AERIAL SURVEYS FOR PACIFIC HERRING IN LIVERPOOL BAY, N.W.T.

Prepared for:

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DISCLAIMER

This report was prepared for the Fisheries Joint Management Committee, as part of the implementation terms of the Inuvialuit Final Agreement. The opinions, findings, conclusions and recommendations expressed in this report are those of the Authors and do not necessarily reflect the views of the Fisheries Joint Management Committee.

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SUMMARY

Aerial surveys were conducted in Liverpool Bay in an attempt to locate and measure schools of Pacific herring (*Clupea harengus pallasi*). Four aerial surveys were conducted during two 1 week periods - August 16-20 and September 4-7 - with gillnet sampling conducted in lower Liverpool Bay on the down days between flights. A mixed strip transect - shore transect survey model was used providing visual search of 34% of the 6,000 km^2 study area. Aerial surveys were not successful in locating schools of fish although feeding activity by flocks of seagulls and beluga whales indicated the presence of fish. Gillnet studies conducted in the lower portion of Liverpool Bay revealed that herring were the most abundant fish species, outnumbering other species by a factor of two. The presence of beluga whales in Liverpool Bay during all four surveys indicates the importance as a feeding area which may relate to abundance of herring. Using estimates of beluga whale abundance and published values for food ration, predator consumption rates ranged from 0.6 to 3.7 tonnes per day. A large part of this may be related to herring and, when considering the residency times of beluga whales in Liverpool Bay, may indicate the size of this resource is large. Based on the results of this study and a review of the literature specific areas of needed research are identified.

ACKNOWLEDGMENTS

The following people and organizations were helpful in conducting this study.

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- Ms. Elisabeth Hooke kindly prepared the technical drawings.

INTRODUCTION

An isolated population of Pacific herring (*Clupea harengus pallasi*) occurs in the Beaufort Sea in the vacinity of the Mackenzie River delta region. The general range for this population includes coastal areas around the Mackenzie delta from Hershel Island (Kendel *et al.* 1975), along the Tuktoyaktuk Peninsula (Lawrence *et al.* 1984), throughout Liverpool Bay (Gillman and Kristofferson, 1984a), Eskimo (Husky) Lakes (Poulin, pers. comm.) and Coppermine River (Gillman and Kristofferson, 1984b). Collection of this species have also been made from Bathurst Inlet in Coronation Gulf and on Prince of Whales Island in Melville Sound (Hunter and Leach, 1984). In 1980 the Department of Fisheries and Oceans initiated a study to determine the feasibility of establishing a herring roe fishery on this population. This research was initiated in response to a request the Inuvaluit Development Corporation, who were interested in examining the potential for commercial fisheries in the Mackenzie Delta and coastal Beaufort Sea region. Although previous efforts to develop a commercial fishery for food herring in 1963 at Baillie Island failed due to prohibitive transportation costs, a herring roe fishery was considered feasible because of the much higher dollar value per unit weight of the extracted roe product.

The Fingers Area of Liverpool Bay was identified, from the standpoint of logistics, as having good potential for developing a herring roe fishery. The goals of the DFO studies were to determine:

1. When herring spawn in the Fingers area of Liverpool Bay.
2. If it was possible to capture herring, in quantity, just

prior to spawning when the roe are in optimum condition.

3. Whether the roe can be processed on site or at a facility nearby.
4. Whether the roe is a market-acceptable product.

To date these objectives have been met (Gillman and Kristofferson, 1984a). Both ripe and spent herring have been taken in Tuktoyaktuk Harbour and the Fingers Area of Liverpool Bay in early summer. In late June 1983, approximately 8,600 kg of mature herring were harvested from the lower end of Finger One and approximately 400 kg. of roe was extracted from 4,580 kg of this catch (8.7% roe yield). The roe was shipped to Vancouver for market evaluation and assessed as marketable.

A lingering keystone, essential to planning a fishery and allowing commercial harvest of prespawning herring, is an understanding of the size of the Arctic herring population. During the summer of 1985, using spawn survey methods developed on Pacific herring in British Columbia, Archipelago Marine Research conducted a large scale underwater survey in the Fingers Area of Liverpool Bay to locate and quantify herring spawns (Shields 1985). While the research team identified several spawns, areas were small and spawning intensity light providing an overall estimate of 5.68×10^8 eggs or 8.2 tonnes of spawning fish for the Fingers region of Liverpool Bay. This estimate was considered unrealistically low in view of other apparently conflicting information. When gillnets are placed in Finger One prior to spawning, herring catch rates are at a considerably higher rate than would be expected for 8.2 tonnes of spawning fish. A small scale shore based fishery at Ballie Island in 1963 realized a catch of 8.2 tonnes (Hunter 1975) and in 1983 8.6

tonnes of herring were collected by gillnet from Finger One alone (Gillman and Kristofferson 1984a). Large schools of herring have been observed on previous occasions by pilots during the ice free season. In July 1985, a pilot reported a school of fish along shore near the Moose River measuring roughly 5,000 m in length. As a consequence of this information it was reasoned that the spawn survey method may not be an appropriate method for stock assessment and the population of Arctic herring may be considerably larger.

This report describes survey efforts conducted during the 1986 ice free season to estimate herring stock sizes in Liverpool Bay. The primary objective of this project was to conduct aerial surveys in Liverpool Bay during late summer, a period when populations of herring occur inshore. The survey methods used were similar to those used in western Alaska, where aerial surveys are routinely used to enumerate prespawning aggregations of herring along an approximately 4,000 mile expanse of coast from the Aleutian Peninsula to the Bering Strait (Fried, 1983). Schools of herring lying near the surface in shallow water can be readily spotted by aircraft and their surface areas measured using a simple occular grid tube. Application of a correction factor based on water depth allows the estimation of herring school volume and finally tonnage of fish.

A secondary objective of this project was to sample the fish community in the lower Liverpool Bay area using gillnets. As the aerial survey schedule provided down days between flights, the gillnet work was conducted to obtain a better understanding of herring use of nearshore areas during this season of the year.

MATERIALS AND METHODS

Study Area

Liverpool Bay, situated between Tuktoyaktuk Peninsula and Franklin Bay (Figure 1) is approximately 6,000 km^2 in area. As with many areas of the Beaufort Sea coast, water depths are shallow throughout much of Liverpool Bay; maximum water depths of 14 metres occur in mid bay although most of the bay is less than 10 m deep. The shore slope is very gradual in most of the bay with slope gradients of less than 0.1%. Liverpool Bay is a unique coastal feature of the Beaufort Sea forming part of a vast semi-enclosed brackish marine water body that also includes the Fingers Area and Eskimo (Husky) Lakes. Several rivers feed into Liverpool Bay, the most noteworthy of which are the Anderson River and the Kugaluk River.

The study area included Liverpool Bay from Kugaluk Inlet at the southern end to Baillie Island at Cape Bathurst. The northern extent of the study area was along 70° 39' latitude to a point due north of Cape Dalhousie on Tuktoyaktuk peninsula at 129° 40'W. Gillnets were set within a 13 km radius of the base camp located near the mouth of Kugaluk Inlet (Figure 2). A variety of locations were sampled including Moose Bay, Egg Island, Kugaluk Inlet and Finger One.

