White Whale *(Delphinapterus leucas)* Distribution and Abundance and the Relationship to Physical and Chemical Characteristics of the Mackenzie Estuary

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ERRATA

p. 9, Fig. 6.	The diagonal line pattern should be within the unpatterned area enclosed by the dashed line near Hendrickson Island.
p. 14, Fig. 9.	The figure panels should be lettered "a" through "f", starting at the top and going left to right.
p. 20, Fig. 12.	Same as above.
p. 22, Fig. 13.	Same as above.
p. 19, col. 2, last para.	Replace "Measurements of vertical stratification" with "The depths of the halocline measured".
p. 33, col. 1, para. 4, line 4.	"Fig. 16a, c" should read "Fig. 21a, c".
p. 41, col. 2, para. 3, line 3.	"1%" should read "1^{o}/oo".
p. 41, col. 2, para. 7, line 3.	"1-2%" should read "1-2^{o}/oo".
p. 42, Fig. 26.	"12 July 1977" should read "12 July 1976".
p. 43, Fig. 27.	"368" should read "500".
p. 49, col. 1, para. 3, line 5.	Insert "deep" after "30-50 m".
p. 49, col. 2, para. 7, line 5.	After "depth" insert "(except under stormy conditions)".

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WHITE WHALE *(Delphinapterus leucas)* DISTRIBUTION AND ABUNDANCE AND THE RELATIONSHIP TO PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE MACKENZIE ESTUARY

by

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PREFACE

This report is presented in fulfillment of Department of Supply and Services Contract DDS 04 SZK KE - 709 - 7 - 00220 let to F.F. Slaney & Company Limited for a study of the white whale distribution and abundance and the relationship to physical and chemical characteristics of the Mackenzie estuary. The work was done on behalf of the Fishery Management Division, Fisheries Resources Section, Research and Resource Services Directorate, Fisheries and Marine Service, Western Region, Fisheries and Environment Canada. The report is published upon recommendation by Mr. R.F. Peet, Supervisor for the contract to Dr. G.H. Lawler, Scientific Authority for Marine Mammals, Western Region.

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Between 18 June and 11 August 1977, the distribution and abundance of white whales *(Delphinapterus leucas)* were studied in relation to water temperature, salinity, turbidity, depth, and shelter from wind of the estuary of the Mackenzie River.

The water column in the study area was usually homogeneous Mackenzie River water to a depth of 3-5 m. Beyond this, a wedge of freshwater, which grew gradually thinner seaward, overlay the denser sea water.

General warming of the estuary occurred from early July to early August, after which there was rapid cooling. The warmest temperatures (20.5^{0}C maximum) were in shallow (<2m) nearshore areas.

Salinity at all depths generally increased during the course of the study, and turbidity decreased. These resulted from lowered river flows following freshet.

Prevailing winds are from the northern quadrant. Under such conditions, Shallow Bay is sheltered and the eastern parts of Niakunak and West Mackenzie Bays are moderately sheltered.

The first whales in the estuary were observed on 30 June. Numbers increased rapidly and peaked on 8 July with an estimated 3820 whales. Numbers remained high until late July, but declined to nearly zero in the first 10 days of August. The highest densities were observed in Niakunak Bay.

Early in the season, most whales in East and West Mackenzie Bays appeared to be transients, en route to Niakunak Bay. After mid-July, many whales periodically moved out into West Mackenzie Bay. Most of these apparently came from Niakunak Bay; others probably came from Kugmallit and East Mackenzie Bays.

The concept of concentration areas is discussed in the context of location, duration of use by whales, and behavior of whales. The Niakunak and Kugmallit Bay area concentration areas are used more consistently and by larger numbers of whales than the area in West and East Mackenzie Bays. The main period of use of concentration areas is the month of July.

A previously undescribed social behavior is reported. Whales in concentration areas were frequently observed in small groups which often were practically motionless. We have termed this behavior gamming, and the groups of whales, gams. Gamming implies a social significance to the concentration areas.

Large numbers of whales occasionally occupied parts of East and West Mackenzie Bays which had previously been termed intermittent-use areas. Probable feeding was observed in the deeper (>5m) parts of West Mackenzie Bay.

Warm water temperature appears to be the main factor governing the distribution of whale concentrations in the estuary. Water depth, salinity, turbidity, and shelter from rough water appear to be unimportant. Thus the hypothesis of Fraker et al. (1978) that whales of all ages and both sexes use the estuary for the thermal advantage it affords has been supported. There was no apparent relationship between whale distribution and wave conditions, and thus a secondary hypothesis that the whales were also seeking shelter was not supported.

Although some calving probably does take place in the Mackenzie and other estuaries, some calving also occurs outside the estuary in cold, oceanic waters. The overall observations are consistent with Brodie's (1975) hypothesis that the migrations of many species of whales to warm water areas serves to conserve energy for all classes.

Key words: aerial surveys; behavior; oceanography; water temperature; salinity; turbidity; waves; Beaufort Sea; timing; hydrocarbon exploration.

RESUME

Fraker, M.A., C.D. Gordon, J.W. McDonald, J.K.B. Ford, and G. Cambers. 1979. White whale *(Delphinapterus leucas)* distribution and abundance and the relationship to physical and chemical characteristics of the Mackenzie estuary. Can. Fish. Mar. Serv. Tech. Rep. 863: v + 56 p.

Entre le 18 juin et le 11 août 1977, les auteurs ont étudié la répartition et l'abondance du béluga (*Delphinopterus leucas*) en fonction de la température, de la salinité, de la turbidité et de la profondeur des eaux de l'estuaire du Mackenzie, ainsi que de la direction du vent.

Dans la zone étudiée, l'eau, généralement homogène jusqu'à 3 à 5 mètres de profondeur, provenait du Mackenzie. Au-delà, un coin d'eau douce, de plus en plus mince à mesure que se rapprochait la mer, recouvrait l'eau salée, plus dense.

L'estuaire s'est réchauffé du début de juillet au début d'août, après quoi il s'est rapidement refroidi. Les températures les plus élevées, 20.5° C au maximum, ont été enregistrées dans les zones situées près du littoral, à une profondeur inférieure à 2 mètres.

Durant l'étude, la salinité a généralement augmenté à toutes les profondeurs, tandis que la turbidité a diminué. Cela vient de la baisse du débit du fleuve après les crues.

Les vents dominants étant du nord, la Shallow Bay s'en trouvait protégée, et la partie est des baies Niakunak et West Mackenzie l'était modérément.

La présence des bélugas a été signalée pour la première fois le 30 juin. Leur nombre s'est accru rapidement pour atteindre un maximum d'environ 3820

le 8 juillet. Il est demeuré élevé jusqu'à la fin de juillet, pour retomber presque à zéro au cours des 10 premiers jours d'août. Les densités les plus fortes ont été dans la Niakunak Bay.

Au début de la saison, la plupart des bélugas vus dans les baies East et West Mackenzie semblaient en route vers la Niakunak Bay. Après la mi-juillet, beaucoup d'entre eux passaient périodiquement dans la West Mackenzie Bay. Ils venaient sans doute principalement de la Niakunak Bay et le reste, des baies Kugmallit et East Mackenzie.

La notion de zones de concentration se caractérise par le lieu et la durée de séjour des bélugas et leur comportement. Les baies Niakunak et Kugmallit ont été systématiquement plus occupées que les baies East et West Mackenzie, les zones de concentration sont occupées principalement en juillet.

Les auteurs signalent un comportement social non relevé jusqu'ici. En de nombreux cas, les bélugas situés dans ces zones de concentration se sont groupés en petits troupeaux pour demeurer quasi immobiles. Ce comportement, qui a reçu le nom de gamming, et les groupes ainse formés celui de gams, revêt une importance sociale dans les zones de concentration.

De temps en temps, les bélugas se sont concentrés dans des secteurs des baies East et West Mackenzie, précédemment classés comme zones d'occupation intermittente. Certains se sont sans doute alimentés dans les eaux de la West Mackenzie Bay (>5 m).

L'élévation de la température des eaux semble être le principal facteur de la répartition du béluga dans l'estuaire. La profondeur, la salinité et la turbidité des eaux ainsi que la tranquilité des eaux tiendraient un rôle secondaire. L'hypothèse de Fraker et al. (1978) selon laquelle le béluga, indépendamment de son sexe ou de son âge, séjournerait dans l'estuaire en raison du réchauffement de ses eaux se trouve ainsi renforcée. Rien n'ayant permis d'affirmer qu'il existait une relation entre sa répartition et l'état de la mer, l'hypothèse qui veut que l'animal recherche les eaux tranquilles n'a pu être vérifiée.

Bien que la béluga mette sans doute bas dans des estuaires, notamment dans celui du Mackenzie, il arrive aussi qu'il le fasse plus au large, dans les eaux froides de l'ocean. Les présentes observations s'accordent dans leur ensemble avec l'hypothèse de Brodie (1975), selon laquelle bon nombre d'espèces de baleines migreraient dans les eaux chaudes pour limiter leurs dépenses d'énergie, indépendamment de leurs classes d'âge.

Mots-clés: relevés aériens; comportement; océanographie; température de l'eau; salinité; turbidité; vagues; Beaufort Sea; calendrier; recherche d'hydrocarbures.

INTRODUCTION

Each summer, large numbers of white whales *(Delphinapterus leucas)* migrate to a few specific river estuaries in arctic Canada. One of the largest concentrations occurs in the Mackenzie River estuary, the only known concentration west of Prince of Wales Island. In addition to being an important part of the marine fauna of the Mackenzie region, this white whale population supports an Inuit harvest of about 150 animals per year. The harvest not only provides a winter food supply, bur also allows native persons to maintain an important part of their cultural identity.

Over the past seven years, hydrocarbon exploration has been taking place in the Mackenzie estuary, and will likely continue in the foreseeable future. Since the first offshore exploration began there, considerable concern has been expressed about the implications to white whales. In 1977, the Commissioner of the Mackenzie Valley Pipeline Inquiry, Mr. Justice Thomas Berger, proposed that a sanctuary be created in Naikunak Bay to protect the whales from any adverse effects that oil and gas exploration and development might have.

Prior to 1972, relatively little was known about white whales in the Mackenzie estuary. Since then, studies conducted by F.F. Slaney & Company on behalf of Imperial Oil Limited (Slaney 1973, 1974a, 1975a; Fraker 1976, 1977a, b), by the Arctic Biological Station (Sergeant and Hoek 1974), and by the Beaufort Sea Project (Fraker et al. 1978) have provided some insights into numbers, distribution, movements, and behavior of the species in this area. However, because of year-to-year variations in both the behavior of the whales and the environmental conditions of the Beaufort Sea, many gaps remain in our understanding of the patterns of distribution, abundance, and movements and of the role underlying environmental factors in determining these patterns.

Similarly, little was known about the oceanography of the Beaufort Sea prior to 1972. Since then a number of studies have been completed with support from members of the Arctic Petroleum Operators' Association and government (e.g. Herlinveaux and de Lange Boom 1975; Reed and Sater 1974). As a part of environmental studies related to offshore exploration drilling, F.F. Slaney & Company has conducted oceanographic studies in the Mackenzie estuary (Slaney 1974b, 1975b; McDonald and Martin 1976). While these studies have contributed to a general understanding of the estuary, they have not dealt with Shallow, Niakunak, and West Mackenzie Bays, nor were the studies designed to be timed or conducted in sufficient detail to be related directly to particular distributions of white whales.

The present study had two principal objectives: first, to make detailed observations of the relative abundance, distribution, and movements of whales; and second, to conduct detailed oceanographic surveys with simultaneous aerial whale surveys in order to relate whale distribution to aspects of the physical and chemical environment.

STUDY AREA

This study focused on Niakunak Bay (Fig. 1), the area proposed for a white whale sanctuary by Berger (1977). In order to gain an appreciation of patterns of movement and a comparison between areas, the study also included Shallow, West Mackenzie, and East Mackenzie Bays. This also preserved the continuity of previous and concurrent studies (Slaney 1973, 1974a, 1975; Fraker 1976, 1977a, b).

The outflow of the Mackenzie River is the dominant influence on the chemical and physical characteristics of the waters of the study area. The river drains some 1,800,000 sq km of the Northwest Territories, the Yukon, British Columbia, Alberta, and Saskatchewan. Its discharge at Norman Wells, about 600 km south of the study area, is minimal in mid-April and maximal in June - July when the volume reaches an average of 1.5 - 2.0 x 10^4 m^3/sec (Anderson and Mackay 1973).

There are three main channels which carry water through the Mackenzie Delta; the Peel, Middle, and East Channels (Fig. 2). Middle Channel carries about 85% of the total Mackenzie River discharge (Davies 1975), and it separates near Tununuk into Middle Channel (25% of total), East Channel (28% of total), and Reindeer Channel (32% of total). Most of the final Middle Channel flow (17 of the 25%) is carried by Kumak Channel into East Mackenzie Bay near Kendall Island. All of the East Channel flow empties into Kugmallit Bay, and all of Reindeer Channel flows into Niakunak and Shallow Bays.

The Mackenzie River estuary lies within the continental shelf zone of the Beaufort Sea and is extremely shallow. Most of Niakunak Bay, the focus of the study, is less than 2 m deep, and the greater part of the study area is less than 10 m in depth (Fig. 3). The sea floor in the study area is composed of sediments of small particle size, mainly silt with some sand and clay (Pelletier 1975). Pelletier and Shearer (1972) estimate a sedimentation rate of 1m/100 years for flat areas of the Beaufort Sea continental shelf.

Ice covers the study area for 8-9 months each year. Break-up comes in June and freeze-up in September or October. The entire area is in the region of stationary landfast ice. Break-up in the Mackenzie estuary results from the combined actions of the relatively warm river discharge water, radiant heating from 24 h/day of sunlight, and the break-up of the southern Beaufort Sea (see Marko 1975).

During the open-water period, the overall pattern of currents in the estuary results largely from Mackenzie River discharge, upon which is superimposed the Coriolis effect caused by the Earth's rotation. Outside of the study area, the Beaufort Sea circulation is clockwise with mean velocities of about 4 cm/sec (Herlinveaux and de Lange Boom 1975). Winds complicate general flow patterns in the estuary and can cause large

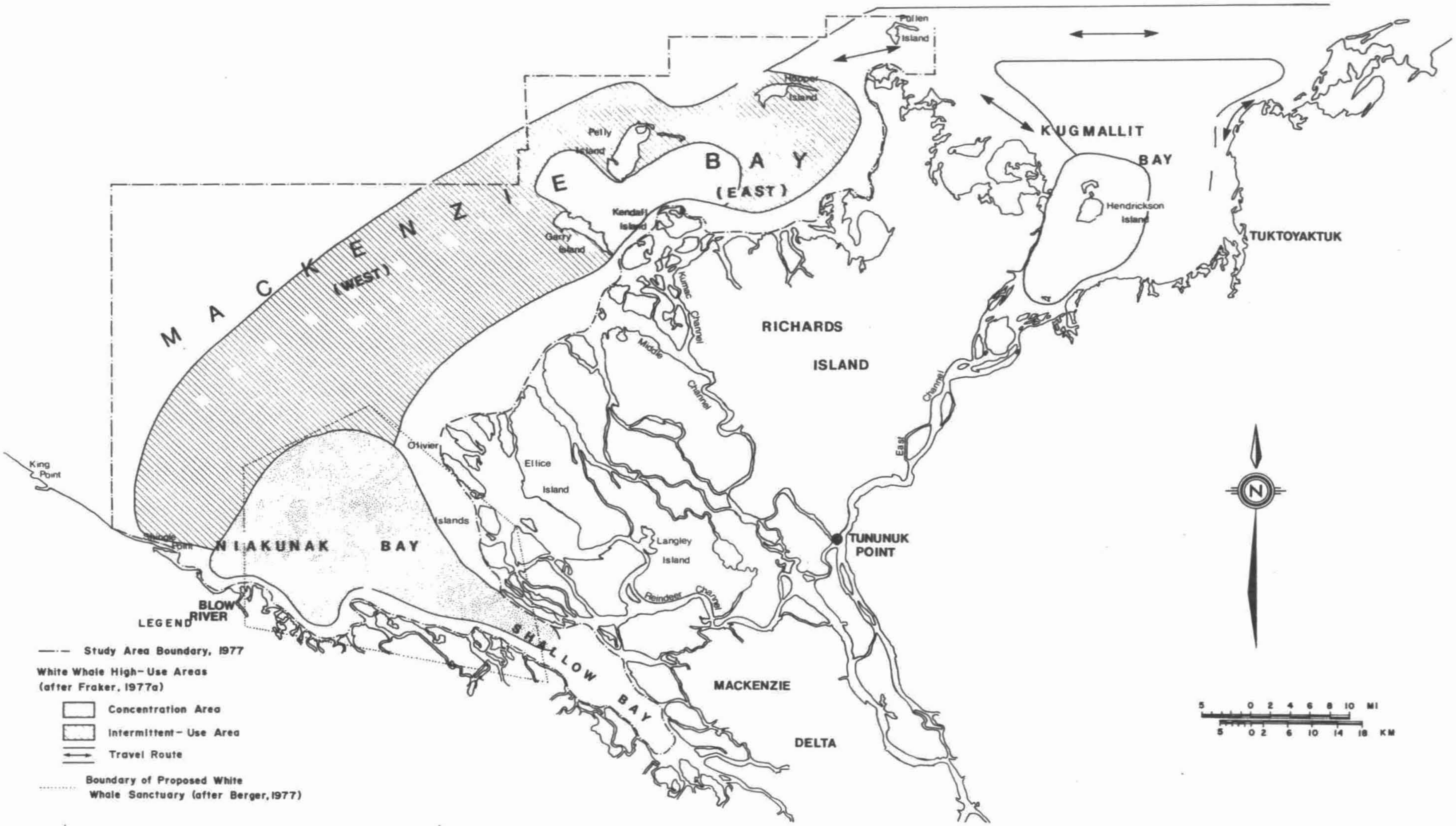

Fig. 1. The 1977 study area, white whale high-use areas, and proposed white whale sanctuary boundaries, Mackenzie estuary, N.W.T.

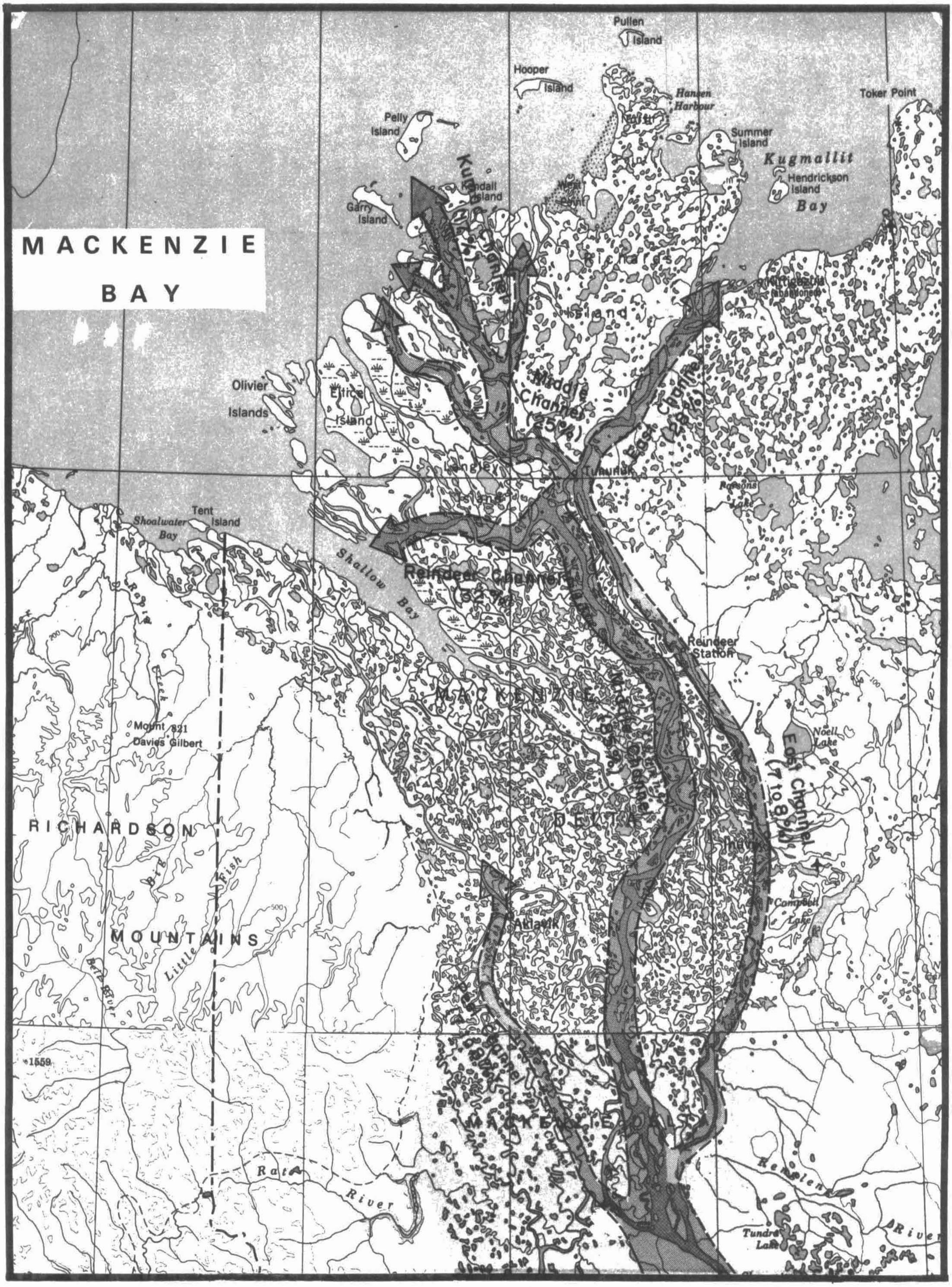

Fig. 2. Generalized distribution of Mackenzie River outflow through channels of the Mackenzie Delta, N.W.T. Percentages indicate the approximate proportion of the total Mackenzie River discharge carried by various channels based on Davies (1975) and Slaney (1974b, 1976a,b).

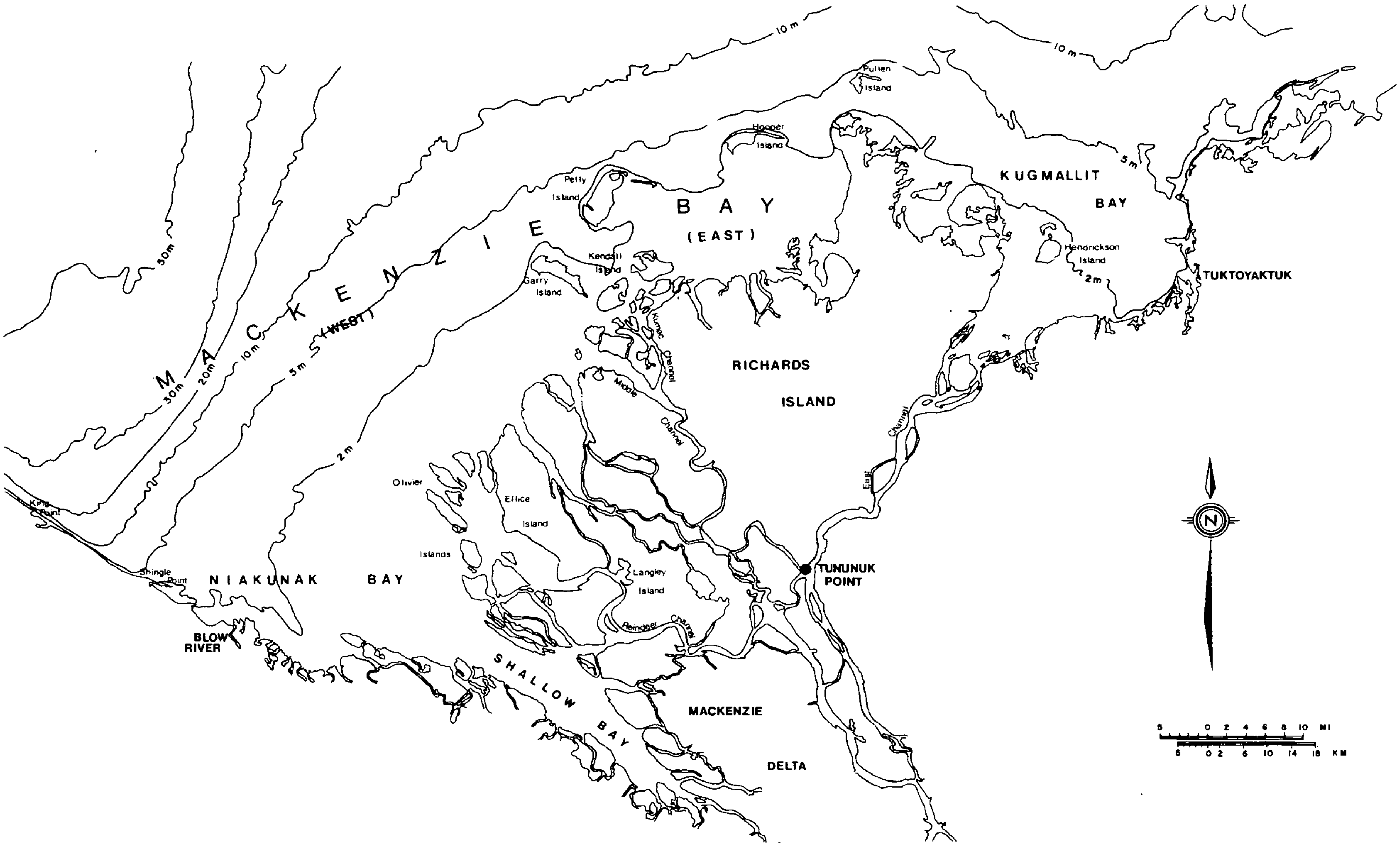

Fig. 3. Bathymetry of the study area.

eddies (Slaney 1975; McDonald and Martin 1976). The warm, fresh Mackenzie River outflow has its greatest effect on the chemical and physical oceanography of the estuary in late June and early July when river flows are maximal. Because of the Coriolis effect, there is a generally northeastward movement of surface discharge water at about 50 cm/sec (Figs. 4, 5). The result is that Mackenzie River water tends to move along the Tuktoyaktuk Peninsula and relatively cold, clear Beaufort Sea water tends to intrude into the study area from the west. However, strong easterly winds can have a large enough effect to cause a temporary northwestward movement of water.

Lunar tides throughout the southeastern Beaufort Sea are small, with a range of only 0.1 - 0.3 m (Huggett et al. 1975). However, strong northerly winds can cause large increases in water level, which are termed storm surges or wind tides, when Beaufort Sea water is blown toward the coast and is funneled into channels and bays. In 1970, a severe storm surge, of such magnitude to have an average return period greater than 25 years, caused an increase of 3.3 m at Tuktoyaktuk where low-lying roads and buildings were inundated. Smaller surges of up to 1 m occur on an average of once or twice a year (McDonald and Martin 1976).

Water temperature usually increases until August over a large part of the estuary. A variable range of surface temperatures (about 0^0 to 18^0C) and salinities (1^0/oo to 25^0/oo) can be expected in June, July, and August in the study area, depending on several factors which include the time of retreat of the ice, the Mackenzie discharge, and wind and barometric pressure systems.

Turbidity and the level of settleable materials generally varies directly with the volume of Mackenzie River discharge. Thus there is a tendency for sediment loads to be highest in late June and early July, and lowest as freeze-up approaches. However, localized increases in turbidity may result from wave action in shallow water (Slaney 1975; McDonald and Martin 1976).

The vertical extent of the Mackenzie freshwater plume in the water column diminishes with distance offshore. Near the mouth of major discharge channels, the warm turbid freshwater is practically homogeneous to a depth of about 3 m (Slaney 1975; McDonald and Martin 1976). Further offshore the layer of warm freshwater overlies the colder, more saline sea water, and it gradually becomes thinner as one moves seaward.

WHITE WHALES IN THE MACKENZIE ESTUARY

White whales enter the Mackenzie estuary in late June or early July, shortly after the first large breaks occur in the continuous landfast winter ice which extends across Mackenzie and Kugmallit Bays from the Yukon Coast to Tuktoyaktuk Peninsula. After arriving, the whales do not distribute themselves evenly or randomly in the estuary, rather they use some areas more than others. Based on five years' data, Fraker (1977a) divided white whale high-use areas into three distinct types (Fig. 1), which reflect important differences in the type and degree of use:

CONCENTRATION AREA: An area where relatively large numbers of whales consistently congregate during much of the summer (open-water) season, year after year.

