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Canada's Most Northerly Postglacial Bowhead Whales (*Balaena mysticetus*): Holocene Sea-Ice Conditions and Polynya Development

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ABSTRACT. Rare remains of postglacial bowhead whales occur in the Norwegian Bay–Eureka Sound region. These are the northernmost remains known from the Canadian Arctic. The region is beyond the bowhead's current range because of persistent summer sea ice. We argue that the region has been beyond the bowhead's range for most of postglacial time for the same reason. With one exception, the 16 known subfossil bowheads from the region date to the last 4000 ^{14}C years. Within the region, whale bones are most common adjacent to polynyas, which connect to more southerly channels extending from Baffin Bay. This distribution suggests that the polynyas, which here occupy areas of strong currents, developed as a result of shallowing of inter-island channels due to postglacial uplift. The whale remains beyond the polynyas are seen as those of doomed strays that reached the polynyas from Baffin Bay and foraged farther along coastal leads before being trapped by freeze-up. This interpretation of Holocene sea-ice history agrees with the limited development of Holocene raised beaches in the region. However, it contradicts other interpretations of greatly ameliorated marine conditions in northernmost Canada at about 6000 ^{14}C years B.P.

Key words: Holocene bowhead whale, Arctic Ocean, sea-ice paleoclimate, Canadian Arctic Archipelago

RÉSUMÉ. La région de la baie Norwegian et du détroit d'Eureka abrite un petit nombre de restes organiques de baleines boréales postglaciaires. Ce sont les restes trouvés le plus au nord de l'Arctique canadien. Cette zone est située en dehors du territoire actuel de la baleine boréale en raison de la présence constante de glace marine estivale. On soutient que la région s'est trouvée en dehors du territoire de la baleine boréale durant la plus grande partie de la période postglaciaire, et ce, pour la même raison. À une exception près, les 16 baleines boréales subfossiles qui ont été découvertes dans cette zone datent des 4000 dernières années (âge radiocarbone). Dans la région, les os de baleines se trouvent en plus grand nombre au voisinage immédiat de polynies, celles-ci étant reliées à des chenaux plus méridionaux qui sinuent depuis la baie de Baffin. Cette distribution suggère que les polynies, qui occupent ici des zones de courants forts, se sont formées à la suite d'une diminution de la profondeur des chenaux séparant les îles provoquée par un soulèvement postglaciaire. On pense que les restes de baleines qui se trouvent en dehors des polynies appartiennent à des baleines qui ont rejoint les polynies depuis la baie de Baffin et qui se sont égarées plus loin en quête de nourriture le long des passages côtiers avant d'être bloquées par les glaces. Cette interprétation de l'histoire de la glace marine de l'holocène concorde avec l'évolution restreinte des plages soulevées de la région, qui datent de l'holocène. Elle contredit toutefois d'autres interprétations de conditions marines nettement améliorées dans l'extrême nord du Canada il y a environ 6000 ans (âge radiocarbone) BP.

Mots clés: baleine boréale de l'holocène, océan Arctique, paléoclimat de la glace marine, archipel Arctique

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INTRODUCTION

Bones of the bowhead whale are the most common postglacial marine mammal remains found in the Canadian Arctic Archipelago (CAA; Fig. 1). Areas of former marine submergence in this region are extensive, commonly rising to 100–150 m elevation. In many places, conspicuous raised shorelines, which formed during emergence, represent continuous Holocene sequences. Dyke and colleagues have located the remains of more than 1000 Holocene bowheads in the eastern, central, and southwestern CAA (Dyke and Morris, 1990; Dyke et al., 1996a; Savelle et al., 2000; Dyke and Savelle, 2001). They have surveyed bone abundance by elevation at the sites indicated on Figure 1 and have obtained radiocarbon dates on several hundred specimens. These data have been interpreted as indicating that the bowhead ranged commonly into various parts of the archipelago during two intervals (ca. 10–8 ka and 5–3 ka B.P. [ka = 1000 years; all ages in radiocarbon years]) but not during others (ca. 8–5 ka and 3–0 ka B.P.; Dyke and Morris, 1990; Dyke et al., 1996a; Fig. 2). Range extensions at any particular site are represented by intervals of relative bone abundance, whereas range retractions are represented by bone scarcity or