Aerial Survey Techniques

Four aerial surveys were flown, two during mid August (the 16th and 20th) and two during early September (the 4th and 7th). Aerial surveys were conducted using a Cessna 206 float plane chartered from Inuvik. Surveys were conducted from an altitude

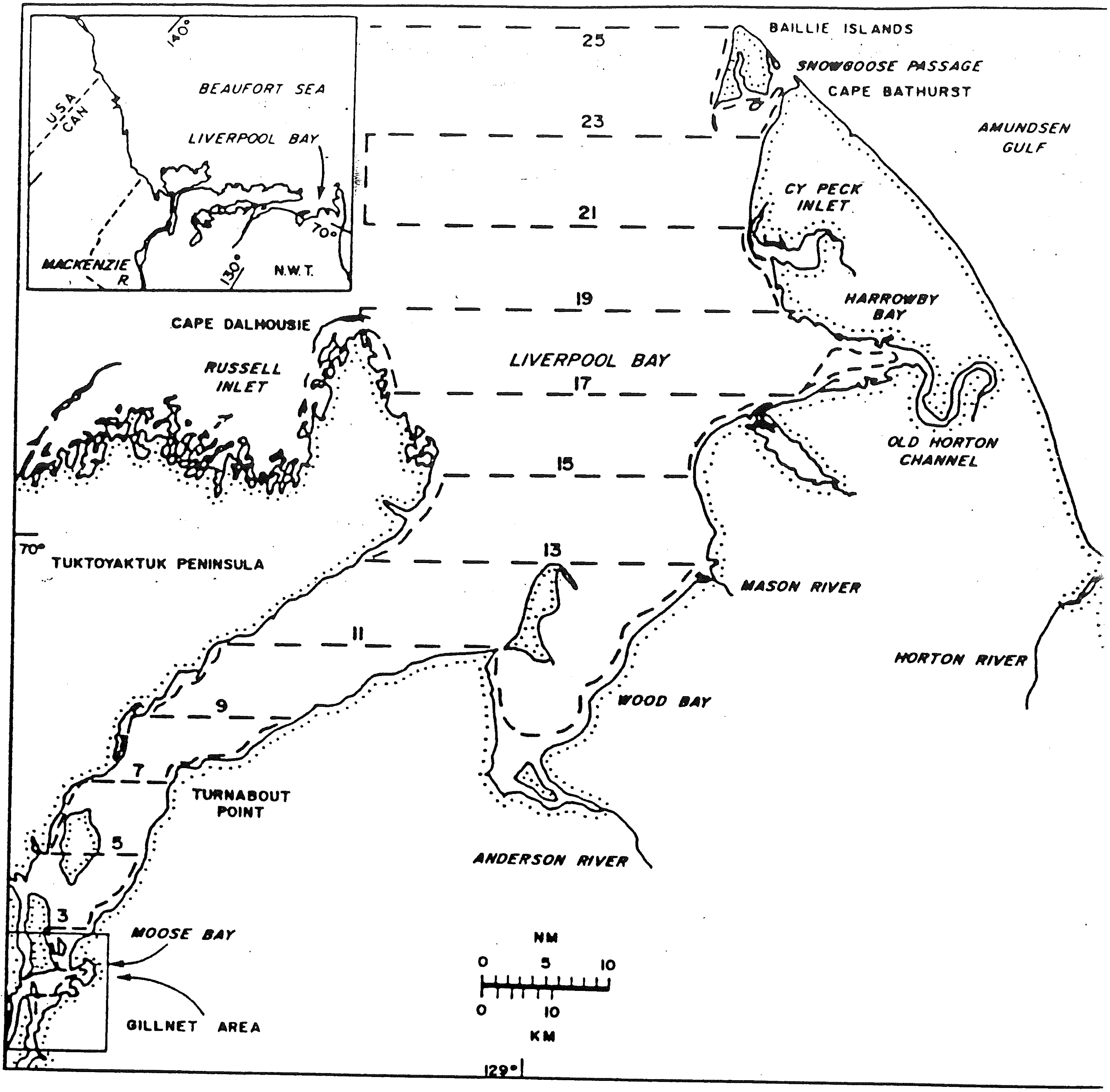

Figure 1. Map of the Liverpool Bay study area showing the location of aerial survey transects and the gillnet study area.

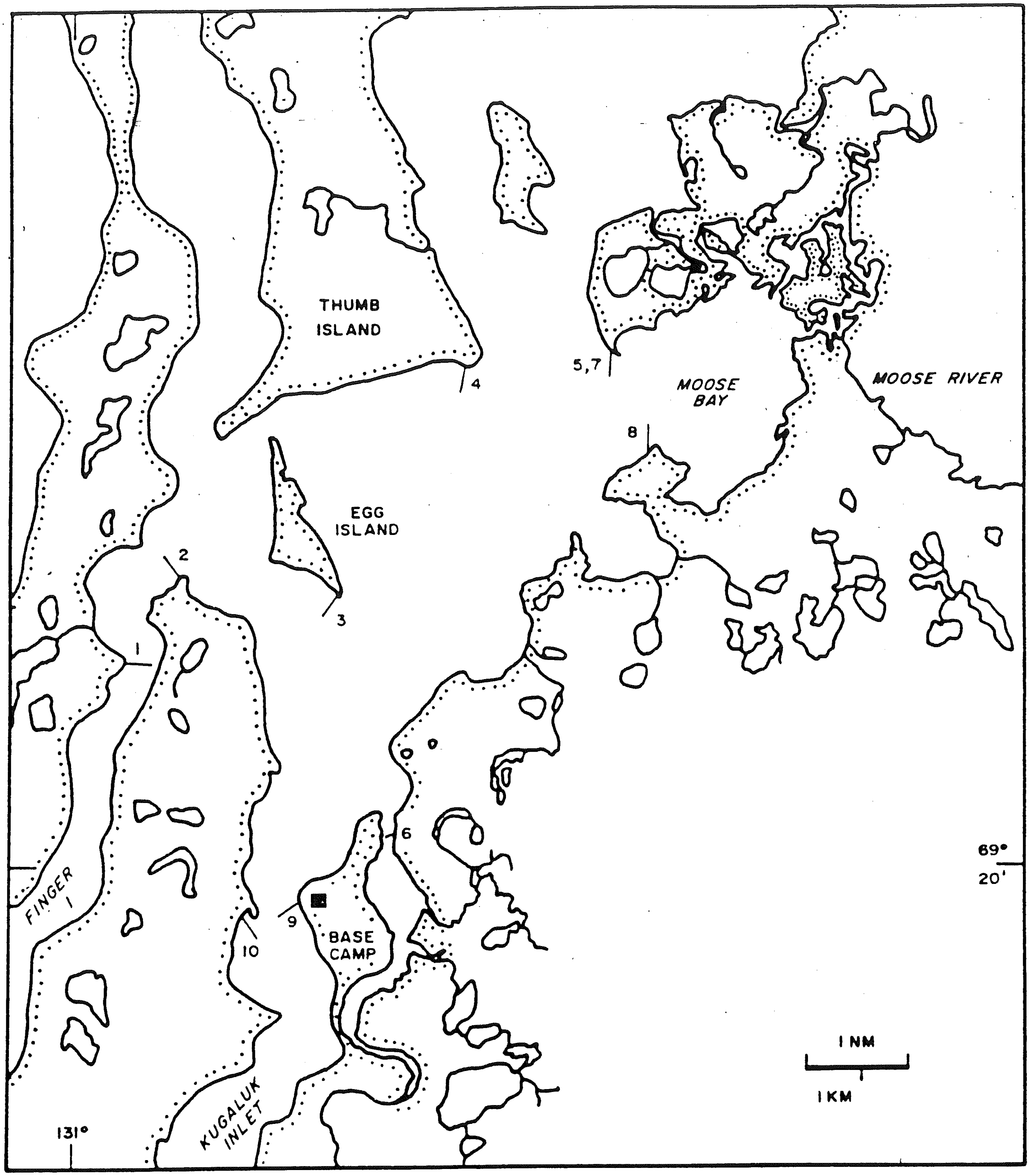

Figure 2. Map of southern Liverpool Bay showing the location of gillnet sample locations.

of 1600′ (487 metres) above ground level, flying at a speed of 110 knots (200 km/hr) along fixed transects (Figure 1). In the absence of specific information regarding the distribution and abundance of herring in Liverpool Bay, transects were established in a systematic fashion perpendicular to depth gradients, a survey procedure recommended by Eberhart (1978), and Anderson *et al.* (1979). Odd numbered transects ran east-west and were spaced approximately 13 km apart, while even numbered transects followed the shore. The total linear transect distance was 780 kms and east-west transects made up 62% of this amount.

