2-8), from waters 10-15 m deep approximately 8 km east of King Point.

The seals were collected by an Inuit hunter, and necropsied within 1.5 hr of death. Body measurements included standard length, heart girth, flipper length, flipper width, and blubber thickness, and were made according to American Society of Mammalogists (1967). Body weight uncorrected for blood loss was measured using a spring scale. Indices of body condition were calculated after Smith (1987), as total weight/standard length, x 100.

Lower jaws, stomachs, intestines and reproductive organs were removed from each seal and frozen. Approximately 100 cc samples of liver, muscle, kidney and blubber were removed, frozen and sent to Dept. of Fisheries and Oceans for another study. Carcasses were retained by the hunter for dog food. In the laboratory, canine teeth from the lower jaws were extracted, decalcified, sectioned and then aged separately by two readers (Stirling et al. 1977).

Stomachs were thawed for 24 hr, slit along their entire length, and solid volume of contents measured by water displacement in a graduated cylinder. Contents were rinsed 2 - 3 times on a Mesh. No. 14 (1.168m) sorting pan, and sorted macroscopically to taxonomic group (e.g. euphausiids, mysids) using a reference collection prepared on board the ship. Unidentifiable material was examined under a dissecting microscope and weighed using a triple beam balance. Intact prey items were identified, counted, weighed, a subsample measured, and all preserved in 10% buffered formalin.

Otoliths recovered from the stomach and gut were measured by a micrometer to the nearest 0.1 mm. Fork lengths were estimated based on the otolith lengths, using the regression equation developed by Bain and Sekerak (1978). Cross sections of otoliths were prepared for aging by grinding and burning, and ages determined by two readers.

Intestines were thawed overnight, tied at approximately 1 m sections, and total length measured. Sections were opened sequentially, and contents diluted with tap water and examined macroscopically. Estimates of percent fullness and colour of contents were noted. Parasites were removed, counted, identified, and preserved in saline.

3.3 RESULTS

OCEANOGRAPHIC SAMPLING

I assigned oceanographic sampling stations to their appropriate grid cell, and prepared a list of grid cells with both aerial survey coverage (one or more transect segments therein) and oceanographic sampling (one or more zooplankton stations therein) (Table 3-1). In cases where there was more than one station within the grid cell sampled for zooplankton within the same 24 h period, mean zooplankton

Table 3-1

Grid cells in the SE Beaufort Sea with coincident zooplankton sampling and aerial surveys, August-September 1986

Zooplankton Stations		Survey Transect Segments		
No.	Sample Date	Grid Cell	Survey Date	Seals/100 km^2
30	Sept. 5	95a	Sept. 5	67.50
5,4	Sept. 5	109c	Sept. 7	0
3,2	Sept. 6	109b	Sept. 5	?**
32	Sept. 6	79d	Sept. 7	18.00
15	Sept. 6	94a	NS	?
14,13	Sept. 6,7	93d	Sept. 7	13.50
12	Sept. 7	108c	Sept. 7	121.46*
34	Sept. 7	64b	NS	?
25	Sept. 7	78d	Sept. 7	0
24	Sept. 7	78b	Sept. 7	13.50
23,22	Sept. 8	93a	Sept. 7	27.00
51	Aug. 28	85c	Aug. 31	0
52	Aug. 29	70d	Aug. 31	13.50
53	Aug. 29	70c	Aug. 31	0
54	Aug. 29	55d	Aug. 31	0
55	Aug. 30	40d	Aug. 31	0
60	Aug. 30	39b	Sept. 10	13.50
59	Aug. 30	54b	Sept. 10	40.50
58	Aug. 30	69a	Sept. 10	215.92*
57	Aug. 31	69b	Sept. 10	13.50
56	Aug. 31	84a	Sept. 10	0
61	Sept. 4	83a	Sept. 10	0
62	Sept. 4	68b	Sept. 10	0
63	Sept. 5	68a	Sept. 10	0
64	Sept. 5	53b	Sept. 10	13.50
65	Sept. 5	38b	Sept. 10	0
70	Sept. 1	37b	Sept. 10	27.00
69	Sept. 1	52b	Sept. 10	0
68	Sept. 1	67a	Sept. 10	40.49
67	Sept. 2	67b	Sept. 10	27.00
66	Sept. 2	82a	Sept. 10	0
76	Sept. 3	71a	Aug. 31	0
77	Sept. 3	56b	Aug. 31	0
78	Sept. 3	56a	Aug. 31	13.50
79	Sept. 3	41b	Aug. 31	175.44*
80	Sept. 3	41a	Aug. 31	53.98

NS= not surveyed, not considered further
* aggregation area (n=3)
**aggregation area (n=1), determined from seal collections

densities for the two stations were used. In cases where there was more than one zooplankton station in a grid cell, but when these were sampled on different days, those collected on the day closest to the time of the aerial survey were used. In cases where there was more than one aerial survey sample for a grid cell, the aerial survey sample made closest to the time of the zooplankton sampling was used.

Three of the grid cells had transect segments with seal densities ≥120 seals/100 km^2 (108c, 69a, 41b), and a fourth (109b), had no survey information but was where four seals were collected while feeding. These I have designated as seal aggregation areas. The remaining 30 grid cells had seal densities ≤70/100 km^2, and are designated as non-aggregation areas. These 34 grid cells, and the corresponding seal and zooplankton densities therein, form the basis of analyses described below (Table 3-1). The four grid cells designated as aggregations are located within regional aggregation areas depicted on Figure 2-11 ("D" cell 41b; "E" cell 69a; and "F" cells 108c and 109b, see Figure 3-1).

Because some forms of zooplankton can avoid sampling nets, the mean biomass of various taxa in the tows cannot be compared among taxa. This is particularly important when considering larger, faster swimming zooplankton such as mysids, euphausiids, and decapods, and precludes a comparison of biomass among taxa. However, a given zooplankton taxon probably avoids the net at some relatively constant rate, so it is possible to compare, for example, euphausiid biomass among stations.

There was no correlation ($p>0.05$, Spearman ranked correlation) between any taxonomic group listed or chlorophyll _a_ concentration and ringed seal density for the 34 grid cells. However, mean density of euphausiids, pteropods, decapods, copepods, hyperiids and gammariids was greater in seal aggregation areas than in non-aggregation areas (Figure 3-2a, Table 3-2). Despite the low power of tests applied to a sample size of four, differences were statistically significant for euphausiids (ANOVA of ranks, p=0.0469, df=33) and copepods (p=0.0328, df=33) (Figure 3-3a and 3-3b).

Concentration of surface chlorophyll a was not significantly different with respect to seal aggregation and non-aggregation areas (Figure 3-2b, p=0.9746, df=33). The highest concentration of surface chlorophyll a was revealed at one station within one of the aggregation areas ("E"). However, a horizontal tow at this station (LGL 1988) had a low biomass of zooplankton at the surface (total= 0.6 mg/m^3); the oblique tow found only high densities of copepods (204.6 mg/m^3 copepods, 290.6 mg/m^3 total).

SEAL COLLECTIONS

Four ringed seals collected between 2000 and 2300 h September 5, 1986 near Sabine Point (Table 3-3, aggregation "F" Figure 2-11) ranged in age from 1^+ to 8^+ years. Two were females and two were males. Indices of body condition were comparable to those calculated by Smith (1987) for ringed seals during late summer in Amundsen Gulf. Actual body weights were ±3 kg of predicted body weights based on formulae derived by Usher and Church (1969).

These four seals all had full stomachs, and in each stomach about half of the contents were identifiable (Table 3-4); Mysis littoralis

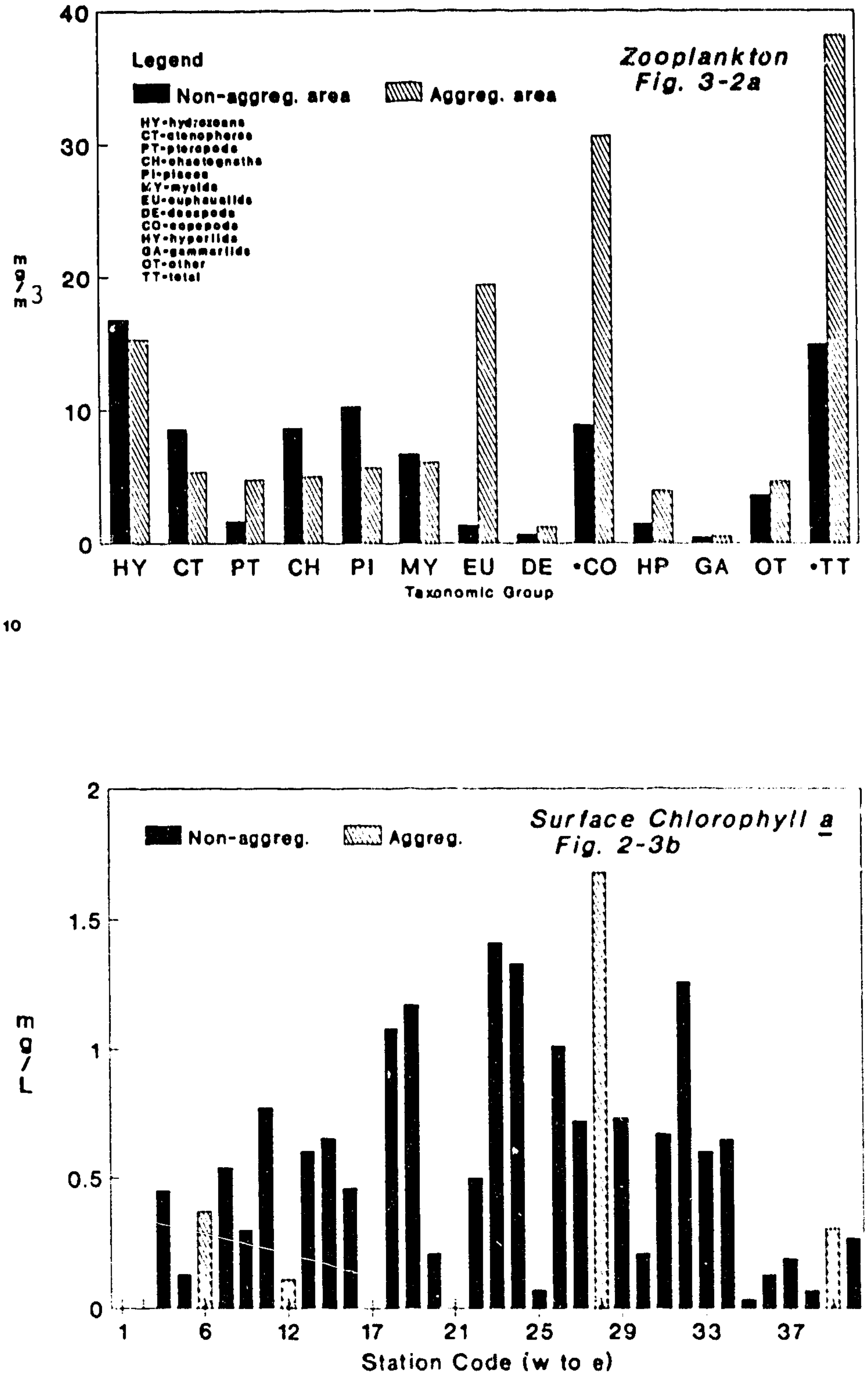

Figure 3-2. Density of zooplankton and concentration of surface chlorophyll a within and outside areas where ringed seals aggregated in the southeast Beaufort Sea during late summer 1986

Table 3-2

Mean concentration of surface chlorophyll a and mean biomass of zooplankton in ringed seal aggregation and non-aggregation areas in the SE Beaufort Sea August-September 1986 (zooplankton data from LGL 1988)

	(mg/m^3 wet weight)		
	Non-Aggregation Area (n=30 cells)	Aggregation Area (n=4 cells)	Mean Biomass (All tows, n=40 stations)
Hydrozoa	16.79± 9.61	15.30± 14.61	16.5
Ctenophora	8.56± 9.38	5.35± 4.92	7.2
Pteropoda	1.68± 1.65	4.75± 5.69	2.0
Chaetognatha	8.64± 15.13	4.98± 4.90	7.5
Pisces	10.24± 11.55	5.63± 6.02	8.8
Mysiidacea	6.66± 12.13	6.08± 8.58	6.3
Euphausiacea	1.36± 2.85	19.40± 31.08	4.6
Decapoda	0.67± 0.99	1.23± 0.69	0.7
Copepoda	88.61± 78.62	306.30± 202.80	112.4
Hyperiidae	1.51± 1.77	3.93± 2.82	2.2
Gammaridea	0.45± 0.66	0.53± 0.30	0.5
Other	3.61± 3.64	4.65± 3.27	3.3
Total	148.81± 82.85	381.50± 236.10	171.9
Chlorophyll a (mg/L)	0.54± 0.43	0.62± 0.72	0.53