INTERMITTENT-USE AREA: An area in which relatively large numbers of whales have been observed occasionally, but where large numbers of whales usually do not persist for more than a few days. Large numbers of whales may not be observed at all in these areas in some years.

TRAVEL ROUTE: An area in which whales in significant numbers are normally observed travelling, and are rarely observed engaged in other activities such as resting or feeding.

Of the three major concentration areas, those in Niakunak and Kugmallit Bays (Fig. 1) are usually occupied earlier and by larger numbers of whales than the Kendall Island area (Fraker 1977 a). After the first whales arrive, the numbers increase rapidly, reaching a peak within about a week to 10 days. The numbers remain high for most of July and then decline rapidly in early August; only a few whales are found in the estuary through August and into September.

Although most whales occupy concentration areas, there is considerable movement within, to, and from the estuary (Fraker 1977a, b). In Kugmallit Bay and along the Tuktoyaktuk Peninsula there are well-defined travel routes. Occasionally, large numbers of whales move out into the parts of East and West Mackenzie Bay which have been defined as intermittent-use areas.

Although obviously important, the reason for the whales' annual visit to estuaries is unknown. It has been assumed by some (eg. Kleinenberg et al. 1964) that the visits to the estuaries are for feeding, and this is undoubtedly true in some instances. However, Sergeant (1973) observed that a very large proportion of the stomachs of whales taken in estuaries in western Hudson Bay were empty and that there were many newborn calves present. Therefore, Sergeant hypothesized that the whales were using the warm estuarine waters as a calving ground. The calves, he reasoned, with their large surface-to-volume ratio, would tend to lose heat rapidly and hence would benefit from being in warmer water. The situation in the Mackenzie estuary is similar in many respects to that which Sergeant described for Hudson Bay in that newborn calves are common and few whales taken in the native harvest have food in their stomachs. On the other hand, Fraker et al. (1978) pointed out that in the Mackenzie estuary, in addition to females which may be calving, there are also females pregnant with next year's calves, adult males, and juvenile whales of both sexes. Thus they hypothesized that "...white whales congregate in estuaries in the summer primarily for the thermal advantage to all classes of whales, including newborn calves." Because white whales have been observed reacting to rough water by orienting into the waves (Fraker 1976; Slaney 1974), it was also suggested that shelter from wind might be an additional, secondary factor influencing the location of whale concentrations.

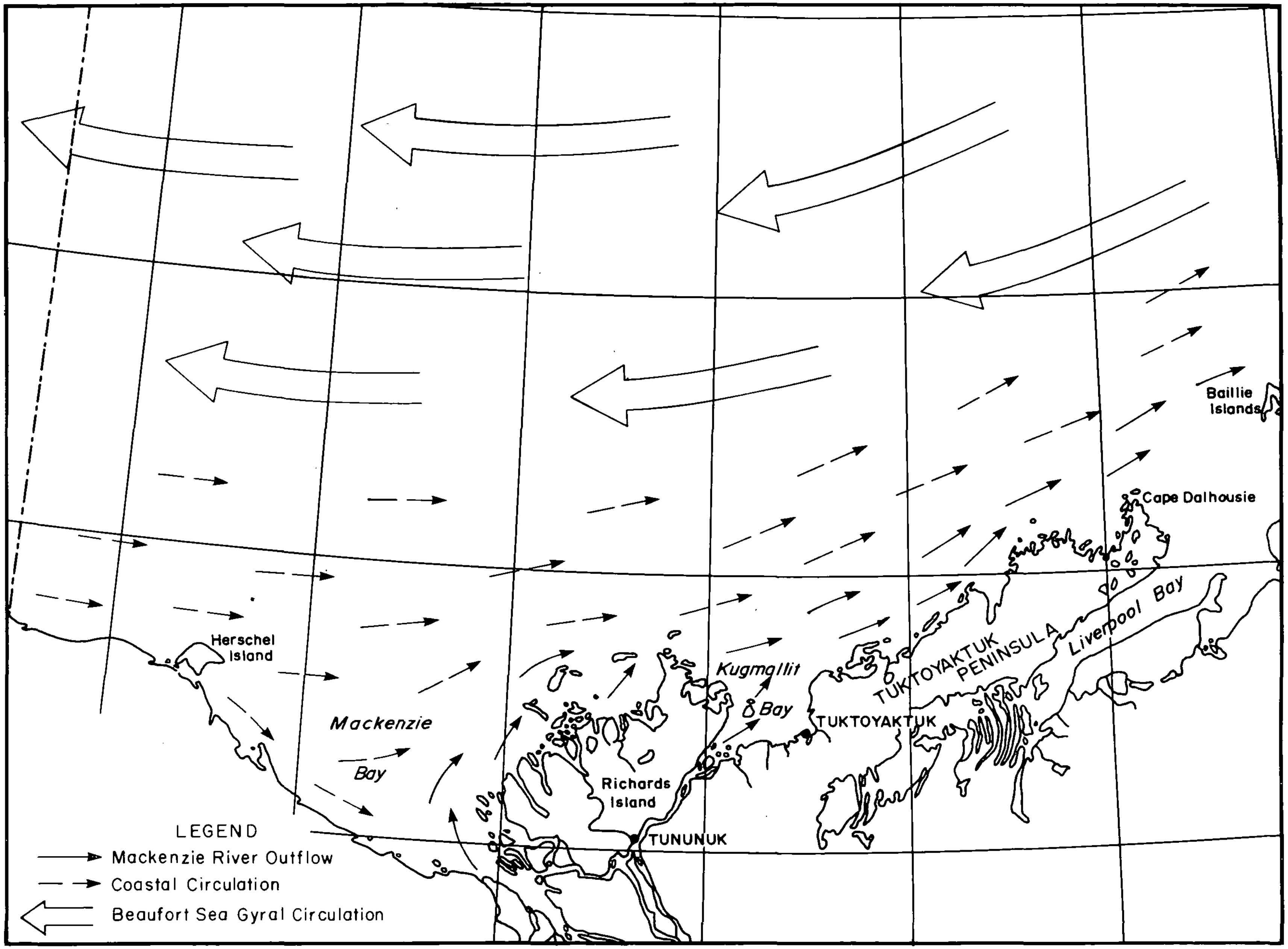

Fig. 4. Generalized pattern of circulation of water in the Mackenzie estuary and adjacent Beaufort Sea.

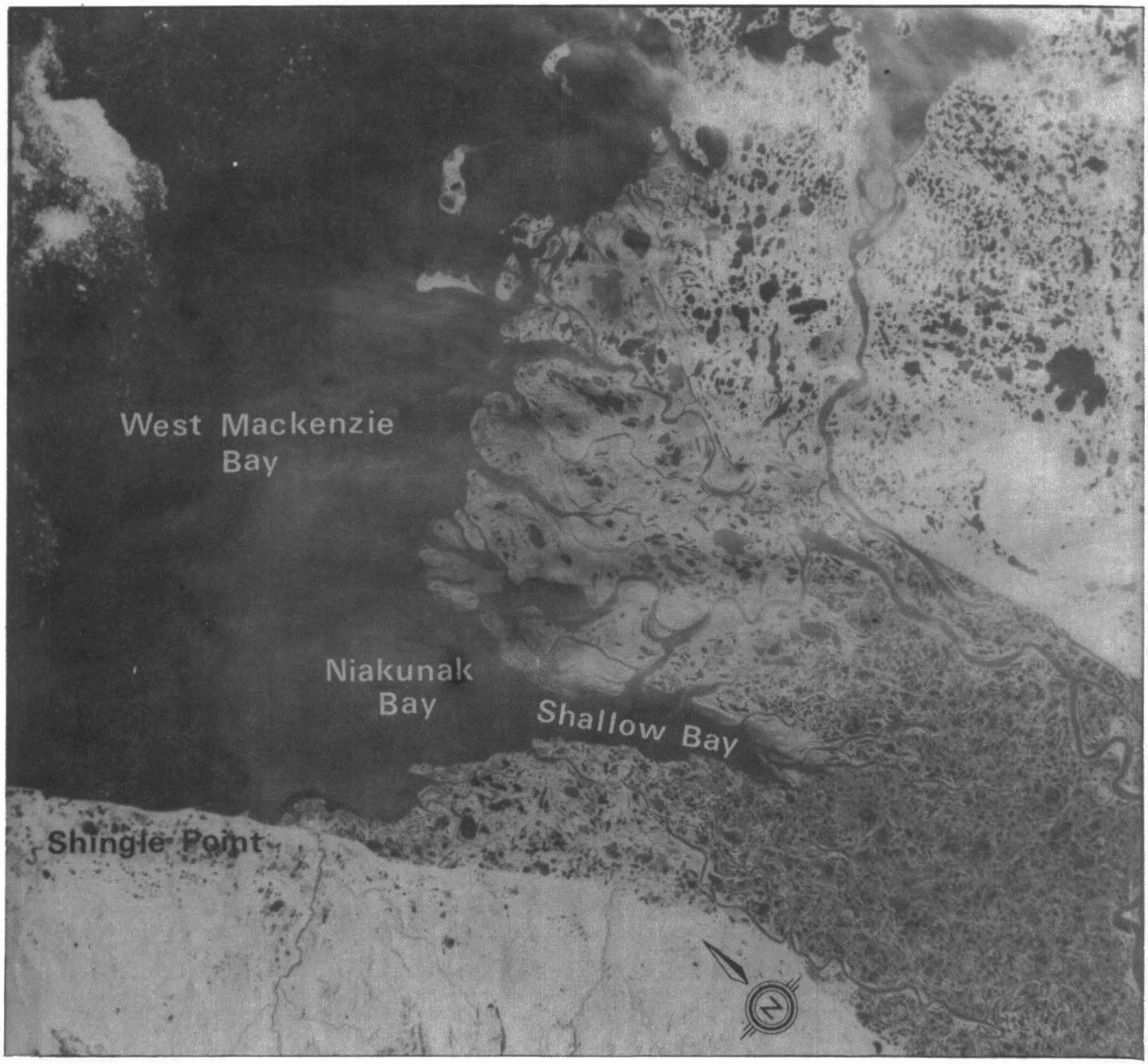

Fig. 5. Landsat image of the western and central Mackenzie estuary, 20 July 1977.
Note the generally northeastward flow of turbid Mackenzie River discharge water.

Inuit hunting in the Mackenzie estuary is an important feature of the whales' environment (Fraker 1977b; Fraker et al. 1978). Typically, whaling begins toward the end of June, soon after the whales arrive. Hunting activity reaches a peak in the first half of July, and dwindles by early August. The whales are pursued on relatively calm days when they can be more easily located and conditions are relatively safe. The hunters, usually two per craft, pursue the whales in boats and freighter canoes powered by large (20-80 hp) outboard motors. One hunter stays in the bow while the other operates the motor. The man in the bow is armed with a rifle and a harpoon attached by several meters of line to a float. When the boat approaches to within about 20-30 m of a whale, the bowman begins to shoot to wound and slow the animal. As soon as the boat can approach the whale closely, the hunter throws the harpoon. When the harpoon and float are secured to the animal, the hunter shoots to kill. Hunting takes place over a large part of each of the three concentration areas (Fig. 6).

METHODS AND MATERIALS

OCEANOGRAPHIC SURVEYS

A systematic sampling grid was established in order to obtain a representative picture of oceanographic conditions in Shallow, Niakunak, and West Mackenzie Bays (Fig. 7). There were 26 stations 10 mi.[a] (16 km) apart along the north-south axis. Five oceanographic surveys were conducted: 4 July, 19-20 July, 25 July, 4 August, and 11 August. Simultaneous aerial whale surveys were also flown, except for 4 July; data from whale surveys on 3 and 5 July were related to oceanographic data of 4 July. The oceanographic variables measured were water temperature, salinity, and turbidity. In addition, observations on wind and waves were made during aerial whale surveys.

Because a basic objective of the program was to relate the distribution of whales at a particular time to the existing physical and chemical conditions, it was necessary to conduct the oceanographic surveys quickly. To make this possible, a float-equipped Bell 206 helicopter was employed for all water sampling. During favourable weather (good visibility and waves <0.25 m), the helicopter landed at each oceanographic station. Water temperature and salinity were measured by lowering a conductivity-temperature probe vertically through the water column. Surface and bottom water samples were collected using a Van Doren bottle.

It was planned to conduct the oceanographic surveys at regular intervals, but weather determined the actual timing. Close liaison was maintained with the Inuit hunters in the study area to ensure that the helicopter oceanographic surveys did not interfere with whale hunting.

When wave heights exceeded approximately 0.25 m, it was unsafe for the helicopter to land on the water. Sampling under these conditions had to be conducted while the helicopter hovered 1-3 m above the surface. While hovering, only surface measurements of temperature and conductivity and the collection of surface water samples were possible. However, the hovering technique allowed considerable flexibility in timing the oceanographic surveys, because it could be carried out in winds up to about 15 knots (28 km/h) and wave heights to 1 m.

Nearshore stations were easily located by using landmarks and by flying either north-south or east-west at a given speed for an appropriate period. The position of the most seaward stations was determined by triangulation using the helicopter's Automatic Direction Finder (ADF) tuned to the Shingle Point DEW (Distant Early Warning) Line Station transmitter and the VHF (very high frequency) Omnidirectional Range (VOR) tuned to the Garry Island transmitter. Station positions could then be located to an accuracy of about 0.25 mi. (400 m).

A Hydrolab Model TC-2 Conductivity Meter was used to measure water temperature and conductivity. Conductivity was later translated to salinity using standard oceanographic tables. The cable connecting the temperature-conductivity probe to the instrument case was marked at 0.5 m intervals and was weighted to make the probe sink steeply and quickly. Temperature and conductivity were recorded at 0.5 m intervals at shallow stations (less than 3 m deep), while at deeper stations measurements were taken at 1 m intervals down to 10 m, and below this depth at 5 m intervals. The TC-2 conductivity meter was calibrated using a Lambrecht mercury thermometer as a standard.

At each station a water sample was collected in a Van Doren bottle at the surface and at 20 m or 1 m from the bottom at shallower stations. The water was stored in 1 L polyvinylchloride (PVC) bottles. About 20 mL was used at the field laboratory immediately after each survey for turbidity analysis.

The turbidity (in ppm SiO_2) was measured with a Hellige turbidimeter model 7000 TS using a precalibrated bulb and turbidity graph. The recorded values were the means of three consecutive readings taken by one observer. If the turbidity was very high, it was necessary to dilute the sample with distilled water prior to testing.

Wave and wind observations were made during all oceanographic and aerial whale surveys. Direction was determined using a hand-held compass. During oceanographic surveys, wave period was determined by using a stopwatch to measure the time required for ten waves to pass a fixed point, and wave height was estimated relative to fixed marks on the helicopter.

During aerial whale surveys, observations of wave direction and sea state were made on each transect line. Later the data were converted into wave heights, and maps were constructed for each flight showing areas of different wave height and direction. Wave height was calculated on the basis of the Beaufort Wind Scale (Watts 1975). Wave height can be calcula-

[a] Aircraft instruments, which are calibrated in the English system of measurement, were used for field measurements and thus, the resulting discussion is presented in English units with the metric conversion in parentheses.

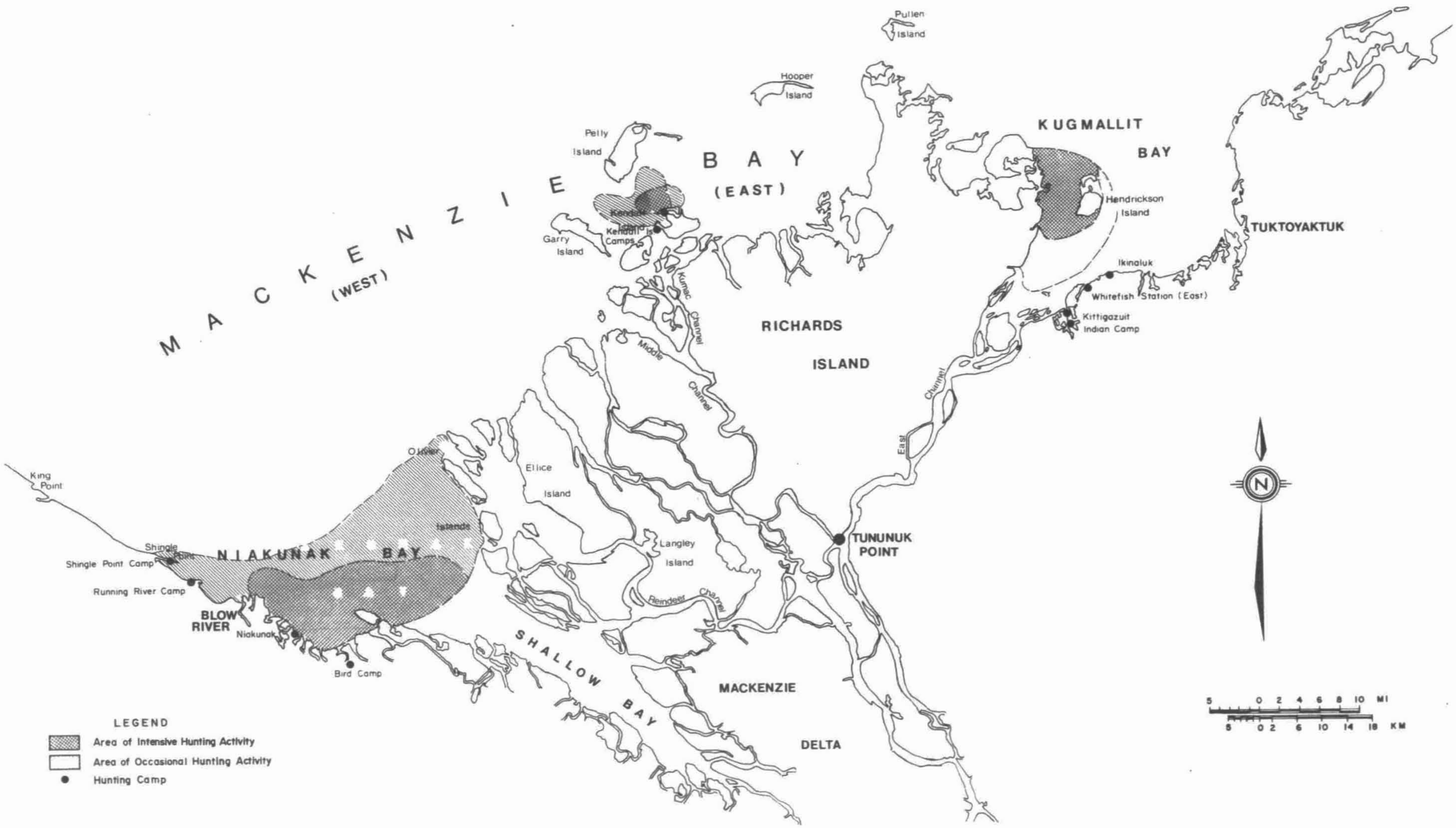

Fig. 6. White whale hunting areas and camp locations (from Fraker et al. 1978).

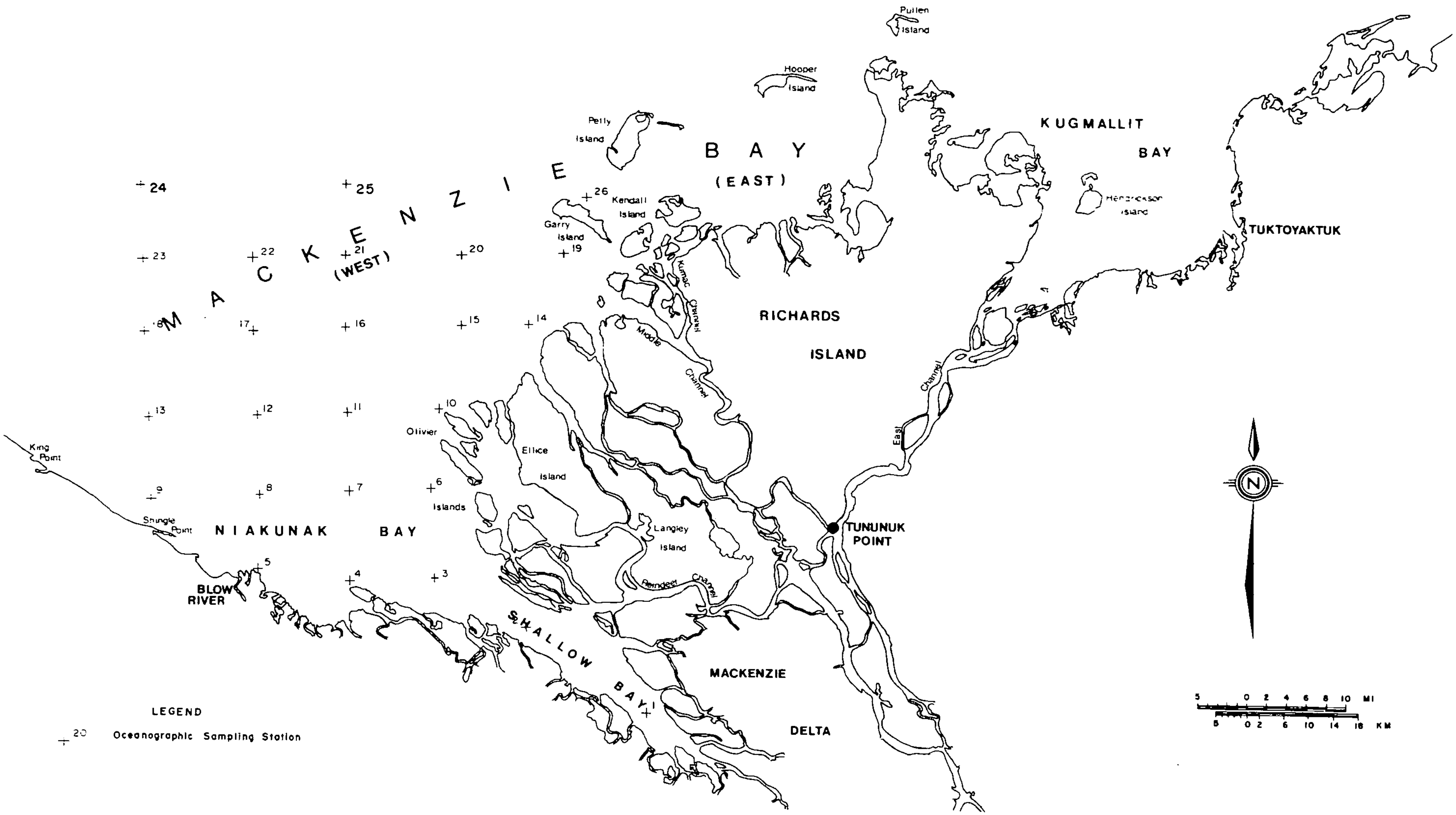

Fig. 7. Oceanographic sampling stations.

ted from the Beaufort number provided the duration and fetch are known. Duration is the length of time that the wind has blown within 30^{o} of a given direction; fetch is the distance of open water over which the wind has blown.

AERIAL WHALE SURVEYS

The study area was divided into three zones, each of which could be surveyed during a single flight from Tununuk Point, the base of operations (Fig. 8). A standard set of transect lines was established for each zone, and in the case of Niakunak Bay, the lines included those used in a previous study (Fraker 1977a). The transect lines in East Mackenzie Bay and most of Niakunak/Shallow Bay were 2 mi (3.2 km) apart, while the lines in West Mackenzie Bay and the Northwestern part of Niakunak Bay were 3 mi (4.8 km) apart. The main area of interest was Niakunak/Shallow Bay, but in order to gain a more compelte picture of the overall use of the general region by whales, West and East Mackenzie Bays were also surveyed. A total of 36 surveys were flown: 19 of Niakunak Bay, 9 of West Mackenzie Bay, and 8 of East Mackenzie Bay.

Surveys were flown at 1000 ft (305 m) and an airspeed of 120 mph (192 km/h) in a float-equipped Cessna 185 aircraft. Two observers, one on each side of the aircraft, counted whales in a 0.5 mi (0.8 km) wide strip. In order to be able to confine counts to this (0.8 km) strip, the aircraft was flown over a 0.5 mi aircraft runway and the wing struts were marked so that the projected area on the water viewed between the floats and strut marks at 1000 ft (305 m) altitude was 0.5 mi wide. Because a 0.5 mi (0.8 km) strip was searched on each side of the transect line, 50% of the water area was covered when the lines were 2 mi (3.2 km) apart and 33% when the lines were 3 mi (4.8 km) apart.

Submerged whales cannot be seen in the highly turbid water which usually occurs over most of the Mackenzie estuary, therefore, it is possible to count only those whales which are at the surface. An accurate count depends on knowing what proportion of the total number of whales in the area is at the surface, but this is unknown. Sergeant (1973) watched whales from a cliff near Churchill, Manitoba, and observed that they spent about one-third of the time at the surface, and thus he applied a visibility factor of three to his counts to arrive at an estimate of total numbers.

Sergeant's visibility factor assumes that only an instantaneous count of whales in any given area is made. However, the longer an area is viewed, the greater the number of whales which will be seen as they come to the surface. In the present study, if the counts had been restricted to a narrow band across the transect strip, which would have approximated an instantaneous count, whales would have been recorded as absent from areas where they occurred in low density, but this procedure would have been unacceptable because information about distribution was just as important as abundance. By viewing objects while flying over land under survey conditions, Fraker (1976) determined that any given point is in view for about 15 sec. under the standard observation technique used in the present and other studies (Fraker 1976, 1977a, b). To compensate for the fact that the assumption of an instantaneous count of whales in any given area was not met, the visibility factor was reduced from three to two, and this factor has been applied consistently in whale studies in this area since 1975 (Fraker 1976, 1977a,b). Although we believe that this factor results in conservative estimates of total whale numbers, it must be emphasized that the resulting figures should be treated as indices rather than estimates of absolute abundance. The most important feature of such surveys is that the methods be consistent so that results are comparable.

Observation conditions also affect the number of whales observed during surveys. Glare from the sun can seriously hamper survey efforts, but this was controlled by timing survey flights so that the sun was either in front of or behind the aircraft and did not interfere with the view out the sides. It was obviously not possible to compensate for weather conditions which can modify the effectiveness of observations, so a visibility rating scheme was developed (Fraker 1977b):

EXCELLENT: no glare or water disturbance to interfere with whale observations.

GOOD: small amount of glare and/or a few whitecaps which offer a minor amount of interference.

FAIR: glare and/or whitecaps which offer significant interference.

POOR: severe winds generating rough water, may be glare, and air turbulence may interfere with navigation and observation.

The visibility conditions which prevailed during each survey were taken into account in interpreting the results. Generally, estimates of numbers mentioned in the text derive from surveys conducted under excellent or good visibility conditions, unless otherwise noted. However, surveys flown under fair or poor conditions still provided valuable data on distribution, movement, and behaviour.

The observers used Seiko Liquid Quartz digital watches which were synchronized before each survey. The time was recorded to the nearest 15 sec at the start and finish of each transect line and at 25-sec intervals when whales were observed. Because the aircraft flew at an airspeed of 120 mph (192 km/h), approximately 0.5 mi (0.8 km) was covered each 15 sec. Cassette tape recorders were used to record the above data as well as observations on direction of movement and behavior. Shortly after each survey the tapes were transcribed onto a standard data form and the data on distribution, abundance, behavior, and direction of travel were plotted onto individual maps for each survey.