Two observers were present for each aerial survey, one seated in the copilot position and one on the left side behind the pilot. A cassette recorder was used to record transect information such as start and stop times, general weather and sea conditions, and sightings of fish, birds and marine mammals. Each observer was equipped with binoculars and polarized sunglasses to better identify surface objects. Surveys were alternated between flying transect 1 to 25 and 25 to 1 in order to reduce bias resulting from eye fatigue for any part of the study area.

Horizontal distance from the transect path was measured to determine the effective visual search area. While the plane was stationary on the water an inclinometer was used to mark horizontal, 10^o, 15^o, 30^o, and 45^o positions along the wing struts. While flying at survey altitude it was determined that the area from the edge of the aircraft float (50^o) to the 15^o mark on the wing struts comprise the effective search area. Consequently, flying at an altitude of 1600′, there was a blind spot 840 m wide directly below the plane and a visual area of 1400 m width on either side of the aircraft. Applying this estimate (excepting some instances where one side only was visible such as flying along shore) and the total transect distance (783 km) the total visual search area was estimated as 2117 km^2 or 34% of the study area. This estimate of horizontal search area was considered reasonable for detecting schools of herring, flocks of birds and marine mammals such as beluga whales.

Schools of herring, if encountered, were to be measured using an occular grid tube developed by Fried (1983). This instrument consists of a viewing tube with a plexiglass end plate on which was inscribed a square grid pattern. Surface area is measured by counting the number of grid units corresponding to the length and width dimensions of the object. These units are scaled to determine the object size using the equation:

$$X = A\ (L/F),\ \text{where:}$$

X = size of object (m)
A = survey altitude (m)
L = grid length unit (m)
F = focal length of grid tube (m)

To test this method two plots were laid out on the tundra near the base camp: a 100 x 100 square (10,000 m^2) and a 50 x 50 m square (2,500 m^2). While flying at survey altitude these plots were measured at 12,419 m^2 and 3,104 m^2 for the large and small plots, respectively. This error of 24% is attributable to instability of the aircraft when observations were made, the angle from vertical that observations were made and the amount of time available to make the observations. The degree of error could be reduced with practice.

Gillnet Studies

Gillnet sets were made between aerial surveys on 15-19 August and 4-6 September 1986. "Scientific" variable mesh sinking gillnets were used in this study. Each net consisted of five 5 m x 2 m panels of 1 1/2", 2", 2 1/2", 3" and 3 1/2" stretch mesh dimension) monofilament net. All sets were made perpendicular to shore. Soak times ranged from 4 to 25 hours and most (8 of 10) were in excess of 12 hours. All fish caught were enumerated by species. Herring were sampled for length, total weight, sex and gonad weight.

RESULTS

Aerial Surveys

Observation conditions for the four aerial surveys were very favourable considering the type of weather that is common during late summer (Table 1). In general the wind was light (<15 knots) and the sky conditions were clear or high overcast. Occasional low cloud on transects 23 to 25 and 17 required flying at 1,000 ft. elevation for brief periods during survey number two. Survey flight time ranged between 3 hours 26 minutes and 3 hours 51 minutes. All four surveys were flown in the afternoon between 12 noon and 20:00 hrs. During the first two surveys no ice was present in the study area. Ice was present in the northern part of the study area during survey numbers 3 and 4 and coverage was less than 10%.

Water colour for much of Liverpool Bay was generally green to blue green with periodic areas of brown water along the lee shore and extending from prominent land marks. On one occasion during survey number two the bottom at 13 m was faintly visible on transects 23 and 25. In most cases, however, the visibility of green non-turbid water was probably not more than 2 m. This was estimated on occasion by watching beluga whales disappear from view as they sounded. Turbidity was consistently high in several of the bays and inlets within the study area such as the mouth of Kugaluk Inlet, Moose Bay, Wood Bay, Harrowby Bay and Snowgoose Pass at Cape Bathurst. Water around the north tip of Tuktoyaktuk Peninsula was very turbid for distances of up to 10 km.

Table 1. Summary of aerial survey flight conditions and wildlife counts. F represents uncounted bird flocks.

	Survey Number 1	2	3	4
Date	Aug. 16	Aug. 20	Sept. 4	Sept. 7
Flt. time	3:51	3:41	3:26	3:43
Weather				
Wind Dir	NE	SW	W	NE
Speed	10-15	10-15	10-15	13
Cloud	clear	occ. low clds	clear	clear
Marine Mammals				
Beluga whale	50	69, 3*	22	8,1*
Bowhead whale	3,2*	1	0	0
Ringed seal		1	4	15
Bearded seal		1	2	0
Birds				
Diving ducks	1,000+2F	3,395+F	345	0
Snow geese	70	525	173	0
Whitefronted geese	295+2F	15	0	0
Seagulls	7+F	72	170+F	153

* observed off transect

Table 1 summarizes the animals censused during the four aerial surveys. Diving ducks, geese, and gulls were the most abundant animal group followed by beluga whales and seals. There were no confirmed sightings of fish schools observed during any of the four surveys, although there was one unconfirmed school sighting and one sighting of animals feeding on fish. The former incident occurred during aerial survey number one along transect 15 in approximately the middle part of Liverpool Bay. A small, oblong patch (30 x 100 m) of slightly darker water was observed by both the pilot and left side observer. The patch was streaked in appearance along the long dimension. The pilot circled and descended to 1,000 ft. altitude but visual contact was lost as the patch was faint and became hidden by sun glare.

During the fourth aerial survey approximately 10 km east of the Tuktoyaktuk Peninsula on transect 11 a group of approximately 125 seagulls, 4 beluga whales and 15 ringed seals were spotted. The whales and seals were actively sounding and surfacing while birds were both flying overhead and sitting on the water but not diving. Upon closer inspection, silver fish could be observed from the mouths of the seals as they surfaced. The aircraft circled twice at 1500 ft. and twice at 600 ft. but observers were unable to detect a body of fish. Water colour was dark green although beluga whales disappeared within 2 metres of the surface as they sounded. Water depth at this location was approximately 10 metres.

Observations of wildlife observed during the four aerial survey dates are summarized by animal group in Table 1. Four marine mammal species were distinguished in the surveys: beluga whales (*Delphinapterus leucas*), bowhead whales (*Balaena mysticetus*), ringed seals (*Phoca hispida*) and bearded seals (*Erignathus barbatus*). The latter two species were distinguished on the basis of size only (ringed seal being smaller) and identification error is possible. Beluga whales were the most abundant marine mammal observed, occurring at a variety of locations in the study area. Bowhead whales were infrequent and observed more often in the outer parts of Liverpool Bay. Seals occurred throughout the study area and were few in number except for the 15 observed in the feeding aggregation. Two bearded seals were observed during the surveys.

Avifauna distinguished on the surveys were as follows: diving ducks - principally the scoter (*Melanitta sp.*), snowgeese (*Chen caerulescens*), whitefronted geese (*Anser albifrons*) and seagulls - principally the glaucous gull (*Larus hyperboreus*). Diving ducks occur throughout the study area in flocks of 100 to over 1,000 birds. They were usually observed in bays or protected shoreline either sitting on the beach or rafting in shallow water. Geese were primarily observed in flocks of 10 to 50 along the perimeter of Liverpool Bay. Snowgeese were more numerous occurring throughout the study area most notably the Anderson River Delta. Whitefronted geese were more common in southern Liverpool Bay near Campbell Island. Glaucous gulls were present both in groups and as individuals throughout the study area including open water areas.

