

**BEHAVIOUR AND HABITAT SELECTION
OF BOWHEAD WHALES (*Balaena mysticetus*)
IN NORTHERN FOXE BASIN, NUNAVUT**

BY

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**A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of**

MASTER OF SCIENCE

**Department of Zoology
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Winnipeg, Manitoba**

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**Behaviour and Habitat Selection of Bowhead Whales (*Balaena mysticetus*)
In Northern Foxe Basin, Nunavut**

BY

Tannis A. Thomas

**A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University
of Manitoba in partial fulfillment of the requirements of the degree
of
Master of Science**

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Abstract

Behaviour And Habitat Selection of Bowhead Whales (*Balaena mysticetus*) In Northern Foxe Basin, Nunavut.

**Tannis A. Thomas,
University of Manitoba, 1999**

**Advisor:
Dr. Susan E. Cosens**

This is the first study of the behaviour and habitat preferences of bowhead whales (*Balaena mysticetus*) in northern Foxe Basin, Nunavut, Canada. The study is divided into two parts; the first part examined the characteristics of bowhead habitat and the second part describes the behaviour of bowheads during the ice-edge season.

Characteristics of bowhead habitat were identified by quantifying relationships between habitat variables (water depth, surface temperatures, ice conditions, and zooplankton densities) and the distribution of whales recorded during strip-transect surveys through a 4 x 4 km quadrat system, in July and August 1997. Two study areas were examined: "A" was examined in July (ice-edge season), when land-fast ice was present on the northern edge of the study area and "B" was examined in August (open-water season), when pack ice is present. Relationships between habitat variables and whale distribution were identified with Mantel tests.

During the ice-edge season, bowhead whales were generally distributed at the ice-edge where the surface water temperatures were colder due to their proximity to the ice-edge. Zooplankton densities in quadrats where bowhead whales were present were

significantly greater than in quadrats where bowheads were absent. This suggests that the whales fed at the ice-edge where prey was abundant. Zooplankton concentrations were highest at the ice-edge. The habitat of bowhead whales in northern Foxe Basin during the ice-edge season was primarily characterized by the abundance of their primary prey species, whereas associations with physical habitat characteristics appeared to be largely incidental to the presence of high densities of zooplankton.

During the open-water season, bowhead whales were found mainly in deep water where pack ice was absent. Although the accumulation of zooplankton is associated with deep water in other studies, results of zooplankton density in my study are inconclusive due to small sample sizes.

The second part of the study examined the behaviour of bowheads during the ice-edge season. Bowhead behaviour varied with the condition of the land-fast ice. The melting of the land-fast ice was divided into three phases: 1) solid ice phase (week one), 2) melt-hole phase (week two), and 3) breakup phase (week three). Bowhead feeding (water-column and ice-edge) behaviour occurred 64-95% of the time and was thus the dominant type of behaviour occurring throughout the ice-edge season. Travelling behaviour was observed throughout the ice-edge season, but comprised only 4 to 17% of the bowhead behavioural time budget. Social behaviour was observed primarily during the melt-hole phase of the ice-edge season, comprising 29% of the time budget. Resting behaviour was observed only once during the melt-hole phase of the ice-edge season. Bowhead feeding behaviours changed from water-column feeding during the first part of the season to ice-edge feeding during the later part of the season.

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General Introduction

The bowhead whale (*Balaena mysticetus*) is a baleen whale belonging to the Family Balaenidae. It is the stockiest of the baleen whales with a head measuring about one-third of the total body length. The jaw is bowed sharply upward, giving a mouth capacity that allows the baleen plates to reach lengths of 4.5 meters, the longest baleen of any whale species (Barnes and Creagh 1988). The baleen in bowhead whales is used to filter small crustaceans out of the water. There is no dorsal fin and the flukes are pointed. Colour is generally blackish except for patterns of white along their ventral surface and visible dorsally on their lower jaws, caudal peduncles, and flukes. These patterns are distinguishing features used in photo identification methods (Rugh *et al.* 1992). Another feature used in identification of individual bowheads is the scarring on their bodies caused by ice and killer whale attacks (Cubbage and Calambokidis 1984; Finley 1990). At birth they are about 4-4.5 meters in length and can grow to 20 m or more as adults (Nerini *et al.* 1984).

The bowhead whale has a disjunct circumpolar distribution spanning approximately 54°N to 75°N latitude in the North Pacific basin and 60°N to 85°N latitude in the North Atlantic basin (Moore and Reeves 1993). Five stocks, some or all of which may be distinct populations are recognized: the Baffin Bay-Davis Strait, Hudson Bay-Foxe Basin and Spitsbergen stocks in the North Atlantic, and the Bering-Chukchi-Beaufort Sea and Okhotsk Sea stocks in the North Pacific (Montague 1993).

The genetic discreteness of these bowhead stocks is unproven. However, preliminary data from a current study suggests genetic discreteness between the Hudson Bay-Foxe Basin and the Baffin Bay-Davis Strait stock (Maier *et al.* 1999).

The bowhead whale has a long history of exploitation. Commercial whaling of bowheads in the Arctic began about 1610 and continued until 1920 (Ross 1979). The Hudson Bay-Foxe Basin stock experienced a brief period of whaling activity between 1860 to 1915 (Ross 1974). Although commercial whaling took place in the southern portion of Foxe Basin, northern Foxe Basin was never a commercial whaling ground due to the extensive ice cover there (Reeves *et al.* 1983; Reeves and Mitchell 1990). Reeves *et al.* (1983) estimated an initial population size of about 680 bowheads in 1859 for the Hudson Bay-Foxe Basin stock. At least 688 bowheads were killed during the 55 years of whaling in Hudson Bay and Foxe Basin. There are no current estimates of the entire Hudson Bay-Foxe Basin stock, although Cosens *et al.* (1997) estimated 256 to 284 bowheads were present in northern Foxe Basin in August of 1994. Cosens and Innes (in prep) estimated that there were about 75 whales summering in northwestern Hudson Bay in 1995.

Analyses of relationships between environmental variables and cetacean distributions has only recently been studied. This is due to the difficulty of quantifying characteristics of marine habitats that are often in a state of flux due to the influence of winds and tides (Smith and Gaskin 1983). In the past, quantification of habitats utilized by cetaceans consisted of simple comparisons between cetacean distribution and patterns of environmental characteristics (Woodley 1992). For example, the distribution of cetaceans has been related to sea-surface temperature (Au and Perryman 1985; Whitehead and Glass 1985; Selzer and Payne 1988), surface salinity (Selzer and Payne 1988), water depth (Hui 1979; Whitehead and Glass 1985; Heimlich-Boran 1988; Moore and Reeves 1993; Finley *et al.* 1994; Smultea 1994; Frankel *et al.* 1995), seafloor

topography (Hui 1979, 1985; Heimlich-Boran 1988, Finley *et al.* 1994), tidal activity and amplitude (Shane 1980; Gaskin and Watson 1985; Finley *et al.* 1994), prey abundance (Whitehead and Carseadden 1985; Payne *et al.* 1986; Selzer and Payne 1988, Heimlich-Boran 1988; Finley *et al.* 1994), wind phase (Gaskin and Watson 1985; Finley *et al.* 1994), fronts and mixing regimes (Volkov and Moroz 1977; Moore and Reeves 1993), and ice conditions (Ribic *et al.* 1991; Moore and Reeves 1993; Finley *et al.* 1994).

One study that has established a strong relationship between whale distribution and habitat characteristics was done by Woodley (1992). Studying the habitat of northern right (*Eubalaena glacialis*) and fin whales (*Balaenoptera physalus*), Woodley (1992) examined the relationship between environmental variables and the distribution and density of whales. They found that right whale distribution was correlated to a flat bottom topography, highly stratified waters, high tide, and high prey abundance. Fin whale distribution was correlated to shallow areas with high topographic variation, strong tidal currents, and well-mixed or frontal interfaces between mixed and stratified waters. As in the right whales, fin whale distribution was correlated to areas of high prey abundance. Woodley (1992) concluded that the habitat of right and finback whales were primarily characterized by the distribution and abundance of their primary prey species, whereas associations with physical environmental characteristics appeared largely indirect.

Finley *et al.* (1994) focused on a more specific type of habitat use by bowhead whales (*Balaena mysticetus*). They looked at the feeding and socializing behaviour of the whales while the whales occupied a particular habitat. Feeding bowheads were found on the north side of deep (>100m deep) troughs where zooplankton (their prey species)

concentrations were abundant. Socializing bowheads occurred in shallow (<50 m deep) sheltered water areas with low zooplankton densities.

If bowheads use different microhabitats (i.e. shallow (<50 m) and deep (>100 m) water areas) for different behaviours, then habitat variables may differ between habitats. To determine what features whales select, each habitat must be analyzed separately. Thus to determine whether bowhead whales in northern Foxe Basin select particular habitats for feeding and socializing, the behaviour of the whales must be determined first. Once behaviour has been identified, oceanographic variables can be measured to determine whether specific variables influence their selection of habitat, or whether there is a combination of variables that interact to create a habitat suitable for different behaviours.

Most information on bowhead whales has been collected on the Bering-Chukchi-Beaufort stock. In a three-year study in the Canadian Beaufort Sea, Würsig *et al.* (1984) described two predominant types of behaviour observed in bowheads while on their summering grounds, feeding and socializing. Three types of feeding behaviour were observed: 1) near the bottom as evident by surfacing with mud streaming from their mouths, 2) in the water column suspected during long dives, and 3) skim-feeding at the surface as evident from mouths open (Würsig *et al.* 1984). Behaviour was termed social when whales appeared to be pushing, nudging, chasing, or within half a body length of one another (Würsig *et al.* 1984). At times, whales alternated between socializing and feeding (Würsig *et al.* 1984). Other behaviours observed were travel, adult-calf interactions, aerial and play activity, and synchrony in surfacings (Würsig *et al.* 1984).

Richardson and Finley (1989) looked for differences between bowhead behaviours in the Bering-Chukchi-Beaufort stock (Western Arctic) and the Baffin Bay-

Davis Strait stock (Eastern Arctic). They measured the breathing characteristics (mean blow interval, number of blows per surfacing, duration of surfacing, and duration of dive) of each behaviour (feeding in deep water, socializing in shallow water, local travel, and migration) and compared them within each stock. Within each stock, the breathing characteristics differed significantly between behaviours in seven of the eight comparisons, suggesting that behaviour can be defined by breathing characteristics.

Other than a long-term foraging study in Isabella Bay (Finley *et al.* 1994), little research has been done on habitat use by eastern arctic bowheads. Recent studies in northern Foxe Basin have shown that bowheads consistently use a relatively small, well-defined area during the summer (Cosens *et al.* 1997). To look at habitat selection in these bowhead whales, I will try to answer three questions in this thesis: 1) what behaviours do bowheads exhibit in their summering habitat, 2) are microhabitats chosen based on behaviour and 3) what habitat variables define bowhead habitat or microhabitats?

The results of this study will have management implications. The eastern arctic stocks are still considered endangered, so any information on the habitat and behaviour of this stock will be valuable in developing conservation plans. By understanding how bowheads use the habitat, we may be better able to manage the population by establishing some habitat protection areas.

Chapter 1
Habitat selection of bowhead whales
(*Balaena mysticetus*) in
northern Foxe Basin, Nunavut

Introduction

A habitat is the place in which an organism lives, which is characterized by its physical features (Isaacs *et al.* 1996). Habitat selection is how an organism chooses to occupy a habitat. The way an organism chooses a suitable habitat varies with species, age and/or sex of the organism, time of year, etc. Some studies have demonstrated a strong correlation between structural features of the environment and the species present (MacArthur 1972). MacArthur's (1972) studies demonstrated that the overall aspect is important in the selection of a habitat--the type of terrain, whether rolling or flat, open or grown with woody vegetation, homogenous or patchy (Smith 1980). An example of this type of habitat selection may be seen in two subpopulations of killer whales (*Orcinus orca*) off the coast of British Columbia and Washington. The resident killer whale population prefers the coastal waters and the transient population prefers the offshore waters (Heimlich-Boran 1988). In addition to overall aspect there are specific features that determine a habitat's suitability (Hilden 1965). For marine mammals these specific features have been hypothesized to be shelter (Finley *et al.* 1994; Smultea 1994), food (Whitehead and Carseadden 1985; Payne *et al.* 1986; Selzer and Payne 1988, Heimlich-Boran 1988; Finley *et al.* 1994), sea surface temperature (Au and Perryman 1985; Whitehead and Glass 1985; Selzer and Payne 1988), surface salinity (Selzer and Payne

1988), water depth (Hui 1979; Whitehead and Glass 1985; Heimlich-Boran 1988; Moore and Reeves 1993; Finley *et al.* 1994; Smultea 1994; Frankel *et al.* 1995), seafloor topography (Hui 1979, 1985; Heimlich-Boran 1988, Finley *et al.* 1994), tidal activity and amplitude (Shane 1980; Gaskin and Watson 1985; Finley *et al.* 1994), wind phase (Gaskin and Watson 1985; Finley *et al.* 1994), fronts and mixing regimes (Volkov and Moroz 1977; Moore and Reeves 1993) and ice conditions (Ribic *et al.* 1991; Moore and Reeves 1993; Finley *et al.* 1994).

A species of whale that has been studied extensively in its winter habitat is the humpback whale (*Megaptera novaeangliae*) in waters around the islands of Hawaii. In winter the Hawaiian population is coastal, restricted to shallow water within the 100-fathom (1 fathom = 1.828 m) contour line (Smultea 1994). Humpback cows with their calves are found in significantly shallower water than males and unmated females, the latter occurring mostly in deeper, more exposed water (Smultea 1994). Smultea (1994) hypothesizes that maternal females select sheltered habitats to avoid harassment and injury to calves by sexually active males, turbulent offshore conditions, or predators (various sharks and killer whales). Calm, warm, shallow water of the nearshore areas may minimize energy expenditure for cows and calves. Smultea (1994) suggests that mature males and unmated females select deeper and more open water to facilitate breeding behavior. Frankel *et al.* (1995) has found singing male humpbacks in water depths of 305 fathoms. Humpbacks may select deep water to avoid collisions with the sea floor (Jones and Swartz 1984 in Smultea 1994) or coral in shallow water. During mating, male humpback whales sing. Deep water and the lack of physical obstructions that absorb sound may make deeper water a better habitat for singing. If Smultea's (1994) hypotheses

are true, then sex and reproductive state govern the habitat selection of a humpback whale in winter. If a female has a calf, the primary factors influencing habitat selection will be thermoregulation, predator avoidance, or energy expenditure. If it is a mature male or unmated female, the primary factor influencing selection of a habitat will be reproduction.

In the Bay of Fundy, Woodley and Gaskin (1995) found that right whales (*Eubalaena glacialis*) select habitat with a flat bottom topography, highly stratified waters, high tide, and high prey (copepods) abundance. The topography of the basin, prevailing summer currents, and orientation of transition zones from mixed to stratified waters combine to facilitate accumulation of copepods in the Bay of Fundy (Murison and Gaskin 1989). Woodley and Gaskin (1995) concluded that right whale habitat was characterized primarily by the distribution and abundance of their primary prey species (copepods), while physical environmental characteristics appeared indirectly associated with the selection of the habitat.

Bowheads from the Bering-Chukchi-Beaufort stock were studied extensively in the early 1980's (Würsig *et al.* 1984; Richardson *et al.* 1987). This stock undergoes a spring migration to the Canadian Beaufort Sea where individuals reside for 3½ to 4 months, feeding extensively on dense patches of zooplankton, of which copepods are usually the dominant group (Richardson *et al.* 1987). Feeding was the predominant activity observed in the Beaufort Sea, and was generally observed in waters <50 m deep. Social behavior was observed less frequently and was often interspersed with feeding or traveling. In these studies, bowhead distribution and the frequency and type of feeding were the main attributes that varied from year to year. These variations are believed to

reflect changes in prey distribution, abundance or species composition (Würsig *et al.* 1984).

Finley *et al.* (1994) studied aggregations of bowhead whales of the Davis Strait stock in Isabella Bay during late summer and early fall. They found that bowheads select two distinctly different habitats for feeding and socializing (microhabitats). The two deep troughs (Aquik and Kater Troughs, both > 200m) are used as feeding areas, whereas the shallow inshore bank (Isabella Bank, < 50m) is used as a socializing (Figure 1.1). The shallow bank is probably selected as a socializing habitat for its sheltering features (Finley *et al.* 1994). The shallow bank allows whales to avoid turbulent offshore or deep-sea conditions that may help to minimize energy expenditure. Finley *et al.* (1994) also found that bowhead feeding habitat was related to depth and topography. They found whales aggregating in water >100 m deep and along the sides of the troughs, where the bottom current enters. The convergence of whales in this area is believed to be a result of the abundant supply of zooplankton. Feeding behaviour occupies most of the bowheads' time while in Isabella Bay. Finley *et al.* (1994) state that bowheads use Isabella Bay primarily for its food supply. The socializing habitat on the Isabella Bank is of secondary consideration after the feeding habitat is chosen.