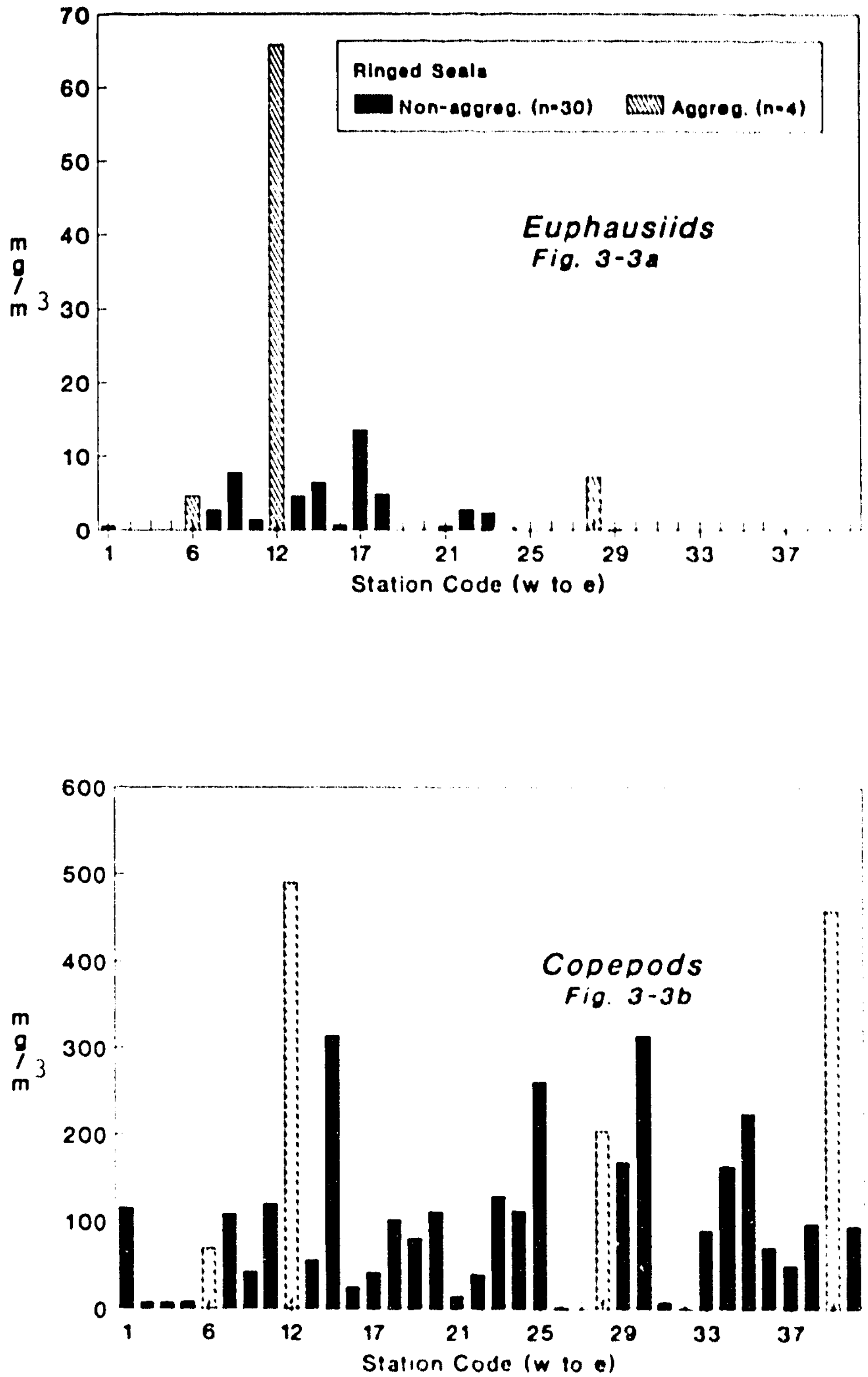

Figure 3-3. Density of euphausiids and copepods at sampling stations within and outside ringed seal aggregation areas in the southeast Beaufort Sea, late summer 1986

Table 3-3

Ringed seal specimens from which stomach contents were examined

Sample No.	Sex	Age	Standard Length (cm)	Heart Girth (cm)	Blubber (Chest) (cm)	Body Weight (kg)	Condition Index	Total Length (m) Intestine	# *Corynosoma* spp. Large Intestine	# *Corynosoma* spp. Small Intestine
WC-86-1	M	6^{+1}	121	85	2.6	43	0.36	13.9	26	23
WC-86-4	F	8^{+1}	114	93	2.9	45	0.39	15.8	217	117
WC-86-2	F	3^{+1}	107	77	2.3	28	0.26	-	-	-
WC-86-3	M	1^{+1}	101	69	1.5	23	0.23	16.2	50	6

Table 3-4

Stomach contents from four ringed seals collected at
Sabine Point, September 5, 1986

Sample No.	Sex	Age	Stomach Contents solid volume (ml)	Stomach Contents % identified (by weight)	% Composition of Identifiable Material by Weight* Mysids	Euphausiids	Decapods	Hyperiids	Gammariids	Estimate kcal of prey**
WC-86-1	M	6+1	375	49.4%	80.2	1.8	4.8	9.2	4.0	349
WC-86-4	F	8+1	122	46.2	94.1	0.7	3.9	1.3	0	121
WC-86-2	F	3+1	92	57.0	79.5	6.2	0.8	12.5	0	81
WC-86-3	M	1+1	114	56.6	70.5	25.2	0.3	4.1	0	115
Caloric value of prey (cal/gram wet weight) (from LGL 1988)					1010	1033	552	821	812	

* by volume for WC-86-2
** of all prey found in that stomach, extrapolations for unidentified items

was the dominant food item. Mean length of mysids from the stomach contents was 30 mm, and the number of identifiable mysids in the stomachs ranged from 253-272. Other taxa in the stomachs included euphausiids, decapods, and hyperiid and gammariid amphipods; the euphausiid Thysanoessa raschii and hyperiid amphipod Parathemisto libellula were the next most common species. Mysids and euphausiids were the prey with the highest caloric content (Table 3-4). Six otoliths found in the stomach and gut contents of the seals (at least one in each, and maximum of two) were identified as arctic cod aged 2^+ years, with estimated fork lengths ranging from 84-96 mm. The extent of degradation of the otoliths, and therefore underestimation of age of the cod, was not evaluated.

The zooplankton tow at the station where the seals were collected had high concentrations of euphausiids (39.2 mg/m^3) and copepods (706.2 mg/m^3), these being 7 to 10 times more concentrated than their mean densities in all tows (Table 3-2). However, mysid concentrations at this station were only slightly greater than the mean regional density (8.2 vs 6.3 mg/m^3). Since mysids often concentrate near the seafloor where they are missed or underestimated by zooplankton tows (M. Bradstreet, pers. comm.; LGL 1988; Kim and Oliver 1989), and since the tow at this station was made to within 4 m of the seafloor, it is probable that sampling in this area missed the concentration of mysids that the seals were feeding on. The presence of mollusc shells (Portlandia spp.) and pebbles in the stomach contents confirm that these seals had fed near the seafloor.

Body condition indices for the four seals collected from an aggregation in 1986 were similar to those calculated by Smith (1987) for same age classes in Amundsen Gulf, and none of the seals sampled showed evidence of poor condition.

The age structure of the four seals was younger than the mean (14.7 years, n=100) reported by Smith (1987) for late summer aggregations of seals feeding in Prince Albert Sound. Sample size in this study was too small to determine if the relatively young seals collected from the King Point area were engaged in a westward migration, as Smith (1987) suggested occurs.

Using samples collected from the Ivik sampling program (LGL 1988), the estimated caloric value of contents found in the stomachs of ringed seals collected in this study ranged from 81 kcal to 349 kcal. Based on information collected on captive seals by Parsons (1977) and daily caloric requirements estimated by Lowry *et al.* (1980) (1529 kcal for 13.9 kg pups and 1614 kcal for 46.1 kg adults over 5 years of age, n=761 known age seals), I calculated that pups and adults would have to consume 1.5 kg and 1.6 kg of mysids per day to meet daily minimum requirements. Consumption of arctic cod would have to be about 1.1 kg per day.

The most prevalent parasite found in the gut and stomach of three of the seals (Table 3-3) were *Corynosoma* spp. *Corynosoma* infections varied among individuals; the largest number of parasites was in the age 8^+ seal (n=334), and the least in the age 6^+ seal (n=49).

Corynosoma were found in both anterior and posterior portions of the gut, and in most cases were still attached to the intestinal wall.

Even though the gut was not tied off at the time of necropsy, the observed distribution of the parasites probably represents their distribution while the animal was alive since in most cases they were still attached to the intestinal wall.

3.4 DISCUSSION

In late summer and fall, energy requirements of seals are substantial since they must regain condition after reproduction and moulting activities of the previous spring, and build reserves for the coming winter. During most years, seals in this (Smith 1987) and other (Lowry et al. 1980) areas succeed in regaining this energy balance by September. Evidence that feeding is extensive in fall includes an increase in body condition indices in September compared with July and August, greater mean stomach weights in fall compared to spring, greater proportions of stomachs with food in fall than in spring (Lowry et al. 1980; Smith 1987), and obvious increases in the buoyancy (e.g. fat content) of seals shot in the fall harvest.

Lowry et al. (1980) suggest that ringed seals depend on concentrations of prey (cod, zooplankton) to obtain their annual energy requirements. In this Chapter, I examine the relationship between aggregations of seals seen in late summer and fall (Chapter 2) and extensive feeding in those areas on concentrations of prey.

Regional wind patterns are important determinants of the physical oceanographic regime of the southeast Beaufort Sea. They influence the location and extent of ice, the Mackenzie River plume (Thomson et al.

1986), induce coastal upwelling (Borstad 1985), and thus have a large effect on the distribution and abundance of zooplankton. Although aerial survey and oceanographic data were never collected in exactly the same place at the same time, they were separated by as little as 1-2 hours, and as much as 11.2 days (mean=4.6 days). In no case were they separated by a major storm, so the two data sets should be comparable.

Data collected from the oceanographic sampling program suggest that areas where ringed seals aggregated were productive; biomass of pteropods, euphausiids, copepods, hyperiid and gammariid amphipods, and decapods was greater in seal aggregation areas than in non-aggregation areas, although the differences were only significant for copepods and euphausiids (possibly due to small sample size). The fact that mysids, found in the stomachs of seals collected from aggregation "F" were not particularly prevalent in the zooplankton samples is probably a sampling artifact.

Further, each seal aggregation seen in 1986 had arctic water present, the water type determined by LGL (1988) to consistently have greatest densities of zooplankton. Arctic water was present at depths [illegible] m at seal aggregations "D" and "E", and at the surface (upwelled) at the coast at "F". Arctic water found at aggregation "D", the approximate location of the Bathurst polynya (Smith and Rigby 1981), was 3-4 ^{o}C warmer than Arctic water elsewhere.

The aggregations of ringed seals, bearded seals and bowheads seen over a period of weeks in the same general area (Figure 2-12) suggest these areas were productive. Bowhead aggregations are considered as indicators of some (but likely not all) areas where biological productivity is high (IGL 1988).

Aggregations of seals and whales along the Yukon coast ("F") were in an area with upwelling of subsurface Arctic water. While the copepod (Limnocalanus macrurus), the probable main prey of bowheads feeding in Yukon coastal waters, was not found in the stomachs of seals sampled from this same area, it was prevalent in the oblique zooplankton tows in this area (7 times greater than mean biomass of all tows). This area is well known for higher levels of productivity under certain (easterly) wind regimes (Thomson et al. 1986). Consequently, ringed seals probably aggregated there because of a greater abundance of prey. Information on four seals collected from aggregation "F" support this conclusion, since all had full stomachs and intestines (indicative of active feeding), and had fed on the same type of prey (indicative of a concentration of prey).

Ringed seals also aggregated approximately 100 km north of Shingle Point in 1982 ("A"), and were common but not aggregated (by the definition used here) near this area in 1985 and 1986. This area is located at the edge of the continental shelf, with relatively steep bottom slopes, apparently conducive to upwelling similar to that which is known to concentrate zooplankton in other areas of the Beaufort. However, it was not included in the Ivik sampling program.

The behaviour of seals in the aggregation areas, and the behaviour of seabirds seen there at the same time, provide further evidence that prey were locally abundant and feeding was a major activity therein. Seal groups in circular and linear formations were common (only) in seal aggregations (Chapter 2), and these may be indicative of cooperative feeding. Seabirds were seen in association with, and pirating fish from, seals in aggregations in Prince Albert Sound by Smith (1987); birds collected at the site had cod in their stomachs. McLaren and Davis (1985) and Ellis (1957) reported on the presence of seabirds at seal aggregations in the Beaufort Sea and eastern Arctic, respectively. Associations between feeding seabirds and cetaceans have also been well documented (see Evans 1982).

On the basis of limited data, it appears that the composition of prey species may differ between aggregation areas. For example, seals sampled from aggregations in Prince Albert Sound (Smith 1987), three to four weeks prior to freeze-up, consisted of groups of 30 or more adults which had actively fed on Arctic cod. In contrast, seals sampled in this study from aggregation "F" had fed extensively on mysids. However, the possibility that these variations represent differences in prey choice (e.g. between adults preparing to winter and reproduce, and subadults without reproductive constraints) cannot be ruled out.