The distribution and abundance of selected species is plotted in Figures 3-6 for the four surveys respectively. Species included are those which may be trophically linked to Pacific herring such as beluga whales, seals and glaucous gulls. During the first survey (Figure 3), beluga whales were found primarily in the northern part of Liverpool Bay in two concentrations: 4-5 km northeast of Cape Dalhousie (25 individuals) and off the mouth of Cy Peck Inlet (13 individuals). A small flock of seagulls was also present among the latter group. Of incidental interest during the first survey, 5 bowhead whales were observed, 2 in Wood Bay , 2 north of Russell Inlet and 1 east of Baillie Island.

The distribution of marine mammals was very different four days later during the second survey (Figure 4). No beluga whales

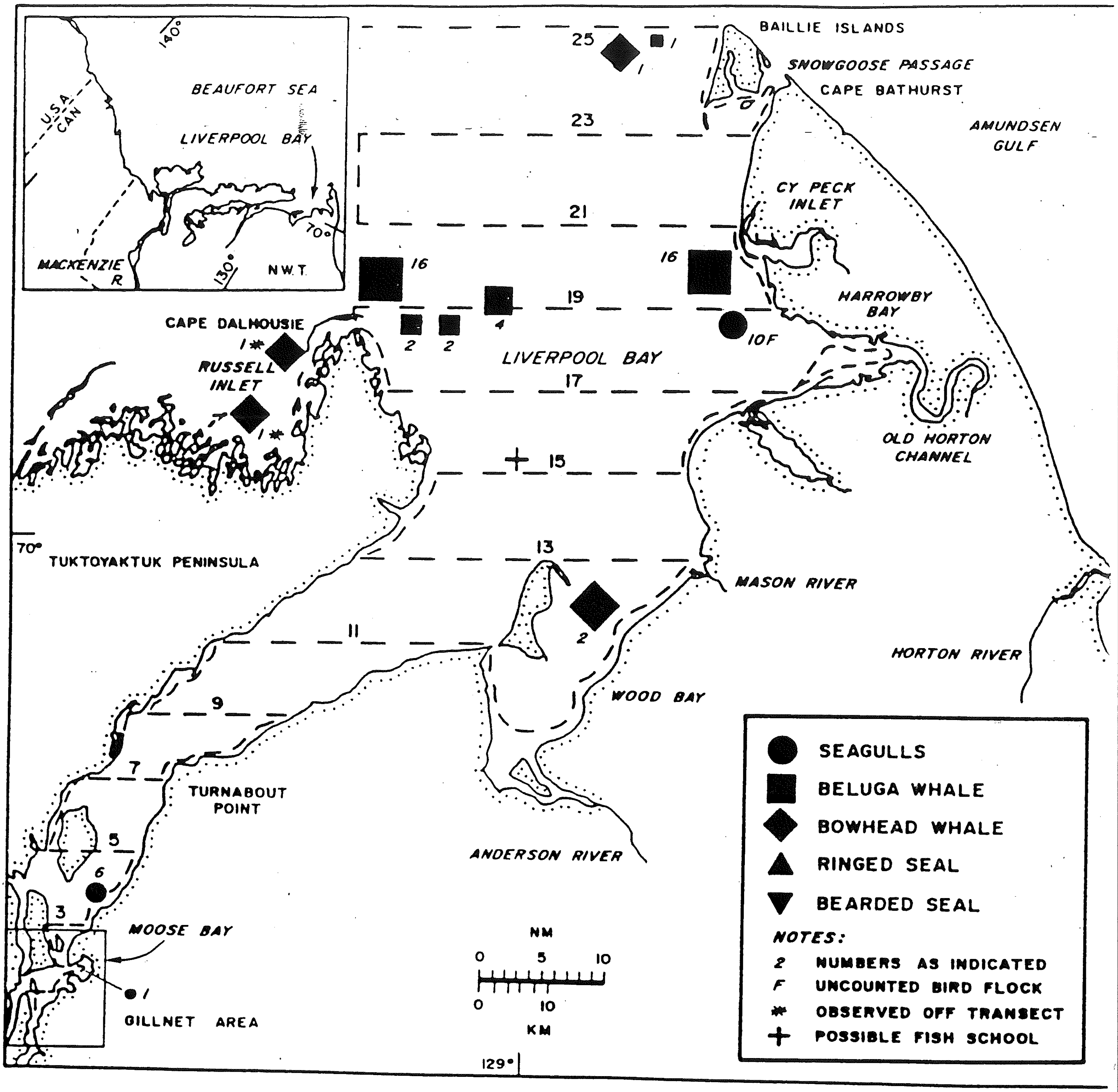

Figure 3. The distribution and abundance of marine mammals and seagulls in Liverpool Bay during the first aerial survey (16 Aug. 1986).