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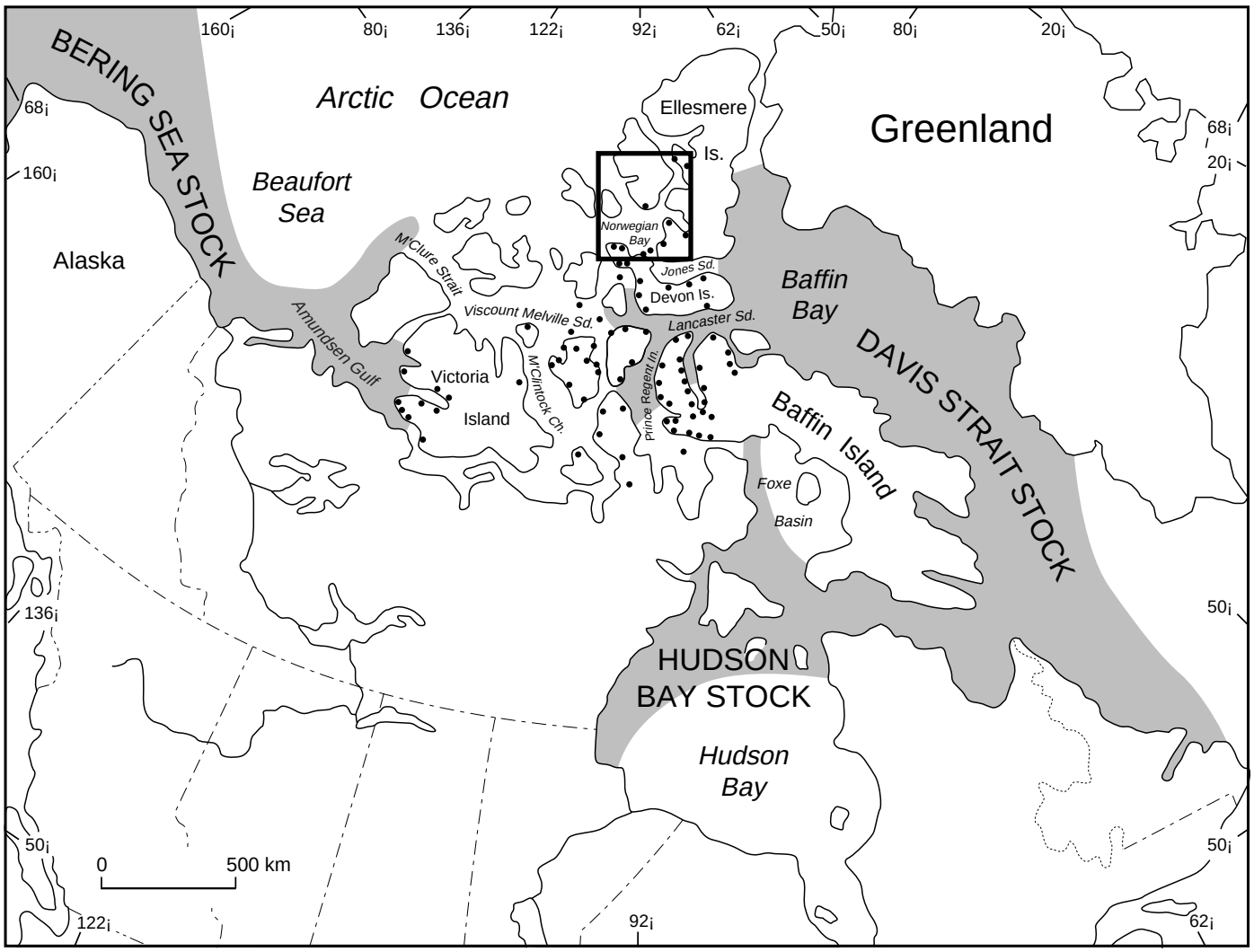

FIG. 1. Map of bowhead whale stocks (from Dyke and Savelle, 2001). Dots indicate field camp locations systematically searched for bowhead remains. The box indicates the area discussed in this paper.

absence in raised beach sequences. The annual migration of the bowhead is controlled primarily by changing sea-ice cover and by the bowhead's strong preference for ice-edge habitat (e.g., Finley, 2001). Therefore, extensions of Holocene bowheads into (and retractions from) the CAA, one of their summer feeding grounds, can be interpreted in terms of changing summer sea-ice extent. This interpretation assumes that the bowheads of the general northwest Atlantic population did not experience major population peaks and crashes before humans began to hunt them, which occurred less than 1000 years ago.