Bowheads consume the bulk of their annual food requirements primarily in the summer on preferred feeding habitats (Finley *et al.* 1994) and while migrating to and from the summer feeding habitats (Richardson 1987). If this is true, then food should be the primary factor governing the selection of a habitat by bowheads in summer. Finley *et al.* (1994) suggests bowhead migrations are timed according to the seasonal life cycles of copepods. If their hypothesis is true, I would expect to see maximum bowhead numbers

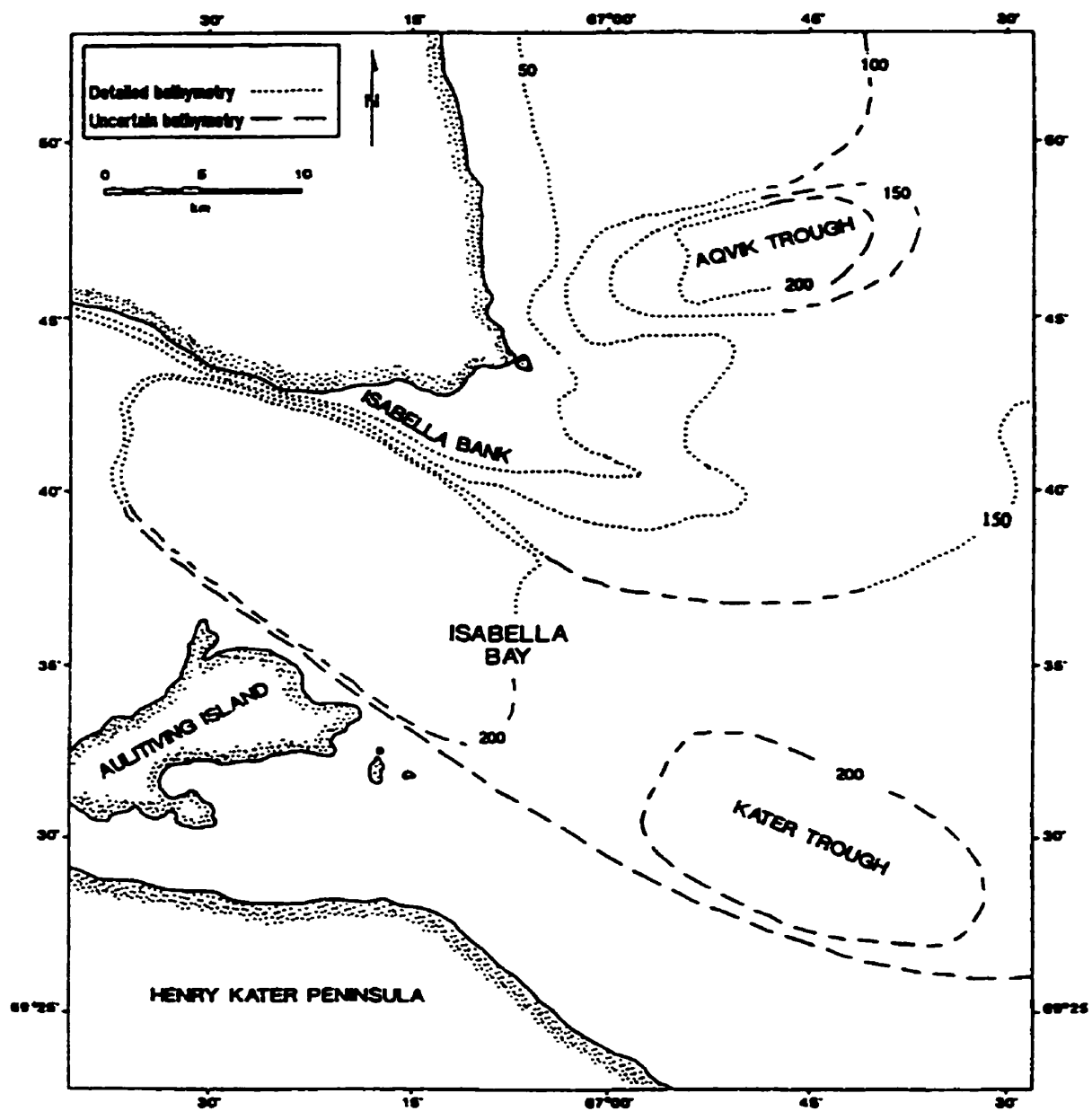


Figure 1.1. Map of Isabella Bay in Davis Strait showing Aquik and Kater troughs (feeding areas) and Isabella Bank (socializing area) (from Finley *et al* 1994).

during times of peak concentration of zooplankton in our study area in northern Foxe Basin. At a sampling station near Igloolik, Grainger (1959) conducted a one-year study of the zooplankton in Foxe Basin and found maximum concentrations of zooplankton during July, August and early September with peak concentrations in September. Bowheads have been seen in the Igloolik area as early as June and as late as November, and peak bowhead numbers occur between July and September (Reeves and Mitchell 1990).

Research Objectives

The primary objective of this study was to investigate the relationship between bowhead distribution and habitat variables in northern Foxe Basin. In order to look at habitat selection in bowhead whales, an understanding of what the whales are doing in Foxe Basin and how they are using the area is required. Thus, I first determined whether bowheads use Foxe Basin as a feeding habitat. If bowheads were using Foxe Basin as a feeding habitat, then it had to be determined whether there is more than one type of habitat in Foxe Basin. By habitat type I am referring to a habitat used for a specific activity as in a feeding habitat or a socializing habitat. Once the habitat or microhabitats were identified, I then proceed to look at what features the bowheads selected. If bowheads and one or several habitat variable(s) co-occur spatially and temporally, the information would be useful in defining bowhead habitat and may be used for management purposes or in population surveys. To address this objective three questions were posed:

- 1) Are bowhead distribution and zooplankton densities independent?
- 2a) Are the distributions of bowhead behaviour and zooplankton densities independent?
- 2b) Are bowhead behaviour and water depth independent?
- 3) Are bowhead distribution and one or more habitat variables independent?

Research Question Rationale

The first question was posed to determine if the bowheads use Foxe Basin as a feeding habitat or if they are just migrating through the area. Higher zooplankton densities in an area where bowheads are present and low densities in areas where they are absent infers that bowheads are feeding in the areas of high zooplankton density.

Questions 2a and 2b were addressed to determine if bowheads in Foxe Basin use more than one type of habitat. Higher zooplankton densities occurring in areas where bowheads are feeding and lower concentrations occurring in areas where bowheads are socializing would suggest that bowheads are selecting different habitats based on zooplankton concentrations. If water depths differ between areas used by feeding and socializing whales, then bowheads may be selecting different habitats based on water depth. If Foxe Basin bowheads are using the study area in a similar fashion as bowheads in Isabella Bay, I should expect to see feeding whales congregating in deep water areas with high zooplankton concentrations and socializing whales congregating at shallow water areas with low zooplankton concentrations. Data collected to answer questions 1 and 2 (a and b) were used to develop an experimental design to answer question three. If there is more than one habitat type, each habitat would have to be sampled and analyzed separately.

Question 3 is fundamental to this investigation; do bowhead and one or more habitat variables occur together more often than would be expected by chance? A positive co-occurrence of bowhead and habitat variables suggests that bowheads prefer to locate at or near specific habitat features.

Methods and Materials

Study Area

Foxe Basin is a large shallow inland sea, located within the southern limits of the Canadian Arctic. The north side of the basin is bounded by Baffin Island, the west side by Melville Peninsula and the south side by Southampton Island and Foxe Peninsula. Foxe Basin is connected to Hudson Bay in the southwest by Frozen Strait, to Hudson Strait in the south by Foxe Channel and to the Canadian high arctic in the north by Fury and Hecla Strait (Figure 1.2).

The study area encompassed about 850 km², near the area of Igloolik at the east entrance of Fury and Hecla Strait. The area extends from the 69° 07'N to 69° 33'N latitude, and from 80° 45'W to 81° 30'W longitude. Water depth ranges from 10-150 m. In June and July, 1996 and 1997, my camp was located on Igloolik Island, in the northwest part of the basin, off the northeast coast of Melville Peninsula, where Fury and Hecla Strait enter the basin (Figure 1.3). During this study there was land-fast ice present on the northern edge of the study area. Land-fast ice is a stationary solid sheet of ice connected to land. In August of 1997, the camp was located on the south shore of northern Baffin Island (Figure 1.3). During August, the land-fast ice has melted and only

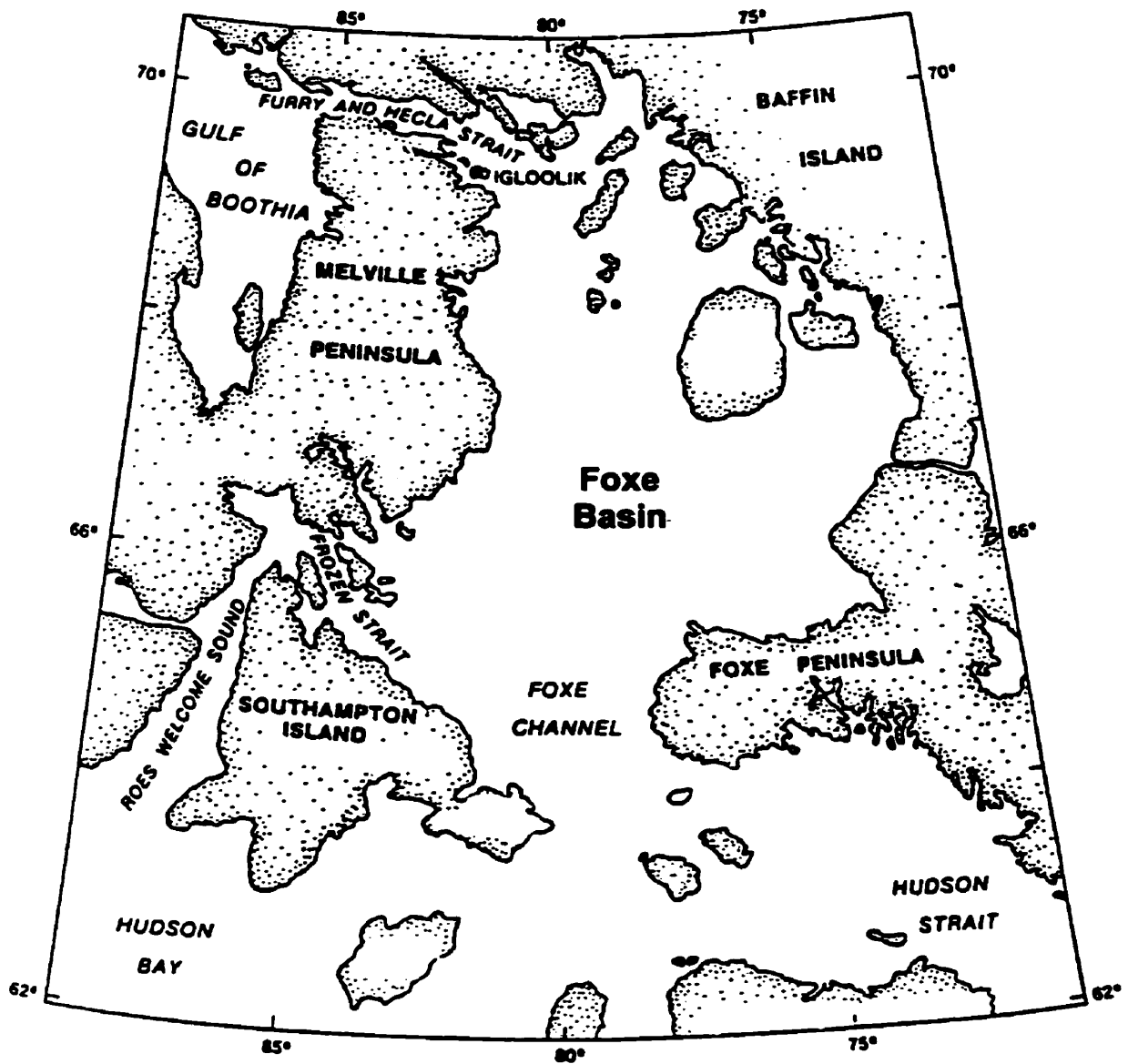


Figure 1.2. Map of Foxe Basin (from Prinsenber 1986).

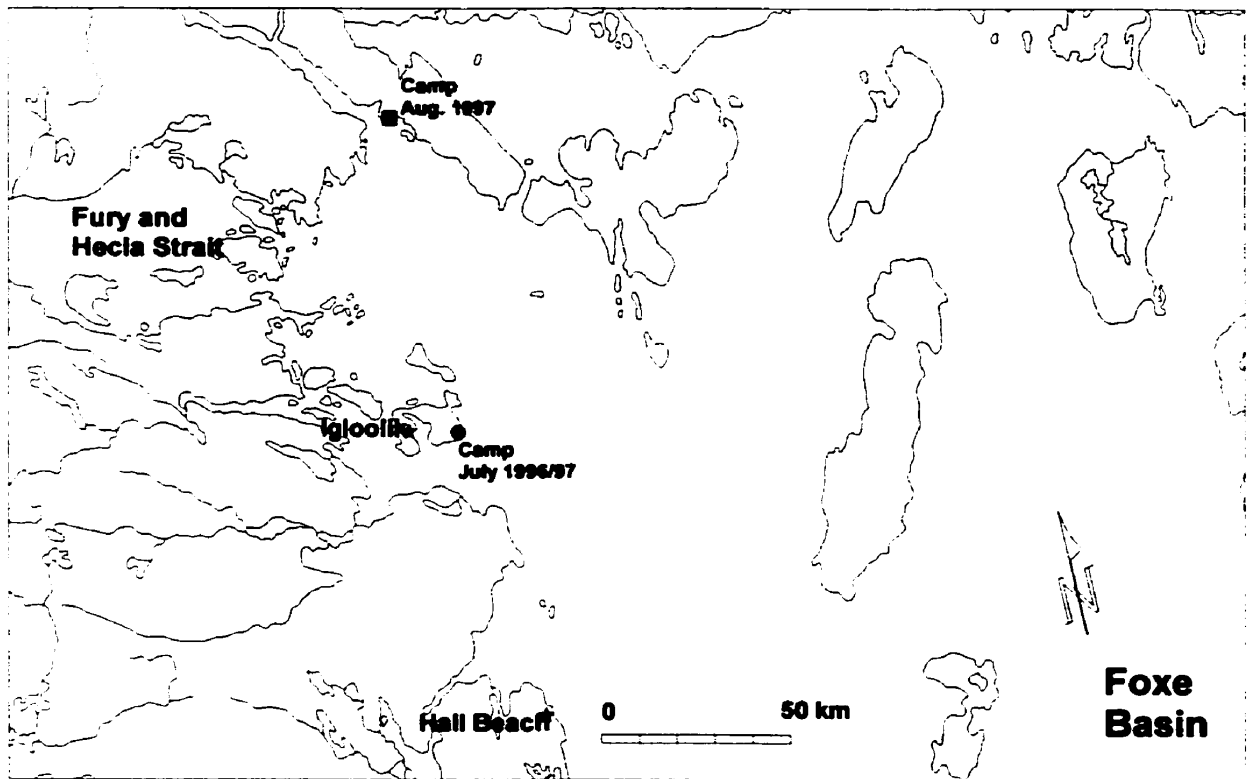


Figure 1.3. Map of northern Foxe Basin, illustrating camp locations used for the 1996 and 1997 field seasons and the local communities.

floes of pack ice are present. Pack ice consists of ice pieces of varying size that move with the current and wind.

Data Collection

1996 Field Season:

Behavioural data were collected on bowheads in northern Foxe Basin from aboard a 15- foot boat driven by Adam Qanatsiaq, a resident of Igloolik. Observations were made on 29 June until 25 July 1996, at which time the land-fast ice was still present. I recorded observations on 16 of the 27 days when weather conditions were acceptable for boat travel. Whales were located using a similar technique used by Sue Cosens (pers. comm) to find whales in previous years. We traveled east along the ice edge or south towards Melville Peninsula, using binoculars to scan the water for whales. If no whales were seen within 10 minutes, we stopped the boat and listened to hear them blowing. Blows can be heard for several km. If no blows were heard or whales seen within five minutes we then continued to look for the whales while the boat was moving. We continued in this fashion until a whale or group of whales was spotted. When a group was spotted, we slowly moved to within 100 m of the group. The engine was then turned off and I observed the group for a maximum of three hours or until the group moved out of the area. I did not follow whales traveling through the area to avoid disturbing them. If whales reacted to the boat while the observation session was taking place, the session was stopped and I moved into a new area.

For each whale or group of whales observed, feeding, socializing, travelling, resting, or ice edge behaviour was noted. For feeding behaviour, only data on water-

column feeding were used in my analysis as skim feeding was observed only once. Whales were described as feeding if they dove repeatedly in the same area, dove with 'fluke-out' dives or showed synchrony of surfacing. Whales were described as socializing if they were engaged in active social interactions such as touching, pushing, nudging or chasing. Whales were described as travelling if they were moving through an area at medium speed (small wake visible behind whale) and were orientated in the same direction after repeated surfacing and dives. Whales were described as resting if they were motionless at the surface or just below the surface for a period greater than five minutes. Ice-edge behaviour was defined as diving into or surfacing out of the water under land-fast ice. Ice edge was given its own behaviour because it could not be determined whether the whales were feeding under the ice or if they were looking for openings on the other side where better a habitat may have been.

For all observation sessions in which feeding, travelling, resting, and/or ice-edge behaviour was identified, each whale was treated as an independent observation. The size of the group, and the time I spent observing them was also noted. The location of each whale sighted was estimated using a hand held 12 channel Eagle Explorer™ global positioning system (GPS). When multiple sightings of whales were recorded, the first was used to establish location.

Habitat Variables:

Two habitat variables were examined while behavioural observations were being observed in 1996.

- 1) **Water depths were measured in meters using a Lowrance X-16™ depth sounder. Water depth was determined for each location where there was a behavioural observation or a zooplankton sample collected.**
- 2) **Zooplankton samples were collected using a plankton net with a 440-micron mesh and a diameter of 40 cm. The samples were collected by vertical hauls from bottom to top, with a minimum of two samples per location. A depth sounder was used at each sample site to determine to what depth of water the net was to be dropped. A GPS unit was used to determine the location of the samples. Samples were collected at locations where bowheads were feeding, and also at locations where they were not feeding (i.e. travelling, resting, socializing, ice edge, and absent). A total of 42 samples were collected at 17 different locations. Samples caught in the net were preserved in 5-10% formalin and shipped to the Freshwater Institute in Winnipeg to be analyzed for species composition and zooplankton density. Six samples were selected at random for species identification. The remaining samples were dried and weighed to obtain biomass. Zooplankton density was calculated by dividing the biomass per sample by the volume of water sampled. When more than one sample was collected at a site the mean zooplankton density was calculated and used in the analyses.**

Bowheads feed on dense concentrations of zooplankton located in small patches throughout the water column. Due to the nature of the sampling procedure used in this study (the entire water column sampled), relative density estimates were obtained rather than the actual zooplankton density that bowheads would be feeding on. The zooplankton samples collected for this study were used to look for differences

between sample locations, not to determine the actual zooplankton density on which the whales would be feeding.

1997 Field Season:

Three surveys were conducted in northern Foxe Basin in 1997. The first two surveys (replicates) took place in study area "A" (Figure 1.4) from 8 to 15 July. Data collected during this time were classified as being collected during the ice-edge season due to the presence of the land-fast ice edge on the northern border of the study area. The third survey took place in study area "B" (Figure 1.4) from 15 to 21 August. Data collected during this time were classified as being collected during the open water season due to the absence of the land-fast ice. Methods used to collect data in 1997 were based on Woodley (1992).

Quadrat and Transect Systems:

Study area "A" was partitioned into 28, 4 km by 4 km quadrats (Figure 1.5). Study area "B" was partitioned into 25 four by four km quadrats (Figure 1.6). A 15-foot boat equipped with the 12 channel Eagle Explorer™ GPS was used to follow transects to the mid-longitude (for study area "A" numbers (nos.) 1-5; for study area "B" nos. 6-10) coordinates of the quadrats (Figure 1.5 and 1.6; transects were run through the middle of quadrats). Transects were used to conduct whale surveys and the collection of habitat variables.