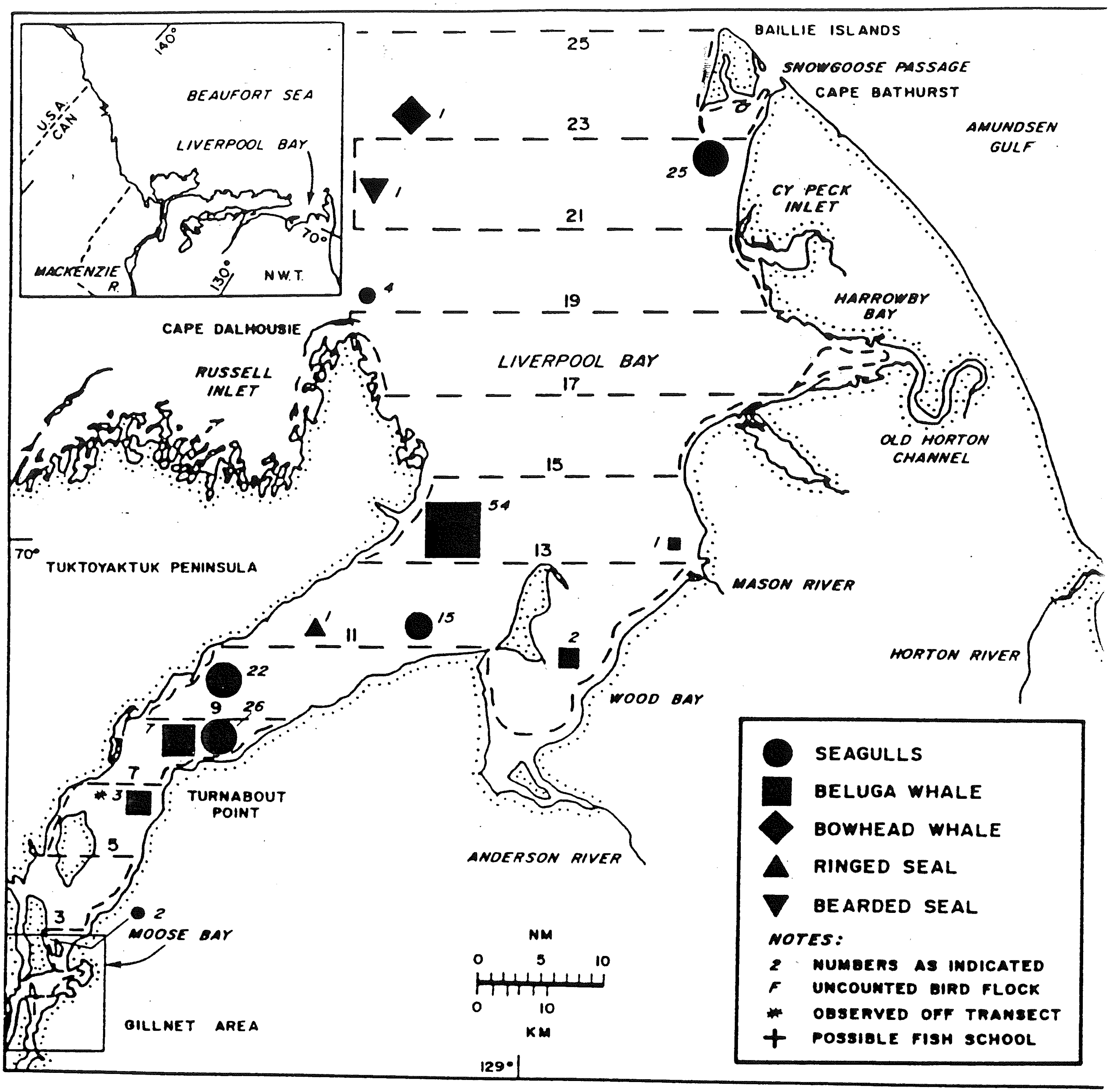

Figure 4. The distribution and abundance of marine mammals and seagulls in Liverpool Bay during the second aerial survey (20 Aug. 1986).

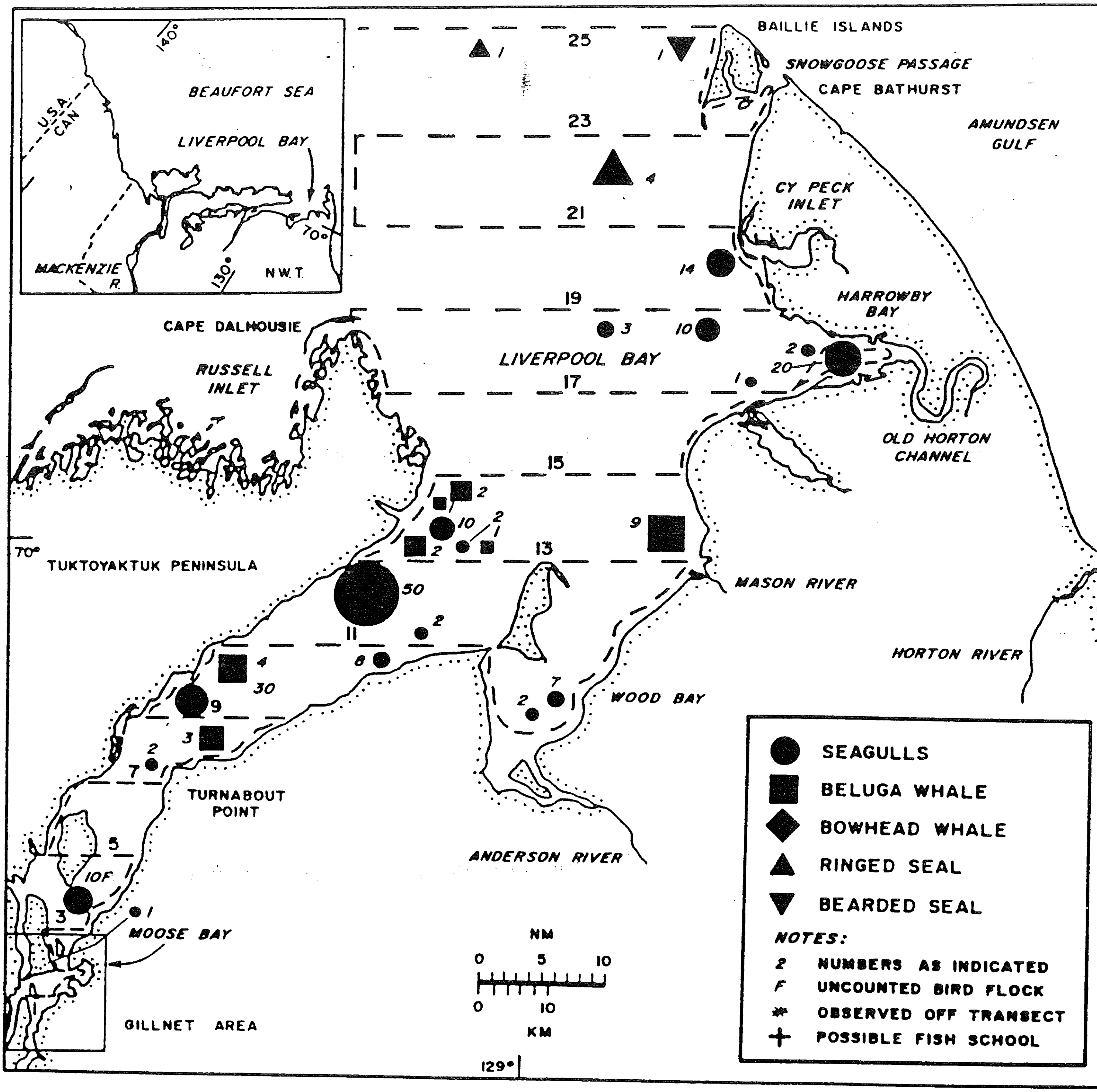

Figure 5. The distribution and abundance of marine mammals and seagulls in Liverpool Bay during the third aerial survey (4 Sept. 1986).