This paper presents new observations and radiocarbon dates on bowhead whale remains in the northern CAA (Fig. 1). We compare these data to previously published bowhead time series (one of which is reproduced here as Fig. 2). We also evaluate a hypothesis (discussed in Dyke et al., 1996a) that these whales extended into the northernmost CAA or the Arctic Ocean during the early middle Holocene interval (8–5 ka B.P.), when bowheads were rare or absent in the central CAA.

PROBLEM AND STUDY AREA

To date, no counter-argument has appeared for our suggestion that intervals of bone abundance in areas at and beyond the historic summer range of the bowhead—such as M'Clintock Channel (Fig. 1)—represent times of reduced summer sea-ice cover. Similarly, no disagreement has arisen over the interpretation that the scarcity of bones during the last 3 ka in these same areas (Fig. 2) represents exclusion of whales by sea ice, as it does at present. However, it has been suggested (see Dyke et al., 1996a for discussion) that the interval of rare to absent bones in the central CAA between ca. 8 and 5 ka B.P. can be interpreted instead as a time when there was too little sea ice to provide the bowhead with its preferred ice-edge habitat, and the bowhead therefore ranged far to the north, perhaps into the Arctic Ocean. A recent interpretation that marine conditions in the northernmost CAA at 6 ka B.P. were similar to those currently prevailing in the Low Arctic marine zone of western Hudson Strait and Hudson Bay (Gajewski et al.,

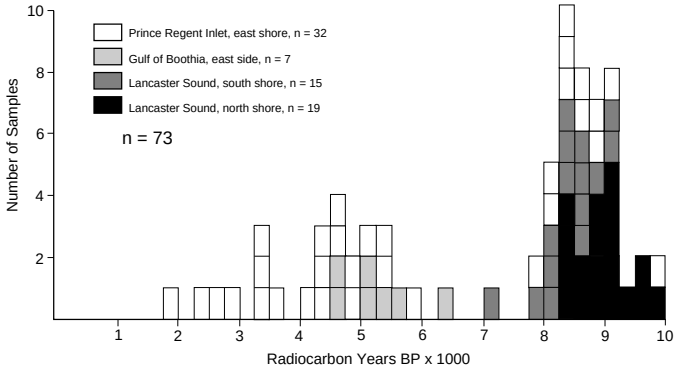

FIG. 2. Histogram of radiocarbon dates on bowhead remains from the east-central channels of the Canadian Arctic Archipelago (from Dyke et al., 1996a). Uncorrected ages are plotted.

2000) can be seen as supporting the open-water hypothesis. From the abundances of foraminifera in two marine sediment cores, these authors concluded that, on the continental shelf north of the CAA and in the Norwegian Bay area of the north-central CAA, winter sea-ice conditions were less severe than at present, and summertime open water was more extensive than that found in many Low Arctic areas today. They therefore shifted the High Arctic–Low Arctic boundary at 6 ka B.P. to a position nearly 2000 km north of its present position in southern Foxe Basin.

The Norwegian Bay–Eureka Sound region of the CAA (Figs. 1 and 3) rarely clears of sea ice under present climatic conditions and is therefore beyond the present and historic range of the bowhead (Reeves et al., 1983). Furthermore, the bay and sound are extensions of the Arctic Ocean, and ice-laden currents flow into them from the north. Hence, if there were intervals when the Davis Strait stock of bowheads ranged into the Arctic Ocean, they ought to have seasonally migrated through Norwegian Bay and Eureka Sound.