Sampling order of the transects was decided on a daily basis to maximize the area covered. Transects were not selected at random because the amount of extra travelling

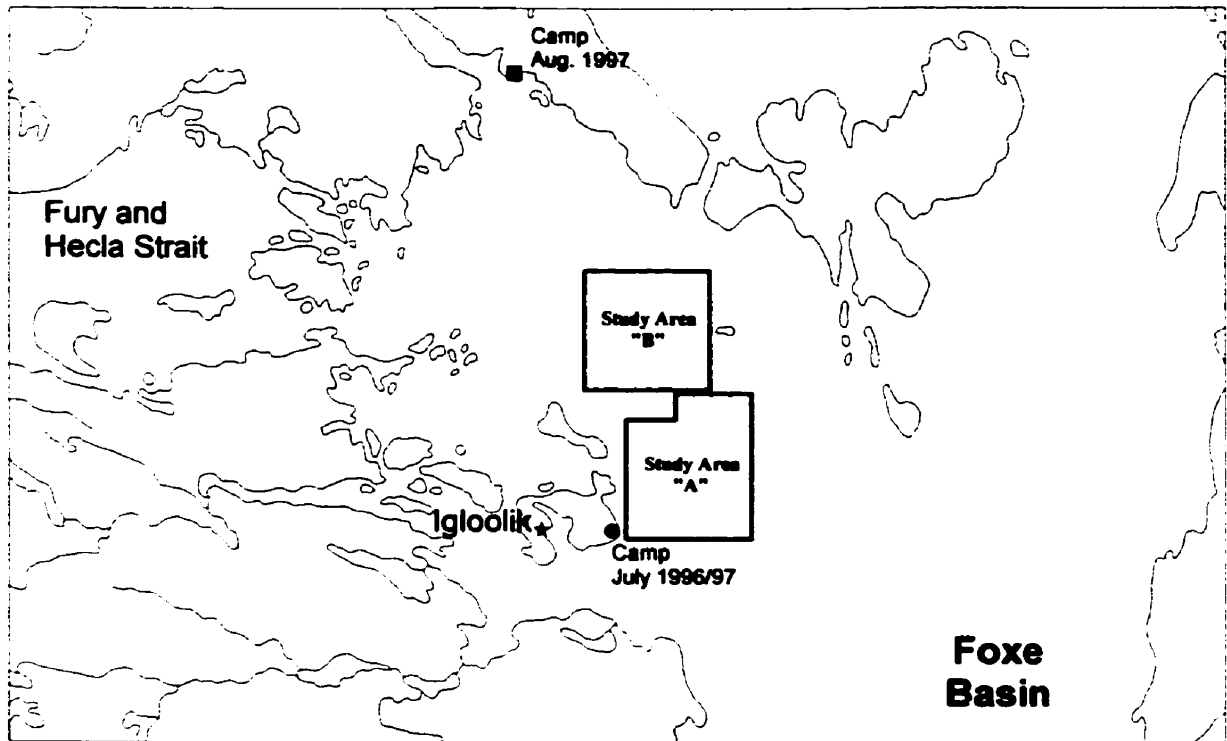


Figure 1.4. Map of Northern Foxe Basin, illustrating study areas used in the collection of data for the 1997 field season. Study area "A" was used in July during the ice edge season and study area "B" was used in August during the open water season.

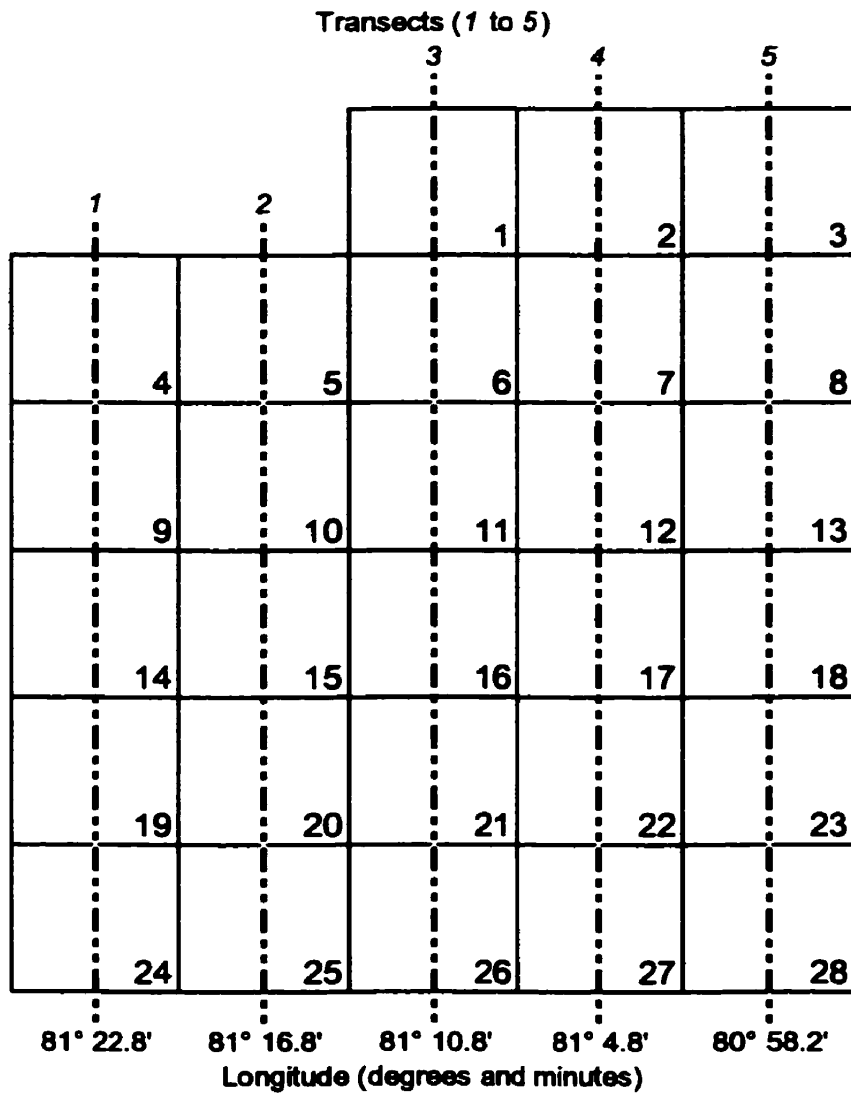


Figure 1.5. Quadrat and transect system used in study area "A" during the ice edge season. Quadrats numbers (1 to 28) in the bottom right of each quadrat. Transect numbers (1 to 5) on the top and coordinates of longitudinal (degrees and minutes) on the bottom of transects through quadrats .

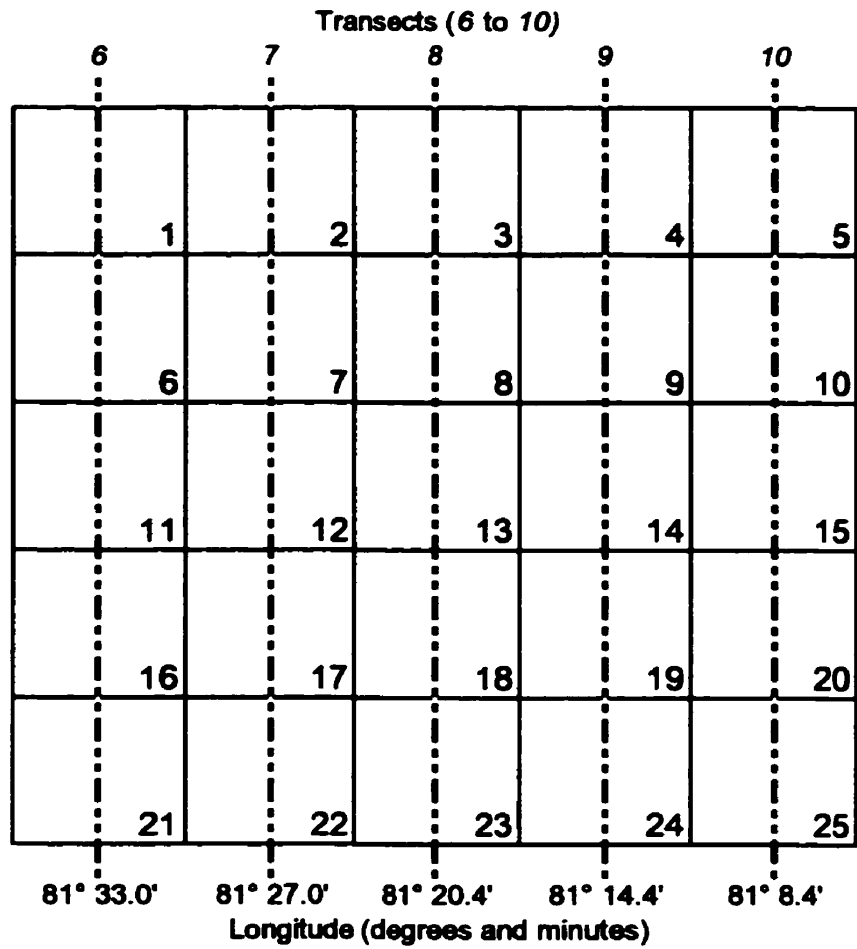


Figure 1.6. Quadrat and transect system used in study area "B" during the open water season. Quadrats numbers (1 to 25) in the bottom right of each quadrat. Transect numbers (6 to 10) on the top and coordinates of longitudinal (degrees and minutes) on the bottom of transects through quadrats.

required would have restricted the number that could have been completed on a given day. To keep the data collection random and unbiased the position of the first transect of the study area was selected at random. Subsequent transects were sampled systematically.

Whale Surveys:

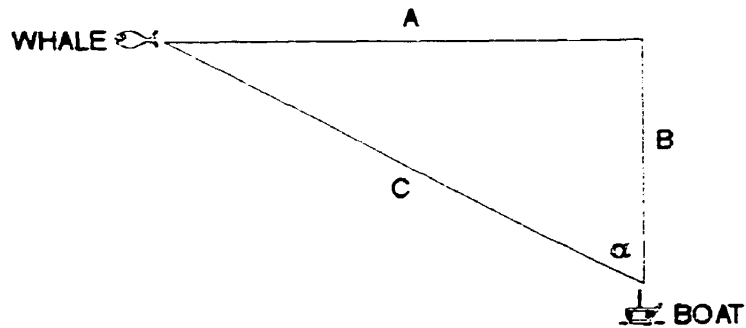
Strip width on either side of the transect was set at 2 km to correspond with the width of quadrats. Doi (1974) indicated that all southern right whales (*Eubalaena australis*) are visible out to 2.4 km from boats and, since the bowhead is of similar size and shape as the right whale, I assumed that bowheads are also visible out to 2.4 km.

Following Murison and Gaskin (1989), surveys were restricted to daylight hours when sea states were Beaufort 3 (wind speed 3.6-5.1 m/s, wave heights 0.1-0.5 m described as smooth wavelets) or less. Surveys were only conducted when visibility was 2 km or more. The boat was set to travel at 18 km/h during surveys, although winds and water currents influenced actual speed.

One observer on each side of the boat scanned an arc of 180°. For each sighting, the time, position of the boat, number of animals, distance from the boat, and angle relative to the bow of the boat were recorded and later used to estimate distance of the sighted whales from the boat. Once sighted, the movement of the whales was monitored for several minutes to minimize the chance of them being recounted as a new sighting.

For each sighting, the latitude and longitude and the quadrat in which the sighting occurred were calculated. The known position of the boat, the angles and distances of the sightings from the boat were used to calculate the coordinates of sightings with

trigonometric functions. The coordinates of sightings were used to establish the quadrats in which they occurred.



Known Values: BOAT decimal latitude and longitude (B.lat. and B.long.), and α (degrees).

Estimated Value: C (km)

$$A = C \times \sin \alpha$$

$$B = C \times \cos \alpha$$

Known: one latitude (i.e. 140° to 141°) = 111 km
one longitude = 40 km

Whale decimal latitude = $B \times (1/111) \pm B.\text{lat.}$

Whale decimal longitude = $A \times (1/40) \pm B.\text{long.}$

The number of whale sightings within each quadrat was totaled. When multiple sightings of whale(s) occurred, the first whale sighted was used to establish quadrat location. Mothers with calves were counted as single sightings because their distributions are not independent.

Habitat Data Collection:

A Lowrance X-16™ paper-chart depth sounder was used to obtain continuous recordings of depth profiles along transects within each quadrat. Quadrat boundaries were

marked on the paper-chart. Sea surface temperatures were recorded at 1-km intervals across quadrats with a submersible temperature probe that was calibrated against a mercury thermometer. Five measurements were made for each quadrat. The presence of landfast ice or pack ice was coded as a binary variable (present =1 , absent =0) in each quadrat.

Zooplankton Sampling and Density Estimates:

Vertical bottom-to-surface zooplankton hauls were made at the mid-point of a randomly chosen quadrat along each transect and when the number of bowhead whales within 1 km of the boat exceeded 4. In study area "A" a total of 22 zooplankton hauls was collected at 11 different sites. In study area "B" a total of 8 zooplankton hauls was collected at 4 different sites.

Data Analysis

1996 Data:

Question 1:

A bivariate test (Zarr 1999) was calculated to determine if zooplankton densities differed between areas where bowheads were present and where they were not. Zooplankton samples were divided into two categories, with one category being the mean zooplankton density of samples collected in the presence of bowheads and the second category being the mean zooplankton density of samples collected in the absence of bowheads. A two-tailed t-test was used to determine if sample means were significantly different. The test hypotheses were:

- H_0 = Bowhead distribution and zooplankton densities are not correlated.
- H_a = Bowhead distribution and zooplankton densities are correlated.

Question Two:

To address the second question of how bowheads use Foxe Basin, a Fisher exact analysis of a contingency table was calculated to determine whether the distribution of feeding and socializing behaviour was dependent on water depth as it appears to be in Isabella Bay. Water 50 m deep was chosen as the transition zone between shallow and deep water because Finley *et al.* (1994), defined water depths of <50 m as shallow water in which socializing bowheads were observed. For each observation session, water depth was classified as being either shallow or deep and behaviour was classed as either socializing or feeding. All other behaviours were excluded from the Fisher exact test because Finley *et al.* (1994) found them to be independent of water depth. The test hypotheses were:

- H_0 = Bowhead behaviour and water depth are not correlated.
- H_a = Bowhead behaviour and water depth are correlated.

$$P = \frac{R_1! R_2! C_1! C_2!}{f_{11}! f_{21}! f_{12}! f_{22}! n!}$$

where: R_1 is the frequency observed in row 1,
 R_2 is the frequency observed in row 2,
 C_1 is the frequency observed in column 1,
 C_2 is the frequency observed in column 2,
 f_{11} is the frequency observed in row 1 and column 1,
 f_{21} is the frequency observed in row 2 and column 1,
 f_{12} is the frequency observed in row 1 and column 2,
 f_{22} is the frequency observed in row 2 and column 1,
 n is the sum of all rows or columns.

A second test was calculated to determine if feeding and socializing behaviour was dependent on zooplankton densities. A t-test was run on the zooplankton data to determine if zooplankton densities differed between feeding and socializing areas. The mean zooplankton density of samples collected in areas where bowheads fed was compared to the mean zooplankton density of samples collected in areas where bowheads were socializing. The test hypotheses were:

- H_0 = Bowhead behaviour and zooplankton densities are not correlated.
- H_a = Bowhead behaviour and zooplankton densities are correlated.

1997 Data:

Question Three:

To address the third question of what habitat variables define bowhead habitat in northern Foxe Basin, Mantel analyses (Appendix 2) were performed to determine if bowhead distribution was dependent on one or more habitat variables. The test hypotheses were:

- H_0 = Bowhead distribution and habitat variables are not correlated.
- H_a = Bowhead distribution and habitat variables are correlated.

Ten physical and biological variables were calculated for each quadrat during the ice-edge and open-water seasons. Abbreviated names for environmental variables are indicated in Table 1.1 and in bold when first used in the text.

Whales:-- The number of whale sightings (**Whales**) in each quadrat was calculated for each survey.

Distance:-- A euclidean distance (**Distance**) was calculated between each quadrat, using the distance between two adjacent quadrats as one. These were required to run the Mantel tests in order to account for spatial autocorrelation.

Temperature:--The average surface temperature (**TempMean**) for each quadrat was calculated from the five temperature readings collected from transects. The range in surface temperature (**TempRange**) for each quadrat was calculated as the difference between the highest and lowest temperature readings.

Depth Estimates:--Depths within each quadrat were calculated from a single longitudinal pass through each quadrat. Minimum (**DepthMin**) and maximum (**DepthMax**) depth for each quadrat were recorded from the depth sounder. Depth estimates for each quadrat were used to calculate the maximum topographic variation, where,

$$\text{MaxTopVar} = (\text{DepthMax} - \text{DepthMin}) / (\text{DepthMax}) \times 100$$

(Hui 1979).

Ice:--A binary system (absent (0) or present (1)) was used to identify presence or absence of the land-fast **Ice Edge** in each quadrat during the ice edge season. During the open water season the presence or absence of **Pack Ice** in each quadrat was also recorded using the binary system.

Zooplankton Density:--Zooplankton density (**ZooDensity**) for each quadrat sampled was calculated as the mean density of the two samples collected at each sample site.

The first and second surveys of the ice edge season (in study area 'A') were analyzed separately because the location of the ice edge and the mean sea surface temperature varied from one survey to another. Tidal amplitude in northern Foxe Basin is

Table 1.1 Abbreviations for variables as used in the text.

Variable Abbreviations	Variable Descriptions
TempMean	the average of surface temperature readings
TempMean1	the average of surface temperature readings for the first survey of the ice edge season
TempMean2	the average of surface temperature readings for the second survey of the ice edge season
TempRange	range in surface temperature readings
TempRange1	range in surface temperature readings for the first survey of the ice edge season
TempRange2	range in surface temperature readings for the second survey of the ice edge season
DepthMin	minimum depth readings within a quadrat
DepthMax	maximum depth readings within a quadrat
MaxTopVar	maximum topographic variation
Pack Ice	the presence or absence of Pack Ice within a quadrat
Ice Edge1	the presence or absence of land-fast ice within a quadrat for the first survey of the ice edge season
Ice Edge2	the presence or absence of land-fast ice within a quadrat for the second survey of the ice edge season
ZooDensity	zooplankton biomass within a quadrat
Whales1	sightings of whales during the first survey of the ice edge season
Whales2	sightings of whales during the second survey of the ice edge season
Whales3	sightings of whales in quadrats that were within 1 km of zooplankton sample
WhalesTot	sightings of whales during the first and second survey of the ice edge season
Whales4	sightings of whales during the survey of the open water ' season'
Whales5	sightings of whales of the open water season (aerial data included)*
Distance1	euclidean distance between quadrats for a study area with 28 quadrats
Distance2	euclidean distance between quadrats for a study area with 27 quadrats
Distance3	euclidean distance between quadrats for a study area with 11 quadrats
Distance4	euclidean distance between quadrats for a study area with 25 quadrats

* whale distribution data from aerial surveys were combined with the boat surveys for a larger sample size

only 0.5 m (Prinsenberg 1986), so water depths were considered to be constant for each location, thus the bowhead distributions for the two surveys of the ice edge season can be combined for the analysis of water depth.