The apparent differences in relative abundance of seals among aggregation areas may be influenced by differences in the abundance of prey ("patch size") among aggregation areas, but nothing is known about the size of schools of arctic cod expected at offshore areas where seals may have been feeding on cod. This is presumably limited by the size of zooplankton patches on which the cod themselves feed. The size and shape of zooplankton patches in this region are also not well documented, but presumably highly variable among species, areas, seasons and age-classes as documented for other oceans (Omori and Hamner 1982; Hamner 1988).

The calories obtained by a seal feeding in an aggregation area compared to a seal feeding elsewhere could not be evaluated with the data from this study. However, I calculated that the seal with greatest amount of food in its stomach would have to consume five times this amount to meet daily requirements calculated by Lowry et al. (1980). The other three seals would have needed 12-14 times the volume in their stomachs when collected, a similar number of stomachfulls (>10) estimated for seals in Alaskan waters by Lowry et al. (1980). However, it is difficult to interpret the caloric requirements and passage times for food consumed by captive animals (Parsons 1977) in relation to free-ranging seals. Similarly, the concept of "stomachfulls", which describes the contents of a stomach at some point in time, is not intuitively applicable to ringed seals which likely feed continuously.

Helminth parasite loads in three of the seals were low (10's), and higher (100's) in the fourth (oldest) seal, but all of these are within ranges for Corynosoma infections in ringed seals in the Bothnian Sea (Helle and Valtonen 1980) and ribbon seals in the Bering Sea (Shults and Frost 1988). Corynosoma infections are known to vary with seasonal changes in diet; mature infections are more common in Bothnian Bay in fall than spring (Helle and Valtonen 1981). It may be possible to study seasonal changes in diet of ringed seals in the Beaufort Sea through study of seasonal variation in Corynosoma infections, but at the present time, the intermediate hosts for these parasites are not known for this region.

In conclusion, the relative importance of the aggregation areas to seals during fall is suggested by high densities of seals seen in these areas (approximately 6-13 times greater than the regional mean), and the length of time they appeared to persist (several weeks). There is considerable evidence in the literature that fall feeding is important to ringed seal populations (Lowry et al. 1980; Smith 1987). Findings reported in this Chapter strongly suggest that the reason seals aggregate in late summer and fall is to feed on concentrations of prey found in these areas.

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4. SUMMARY

RINGED SEAL AGGREGATIONS AND FALL FEEDING

Ringed seals are the most abundant and widespread marine mammal in the Canadian Arctic, and are important in arctic marine ecosystems as both consumers and prey. Most research on ringed seals in the southeast Beaufort Sea and Amundsen Gulf has been conducted during ice-covered periods (Stirling et al. 1982; Kingsley 1986; Smith 1987).

In Chapter 2, I examined the distribution of ringed seals during the open water period at three scales (distribution of seals into groups, distribution of groups, and distribution across region). In late summer and early fall 1982, 1984 and 1986, ringed seals were clumped in groups, and groups were clumped together in one or more broad areas, termed aggregations. The locations of the aggregations varied among years, as did the apparent size and number of aggregations in a given year. The maximum number of groups seen in an aggregation was 27, and group sizes ranged from one to 21. In late August 1985, a summer of particularly heavy ice conditions, seals were seen only as individuals and pairs, and no large aggregations were seen.

During late summer and fall, ringed seals must acquire and exceed their daily energy requirement in order to gain weight and regain condition. This implies that feeding is particularly important to the population at this time of year; evidence of extensive feeding during late summer and fall includes an increase in body condition indices in September, greater mean stomach weights in fall compared to spring, greater proportions of stomachs with food than in spring than fall (Lowry et al. 1980; Smith 1987), and an increase in the buoyancy (i.e. fat content) of seals shot in the fall harvest.

In Chapter 3, I examined the relationship between these late summer and early fall aggregations of seals and extensive feeding in aggregation areas on concentrations of prey. The relative importance of the aggregation areas to seals was suggested by the high densities of seals seen in these areas (6 to 13 times greater than the regional mean), and the length of time that they persist (several weeks). Mean densities of several zooplankton taxa were greater in seal aggregation areas than in non-aggregation areas. Further, the location of seal aggregations overlapped with that of bowhead feeding aggregations on three occasions, and bowheads are known to aggregate where food is abundant (LGL 1988).

Each of the areas where seals aggregated have oceanographic characteristics known to be associated with productive areas (Harwood and Borstad 1985; Thomson et al. 1986; LGL 1988; Richardson 1987). Stomachs and intestines of four seals collected from one aggregation area along the Yukon coast were full (indicative of active feeding) and contained the same prey type (indicative of concentration of prey). Finally, the presence and behaviour of seabirds at some of the seal aggregations, as reported in Prince Albert Sound by Smith (1987), suggest that prey were locally abundant and that both seals and seabirds were actively feeding. These findings suggest that seals aggregate in late summer and fall to feed on concentrations of prey found in the aggregation areas.

REPRODUCTIVE SUCCESS, ABUNDANCE AND CHANGES IN THE ECOSYSTEM

The apparent relationship between fall feeding and subsequent reproductive success (Smith 1987) could not be demonstrated in this study, but the results of this and concurrent studies between 1982 and 1987 suggest that this ecosystem is prone to large-scale fluctuations, as were first reported in the mid-1970's.

During late summer and fall, the relative abundance of ringed seals varied among the four years of the study, with the maximum in 1982, declining through 1984 and 1985, and increasing again in 1986. At the same time, hunters from Sachs Harbour, on the west coast of Banks Island, reported a reduction in ringed seal pups in their harvests in fall 1984, and for the three years following (Kingsley and Byers 1989). Data on age structure and reproductive status from 1987 and 1988 confirmed a substantial failure of recruitment from 1984-1987, but as in the 1970's, this was temporary and reproduction returned to normal levels by 1988 (Kingsley and Byers 1989).

The reason for the apparent changes in reproductive success and abundance of ringed seals between 1984-1987 is not known, but could be related to changes in ecosystem productivity as was suggested for similar fluctuations in the 1970's (Stirling et al. 1982; Smith 1987). Smith (1987) found that a reduction in seal body condition (an index of quality and quantity of food) was correlated to a reduction in ovulation rates (and population fluctuations documented by Stirling et al. 1982). The specific biological responses which alone or together could lead to decreases or increases in recruitment might also include changes in rates of conception or implantation of the blastocyst, changes in rates of pup survival, or immigration or emigration.

While the distribution of bearded seals during late summer was different from that of ringed seals, years of high and low abundance for each species were the same. This pattern also occurred in spring surveys during periods of fluctuation (Stirling et al. 1982) and apparent stability (Kingsley 1986). Since the diets of these species generally do not overlap, parallel trends in ringed and bearded seal abundance in this study also provide evidence that changes in ecosystem productivity occurred between 1982 and 1986. Indeed, such changes appeared to be of sufficient magnitude to affect more than one species.

Information on the distribution and relative abundance of bowheads in summer 1985 suggests productivity was lower in that year than in 1982, 1984 or 1986. This appeared correlated with severe ice conditions, since bowheads aggregated only in ice-free waters near the Yukon coast and 30 km to the northeast, and not in ice-covered waters offshore of Cape Dalhousie which appeared important in other years. The density of bowheads in 1985, while comparable to density in 1986, suggests fewer whales were present in the region since they were found in fewer areas. These observations suggest a probable reduction in bowhead prey in 1985, and possibly a change (in this case a reduction) in ecosystem productivity.

Given the overlap in the diet of ringed seals and bowhead whales, late summer and fall 1985 may have been a season of lower food availability for ringed seals as well. This may have impeded recovery of reproduction in the seal population, already at a reduced level, as suggested by the lack of pups in the 1986 and 1987 fall harvests at Sachs Harbour. There was a detectable increase in seal abundance in fall 1986 but this did not result in an increase in reproduction in spring 1987. Normal reproductive rates were not detected until spring 1988. The time required for recovery of reproduction may relate to some environmental factor, or possibly reflect a sampling artifact associated with the relatively small (n=25 sexually mature females) 1987 fall harvest sample.

Changes in the polar bear population were also documented during the same period. While there were no significant differences in the mean weight of female polar bears handled between 1985 and 1987 (n=318), cubs born to females of all age classes weighed significantly less in 1986 and 1987, than in 1985 (Stirling et al. 1988). Mean litter size also declined, and litter-produced rate for females breeding for the first time (six year olds) was lower in 1986 (0.13) and 1987 (0.12) than in 1985 (0.50). These changes appeared to be directly correlated with decreased production of ringed seal pups, their preferred food (Stirling et al. 1988).

In summary, evidence from several sources indicates that seal recruitment and abundance fluctuated during the period between 1982 and 1987. The reasons for these changes are not known, but may relate to food availability as was apparently the case in the 1970's (Smith 1987). Severe ice conditions in 1985 may have reduced the availability of seal prey in late summer of that year, and thus impeded recovery of reproduction in the ringed seal population, already at a lower level. The magnitude of the fluctuations in the seal population seen in this and concurrent studies, together with findings that bowhead whales, polar bears, and bearded seals were affected as well, provide further evidence that this ecosystem is prone to large-scale fluctuations.

Research and management activities directed to ringed seals, and assessment of impacts of development on ringed seal populations, must recognize these natural fluctuations as characteristic of the ecosystem. The physical and biological mechanisms which cause, contribute to, or influence these fluctuations are not understood. These mechanisms require further investigation to ensure they are considered and incorporated in the collection and interpretation of data on marine mammals in this region.

POTENTIAL COMPETITION BETWEEN RINGED SEALS AND BOWHEAD WHALES

Even though bowhead whales are present and feeding for only about 150 days annually, I calculated that they have a 5 to 30 times greater demand on the ecosystem than ringed seals which are present throughout the year. The ecological role of the bowhead, at both current and historic population sizes, is obviously major. However, the ecological role and demand of the regional ringed seal population, appears to approach that of the bowhead, particularly in years of high abundance.

Overlap in the diet of ringed seals and bowhead whales suggests there may be some competition for food between the species in some areas (Lowry et al. 1978; Frost and Lowry 1984). Given this overlap, the marked reduction in the bowhead stock in the late 1800's could have allowed for a substantial increase in the ringed seal population, as apparently occurred with seal and minke populations in the Antarctic after cessation of commercial whaling (Laws 1983).

Such an increase may have been followed by competition for food among bowheads and ringed seals, and this competition may be limiting, at least in part, recovery of the bowhead stock (Frost and Lowry 1984). However, there are no data to evaluate this hypothesis, since the extent of dietary overlap among these species, and the current and pre-whaling size of the ringed seal population are unknown. Nevertheless, since the reproductive potential of ringed seals (reproduce annually, sexually mature at 5.6 years) is greater than that for bowheads (calving interval 3-5 years, length at sexual maturity 14m, age unknown, Nerini et al. 1984), it is probable that ringed seals would respond more quickly to a surplus of food than bowheads would. Thus it is more likely that ringed seals are limiting bowheads than vice-versa.

The question of whether or not ringed seal populations in this or other regions are food limited remains unanswered. McLaren (1958) suggested that ringed seals were not food limited, based on the observation that they feed opportunistically and at many trophic levels. In waters of southeastern Baffin Island, Smith and Hammill (1981) suggest that the ringed seal population is regulated, at least in part, by the availability of suitable fast ice habitat for breeding and feeding. Lowry et al. (1980) suggest seals may be food limited in areas and during times when concentrations of prey are not available. The results of this study showed that ringed seals aggregate during late summer, and probably do so to take advantage of abundant prey in these areas. Whether or not prey availability in aggregation areas limits the ringed seal population is not known, but this would be most likely during years when prey abundance is low (e.g. late summer 1985).