A t-test was used to determine whether or not there was any difference between the counts made from the right or left side of the aircraft or between observers. There were two main pairs of observers (JF/GC and JF/JM) who surveyed for

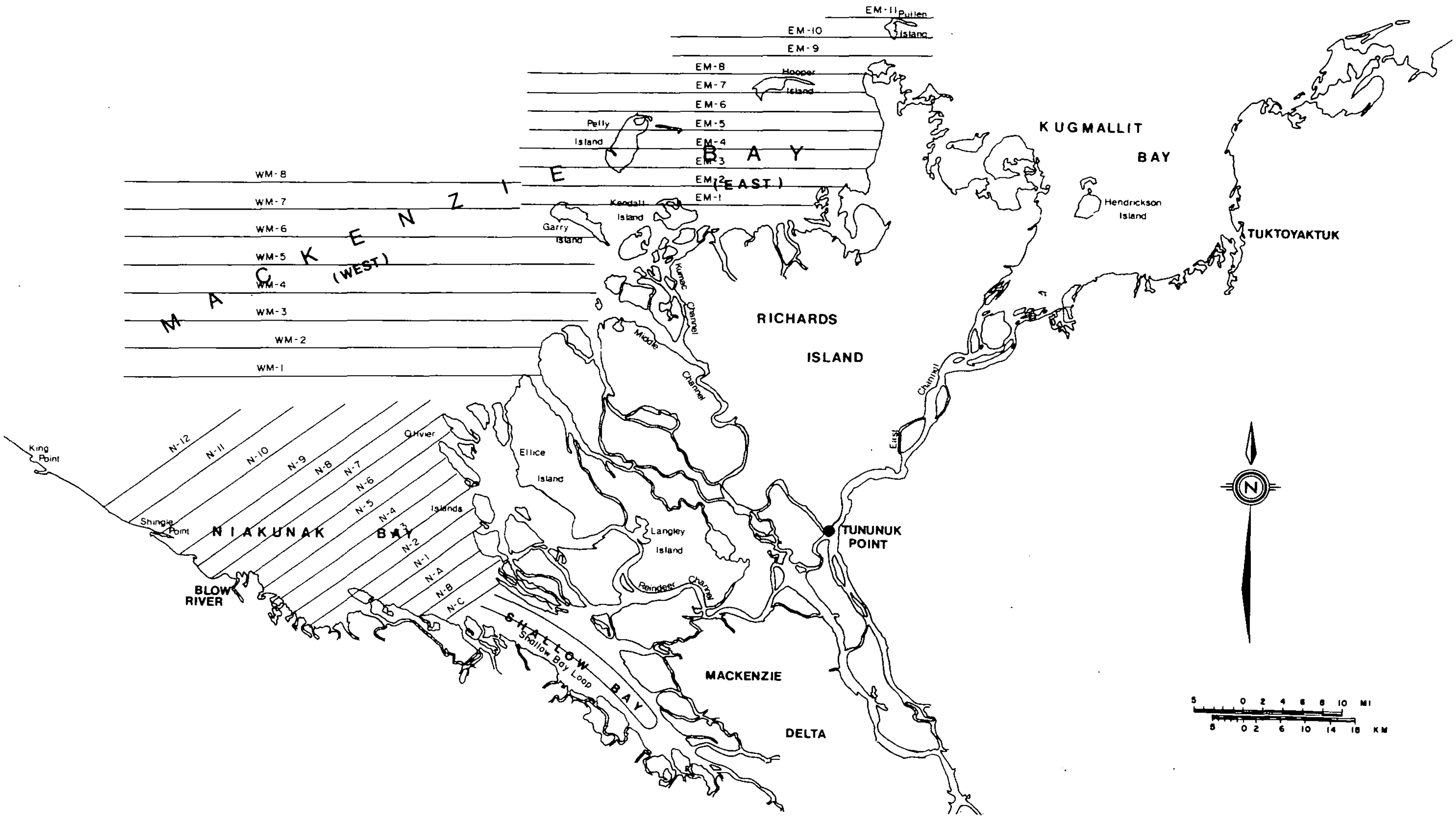

Fig. 8. Aerial whale survey transect lines, 1977.

whales. Because he participated in about 90% of the surveys, JF was used as the standard observer against whom the others were compared. Where there were statistically significant differences between observers, the counts were adjusted.

RESULTS AND DISCUSSION

OCEANOGRAPHY

Water temperature

The first oceanographic survey was conducted on 4 July 1977, following a week during which strong winds (40-70 km/h) had blown from the northwest. These winds forced ice back into the northwestern part of Niakunak Bay and confined the warm, turbid discharge of the Mackenzie River close inshore. The effect of the river discharge is clearly shown in the eastern part of the study area (Figs. 9a, b). Generally, the stations in 2 m of water or less had surface temperatures varying between 7° and 10.4°C, and there was only a slight decrease in temperature with depth (Figs. 9a, b; 10). The warmest surface and bottom temperatures were in the waters west of the Olivier Islands and south of Garry Island (Table 1; Fig. 9a, b). The bottom temperatures decreased in a westward direction, with the 0°C isotherm following the outer edge of the ice pack. The deeper stations in the northern part of Niakunak Bay and within the ice (Figs. 9a, b) had surface temperatures between 1.5° and 2.5°C, and instead of a marked thermocline, there was a steady decrease in temperature to -2°C at 10 m (Fig. 10).

Prior to the 19-20 July 1977 survey, a high-pressure area persisted over the southern Beaufort Sea resulting in an east-northeasterly air flow. This caused a general retreat of the ice to northwest of the study area and a general warming of air and water temperatures. The warmest surface temperatures were west of the Olivier Islands and in shallow water near Garry Island (Table 1, Fig. 9c). The warmest temperature recorded was 15.2°, compared to 11.6°C on 4 July.

The third oceanographic survey was carried out on 25 July. Since the previous survey, a stationary high-pressure system dominated the study region and produced light northeasterly winds. Only scattered fragments of ice were present in the northwestern part of the study area. The warmest water temperatures were again found in the shallow region west of the Olivier Islands and in the northern part of Shallow Bay, where they reached up to 17.5°C (Table 1; Fig. 9d). Stations 20 and 26 near Garry Island were 3-4°C cooler, and although the depths at these stations were less than 3 m, there was a 3-4°C decrease in temperature at the bottom. The cooler bottom water was also more saline (Table 2), indicating that denser sea water had intruded beneath the fresh river water in this area. At the deeper, offshore stations (Fig. 11, stns. 17, 23) there was a slight temperature inversion near the surface which was probably due to colder water from melting ice. The thermocline appeared at approximately 4 m, below which the temperature decreased to -1.8°C.

During the period 25 July - 4 August 1977, a high-pressure system dominated the study area giving rise to east-northeasterly winds and warm air temperatures. The surface waters of the estuary showed a striking increase in temperature with more than half of the study area being within the 18°C isotherm (Fig. 9e). The lowest temperature recorded was 13.6°C and the highest was 20.5°C.

During the week between 4 and 11 August, strong winds from the eastern quadrant resulted in air temperatures which were cooler by 5-10°C. A general cooling of surface water temperatures resulted, and cold sea water intruded into the western part of Niakunak Bay (Fig. 9f). Although the water was relatively warm compared to the conditions seen on 4 July, a month earlier, it was much cooler than it had been the week previous. The maximum surface temperature recorded was 16.8°C, approximately 4°C cooler than the maximum of a week earlier.

A general warming occurred throughout the estuary from early July through to the first week of August, after which there was a rapid cooling. The maximum water temperature recorded on 4 July was 11.6°C, while the maximum recorded during the study was 20.5°C on 4 August (Table 1). The increase in temperature was both in magnitude and geographical extent. The maximum temperature on 11 August dropped to 16.8°C which was still higher than the maximum recorded on 4 July (Table 1). Consistently, the warmest temperatures were in Shallow Bay, in Niakunak Bay west of the Olivier Islands, and in the nearshore areas of West Mackenzie Bay between Garry Island and the Olivier Islands. All of these areas are less than 2 m deep. The warming factors in influencing water temperature in the estuary were the warm Mackenzie River discharge and radiant heating from the sun, particularly in the shallower areas.

The water column in the study area usually was homogeneous Mackenzie River water to a depth of 3-5 m. Beyond this depth, a wedge of freshwater, which grew gradually thinner seaward, overlay the denser sea water. This situation was altered near the Yukon coast where the general circulation drew water eastward into the study area. However, this cold oceanic water generally was kept outside of the nearshore parts of the study area by the shear volume of the Mackenzie discharge. Strong winds periodically modified conditions by blowing sea water toward shore or by carrying Mackenzie River water further offshore, but in either case the warm river water dominated nearshore conditions.

The most extensive oceanographic work conducted previously in the study area was carried out in 1974 by Slaney (1975) in East Mackenzie Bay and the easternmost part of West Mackenzie Bay. On 21-22 July 1974, the surface waters between Garry and Pelly Islands were between 14° and 12°C, and the area southwest of Garry Island was 14° or above. This is similar to the results observed on 19-20 July and 25 July 1977 (Fig. 9c, d). The conditions observed on 8 August 1974 were intermediate between those observed in 1977 on 4 and 11 August 1977 (Fig. 9e, f). In Kugmallit Bay in mid-July 1975, temperatures up to approximately 18°C were recorded (McDonald and Martin 1976).

Text continued on page 19.

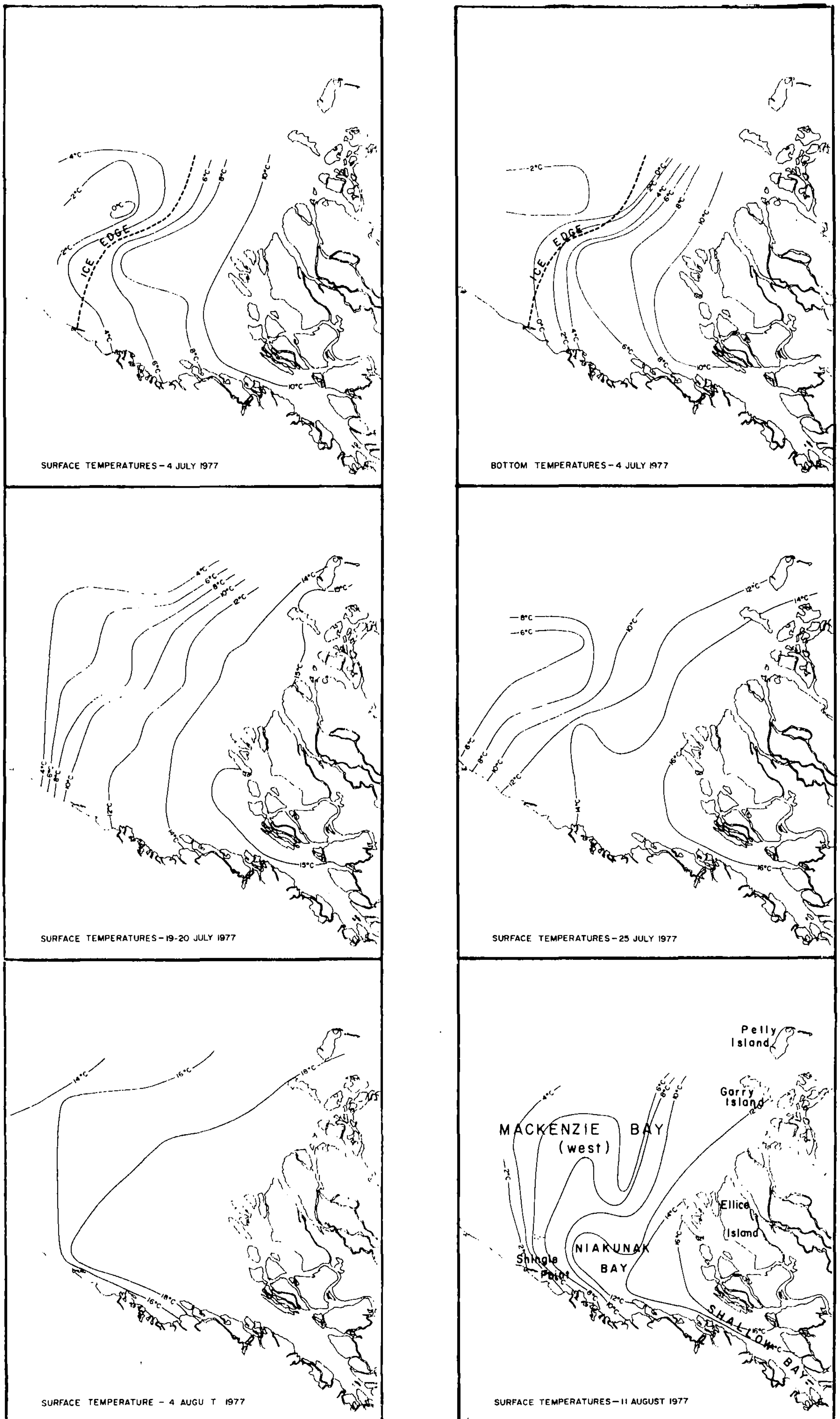

Fig. 9. Water temperature distribution, Mackenzie estuary, 1977.

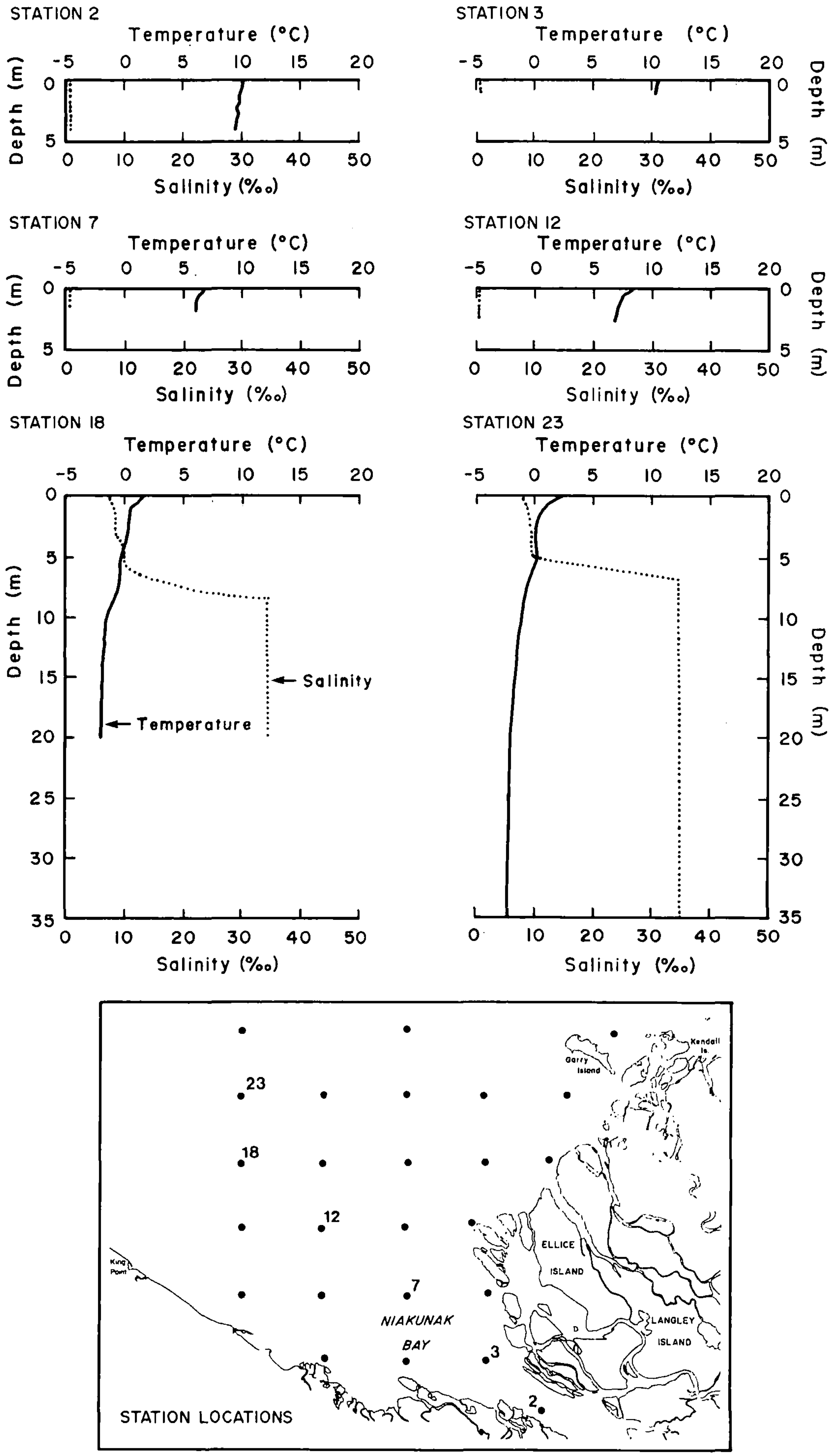

Fig. 10. Temperature-salinity diagrams, 4 July 1977.

Table 1 Water temperatures and salinity values recorded during oceanographic surveys.

Station Number[a]	Station Depth m	4 July Temperature (°C)		19-20 July Temperature (°C)		25 July Temperature (°C)		4 August Temperature (°C)		11 August Temperature (°C)
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface
1	1.0	9.4	8.7	14.5	-	15.0	14.7	20.5	19.5	14.8
2	3.6	10.0	9.7	15.2	25.2	16.4	16.2	19.0	18.8	16.8
3	1.8	10.4	10.3	13.0	-	16.2	16.3	18.9	18.6	15.5
4	2.0	-[b]	-	14.3	-	14.5	-	19.0	-	14.0
5	2.0	5.5	4.6	13.3	-	14.1	-	16.0	-	8.0
6	2.1	11.0	10.8	15.1	-	17.5	-	18.5	-	16.0
7	1.2	7.0	6.4	14.7	-	14.5	-	19.4	-	11.5
8	2.0	-	-	13.6	-	14.2	-	18.9	-	13.5
9	7.0	3.6	-0.5	10.6	-	13.0	5.7	18.0	-	2.3
10	0.5	10.0	10.0	13.4	-	14.2	14.0	18.5	-	12.7
11	1.6	9.5	8.4	14.0	-	13.6	-	19.4	-	6.0
12	3.8	8.4	7.0	11.6	-	14.5	-	18.2	-	8.0
13	17.8	4.0	-0.2	9.7	-	10.8	-	17.7	-	1.9
14	0.5	11.6	11.4	14.4	-	15.0	14.9	18.9	-	12.7
15	1.2	-	-	14.9	-	15.5	15.4	18.7	-	11.3
16	2.8	4.5	-1.2	11.6	-	11.9	-	18.5	-	6.8
17	7.0	0.0	-2.1	8.3	-	7.9	-1.6	17.8	-	7.9
18	34.0	1.6	-2.0	7.2	-2.0	6.6	-1.6	16.5	-	4.0
19	1.4	-	-	14.5	-	15.0	14.8	18.6	-	-
20	2.7	-	-	13.9	-	13.6	10.5	17.5	-	-
21	6.0	-	-	11.9	-	10.4	0.2	16.6	-	-
22	16.0	1.6	-2.0	7.9	-	5.2	-1.4	16.7	-	-
23	44.0	2.8	-2.0	5.2	-1.6	5.8	-1.6	16.6	-	-
24	10.5	-	-	6.0	-1.7	-	-	-	-	-
25	52.3	-	-	4.6	-1.7	8.2	-1.7	13.6	-	-
26	1.0	-	-	15.4	-	13.6	12.0	18.3	-	-

Station Number[a]	Station Depth m	4 July Salinity (°/oo)		19-20 July Salinity (°/oo)		25 July Salinity (°/oo)		4 August Salinity (°/oo)		11 August Salinity (°/oo)
1	1.0	1.0	1.0	1.0	-	1.0	1.0	1.0	1.0	1.0
2	3.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
3	1.8	1.0	1.0	1.0	-	1.0	1.0	1.0	1.0	1.0
4	2.0	-[b]	-	1.0	-	1.0	1.0	1.0	-	1.0
5	2.0	1.0	1.0	5.0	-	1.0	-	10.5	-	34.0
6	2.1	1.0	1.0	1.0	-	1.0	-	1.0	-	1.0
7	1.2	1.0	1.0	1.0	-	1.0	-	1.0	-	1.0
8	2.0	-	-	13.2	-	0.6	-	1.8	-	1.0
9	7.0	1.0	35.4	6.5	-	3.7	24.6	2.8	-	35.0
10	0.5	1.0	1.0	1.0	-	1.0	1.0	1.0	-	1.0
11	1.6	1.0	1.0	1.0	-	0.4	-	1.0	-	26.7
12	3.8	1.0	1.0	7.7	-	3.5	-	2.4	-	21.2
13	17.8	0.4	4.9	9.9	-	15.9	-	4.4	-	35.0
14	0.5	1.0	1.0	1.0	-	1.0	1.0	1.0	-	1.0
15	1.2	-	-	1.0	-	1.0	1.0	1.0	-	1.0
16	2.8	0.5	35.0	1.5	-	4.6	-	1.9	-	35.0
17	7.0	9.7	35.0	5.3	-	4.3	35.0	4.8	-	26.4
18	34.0	7.7	35.0	3.6	35.0	6.0	35.0	5.5	-	35.0
19	1.4	-	-	1.0	-	1.0	1.0	1.0	-	-
20	2.7	-	-	4.8	-	2.4	6.4	3.5	-	-
21	6.0	-	-	6.7	-	18.8	35.0	6.0	-	-
22	16.0	8.3	35.0	3.6	-	5.3	35.0	6.8	-	-
23	44.0	8.2	35.0	4.4	35.0	5.6	35.0	8.2	-	-
24	10.5	-	-	3.3	35.0	-	-	-	-	-
25	52.3	-	-	3.6	35.0	4.2	35.0	10.0	-	-
26	1.0	-	-	1.0	-	1.0	3.8	2.2	-	-

[a] See Fig. 3 for station locations
[b] Dash indicates missing data

Table 2. Turbidity values recorded during oceanographic surveys.

Station Number	Station Depth (m)	4 July Turbidity (ppm)		19-20 July Turbidity (ppm)		25 July Turbidity (ppm)		4 August Turbidity (ppm)	11 August Turbidity (ppm)
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Surface
1	1.0	183	143	47	-	21	-	129	70
2	3.6	117	105	63	-	33	-	172	35
3	1.8	117	177	54	-	45	-	180	62
4	2.0	-	-	53	-	25	-	70	78
5	2.0	150	188	70	-	39	-	13	42
6	2.1	122	200	73	-	37	-	140	66
7	1.2	182	174	63	-	31	-	124	70
8	2.0	-	-	61	-	31	-	16	70
9	7.0	208	48	21	-	27	-	13	23
10	0.5	140	100	56	-	31	-	148	78
11	1.6	106	140	66	-	31	-	104	62
12	3.8	140	108	25	-	23	-	14	66
13	17.8	172	164	14	-	6	-	6	7
14	0.5	146	-	59	-	31	-	124	39
15	1.2	-	-	63	-	25	-	164	39
16	2.8	200	16	56	-	14	-	23	78
17	7.0	6	7	21	-	10	4	9	39
18	34.0	17	2.5	37	2.0	6.5	2.5	6	70
19	1.4	-	-	54	-	19	-	132	-
20	2.7	-	-	45	-	25	-	21	-
21	6.0	-	-	37	-	6	9	7	-
22	16.0	7	4	35	-	7	4	6	-
23	44.0	16	4	33	8.5	9	6	6	-
24	10.5	-	-	27.0	2.1	-	-	-	-
25	52.3	-	-	43	3.9	14	6	4	-
26	1.0	-	-	-	-	23	25	132	-

[a] See Fig. 3 for station locations.
[b] Dash indicates missing data.

Table 3. Whale distribution and wave height observations.

Date	Range of wave height over entire survey area (m)	Wave height within whale concentration (m)	Date	Range of wave height over entire survey area (m)	Wave height within whale concentration (m)
(1) Niakunak Bay			(2) West Mackenzie Bay		
4/7/77	0-0.9	0-0.3	6/7/77	0.6	0.6
6/7/77	0-0.6	0.6	13/7/77	0.3-0.9	0.3-0.9
8/7/77	0.3-0.6	0.6	19/7/77	0.3-0.9	0.9
9/7/77	0.3-0.6	0.6	28/7/77	0.6-0.8	0.6-0.8
10/7/77	0-0.9	0.6	31/7/77	0.3-0.6	0.3-0.6
12/7/77	0.1-0.9	0.1-0.9	6/8/77	0.3-1.2	No whale concentration
18/7/77 [a]	0.3-0.9	0.3-0.9			
21/7/77	0.3-0.9	0.3-0.9			
24/7/77	0-0.1	0-0.1			
25/7/77	0-0.9	0.6-0.9	(3) East Mackenzie Bay		
27/7/77	0.1-0.9	0.6-0.9			
29/7/77	0.3-0.5	0.3-0.5	8/7/77	0.3-0.6	
1/8/77	0.3-0.9	0.6-0.9	13/7/77	0.3-1.2	No whale concentration
4/8/77	0.2-0.9	0.3-0.9			
7/8/77	0.3-0.9	No whale concentration	20/7/77	0.3-0.9	0.6-0.9
			27/7/77	0.3-0.6	0.6
			30/7/77	0.6-0.9	0.6
			2/8/77	0.3-1.2	0.3-0.6

[a] Incomplete survey due to fog.

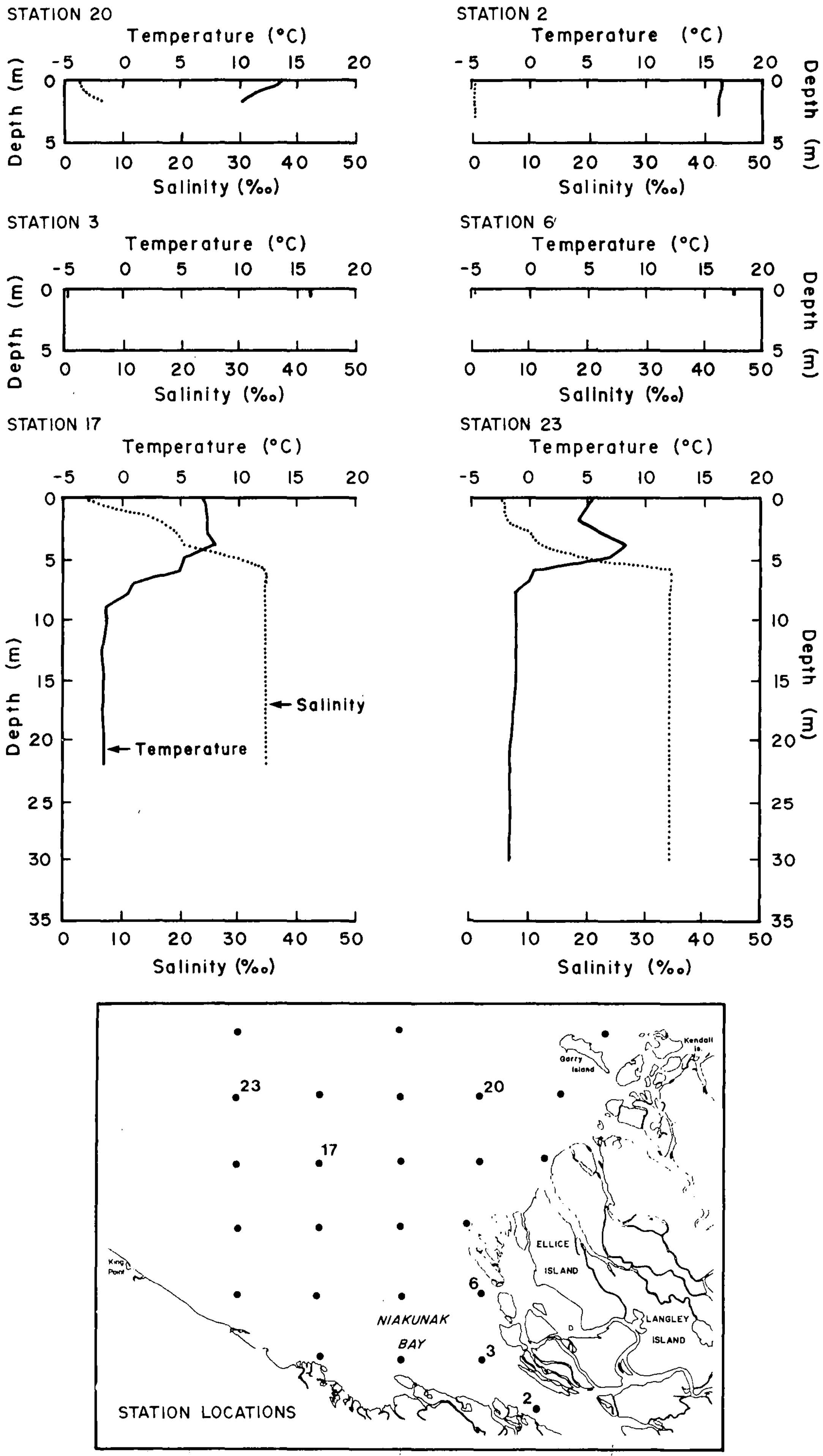

Fig. 11. Temperature-salinity diagrams, 25 July 1977.