Due to weather conditions and time, only one boat survey was completed during the open water season in study area 'B'. Additional data on bowhead distribution were derived from a photographic aerial survey (Cosens and Blouw 1999). I used the locations of bowheads from the boat and aerial surveys in my analysis for water depths because the number of bowheads seen during the boat survey was small.

Results

1996 Field Season

During the 1996 field season, bowheads (Figure 1.7) appeared to aggregate along the ice edge. Zooplankton density decreased with increasing distance from the ice edge (Figure 1.8). There was a negative correlation between zooplankton density and distance from the ice edge ($r = -0.60$, $p = 0.0150$). Zooplankton densities also increased as the field season proceeded (Figure 1.9). There was a positive correlation between zooplankton density and day of the month ($r = 0.74$, $p = 0.0006$). Table 1.2 shows that copepods were the dominant zooplankton present in six subsamples collected in 1996. The two dominant copepod species were identified to life stages (Table 1.3).

Test for question one:

The null hypothesis that bowheads were not using Foxe Basin as a feeding habitat by selecting areas with high zooplankton concentrations was rejected ($t_{24} = 2.760$, $p =$

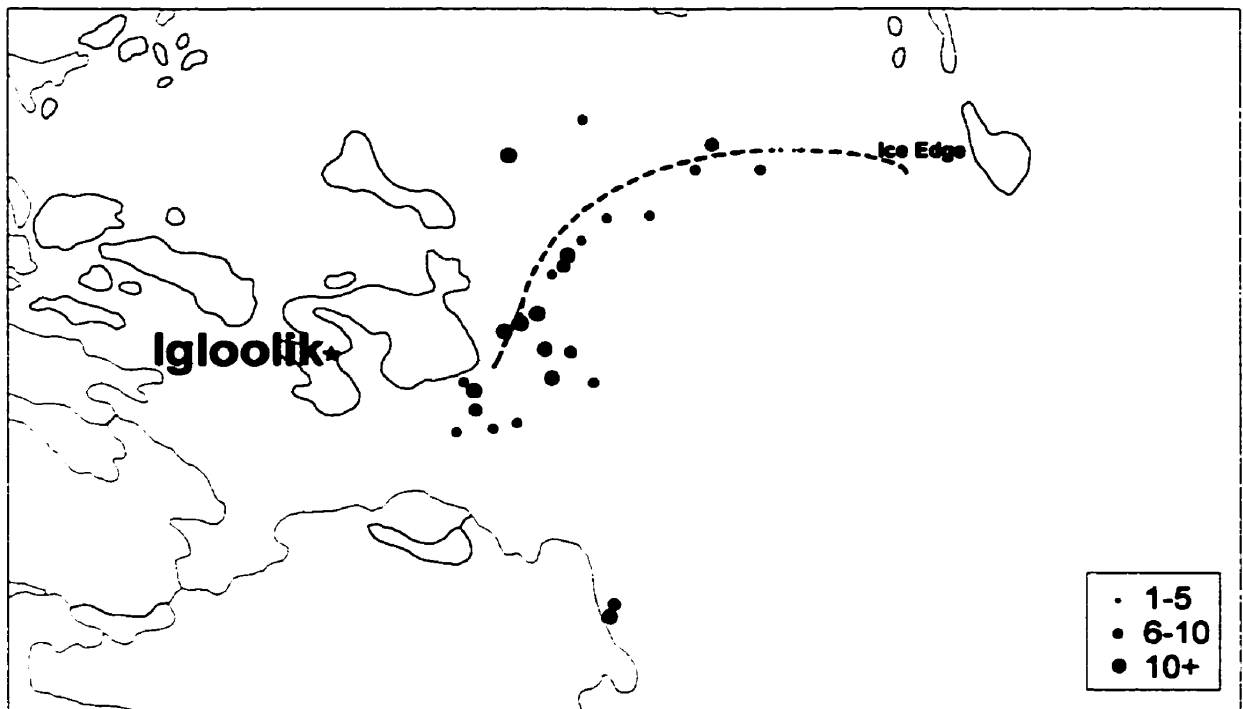


Figure 1.7. Locations of bowhead whale sightings in northern Foxe Basin, July 1996. Dashed line indicates the location of the ice edge on 7 July 1996.

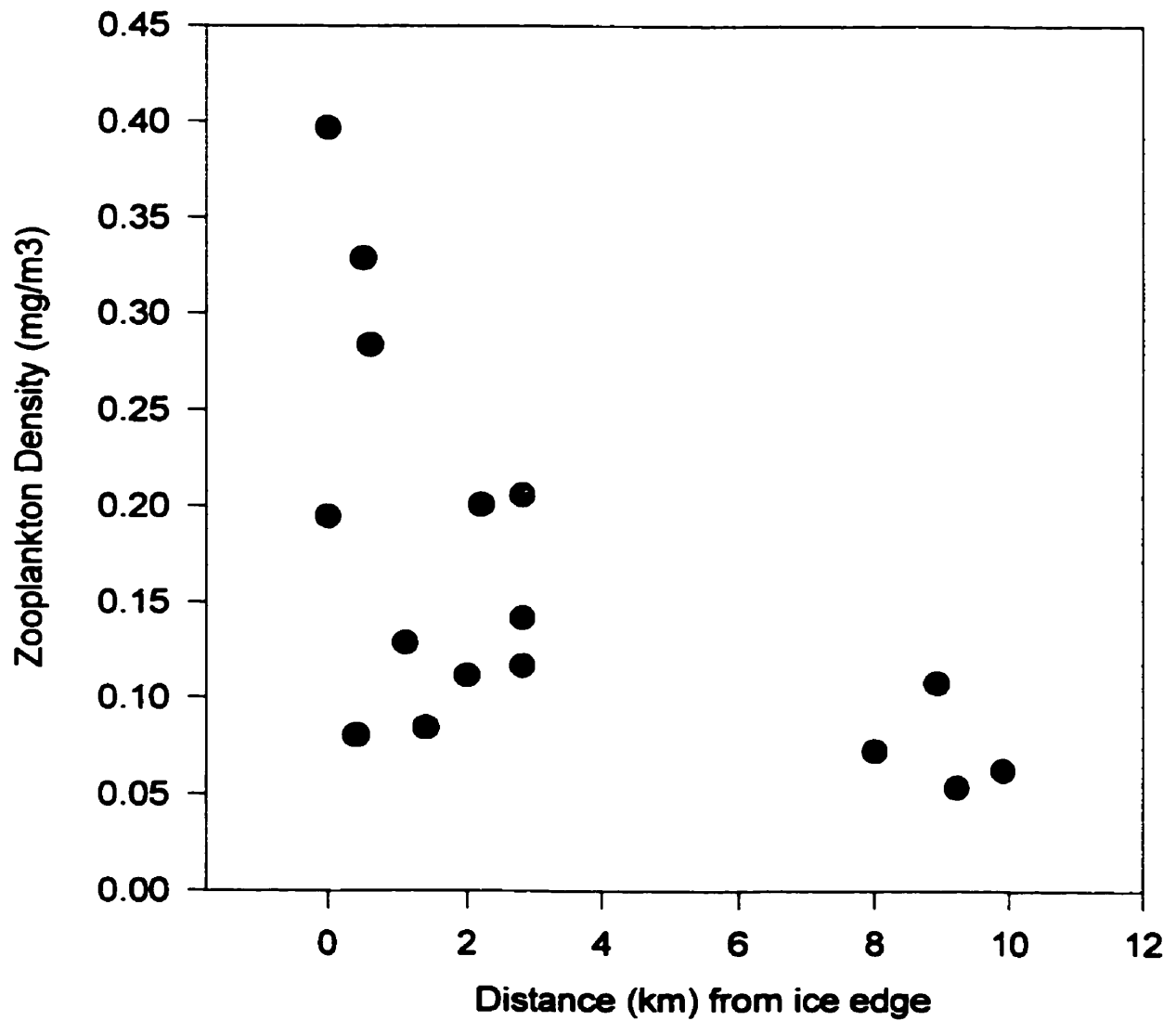


Figure 1.8. Changes in zooplankton density (mg/m³) with distance from the ice edge. There is a negative correlation between zooplankton density and distance from the ice edge ($r = -0.60$, $p = 0.0150$, $n = 17$).

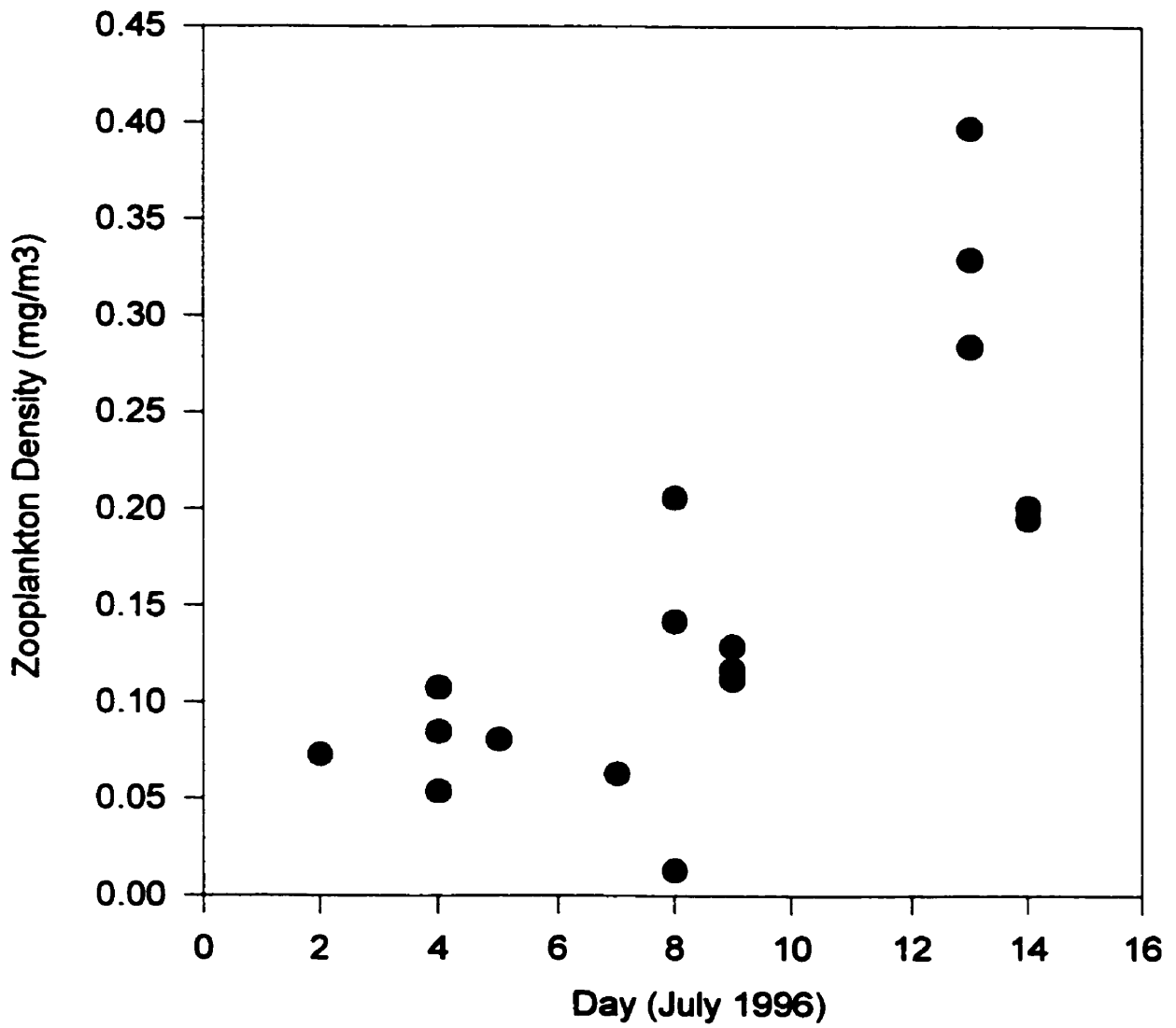


Figure 1.9. Changes in zooplankton density (mg/m^3) during July 1996. There is a positive correlation between zooplankton density and day of the month ($r = 0.74$, $p = 0.0006$, $n = 17$).

Table 1.2. Number of specimens counted for each zooplankton species or group in each of the six subsamples (selected at random from 42 zooplankton samples), collected in northern Foxe Basin July 1996.

Zooplankton Composition	Subsample Number and Date						Total
	F002 (2-Jul)	F004 (4-Jul)	F005 (8-Jul)	NF101 (8-Jul)	NF106 (9-Jul)	NF110 (14-Jul)	
Order: Copepoda							
<u>Calanus hyperboreus</u>	32	17	14	37	31	19	150
<u>Calanus glacialis</u>	159	20	87	114	71	40	491
<u>Pseudocalanus minutus</u>	54	44	58	65	40	18	279
<u>Metridia longa</u>	3		16	2	4	1	26
<u>Euchaeta</u> nauplii	1		1				2
					34		34
Order: Chaetognatha							
<u>Sagitta elegans</u>		1					1
Order: Cirripedia							
Barnacle nauplii	137	16				9	162
Order: Pteropoda							
<u>Limacina</u>	6		1	5	1	6	19
Order: Amphipoda	1				2	4	7
Order: Decapoda			1		1		2
Family: Medusae							
Cnidaria			2	2	1	1	6
Family: Spionidae							
Polychaete		1					1
Family: Mysidacea							
<u>Mysis oculata</u>			3		1		4

Table 1.3. Number of specimens counted in each life stage for two major zooplankton species in each of the six subsamples (selected at random from 42 zooplankton samples), collected in northern Foxe Basin July 1996.

Species Life Stage	Subsample Number and Date						Total
	F002 (2-Jul)	F004 (4-Jul)	F005 (8-Jul)	NF101 (8-Jul)	NF106 (9-Jul)	NF110 (14-Jul)	
<u>Calanus hyperboreus</u>							
<u>VI</u>	10	2	4	13	9	5	43
<u>V</u>	15	2	7	17	17	13	71
<u>IV</u>	7	9	3	7	4	1	31
<u>III</u>		1			1		2
<u>II</u>		3					3
<u>Calanus glacialis</u>							
<u>VI</u>	22	1	11	11	10	4	59
<u>V</u>	16	2	11	20	9	8	66
<u>IV</u>	86	13	41	66	42	27	275
<u>III</u>	35	4	24	17	10	1	91

0.011). There was a difference in zooplankton densities (mg/m^3) between areas where bowheads were present (mean = 0.156, s.d. = 0.104, n = 19) and areas where they were absent (mean = 0.085, s.d. = 0.037, n = 13), with zooplankton densities significantly higher in areas where bowheads were present.

Test for question two:

When the locations of sightings of feeding and socializing whales were mapped (Figure 1.11), there did not appear to be distinct habitats based on behaviours. There were 25 observation sessions in which feeding and socializing behaviour was observed and depth measurements taken. The null hypothesis that bowheads do not choose different water depths in which to feed and socialize was not rejected ($p > 0.05$) (Table 1.4), indicating that bowheads in northern Foxe Basin do not have discrete habitats based on water depth. The null hypothesis that bowheads do not choose different zooplankton densities in which to feed and socialize also was not rejected ($t_5 = -0.851$, $p = 0.433$), there was no difference in zooplankton densities (mg/m^3) between areas where bowheads were feeding (mean = 0.140, s.d. = 0.058, n = 6) and areas where they were socializing (mean = 0.200, s.d. = 0.149, n = 5). This suggests that bowheads in northern Foxe Basin do not have discrete habitats based on zooplankton density.

1997 Field Season

Ice-Edge Season:

Results for the first survey of the ice edge season are shown in Table 1.5 and Appendices 1a) to 1c). Sixty nine bowheads were seen during the first survey. The ice

Table 1.4. Contingency table of bowhead behaviours (feeding and socializing) in shallow or deep water in northern Foxe Basin, July 1996. Differences in behaviour with water depth were examined using a Fisher exact test. Water depths were not significantly different between behaviours (P=0.122).

Behaviour of whales in area sampled	Number of areas sampled by water depth	
	Shallow (< 50 m)	Deep (> 50m)
Feeding	11	2
Socializing	3	4

Table 1.5. Summary of data collected during the first survey of the ice-edge season. Refer to Table 1.1 for description of column headings, and Figure 1.5 for position of quadrats. Refer to Appendices 1a to 1c.