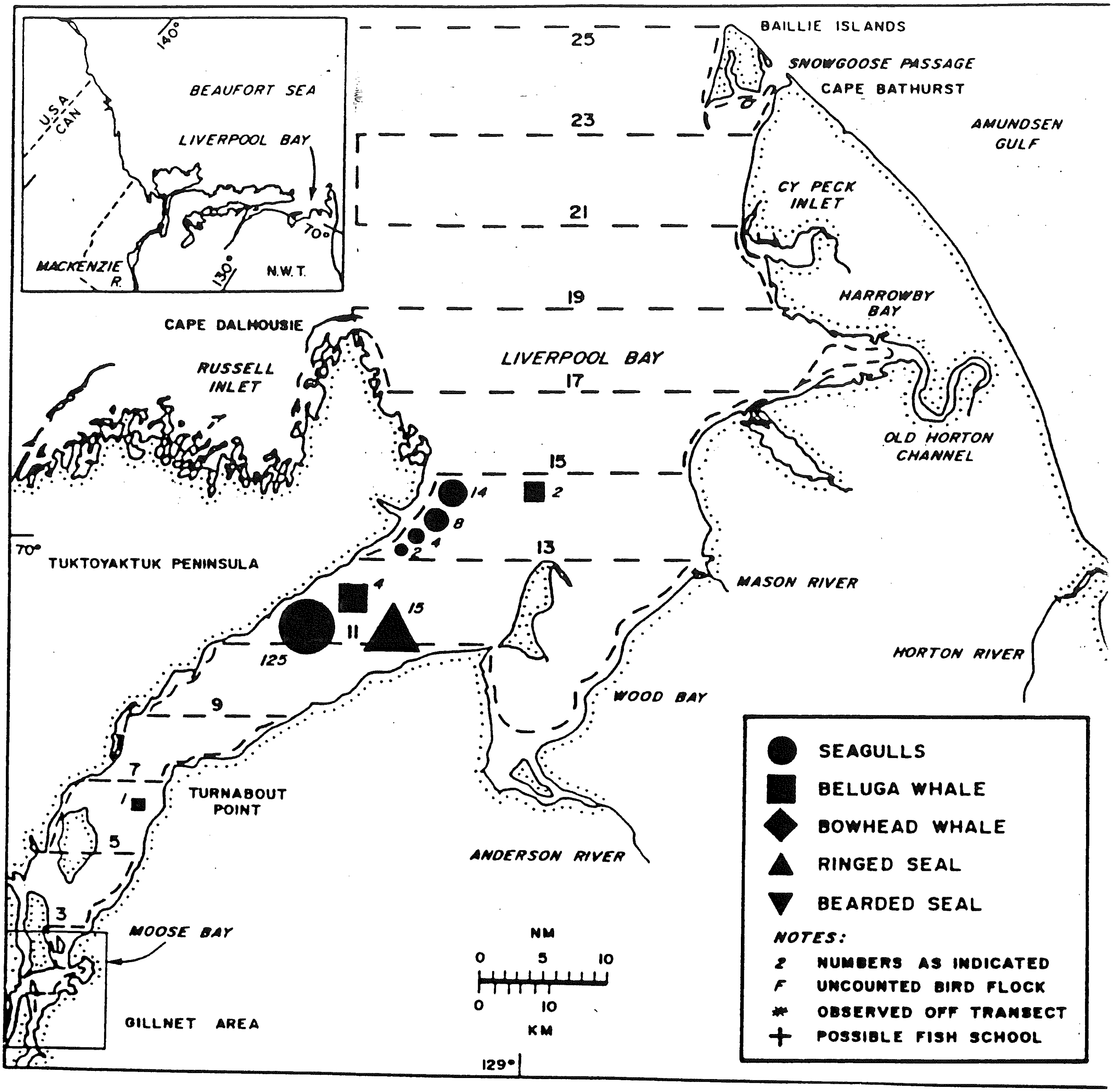

Figure 6. The distribution and abundance of marine mammals and seagulls in Liverpool Bay during the fourth aerial survey (7 Sept. 1986).

were observed at the previous locations and instead, groups of 54 and 7 were observed along shore of transect 14 and 8, respectively. Among the latter group were also observed 26 seagulls which were both sitting on the water and flying over top of the whales. Three other beluga whales were observed in Wood Bay along transect 12. One bowhead whale was observed during the survey near the west end of transect 23.

During the third survey (Figure 5) beluga whales were found chiefly in 4 small groups: 3 at Turnabout Point, 4 along the west shore on transect 10, 5 along transect 14 and 9 off the Mason River delta near the start of transect 13. Seagulls were associated with two of these groups. Seals were observed along transects 23 and 25 among drift ice. No bowhead whales were observed during this survey.

Very little wildlife was observed during the fourth aerial survey (Figure 6). Eight beluga whales were sighted, 4 among seagulls and ringed seals along transect 11 as described previously and 2 on each of transects 15 and 17. Seagulls were numerous along transect 14 and elsewhere scarce. No bowhead whales were observed during this survey.

Gillnet Studies

Ten gillnet sets were made during the course of this study at locations shown in Figure 2. Eight species of fish were caught during these surveys (Table 2) the most common being Pacific herring (53.4%) followed by Arctic and least cisco (21.8%), Lake whitefish (11.7%) and broad whitefish (8.5%). Species composition and catch rates varied considerably between

Table 2. Summary of fish species caught in gillnet sets by marine code and percent overall abundance.

Common Name	Latin Name	Code	%	N
Pacific herring	*Clupea harengus pallasi*	PCHR	53.4	164
Lake whitefish	*Coregonus clupeaformis*	LKWT	11.7	36
Broad whitefish	*C. nasus*	BDWT	8.5	26
Cisco (not differentiated)	*C. autumnalis* *C. sardinella*	CSCO	21.8	67
Inconnu	*Stenodus leucichthys*	INCO	0.3	1
Arctic flounder	*Liopsetta glacialis*	ARFL	2.0	6
Saffron cod	*Eleginus gracilis*	SFCD	1.6	5
Fourhorn Sculpin	*Myoxocephalus quadricornus*	FHSC	0.6	2

gillnet sets (Table 3). Although Pacific herring were absent during the 4 sets in August and present on each of the 6 September sets, a temporal distribution pattern is implied but not demonstrated as most set locations were unique. Interestingly, catches of Pacific herring usually occurred as the sole species caught in a set while the whitefish and cisco species often occurred together. In only one instance was a gillnet set repeated in the same site - sets 5 and 7. Species composition was identical (both exclusively herring) and catch rates were similar (3.35 vs 2.77 fish/hr/25 m).

The size range of gillnetted herring was between 110 and 290 mm fork length with most fish between 210 and 270 mm. The average male size was slightly smaller than females (Figure 7a) although this difference was not significant (Kolmogorov-Smirnov

Table 3. Summary of gillnet sets and catch data. Catch per unit effort (CPUE) values are expressed in number of fish/hours/25 m of gillnet. See Table 2 for species codes.

Set No.	Date (mm/dd)	Time in	Soak (hr:min)	CPUE All	CPUE Herring	Species PCHR	LKWF	BDWF	CSCO	INCO	ARFL	SFCD	FHSC	Total
1	08/17	12:00	8:30	1.4	0	0	6	2	4	0	0	0	0	12
2	08/17	12:20	8:30	2.11	0	0	15	0	3	0	0	0	0	18
3	08/18	12:30	7:50	2.29	0	0	4	3	6	0	5	0	0	18
4	08/18	12:40	7:50	1.02	0	0	0	5	6	0	0	0	0	8
5	09/05	12:30	23:15	3.35	3.27	76	0	0	0	0	0	2	0	78
6	09/05	14:20	20:10	4.16	0.25	15	10	11	43	1	1	2	1	84
7	09/06	12:00	8:40	2.77	2.77	24	0	0	0	0	0	0	0	24
8	09/06	12:45	4:25	3.85	0.23	1	1	5	8	0	0	1	0	17
9	09/06	19:75	13:20	1.05	1.05	14	0	0	0	0	0	0	0	14
10	09/06	19:50	13:10	2.58	2.58	34	0	0	0	0	0	0	0	34

two sample test, Campbell 1975). Males also outnumbered females (92 vs 62) although this result was not significantly different from a 50:50 ratio ($p>0.10$, Chi-square test, Zar 1974). In contrast, Riske (1960) reported male female ratio of 32.5:67.5 for a sample taken in Tuktoyaktuk Harbour. The herring sample in this study was subdivided into the two principal areas where fish were caught: Moose Bay (sets 5,7, and 8) and Kugaluk Inlet (sets 6,9, and 10). Interestingly, the Kugaluk Inlet sample had a higher percentage of small fish as shown in Figure 7b which was significant ($p<0.01$, Kolmogorov-Smirnov two sample test). This difference is not related to smaller male size as there was no significant difference between sex ratios of these samples ($p>0.25$, Chi-square test).