Information on vertical stratification in 1974 is available for only 8 August, and on that date the depth of the thermocline at three locations was between 3 and 5 m, similar to that observed in 1977. In 1970, in open water north of East Mackenzie Bay, Healey (1971) found surface temperatures ranging between 5-7°C and a distinct thermocline at 5 m, below which temperatures dropped to about -1°C. Healey's results were similar to those recorded in 1977 at deeper stations, where the boundary between the warmer Mackenzie water and the colder oceanic water was at 5-7 m (Fig. 11).

In summary, the annual variations of surface water temperature in the nearshore reaches (<5 m) of the study area appear to be relatively consistent from year to year. The large volume of warm Mackenzie River discharge effectively buffers against large changes which might otherwise result from local variations in climatic conditions. The constancy of conditions within the study area is mainly a function of the proportion of the total Mackenzie discharge which flows through a particular region. Only if there was a major change in the distribution of river discharge in the region would one expect a significant departure from the overall pattern seen during this study.

Salinity

On 4 July 1977 the 1°/oo isohaline closely followed the edge of the ice pack. The Mackenzie River water appeared to be dammed up against the edge of the ice in most areas, although there were a few places where it flowed beneath the ice (Fig. 12a). Within the ice, surface waters were more saline with a maximum observed value of 9.7°/oo (Table 1). Saline bottom water extended along the southern coast of Niakunak Bay almost as far as the Blow River delta (Fig. 12b). Grainger (1974) measured salinity in the southern Beaufort Sea in July 1973 and found that the 1°/oo surface isohaline extended from Shingle Point to Pelly Island. This was similar to the position described for 4 July 1977. At the shallower stations, within the influence of the Mackenzie discharge, salinity was uniform with depth (Fig. 10). At deeper stations within the ice a distinct halocline was found at 7 m with very saline (35°/oo) sea water below.

Between 4 and 19 July 1977 strong northeasterly winds resulted in considerable mixing of river and oceanic waters. The 1°/oo isohaline was just west of the Olivier Islands (Fig. 12c). The maximum surface salinity value, 13.2°/oo, was found northeast of Shingle Point, indicating the advection of oceanic water into the study area from the west.

On 24 July 1977 practically no change was observed in the position of the 1°/oo surface isohaline from that of 19-20 July (Fig. 12d). Seaward of this, the salinity was transitional between the Mackenzie discharge water and saline sea water. The intrusion of saline water from the north was a result of wind. High salinity water was also present north of Shingle Point, and this reflects the generally eastward flow along the Yukon coast. The vertical profiles show uniform salinity with depth at shallow stations in Niakunak Bay. However, at station 20 near Garry Island, the salinity increased with depth, which resulted from the advection of more saline water into this area (Fig. 12d). The deeper stations showed surface salinities between 4 and 18°/oo, and haloclines at about 5 m, below which there was oceanic water (Fig. 11).

The position of the 1°/oo surface isohaline on 4 August 1977 was unchanged from that of 25 July 1977. An intrusion of more saline water extended along the west coast from Shingle Point to the Blow River Delata causing a steep horizontal salinity gradient (Fig. 12e).

The survey of 11 August 1977 showed the 1°/oo surface isohaline closer to the coast of the Mackenzie delta, and seaward of this line the horizontal salinity gradient was much steeper than on previous occasions. Strong winds from the north and northeast had carried saline oceanic water from offshore into the northwest part of the study area (Fig. 12f).

In summary, salinity at all depths in the study area generally increased during the study. The low surface salinities observed in early July resulted mainly from the large volume of freshwater from the Mackenzie River at freshet, with a minor effect from the meltwater from thawing ice in West Mackenzie Bay. Later, as the volume of Mackenzie outflow diminished, the 1°/oo isohaline moved closer inshore. On 19-20 July and 4 and 11 August the effect of the flow of seawater along the Yukon coast was evident, particularly on 19-20 July and 4 August. On 4 July the halocline was obvious and very distinct at about 6 m owing to the effect of melting ice and of the water's being protected from wind disturbance. Haloclines observed on 25 July were at about 5 m and were less distinct than they had been earlier, owing to increased mixing near the surface.

In contrast with observations from other years, Slaney (1975) found that all salinities were less than 1°/oo on 21-22 July 1974 in East Mackenzie Bay and adjacent West Mackenzie Bay. Even at this late date there was a 4/10 concentration of first-year ice close inshore which supplied fresh melt-water and which tended to confine the Mackenzie River outflow. On 8 August 1974, Slaney (1975) found that the 2°/oo isohaline ran between Garry and Pelly Islands in a position similar to that seen on 25 July 1977 (Fig. 12d). However, on 2-4 August 1975 following a period of northeasterly winds, the 5°/oo isohaline lay between Garry and Pelly Islands and extended west-southwest into West Mackenzie Bay (McDonald and Martin 1976). This is significant because it reflects a vulnerability of this area, where there is a regular but small concentration of whales, to intrusions of arctic marine water. The vulnerability of this area to intrusions is apparently much greater than in either Niakunak or Kugmallit Bays into each of which approximately one-third of the flow of the Mackenzie River is discharged, compared to the 17 percent which is discharged into East Mackenzie Bay through Kumak Channel (Fig. 2).

Measurements of vertical stratification in 1974 by Slaney (1975) and in 1975 by McDonald and Martin (1976) were at approximately 3-5 m in nearshore areas. Healey (1971) measured

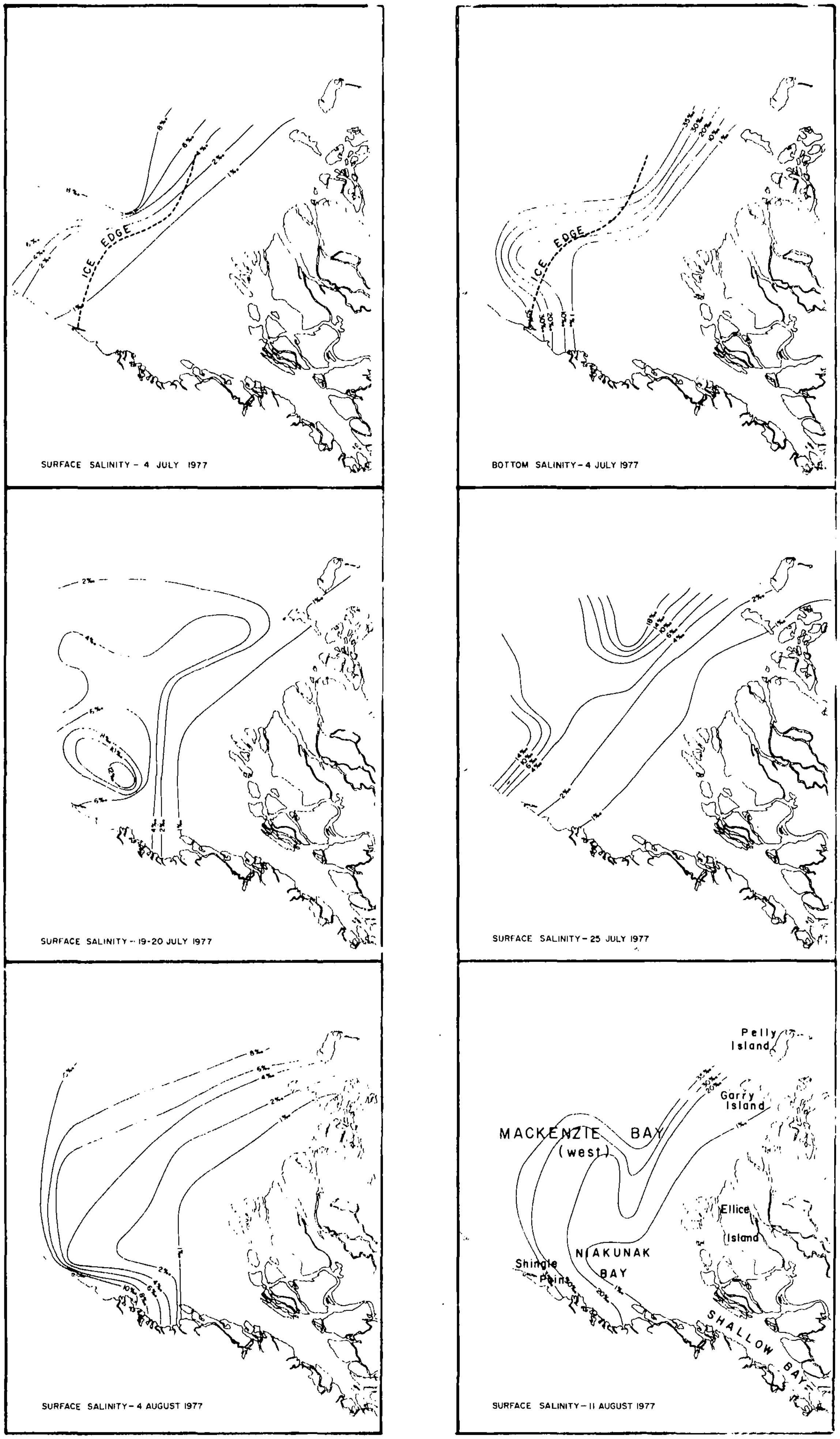

Fig. 12. Salinity distribution, Mackenzie estuary, 1977.

salinity seaward of the Barrier Island in July 1970 and found haloclines at 4-5 m.

As with temperature, the pattern of salinity variations observed in nearshore areas in 1977 appears comparable to those observed in other years. The discharge of Mackenzie River water to nearshore areas (<5m) maintains relatively constant conditions of low salinity in a lens of water 3-5 m thick during the peak of freshet. Although warmer water becomes generally more widespread during July, the area of freshest water (e.g.<1^{o}/oo) contracts as the ice disappears, the river flows decrease, and wind-advected salt water intrudes.

Turbidity

On 4 July, 1977, turbid water from the Mackenzie River was partially dammed by remnants of the landfast ice, and consequently, the highest turbidity values were found near the ice edge (Fig. 13a). Sharply lower turbidities were recorded under the melting ice. The overall pattern of bottom turbidity was similar to that seen at the surface, although the highest turbidities were observed just west of the Olivier Islands (Fig. 13b).

By 19-20 July 1977, turbidity throughout the study area had decreased considerably (Fig. 13c; Table 2). The highest value recorded was 70 ppm, only one-third of the highest value recorded on 4 July. Turbidity continued to decline, and on 25 July 1977 the highest value recorded was only 45 ppm (Fig. 13d; Table 2). The decrease in turbidity was associated with the usual seasonal reduction in the volume of the river discharge and the sediment loads which can be carried.

Prior to the survey on 4 August 1977, east-northeasterly winds increased the wave action and forced an increased amount of sediment into suspension in the shallower waters. Consequently, higher turbidity values were recorded at some inshore stations, although there was a rapid decrease offshore in water deeper than approximately 2 m. Subsequently, the turbidity decreased, and on 11 August 1977, the maximum values were only about one-half of those a week earlier (Fig. 13f; Table 2).

On 21-22 July 1974, Slaney (1975) measured turbidities of 150-160 ppm in the easternmost part of West Mackenzie Bay, which was about twice the turbidity observed on 19-20 July 1977 (Fig. 13c). Although a small portion of this turbidity resulted from wave action bringing bottom sediments into suspension, the Mackenzie River outflow at the time had turbidities of approximately 150 ppm. Abnormally high precipitation in the Mackenzie River watershed during 1974 resulted in higher-than-usual turbidity in August. Outer Middle Channel, which discharges into northeastern West Mackenzie Bay, showed turbidity values ranging between 400 and 600 ppm in August 1974. Thus, the maximum turbidities observed in 1974, were two to three times as great as those seen in 1977, and they occurred late in the season.

In contrast to 1974, the maximum turbidity which was measured in 1975 was 210 ppm (McDonald and Martin 1976), which is similar to the maximum value observed in 1977. Turbidity values offshore of Garry Islands were in the 50-100 ppm range on 2-4 August 1975. This is similar to the observations made on 4 August 1977.

There is greater year-to-year variation in turbidity in the Mackenzie estuary than in either salinity or temperature. As the river water is discharged from the channels and spreads over a broad area, it loses velocity and the heavier particles settle out. Thus Mackenzie River water tends to be less turbid with distance offshore, and this tendency is accentuated by any dilution with clearer marine water. The usual pattern is for the highest turbidities to occur in conjunction with the highest river flows. These usually come in late June or early July. However, at any time high winds can generate waves which force bottom sediments in shallow areas into suspension and increase local turbidity. Maximal values of about 200 ppm appear to be usual in the Mackenzie estuary, although values of up to 800 ppm can occur.

Wind and waves

During the 1977 study period, northerly and easterly winds predominated. Under such winds Shallow Bay was nearly always calm, while the eastern and shoreward portions of Niakunak and West Mackenzie Bays were moderately exposed causing a rippled sea surface sometimes with scattered whitecaps (Figs. 14, 15). East Mackenzie Bay was moderately sheltered from northwesterly winds by the Barrier Islands, although the western half was exposed when the wind shifted to northeasterly. In most of West Mackenzie Bay and the outer part of Niakunak Bay there were usually definite wave forms with occasional or numerous whitecaps. Under southeasterly winds, Shallow Bay was calm while all the nearshore parts of the study area were moderately sheltered (Fig. 16).

The maximum estimated wave height was 1.2 m which was observed in early August in both East and West Mackenzie Bays (Table 3). The maximum wave height observed in Niakunak Bay was 0.9 m. It should be pointed out that higher waves undoubtedly occurred during periods of stronger winds when aerial whale surveys could not be flown.

McDonald and Martin (1976) state that the prevailing winds in the study area are from the northerly quadrant. Under such conditions, Shallow Bay is sheltered while East Mackenzie Bay and the eastern parts of Niakunak and West Mackenzie Bay and the seaward part of Niakunak Bay is generally exposed.

WHITE WHALES

Patterns of abundance and distribution

Niakunak Bay: Reconnaissance surveys were flown on 18 and 24 June and a partial systematic survey was flown on 26 June (Table 4). No whales were seen until 30 June when there was an estimated 80 whales in the mouth of Shallow Bay at the east end of line N-B. The numbers

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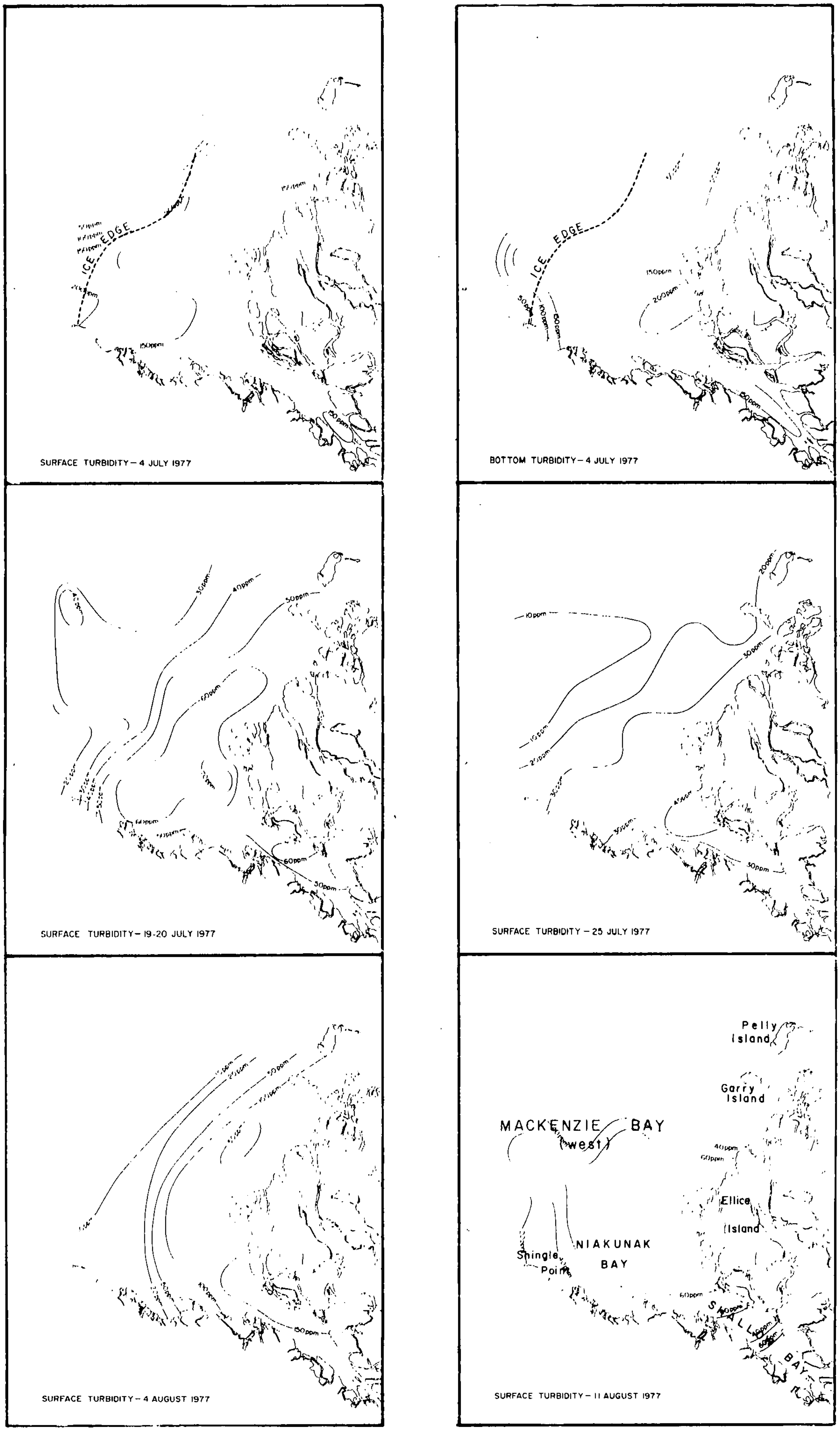

Fig. 13. Turbidity distribution, Mackenzie estuary, 1977.

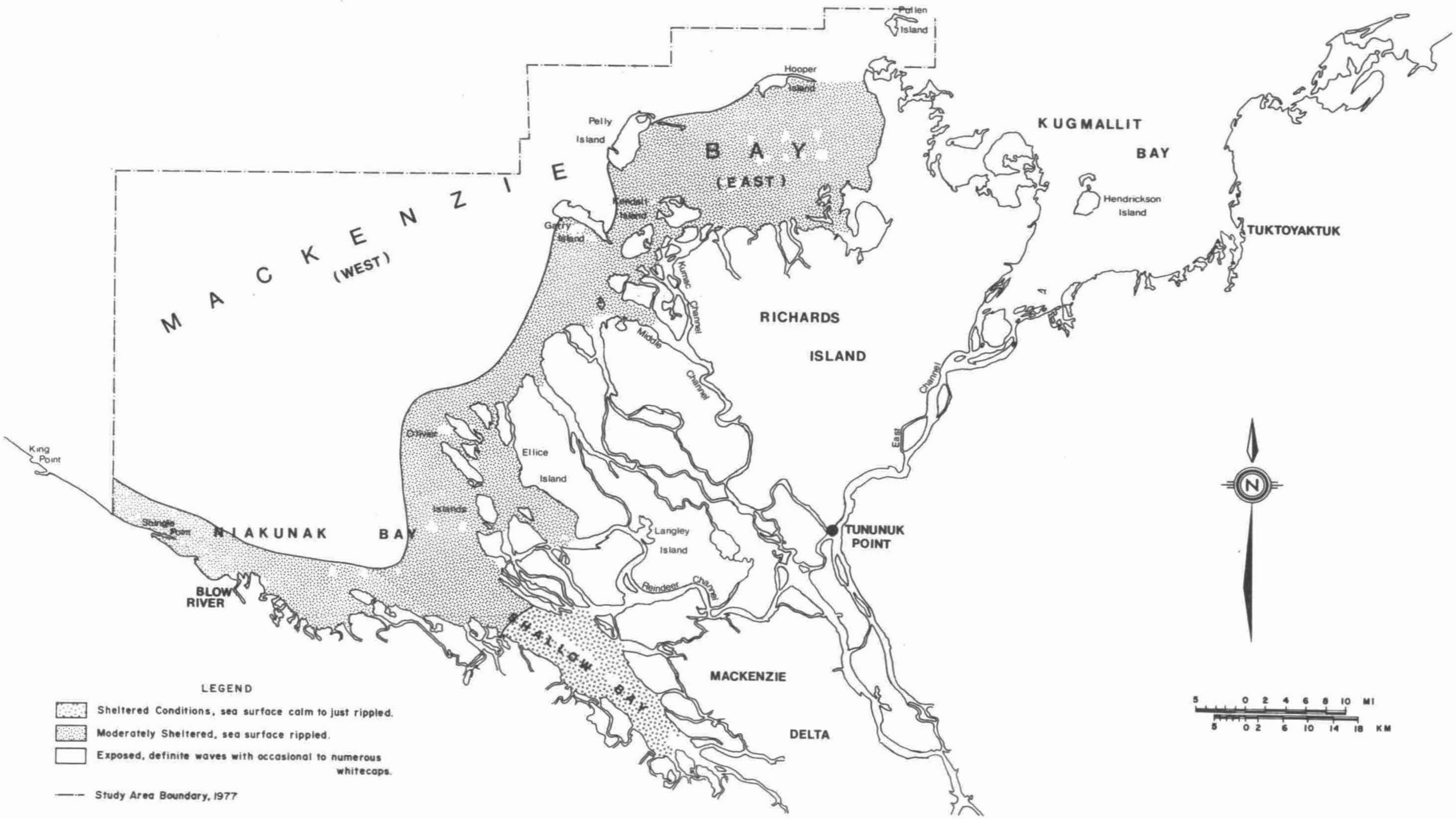

Fig. 14. Exposure ratings for the study area for winds from the northwestern quadrant.

Fig. 15. Exposure ratings for the study area for winds from the northeastern quadrant.

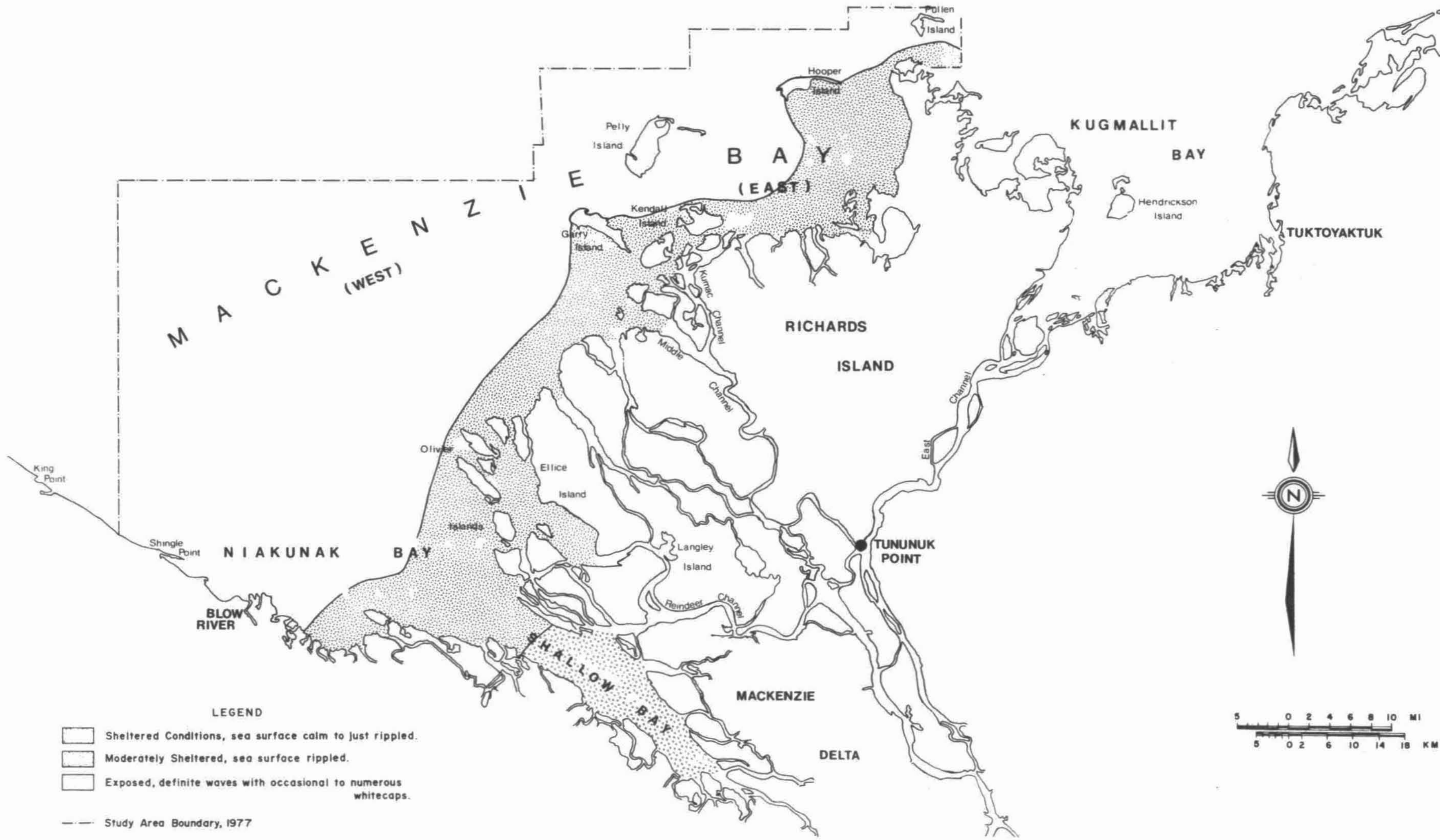

Fig. 16. Exposure ratings for the study area for winds from the southeastern quadrant.

Table 4. Summary of systematic whale surveys and population estimates; Niakunak, West Mackenzie, and East Mackenzie Bays: 1977.

Date	Location	Lines Flown	Whales Observed[a]	Visibility Rating	Extrapolation Coefficient	Visibility Factor	Estimated Numbers
26 June	Niakunak Bay	NC-N6	0	Good	2	2	0
30 June	Niakunak Bay	NC-N7	20	Good	2	2	80
3 July	Niakunak Bay	NC-N12	500[b]	Excellent	-	-	500
5 July	West Mackenzie Bay	WM1-WM8	64	Good/Excellent	3	2	384
5 July	East Mackenzie Bay	EM1-EM11	164	Fair	2	2	656
6 July	Niakunak Bay	NC-N12	329/206[c]	Excellent	2/3[c]	2	2752[d]
6 July	West Mackenzie Bay	WM1-WM8	102[c]	Good	3	2	612[d]
6 July	East Mackenzie Bay	EM1-EM3	137	Good	2	2	548
8 July	Niakunak Bay	NC-N12	1910	Excellent	2/3	1	3820[e]
8 July	East Mackenzie Bay	EM1-EM11	23	Good/Fair	2	2	92
9 July	Niakunak Bay	NC-N6	149	Fair	2/3	2	596
10 July	Niakunak Bay	NC-N12	649	Poor	2/3	2	2676
12 July	Niakunak Bay	NC-N12	503	Good/Fair	2/3	2	2084
13 July	West Mackenzie Bay	WM1-WM8	73	Good	3	2	438
13 July	East Mackenzie Bay	EM1-Em11	9	Good/Fair	2	2	36
18 July	Niakunak Bay	NC-N4, N5-N12[f]	599	Good	2/3	2	2424
19 July	West Mackenzie Bay	WM1-WM8	268	Good	3	2	1608
19 July	Niakunak Bay	NC-N12	294	Good	2/3	2	1190
20 July	East Mackenzie Bay	EM1-EM11	67	Fair/Poor	2	2	268
21 July	Niakunak Bay	NC-N12	1031	Good	2/3	2	2612
24 July	West Mackenzie Bay	WM1-WM8	376	Excellent	3	2	2256
25 July	Niakunak Bay	NC-N12	522	Excellent	2/3	2	2116
27 July	Niakunak Bay	NC-N12	445	Good/Fair	2/3	2	1814
27 July	East Mackenzie Bay	EM1-EM11	125	Good	2	2	500
28 July	West Mackenzie Bay	WM1-WM8	123	Good	3	2	738
29 July	Niakunak Bay	NC-N12	797	Excellent/Good	2/3	2	3348
30 July	East Mackenzie Bay	EM1-EM11	117	Fair	2	2	468
31 July	West Mackenzie Bay	WM1-WM8	388	Excellent	3	2	2328
1 August	Niakunak Bay	NC-N12	246	Good	2/3	2	984
2 August	East Mackenzie Bay	EM1-EM11	55	Fair/Poor	2	2	220
4 August	Niakunak Bay	NC-N12	153	Good/Fair	2/3	2	650
6 August	West Mackenzie Bay	WM1-WM8	29	Fair/Poor	3	2	174
7 August	Niakunak Bay	NC-N12	7	Good/Fair	2/3	2	36
9 August	Niakunak Bay	NC-N8	66	Good	2/3	2	264
11 August	Niakunak Bay	NC-N12	4	Good	2/3	2	16
11 August	West Mackenzie Bay	WM1-WM8	0	Good	3	2	0

a Figures adjusted for observer bias.
b Visual estimate made prior to the disturbance of whales by native hunting activities.
c Lines NC-N9 had an extrapolation coefficient of 2, lines N10-N12 had an extrapolation coefficient of 3.
d On 6 July a portion of the Niakunak whale concentration extended on to line WM1, and the whales counted on this line have been added to the estimate for Niakunak Bay.
e On 8 July practically all of the whales appeared to be at the surface, therefore a visibility factor of 1 was used (see text).
f Partially incomplete.

increased rapidly in the next 10 days, peaking at an estimated 3820 on 8 July (Table 4; Fig. 17a, c). The number remained high, usually over 2,000 until late July, after which they declined dramatically; only an estimated 16 whales were present on 11 August.