Quadrat Number	Whale1 (no.)	Ice Edge1 (absent=0) (present=1)	Temp Mean1 (°C)	Temp Range1 (°C)
1	9	1	0.0	0.5
2	0	1	0.7	2.1
3	0	0	0.2	1.0
4	16	1	0.0	0.8
5	10	1	-0.3	0.3
6	8	0	0.5	0.5
7	0	0	0.7	0.4
8	0	0	0.9	0.5
9	2	0	0.7	1.4
10	5	0	-0.2	0.3
11	1	0	0.6	1.1
12	0	0	0.4	0.3
13	2	0	1.1	0.1
14	0	0	1.0	0.9
15	0	0	-0.3	0.5
16	8	0	0.3	0.5
17	0	0	0.5	0.8
18	0	0	1.2	0.2
19	5	0	1.3	1.8
20	1	0	-0.4	0.1
21	0	0	0.6	0.5
22	0	0	0.4	0.6
23	1	0	1.3	0.1
24	0	0	1.7	0.1
25	0	0	0.0	nd
26	0	0	0.6	0.9
27	0	0	0.4	0.5
28	1	0	1.3	0.3

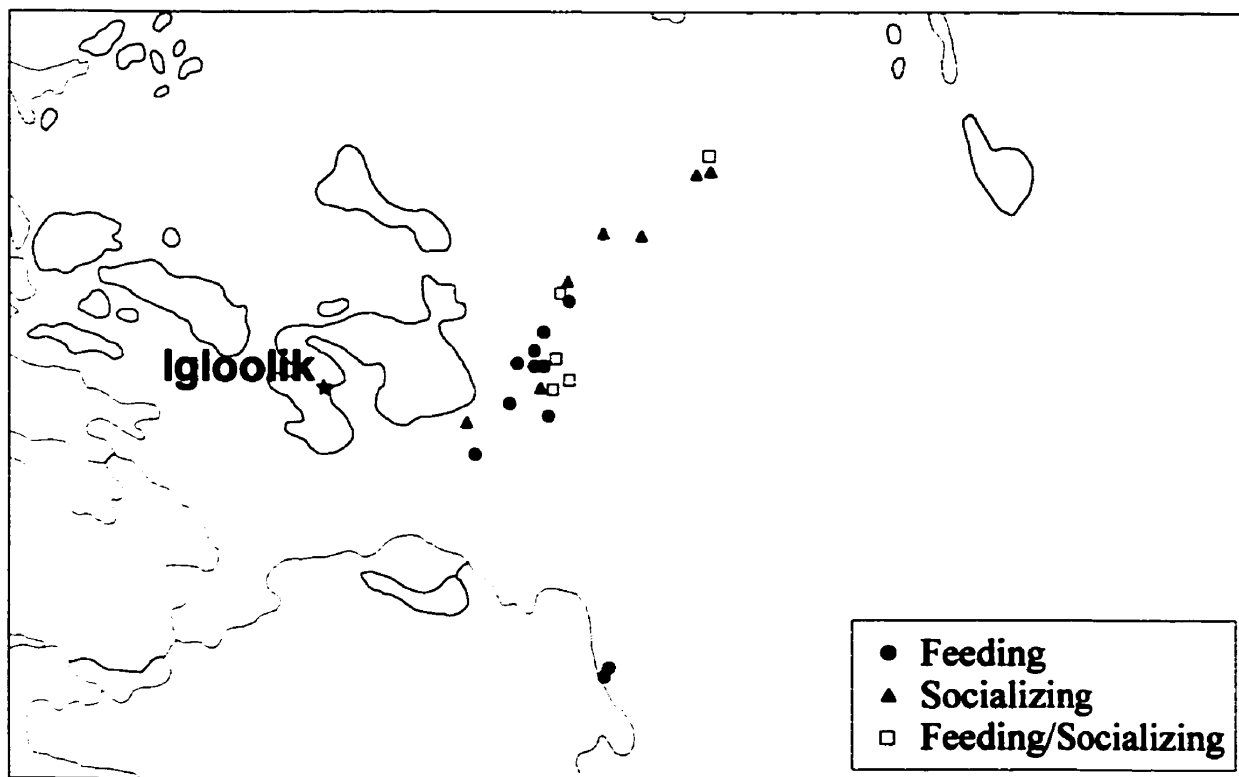


Figure 1.10. Locations of bowhead feeding and socializing areas in northern Foxe Basin, July 1996. Feeding/Socializing refers to observations of whales within a single group.

edge was present in the northwestern corners of quadrats 1, 2, 4 and 5. Mean sea surface temperatures varied from -0.4 to 1.7°C between quadrats, with a mean surface temperature of 0.5°C for the entire study area during the first survey. Sea-surface temperatures at the northern ends of the transects were lower than the temperatures farther out from the ice edge. Sea surface temperature range within quadrats varied from 0.1 to 2.1°C .

Results for the second survey of the ice edge season is shown in Table 1.6 and Appendices 1d) to 1f). A total of 21 bowheads were seen within the study area, although many bowheads could be heard and blows seen in the melt-holes within the land-fast ice. The ice edge was present on the northwestern corners of quadrats 1, 2, 5 and 9 during the second survey. Quadrat 4 had to be excluded from the analysis for the second survey because it was covered with ice and was not accessible. Mean surface temperatures varied from -0.2 to 6.0°C between quadrats, with a mean surface temperature of 2.9°C for the entire study area during the second survey. As in the first survey, sea surface temperatures at the northern ends of the transects were lower than the temperatures farther out from the ice edge. Sea surface temperature range within quadrats varied from 0.2 to 4.1°C .

Results for the combined ice edge surveys water depth are shown in Table 1.7 and Appendices 1g) to 1j). Maximum water depths ranged from 13 to 131 m between quadrats. Minimum water depths ranged from 2 to 102 m between quadrats. Maximum topographic variation ranged from 12 to 90 m between quadrats.

Table 1.6. Summary of data collected during the second survey of the ice edge season. Refer to Table 1.1 for description of column headings and Figure 1.5 for position of quadrats. Refer to Appendices 1d to 1f. (nd= data not measurable due to ice cover)

Quadrat Number	Whale2 (no.)	Ice Edge2 (absent=0) (present=1)	Temp Mean2 (°C)	Temp Range2 (°C)
1	1	0	4.9	1.6
2	7	1	0.1	0.8
3	0	0	4.4	0.5
4	nd	nd	nd	nd
5	1	1	-0.2	0.2
6	0	0	4.1	1.2
7	1	0	0.6	0.3
8	0	0	4.5	1.9
9	0	1	5.7	0.6
10	3	0	-0.2	0.4
11	0	0	3.5	1.3
12	0	0	0.8	0.6
13	0	0	4.5	2.4
14	0	0	4.3	1.8
15	3	0	1.3	0.5
16	0	0	4.0	2.9
17	1	0	1.1	0.8
18	0	0	3.9	2.8
19	0	0	4.3	0.3
20	0	0	0.7	1.4
21	3	0	4.6	4.1
22	0	0	1.1	0.7
23	0	0	2.4	2.6
24	0	0	4.6	1.2
25	0	0	0.3	0.9
26	0	0	6.0	0.3
27	1	0	3.4	0.7
28	0	0	3.2	1.1

Table 1.7. Summary of data collected during both surveys of the ice edge season. Refer to Table 1.1 for description of column headings and Figure 1.5 for position of quadrats. Refer to Appendices 1g to 1j.

Quadrat Number	WhaleTot (no.)	DepthMin (m)	DepthMax (m)	MaxTopVar (m)
1	10	71	131	46
2	7	26	81	68
3	0	53	79	33
4	16	28	75	63
5	11	75	113	34
6	8	102	117	13
7	1	26	104	75
8	0	12	79	85
9	2	5	28	82
10	8	27	94	71
11	1	75	104	28
12	0	81	100	19
13	2	31	97	68
14	0	2	17	88
15	3	17	65	74
16	8	62	75	17
17	1	71	81	12
18	0	73	103	29
19	5	2	20	90
20	1	13	29	55
21	3	14	62	77
22	0	62	81	23
23	1	81	107	24
24	0	8	13	38
25	0	10	69	86
26	0	29	76	62
27	1	69	80	14
28	1	71	105	32

Zooplankton densities in each quadrat sampled and the number of bowheads seen within 1 km of the sample is shown in Table 1.8. Zooplankton densities ranged from 0.037 to 0.271 mg/m³ between quadrats.

Open Water Season:

Results for the boat survey (survey three) during the open water season are shown in Table 1.9 and Appendices 1k) to 1m). A total of 12 bowheads were seen during the boat survey. Pack ice was present in quadrats 6, 11, 12, 17, 18, 19, 22, 23, 24 and 25 during the boat survey. Mean surface temperatures varied from 0.3 to 3.2°C between quadrats, with a mean surface temperature of 2.0°C for the entire study area. Surface temperature range within quadrats varied from 0.1 to 3.0°C.

Results from the combined boat and aerial surveys of the open water season are shown in Table 1.9 and Appendices 1n) to 1q). Maximum water depths ranged from 73 to 141 m, minimum water depths ranged from 42 to 128 m and maximum topographic variation ranged from 6 to 65 m between quadrats.

Zooplankton densities in each quadrat sampled and the number of bowheads seen within 1 km of the sample are shown in Table 1.9. Zooplankton densities ranged from 0.079 to 0.136 mg/m³ between quadrats.

Test for question three:

Ice-edge Season:

TempMean was significantly lower (colder) and ZooDensity was significantly higher in quadrats where bowhead whales were sighted (Table 1.10). In quadrats where

Table 1.8. Summary of data collected during the ice edge season for zooplankton samples. Refer to Table 1.1 for description of column headings and Figure 1.5 for position of quadrats.

Quadrat Number	Zooplankton Density (mg/m³)	Whale3 (no.)
4	0.271	15
5	0.085	8
7	0.046	0
11	0.088	0
13	0.037	0
14	0.109	0
23	0.055	0
24	0.037	0
25	0.156	0
26	0.051	1
27	0.093	1

Table 1.9. Summary of data collected during the open water season (survey three). Refer to Table 1.1 for description of column headings and Figure 1.6 for the position of quadrats. Refer to Appendices 1k to 1q.

Quadrat Number	Whale4 (no.)	Pack Ice (present=1) (absent=0)	Temp Mean (°C)	Temp Range (°C)	Whale5 (no.)	Depth Max (m)	Depth Min (m)	MaxTopVar (m)	Zooplankton Density (mg/m3)	Whale (no.)
1	0	0	1.8	0.2	1	73	42	42	-	-
2	0	0	2.7	0.3	4	96	56	42	-	-
3	0	0	2.8	0.7	2	90	51	43	-	-
4	0	0	2.5	0.4	0	111	62	44	-	-
5	0	0	2.2	0.2	0	74	55	26	-	-
6	0	1	1.4	0.6	2	110	73	34	-	-
7	3	0	3.0	0.2	17	141	96	32	0.085	3
8	0	0	3.0	0.3	0	129	90	30	-	-
9	2	0	2.9	0.4	11	139	111	20	-	-
10	0	0	2.3	0.3	0	123	74	40	-	-
11	0	1	1.4	0.2	7	136	83	39	-	-
12	1	1	3.0	0.8	5	125	71	43	-	-
13	3	0	2.8	0.9	3	138	119	14	0.146	3
14	2	0	3.2	0.4	2	139	126	9	-	-
15	0	0	2.3	0.2	0	127	119	6	-	-
16	0	0	1.3	0.4	0	140	105	25	-	-
17	0	1	1.9	2.2	0	128	71	45	-	-
18	0	1	1.1	2.3	0	127	100	21	-	-
19	1	1	2.1	3.0	1	141	128	9	-	-
20	0	0	1.6	1.1	0	119	82	31	0.079	0
21	0	0	1.2	0.3	0	135	47	65	-	-
22	0	1	1.2	0.6	0	122	87	29	-	-
23	0	1	1.5	0.9	0	103	59	43	-	-
24	0	1	0.3	0.1	2	131	121	8	0.136	0
25	0	1	1.3	0.1	0	88	71	19	-	-

Table 1.10. Comparisons of whale sightings and zooplankton densities (matrix AB) with habitat variables (matrix C) in northern Foxe Basin during the ice edge season, July 1997. Mantel test correlation's are significant if p-value < 0.05. Refer to Table 1.1 for variable (matrix A, B, C) abbreviations and descriptions.

Ice Edge Season 1997			
Matrix AB	Matrix C	r-value	p-value
Whales1 - Distance1	-	-0.1506	0.003
Whales1 - Distance1	Ice Edge1	-0.1359	0.001
Whales1 - Distance1	TempMean1	-0.0282	0.012
Whales1 - Distance1	TempRange1	0.0051	0.334
Whales2 - Distance2	-	-0.0275	0.369
Whales2 - Distance2	Ice Edge2	-0.0306	0.229
Whales2 - Distance2	TempMean2	-0.0096	0.254
Whales2 - Distance2	TempRange2	-0.0025	0.512
Whales3 - Distance3	-	-0.1957	0.026
Whales3 - Distance3	ZooDensity	-0.1357	0.007
WhalesTot - Distance1	-	-1.9278	0.001
WhalesTot - Distance1	DepthMax	-0.0904	0.402
WhalesTot - Distance1	DepthMin	-0.2255	0.172
WhalesTot - Distance1	MaxTopVar	-0.2261	0.184
ZooDensity - Distance3	-	-0.0650	0.241
ZooDensity - Distance3	Ice Edge	-0.1528	0.018
ZooDensity - Distance3	TempMean	-0.0311	0.287
ZooDensity - Distance3	TempRange	0.0103	0.294
ZooDensity - Distance3	DepthMax	-0.0330	0.441
ZooDensity - Distance3	DepthMin	-0.0645	0.198
ZooDensity - Distance3	MaxTopVar	0.0005	0.469

the land-fast ice edge was present, bowhead numbers and ZooDensity were significantly higher than in quadrats where ice was not present. Ice Edge and TempMean were significantly correlated.

Open Water Season:

DepthMax was significantly higher ($p = 0.036$) in quadrats where bowhead whales were sighted (Table 1.11). Bowhead numbers were significantly higher ($p = 0.027$) in quadrats where pack ice was absent than in quadrats where pack ice was present. Most bowhead sightings were in quadrats next to areas of pack ice. During the open water season deep-water areas and possibly the absence of pack ice influenced bowhead distribution. There were not enough zooplankton samples collected during the open water season in study area 'B' to analyze.

Discussion

In Isabella Bay, whales congregate in areas that correspond to major underwater bathymetric features and their behavioural activities (feeding and socializing) vary with location (Finley 1990, Finley *et al.* 1994). Most feeding activity takes place in the two deep troughs, Aqvik and Kater, as this is where the food is most concentrated. Social-sexual activity takes place on Isabella Bank probably because it offers both protection from killer whales and shelter from high sea states and strong currents (Finley 1990, Finley *et al.* 1994). The shallow bank allows the whales to avoid turbulent offshore or deep-sea conditions, which may help the whales to minimize energy expenditure. Otherwise, bowheads usually travel between areas. Bowheads in Isabella Bay appear to

Table 1.11. Comparisons of whale sightings (matrix AB) with habitat variables (matrix C) in northern Foxe Basin during the open water season, August 1997. Mantel test correlation's are significant if p-value < 0.05. Refer to Table 1.1 for variable (matrix A, B, C) abbreviations and descriptions.

Open Water Season 1997			
Matrix AB	Matrix C	r-value	p-value
Whales4 - Distance4	-	0.1048	0.068
Whales4 - Distance4	Pack Ice	0.0909	0.027
Whales4 - Distance4	TempMean	0.0080	0.288
Whales4 - Distance4	TempRange	0.0051	0.370
Whales5 - Distance4	-	0.0447	0.328
Whales5 - Distance4	DepthMax	0.0289	0.036
Whales5 - Distance4	DepthMin	0.0174	0.149
Whales5 - Distance4	MaxTopVar	0.0036	0.440

select different microhabitats based on feeding and socializing. In Foxe Basin I did not find the kind of a relationship seen in Isabella Bay. Bowheads in Foxe Basin aggregated along the land-fast ice edge in July 1996 (Figure 1.7). The whales in Foxe Basin appeared to be choosing one habitat type because their behavioural activities were not spatially separated. I did not see a difference in zooplankton densities or water depths between feeding and socializing areas. In Foxe Basin, the whales may use the same areas for socializing and feeding possibly because the ice edge offers both food for feeding habitat and shelter for socializing habitat. The waters were generally more calm at the ice edge than they were farther out from the land-fast ice and it was in these calm waters that feeding and socializing behaviours were observed (pers. obs.). There were also times where feeding behavior was interspersed with socializing behavior. Studies of bowheads in the Beaufort Sea show a similar pattern to that in northern Foxe Basin. Richardson *et al.* (1995) observed that feeding and socializing behaviours were often seen in deep as well as shallow areas (most sightings were in shallow areas <50 m deep) and socializing was often interspersed with feeding.

High zooplankton densities are believed to be important to feeding bowhead whales (Griffiths and Buchanan 1982 in Bradstreet and Fissel 1986). Bradstreet and Fissel (1986) found that during the summer months in the Beaufort Sea, bowheads congregate in areas where copepod biomass is high in relation to that in other areas. In northern Foxe Basin, I also found significantly higher concentrations of zooplankton in areas where bowheads were present than in areas where they were absent (Figure 1.10).

In July 1996 during the ice edge season, bowhead distribution, high zooplankton density and the presence of the ice edge were all significantly associated with each other

(Table 1.11). This association suggests that bowheads are using the ice edge as a feeding habitat. Copepods are believed to be the major food source for bowhead whales in the Alaskan Beaufort Sea (Griffiths 1999), Canadian Beaufort Sea (Bradstreet 1986), and in Isabella Bay in Davis Strait (Finley *et al.* 1994). In Foxe Basin, the six zooplankton subsamples analyzed for species composition also showed copepods to be the dominant group (Table 1.2). The arctic copepod *Pseudocalanus* can be highly concentrated in the first few centimeters under land-fast ice during the spring (Conover *et al.* 1986).

Conover *et al.* (1986) believes that the *Pseudocalanus* feed opportunistically near the ice-water interface, either directly on the attached epontic (under ice) algae or on algae as it erodes from the ice. Smith and Nelson (1985) found a dense phytoplankton bloom near a receding ice edge off the coast of Antarctica. Phytoplankton is the food source of most zooplankton, thus it is likely that where phytoplankton is dense, zooplankton will also be found in high densities. This, along with high concentrations of *Pseudocalanus*, may make the area under the ice a much richer food source for bowheads than areas in open water.

In Foxe Basin there is a distinct correlation between the time of successful reproduction of plant-eating species (phytoplankton) and the presence of plant food (Grainger 1959). Temperature change and food supply (phytoplankton) are believed to be the two most probable inducements for the spawning of zooplankton (Thorson 1946 *in* Grainger 1959). Smith and Nelson (1985) also found that the phytoplankton bloom was restricted to waters where ice-melt had reduced the salinity. In Foxe Basin the salinity during the ice edge season averaged 29.2 ppm in open water areas and it averaged 20.4 ppm along the ice edge with concentrations as low as 7 to 11 ppm during ice edge break-

up (Appendix 1r). This region of low saline water at the ice edge is due to the melting of the land-fast ice edge.

Other whale species have been found to be associated with ice. Minke whales (*Balaenoptera acutorostrata*) were associated with ice from the spring to the fall (Ribic *et al.* 1991). Ribic *et al.* (1991) hypothesized that the presence of minke whales in the marginal ice zone was due to the enhanced zooplankton productivity along the ice edge. A similar trend occurs in northern Foxe Basin with bowheads during the ice edge season in late June and early July.

In August during the open water season, bowhead distribution was significantly associated with deep waters and the absence of pack ice, although most bowhead sightings were in areas adjacent to pack ice (Appendix 1k). This distribution suggests a preference of bowheads to be close to ice, but this hypothesis was not tested.

