Sealing, whaling and caribou: the skeletal isotope chemistry of Eastern Arctic foragers

Joan Brenner Coltrain a *, M. Geoffrey Hayes b, Dennis H. O’Rourke a

a Department of Anthropology, University of Utah, Salt Lake City, UT 84112, USA
b Department of Human Genetics, University of Chicago, 920 E. 58th St.-CLSC 507, Chicago, IL 60637, USA

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Abstract

We obtained stable isotope signatures (δ¹³C, δ¹⁵N) and AMS radiocarbon dates for a small set of Dorset remains, Thule-era burials from northwest Hudson Bay and proto-historic burials from Southampton Island to assess the importance of whaling in eastern Canadian Arctic economies. Classic Thule occupation of the Eastern Arctic (ca. AD 1000–1350) coincided with the Medieval Warm Period and was thought to have been facilitated by dog traction and open-sea hunting of bowhead whale. Despite the potential economic importance of whaling, dietary reconstructions for this period are based on the relative frequency of common prey types in midden faunal assemblages and rarely include bowhead whale skeletal elements, which often comprise the superstructure of Classic Thule residential dwellings. Although our findings are constrained by the paucity of Classic Thule burials at sites under study, they provide an empirically derived estimate of reliance on whaling for the Modified Thule, those who post-date AD 1350, indicating whaling accounted for approximately 12% of dietary intake. We also examine the relationship between Thule whaling and indicators of status and identify a Dorset-aged burial and three individuals with European diets among the proto-historic collection from Southampton Island.

Keywords: Stable carbon isotope ratio (δ¹³C); Stable nitrogen isotope ratio (δ¹⁵N); Marine reservoir effect; Bowhead whale (Balaena mysticetus); Dorset; Thule; Sadlermiut; Kamarvik; Silumuit; Southampton Island

“The bowhead whale … is a planktivore of the baleen group of whales adapted to live in the loose edges of the north polar sea ice. Its annual migration roughly tracks the advance and retreat of the floe edge” ([26]:235).

The role of bowhead whales (Balaena mysticetus) in Eastern Arctic economies has been a topic of particular interest over the past two decades [50,62,64–66,102,104–107]. Although bowheads are rarely included in faunal assemblage counts, their mandibular elements and ribs commonly form the superstructure of Classic Thule winter houses. The Thule are high latitude foragers who migrated east from northern Alaska [53,110] coincident with the Medieval Warm Period (ca. AD 900–1300/1350 [9,23,29,45,121]), which also saw the expansion of Europeans into Iceland and Greenland [35,70,71,83]. Their successful colonization of the central and eastern Canadian Arctic is thought to have been facilitated by dog traction and open-sea hunting of bowhead whale. Yet the relative contribution of bowhead whale to Thule diets and their importance in later economies is the subject of ongoing debate [26,38,50,62,64–66,69,102,104–107]. Here we report the results of research to reconstruct Eastern Arctic diets from the bone collagen, stable isotope chemistry of adult Dorset, Thule and proto-historic skeletal remains. Thule burials were recovered from Kamarvik and Silumuit on north-west Hudson Bay [61]; the Sadlermiut proto-historic collection originated at Native Point on Southampton Island. The temporal affiliation of each individual was established by AMS radiocarbon dating.
1. A brief prehistory of the Eastern Arctic

1.1. Dorset culture

Dorset culture emerged from a Pre-Dorset tradition between 800–500 BC [34,60,68,79,126] coincident with the onset of deep permafrost and less stable climatic conditions accompanied by colder winters. Ice creepers and hand-drawn sleds with bone runners suggest an increase in winter/spring sealing on sea ice. Dogs were less prevalent, signaling a reduction in their economic utility coincident with a decline in fall/winter exploitation of caribou [34,74]. Walrus (Odobenus rosmarus) and seals are the most abundant taxa in faunal assemblages, the latter taken using ice-edge not breathing hole techniques [21]. There is little evidence that whales were hunted and the occasional whalebone implement is thought to have been worked from scavenged bone. The bow and arrow was less common and it is believed that lances were used to take caribou and muskoxen. Winter houses were of snow block construction and meals were prepared in soapstone vessels over wick and oil heat.