Locally open water occurs in small polynyas at Hell Gate, Cardigan Strait, and Penny Strait, where fast currents exit Norwegian Bay to enter Jones Sound and Wellington Channel to the south (Fig. 3). Only two radiocarbon-dated bowhead remains have been reported previously from the Norwegian Bay–Eureka Sound region. However, one of these falls within the 8–5 ka B.P. interval (Bednarski, 1990), an interval of bone scarcity farther south and the point of discussion outlined above.

Below we report new bowhead bone finds from Norwegian Bay and Eureka Sound and radiocarbon dates on them. Our observations were made along the Norwegian Bay coast of Devon Island and southwest Ellesmere Island in 1993 and 1994, along the west coast of Ellesmere Island in 1997 and 1999, and along the south and west coasts of Axel Heiberg Island in 1999 and 2000. These surveys involved extensive ground traversing by all-terrain vehicles and low-level surveys from a helicopter. Although the latter method is less satisfactory for locating bones, at least three observers made concerted efforts to spot probable

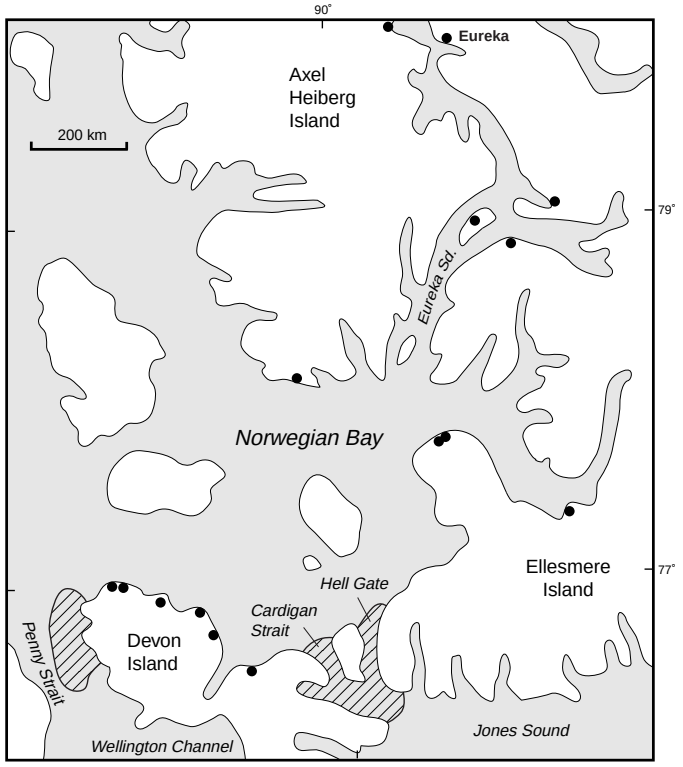

FIG. 3. Map of Norwegian Bay region, showing polynyas (cross-hatched; modified from Smith and Rigby, 1981) and bowhead bone occurrences (black dots).

bones during most flights, and with some success, as outlined below.

RESULTS

Our surveys indicate that bowhead whale remains are rare in the region. We located the remains of 14 whales (Table 1), bringing known occurrences to 16. We obtained radiocarbon ages for nine of these and list them, along with the two previous age determinations, in Table 2. Seven of the bowhead remains occur along the south shore of Norwegian Bay—one site has remains of two animals—near the polynyas mentioned above. We have not yet surveyed shorelines within the actual polynyas for bowhead bones. Remains of another three bowheads occur on the eastern shore of Norwegian Bay, and another bowhead is on the north shore (Fig. 2). The remainder occur along Eureka Sound. One of these is a skull that in 1997 was resting against a utility pole at the Eureka Weather Station; station personnel had brought it there from an unknown location. Rumors of bowhead bones found during construction of the Eureka airstrip, which lies over 100 m asl and was submerged only during the early Holocene (Bell, 1996), prompted us to obtain a date on this specimen. The age (ca. 3.5 ka) indicates that the skull did not come from the airstrip site; it must have come from a site at much lower elevation, probably less than 15 m. Remains at most other sites include large skull bases, which are usually

TABLE 1. Recorded bowhead whale remains from the Norwegian Bay–Eureka Sound region of the Queen Elizabeth Islands, Canadian Arctic Archipelago.