The pattern of an early peaking of numbers, followed by a moderate decline and relative stability to the end of July may be typical. On 3 July 1972, there was a maximum estimate of 1500-2000 whales based on reconnaissance surveys by Slaney (1973), and Slaney (1974) reported that the number of whales in Niakunak Bay peaked on 2 July 1973. The pattern of change in abundance seen in 1975 indicated a peak in the latter part of July (Fig. 19), but this result may have been the consequence of greater variability owing to less intensive survey coverage. Fraker (1977a) observed what may have been maximum numbers on 12 July 1976 (Fig. 19), although the 1976 study of Niakunak Bay did not extend beyond this date.

Some of the changes in the number of whales in Niakunak Bay in July 1977 clearly resulted from the movement of whales to West Mackenzie Bay, probably to East Mackenzie Bay, and possibly to Kugmallit Bay. For example, the survey on 19 July indicated an abrupt decline in numbers in Niakunak Bay at the same time that there was an increase in West Mackenzie Bay (Fig. 17). Fig. 19b shows a large number of whales in West Mackenzie Bay, and the movement of many whales away from Niakunak Bay strongly suggests that they had come from there. In contrast, the increase in the number of whales in Niakunak Bay on 29 July was apparently associated with a simultaneous decline in West Mackenzie Bay observed on 28 July (Table 4; Fig. 17). A similar pattern of movement has been reported for this area in previous years (Fraker 1976; Slaney 1973; 1974, 1975).

A dramatic decline in numbers occurred during early August, and by 11 August very few whales were present in Niakunak Bay (Table 4; Fig. 17). The decline in 1975 followed the same pattern (Fraker 1976), and similar declines in abundance have been reported at this time in other years (Slaney 1973, 1974, 1975). Although the number of whales using Niakunak Bay after mid-August is very low, there are several recorded sightings from nearby areas indicating that a few whales may continue to use the bay into the latter half of September (Fraker et al. 1977).

The whale distribution seen in 1977 was largely within the concentration area boundaries drawn by Fraker (1977a) on the basis of five years' data (Fig. 1). However, the 1977 whale distribution apparently differed from those of previous years in two respects: first, in early July the whales tended to occupy an area further northeast in the concentration area than is usual (Fig. 18a, b), and second, the whales failed to make use of the southeastern part of Niakunak Bay below line N-3 (Fig. 18c, d).

On 30 June and 3 July the relatively small number of whales present were at the mouth of Shallow Bay near the eastern ends of lines N-B and N-C. This changed rapidly on the evening of 3 July when three parties of hunters pursued the whales. For approximately the next week the whales occupied the northeastern portion of Niakunak Bay (Fig. 18a, b). Local hunters confirmed that this was an unusual distribution (J. Archie, pers. comm.). Possibly the whales were seeking particular environmental conditions; after having been chased from the first place they had occupied, they may have selected an alternate location with conditions similar to those of the first area.

Although the whales made use of a larger area of Niakunak Bay after 8 July (Fig. 18c, d), with the exception of a single animal, we saw no whales southeast of line N-3. This was in contrast to other years. One possible explanation for this is that persistent hunting activities in 1977 may have kept the whales from approaching closer to Shallow Bay. Relatively poor weather during 1977 resulted in the hunting effort being protracted more-or-less evenly over a long period. In 1976 and 1975 most of the hunting effort tended to be concentrated into a few relatively short periods; for example, 11 whales or one-third of the 1976 harvest was taken on one evening (Fraker 1977a). Further evidence of the possible effect of hunting on distribution was seen in 1975 when hunting practically stopped by 20 July and the whales penetrated into Shallow Bay south of Reindeer Channel (Fraker 1976). Hunting in 1977 continued into the first week of August. Thus it may be that in the absence of respites from hunting pressure, the whales did not move as far southeast during the summer.

East and West Mackenzie Bays: Whales probably entered East and West Mackenzie Bays a few days before they were observed in Niakunak Bay (30 June), but poor weather prevented surveys of these areas before 5 July. On this date there were 384 whales estimated to be in West Mackenzie Bay (Table 4; Fig. 20a).

Numbers remained relatively low in West Mackenzie Bay until after mid-month when they increased substantially (Fig. 17). High numbers were recorded until 31 July followed by a rapid decline in early August. The results of previous studies (Fraker 1976; Slaney 1974, 1975) suggest that this pattern of change in abundance is typical.

In East Mackenzie Bay, 656 whales were estimated on a complete survey on 5 July, and 548 were estimated on a survey of lines EMI-EM3 on 6 July (Table 4; Fig. 21a). Very poor weather hampered surveys of this area throughout the study period, but the numbers in the area were undoubtedly very low through mid-month. The numbers then increased moderately in the third week of July. A survey under fair-to-poor conditions on 4 August revealed the presence of an estimated 220 whales. Presumably numbers declined afterwards.

Present information suggests that East Mackenzie Bay is not usually occupied continuously by many whales until later than in Niakunak or Kugmallit Bays. For example, Slaney (1975) did not report seeing substantial numbers of whales in this area until the last week of July in 1974. This was a severe ice year in which the movement of whales to the estuary was

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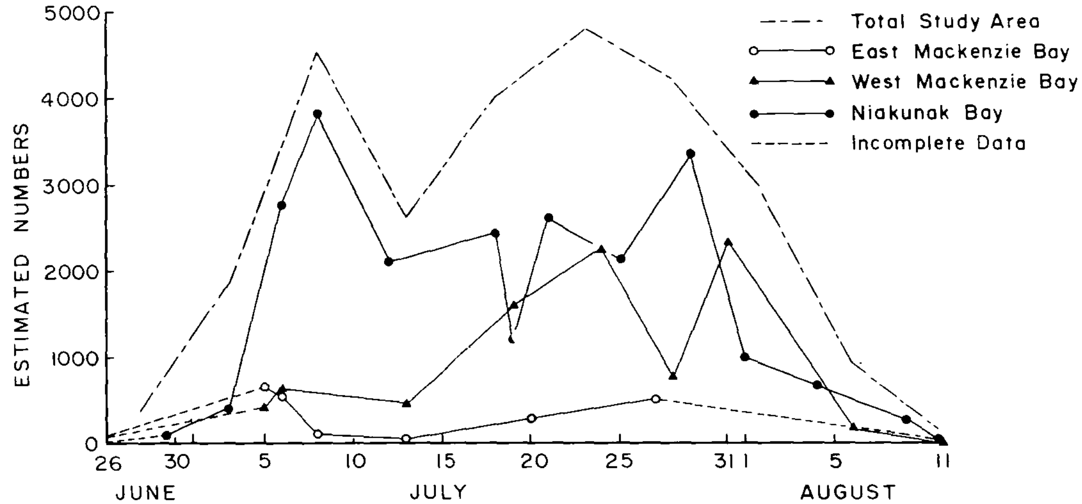


Fig. 17. Seasonal changes in the abundance of whales in the study area, 1977. (Total study area curve extrapolated from the curves for individual areas.)

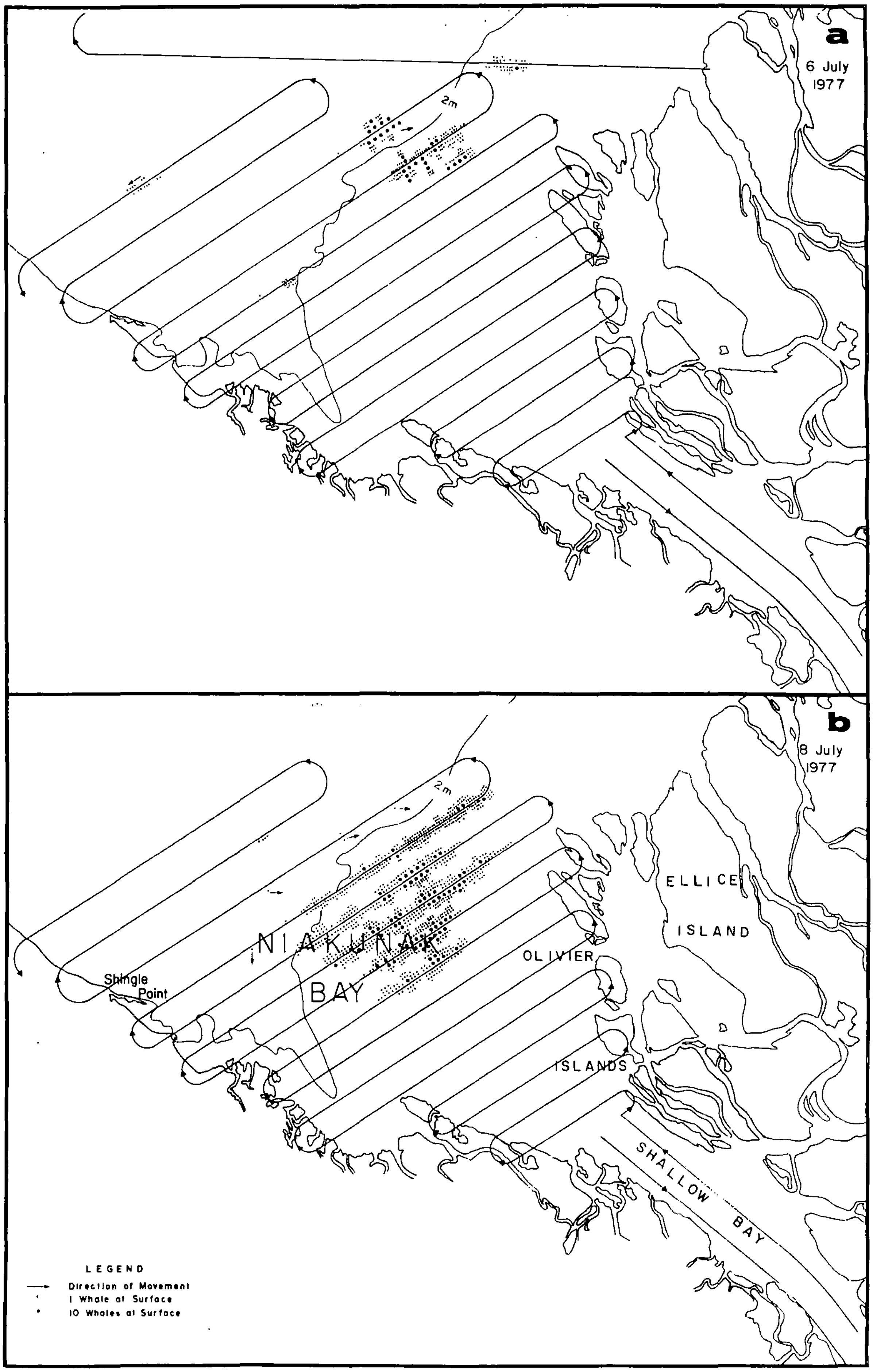
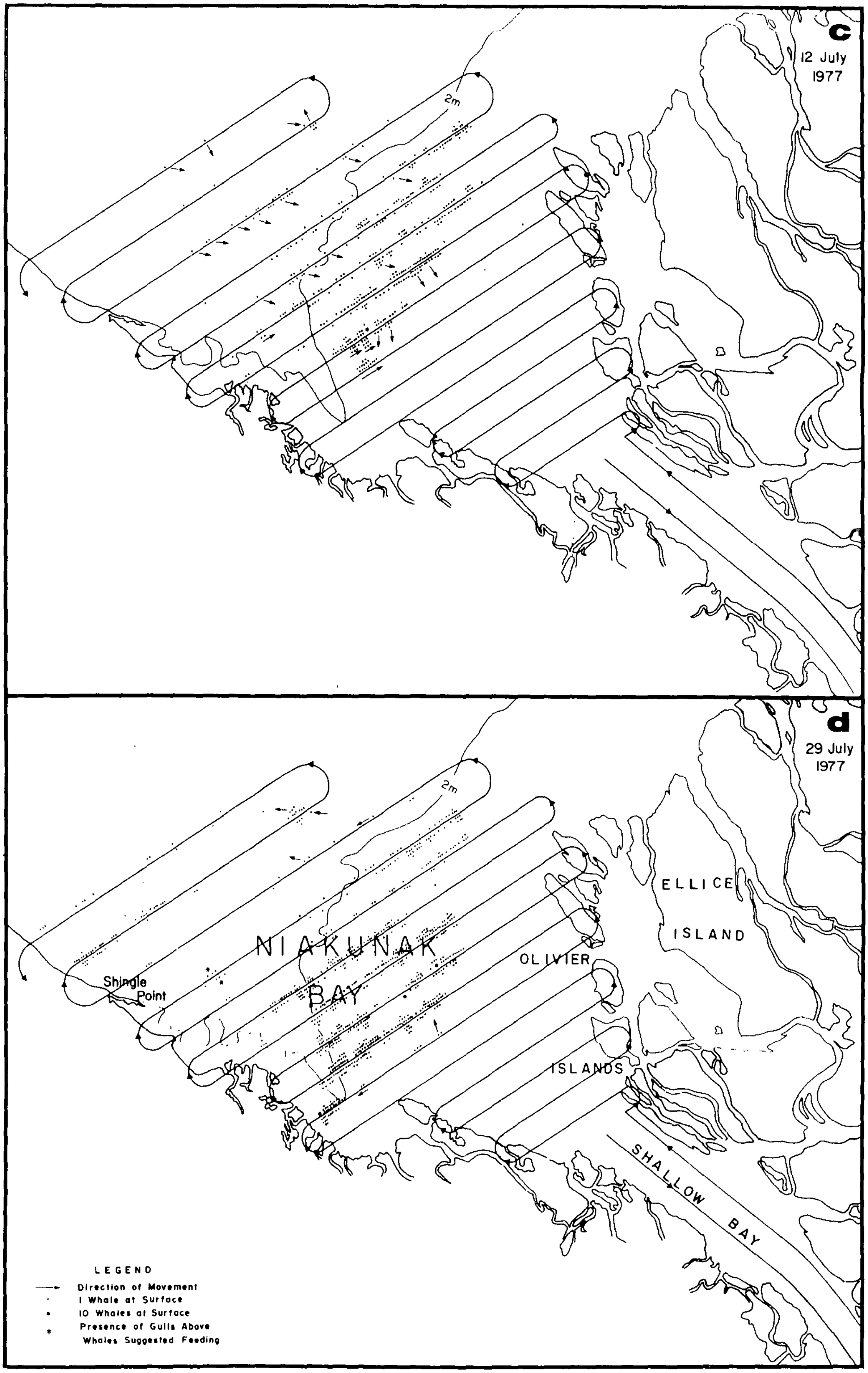


Fig. 18. Distribution and relative abundance of whales in Niakunak Bay: 6, 8, 12 and 29 July 1977.



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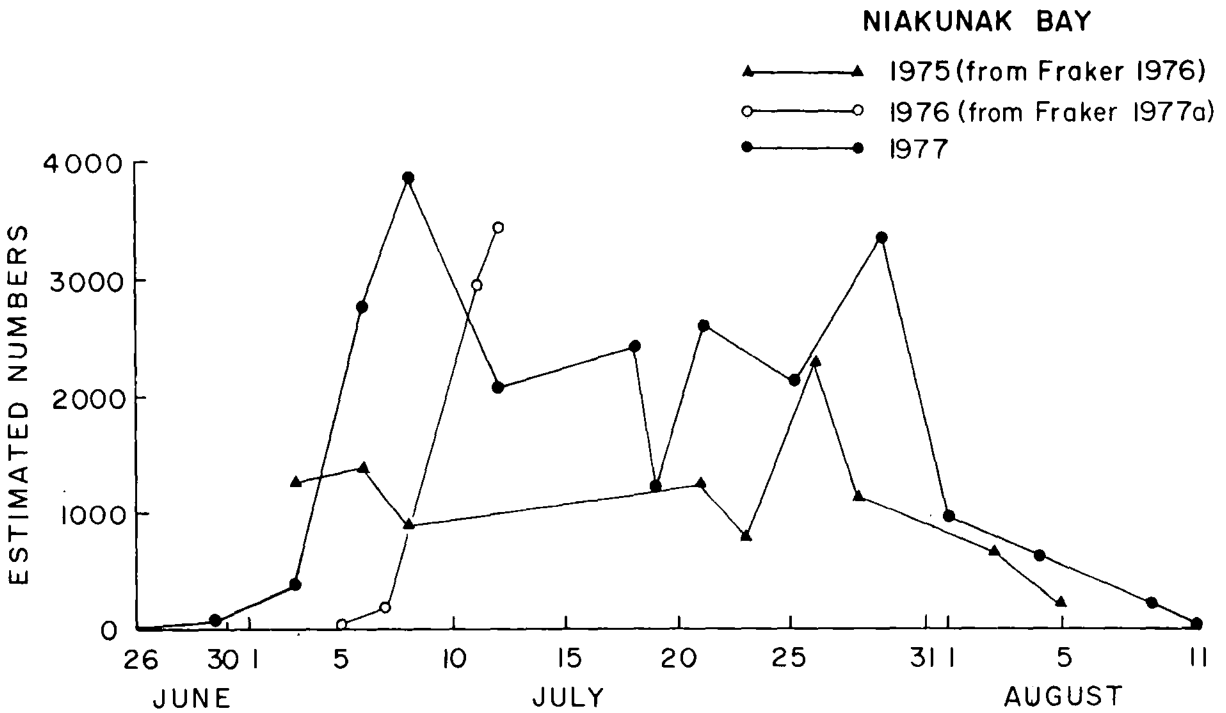

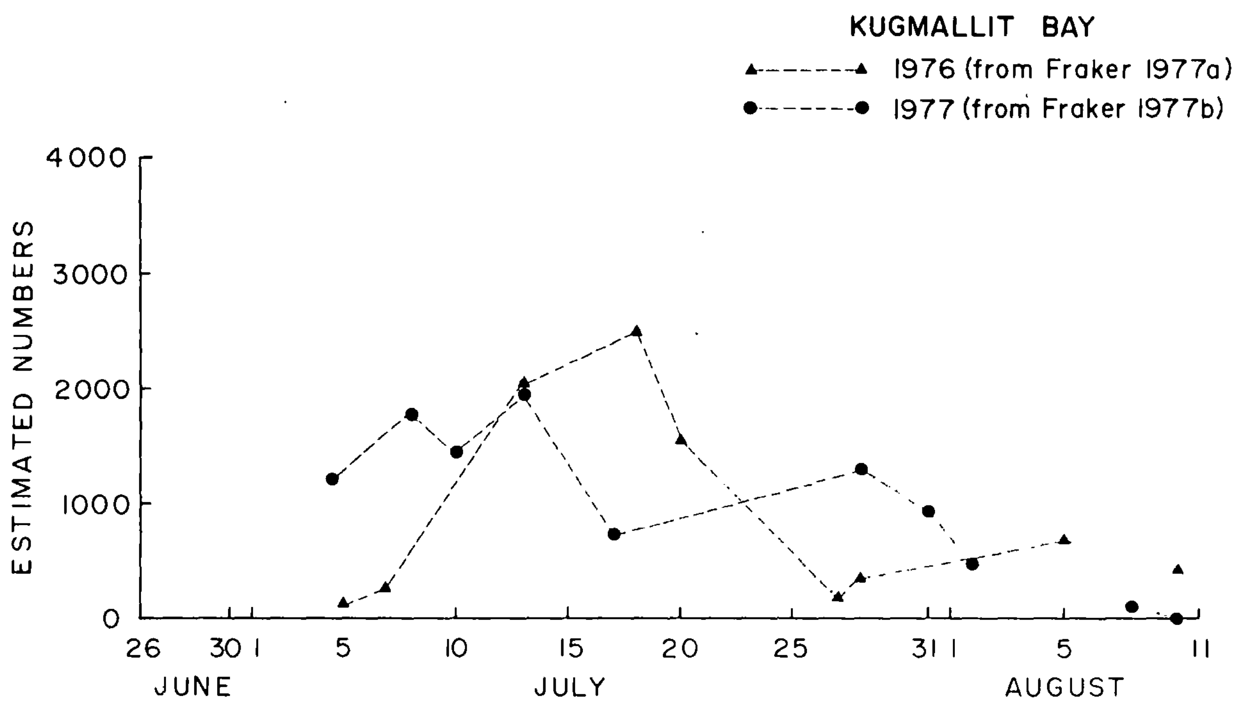

Fig. 19. Seasonal changes in abundance of white whales in Niakunak and Kugmallit Bays, 1975-1977.

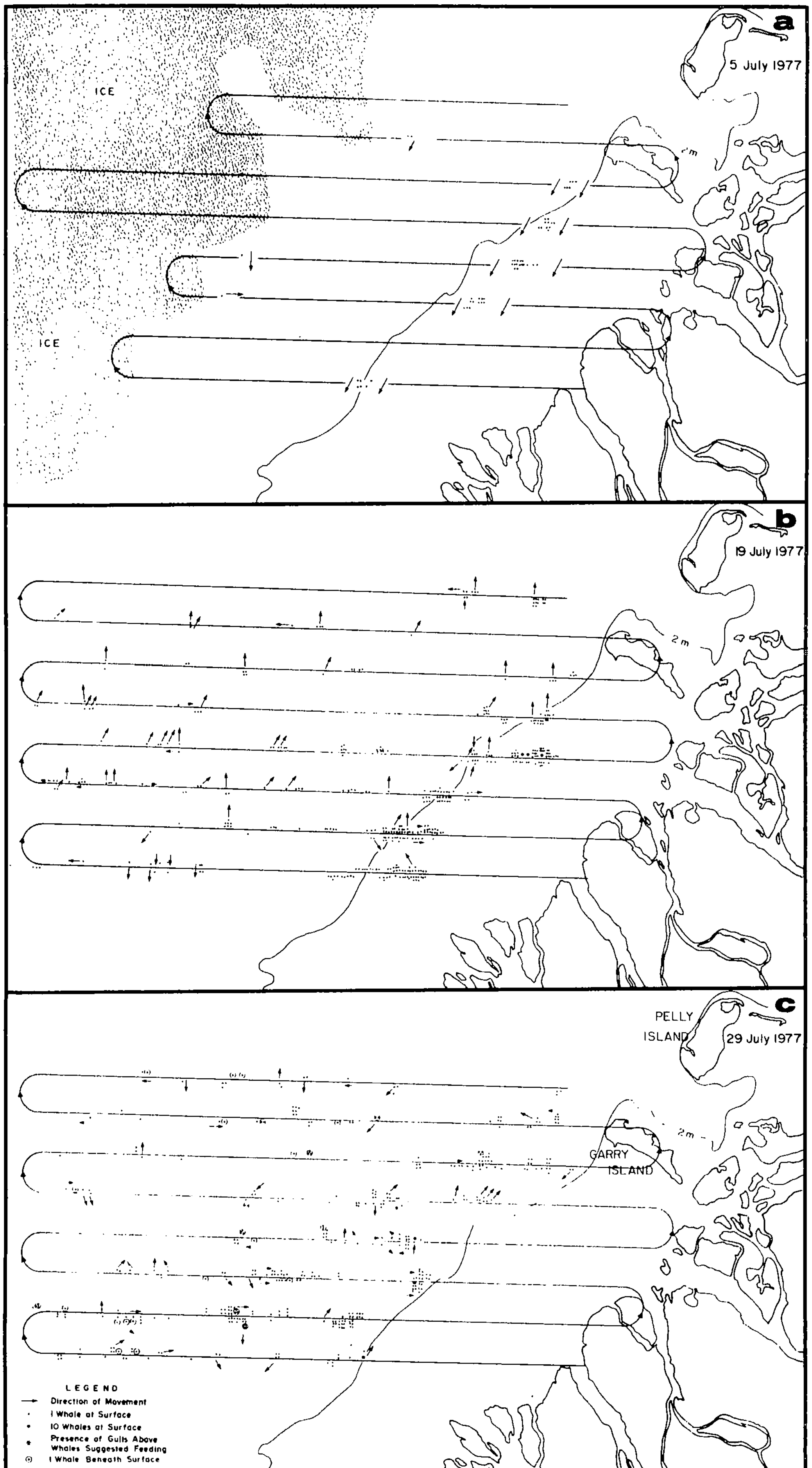

Fig. 20. Distribution and relative abundance of whales in West Mackenzie Bay: 5, 19 and 24 July 1977.

delayed. Thus the relatively large number of whales seen on 5 and 6 July may have been transients, possibly en route to Niakunak Bay. After 6 July northerly winds were prevalent in this region, and it may have been that cold oceanic water intruded into East Mackenzie Bay making conditions less favourable for the whales. Also, the early decline in numbers in East Mackenzie Bay followed the initiation of both hunting from Kendall Island and a brief (5-day) small-scale Imperial Oil operation at the northwest end of Garry Island. While hunting and/or the industrial operations may have had some effect, neither activity seemed to be extensive enough to adequately explain the decline, in abundance. Therefore the movement of the whales was probably normal (Fraker 1977b), possibly a response to an intrusion of cold, marine water.

After an apparent decline in abundance in the study area after 8 July, there was an increase and maintenance of relatively high numbers in East and West Mackenzie Bays during the latter half of the month (Fig. 17). At approximately the same time there was a decline in numbers in Kugmallit Bay (Fraker 1977b), and thus it may be that there was a movement of some whales from Kugmallit Bay to other parts of the estuary. There is nearly always movement of some whales along the east coast of Richards Island, some to and some from East Mackenzie Bay, also with some possibly moving to areas north of the surveyed area. Because many whales were seen out to the periphery of the surveyed area in West Mackenzie Bay (Fig. 20b, c), clearly an unknown, but possibly substantial number of whales were using the region beyond. Thus the suggestion that there was an influx of whales from Kugmallit Bay to West Mackenzie Bay is strengthened since the high estimates, which were maintained more-or-less consistently over several surveys, were based on observations of less than the entire area used by the whales.

In West Mackenzie Bay, the first observed whales (5 July) were travelling toward Niakunak Bay in a narrow band along the east side of the Bay (Fig. 20a). Although the whales spread out to use more of this area later in the month, there was a tendency for the highest densities to be in the eastern portion (Fig. 20b, c). Many of the whales in the northern and western portions were diving and possibly feeding (see section on Feeding).

As observed in previous studies (Fig. 1), the whales in East Mackenzie Bay tended to be most dense in the Kendall-Garry-Pelly Island area (Fig. 16a, c). The area near Pullen Island was also heavily used by whales, most travelling, some probably feeding.

The 1977 study concentrated more attention on East and West Mackenzie Bays than had previous studies, and consequently more details of whale distribution and abundance are now available. In past years large numbers of whales occupied parts of these two areas intermittently, especially in the latter half of July (Fig. 20b, c, 21b).

In southeastern West Mackenzie Bay, the densities and behavior of the whales were similar at times to those seen in concentration areas such as Niakunak Bay (Fig. 20b). The high densities of stationary animals were all within the 2 m isobath. Some of the whales in this area also appear to be travelling, some toward Niakunak or East Mackenzie Bay, and some toward offshore parts of West Mackenzie Bay, where feeding may have been taking place.

The relatively few surveys which could be flown in East Mackenzie Bay revealed only modest numbers of whales compared to other parts of the study area and Kugmallit Bay (Figs. 17, 19). The concentrations which were observed were in the Kendall concentration area, as defined in Fig. 1. In the intermittent-use area of East Mackenzie Bay, a relatively high density of whales was seen only once (Fig. 21b). As noted previously (Fraker 1977a; Fraker et al. 1978), the region near Pullen Island was used heavily by whales which were travelling to and from East Mackenzie Bay.