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APPENDIX I

Location of Survey Transects, SE Beaufort Sea, August-September 1982, 1984, 1985 and 1986

TRANSECT NO.	SURVEY DATE	LONGITUDE (°W)	LATITUDE (°N) South	North	TRANSECT LENGTH (km)
3	82-08-18	139°57.1'	69°37.1'	70°20'	79.5
4	82-08-18	139°31.8'	69°34.0'	70°20'	85.2
5	82-08-18	139°06.7'	69°38.8'	70°20'	76.4
6	82-08-18	138°41.5'	69°20.7'	70°20'	109.9
7	32-08-18	138°16.4'	69°14.9'	70°20'	120.6
8	82-08-18	137°51.1'	69°05.4'	70°20'	138.2
9	82-08-19	137°26.0'	69°00.7'	70°20.5'	147.9
10	82-08-19	137°00.8'	69°03.7'	70°21.3'	143.8
10A	82-08-19	136°48.3'	69°09.8'	70°24.1'	137.7
11	82-08-19	136°35.6'	69°14.4'	70°26.5'	133.6
11A	82-08-19	136°22.9'	69°21.7'	70°29.4'	113.5
12	82-08-19	136°10.3'	69°26.0'	70°31.7'	95.0
12A	82-08-19	135°57.7'	69°29.5'	70°35.2'	78.6
13	82-08-19	135°45.1'	69°31.3'	70°37.0'	67.8
13A	82-08-22	135°32.5'	69°38.0'	70°39.8'	114.5
14	82-08-22	135°20.0'	69°34.0'	70°44.0'	129.7
15	82-08-22	134°54.8'	69°35.5'	70°51.4'	135.0
16	82-08-22	134°29.6'	69°44.0'	70°56.0'	124.1
17	82-08-22	134°04.5'	69°42.4'	70°56.2'	136.8
18	82-08-22	133°39.4'	69°36.8'	71°00.5'	155.1
19	82-08-23	133°14.1'	69°35.6'	71°03.9'	163.6
20	82-08-23	132°48.8'	69°41.0'	71°07.4'	160.1
21	82-08-23	132°23.5'	69°48.7'	71°10.5'	151.6
22	82-08-23	131°58.4'	69°47.9'	71°14.3'	160.1
23	82-08-23	131°33.1'	69°55.6'	71°16.8'	150.5
24	82-08-23	131°07.9'	70°00.6'	71°18.8'	143.1
25	82-08-24	130°42.7'	70°11.0'	71°21.5'	129.0
26	82-08-24	130°17.5'	70°10.5'	71°29.8'	147.0
27	82-08-24	129°52.3'	70°15.4'	71°29.1'	136.6
28	82-08-24	129°27.2'	70°14.2'	71°28.6'	137.9
29	82-08-24	129°01.9'	70°00.7'	71°27.5'	129.5
1	82-09-05	140°47.4'	69°37.8'	70°20'	78.2
2	82-09-05	140°22.3'	69°36.0'	70°20'	81.5
3	82-09-05	139°57.1'	69°37.1'	70°20'	79.5
4	82-09-05	139°31.8'	69°34.0'	70°20'	79.9
5	82-09-05	139°06.7'	69°38.8'	70°20'	76.4
6	82-09-05	138°41.5'	69°20.7'	70°20'	109.9
7	82-09-13	138°16.4'	69°14.9'	70°20'	120.6
8	82-09-13	137°51.1'	69°05.4'	70°20'	138.2
9	82-09-13	137°26.0'	69°00.7'	70°20.5'	147.9
10	82-09-13	137°00.8'	69°03.7'	70°21.3'	143.8
11	82-09-13	136°35.6'	69°14.4'	70°26.5'	133.6
11A	82-09-13	136°22.9'	69°21.7'	70°239.4'	125.5

TRANSECT NO.	SURVEY DATE	LONGITUDE (°W)	LATITUDE (°N) South	North	TRANSECT LENGTH (km)
12	82-09-13	136°10.3'	69°26.0'	70°31.7'	121.8
12A	82-09-13	135°57.7'	69°29.5'	70°35.2'	121.8
13	82-09-13	135°45.1'	69°31.3'	70°37.0'	121.8
14	82-09-13	135°20.0'	69°34.0'	70°44.0'	129.7
15	82-09-09	134°54.8'	69°35.5'	70°51.4'	140.7
16	82-09-09	134°29.6'	69°44.0'	70°56.0'	138.4
17	82-09-09	134°04.5'	69°42.4'	70°56.2'	136.8
18	82-09-09	133°39.4'	69°36.8'	71°00.5'	155.1
19	82-09-09	133°14.1'	69°35.6'	71°03.9'	163.6
20	82-09-09	132°48.8'	69°41.0'	71°07.4'	160.1
21	82-09-12	132°23.5'	69°48.7'	71°10.5'	151.6
22	82-09-12	131°58.4'	69°47.9'	71°14.3'	160.1
23	82-09-12	131°33.1'	69°55.6'	71°16.8'	150.5
24	82-09-12	131°07.9'	70°00.6'	71°18.8'	143.1
25	82-09-12	130°42.7'	70°11.0'	71°21.5'	130.6
26	82-09-12	130°17.5'	70°10.5'	71°29.8'	147.0
27	82-09-12	129°52.3'	70°15.4'	71°29.1'	136.6
1	84-08-27	140°42.9'	69°37.2'	71°30'	209.0
2	84-08-27	140°11.9'	69°36.2'	71°30'	211.0
3	84-08-27	139°39.8'	69°35.1'	71°00'	157.0
4-N	84-08-27	139°07.7'	69°50.0'	71°00'	130.0
7	84-08-18	137°34.7'	69°40.2'	71°30'	203.0
8	84-08-18	137°02.8'	69°02.2'	71°30'	274.0
13	84-08-22	134°24.5'	69°44.2'	71°50'	233.0
14	84-08-22	133°53.9'	69°39.5'	71°50'	242.0
17	84-08-22	132°19.9'	69°48.8'	72°05'	252.0
18	84-08-22	131°47.9'	69°51.6'	72°05'	247.0
23	84-08-23	129°09.8'	70°03.2'	71°22.4'	147.0
24	84-08-23	128°39.9'	69°51.2'	71°25'	174.0
25-N	84-08-23	128°08.8'	70°40.7'	71°35.5'	101.0
26-N	84-08-23	127°34.2'	70°49.0'	71°35.0'	85.0
3c	84-08-27	139°21.2'	69°34'	69°50'	29.6
3d	84-08-27	139°15.0'	69°36.5'	69°50'	25.0
4-S	84-08-27	139°07.7'	69°38.0'	69°50'	22.2
4a	84-08-27	139°01.5'	69°38.0'	69°50'	22.2
4b	84-08-27	138°55.3'	69°37.0'	69°50'	24.1
4c	84-08-27	138°49.1'	69°23.5'	69°40'	30.6
4d	84-08-27	138°42.9'	69°21.5'	69°40'	34.3
25-S	84-08-23	128°08.8'	70°30.6'	70°40.7'	18.7
26-S	84-08-23	127°34.2'	70°26.1'	70°49.0'	42.4
1	84-09-06	140°42.9'	69°37.2'	71°30'	209.0
2	84-09-06	140°11.9'	69°36.2'	71°30'	211.0
3	84-09-11	139°39.8'	69°35.1'	71°20'	194.0
4	84-09-11	139°07.7'	69°38.0'	71°20'	189.0
6	84-09-11	138°06.5'	69°08.5'	71°21'	245.0
9	84-09-11	136°31.1'	69°17.1'	71°40'	265.0
10	84-09-11	136°00.0'	69°29.1'	71°40'	242.0
13	84-09-11	134°24.5'	69°44.2'	71°20'	177.0
14	84-09-11	133°53.9'	69°39.5'	71°20'	186.0

TRANSECT NO.	SURVEY DATE	LONGITUDE (°W)	LATITUDE (°N) South	North	TRANSECT LENGTH (km)
17	84-09-12	132°19.9'	69°48.8'	70°34'	121.0
18	84-09-12	131°47.9'	69°51.6'	70°30'	71.0
19	84-09-17	131°17.2'	70°00.0'	71°40'	185.0
20	84-09-17	130°46.1'	70°10.9'	71°40'	165.0
21	84-09-17	130°14.9'	70°10.2'	71°40'	166.0
22	84-09-17	129°42.1'	70°16.9'	71°40'	154.0
27	84-09-18	127°03.2'	70°10.0'	71°00'	93.0
28	84-09-18	126°33.8'	69°40.3'	71°00'	148.0
29	84-09-18	126°02.8'	69°25.8'	70°13'	87.0
1	85-08-18	140°42.9'	69°37.2'	71°50'	134.8
2	85-08-18	140°11.9'	69°36.2'	70°50'	136.7
3	85-08-18	139°39.8'	69°35.1'	70°45'	129.5
4	85-08-18	139°07.7'	69°38.0'	70°45'	124.1
5	85-08-19	138°37.0'	69°18.6'	70°10'	95.2
6	85-08-19	138°06.5'	69°08.5'	70°10'	113.9
7	85-08-19	137°34.7'	69°02.2'	70°05'	116.3
8	85-08-19	137°02.8'	69°02.2'	70°05'	116.3
9	85-08-19	136°31.1'	69°17.1'	70°26'	127.6
10	85-08-19	136°00.0'	69°29.1'	70°25'	88.7
11	85-08-20	135°28.7'	69°39.6'	70°40'	111.9
12	85-08-20	134°57.2'	69°41.7'	70°40'	108.0
13	85-08-20	134°24.5'	69°44.2'	70°40'	103.3
14	85-08-20	133°53.9'	69°39.5'	70°40'	112.0
15	85-08-20	133°23.2'	69°38.1'	70°35.'	105.4
16	85-08-20	132°50.8'	69°39.5'	70°35'	102.8
17	85-08-21	132°19.9'	69°48.8'	70°35'	85.6
18	85-08-21	131°47.9'	69°51.5'	70°50'	108.2
19	85-08-21	131°17.2'	70°00.6'	70°50'	92.6
20	85-08-21	130°46.1'	70°10.0'	70°50'	72.4
21	85-08-21	130°14.9'	70°10.9'	71°00'	92.2
22	85-08-21	129°42.1'	70°16.2'	71°00'	79.8
23	85-08-21	129°09.8'	70°00.9'	71°00'	111.1
24	85-08-21	128°39.9'	69°51.2'	71°00'	127.4
25	85-08-24	128°08.8'	70°36.3'	71°27'	93.9
26	85-08-24	127°34.2'	70°26.1'	71°32.3'	122.6
2	86-08-25	140°11.9'	69°36.2'	70°25.1'	72.1
3	86-08-25	139°39.8'	69°35.1'	70°26.4'	88.4
4	86-08-25	139°07.7'	69°38.0'	70°21.8'	67.1
5	86-08-25	138°37.0'	69°18.6'	70°16.6'	101.0
6	86-08-26	138°06.5'	69°08.5'	69°41.5'	61.2
7	86-08-26	137°34.7'	69°02.2'	69°34.2'	59.3
8	86-08-26	137°02.8'	69°02.2'	70°36.8'	163.8
9	86-08-26	136°31.1'	69°17.1'	70°40.1'	152.3
10	86-08-26	136°00.0'	69°29.1'	70°47.4'	145.1
11	86-08-26	135°28.7'	69°39.6'	70°52.8'	126.9
12	86-08-29	134°57.2'	69°41.7'	70°35.0'	81.9
13	86-08-29	134°24.2'	69°44.2'	70°35.0'	70.0
14	86-08-29	133°53.9'	69°39.5'	70°50.0'	126.0
15	86-08-29	133°23.2'	69°38.1'	70°50.0'	124.7

TRANSECT NO.	SURVEY DATE	LONGITUDE (°W)	LATITUDE (°N) South	North	TRANSECT LENGTH (km)
16	86-08-31	132°50.8'	69°39.5'	70°45.0'	97.1
17	86-08-31	132°19.9'	69°48.8'	70°45.0'	67.6
18	86-08-31	131°47.9'	69°51.6'	71°07.0'	116.2
19	86-08-31	131°17.2'	70°00.0'	71°08.1'	97.1
20	86-08-31	130°46.1'	70°10.2'	71°00.0'	85.4
21	86-08-31	130°14.9'	70°10.2'	71°00.0'	80.6
22	86-08-31	129°42.1'	70°16.9'	71°05.0'	79.7
23	86-08-31	129°09.8'	70°02.9'	71°05.0'	109.0
24	86-09-01	128°39.9'	69°51.2'	71°27.0'	168.1
25	86-09-01	128°08.8'	70°36.5'	71°27.0'	81.7
1	86-09-07	140°42.9'	69°37.2'	70°20.0'	79.3
2	86-09-07	140°11.9'	69°36.2'	70°20.0'	81.2
3	86-09-07	139°39.8'	69°35.1'	70°20.0'	83.2
4	86-09-07	139°07.7'	69°38.0'	70°20.0'	77.8
5	86-09-07	138°37.0'	69°18.6'	70°20.0'	113.8
6	86-09-07	138°06.5'	69°08.5'	70°20.0'	132.5
7	86-09-07	137°34.7'	69°02.0'	70°20.0'	144.2
8	86-09-07	137°02.8'	69°02.2'	70°20.0'	144.2
11	86-09-10	135°28.7'	69°39.6'	70°53.8'	136.4
12	86-09-10	134°57.2'	69°41.7'	71°03.3'	151.2
13	86-09-10	134°24.2'	69°44.2'	71°08.7'	156.6
14	86-09-10	133°53.9'	69°39.5'	71°10.5'	168.6
15	86-09-10	133°23.2'	69°38.1'	71°14.4'	145.8
16	86-09-10	132°50.8'	69°39.5'	71°08.6'	165.1
17	86-09-10	132°19.9'	69°48.8'	71°06.3'	143.6
18	86-09-10	131°47.9'	69°51.6'	71°09.6'	144.5
19	86-09-14	131°17.2'	70°00.0'	71°30.0'	166.8
20	86-09-14	130°46.1'	70°10.9'	71°33.2	152.5
21	86-09-14	130°14.9'	70°10.2'	71°42.3'	170.7
22	86-09-14	129°42.1'	70°16.9'	71°42.0'	157.7
23	86-09-14	129°09.8'	70°03.2'	71°42.0'	183.1
24	86-09-14	128°39.9'	69°59.2'	71°36.5'	180.3
X	86-08-21	130°00.0'	70°08.5'	71°26.8'	157.4
6	86-08-21	131°26.6'	69°57.0'	71°26.8'	171.3
7	86-08-21	132°52.5'	69°39.5'	71°12.0'	166.3
8	86-08-21	133°58.0'	69°40.0'	71°05.0'	145.0
J	86-09-05	137°20.0'	69°10.0'	70°00.0'	92.6
K	86-09-05	137°05.0'	69°15.0'	70°00.0'	83.3
L	86-09-05	136°50.0'	69°15.0'	70°00.0'	83.3
M	86-09-05	136°35.0'	69°20.0'	70°00.0'	74.1
A	86-09-23	132°50.0'	70°10.0'	70°30.0'	55.6
B	86-09-23	131°55.0'	70°40.0'	71°10.0'	55.6
D	86-09-23	131°05.0'	70°40.0'	71°10.0'	55.6
E	86-09-23	130°40.0'	70°40.0'	71°10.0'	55.6
F	86-09-23	130°15.0'	70°40.0'	71°10.0'	55.6
G	86-09-23	129°50.0'	70°40.0'	71°10.0'	55.6
H	86-09-23	129°25.0'	70°40.0'	71°10.0'	55.6