Locality	Bone Elements	Lab Code or Probable Age
93-DCA-200	Skull (periotic dated) 50% buried in gravelly beach sand at 10.5 m elevation	S-3537
93-DCA-161	Rib collected; skull, mandible, other bones present; raised beach at 5.5–6 m elevation	1.5–2.5 ka
93-DCA-191	Rib collected from beach gravel at 4–4.25 m elevation; much of skeleton present	1.5–2.0 ka
94-DCA-72	Skull (periotic dated) 90% buried in beach gravel at 12 m elevation; vertebrae and ribs in vicinity	S-3566
94-DCA-75	Periotic collected from skull on gravel surface of stream cut through raised beach at 3.5 elevation; probably same age as nearby sample 94-DCA-76	1.4 ka
94-DCA-76	Skull (periotic dated) on surface of beach gravel at 3.5 m elevation; several other bones nearby	S-3567
94-DCA-155	Skull (periotic dated) 10% buried in beach gravel at 7 m elevation	S-3568
97-SF-36	Skull (periotic dated) partly buried in beach gravel at 1.5–3 m elevation	TO-8147
97-Eureka	Skull resting against a utility pole at Eureka weather station; brought to the site by an employee from unknown location in the Eureka Sound region	TO-8146
97-VF-24B	Skull (periotic dated) 50% buried in silt at 11.5 m elevation	TO-8145
97-SI-38B	Humerus collected from a scatter of bones including ribs and vertebrae along a raised beach at 4.5 m elevation	1.5–2.0 ka
99-DCA-18	Three skull fragments on the surface of beach sand at 2.5 m elevation	TO-8440
99-DCA-116	Skull 95% buried in gravelly beach sand at 5.5 m elevation; too little collagen to date	TO-8441, 1.5–2.5 ka
99-DCA-117	Fragmented skull (periotic dated) 50% buried in gravelly beach sand at 15 m elevation	TO-8442

TABLE 2. Radiocarbon dates on bowhead whale bone collagen from the Norwegian Bay–Eureka Sound region.

Laboratory Code	Latitude, Longitude	Age Normalized [uncorrected; ^{13}C]
New results:		
S-3537	76˚57′27″ N; 94˚33′09″ W	2725 ± 200 [2580; -16.0[1]]
S-3566	77˚03′03″ N; 95˚24′06″ W	2965 ± 170 [2820; -15.9]
S-3567	77˚03′24″ N; 95˚32′52″ W	1390 ± 170 [1240; -15.5]
S-3568	76˚36′56″ N; 92˚32′11″ W	2260 ± 200 [2110; -15.6]
TO-8145	79˚01′96′ N; 83˚26′ W	3480 ± 90[2]
TO-8146	80˚00′ N; 85˚50′ W	3120 ± 70
TO-8147	77˚18′ N; 84˚28′ W	1230 ± 60
TO-8440	78˚10′30″ N; 91˚23′29″ W	1760 ± 60
TO-8441	77˚52′49″ N; 87˚02′14″ W	insufficient collagen
TO-8442	77˚52′34″ N; 87˚05′45″ W	3780 ± 70
Published results:		
S-3035	80˚42′ N; 90˚43′ W	7635 ± 220 [7475; (-15)[3]]
GSC-452	78˚54′ N; 85˚10′ W	1540 ± 130 [1380; (-15)]

[1] Measured ^{13}C values. However, the age reported by the laboratory is the uncorrected age.

[2] IsoTrace Laboratory does not report ^{13}C values. Their ages are conventionally normalized based on measured ^{13}C values that incorporate both natural and sputtering fractionation.

[3] Values inside brackets are assumed for the purpose of calculating a conventionally normalized age. The uncorrected age is the result reported by the laboratory.