Concentration areas

The concept of concentration areas is central to a discussion of white whale distribution and the possible governing factors. Fraker (1977a) defined a concentration area as "an area where relatively large numbers of whales congregate consistently during much of the summer (opern-water) season, year after year." In the following paragraphs we will discuss this concept further and expand on its definition.

However defined, an indication of the probable constancy of concentration areas is provided by the long-term presence of Inuit whaling camps. While minor changes in location have occurred, camps have been in the same general area for a long period of time. For example, whaling camps have been present near the mouth of East Channel for at least 500 years (McGhee 1974). Stefansson (1913) found the Inuit whaling at Niakunak in 1907, and Fraker's (1977a) informant told of hunting in the same area since near the beginning of the 20th century. Hunting has also taken place near Kendall Island for many years (McEwen 1955).

Geographical extent: At any given time, a concentration of whales does not occupy the entire concentration area as shown in Fig. 1. Instead, a smaller area is used as, for example, in Niakunak Bay on 8 July (Fig. 18b). It is easy to place a geographical boundary when the concentration is sharply defined, but when the whales are more spread out, the perimeter of the concentration is more difficult to decide on. Clearly high density (the number of whales per unit area) is implicit in the word concentration, but because of inherent limitations in the technique of surveying whales in turbid water under various weather conditions and the possible flux of animals within the study area, absolute density cannot be used.

Absolute density could vary for several reasons. Early and late in the season there are fewer whales in the concentration areas, as there is a general movement to or from the estuary. Occasionally a large proportion of

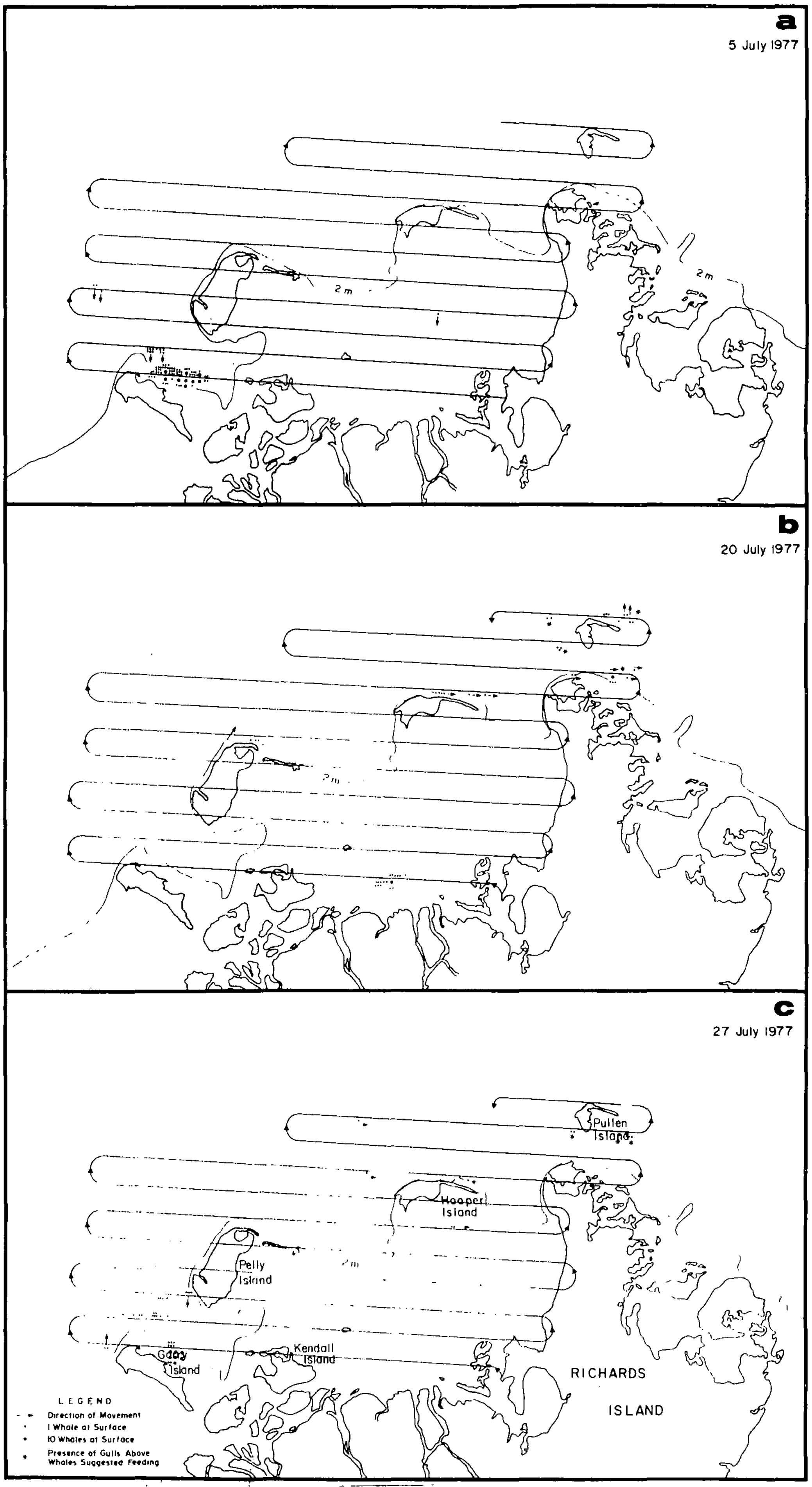

Fig. 21. Distribution and relative abundance of whales in East Mackenzie Bay: 5, 20 and 27 July 1977.

the whales may leave one concentration area to utilize an intermittent-use area or another concentration area (Fraker 1977a, see below). In addition, the whales may at times spread out over a much larger area (Figs. 18, 20), possibly as the parameter(s) they may be seeking becomes more generally available. Apparent density, based on the observations during aerial surveys, can vary according to the prevailing visibility conditions and the behavior of the whales.

Thus, while the density of whales must be taken into account in defining a concentration on any given day, the factors affecting apparent density, ie. the density which is actually seen during aerial surveys, defy objective, quantitative analysis under the conditions prevailing in the Mackenzie estuary.

Behavior: Whales in the concentration areas were frequently observed in small groups of 3-20 individuals (Fig. 22). Often the whales in such groups were practically motionless, and any activity took place at a slow pace. The animals were most often oriented in a variety of directions, but sometimes they were all oriented in the same direction. Rarely, the whales formed a rosette with their heads all directed toward the centre of the group. We have termed this behavior gamming, which is an old whalers' term defined by Webster's New Collegiate Dictionary (1973) as ". . . a visit or friendly conversation . . . ." A group of gamming whales we have termed a gam.

Gams are comprised of different size categories (probably representing different ages and both sexes) including calves. When the animals are active, movement is at a slow pace and diving and surfacing tend to be synchronous or nearly so. Gams were observed most commonly under practically calm water conditions, but they were also seen under rougher sea conditions. The apparent decrease in the number of gams observed under rougher sea conditions may have been a function of poorer observation conditions, or possibly the whales may have more difficulty remaining close to one another. In rougher seas, most individuals within a gam were oriented into the wind.

The association of small numbers of whales into groups appears to be a form of social behavior which has not previously been described for white whales. Gams were seen only in the concentrations, and we believe that this indicates that the concentration areas may serve a social function. However, not all whales in a concentration form gams, at least not at any one time. Even on calm days, many whales can be seen swimming alone or in pairs near gams. Whether these individuals do not form gams, or whether gamming is a short-lived phenomenon in the activity cycle of white whales is not known.

Because the whales in gams often are apparently resting at the surface or moving slowly and more-or-less synchronously, it seems probable that they are communicating with each other. This possibility is reinforced by the fact that they sometimes form a rosette with their heads forming the center. Gams may represent a social unit similar to the small pods of other gregarious odontocetes such as killer and pilot whales.

We suspect that gamming is a significant aspect of the whales' life history in the estuary, and future studies should place emphasis on determining the details of this phenomenon.

Duration of stay: An area where whales congregate briefly in large numbers probably differs in significance from an area where whales (usually associated in concentrations) regularly gather. Figure 19 shows that large numbers of whales, mostly in concentrations, occupied Niakunak Bay during July in 1975 and 1977. The limited data available suggest that the concentration area defined for the Kendall-Garry-Pelly Islands area of East Mackenzie Bay is not occupied until later, and is not used for as long a period as similar areas in Kugmallit and Niakunak Bays (Fig. 17, 19: Fraker 1976, 1977a; Slaney 1973, 1974a, 1975).

Occasionally, some of the whales in West Mackenzie Bay associated in concentrations (Figs. 20b, c). These were seen during surveys conducted in the latter half of July (19, 24, 31 July); no concentrations were observed on 5, 13, or 28 July. The concentrations in East and West Mackenzie Bays were similar to those in Niakunak and Kugmallit Bays in every apparent way, except that they were not continuously present during the summer. Previous whale research in the study area has not been sufficiently intensive to firmly resolve the question as to whether or not the pattern observed in 1977 is typical, but tentatively it appears the concentration areas defined in East and West Mackenzie Bays may be used less intensively than those in Niakunak and Kugmallit Bays.

Redefinition of concentration area: At this point the following refinement of the definition of concentration area is offered:

CONCENTRATION AREA: An area where relatively large numbers of whales congregate. Concentration areas are used for an extended period during the summer; in the case of the Mackenzie estuary, concentrations may occur for approximately one month, mainly in July. Whales in concentrations appear to be more-or-less stationary. Gamming behavior may be characteristic of concentration areas.

Location of concentration areas: Figure 23 shows the perimeters of the Niakunak and Kendall-Garry-Pelly concentration areas as defined by superimposing the extent of the whale concentrations during each survey conducted in 1977. As seen by examining Fig. 1, with the exception of the northeastern portion, the 1977 Niakunak concentration area falls within the boundary drawn on the basis of five years' data by Fraker (1977a). Thus, the composite perimeter has been expanded slightly to encompass the 1977 information (Fig. 24). As mentioned in the discussion of Niakunak Bay, the whales did not occupy the southeastern portion of that bay in 1977, possibly as a result of disturbance from hunting activities.

There is a greater difference between the Kendall-Garry-Pelly concentration area, as defined on the basis of 1977 data, and the area as previously defined (Fig. 1). This may owe to the fewer data available from this area and/or more variability in the actual area used in any given year.

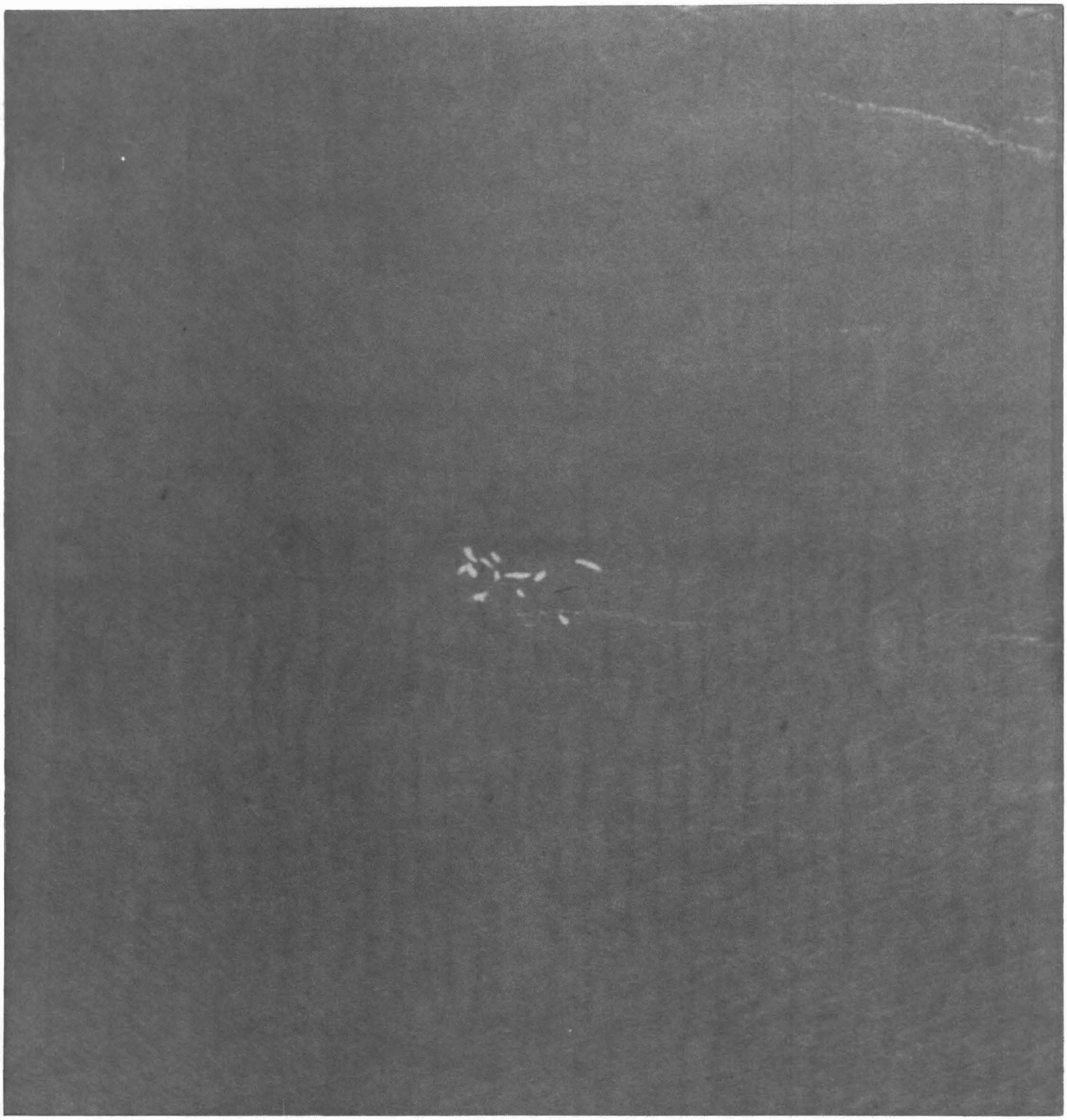

Fig. 22. Photograph of a gam of white whales in Niakunak Bay, July 1973. Gams were observed only in whale concentrations and imply a social significance to the whales' us of the estuary.

Fig. 23. White whale high-use areas, 1977.

Intermittent-use area

Noting that large numbers of whales sometimes occupy parts of East and West Mackenzie Bays, Fraker(1977a) defined these as intermittent-use areas (Fig. 1). Large concentrations of whales apparently do not persist in such areas for more than a few days at a time, and in some years only low numbers may be seen at all in some parts.

Although a few whales were present in the intermittent-use area of West Mackenzie Bay on all surveys during 1977 (Fig. 20a), substantial numbers were not observed in the general region until 19 July when 1608 were estimated. Most of the animals were in the parts of the bay classified as an intermittent-use area (Fig. 20b, c). More than 2000 whales were estimated on 28 July (Fig. 17). Because whales were observed out to the perimeter of the surveyed area, the boundary of the intermittent-use area has been extended (Fig. 24). The actual area used by the whales includes a larger but as yet undefined region.

Except for 20 July, when approximately 100 whales were seen about 6 km east of Kendall Island (Fig. 21b), only very small numbers were present in East Mackenzie Bay outside of the concentration area. However, generally poor weather limited the number of surveys which could be flown in this area, and the paucity of sightings of large numbers of whales may be a reflection of the relatively poor conditions prevailing during the few surveys which were possible.

As discussed below, part of the intermittent-use area may serve as a feeding ground. Also the eastern part of West Mackenzie Bay may function partially as a broadly defined travel route used by whales moving between Niakunak Bay the Garry Island area (Fig. 20b). Similarly, most of the whales observed in East Mackenzie Bay (outside of the concentration area and the previously defined travel route) appeared to be travelling (Fig. 21b, c), although the density of use was not great enough to classify the area as a travel route.

That the intermittent-use areas may be a general phenomenon is indicated by Hay and McClung (1976) who observed periodic use of Barrow Strait by white whales which were concentrated in Cunningham Inlet, Somerset Island. They hypothesized that such behavior was related to feeding.

Travel routes

Most of the whales observed in travel routes appear to be moving from one place to another, although other activities, particularly feeding, have also been observed in such areas (Fraker 1977a, b). The areas which best fit the definition of travel routes are in Kugmallit Bay and along the Tuktoyatuk Peninsula (Fig. 1); geographical constraints probably force the whales to use narrowly defined areas in these regions. Except for the vicinity near Pullen Island, the geography of the study area appears to allow for movement to take place through broadly defined portions of the intermittent-use areas.

Feeding

In many instances in 1977, particularly after mid-July, whales were seen engaged in what was probably feeding. Two types of behavior suggested feeding:

1. Whales diving while gulls (mostly Glaucous Gulls, *Larus hyperboreas*) were present nearby, possibly to take advantage of scraps of food.

2. Whales in the intermittent-use area in West Mackenzie Bay diving deeply, usually in the absence of gulls.

The former behavior was seen most often near points of land around which migrating fish might be concentrated (Fig. 25). Whales which were probably feeding were also seen near the mouth of the Blow River; a whale taken from this location in 1976 contained six fresh loche or burbot (*Lota lota*) (Fraker 1977a).

Anadromous fish make considerable use of coastal regions as they move between the Mackenzie River system and various parts of the Beaufort Sea. In particular, large numbers of arctic and least cisco (*Coregonus autumnalis* and *C. sardinella*, respectively), broad and humpback whitefish (*Coregonus nasus* and *C. clupaeformis*, respectively), burbot, and inconnu (*Stenodus leuchichthys nelma*) move along the coast of the Tuktoyaktuk Peninsula in late summer and fall (Slaney 1977; Poulin 1977): these same species plus arctic char (*Salvelinus alpinus*) are also found in the waters off the Yukon coast. (Kendel et al. 1974). Migrating anadromous fish plus some marine species are found near Pullen Island (Percy 1975; Poulin 1975). Thus, if the whales are feeding in specific areas along coastlines (Fig. 25), it is most probably associated with migrating anadromous fish.

Deeply diving whales, sometimes attended by gulls, were seen in West Mackenzie Bay in the latter part of July 1977 (Fig. 20c). For example, on 24 July about 20 percent of 227 whales observed were diving in the area outside the 3 m isobath; most were in water deeper than 5 m (Fig. 25). It is possible that these whales were seeking some factor, such as cooler water, but is seems more likely that the deep diving represents feeding behavior.

The possible use of offshore areas of West Mackenzie Bay for feeding is in striking contrast to observations in Kugmallit Bay where the large numbers of whales present are never seen spread out or diving deeply (Fraker 1977a, b). The biological productivity of both West Mackenzie and Kugmallit Bays is low (Grainger 1975; Wacasey 1975), but published fisheries data are lacking for the offshore portions of these regions. Grainger (1975) and Wacasey (1975) observed increased productivity in offshore regions which were under less influence from the turbid Mackenzie River outflow. The influence of the Mackenzie decreases as one proceeds north and west in West Mackenzie Bay, and thus it may be that the diving whales are in a zone of relatively high productivity.

If whales are feeding in these areas, how can it be reconciled with the observation that very few stomachs of harvested animals contained anything more than a few squid beaks (Fraker 1976, 1977a, b; Slaney 1974, 1975)? A possible explanation is that food may be digested very

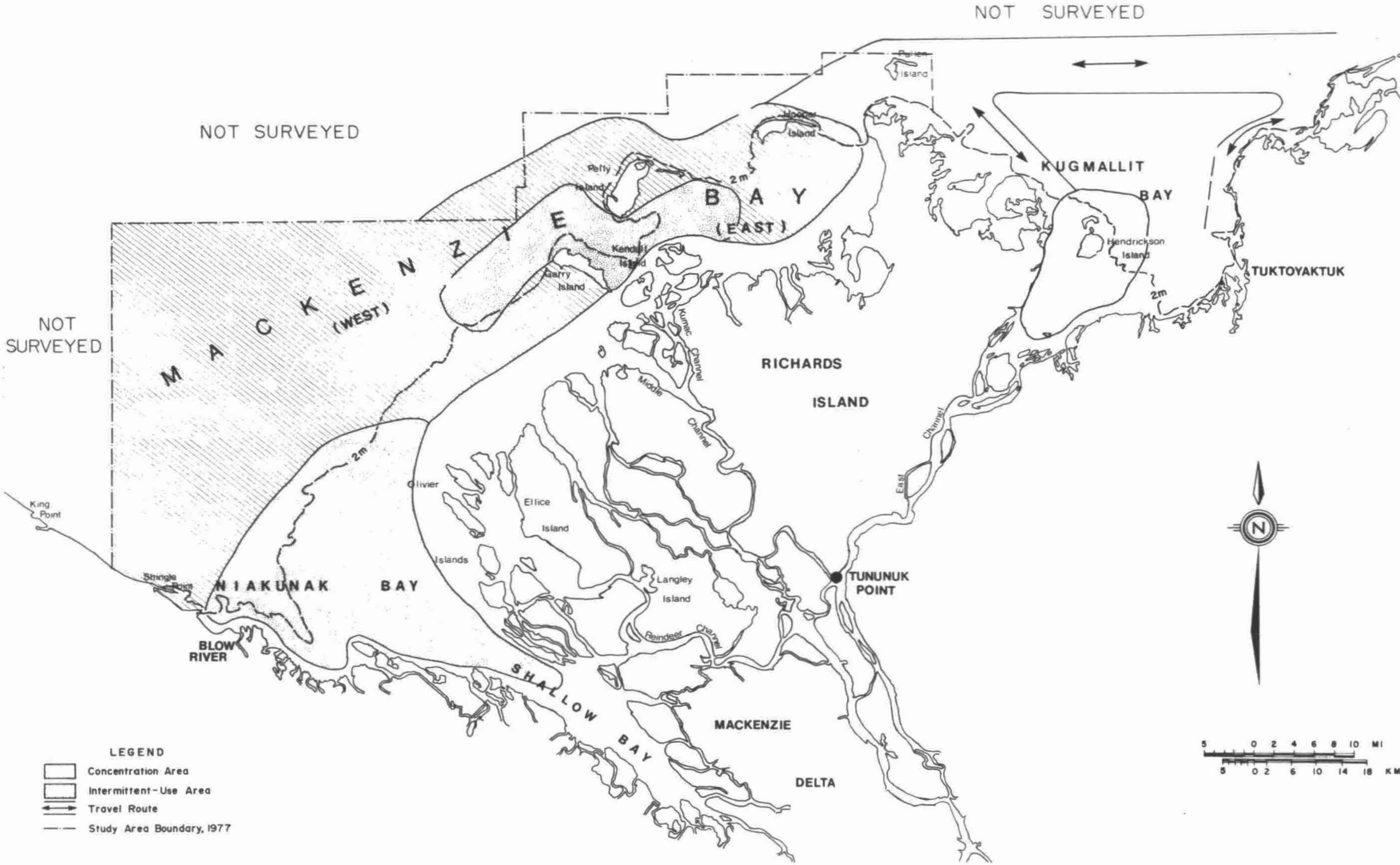

Fig. 24. White whale high-use areas, based on data collected from 1972 to 1977.

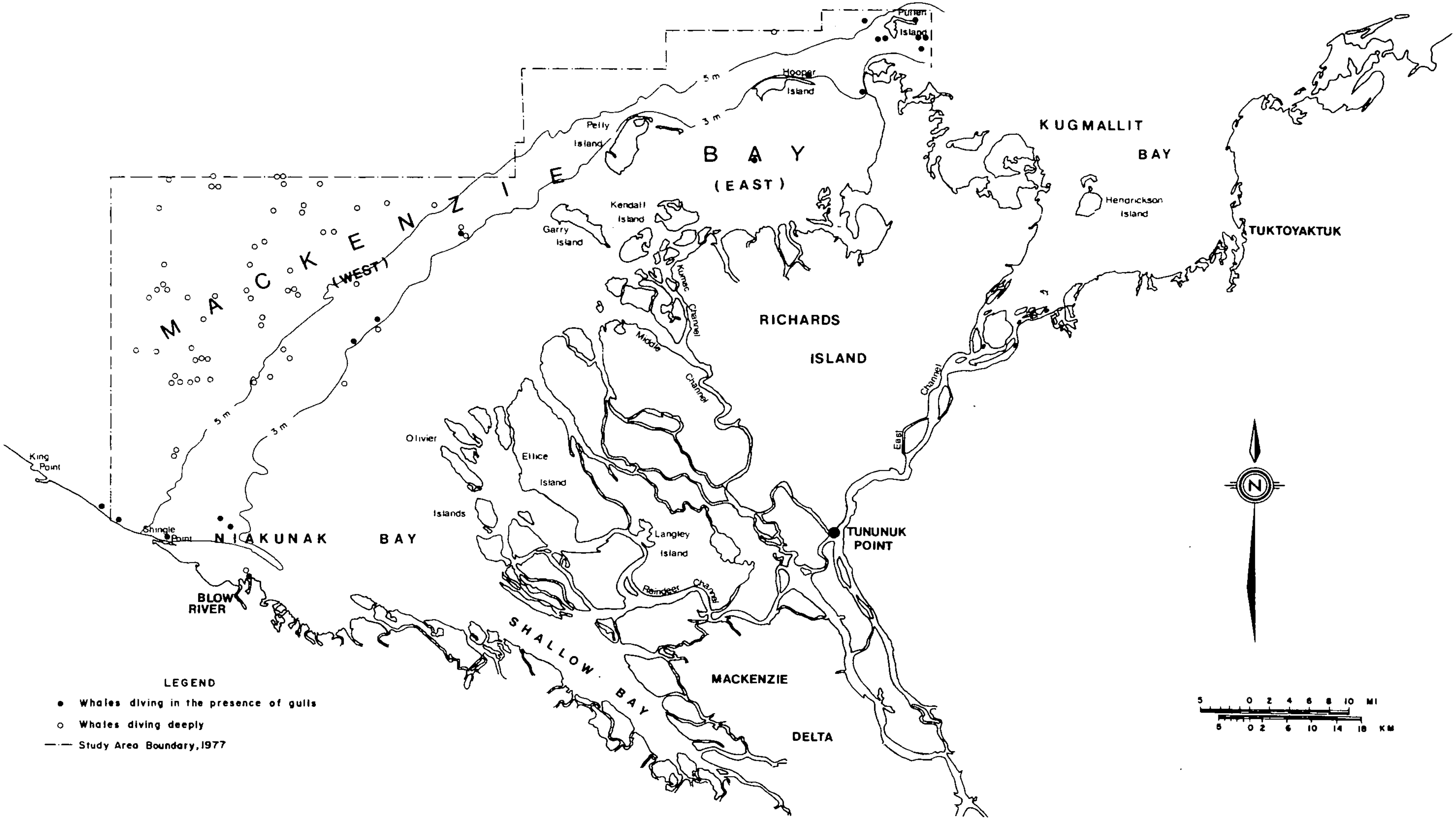

Fig. 25. Location of probable feeding activities.

quickly, so that by the time the animals have returned to the concentration areas where they are hunted, the stomachs are empty. Seals are known to pass food through their systems in as little as two hours (Dr. T.G. Smith, pers. comm.), and whales which consume a similar diet may also digest food rapidly.

WHALE DISTRIBUTION IN RELATION TO OCEANOGRAPHIC FACTORS - RESULTS

Early July 1977

The first oceanographic survey (4 July 1977) was conducted just as large numbers of whales were first appearing in the estuary. On 3 July an estimated 500 whales were concentrated at the mouth of Shallow Bay (Fig. 27a). On 5 July, an estimated 384 whales were observed in the eastern part of West Mackenzie Bay; all were travelling toward Niakunak Bay.

If we assume that the oceanographic conditions on 3 and 5 July were similar to those seen on 4 July, which is reasonable because of the light winds during this period, the relationship of whale distribution to oceanographic factors can be examined.

Nearly all of the whales were in water of less than 2 m (Fig. 27a). The whales in Shallow Bay were in an area where mudflats extend away from shore for a considerable distance and the water is often 1 m or less in depth. Even after hunting began on 3 July and the distribution shifted further north (Fig. 18a, b), the whales were still in water less than 2 m deep.