APPENDIX 2

Distribution of bearded seals, bowhead whales and beluga whales at three scales in the SE Beaufort Sea, August-September 1982, 1984-1986

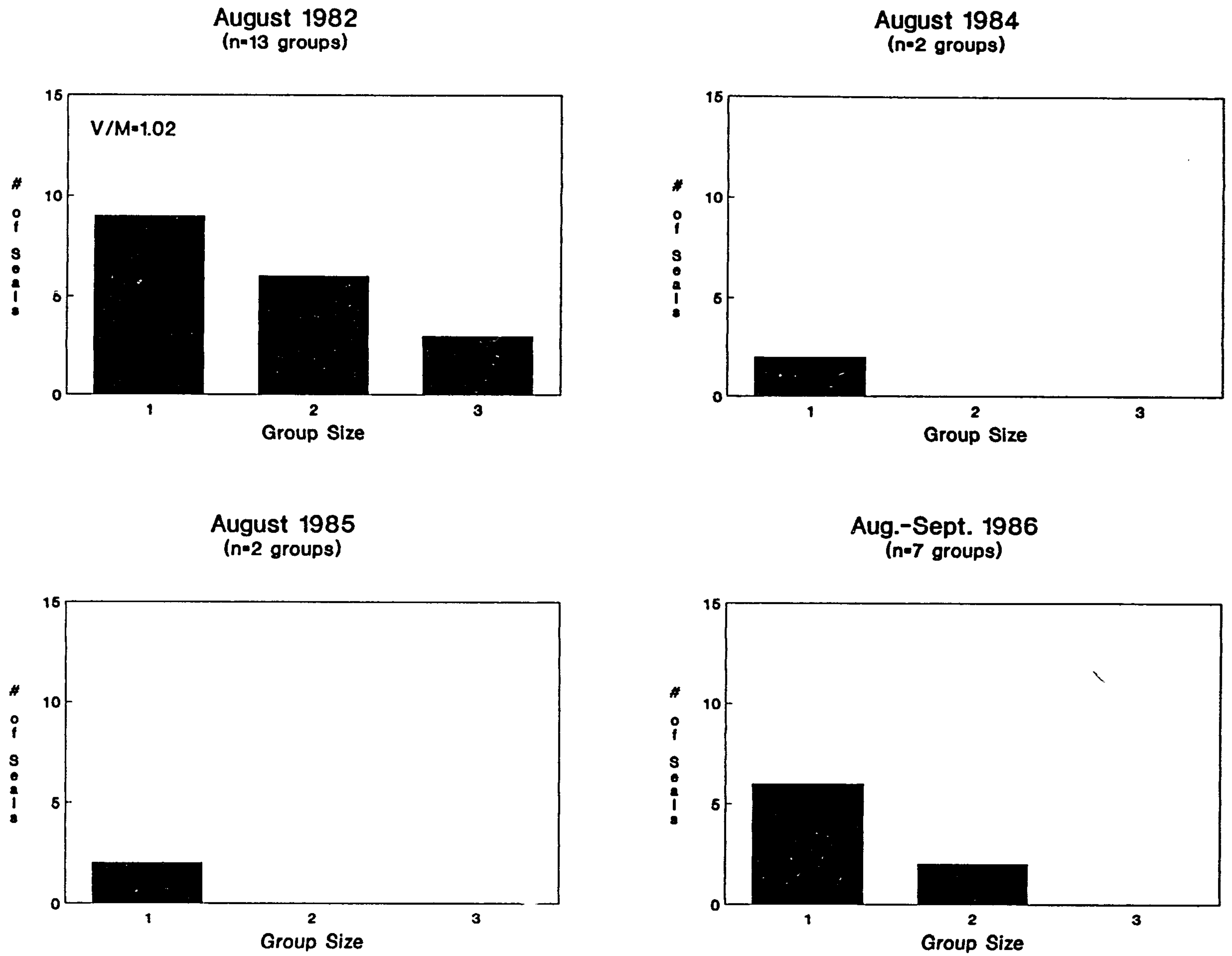

Figure A2-1. Frequency distribution of number of bearded seals per group, southeast Beaufort Sea, late summer 1982, 1984-1986

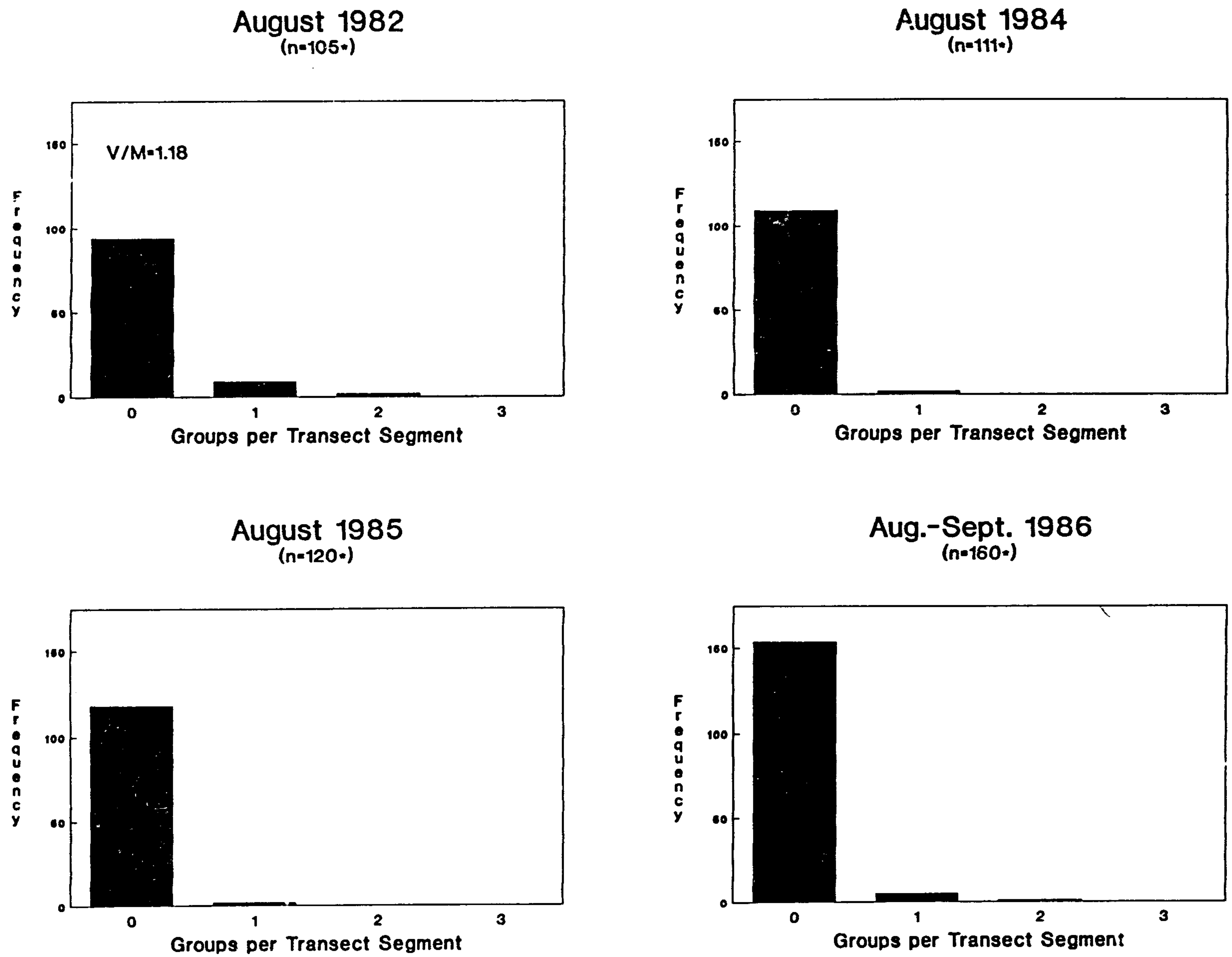

Figure A2-2. Frequency distribution of number of bearded seal groups per transect segment, southeast Beaufort Sea, late summer 1982, 1984-1986

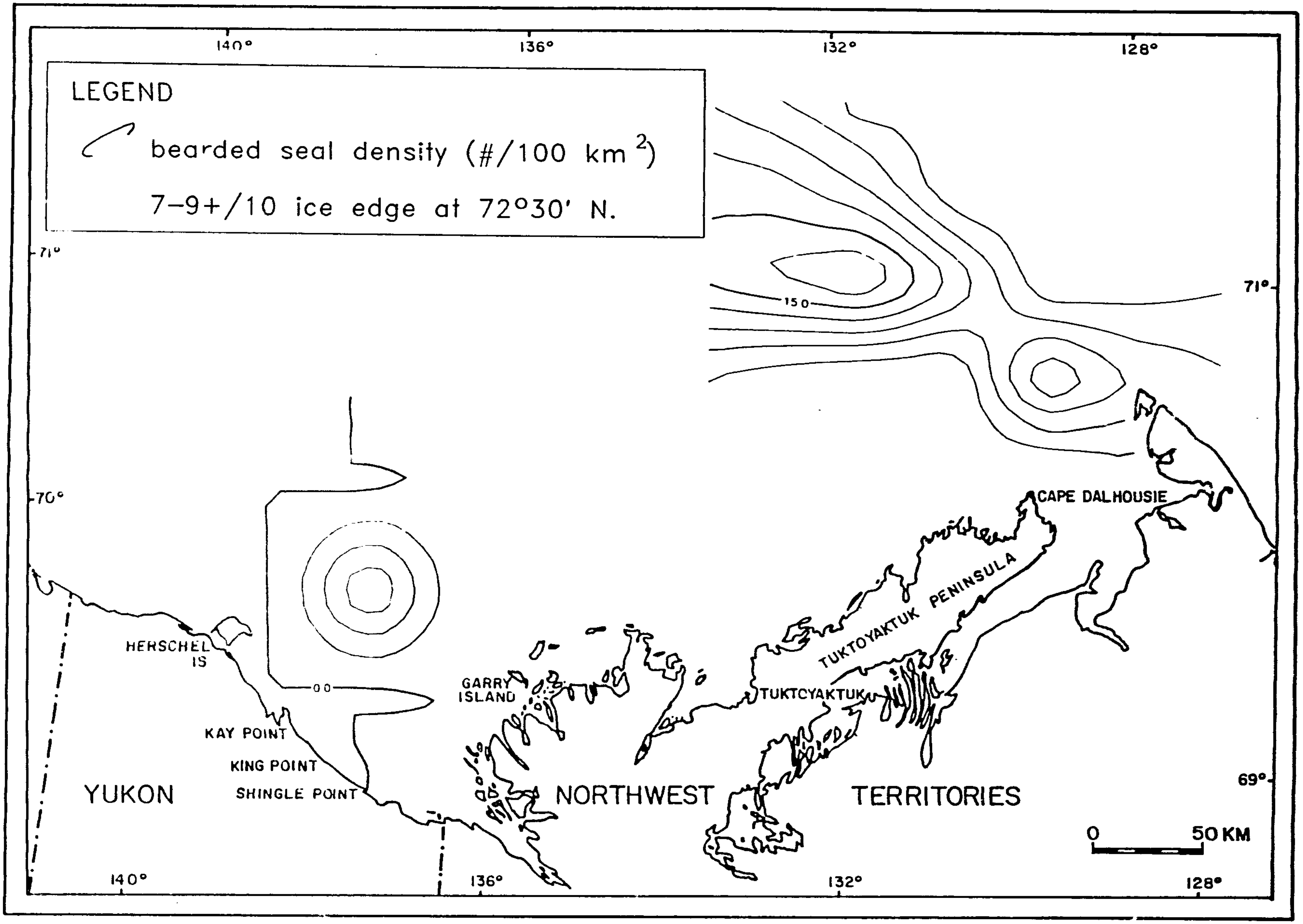

Figure A2-3. Distribution of bearded seals in the southeast Beaufort Sea, August 18-24, 1982