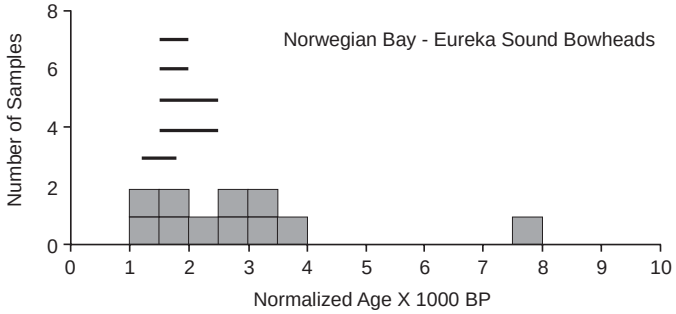

FIG. 4. Histogram of radiocarbon dates (shaded boxes) and estimated ages (bars) of bowhead remains from the Norwegian Bay–Eureka Sound region. Normalized ages are plotted.

accompanied by other skeletal elements and are partly buried in raised beach deposits. All sites are at or below 15 m elevation, which indicates that the remains are of late Holocene age, given the regional relative sea-level history (e.g., Bell, 1996; Dyke, 1998; Ó'Cofaigh, 1999). No archaeological features were seen near the bone sites, and no known prehistoric native whaling villages exist in the region. Thus, the bone occurrences result from natural mortality rather than from hunting.

The radiocarbon dates were obtained on the collagen fraction of bones, mainly on dense, subsurface pieces of ear bones (periotics) or on sectioned and carefully cleaned interior bone. The ages are reported as conventionally normalized for carbon fractionation and without a marine reservoir adjustment. The latter adjustment would reduce the ages by two or more centuries (e.g., Dyke et al., 1996b). The general sparsity of bones, along with the results of the radiocarbon dating (Table 2) and the age estimates (based on regional sea-level history) for the undated samples (Table 1), suggests that bowheads rarely ranged into this region during the last 4 ka (Fig. 4). If the age estimates of undated samples are accepted, the most frequent incursion of bowheads was approximately 2.5–1 ka B.P. There is no evidence so far of any bowhead occupation during the last several centuries or between 7.5 and 4 ka B.P. Only Bednarski's (1990) solitary find falls in earlier postglacial time.

DISCUSSION

The rarity of bowhead remains in the Norwegian Bay–Eureka Sound region contrasts with the abundant remains reported from parts of the CAA to the south, where as many as 120 bowheads have been mapped on the raised beaches of a single cove (Dyke and Morris, 1990; Dyke et

al., 1996a; Savelle et al., 2000). Thus, there is a very sharp northward decline in bone abundance in the eastern CAA, with a particularly abrupt drop between Jones Sound and Norwegian Bay. The Norwegian Bay–Eureka Sound region appears to have remained beyond the range of the bowhead for most of postglacial time.

The slightly increased number of bowhead incursions during the last 4 ka can be explained in terms of bowheads' reaching the polynyas adjacent to Devon Island via Wellington Channel or Jones Sound, and occasionally being able to forage farther along the coast. Evidently, access did not extend to the entire region. The distribution of bowhead remains of only late Holocene age adjacent to the Hell Gate–Cardigan Strait and Penny Strait polynyas may indicate that these features formed after 4 ka B.P. These polynyas occur in areas of strong currents, where large volumes of water are forced through narrow or shallow straits as part of the general outflow from the Arctic Ocean to Baffin Bay. The polynya sites at Hell Gate and Cardigan Strait (between Ellesmere and Devon Islands) and at Penny Strait have become shallower by about 140 m since deglaciation because of postglacial uplift, and all but 18 m of that change occurred before 4 ka B.P. (Dyke, 1998). Similarly, some other polynyas in the CAA, for example the archaeologically significant Flagler Bay polynya of southeastern Ellesmere Island (Schledermann, 1996), likely were initiated in the late Holocene as fiord-mouth sills became shallower with uplift (England et al., 2000).