There is evidence that oceanographic features are important in determining zooplankton abundance. In Isabella Bay, high zooplankton concentrations are associated with the deep-water troughs (Finley *et al.* 1994) and, in the Bay of Fundy, high zooplankton concentrations are associated with physical discontinuities (fronts or cold and warm water) (Murison and Gaskin 1989). I was unable to determine if bowheads select areas with high zooplankton abundance during the open water season due to a low sample size. It is possible that during the open water season zooplankton occurs in deep water areas, as in Isabella Bay.

In Isabella Bay, currents play an important role in the distribution of the zooplankton (Finley *et al.* 1994). In Foxe Basin the steady influx of ice and water via Fury and Hecla Strait may contain high concentrations of zooplankton brought down

from the high arctic (pers comm Buster Welch). Although I did not measure the current in Foxe Basin, there was a notable difference in the current between July during the ice edge season and August during the open water season, with the open water season having a stronger current (pers. obs.). Sadler (1982) calculated the net annual transport into Foxe Basin ($1.2 \times 10^{12} \text{m}^3$) to be about one-quarter of the total volume of the basin, with that of the shallow northern half being ($1.5 \times 10^{12} \text{m}^3$) approximately equal to the total transport (Sadler 1982). This would have important effects on Foxe Basins oceanography particularly in the northern region, which would in turn play a significant role in the distribution of zooplankton and bowheads.

Conclusions and Future Research

Bowheads in northern Foxe Basin do not select different microhabitats based on different behaviours (feeding and socializing) as seen in Isabella Bay. They appear to use a single habitat type for all activities, similar to that seen in the Bering/Beaufort Sea stock.

Bowheads during the ice edge season (July 1996/97) selected ice edge habitat. If bowheads consume the bulk of their annual food requirements during the summer months in Foxe Basin, then the ice edge habitat is selected primarily because it is associated with high concentrations of copepods. This would be the most probable conclusion as feeding behaviour was the predominant activity observed during the ice edge season (Chapter 2). There may be other secondary advantages to selecting ice edge habitat such as shelter from high sea states or protection from killer whales, although killer whales have not been seen in Foxe Basin for over 20 years (pers comm. resident of Igloolik).

During the open water season (August 1997) when the land-fast ice edge has melted, bowheads selected deep-water areas. Results from a comparison of zooplankton samples collected were inconclusive, due to a small sample size. However, the accumulation of zooplankton is associated with deep-water areas in other studies (Finley *et al.* 1994, Woodley 1992). Bowheads may be selecting areas with deep water because that may be where the zooplankton is concentrated during this time of year but more research would have to be done before any conclusions could be made.

Future research on habitat characteristics of this population of bowhead whales should focus on zooplankton distributions in Foxe Basin. Further study of zooplankton distribution during the ice-edge season and the open-water season would help to understand the distribution of bowheads and thus their habitat preferences. Although the current in Foxe Basin was not measured in my study, it may play a significant role in the distribution of the zooplankton during the open water season. Currents could influence where both the pack ice and zooplankton occur. Bowheads tend to occur on the south side of the channel possibly because the zooplankton accumulates there as a result of the current (pers comm Sue Cosens). The ice may end up there as well so this loose association of whales with the ice could be incidental to the influence of currents (pers comm Sue Cosens).

A more detailed study of environmental characteristics and localized phenomena (such as changes in pack ice distribution) that influence zooplankton concentrations in Foxe Basin would give a better understanding of bowhead distributions.

Chapter 2

Behaviour of bowhead whales (*Balaena mysticetus*) along the ice edge in northern Foxe Basin, Nunavut

Introduction

Whale Behaviour

In order to discuss variation in whale behaviour, a working definition of behaviour must be produced. Würsig and Clark (1993) stated that because much of whale behaviour occurs below the surface of the water, only broad categorizations of general behaviours can be defined. These are generally broken down into feeding, travelling, resting, and socializing.

Feeding behaviours vary among whale species. Bowhead whales belong to the Suborder Mysticeti (Family Balaenidae). The Suborder Mysticeti is composed of species that have finely fringed comb-like plates called baleen, hanging from their upper jaw. These whales feed by taking in large quantities of water and prey and then forcing the water out through the baleen which acts as a sieve in which to trap the prey (Würsig, 1988). Although all baleen whales are filter feeders, the structure of the baleen plates varies among families, reflecting the diversity of feeding behaviours in the suborder. In the family Balaenidae, the baleen plates are long and finely fringed. Whales in this family feed primarily in the water column and at the surface and generally feed by moving slowly forward through the water with their mouths wide open, capturing clouds of

zooplankton that includes free-swimming copepods and other crustaceans (Würsig, 1988).

There are three types of feeding behaviour seen in bowhead whales: 1) water-column feeding, 2) skim feeding, and 3) bottom feeding, which vary in importance depending on the distribution of zooplankton (Würsig, 1988; Würsig and Clark, 1993).

Würsig and Clark (1993) identified water-column feeding when a whale dove repeatedly in the same area and generally remained submerged, surfacing only long enough to take in a series of breaths. They also found a high incidence of dives with raised flukes and frequent defecation associated with the behaviour. This type of feeding behaviour occurs when the concentration of zooplankton is highest at mid-depths. When Richardson and Finley (1989) looked at feeding behaviour in eastern arctic bowhead whales migrating south past Cape Adair in the autumn and summering at Isabella Bay in the late summer-early autumn, they found water column feeding to be the predominant feeding mode, occurring in 94% of bowheads observed feeding.

Würsig and Clark (1993) describe skim feeding whales as ones that move slowly and deliberately at the surface with their heads held just above the water and their mouths open wide. They generally orient with their backs to the water's surface or swim on their sides with the lower jaw dropped to varying degrees. They feed alone or in groups of 2-14 individuals, forming echelons reminiscent of geese flying in V formation (Würsig 1988). It is not known why echelon feeding is advantageous but it is believed that each whale behind the lead one gains an advantage by having the wall of another whale beside its mouth, a wall towards which prey is not likely to try to escape, thereby effectively increasing prey intake (Würsig and Clark 1993). At other times, they swim abreast and

parallel to one another (Würsig and Clark, 1993). This type of feeding behaviour occurs when the concentration of zooplankton is at the water surface. In the study done by Richardson and Finley (1989), skim feeding occurred in only 4% of bowheads observed feeding in the eastern arctic bowhead population.

Bowheads from the Bering-Chukchi-Beaufort stock occasionally feed on the bottom substrate (usually at depths of less than 60 m) along the coast but it is not clear how they are able to do so with their type of baleen (Würsig, 1988). Würsig and Clark (1993) believe they skim the substrate and take in clouds of prey near the bottom. Lowry and Burns (1980) and Carroll *et al.* (1987) reported bottom-dwelling prey such as mysids and gammarid amphipods in bowhead stomachs. Würsig and Clark (1993) identified bottom feeding by a whale, when it surfaced with large amounts of mud streaming from its mouth. Bottom-feeding whales were generally widely separated when they surfaced. They also found that bottom-feeding whales were very localized in distribution and showed a tendency toward synchrony of surfacing. This type of feeding behaviour occurs when the supply of food is limited to invertebrates in the bottom substrate or if the distribution of zooplankton is very close to or on the bottom substrate.

Socializing whales are generally tightly grouped and engaged in a variety of physical interactions or aerial activities (breaching, flipper and tail slaps). Physical interactions considered to be active socializing can range from touching, pushing, nudging or chasing each other, to apparent mating or precopulatory activity (Würsig *et al.*, 1984a,c). Some studies consider whales that are within a half body length of each other and not necessarily engaged in active socializing behaviour to also be engaged in a form of social behaviour (Richardson and Finley 1989). A group of whales is considered

to be sexually active if it is known to contain both males and females and a male is seen with his penis extended (Clark, 1983). Sexually active bowheads have been observed during many months and there is no clear indication of a specific mating period (Koski *et al.*, 1993). However, data on fetus size and on calving period from the Bering/Chukchi/Beaufort stock suggest that conception probably occurs during a period in late winter or spring (Koski *et al.*, 1993).

Clark (1983) identified resting behaviour in whales when there were no social interactions between individuals and the whales remained in the same location without any evidence of physical exertion. He found that most resting groups drift at the surface with their nares and a portion of their backs above the water, or they may remain underwater in the same spot and surface occasionally to breath. They can occur in groups, pairs or as singletons.

Local travel is a common activity in whales and involves mainly singletons or pairs of whales. Most travelling whales observed in Isabella Bay moved directly between feeding and socializing areas (Finley *et al.* 1994). Travel behaviour between feeding areas also occurred when feeding habitats were in close proximity. The directed movements were linear or curvilinear. Richardson and Finley (1989) observed bowhead travelling behaviour in Isabella Bay over a wide variety of distances from shore and over different water depths.

Breathing Characteristics

Because whales are forced to surface and breath during any underwater activity, breathing exerts a great influence on the behaviour of whales (Würsig *et al.* 1984).

Breathing characteristics are measured using three different variables. 1) Surfacing is the time a whale spends at the surface of the water between dives. 2) Respiration is the number of blows and the mean blow interval of a single surfacing bout, and 3) diving is the time a whale spends under the water between surfacings. Breathing characteristics should differ during different behaviours and can thus be used as a quantitative description of whale behaviour (Dorsey *et al* 1989).

In this chapter I looked at how the behaviours of bowheads changed as the land-fast ice-edge melted, from a solid mass to the break-up of the ice-edge. In this study I also tested the hypothesis that breathing characteristics differ during different behaviours. Dorsey *et al.* (1989) found that bowheads spent a longer proportion of time at the surface when socializing than during non-socializing behaviours. I predicted that a group of socializing whales would have a longer surface time than whales that are not socializing. Hamner *et al.* (1988) suggested that right whales (*Eubalaena australis*) hyperventilate before long dives, allowing them to dive for longer periods of time. I predicted that bowheads would hyperventilate during water-column feeding behaviour, resulting in longer dive times and smaller blow intervals than socializing and travelling whales. Carroll *et al.* (1987) observed under-ice feeding by bowheads during the spring migration of 1985 in the Beaufort Sea. I predicted that if bowheads are feeding under the land-fast ice-edge in northern Foxe Basin, breathing characteristics will not differ between feeding and ice-edge behaviour.

Methods and Materials

Study Area

The study area where bowhead behavioural observations in northern Foxe Basin were made is described in Chapter 1. Most behavioral data were collected during the 1996 field season along the total length of the ice-edge. Only a few breathing characteristics were measured in 1997.

In Foxe Basin, freeze-up begins in mid-October and by the end of October, the northern half of the basin is 9/10 covered by ice (Prinsenbergh, 1986). It is during this time that land-fast ice forms in sheltered areas, developing along the shore and spreading into the sea until it reaches its maximum offshore extension, beyond which the region of the pack ice is found (Hobbs, 1950). The land-fast ice in northern Foxe Basin forms in a similar location each year (pers. com. Brad Parker). In early spring the Hall Beach polynya grows to create an open water area just south of Igloolik (Fig. 2.1). This open water area is bounded to the north by the land-fast ice-edge and to the east and south by pack ice. By the first of July pieces of the land-fast ice-edge begin to break off and melt, and by late July to early August open water occupies the area that was once covered by land-fast ice. The area north of Igloolik is then open to the east entrance of Fury and Hecla Strait through which ice floes (mostly pack ice) come down from the Gulf of Boothia. In 1996, the land-fast ice did not begin to break-up and melt until mid-July and the ice-edge was present until late-July.

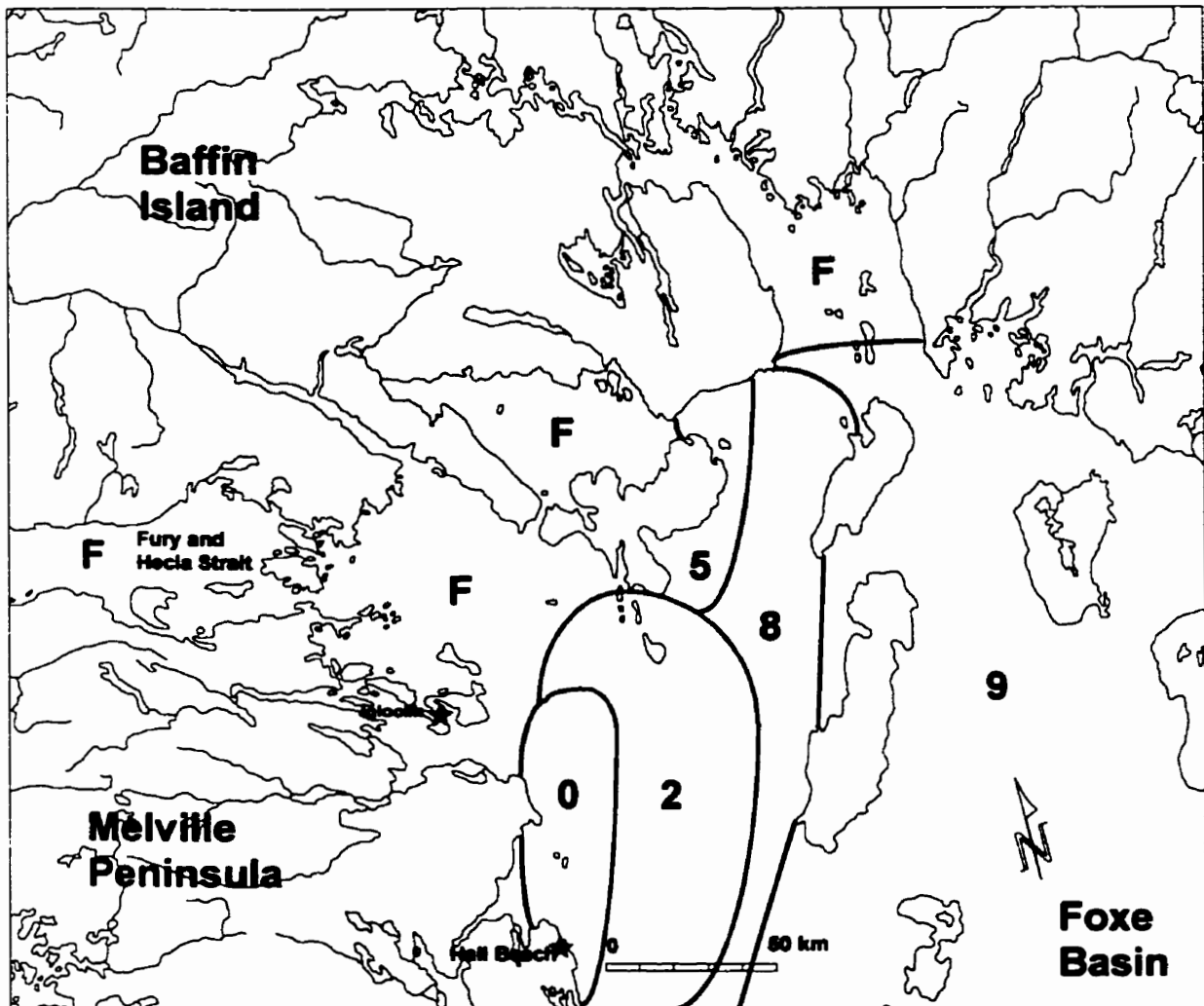


Figure 2.1. Map of northern Foxe Basin showing mean ice concentrations for the time period of late June early July (from Prinsenberg 1986). Numbers indicate the area covered by ice in units of tens, F = frozen solid (land-fast ice). 0 represents the expansion of the Hall Beach polynia.

Data Collection

Behavioural data were collected on bowheads in northern Foxe Basin from aboard a 15- foot boat driven by Adam Qanatsiaq a resident of Igloolik. Behavioural observations were made from 1 to 25 July 1996, at which time the land-fast ice was still present in some form. Behavioural data were recorded on 14 of the 25 days when weather conditions were acceptable for boat travel.

We travelled east along the ice-edge or south towards Melville Peninsula. Using binoculars, we scanned the water for whales while the boat was moving at about 18 km/h. If no whales were seen within 10 minutes, the boat was stopped and we listened to hear whales blowing. Blows can be heard for several miles. If no blows were heard in five minutes we then continued to look for the whales while the boat was moving. We continued in this fashion until a whale or group of whales was spotted. When a whale or group of whales was spotted, we slowly moved to within 100 m of them. When close enough, the engine was turned off and behavioural observations began on the whales for a maximum of three hours or until they moved out of the area. If whales were travelling through the area, they were not followed to avoid disturbing them. The whales usually did not react to the presence of the boat as long as it was stationary with the engines off. If the whales did react to the boat while the observation session was taking place, the session was stopped and we moved into a new area.

For each whale or group of whales observed, behaviour with respect to feeding, socializing, travelling, resting, or ice-edge was noted. Only water-column feeding data were used in my analysis because bottom feeding was not observed and skim feeding was only observed once during the field season. Whales were described as feeding if they

dove repeatedly in the same area, dove with fluke-out dives or showed synchrony of surfacing. Whales were described as socializing if they engaged in active social interactions such as touching, pushing, nudging or chasing. Whales were described as travelling if they were moving through an area at medium speed and were orientated in the same direction after repeated surfacing and dives. Whales were described as resting if they were motionless at the surface or just below the surface for a period greater than five minutes. Ice-edge behaviour was defined as diving into or out of the water under land fast ice. Ice-edge was given its own behaviour because it could not be determined whether the whales were feeding under the ice or if they were testing the ice for openings on the other side.

Once a behaviour was identified, breathing characteristics were measured. These included: 1) duration of dive, 2) duration of surfacing, 3) number of blows per surfacing, and 4) mean time interval between blows, per surfacing. Dive durations were recorded only when whales were individually identifiable from one surfacing to the next. Surface duration and number of blows per surfacing were measured from the time the whale surfaced to the time it dove. The mean blow interval was calculated by dividing the surface duration by the number of blows for each surfacing.

Socializing bowheads were generally observed in large groups of eight or more, which made it difficult to keep track of a single individual. For this reason the duration of dives and surfacings of socializing bowheads were timed as a group (surface time starts when the first whale surfaces and stops when all whales are down, dive time starts when all whales are down and stops when the first whale surfaces). The number of blows and mean blow interval could not be measured for socializing groups. For each observation

session in which feeding, travelling, resting, and ice-edge behaviour was identified, each whale was treated as an independent observation. The size of the group and the time I spent observing them was also noted. The observational data were collected using binoculars and a stopwatch. The location of each whale sighting was estimated using a hand-held global positioning system (GPS). When multiple sightings of whales were recorded in one area, the first was used to establish location.