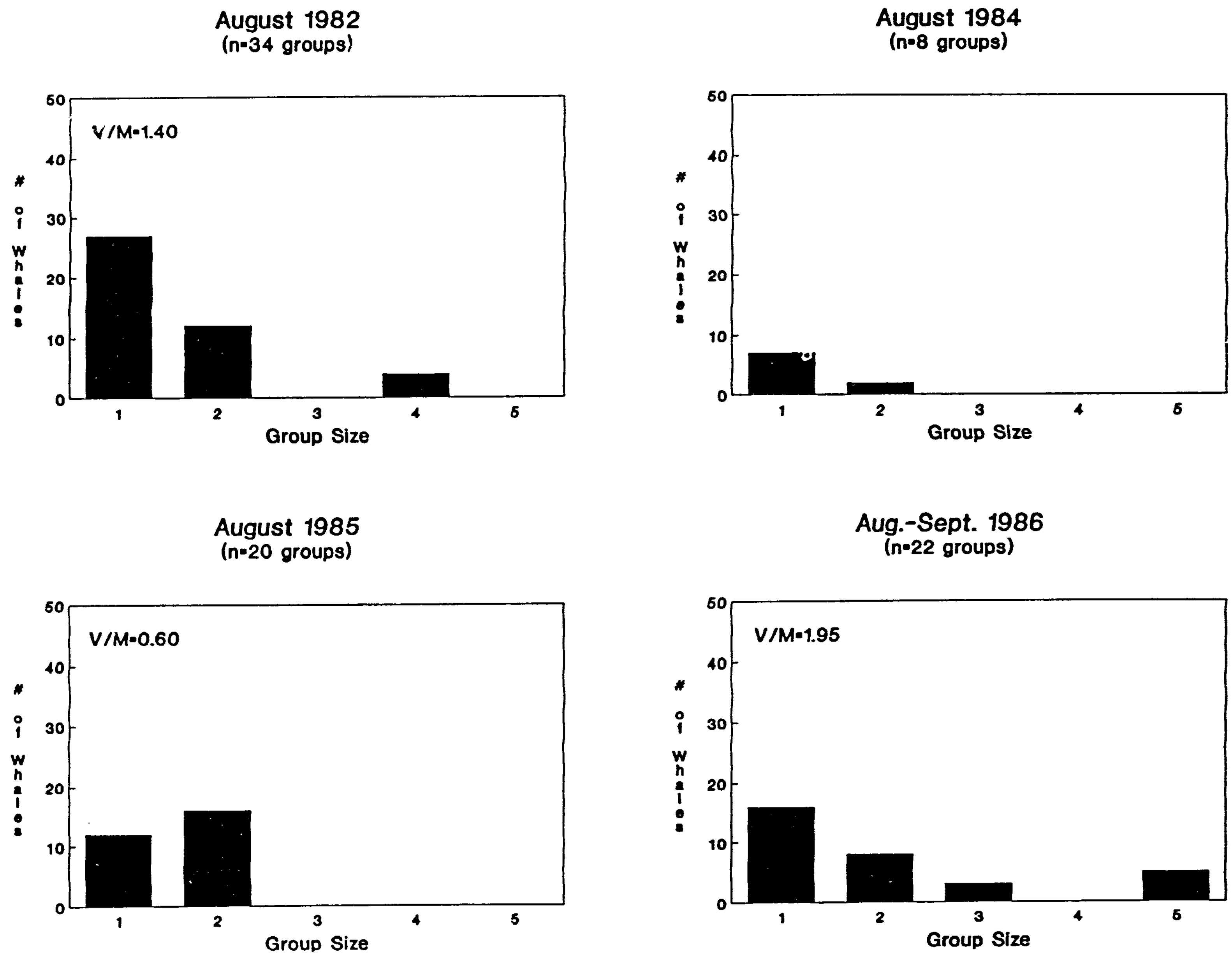

Figure A2-4. Frequency distribution of number of bowhead whales per group, southeast Beaufort Sea, late summer 1982, 1984-1986

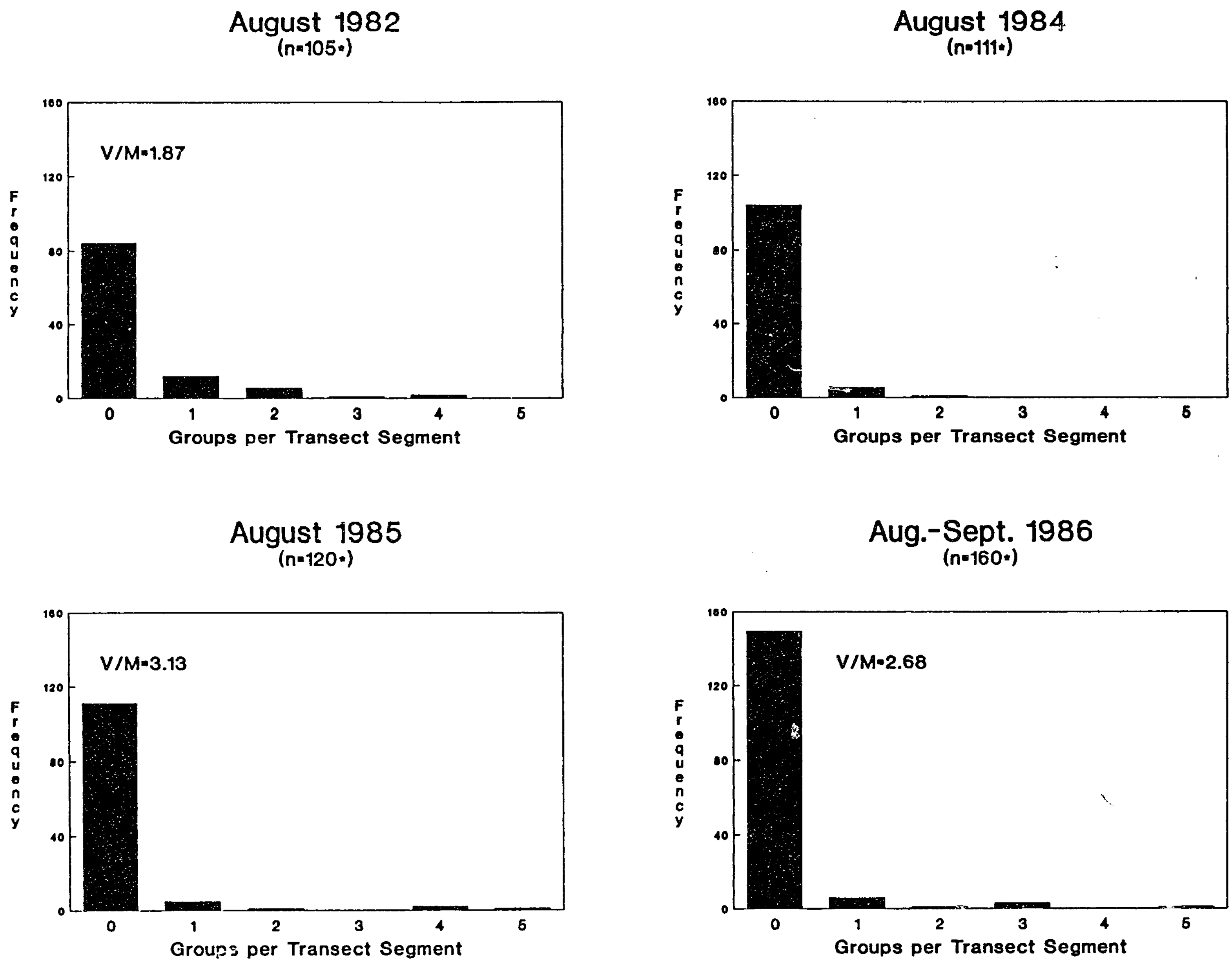

Figure A2-5. Frequency distribution of number of bowhead whale groups per transect segment, southeast Beaufort Sea, late summer 1982, 1984-1986

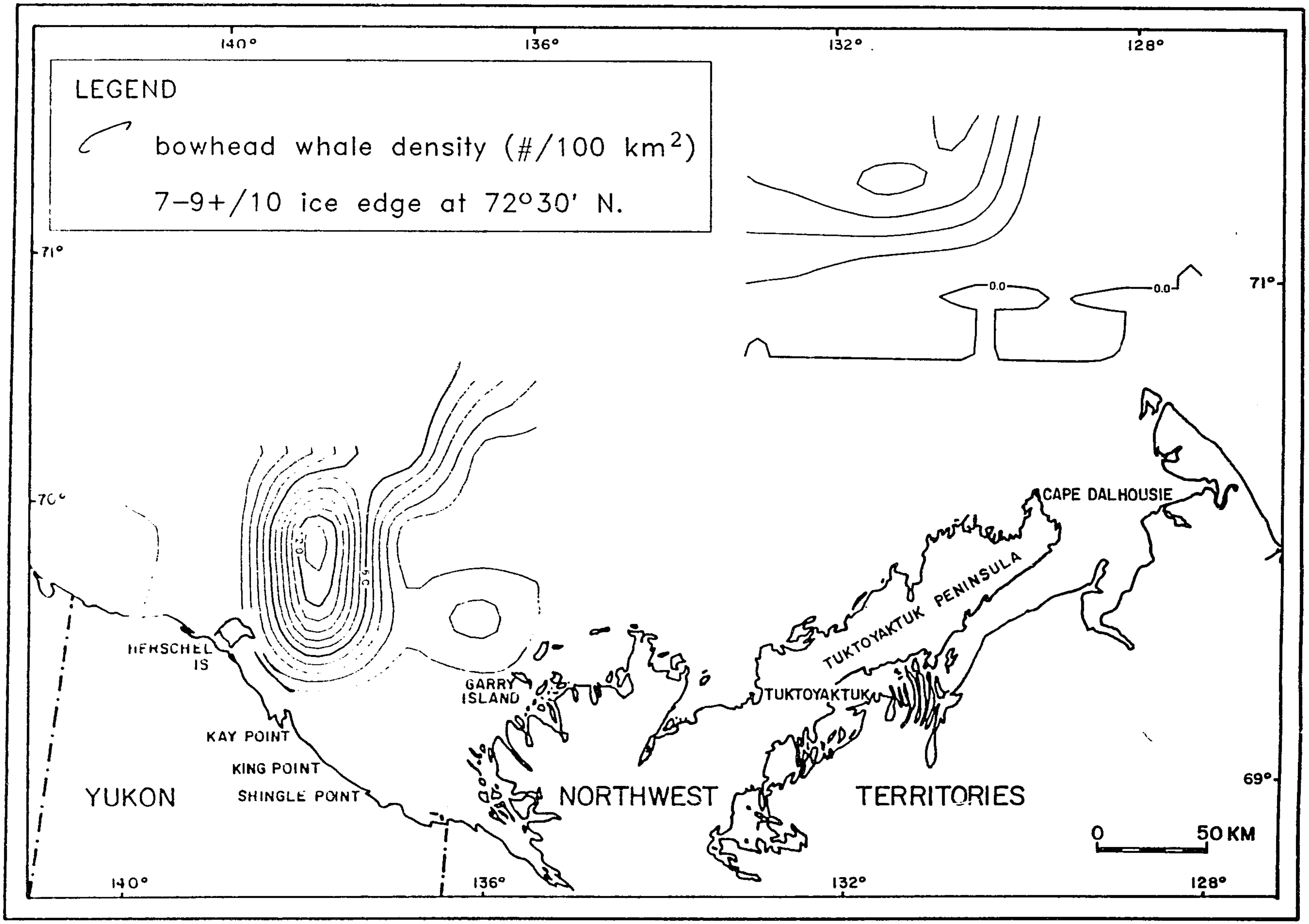

Figure A2-6. Distribution of bowhead whales in the southeast Beaufort Sea, August 18-24, 1982