The relative scarcity and ages of bowhead remains in the Norwegian Bay–Eureka Sound region contradict the hypothesis (see Dyke et al., 1996a) that the bone-barren beaches of 8–5 ^{14}C ka B.P. in the central CAA (Prince Regent Inlet to M'Clintock Channel; Fig. 2) represent an environment with so little summer sea ice that the bowheads shifted northward in the CAA or into the Arctic Ocean in search of ice-edge habitat. On the contrary, bowhead access in the northern CAA appears to have been minimal throughout postglacial time and may have been nil for most of the time before 4 ka B.P. The regional exclusion of bowhead whales throughout the Holocene from areas north of Norwegian Bay and north and east of Eureka Sound is further documented by more than 15 field seasons of coastal surveys around most of Axel Heiberg, Ellesmere, and adjacent smaller islands (England, 1976, 1983, 1990, 1992, 1996; Bednarski, 1986; Lemmen, 1989; Evans, 1990; Bell, 1996; Ó'Cofaigh, 1999; Lamoureux and England, 2000). With the exception of the find reported by Bednarski (1990), no bowhead bones were observed on thousands of kilometres of these surveys. If bowheads used this region commonly during the Holocene, they suffered no mortality while doing so. Mortality-free occupation for thousands of years is a great improbability, considering the fact that ice entrapment is the most probable significant cause of death (Savelle et al., 2000). The singular early Holocene find (Bednarski, 1990) must presently be seen, if the age determination is accurate, as the result of a brief exceptional condition, perhaps one warm summer, or perhaps as the stranding of a far-rafted carcass locked in sea ice, as suggested by Dyke et al. (1996a).

A relatively persistent and largely immobile sea-ice cover is also indicated by the near absence of Holocene driftwood and by the poorly developed raised beaches throughout the Norwegian Bay–Eureka Sound region. Well-formed raised beaches are characteristic of large parts of the CAA, but not of the Norwegian Bay region, nor of the northwest CAA in general (Hodgson, 1982). In the Norwegian Bay region today, well-formed beaches occur near the mouths of streams because small summer polynyas develop and sediment is brought to the coast at these sites. Raised beaches that are visible on aerial photographs form swaths along these streams, but they are generally absent elsewhere, even where sand and gravel are extensive. This pattern indicates a general lack of wave energy due to persistence of summer sea ice throughout the Holocene.

There appears to be firm evidence from ice cores that the early Holocene was substantially warmer than the late Holocene in the northeast CAA (e.g., Fisher et al., 1995). F. Koerner (pers. comm. 2000) estimates from melt-layer and isotopic records of the Agassiz Ice Cap that early Holocene summer temperatures were 3 ± 1˚C higher than present. A strong early Holocene peak of bowhead bone abundance in the central and eastern CAA at 10–8 ^{14}C ka B.P. (Dyke et al., 1996a) may be explained by reduction of summer sea-ice cover due to that greater warmth. However, changing ocean circulation patterns accompanying recession of the Laurentide Ice Sheet can also explain the bowhead peak (Dyke and Morris, 1990). It appears that neither increased warmth nor ocean circulation changes were large enough to clear summer sea ice from Norwegian Bay and areas north of there regularly during the early or the middle Holocene. Furthermore, the Agassiz Ice Cap data indicate that by 6.8 cal ka B.P. (ca. 6 ^{14}C ka B.P.), the percentage of the annual snow layer that was melting at the top of the ice cap had declined to levels similar to present levels (Fisher et al., 1995).

The conclusions outlined above do not agree with the interpretation of Gajewski et al. (2000). They concluded that marine conditions throughout the northernmost CAA at 6 ka B.P. resembled those currently found in western Hudson Strait and northwest Hudson Bay, more than 2000 km to the south. In the southeastern Canadian Arctic, the postglacial thermal maximum was evidently delayed until the middle Holocene (Williams et al., 1995). But even there, summer temperatures in Labrador at 6 ka B.P. remained about 1˚C below present levels, according to transfer functions based on pollen records. If High Arctic marine conditions had been eliminated from the entire CAA at 6 ka B.P. and replaced by Low Arctic conditions, as Gajewski et al. conclude (see their Fig. 10), nothing would have prevented bowheads, walruses (Dyke et al., 1999) and other ice-restricted marine mammals from extending their ranges throughout the region. In addition, warmth-demanding subarctic molluscs, such as *Mytilus edulis* and *Macoma balthica*, ought to have appeared, as

they did when warmer surface waters permitted their ranges to extend northward elsewhere (Dyke et al., 1996c). It is furthermore difficult to imagine what might have prevented strong beach development during the postulated period of summer open-water conditions.

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