Early research placed termination of the Dorset cultural complex at ca. AD 1000 with the appearance of Thule people. However, stylistic similarities between Dorset and Thule harpoon heads led some researchers to conclude that contact was sustained and the transition from Dorset to Thule material culture was a lengthy process during which the Thule borrowed numerous traits from their declining Dorset neighbors [14,15,24,47,58,59,128]. This consensus was later reinforced by several post-AD 1000 radiocarbon dates from Dorset sites in the Labrador–Ungava Peninsula indicating that the Dorset persisted until possibly as late as AD 1500, forced south and east by expanding Thule populations. In rebuttal, Park [84] has argued that post-AD 1000 Labrador–Ungava dates cannot be reliably assigned to Dorset occupations and ongoing Thule contact with Dorset culture was minimal, limited to salvaging harpoon heads and other artifacts from abandoned Dorset sites.

1.2. Classic Thule

The Classic Thule period extends from ca. AD 1000–1350 and is distinguished from earlier Dorset and later Modified Thule adaptive strategies by increased winter sedentism, marked investment in residential site structure and a distinctive and rich material culture [60,62]. Classic Thule sites are located throughout the Canadian archipelago and along the northwest coast of Hudson Bay and coastal Greenland [60]. Winter villages consist of well-built, sod and stone residential dwellings with whale-bone superstructures, paved flagstone floors and raised sleeping platforms. Park [85] has argued for village clusters of less than a dozen co-occupied structures; whereas Grier and Savelle’s [38] research suggests that occupation density may have been greater than Park’s estimates and likely covaried with reliance on whaling. In some cases, houses with a preponderance of whaling gear also contain evidence for high status in the form of tools slotted for metal blades [63,92,134]. Sites with large collections of whale bone correspond well with historic bowhead sightings and are surrounded by extensive midden and storage caches indicating repeated overwintering. Dog traction was in use. Heat and light were furnished by large, crescent-shaped soapstone lamps. Weaponry consisted of multi-component harpoons, lances, spears, throwing boards and the bow and arrow, and cutting tools were commonly fabricated from slate rather than flint.

1.3. Modified Thule

Modified or Developed Thule material culture appears to indicate a reduction in whaling and increased emphasis on breathing-hole sealing. Land-based winter villages also decline in number suggesting a demographic collapse driven by environmental deterioration and/or epidemic disease [69]. A reduction in the encounter rate of whales may have undermined Classic Thule social structure, thought to have been organized under whaling captains, contributing to an overall decrease in population density. In general, foraging groups were more mobile and residential sites both more numerous and ephemeral. Modified Thule subsistence patterns were much like those observed at European contact and cultural continuity between Modified Thule and historic Canadian Arctic Inuit populations is well established.

Changes in Thule diet and settlement pattern vary regionally [104] but generally coincide with the onset of Neo-boreal cooling, culminating in the “little ice age” (ca. AD 1550–1850). Canadian glaciers advanced and both winter and summer temperatures decreased. Accordingly, shore-fast ice formation began earlier in the fall and broke-up later in the spring. Because bowhead whales “…tend to follow the retreating ice margin and enter the high arctic channels only when a maximum of open water is available” ([104]:35), an increase in summer drift-ice may have resulted in fewer whales and less predictable migrations, reducing their encounter rate. Barren ground caribou also declined in number as cooler, drier temperatures reduced Arctic tundra cover [46,120]. Conversely, some evidence exists for an expansion of ringed seal (Phoca hispida) habitats coincident with accelerated shore-fast ice formation [46,102].

2. Thule whaling

Hudson Bay is fed by cold Arctic waters through Fury and Hecla Strait (Fig. 1), a warm Atlantic current flowing west through Hudson Strait, and warm...
fresh-water drainages flowing off the tundra at the bay’s southern margin [34]. In the southern bay, surface water is warmer and fresher than bottom water preventing upwelling and constraining productivity, but along the northwestern shore and through Roes Welcome Sound upwelling creates rich feeding grounds and the influx of water from Hudson Strait leads to favorable winter/spring whaling conditions, reducing the winter ice mantle and increasing shore leads.