The whale concentration on 3 July was inside the 10°C isotherm near the mouth of Shallow Bay. Because radiant heating from the sun can warm the shallow waters considerably, the area occupied by the whales may have been closer to 11°C, as it was at oceanographic station 6 (Table 1). Similarly, the whale concentrations observed on 6 and 8 July (Fig. 18a, b) were also in water which was at least 10°C and probably warmer.

In early July, all of the whales were in water which was 1°/oo or less in salinity (Fig. 27c). The turbidity in the whale concentration areas was between about 100 and 150 ppm (Fig. 27d). A very large part of the study area showed salinity and turbidity levels similar to those seen where the whales concentrated.

In summary, the whales showed an apparent tendency in early July to occupy some of the warmest parts of the study area. Although there were other areas with similar temperature, the area which was first used by the whales was very near Reindeer Channel which carries about one-third of the total Mackenzie River discharge. After hunting began, the whale concentration moved north but still remained in a region of warm water.

19-20 July 1977

On 19-20 July there were high densities of whales in Niakunak Bay and also in eastern West Mackenzie Bay (Fig. 28). Large numbers of whales, many apparently feeding, were spread out in the northern and western parts of West Mackenzie Bay.

The highest densitites were in water which was about 2 m deep (Fig. 28). However because of decreased river flows and generally offshore winds, the actual depths during this time may have been somewhat less than those indicated.

The whale concentrations in Niakunak and West Mackenzie Bays were in water which was about 13°-15°C (Fig. 28b). The high densities of whales were found over a much larger area than they had been earlier, and they extended to include not only part of Niakunak Bay but also shallow areas of eastern West Mackenzie Bay. The general warming of the estuary was striking in comparison with conditions observed two weeks earlier (Fig. 27); and it is possible that the wider distribution of whales was related to the warmer temperatures.

Salinity in the areas occupied by whale concentrations ranged from about 1°/oo to possibly as high as 12°/oo (Fig. 28c). The area of 1% salinity and less was much reduced from that seen on 4 July. Turbidity in the concentration areas was between 40 and 70 ppm, which was about one-half of the values observed two weeks earlier. There was little apparent relationship between whale distribution and salinity or turbidity.

In summary, relatively high densities of whales were found in waters of approximately 2 m on 19-20 July. The whale concentrations were spread out over a much larger area than had been seen earlier, concomittant with a general warming of the water in the estuary. The whales were found in waters ranging from 13°-15°C, which was a minimum of 2° warmer than was observed in areas occupied by the whales two weeks earlier. Marine water intruded into Niakunak Bay with the result that salinities up to 12°/oo were found in the area of whale concentration. Turbidity, on the other hand, was lower than that seen earlier, ranging from 40 to 70 ppm.

25 July 1977

The whale concentration in Niakunak Bay was again mainly in water of less than 2 m, while nearly all of the whales in West Mackenzie Bay were in water deeper than 2 m (Fig. 29a). There were relatively high densities present in water between 2 and 5 m deep, and in deeper water there was a large number of widely dispersed animals.

The concentration of whales in Niakunak Bay was in water of between 14°-16°C, and the relatively high density aggregations in eastern West Mackenzie Bay were in water of 12°-14°C (Fig. 29 b). Some whales near the perimeter of the study area were in water which was at least as cold as 6°C, and those whales which were diving would have encountered water of about -2°C. No whales were observed in water of 16°C or warmer.

The whales occupied areas with a wide range of salinities (Fig. 29c). In the high density areas of Niakunak Bay, salinity ranged from 1-2%, while high densities of whales in West Mackenzie Bay were found in water with up to 4°/oo. Some whales in the study area were in water up to 18°/oo.

Text continued on page 49.

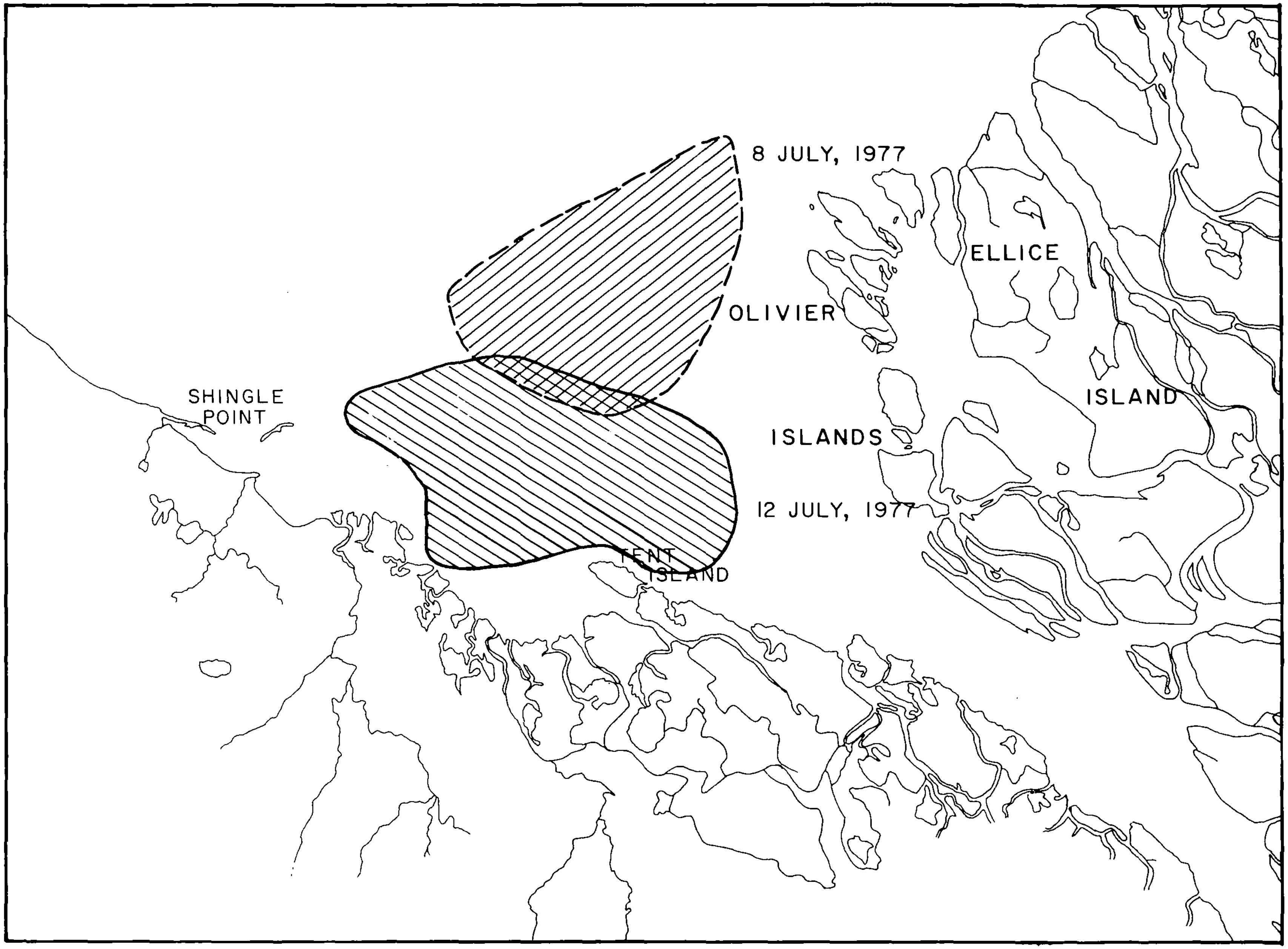

Fig. 26. Comparison of locations of early July whale concentrations in Niakunak Bay, 1976 and 1977.

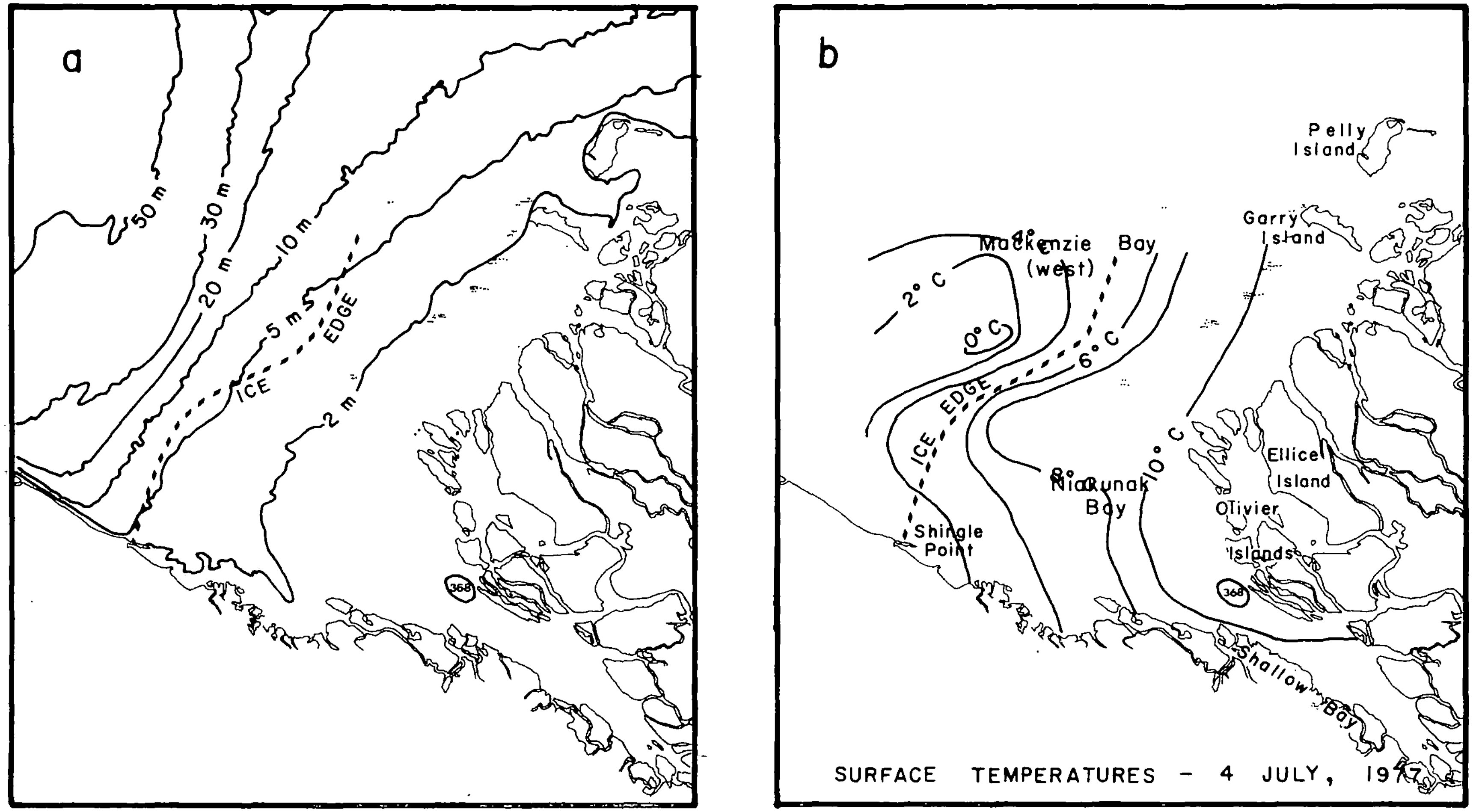

Fig. 27. Whale distribution in relation to oceanographic factors, 4 July 1977.
A. depth, B. temperature, C. salinity, D. turbidity.

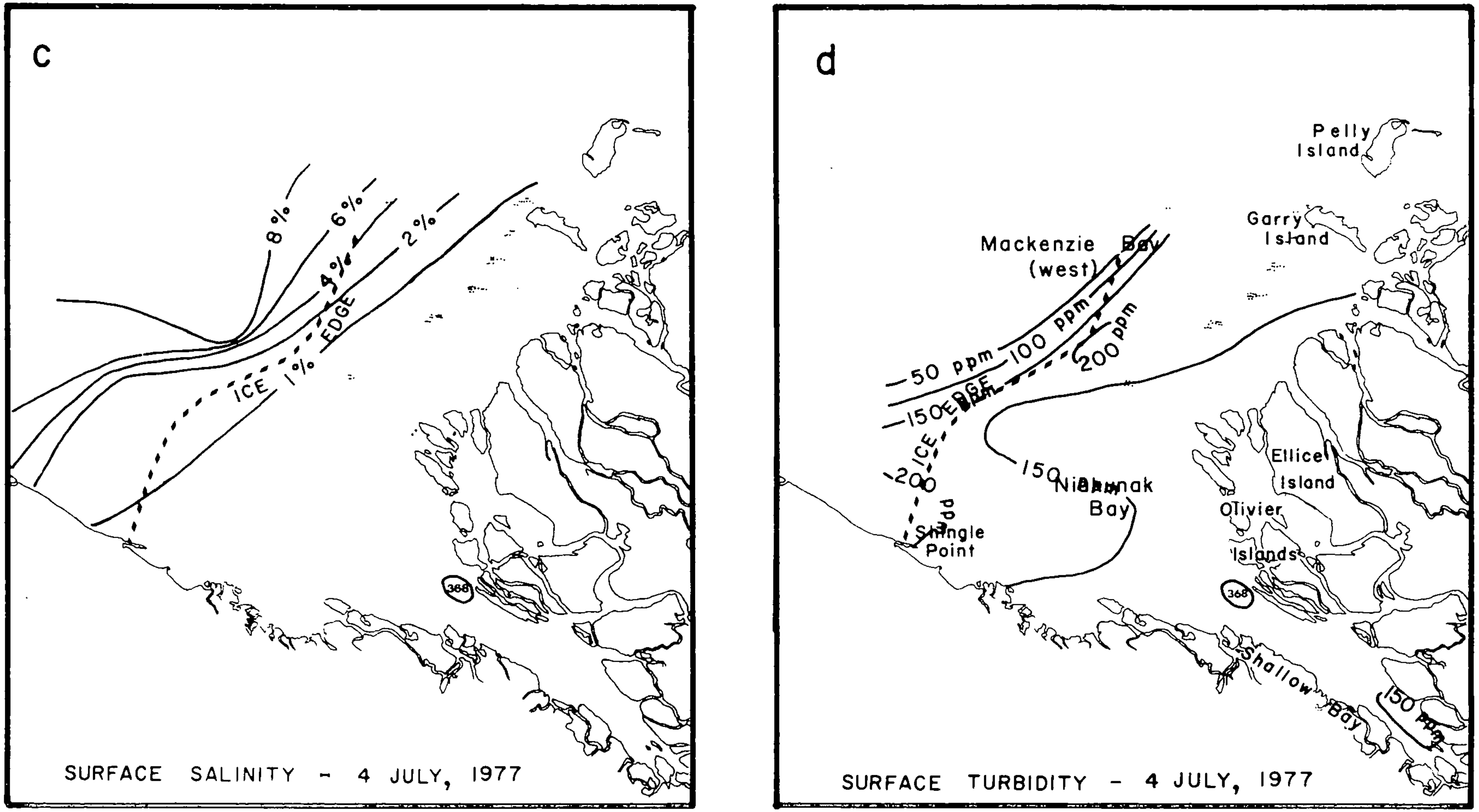
c
8‰
6‰
4‰
2‰
ICE EDGE
1‰
368
SURFACE SALINITY - 4 JULY, 1977
d
Pelly Island
Garry Island
Mackenzie Bay (west)
50 ppm
100 ppm
200 ppm
150
ICE EDGE
200 ppm
Shingle Point
Bay
Ellice Island
Olivier Islands
368
Shallow Bay
150 ppm
SURFACE TURBIDITY - 4 JULY, 1977

Fig. 27. cont'd.

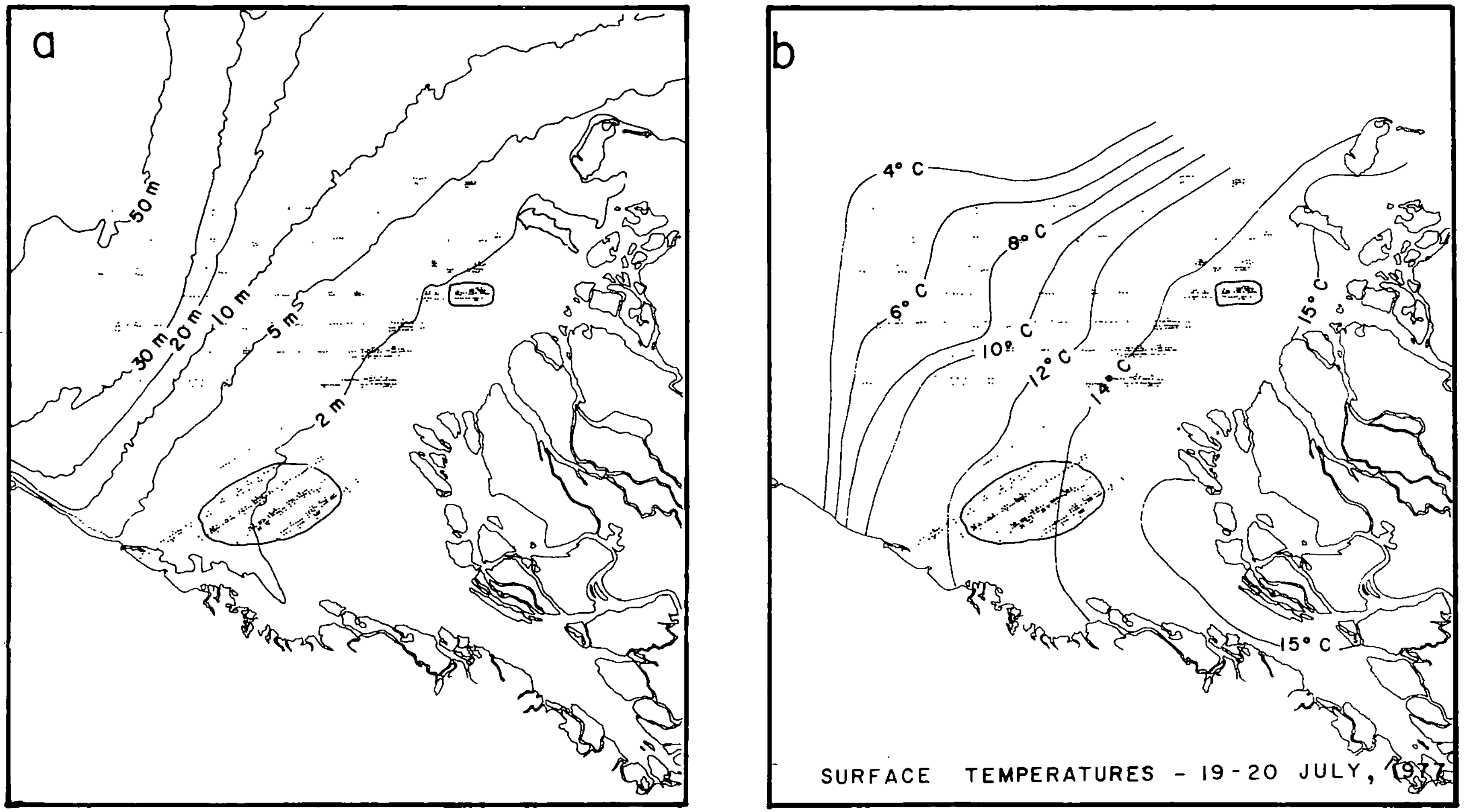

Fig. 28. Whale distribution in relation to oceanographic factors, 19-20 July 1977.
A. depth, B. temperature, C. salinity, D. turbidity.

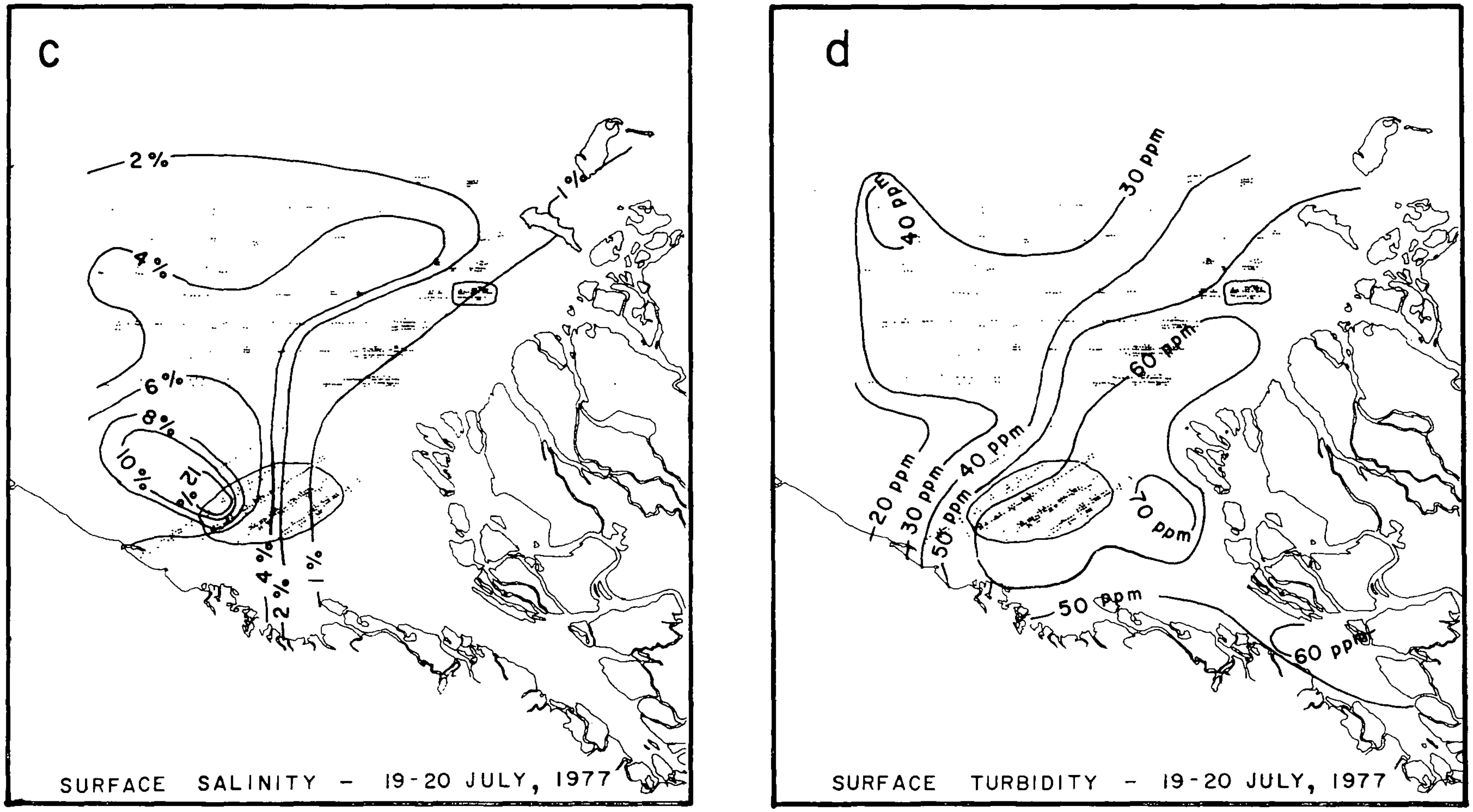
c
2%
4%
6%
8%
10%
12%
1%
4%
2%
1%
SURFACE SALINITY - 19-20 JULY, 1977
d
40 ppm
30 ppm
60 ppm
20 ppm
30 ppm
40 ppm
50 ppm
70 ppm
50 ppm
60 ppm
SURFACE TURBIDITY - 19-20 JULY, 1977

Fig. 28. cont'd.

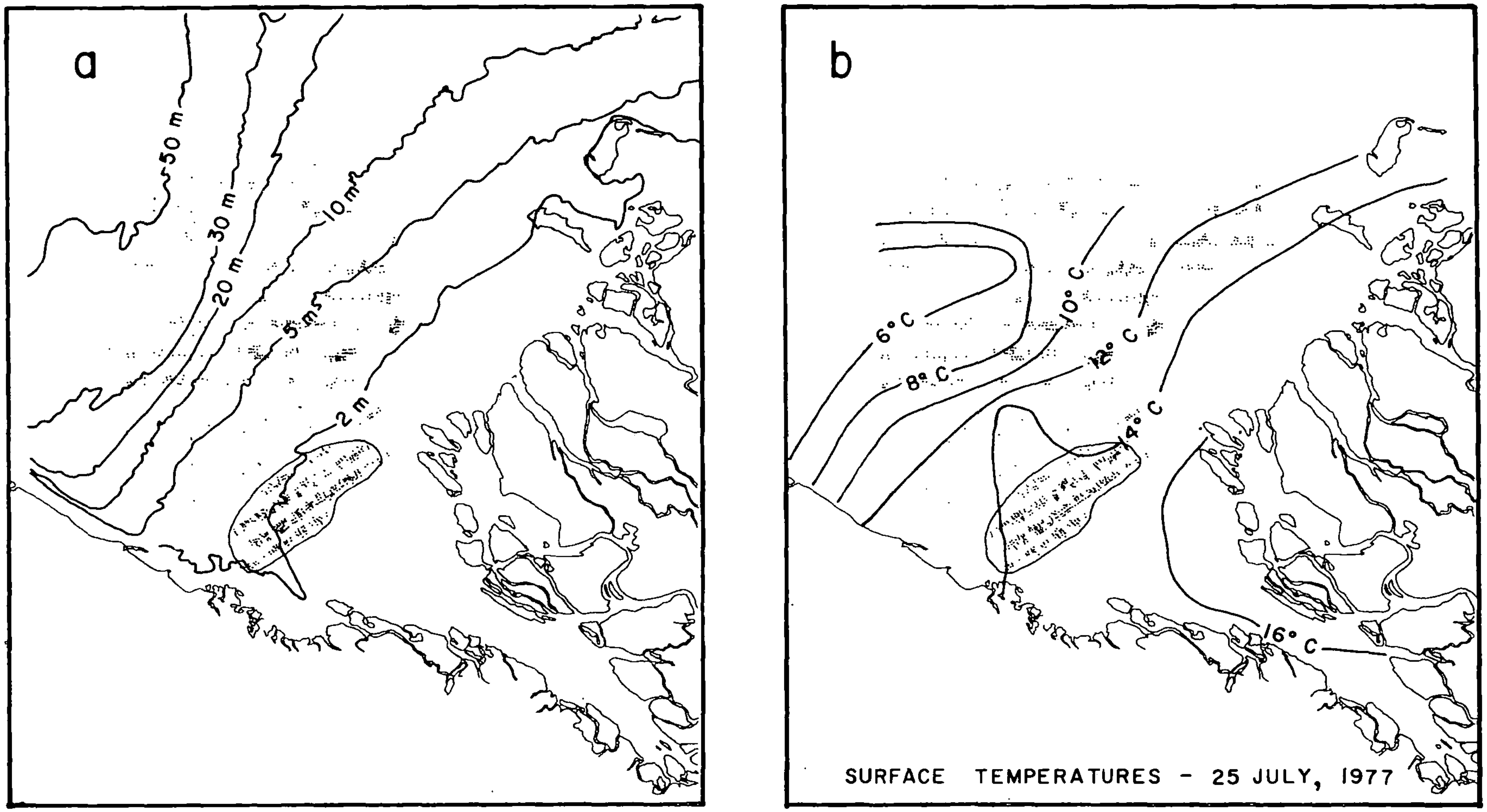

Fig. 29. Whale distribution in relation to oceanographic factors, 25 July, 1977.
A. depth, B. temperature, C. salinity, D. turbidity.