All Pacific herring were viscerally dissected and their gonads inspected and weighed. Negligible gonad development was present in both sexes of less than 200 mm fork length. Among

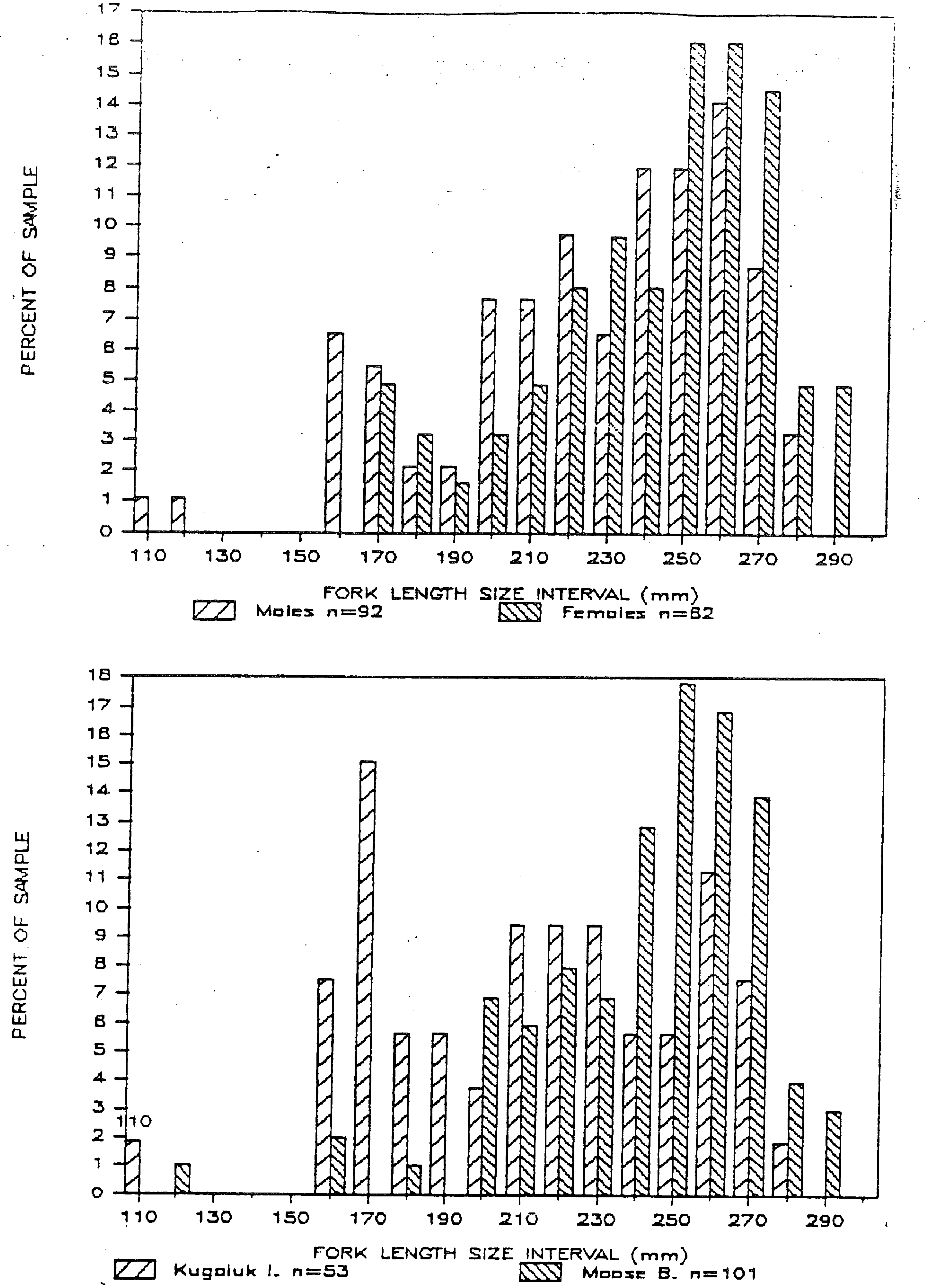

Figure 7. Size frequency histogram of the Liverpool Bay gillnet sample. A shows the sample separated by sex and B shows the sample separated by sample location.

larger individuals, gonosomatic index (GSI) ranged from trace to 14% with males consistently higher than females. Average GSI values for males and females were 7.75 (sd=4.55, n=92) and 2.72 (sd=1.0, n=62), respectively, which was significantly different ($p<0.01$, t-test, Zar 1974). These values are low compared to mean GSI values of 15.8 (males) and 6.14 (females) reported by Riske (1960) for a sample collected early September in Tuktoyaktuk Harbour. In the present study one female was unique with a GSI value of 6.8 while all others were below 4.3. This individual was also unique, having retained eggs present in the ovaries while other females had uniformly fine, granular textured, orange ovaries extending much of the body cavity length. This resembled developmental stages VIII and III, respectively for female Pacific herring (Hay 1985). Male herring examined resembled developmental stage III.

The gillnet sets made in the present study provide some useful information on the life history of Pacific herring. The population of herring sampled includes both mature and immature fish. At least one of the fish examined had spawned during the 1986 season and most were sufficiently developed to be spawning in the 1987 season. As transformation between spent stage (VIII) and developing stage (III) occurs within 6 weeks of spawning (Hay, pers. comm.) it is reasonable that many of these fish had spawned during the 1986 season. Consequently, their reappearance in inshore areas early September indicates that a post spawning migration is either brief or absent. This feature distinguishes this population of Pacific herring from others in the Bering Sea and Pacific Ocean which have distinct offshore migrations.

DISCUSSION

In terms of the main goal of locating and measuring schools of Pacific herring, the aerial surveys provided disappointing results. No schools of fish were directly observed on any of the flights on all four surveys, the surface was relatively calm and water clarity as high as could be expected. The cloud conditions were generally high ceiling or clear skies making it possible to work at the desired survey altitude for most of the flights. The principal visibility problem was from sun glare although this was minimized by the observer looking ahead or abaft of the obscured area. The effective visibility range provided coverage of 34% of the study area during each of the four surveys. This high percentage of coverage and ideal observation conditions make it reasonable to conclude that the probability of overlooking surface schools of Pacific herring was very low.

Although aerial surveys were unsuccessful in locating schools, this result does not reflect abundance patterns of herring. Gillnet studies conducted in the lower portion of Liverpool Bay identified areas where Pacific herring were present. The school in Moose Bay was sampled on September 5-6 and the school in Kugaluk Inlet on September 6. Aerial surveys conducted on the next day were unable to detect bodies of fish in either of these two areas. Similarly, careful inspection of a group of beluga whales and ringed seals that were actively feeding also failed to detect a body of fish. Although in this instance, the fish were not confirmed as Pacific herring, these observations illustrate examples where there was reasonable certainty that fish were present in abundance yet were not observable from an aircraft overhead.

While there were no direct measurements of visibility, indirect evidence indicated that vertical visibility for most of Liverpool Bay did not exceed 2 m. In shallow areas, entrained silt decreases the visibility to less than 0.5 m. Despite the overall shallow depths, the majority of water space in Liverpool Bay would be hidden from view overhead. Consequently, if schools of Pacific herring were present below the surface water (ie. 2 m), they were not visible from the air.

There is other evidence that Pacific herring may occur in the lower portion of the water column. While Pacific herring are often regarded as planktivorous, some studies have demonstrated the importance of epibenthic organisms as prey. Kendel *et al.* (1975) found that of 12 Pacific herring collected during the summer off the Yukon coast, the stomachs of 4 contained exclusively mysids. Percy (1975) observed that of 20 stomachs examined for herring collected from the outer Mackenzie delta, 7 contained epibenthic food items. Lawrence *et al.* (1984) examined the stomachs of Pacific herring collected from the northern side of Tuktoyaktuk Peninsula and found a number of epifaunal and infaunal prey groups were important including Mysidacea, Amphipoda, Acarina, Pelecypoda, Nematoda and plant material.

Instances where herring are visible for overhead aircraft may occur during very clear visibility or when herring move to the surface to feed on plankton. These events are probably very infrequent in the Beaufort Sea as sightings of fish schools have not been known to occur during the aerial surveys of beluga whales conducted during recent years (Norton, pers. comm.). Unconfirmed sightings of fish schools may be mistaken as accumulations of debris which appear as dark patches in shallow water along shore. Effective use of aerial surveys for herring has been made on the Alaskan coast of the Bering Sea (Barton and Wespestad 1980). These surveys are of herring schools moving to or from the intertidal spawning areas. Approximately 25 percent of the fish in the schools are species other than herring such as capelin, cod and smelt. These factors may contribute to the higher visibility of schools by aircraft. The authors point out that populations of herring which spawn subtidally are not directly observed but are induced by the presence of milt. Thus the absence of fish sightings in Liverpool Bay is probably more a reflection of inappropriate sampling methods rather than the absence of herring.