Despite vastly depleted stock, bowhead whales continue to occupy much of their traditional range [98]. Historic whaling accounts indicate that the Davis Strait/Hudson Bay stock entered Hudson Strait from winter feeding grounds off the coast of northeast Labrador or southwest Greenland early in spring, crossed Hudson Bay and appeared in southern Roes Welcome Sound by early summer [32]. Most kills in Hudson Bay and Foxe Basin were made north of Chesterfield Inlet, and Roes Welcome Sound was a center of whaling activity [98]. Based on these accounts, Kamarvik and Silumiut were ideally located to facilitate late spring/early summer whaling and their artifact assemblages attest to whaling activity with toggling-head harpoons, seal bladder drag-floats to tire harpooned animals and seaworthy, driftwood and seal-skin open boats (umiaks), which held four- to eight-man crews [62,105].

The Thule are thought to have preferred bowhead whales over other baleen species because they feed and sleep near the surface, swim at slow speeds, stay afloat when harpooned due to thick layers of blubber and tend not to use their enormous tail flukes as weapons. Whereas “minimally one might guess that food from bowheads equaled the food from all other animals combined” ([65]:42), bowheads are often disregarded in prey species counts due to confounding factors unique to their size and skeletal anatomy. Faunal assemblages are biased towards small prey easily transported from procurement to consumption sites or by “culling” activities that result in selective transport of skins or skeletal elements not readily field processed [103].

Fig. 1. Map of study area showing sites from which human samples were recovered.
<table>
<thead>
<tr>
<th>Museum no.</th>
<th>Field no.</th>
<th>Sex</th>
<th>Grave goods</th>
<th>Atomic C:N</th>
<th>Wt% collagen</th>
<th>δ¹³C‰</th>
<th>δ¹⁵N‰</th>
<th>Date BP</th>
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<th>Cal 2σ range AD</th>
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**Table 1**

Eastern Arctic burials by site with preservation criteria, stable isotope and radiocarbon measurements
3. Site descriptions

3.1. Dorset burials

Dorset skeletal remains are extremely rare. Three fragmentary individuals thought to be from Dorset cultural contexts were recovered by Taylor during the late 1950s [82], one from the Tyara site on Sugluk Island in Hudson Strait [129], the Imaha burial from Pamiok Island in Ungava Bay [52] and the Angekok burial from Mansel Island in Hudson Bay. Our initial Dorset sample consisted of these remains and a second, undated Mansel Island burial.

Tyara (KbFk-7) is located on a raised beach facing the Ungava mainland on the west shore of Sugluk Island [129]. The island, ca. 500 yd from the northern shore of the mainland, is richly vegetated with flat, marshy valleys sloping down to short stretches of beach flanked by rocky outcrops. Deeply stratified, the site lacked evidence for structures, graves or caches but yielded a rich collection of artifacts, faunal remains and a human evidence for structures, graves or caches but yielded a rich collection of artifacts, faunal remains and a human
residential structures; Taylor tentatively considered it
Dorset in age based on characteristics of the lithic
assemblage and the cairn’s thick mantle of lichen. The
Angekok site was not formally reported; however
Taylor [129] felt it was late Dorset in age.

We also identified a Dorset burial among the Native
Point mortuary assemblage dating to 1992±41 BP
(Table 1). Although cataloged with the Sadlermiut col-
lection (Native Point [KkHh-1], Southampton Island),
Burial 21 was recovered by Collins [16] from a rock
enclosure one-eighth of a mile northwest of the Dorset
Tunermiut site (KkHh-3). Located on the southwest
coast of Southampton Island, Tunermiut (also referred
to as T-1) rests on a “70 foot high headland or plateau
one mile east of the Sadlermiut site” ([17]:64) and
consists of a series of shallow middens concentrated on
the northwestern section of the plateau over an area of
more than eight hectares. Covered with sparse, low
vegetation, the site is devoid of structures. The faunal
assemblage is dominated by seal, walrus and waterfowl,
the ubiquity of the latter indicating repeated summer
occupations [17,18]. Four conventional radiocarbon
dates on charred bone range from 2000–2792 BP
[17,18,75]. Given the age of Burial 21, it likely originated
at the Tunermiut site and is herein labeled the T-1
burial.