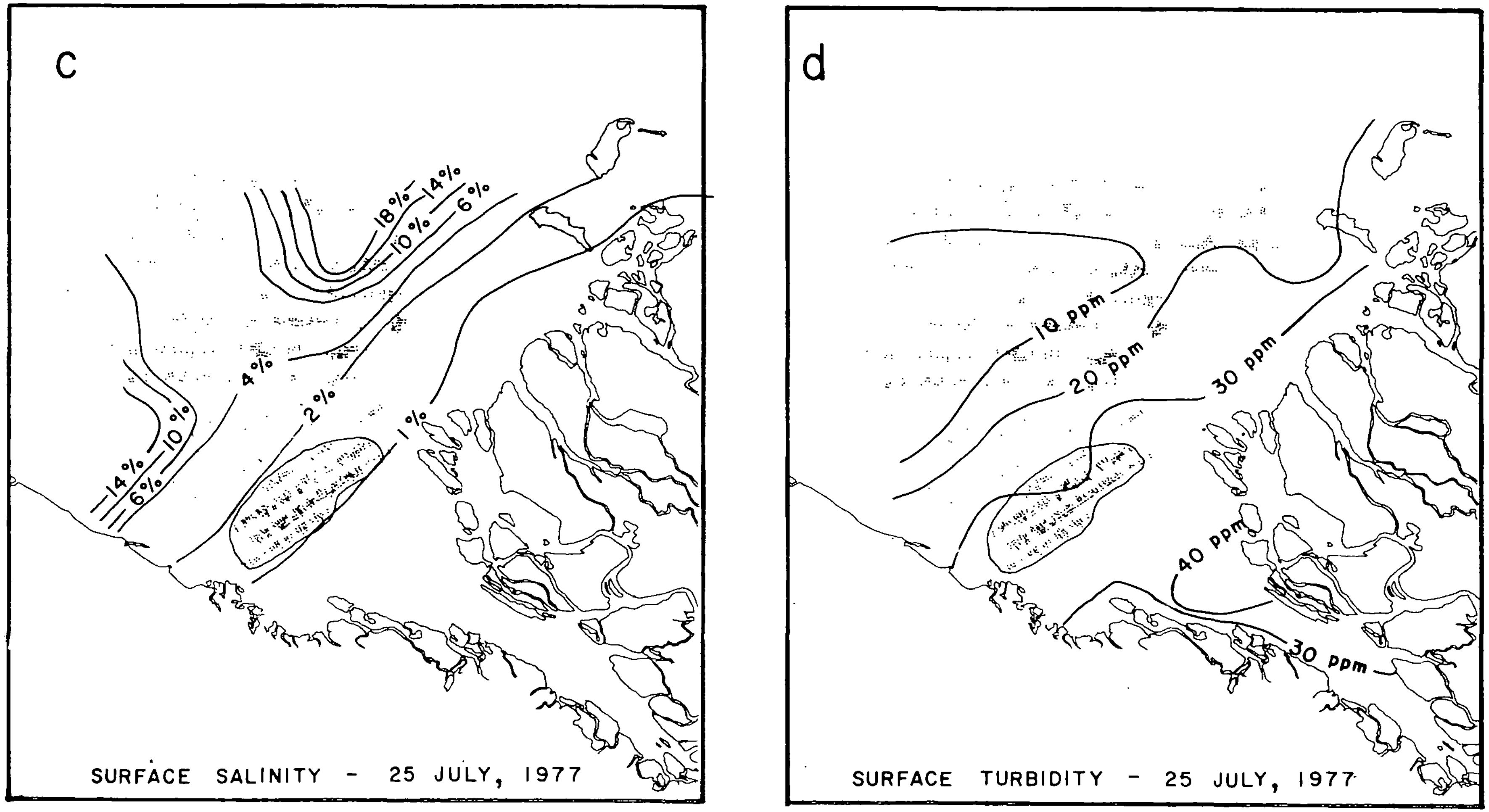
c
18%
14%
10%
6%
4%
2%
1%
14%
10%
6%
SURFACE SALINITY - 25 JULY, 1977
d
10 ppm
20 ppm
30 ppm
40 ppm
30 ppm
SURFACE TURBIDITY - 25 JULY, 1977

Fig. 29. cont'd.

Turbidity in the study area ranged from less than 10 to about 40 ppm, and the whales occupied waters throughout most of this range (Fig. 29d). Most whales were in water of between 10-35 ppm.

In summary, the whales concentrated in Niakunak Bay were in water approximately 2 m deep, while the relatively high densities in West Mackenzie Bay appeared to be in water up to 5 m deep. The water temperatures in the Niakunak Bay concentration areas were between 14° and 16°C. The relatively high densities of whales in West Mackenzie Bay were in water between 12° and 14°C although water up to 17°C was present in Niakunak Bay. The salinity in the Niakunak concentration ranged from 1-2°/oo, while high densities of animals in West Mackenzie Bay were found in water up to 4°/oo. Most whales were in water of between 10-35 ppm turbidity, which was about half that seen the week before and less than one-quarter of the turbidity of three weeks earlier.

4 August 1977

The main concentration of whales of 4 August was located in Niakunak Bay in water less than 2 m deep, although very small numbers were present out to the edge of the study area in water between 30-50 m (Fig. 30a).

The surface temperature in the whale concentration, which was probably also true throughout the water column in the shallow water, was above 18°C (Fig. 30b). Although the surface temperature in West Mackenzie Bay was 14°C or warmer, whales diving in the deeper areas would undoubtedly have encountered water of about -2°C below about 5 m (Fig. 11).

The whale concentration was in water up to about 6°/oo salinity (Fig. 30c). Whales in deeper water further offshore were in water of up to 10°/oo at the surface.

The whale concentration was in water containing 50 to about 125 ppm turbidity (Fig. 30d). Whales further offshore encountered lower turbidities, some less than 10 ppm.

Whale distribution in relation to waves

Whales were observed in relatively high densities over a wide range of wave heights during the aerial surveys (Table 3). Under the conditions when observations were made, there was no tendency for the whales to seek sheltered locales. However, surveys could not be flown in winds greater than Beaufort wind scale force 5.

WHALE DISTRIBUTION IN RELATION TO OCEANOGRAPHIC FACTORS - DISCUSSION

The whale concentrations observed during 1977 in Niakunak, West Mackenzie, and East Mackenzie Bays were generally in water less than 2 m deep (Fig. 18, 20, 27a-30a), and often the depths were probably about 1 m. This relationship also hold true for the Hendrickson whale concentration area in Kugmallit Bay (Fig. 24). The areas occupied by white whales in estuaries elsewhere in the Arctic are also shallow, but depth measurements are not available (Finley 1976; Hay and McClung 1976; Sergeant 1973). There is no apparent reason why depth in itself should be important to white whales, and it is likely that depth is merely correlated with other factor(s) sought by the whales.

The early whale concentrations were in very fresh water (<1°/oo), while later concentrations were in water up to 12°/oo (Figs. 27-30c). The amount of fresh water became more restricted as the summer progressed and the river's flow decreased, while the whales became more widely spread in the study area. There was no consistent pattern of distribution of whale concentrations in relation to salinity.

As with salinity, turbidity appeared not to influence whale distribution (Figs. 27d-30d). There is not obvious reason why whales should find an advantage in turbid water, and whales at several locations in the eastern arctic are found concentrated in clear estuaries (Finley 1976; Hay and McClung 1976).

Under the conditions observed in 1977, there was no tendency for the whales to utilize more sheltered parts of the estuary (Table 3). However, it is emphasized that it was impractical to carry out observations during severe storm conditions.

Temperature appears to most easily explain the location of whale concentrations in the Mackenzie estuary. There are three lines of evidence pointing in this direction:

1. Early in the period when the whales congregate in the estuary, the concentrations are most localized and well defined (Figs. 18-20, 27-30). It is also at this time when the areas of warmest temperature are most localized and limited, and it is in some of these warmest areas where the whales first congregate. As the water in the estuary becomes generally warmer, the whales occupy a much broader area, including parts of East and West Mackenzie Bays. In contrast, low-salinity, highly turbid water is widespread early on, but is more restricted later as the Mackenzie discharge decreases in volume (Figs. 9, 12, 13).

2. The whale concentrations early in the season were associated with particularly shallow areas (Figs. 18a, b, 27). Salinity and turbidity are practically unaffected by water depth, but in contrast, water temperature in shallow areas can become appreciably warmer (several degrees) because of radiant heating by the sun.

3. It is easier to propose a more plausible physiological significance for warm water temperature than for low salinity or high turbidity, and the general pattern of behavior involving migration to areas of warm water during part of the year is common to a number of species of whales.

Although the whales tended to occupy areas of warm water, there were some apparent deviations from this. On 4 July 1977, the warmest temperature was recorded at station 14 which was not particularly near the whale concentration (Table 1). It may be that station 14, which was in

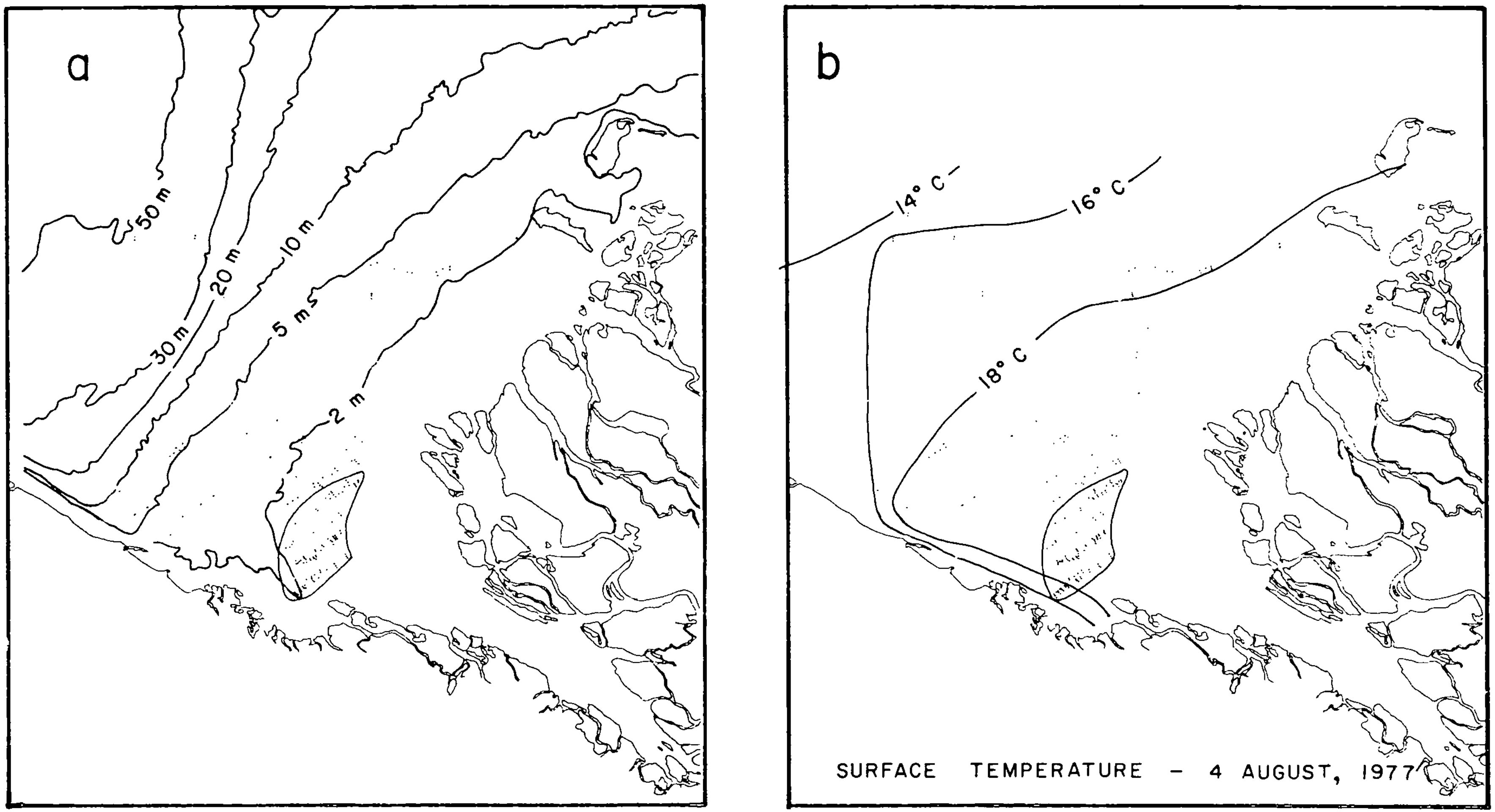

Fig. 30. Whale distribution in relation to oceanographic factors, 4 August 1977.
A. depth, B. temperature, C. salinity, D. turbidity.

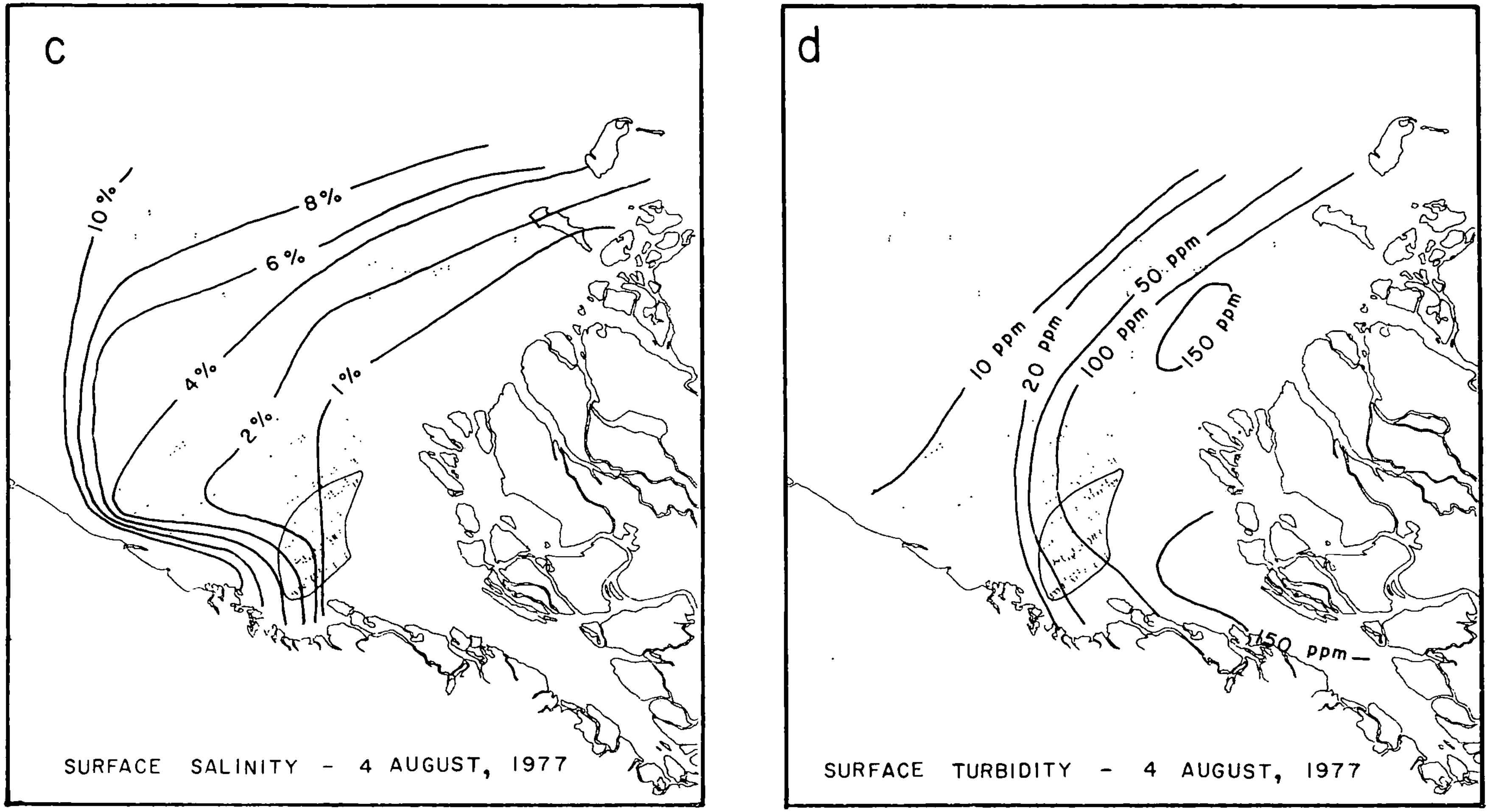
c
10 %
8 %
6 %
4 %
2 %
1 %
SURFACE SALINITY - 4 AUGUST, 1977
d
10 ppm
20 ppm
100 ppm
50 ppm
150 ppm
150 ppm
SURFACE TURBIDITY - 4 AUGUST, 1977

Fig. 30 cont'd.

water of about 0.5 m, was representative of conditions in areas which were too shallow for the whales to utilize.

It may also be that the whales congregate where the greatest volumes of Mackenzie River water discharge into the estuary. Thus, the Niakunak, Kendall, and Hendrickson whale concentration areas are associated with major channels which carry approximately 32, 17, and 28%, respectively, of the Mackenzie River discharge (Fig. 2). This association may be related to the historic reliability of conditions dominated by enormous quantities of discharge, or these large discharge areas may be the principle factor upon which the whales can orient themselves. It is important to note that the oceanographic studies which were conducted, while the most detailed available, show conditions at five particular instants in time in one season, and thus they do not reflect seasonal or year-to-year variability which may be important to the whales.

Native hunting may have significantly affected the apparent relationship between whale distribution and oceanographic factors. On the basis of observations from this and previous studies (Fraker 1976, 1977a), disturbance from hunting activity appears to result in a change in the distribution of the whales in Niakunak Bay. Thus, the effects of this disturbance may have resulted in distribution patterns which the whales might otherwise not have assumed.

There may also be changes in the whales' motivation and behavior over the period when they are present in the estuary. For example, in the latter half of July, the whales periodically moved out into deeper parts of West Mackenzie Bay where the water is colder, probably to feed. This change in behavior may be related to the length of time that the whales may have been fasting in the concentration areas. Possible, after spending a certain period of time in the warm water, the whales' motivation to occupy particularly warm areas may change; in other words, the threshold temperature at which the whales respond may be altered. In fact, one of the most striking results of this study was the observation that the whales vacated the estuary well before there had been any large degree of cooling of the waters. Fraker (1977a) and Fraker et al. (1978) observed the same pattern in Kugmallit Bay.

In conclusion, the hypothesis by Fraker et al. (1978) which states that the annual visit to the estuary by the whales is due to the thermal advantage afforded to whales of all classes has been supported. The secondary hypothesis which stated that shelter from rough water was an additional factor determining the area occupied by the whales has not been supported, however, this study should not be considered a definitive test, because the behavior of the whales under severe wind and wave conditions has yet to be determined.

FUNCTION OF CONCENTRATION AREAS

Because the whales continue to congregate in the concentration areas of the estuary of the Mackenzie and other rivers, year after year, even in the face of considerable disturbance from hunting, we believe that the concentration areas are extremely important. If the visit were not important, the whales probably would have vacated areas such as those in the Mackenzie region, where historically there has been a high hunting disturbance and mortality. But despite the undoubted importance of the concentration areas, their function in the life history of the white whale is unknown.

The annual visit of the white whales at the estuary coincides with the appearance of large numbers of newborn calves (Finley 1976; Fraker 1977a, Sergeant 1973). In the clear water of Creswell Bay, Somerset Island, in the eastern Arctic, Finley (1976) followed the increase in numbers of neonatal calves from late July to mid-August 1975; the proportion of calves present in the bay increased from 4% (24 July) to 17% (21 August). Although a similar pattern probably exists from late June to early August in the Mackenzie estuary, the extremely turbid water precludes counts of the dark-coloured neonates. However, in the absence of information to the contrary, it is reasonable to assume that a similar situation exists in the Mackenzie estuary, although the timing may be somewhat different.

Because there is an increase in the proportion of the herd which is made up of calves while the whales are in the concentration areas, it does not automatically follow that they were born there. In fact, there are observations of substantial numbers of neonatal calves which were certainly born in cold offshore waters. On 6 June 1977, Braham and Krogman (pers. comm.) observed 27 cows with neonatal calves migrating past Point Barrow, Alaska; probably these animals eventually arrived at the Mackenzie estuary later in June or in July (Fraker 1979. During reconnaissance surveys on 21 and 24 July 1977, Fraker (1977b) observed a minimum of 12 females accompanied by neonatal calves travelling southwestward along the Tuktoyaktuk Peninsula. While it is possible that these calves had been born in the Mackenzie estuary, subsequently left, and were observed during their return, it seems more probable that they had been born offshore and were observed travelling to the estuary for their first visit there. Long (pers. comm.), a helicopter pilot, reported seeing a female with a newborn calf a few miles north of Baillie Islands in mid-June 1977. In the eastern Arctic, Finley (1976) made a number of observations of neonates in Barrow Strait; some of these observations were made well offshore and preceded the arrival of whales at estuaries.

In an effort to test Sergeant's (1973) calving hypothesis, Hay and McClung (1976) observed whales in Cunningham Inlet on the north shore of Somerset Island, N.W.T. They logged many hours during observations of whales from a tower in the estuary but failed to observe a single birth. However, a birth is a brief event and the chance of actually witnessing a birth is small.

While it seems possible that a significant proportion of white whale calves is born outside of the estuaries, it is also likely that some are born in or near the concentration areas of the Mackenzie estuary. Slaney (1975) reported that three of 10 female carcasses which were examined in Kugmallit Bay as of 26 July 1974 had afterbirths including severed umbilical cords in the uteri; this indicates that calving had occurred only a short time before they were killed. Fraker (1977a) observed a female taken in Niakunak Bay in July 1976 which also contained an afterbirth.

If the concentration areas do serve as calving grounds, one would predict that females pregnant with term-calves should appear in the harvest. Roughly one-third of the sexually mature female population can be expected to give birth in any given year (Brodie 1971). At any given time in the estuary, if calving takes place there, some of this third will have given birth while the others will still be carrying term-calves, particularly if calving is protracted over one month, as the observations in Creswell Bay suggest (Finley 1976). Because hunting is most intensive early in the season, because the native harvest is composed of 20% females (approximately 30 animals per year), and because practically all of the hunting takes place in the concentration areas (Fraker 1977a, b; Fraker et al. 1977; Slaney 1974), one would predict that a substantial number of females containing term calves would appear in the harvest if the concentration areas were calving areas. But there is only one known instance of such an occurrence when a hunter from Tuktoyaktuk killed a female containing a term calf in 1976 (Fraker 1977a). This was the only one within the memories of the hunters which were interviewed.

The failure of several predictions to be verified casts the calving hypothesis into doubt. There are now a sufficient number of observations of neonatal calves outside of concentration areas to suggest that some whales normally calve outside of estuaries and that at least some calves can survive being born into cold water.

The pattern of several species and stocks of great whales moving to warm water during the period when calves are born is well established. For example, humpback, fin, and blue whales all undertake long migrations from cold regions in each hemisphere to tropical waters during the winter period when the calves are born (Dawbin 1966). Similarly, the California gray whales spend the summers in the Bering and Chuckchi Seas and the winter in the lagoons of Baja California, Sonora, and Sinaloa (Rice and Wolman 1971). All of these species give birth in warm-water regions. But calving cannot be the whole reason why the whales undertake these migrations, because the entire population is involved, not just the calving females. Similarly, the white whales in the Mackenzie estuary in a given year include several classes of animals in addition to females which have or will give birth to a calf in that year: there are adult males (Fraker 1976, 1977a b; Slaney 1973, 1974, 1975), females pregnant with the next year's calves (Slaney 1975), females nursing calves of the previous year (Fraker unpubl.), and probably immature animals of both sexes.

Social factors may require that the whales remain together. In the case of white whales, the gamming behavior observed in the concentration areas suggests that social factors are involved. Feeding does not appear to be a major factor. The great whales practically fast during the periods which they spend in warm waters (Rice and Wolman 1971; Scammon 1974; Small 1971). Similarly, because nearly all the stomachs of whales taken in the Inuit fishery are emptly, the white whales in the Mackenzie estuary appear to feed very little while in the concentrations areas (Fraker et al. 1977), although some feeding probably does occur there (Fig. 25). However, in the case of the white whales in the Mackenzie estuary, a significant amount of feeding may occur in the intermittent-use areas (see section on Feeding).

Because whales of all classes congregate in the concentration areas, Fraker et al. (1977) hypothesized that ". . .white whales congregate in the estuary primarily for the thermal advantage to all classes of whales, including newborn calves." This hypothesis is consistent with Brodie's (1975) hypothesis that the migrations of the great whales reduces energy requirements of whales of all classes. It still seems reasonable that the warm water would be most important to the calves, because the calves, with their surface-to-volume ratio would tend to lose heat more rapidly than the larger adults. Thus it is possible that an importnat function of the concentration areas is to provide a favourable environment for rapid growth of calves. The visit to the estuary may also allow adults to conserve energy. How important possible feeding in the nearby intermittent-use areas might be, is unknown.

RECOMMENDATIONS FOR FURTHER STUDY

This study has resulted in detailed information about patterns of distribution, relative abundance, movement, and behavior of white whales in the Mackenzie estuary and about possible relationships with oceanographic factors. This improved data base can assist in the management and protection of whales in the Mackenzie region and elsewhere. However, there remain important gaps in our understanding which must be addressed before definitive assessments can be made of the implications of exploration and development of offshore oil and gas reserves and of potential oil spills.

Because hydrocarbon exploration and development in the arctic regions will likely increase in the future, more information is needed to ensure that whales are properly protected. Many aspects of the ecology of white whales are complex, variable from year to year, and difficult to study, and therefore considerable time is required before sufficient information can be obtained to allow adequate assessment of the impact of these new activities and the development of management strategies. Although the information on whales in the Mackenzie estuary is sufficient to implement protective measures to ensure minimal and acceptable levels of disturbance at the current level of offshore oil and gas exploration, it is not adequate to assess the implications of development and production or of oil spills. To provide some of the required information, we recommend the following studies:

FURTHER STUDIES OF WHITE WHALE DISTRIBUTION AND ABUNDANCE IN RELATION TO PHYSICAL/CHEMICAL CHARACTERISTICS OF THE MACKENZIE RIVER ESTUARY

To provide an adequate basis for assessing year-to-year variations in the pattern of use of the estuary by whales in relation to the range of variability in oceanographic conditions, more than one year's data are required. It is recommended that at least one further year of whale aerial surveys be conducted concurrently with oceanographic surveys at a similar frequency and level to those conducted during this study. Based on knowledge gained during the 1977 study, greater emphasis should be placed on surveys early in the season when there are the most rapid changes in oceanographic conditions and their influence on whale behavior should be most apparent. These surveys might be supplemented with aerial infrared radiometry to map surface water temperatures. Particular attention should be placed on mapping the occurence of gamming behavior.

Current aerial survey techniques provide valuable information, but are inherently limited because it is not possible to follow individual whales. Therefore, the possibility of conducting concurrent studies utilizing radio transmitters and/or visual identification tags should be considered.

EFFECTS OF HUNTING ON WHALE DISTRIBUTION

As was suspected previously, whale distribution in Niakunak Bay, and probably in other areas, can apparently be affected by activities associated with hunting. A study should be directed at documenting these effects in detail. A change in distribution following the initiation of hunting activities early in the season should be looked for, as should any changes resulting from day-to-day hunting activity. Interviews with old hunters should be conducted to try to ascertain whether there are any changes in whale distribution that are correlated with the advent of modern hunting techniques which utilize power boats, rifles, and harpoons.

In addition to furnishing basic information on the effects of hunting on whale distribution, this study would provide an initial basis for distinguishing between effects caused by hunting and those cause by modern day industrial activities.

STUDY OF WHITE WHALES IN A CLEAR-WATER ESTUARY

Berger (1977) has clearly identified the estuaries of the Mackenzie and other rivers that are used by white whales as a critical habitat. A study of whale distribution in relation to oceanographic factors in another estuary is needed to provide a basis for comparison with the results of this study and for extrapolating our understanding to other estuaries used by white whales. The improved visibility afforded by a clear-water estuary would allow the distribution of whales of different age classes (e.g. calves) to be determined and would enable more detailed observations of behavior to be made. The estuary chosen should be free of disturbance from hunting or industrial operations.

The hypothesis which Fraker et al. (1978) proposed states that newborn calves are likely to be prime beneficiaries of the warmer environment. Thus, a corollary of this hypothesis is that the calves (and their mothers) should tend to congregate in the warmest parts of the estaury, particularly early in the season when warm water is restricted to relatively small areas. This should be field tested.

FEEDING IN THE MACKENZIE ESTUARY REGION

Because of the lack of food in the stomachs of whales taken in the harvest, the possible significance of feeding in the Mackenzie estuary has been largely ignored. However, the results of this study strongly suggest that feeding may be a major activity in the deeper portions of the intermittent-use area in West Mackenzie Bay. Whales may make similar use of unsurveyed waters north of the study area. Aerial surveys should be used to document the presence and behavior of whales in these regions, and there should be surveys of the fish and invertebrates in the area which may serve as food. Whales from this region should be collected and their stomach contents analysed.

These possible feeding areas may prove to be critical habitat because of their proximity to the warm-water concentration areas in the Mackenzie estuary. This knowledge is important in the assessment of the possible impact on the food chain which might result from the effects of a potential oil spill.

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