The herring population in Liverpool Bay may be large despite the lack of sightings. Using gillnets in the lower portion of Liverpool Bay, herring were the most abundant outnumbering other species by a factor of two. Similarly, a study conducted in the Eskimo Lakes (Poulin and Martin, 1976) found Pacific herring to be the most abundant species. Scientific fish collections from other parts of Liverpool Bay have been made (Hunter and Leach 1983) although the results have not been reviewed to identify the importance of herring. Abundance patterns appear to be comparable at Ballie Island where a pilot herring fishery was conducted in 1963 (Hunter 1975). Large catches of Pacific herring have been known to occur during subsistence fishing in Liverpool Bay northwest of Turnabout Point (Gruben, pers. comm.). If abundance patterns are continuous the herring population in Liverpool Bay may be considerable.

A common observation during the four surveys were aggregations of beluga whales, seagulls and occasionally seals. The confirmation of feeding on fish made during the fourth aerial survey identifies at least one purpose for such aggregations. The co association of seagulls with beluga whales is common during the late summer and is thought to indicate active whale feeding (Norton and Harwood 1986). Seagulls are attracted to feed on drifting material created by whale feeding. During the four aerial surveys there were 11 separate instances where individuals or groups of beluga whales were observed and seagulls were present on 6 of these sightings.

During the latter part of July beluga whales move away from brackish water high aggregation areas in the Mackenzie delta, known as concentration areas (Norton and Harwood 1986). Feeding is usually intense as whales recover from a period of low feeding and prepare for fall migration (Finley, pers. comm.). The Beaufort Sea population, estimated at between 11.5 and 17 thousand individuals (Norton and Harwood 1985), either remains inshore or moves northward to the ice edge. Amundsen Gulf, Liverpool Bay and the Eskimo (Husky) Lakes are suspected to be part of the feeding range (Fraker *et al.* 1978). As many as 200 beluga whales have been reported in the Eskimo Lakes (Fraker *et al.* 1978) and occasionally beluga whales become stranded in the upper reaches of the lakes during freeze up (Martell *et al.* 1984). Fraker *et al.* (1978) reports that whales frequently move into Liverpool Bay during late July and August but they uncommonly enter Wood Bay. Other evidence of beluga whale activity in Liverpool Bay is known to occur but is not well documented principally because this area is not censused regularly (Norton, pers. comm.). Admundsen Gulf has large numbers of beluga whales early in the spring and again during the late July and August and is suspected to be a very important feeding area (Fraker *et al.* 1978).

Assuming that the majority of beluga whales observed in Liverpool Bay were feeding it is interesting to roughly calculate their food requirements. The average weight of a beluga whale is approximately 0.5 tonnes and their daily ration is estimated at 4-6% of their body weight (Sergeant, 1969). Taking the actual number of whales observed and scaling to include parts of the study area not surveyed (ie. 0.34^{-1}), the corrected number of beluga whales present in Liverpool Bay during the four survey dates was 147, 203, 65, and 24, respectively. The daily ration for these groups, using 5%, comes to 3.7, 5.1, 1.6 and 0.6 tonnes of food, respectively. This quantity is large, considering the inshore feeding period lasts 30-40 days. Using the same figures, a group of 150 beluga whales, reported in the Eskimo Lakes for a period of 26 days in 1975 (Fraker *et al.* 1978 page 40), would have a total food requirement of 97.5 tonnes. This example is useful to illustrate the magnitude of prey concentrations required to support feeding herds of beluga whales in Liverpool Bay.

Beluga whales feed on a variety of items including fish, crustaceans and cephalopods (Seaman *et al.* 1982) and it is suggested that they eat almost any type of aquatic or marine animal of the appropriate size (Fraker *et al.* 1978). Very little is known about the feeding habits of beluga whales in the eastern Beaufort Sea. It is thought that offshore whales feed primarily on Arctic cod (*Boreogadus saida*) and squid (*Gonatus fabricii*). No information is available on the feeding habits of whales found inshore. Stomach samples have been obtained during the whale hunt during the spring at the Mackenzie delta although many are empty and it is thought that the frequency of feeding is low while whales are in their concentration areas (Fraker *et al.* 1978).If abundance patterns reflected by the gillnet catches are widespread, Pacific herring would probably be a preferred prey species. Unlike other species of fish in Liverpool Bay, schools of Pacific herring may have biomass concentrations in excess of 9 kg/m^3 (Fried 1983, Table 1). High prey concentration levels are of importance to beluga whales as their herd sizes demand large quantities of food (Finley, pers. comm.). For example, the 54 whale herd observed during the second aerial survey would have a daily feeding requirement of 1.4 tonnes.

In the eastern Arctic, studies of marine mammals provide a useful tool in identifying high abundance areas of Arctic cod (Bradstreet *et al.* 1986). The behaviour and distribution of harp seals, narwhale and beluga whales are very descriptive of the activities of their prey. The occurrence of beluga whales in Liverpool Bay and the Eskimo Lakes at a time when they are feeding is similar in identifying important productivity areas. It is very possible that these patterns are related to the abundance of herring.

Results from this study identify areas where further studies would provide a better understanding of the Beaufort Sea Pacific herring population. The late summer season is a time when herring are accessible in nearshore water and future sampling should continue. Collections of herring should be made to collect basic life history data including size frequency (for natural mortality estimates), sex ratios and feeding habits. The latter would be especially beneficial in determining where herring schools may be found if epibenthic prey items are important in the diets of herring. Unlike planktonic species, many epibenthic species have predictable distribution patterns related to water temperature and salinity, depth, substrate and exposure (Griffiths and Dillinger 1981).

In his studies of Arctic herring populations, Riske (1960) identified several meristic and morphometric characters which distinguished an Eskimo Lakes herring sample from a Tuktoyaktuk sample. While these data are based on limited sample sizes, it was suggested that the Arctic herring population may consist of distinct stocks. If, as pointed out in the present study, herring have a restricted offshore migration then the opportunity for stock mixing would be limited. In this regard it would be useful to collect herring samples from a variety of locations including Tuktoyaktuk Harbour, Liverpool Bay, Eskimo Lakes and Darnley Bay to look for evidence of stock separation.

The final topic for future research is to attempt an estimate of herring stock sizes. Based on observations from this study, there appears to be two options for this requirement. The most promising would be to use an ecosystem model developed by Laevaste and Favorite (1978) for eastern Bering Sea herring. In a fashion similar to that demonstrated previously, this model is based on estimating the amount of herring required to sustain the diets of herring predators at reported rates of consumption. While the accuracy of the model has been criticized (Barton and Wespestad 1980), the results would provide a general perspective of magnitude which is thusfar lacking. Use of the model requires input parameters including predator density and feeding rates as provided in this report. In addition it would be necessary to measure residency times and to verify a feeding association between beluga whales and herring. Future aerial surveys for marine mammals in Liverpool Bay should also include the Eskimo Lakes since the herring distribution is continuous throughout this region.

The second research technique for stock assessment would be using hydroacoustic techniques. This method would involve finding schools of herring and measuring the target strength and area. The location of schools would be assisted by observations of marine mammal activity and also an understanding of where herring prey are likely to occur. As herring schools will be found in shallow water areas it would be necessary to use side shooting echo sounding equipment to avoid scattering of fish schools as the vessel passes overhead. This requirement would be more costly than conventional sounding equipment and probably less accurate.

Research efforts directed in the fashion described will provide the necessary information to evaluate the feasibility of developing a commercial herring roe fishery in Liverpool Bay. The studies would also provide an insight into information requirements that would be practical for managing this unique population of Arctic herring.

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