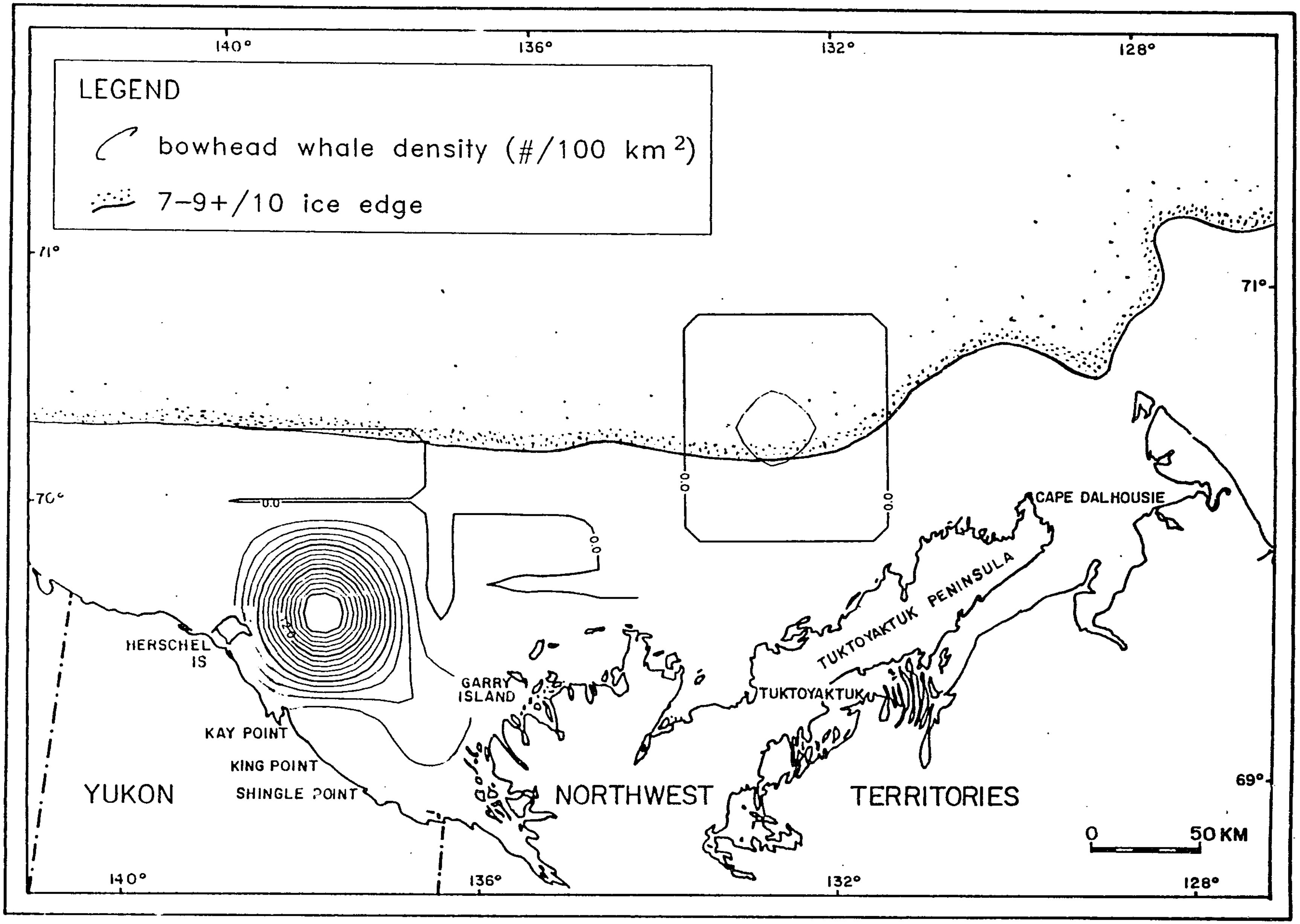

Figure A2-7. Distribution of bowhead whales in the southeast Beaufort Sea, August 18-24, 1985

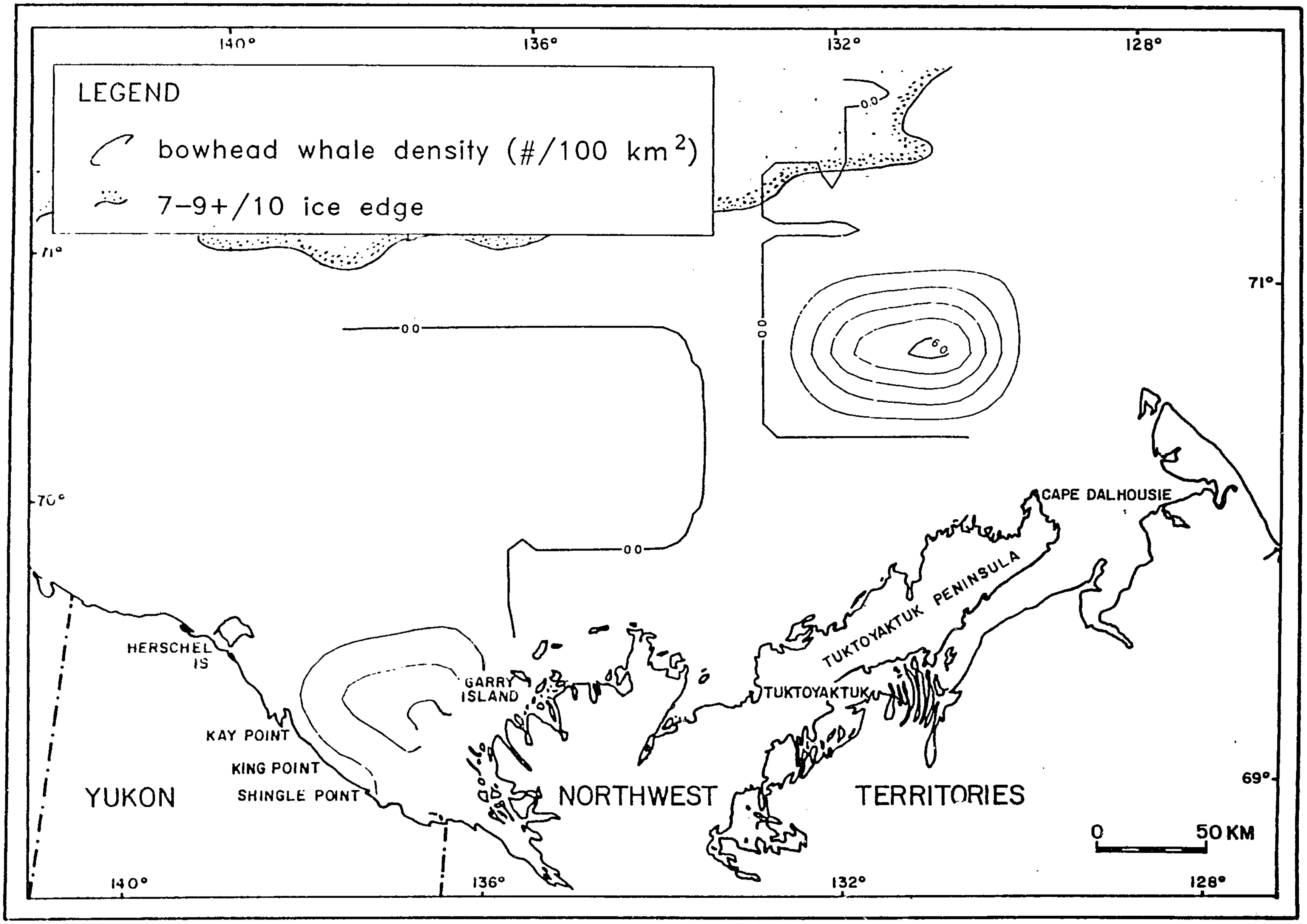

Figure A2-8. Distribution of bowhead whales in the southeast Beaufort Sea, August 31–September 10, 1986

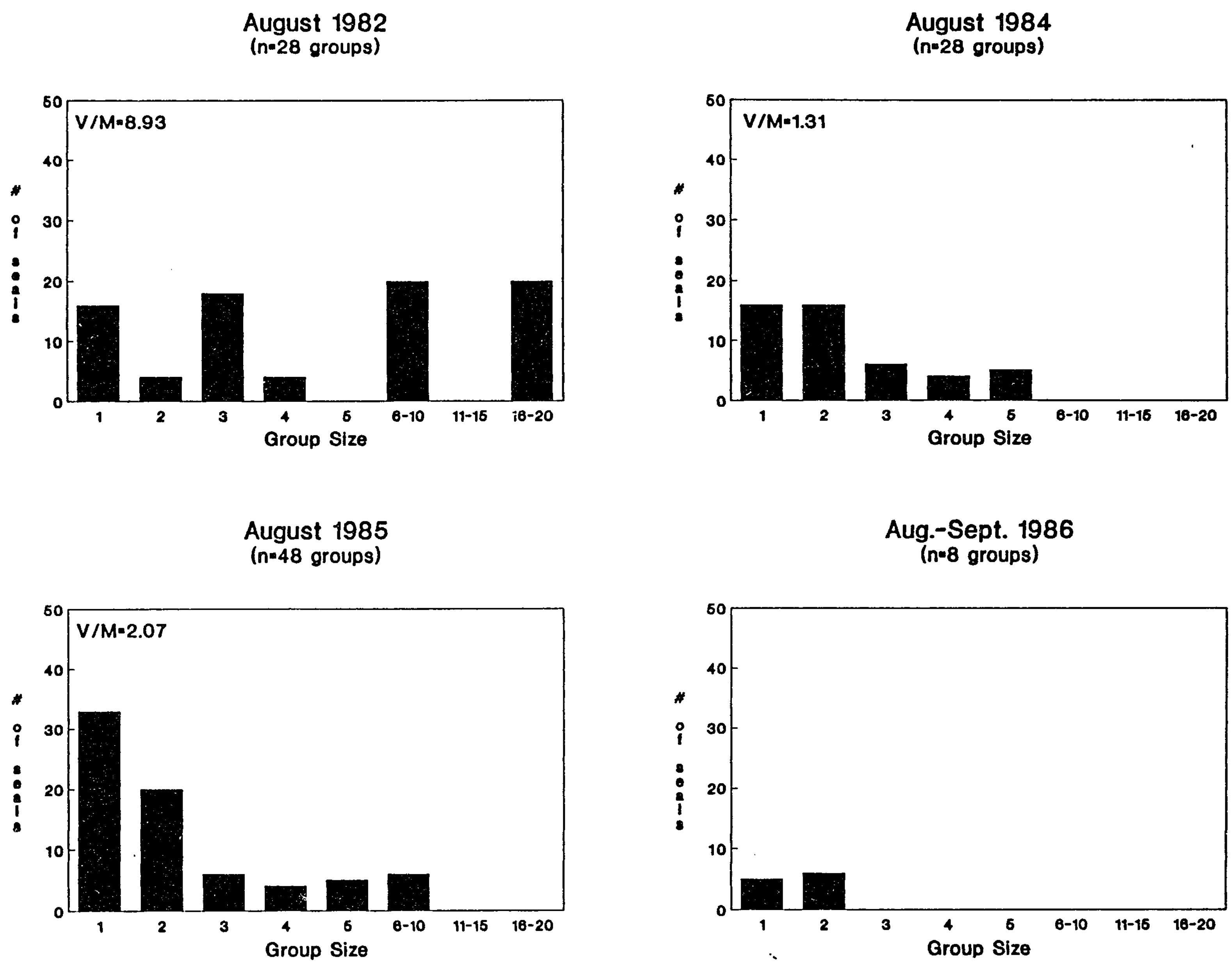

Figure A2-9. Frequency distribution of number of beluga whales per group, southeast Beaufort Sea, late summer 1982, 1984-1986

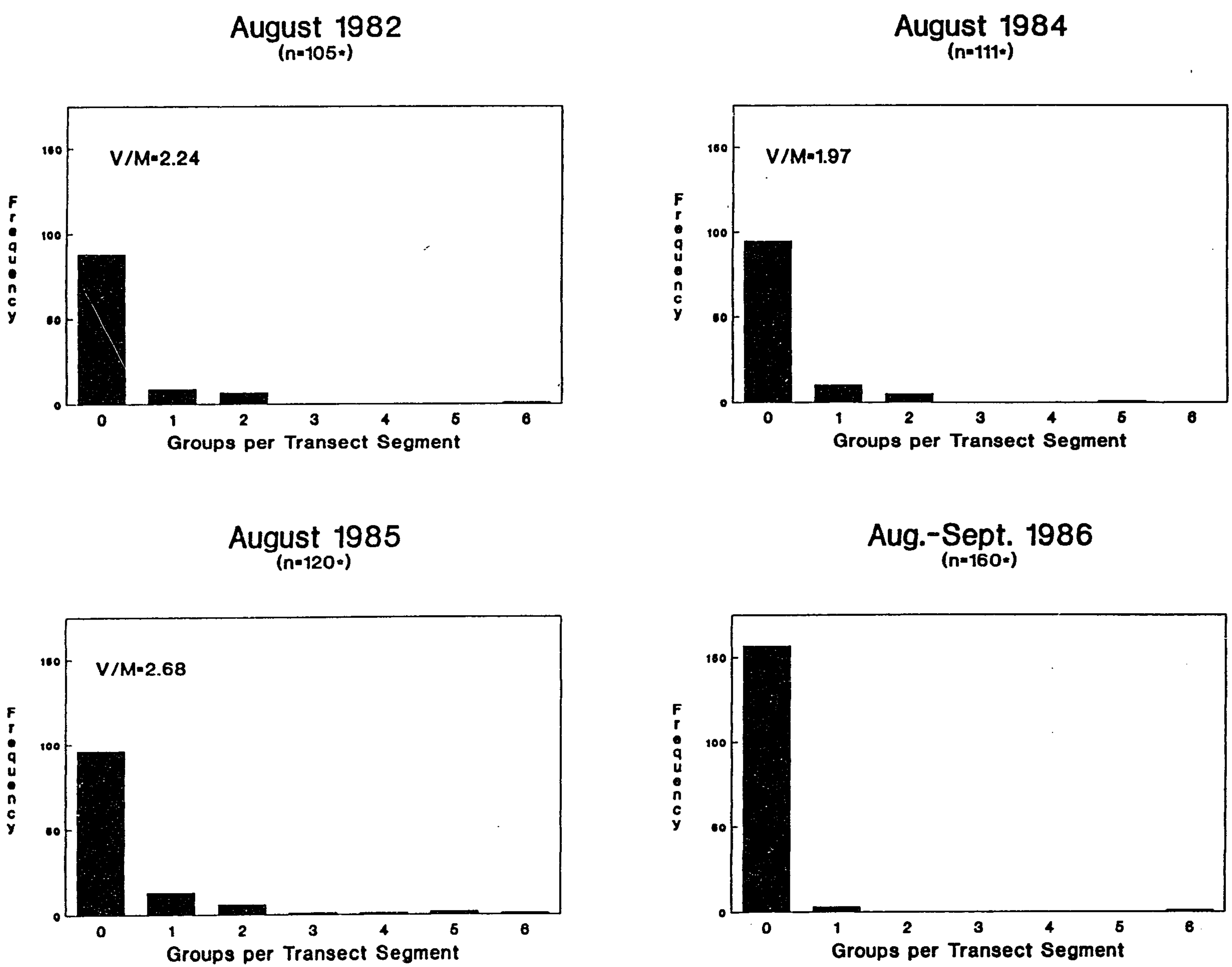

Figure A2-10. Frequency distribution of number of beluga whale groups per transect segment, southeast Beaufort Sea, late summer 1982, 1984-1986