Data Analysis

Time Budget:

A time budget was used to look at the change in bowhead behaviour as the land-fast ice-edge slowly melted. I observed three phases in the melting of the land-fast ice-edge. In phase one (solid phase), the ice was a solid ice mass with $< 1/3$ melt water covering its surface. In phase two (melt-hole phase), the ice showed signs of melting such as the formation of melt holes through the ice and water covered $1/3$ to $2/3$ of the ice surface. In phase three (break-up phase) large pieces of the ice-edge broke off and the melt holes got bigger. During phase three, water covered $> 2/3$ of the ice surface.

The study period was divided into three consecutive time periods coinciding with the three phases of the land-fast ice. During week one (1 to 7 July 1996) of the time budget, I recorded the time (min) spent engaged in each behaviour when the ice-edge was in its solid phase. In week two (July 8 to 14, 1996), I recorded at the time spent engaged in each behavior when the ice-edge was in its melt-hole phase. In week three (July 15 to 21, 1996) I recorded at the time engaged in each behavior when the ice-edge was in its break-up phase (Table 2.1).

Table 2.1. Bowhead time budgets measured for five behaviours for a three-week consecutive time period coinciding with three phases in the land-fast ice. Data collected between 1 to 21 July 1996. Missing days are due to poor weather conditions.

Land-fast Ice Phase	Date 1996	TIMED BEHAVIOURS (min)				
		Feeding	Ice Edge	Socializing	Travel	Rest
1. Solid (week one)	3-Jul	80	-	-	30	-
	4-Jul	339	-	-	-	-
	5-Jul	125	-	-	-	-
	6-Jul	115	-	-	-	-
	7-Jul	5	5	-	28	-
2. Melt-holes (week two)	8-Jul	67	-	222	-	-
	9-Jul	117	15	94	40	-
	13-Jul	302	206	113	15	60
	14-Jul	149	100	-	-	-
3. Break-up (week three)	16-Jul	-	284	30	107	-
	17-Jul	-	-	-	10	-
	20-Jul	-	142	-	-	-
	21-Jul	-	115	-	-	-

Breathing Characteristics:

To determine whether breathing characteristics can be used as a quantitative description of whale behaviour, breathing characteristics were compared between behaviours. Each whale was treated as an independent observation unless there was a group of socializing bowheads, in which case the group was treated as an independent observation. Breathing characteristics (surface time, etc.) were analyzed separately for each of the behaviours except for resting because there were not enough observations of this behaviour. Means and standard deviations of breathing characteristics for each of the behaviours were calculated. Some of the breathing characteristics were not normally distributed in which case they were transformed by squaring the data. ANOVA was used to test for differences in mean breathing characteristics between behaviours. Differences between mean breathing characteristics were analyzed for statistical significance by calculating a One-Way ANOVA of the F statistic using the One-Way ANOVA test in the SPSS for Windows program (Version 7.5). If the means were significantly different (F-statistic, $p < 0.05$), multiple comparison tests were then used to determine which behaviour accounted for the difference. Variances between the means were not equal thus a Tamhane test was used as the multiple comparison test because it does not assume equal variances (SPSS 1996). I concluded that mean breathing characteristics were significantly different between behaviours if pair-wise distances were significant (F-statistic, $p < 0.05$) (Zarr 1999). The test hypotheses (1) were:

- H_0 = Breathing characteristics do not differ during different behaviours.
- H_a = Breathing characteristics differ during different behaviours.

The hypotheses was tested by testing three more specific hypotheses related to specific behaviours. The null hypothesis was to be rejected if all three subsequent null hypotheses (1a,1b,1c) were rejected. The test hypotheses (1a) were:

- H_0 = Socializing bowheads will not have significantly longer surface times than whales that are not socializing.
- H_a = Socializing bowheads have significantly longer surface times than whales that are not socializing.

The test hypotheses (1b) were:

- H_0 = Feeding bowheads will not have significantly lower mean blow intervals than whales that are travelling.
- H_a = Feeding bowheads have significantly lower mean blow intervals than whales that are travelling.

The test hypotheses (1c) were:

- H_0 = Feeding bowheads will not have significantly longer dive times than whales that are travelling and socializing.
- H_a = Feeding bowheads have significantly longer dive times than whales that are travelling and socializing.

If the null hypothesis (1) is rejected I would then test the prediction that bowheads are feeding when they dive under the landfast ice-edge. The test hypotheses (2) were:

- H_0 = Ice-edge and feeding behaviour do not have similar breathing characteristics (surface time, number of blows per surfacing, and mean blow interval).

- H_1 = Ice-edge and feeding behaviour have similar breathing characteristics (surface time, number of blows per surfacing, and mean blow interval).

Results

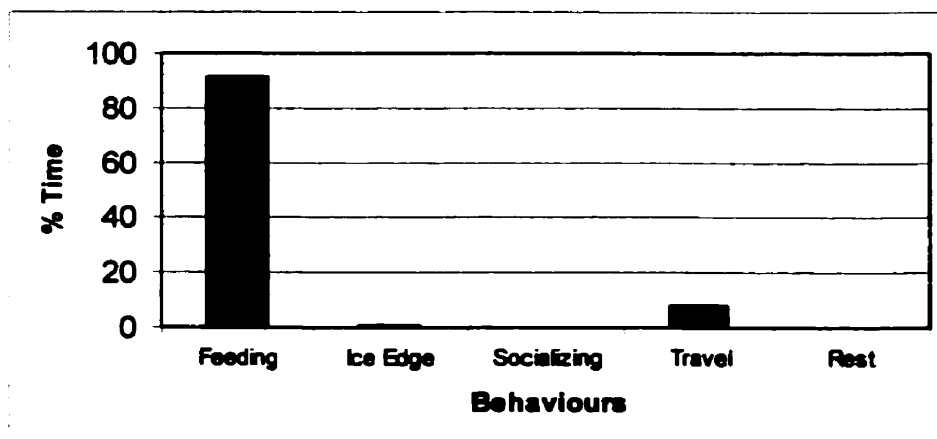
Time Budget

Bowhead behaviour varied considerably as the land-fast ice melted (Figure 2.2). In week one, feeding was the primary behaviour (Fig. 2.2a) observed followed by travelling that consisted of movements between feeding areas. Ice-edge behaviour comprised less than 1% of the time budget, whereas socializing and resting behaviour were not observed. The ice-edge at this point was in the solid phase.

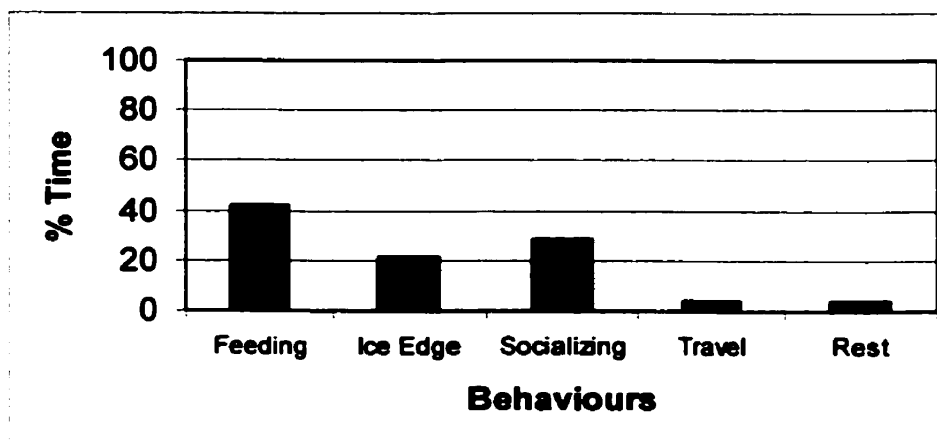
In week two, feeding and travel both dropped over 50% from week one while ice-edge, socializing and resting behaviour rose considerably in frequency (Fig. 2.2a and b). At this point, the ice-edge is in the melt-hole phase and whales were beginning to dive under the ice-edge.

By week three, feeding and resting were no longer observed (Fig. 2.2c). The predominant behaviour was ice-edge behaviour, followed by travel behaviour that primarily consisted of whales swimming toward or along the ice-edge. Socializing behaviour dropped substantially from week two (Fig. 2.2b and c). A high proportion of the population was seen in melt holes in the ice, breathing through the melt holes. There was no longer any feeding behaviour seen in the open water along the ice-edge. At this point in time, the ice-edge was in the break-up phase.

a) Solid Ice Phase



b) Melt-hole Ice Phase



c) Break-up Ice Phase

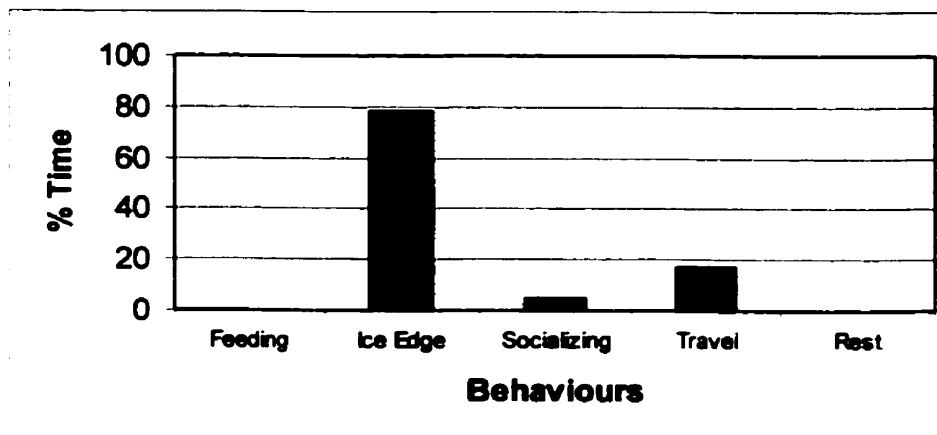


Figure 2.2. Percentage of time bowheads spent engaged in various behaviours (feeding, ice edge, socializing, travel and rest) for each phase in the land-fast ice deterioration: a) solid ice phase, July 1 to 7, 1996; b) melt-hole ice phase, July 8 to 14, 1996; c) break-up ice phase, July 15 to 21, 1996.

Breathing Characteristics

Mean surface time varied between behaviours with a substantially higher surface time being observed during socializing than during feeding, ice-edge or travel behaviours (Table 2.2). Differences between mean surface time were significant (Table 2.2).

Multiple comparison tests performed on each of the behaviours showed that surface times during socializing were significantly higher than during feeding, ice-edge and travel behaviour (Table 2.3a), which resulted in the rejection of the null hypothesis (1a). No significant differences in mean surface time were observed between feeding, ice-edge and travel behaviours (Table 2.3a). Thus socializing behaviour accounts for the significant differences observed between surface time means.

The mean number of blows varied between behaviours with a higher number of blows being observed during feeding than during ice-edge and travel behaviours (Table 2.2). Differences between means were significant (Table 2.2). Multiple comparison tests performed on each of the behaviours showed that the number of blows during feeding was significantly higher than during travel, but there was no significant difference between feeding and ice-edge or between travel and ice-edge (Table 2.3b). Thus feeding and travel accounted for the significant differences observed between the mean number of blows.

Mean blow interval also varied among behaviours with blow intervals during travel being higher than during feeding and ice-edge behaviours (Table 2.2). Differences between the means were significant (Table 2.2). Multiple comparison tests performed on each of the behaviours showed that blow intervals associated with feeding were significantly lower than those associated with travelling (Table 2.3c), resulting in the

Table 2.2. Results of one-way ANOVA performed on breathing characteristics of bowhead whales engaged in various behaviours (feeding, ice edge, social, and travel) in northern Foxe Basin, July 1996/97. n = number of measurements used to calculate means and std. dev., nd = breathing characteristics could not be measured. Differences between behaviours were significant if <0.05.

BREATHING CHARACTERISTICS	BEHAVIORS				ANOVA	
	Feeding	Ice Edge	Social	Travel	F-value	Sig.
Surface Time (min)	n=67	n=34	n=16	n=40		
Mean	1.43	1.37	5.22	1.11	36.873	<.0001
StdDev	0.76	0.93	3.01	0.66		
Number of Blows	n=30	n=21	nd	n=25		
Mean	10.23	7.81	-	5.08	10.523	<.0001
StdDev	4.22	5.42	-	2.52		
Blow Interval (sec)	n=26	n=17	nd	n=18		
Mean	9.13	10.38	-	13.21	13.532	<.0001
StdDev	1.69	2.79	-	3.98		
Dive Time (min)	n=31	nd	n=7	n=25		
Mean	11.07	-	4.61	4.10	22.676	<.0001
StdDev	5.06	-	4.19	2.73		

Table 2.3. Results of multiple comparison tests performed on breathing characteristics of bowhead whales engaged in feeding, ice edge, social, and travel behaviours in northern Foxe Basin, July 1996/97. Numbers in bold indicate a significant difference (<0.05).

LEGEND	
F	= Feeding Behaviour
I	= Ice-Edge Behaviour
S	= Social Behaviour
T	= Travel Behaviour

a) Dependent Variable: Surface Time

Behavior (A)	Behavior (B)	Mean Difference (A - B)	Std. Error	Sig.
F	S	-1.0427	0.113	<.0001
F	T	0.1631	0.081	0.121
F	I	0.0691	0.085	0.967
S	T	1.2058	0.12	<.0001
S	I	1.1117	0.123	<.0001
T	I	-0.094	0.095	0.915

b) Dependent Variable: Number of Blows

Behavior (A)	Behavior (B)	Mean Difference (A - B)	Std. Error	Sig.
F	T	5.1533	1.123	<.0001
F	I	2.4238	1.18	0.258
T	I	-2.7295	1.228	0.123

c) Dependent Variable: Blow Interval

Behavior (A)	Behavior (B)	Mean Difference (A - B)	Std. Error	Sig.
F	T	-4.0051	0.776	<.0001
F	I	-1.1927	0.813	0.28
T	I	2.8125	0.87	0.03

d) Dependent Variable: Dive Time

Behavior (A)	Behavior (B)	Mean Difference (A - B)	Std. Error	Sig.
F	S	1.2479	0.325	0.024
F	T	1.3358	0.209	<.0001
S	T	0.0879	0.332	0.994

rejection of the null hypothesis (1b). No significant difference in blow intervals were observed between feeding and ice-edge behaviours (Table 2.3c). Thus travel accounts for the significant differences observed between mean blow intervals.

Mean dive time varied between behaviours with longer dives observed during feeding than during social behaviour and travel (Table 2.2). There was a significant difference between the mean dive times (Table 2.2). Multiple comparison tests performed on each of the behaviours showed that dive times during feeding were significantly longer than during social behaviour and travel (Table 2.3d), resulting in the rejection of the null hypothesis (1c). No significant difference in mean dive times were observed between socializing and travel behaviours (Table 2.3d). Thus feeding behaviour accounts for the significant differences observed between mean dive times.

All three null hypotheses (1a, 1b, 1c) were rejected so the alternate hypothesis (1) that breathing characteristics differ significantly during different behaviours was accepted, and null hypothesis (2) was tested. Mean surface time, number of blows per surfacing, and mean blow interval per surfacing were not significantly different between ice-edge and feeding behaviour (Table 2.3), resulting in the rejection of the null hypothesis (2).

Discussion

Feeding Behaviour:

Bowheads appear to feed under land-fast ice (i.e. ice-edge behaviour) in northern Foxe Basin when the ice begins to melt. If behaviour can be identified from breathing

characteristics, as concluded from the alternative hypothesis (1), then the similarity seen in breathing characteristics between feeding and ice-edge behaviour would infer that bowheads are feeding under the land-fast ice, as concluded from testing the alternative hypothesis (2). Whales feeding under land-fast ice are most likely feeding on zooplankton in the water-column. Under-ice feeding does not follow the definition of water-column feeding, thus whales feeding under-ice could not be categorized as water-column feeding. The differences between water-column feeding and under ice feeding are 1) during water-column feeding whales generally fluke out at the start of a dive, whereas whales diving under the ice-edge generally did not fluke out at the start of a dive, 2) during water-column feeding whales generally resurface in the same area, whereas whales diving under the ice-edge appeared to resurface in melt-holes within the land-fast ice (pers obs).

As the land-fast ice-edge melted, feeding behaviour changed from feeding in open water to feeding under the land-fast ice. During the first week of behavioural observations, when the ice-edge was in its solid phase, the predominant activity was water-column feeding in open water. During the second week of behavioural observations in the study area, water-column feeding in open water areas declined and feeding under the land-fast ice increased. By the third week of behavioural observations, diving under the ice-edge became the dominant behaviour and water-column feeding was no longer observed. The pattern of increased ice-edge behaviour and the absence of water-column feeding in open water supports the hypothesis that bowheads feed under the ice.

The presence of high zooplankton densities under land-fast ice would help to support the hypothesis that ice-edge behaviour is a type of feeding behaviour. Although no zooplankton samples were collected under the land-fast ice, there are studies that indicate the presence of high zooplankton densities under land-fast ice. The arctic copepod *Pseudocalanus* can be highly concentrated in the first few centimeters under land-fast ice in spring (Conover *et al.* 1986). Conover *et al.* (1986) suggest that *Pseudocalanus* feed opportunistically near the ice-water interface, either directly on the algae attached under the ice or on algae as it erodes from the ice. The formation of melt holes may make this food source more accessible and may be the reason that the whales dive under the ice during the melt hole phase of the land-fast ice.

Whales engaging in water column feeding generally spent more time below the surface in a dive than during social behaviour and travel. This is because the longer they can stay in a dive or dive more deeply, the longer they can feed. Thus the data supports my prediction that water-column feeding behaviour will have a longer dive time than social behaviour and travel. Richardson and Finley (1989) found similar results in their study of the bowheads in the Beaufort Sea and Isabella Bay, with water-column feeding behaviour involving longer dives than the other behaviours.

Ice-edge behaviour was not included in the dive time analyses because it was not possible to measure dives for whales diving into the ice-edge. There was no way of determining where the whale would surface after it entered the ice-edge. Carroll *et al.* (1987) recorded a mean dive time of 14.7 min for bowhead whales in the Beaufort Sea, some of which were feeding under ice. Regardless of whether the whales are feeding under the ice, I would expect dive times associated with ice-edge behaviour to be similar

to dive times associated with feeding. Once a whale dives under the ice it may have to remain in a dive for some time before it is able to find a breathing hole in which it can surface. If whales are searching for melt holes, rather than feeding, they would still benefit from remaining in a dive as long as possible to maximize search time.

Whales engaged in water-column feeding and under-ice feeding blew more frequently and at shorter intervals during surfacings than when travelling. This is due to the whale hyperventilating before going into a dive, thus allowing it to dive longer. Feeding right whales, *Eubalaena australis*, also hyperventilate before long dives (Hamner *et al.* 1988). There was not a significant difference in the number of blows between ice-edge and travelling behaviour, thus I can not rule out the possibility that bowheads both fed and travelled under the ice-edge.