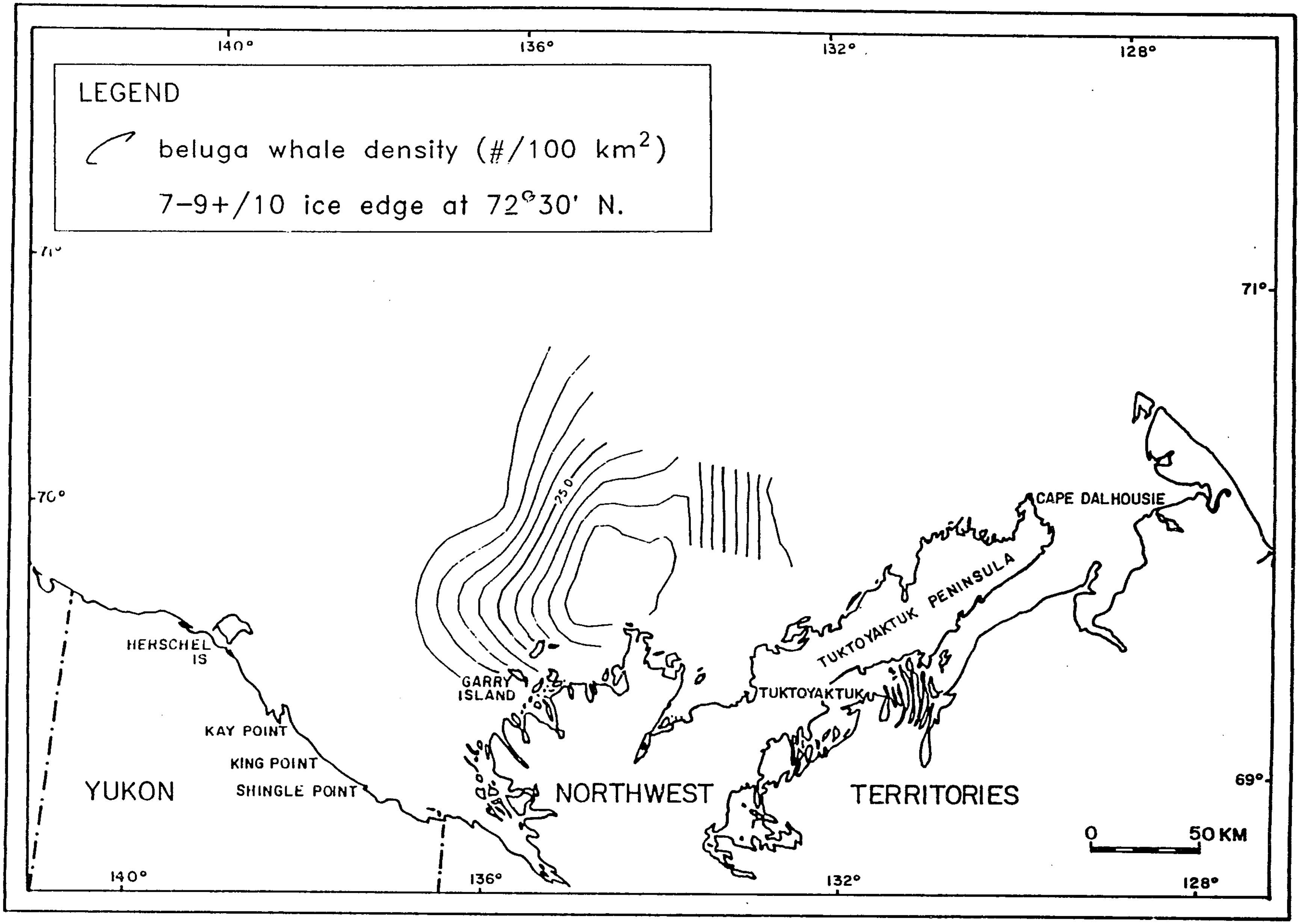

Figure A2-11. Distribution of beluga whales in the southeast Beaufort Sea, August 18-24, 1982

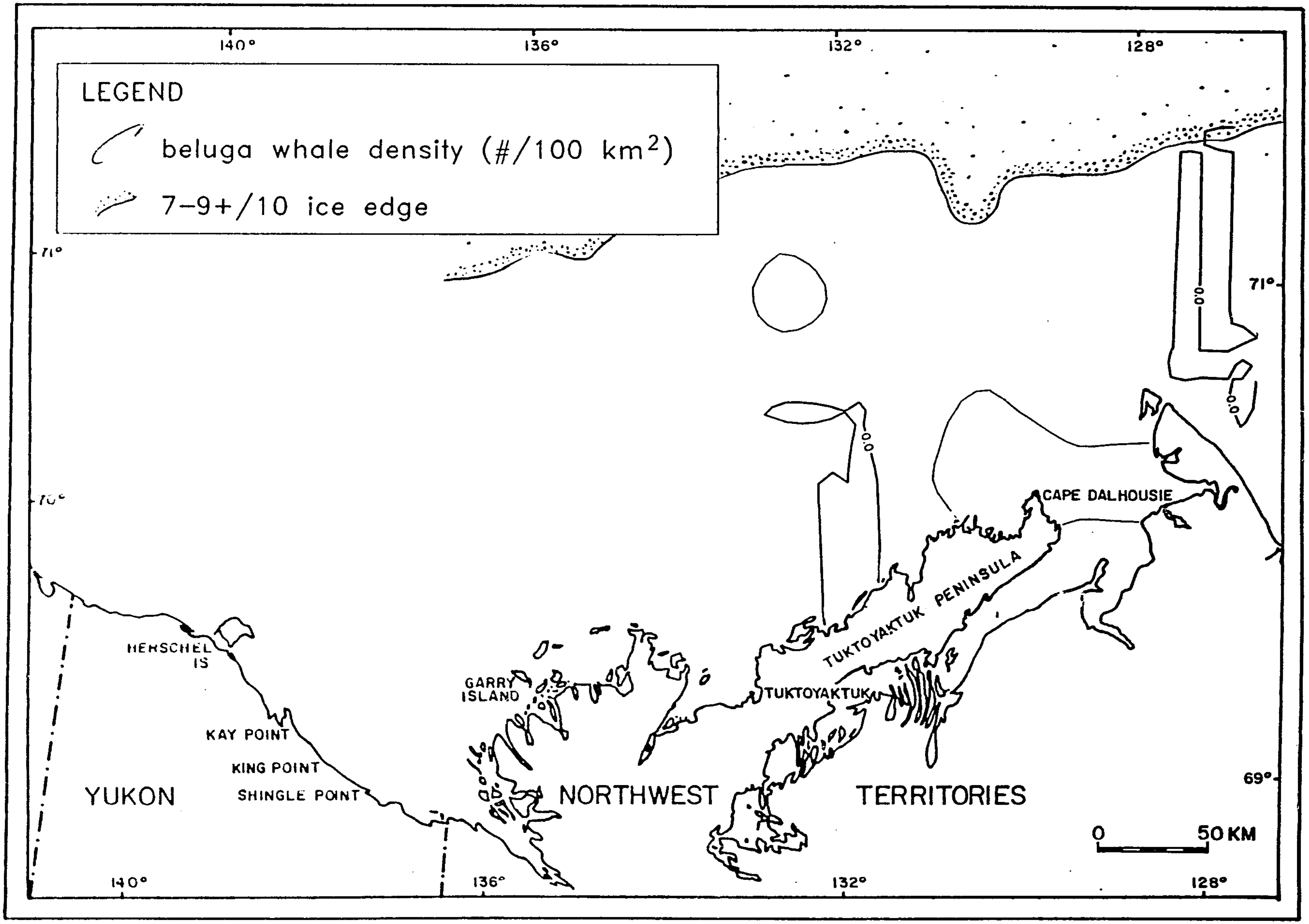

Figure A2-12. Distribution of beluga whales in the southeast Beaufort Sea, August 18-27, 1984

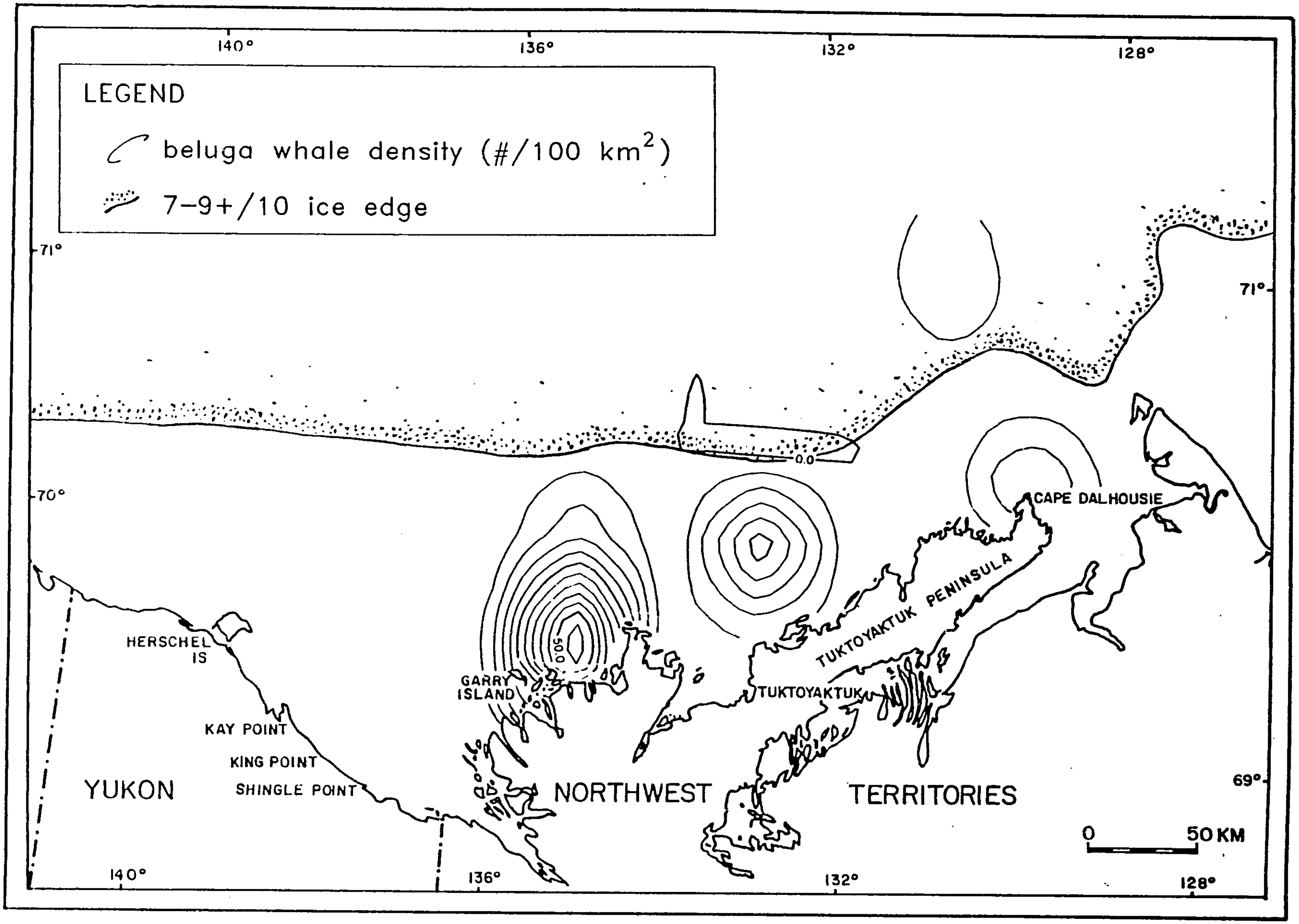

Figure A2-13. Distribution of beluga whales in the southeast Beaufort Sea, August 18-24, 1985