Bowheads are seen in northern Foxe Basin from June until November (Mitchell and Reeves 1982, Reeves *et al.* 1983, Reeves and Mitchell 1990). Feeding behaviour (water-column and under-ice) was the dominant activity observed in bowheads during July 1996 in northern Foxe Basin. It is highly probable that the whales feeding for the duration of the time they spend in Foxe Basin. Bering-Chukchi-Beaufort bowheads feed extensively in the summering areas of the Canadian Beaufort Sea where they reside for 3 1/2 to 4 months (Richardson *et al.* 1987). Whether or not bowheads feed exclusively in the summering areas is not clear. There are observations that some of the Bering-Chukchi-Beaufort bowheads feed opportunistically during the spring and fall migration (Richardson *et al.* 1987). There is no observational evidence as to whether bowheads feed during the winter months, although analysis of stable isotope abundances in bowhead baleen plates suggest it is possible that winter feeding occurs (Schell *et al.* 1987). Little is

known about Foxe Basin bowheads during the winter and spring seasons, thus we can only assume, based on what is known on the Bering-Chukchi-Beaufort bowheads, that they may feed opportunistically during spring and fall migrations and, possibly, in winter.

Social Behaviour:

Social behaviour was observed primarily during the second week of behavioural observations, when the ice-edge was in its melt-hole phase. This short period of increased social behaviour may be a result of the transition in feeding modes, from water-column feeding in open water to feeding under the land-fast ice. During the second week we observed more whales at the ice-edge than during the first or third week. The aggregating of many whales in a confined area may result in increased social interactions.

Socializing whales spent more time at the surface than during other behaviours. In contrast, Richardson and Finley (1989) found that bowhead social behaviour had a lower surface time than feeding or travel behaviour in the Bering-Chukchi-Beaufort population and in the Isabella Bay aggregation. Differences in results between studies could result from differences in group size and activity level. Würsig and Clark (1993) state that breathing characteristics have not been measured for whales in mating aggregations because the whitewater activity (whales rolling and thrashing) associated with this type of socializing makes it difficult to discern and follow recognizable individuals. However, they believe that these sexually active whales may have surface times up to 30 min or more. Sexual behaviour has very rarely been observed in bowhead whales, and I did not identify this behaviour in the Foxe Basin population, although their social behaviour was associated with whitewater activity, which suggests possible sexual behaviour. Social

behaviour observed in the Bering-Chukchi-Beaufort population would include both large and small social groups, whereas socializing behaviour observed in the Foxe Basin population was only observed in large groups. Whales in large social groups appear to be very active and may have long surface durations, as is seen in Foxe Basin. Whales in smaller social groups appear to be less active and may have shorter surface durations, as is seen some of the Bering-Chukchi-Beaufort population (Würsig and Clark 1993).

Differences in study protocols (sampling and definition) could also explain the different results. Firstly, the socializing groups in Foxe Basin were very large and active and individual whales could not be discerned and followed, thus socializing was timed as a group surfacing and dive duration. Richardson and Finley (1989) recorded surface and dive durations of individual whales in less active and, most likely, in smaller social groups. Another difference between the two data sets was in how socializing behaviour was defined. I defined whales as being social only if there was some active socializing taking place (i.e. touching, pushing, nudging, etc.). Würsig *et al.* (1984c) defined bowheads as social if they were within a half body length of each other whether or not they were actively socializing (touching). Dorsey *et al.* (1989) used the same data set from the Bering-Beaufort-Chukchi Sea population as Richardson and Finley but they excluded the category of whales half a body length or less apart but not actively interacting from the data set. By excluding this category and analyzing the data using Multiple Regression techniques, they found that socializing bowheads spent more time at the surface than did water-column feeding and travelling whales, although the difference was not significant. Dorsey *et al.*'s (1989) findings and my data from Foxe Basin supports

my prediction that social behaviour will have a longer surface time than the other behaviours measured in Foxe Basin.

While resting, blows are quiet and exhalations are less visible (Würsig *et al.*, 1984b). Resting behaviour may be underestimated due to the difficulty of observing resting bowheads, which were generally found at the ice-edge or in the land-fast ice in melt-holes. The time budget data collected on Foxe Basin bowheads is assumed to be representative of whale populations during non-migratory periods based on similar results seen in other time budget studies on other whale species (Heimlich-Boran 1988).

Surface times associated with social behaviour were longer than those associated with other behaviours. This suggests that bowheads are more likely to be observed when they are socializing. Dive times during feeding (water-column) behaviour were longer than during other behaviours, as predicted. This suggests bowheads are less likely to be observed when they are feeding. Because the breathing characteristics differ significantly with each behaviour, surface time and dive time can be used to calibrate counts of whales during aerial or shipboard surveys, as they are done in many studies by multiplying the number of sightings by a correction factor (Richardson 1987). Although caution must be taken to know the time budget of the bowheads when doing the survey, because the time budgets vary with time in the early part of the season. Also, the biases in sighting whales and possibly underestimating resting behaviour may affect the ability to construct an accurate time budget.

Sampling Biases:

Due to the difficulty in sighting whales that are in the pack ice, whale distribution may be underestimated in quadrats that have a lot of pack ice due to poor visibility. As a result, a positive (rather than a negative) correlation would be observed between whale distribution and pack ice presence. Another bias in the sampling was by treating each whale as a independent observation when measuring breathing characteristics. By treating each whale independently, I am assuming that each whale is only observed once. However I may have observed the same whale more than once. Although I do not believe this to be true since I did see several different whales on different days. To test this bias individual whales should be photographed and identified using distinguishing marks. Another bias in the sampling was by measuring breathing characteristics of social behaviour as a group instead of individuals as in other behaviours. Using group observations I artificially increased the individual surface time and decreased the individual dive time of social behaviour. This would bias prediction one where I tested whether social behaviour would have a longer surface time than other behaviours. If it takes all the whales in a social group more than 2 minutes to surface after the first one surfaces then prediction one may not have held true. However, in my observations of social behaviour in most social groups all whales surfaced within 2 minutes.

Conclusions and Future Research:

When the land-fast ice is still solid, bowheads concentrate on water-column feeding in the open water just beyond the ice-edge. Zooplankton concentrations were most likely higher in the open water and at mid-depths resulting in water-column feeding

being the dominant behaviour in the early part of the season. The melting of the land-fast ice probably creates a highly productive environment, resulting in high concentrations of zooplankton under land-fast ice. It is at this time that bowheads appear to change their feeding mode from water-column feeding to feeding under the ice.

Whales engaged in water-column feeding spend more time below the surface in a dive, blow more frequently and at shorter intervals during surfacings than during socializing and travelling behaviours. The breathing characteristics of ice-edge behaviour were not significantly different from water-column feeding behaviour, thus I conclude that ice-edge behaviour was indicative of whales feeding under the land-fast ice. Whales socializing spent more time at the surface than during other behaviours.

Results suggest that the whales feed under the ice. Future research should focus on a more extensive study of the distribution and density of zooplankton within and beyond the land-fast ice. By understanding how zooplankton is distributed in Foxe Basin we can determine whether the bowheads feed in relation to the food supply. An oceanographic study of how the land-fast ice, temperature, salinity and currents affect the distribution and density of zooplankton in northern Foxe Basin would help to predict present and future distributions of bowhead whales. Any change in these factors as a result of climate change could have a significant influence on zooplankton and, consequently, bowhead distribution.

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Appendices

Appendix 1. Quadrat system and data from July and August 1997 used to produce matrices for the mantel tests. Data taken from tables 1.5 to 1.7 and 1.9.

		9	0	0
16	10	8	0	0
2	5	1	0	2
0	0	8	0	0
5	1	0	0	1
0	0	0	0	1

Appendix 1a. Bowhead sightings and ice edge presence during the first survey in the Ice Edge Season (Study Area "A"). Numbers indicate the number of bowheads seen in quadrats from the first survey. Referred to as 'Whales1' in the mantel tables. Shaded quadrats refer to the presence of the ice edge. Referred to as 'Ice Edge1' in the mantel tables.

		(-0.3)	(-0.5)	(-0.2)
		0.0	0.7	0.2
(-0.1)	(-0.4)			
0.0	-0.3	0.5	0.7	0.9
0.7	-0.2	0.6	0.4	1.1
1.0	-0.3	0.3	0.5	1.2
1.3	-0.4	0.6	0.4	1.3
1.7	0.0	0.6	0.4	1.3

Appendix 1b. Quadrats during the first survey of the Ice Edge Season (Study Area "A") showing the mean temperature (°C) in each quadrat. Numbers in parentheses are the actual surface temperatures at the northern end of each transect. Referred to as 'TempMean1' in the mantel tables.

		0.5	2.1	1.0
0.8	0.3	0.5	0.4	0.5
1.4	0.3	1.1	0.3	0.1
0.9	0.5	0.5	0.8	0.2
1.8	0.1	0.5	0.6	0.1
0.1	0.1	0.9	0.5	0.3

Appendix 1c. Quadrats during the first survey of the Ice Edge Season (Study Area "A") showing the temperature (°C) range in each quadrat. Referred to as 'TempRange1' in the mantel tables.

		1	7	0
	1	0	1	0
0	3	0	0	0
0	3	0	1	0
0	0	3	0	0
0	0	0	1	0

Appendix 1d. Bowhead sightings and ice edge presence during the second survey in the Ice Edge Season (Study Area "A"). Numbers indicate the number of bowheads seen in quadrats. Referred to as 'Whales 2' in the mantel tables. Shaded quadrats refer to the presence of the ice edge. Referred to as 'Ice Edge2' in the mantel tables.

		(3.1)	(-0.1)	(1.7)
		4.9	0.1	4.4
	(-0.2)			
	-0.2	4.1	0.6	4.5
(6.0)				
5.7	-0.2	3.5	0.8	4.5
4.3	1.3	4.0	1.1	3.9
4.3	0.7	4.6	1.1	2.4
4.6	0.3	6.0	3.4	3.2

Appendix 1e. Quadrats during the second survey of the Ice Edge Season (Study Area "A") showing the mean temperature (°C) in each quadrat. Numbers in parentheses are the actual surface temperatures at the northern end of each transect. Referred to as 'TempMean2' in the mantel tables.

		1.6	0.8	0.5
	0.2	1.2	0.3	1.9
0.6	0.4	1.3	0.6	2.4
1.8	0.5	2.9	0.8	2.8
0.3	1.4	4.1	0.7	2.6
1.2	0.9	0.3	0.7	1.1

Appendix 1f. Quadrats during the second survey of the Ice Edge Season (Study Area "A") showing the temperature (°C) range in each quadrat. Referred to as 'TempRange2' in the mantel tables.

		10	7	0
16	11	8	1	0
2	8	1	0	2
0	3	8	1	0
5	1	3	0	1
0	0	0	1	1

Appendix 1g. Bowhead sightings during the both surveys in the Ice Edge Season (Study Area "A"). Numbers indicate the number of bowheads seen in quadrats. Referred to as 'WhalesTot' in the mantel tables.

		131	81	79
75	113	117	104	79
28	94	104	100	97
17	65	75	81	103
20	29	62	81	107
13	69	76	80	105

Appendix 1h. Quadrats during the Ice Edge Season (Study Area "A") showing the maximum water depth (m) in each quadrat. Referred to as 'DepthMax' in the mantel tables.

		71	26	53
28	75	102	26	12
5	27	75	81	31
2	17	62	71	73
2	13	14	62	81
8	10	29	69	71

Appendix 1i. Quadrats during the Ice Edge Season (Study Area "A") showing the minimum water depth (m) in each quadrat. Referred to as 'DepthMin' in the mantel tables.

		46	68	33
63	34	13	75	85
82	71	28	19	68
88	74	17	12	29
90	55	77	23	24
38	86	62	14	32

Appendix 1j. Quadrats during the Ice Edge Season (Study Area "A") showing the maximum topographic variation (m) in each quadrat. Referred to as 'MaxTopVar' in the mantel tables.

0	0	0	0	0
0	3	0	2	0
0	1	3	2	0
0	0	0	1	0
0	0	0	0	0

Appendix 1k. Bowhead sightings and pack ice presence during the boat survey of the Open Water Season (Study Area "B"). Numbers indicate the number of bowheads seen in quadrats. Referred to as 'Whales 4' in the mantel tables. Shaded quadrats refer to the presence of pack ice. Referred to as 'Pack Ice' in the mantel tables.

1.8	2.7	2.8	2.5	2.2
1.4	3.0	3.0	2.9	2.3
1.4	3.0	2.8	3.2	2.3
1.3	1.9	1.1	2.1	1.6
1.2	1.2	1.5	0.3	1.3

Appendix 11. Quadrats during the boat survey of the Open Water Season (Study Area "B"), showing the mean temperature (°C) in each quadrat. Referred to as 'TempMean' in the mantel tables.

0.2	0.3	0.7	0.4	0.2
0.6	0.2	0.3	0.4	0.3
0.2	0.8	0.9	0.4	0.2
0.4	2.2	2.3	3.0	1.1
0.3	0.6	0.9	0.1	0.1

Appendix 1m. Quadrats during the boat survey of the Open Water Season (Study Area "B"), showing the temperature (°C) range in each quadrat. Referred to as 'TempRange' in the mantel tables.

1	4	2	0	0
2	17	0	11	0
7	5	3	2	0
0	0	0	1	0
0	0	0	2	0

Appendix 1n. Bowhead sightings made during the boat and aerial survey of the Open Water Season (Study Area "B"). Numbers indicate the total number of bowheads seen in quadrats. Referred to as 'Whales5' in the mantel tables.

73	96	90	111	74
110	141	129	139	123
136	125	138	139	127
140	128	127	141	119
135	122	103	131	88

Appendix 1o. Quadrats during the Open Water Season (Study Area "B"), showing the maximum water depth (m) in each quadrat. Referred to as 'DepthMax' in the mantel tables.

42	56	51	62	55
73	96	90	111	74
83	71	119	126	119
105	71	100	128	82
47	87	59	121	71

Appendix 1p. Quadrats during the Open Water Season (Study Area "B"), showing the minimum water depth (m) in each quadrat. Referred to as 'DepthMin' in the mantel tables.

42	42	43	44	26
34	32	30	20	40
39	43	14	9	6
25	45	21	9	31
65	29	43	8	19

Appendix 1q. Quadrats during the Open Water Season (Study Area "B"), showing the maximum topographic variation (m) in each quadrat. Referred to as 'MaxTopVar' in the mantel tables.

[Shaded]		[Shaded]		
			20	30
[Shaded]				31
30, 31	32	25, 32	31	28

Appendix 1r. Surface salinity (ppm) and ice edge presence during the first and second surveys of the Ice Edge Season (Study Area "A"). Numbers indicate the salinity (ppm) measured in each quadrat, and numbers in bold are salinity measures taken at the ice edge. Shaded quadrats refer to the presence of the ice edge.

Appendix 2. Mantel tests: rationale and formulation of matrices.

Mantel test rationale

Habitats are composed of mosaics of patches, with different degrees of spatial autocorrelation within and among them (Fortin and Gurevitch 1993). Fortin and Gurevitch (1993) define spatial autocorrelation as the spatial dependence of the values of a variable. An example of positive spatial autocorrelation is surface water temperatures in a given area are more similar than distant areas. This type of data violates the assumption: independence of the observations in most parametric methods (Fortin and Gurevitch 1993). A Mantel test is a randomization test that takes the spatial and/or temporal autocorrelation of data into account by computing the relationship between two distance matrices (Fortin and Gurevitch 1993).

Formulation of Mantel Matrices from Quadrats

To quantify relationships between whale distribution and the habitat variables, Mantel tests were calculated.

For the Mantel Test, three distance matrices were built;

- 1) The variable distance matrix, A , refers to the differences in the number of the whales in each of the quadrats. I calculated the distances as the square of the absolute difference between all pairs of replicates as follows

$$\text{outcome}(i,j) = (X_i - X_j)^2$$

(Manly 1991). The resulting matrix was then standardized according to Fortin and Gurevitch (1993) in order to obtain the normalized Mantel statistic, r .

- 2) The geographic distance matrix, B , refers to the physical location distances between each of the quadrats. I computed the geographic distances using the inverse of the Euclidean distance, between the spatial coordinates of all possible pairs of quadrats as follows:

$$\text{geographic}(i,j) = 1 / (\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2})$$

(Manly 1991). The resulting matrix was then standardized according to Fortin and Gurevitch (1993) in order to obtain the normalized Mantel statistic, r . Since reciprocal distances for the second matrix were used, a negative correlation between the two matrices is evidence that close quadrats have similar counts (Manly 1991). Thus, a negative correlation will indicate that the bowhead distribution is spatially autocorrelated, supporting the use of Mantels in the analysis.

- 3) The variable distance matrices, C , refer to the differences in the habitat variables in each of the quadrats. For C , eight matrices were built from the following; 1) three water depth variables, 2) two surface temperature variables, 3) two ice variables and 4) one zooplankton density variable. I calculated the distances as the squared absolute difference between all pair of replicates as follows:

$$\text{outcome}(i,j) = (X_i - X_j)^2$$

(Manly 1991). C was rescaled so that the values would lie between 0 and 1. For the depth and temperature matrices, dividing each value in C by the maximum value

carries out this rescaling. Since the ice matrices contain binary data they do not have to be transformed. Refer to Hubert (1985) for a detailed explanation.

All whale distributions have a degree of spatial autocorrelation within them. Bowheads show this very clearly in the way they aggregate together during feeding and socializing behaviours. Mantel tests assess the degree of association between distribution and habitat variables while taking into consideration the spatial autocorrelation of the distribution. The r statistic measures the average magnitude of spatial autocorrelation of a variable for the entire study area, when the r statistic is calculated between a variable distance matrix and the geographic distance matrix (Fortin and Gurevitch 1993).

Mantel tests allow for comparisons between only two matrices. However, in order to test the predictions in this study, a comparison between three matrices was needed. Partial Mantel tests allows for the comparison of three matrices. I ran the partial Mantel test according to Hubert (1985), where C is restricted to lie between 0 and 1. This allowed me to determine if the association between A and B might be attributed to (or explained by) C , thus determining whether the distribution of bowheads was attributable to one or more habitat variables in Foxe Basin.

The significance of the r statistics in partial Mantel tests is calculated using a randomization test of 1000 iterations to construct a reference distribution. Employing a one-tailed t-test on the reference distribution, a p-value is calculated for the normalized Mantel statistic, r , for each comparison.