3.2. Thule burials

3.2.1. Silumiut

Silumiut (KkJg-1) is located on an island immediately
off the coast of northwest Hudson Bay connected to the
mainland at low tide [61]. Strategically situated on the
island’s highest rise, 25 m in elevation, Silumiut affords
an expansive view of Hudson Bay to the south and a
small bay to the west. Excavating in the late 1960s,
McCartney [61] and Merbs mapped 28 semi-
subterranean, whale-bone residential structures and four
storage features located on grass-sedge patches between
bedrock outcrops. Seven structures with associated
midden were excavated; all were of typical Thule winter
village construction. Surface features included a “dance
house,” nearly two hundred burial cairns, meat caches,
stone traps and markers (inuksuks), boat rests and tent
rings. House and midden faunal assemblages consisted
primarily of ringed seal and caribou [104,117]. Whale
bone was not inventoried.

A wooden cairn support produced a calibrated date
of AD 1205 (GAK-2749) [61], which we recalibrated to
AD 1224 with a two sigma range of AD 1039–1296
(Calib 4.2 [123]). Wood from House 3 produced a cal.
AD 1285 date (GAK-2759), recalibrated to AD 1293
with a two sigma range of AD 1163–1427. Nine
additional intercept dates on wood or caribou antler
range from AD 1216–1657 with a two sigma range of
AD 1000 to modern [75].

3.3. Kamarvik

Kamarvik (LeHv-1) extends south into Roes
Welcome Sound. The topography is similar to that of
Silumiut with three house clusters on the highest ridges
of the peninsula. Again, dwellings are of typical Thule
winter village construction. Over one hundred burial
cairns were identified in addition to numerous tent rings,
an inuksuk and boat rest. A smaller but similar artifact
collection was recovered, tentatively identifying the site
as Classic Thule. Faunal remains were not reported.
McCarty [61] obtained one conventional radiocarbon
date on wood from a house midden (GAK-2748), which
we recalibrated to AD 1221 with a two sigma range of
AD 1018–1387.

3.4. Native Point Sadlermiut

The Sadlermiut burial collection was thought to
represent a declining historic population that occupied
Native Point (KkHh-1), on the southeast coast of
Southampton Island, until succumbing en masse to
typhus or dysentery during the winter of 1902–03
[13,100,101,127,131]. In the early 1950s, Laughlin and
Collins [17] removed burials from cairns and more than
75 stone and sod house ruins. Sadlermiut origins are
uncertain; however our genetic data, reported elsewhere
[40], indicate that the Sadlermiut may derive from a
remnant Dorset population that experienced significant
geneological isolation resulting in distinctive patterns of
speech, dress and material culture [101]. The Sadlermiut
appear to have exploited a range of prey species similar
to other historic Inuit groups.

4. Methods

4.1. Stable carbon isotopes

Stable carbon isotope ratios have frequently been
used to address the importance of marine foods in
forager diets lacking a C4 component. The technique
was introduced by Tauber [125] to demonstrate a
reduction in dependency on marine resources at the
Mesolithic to Neolithic transition in coastal Denmark.
Since then a number of studies have employed stable
carbon isotope analysis to reconstruct mixed marine/
terrestrial diets [4,12,56,72,86,87,99,113–116,133]. The
technique is also commonly used to estimate the
role of marine resources in non-human food webs
[10,36,42,44,49,132] and as a device for tracking
migration patterns among human populations and array
of Arctic species including bowhead whale, anadromous
fish and migratory waterfowl [51,108,109].
Carbon occurs naturally in two stable forms or
isotopes. 12C is the most common making up approxi-
mately 98.89% of global carbon; whereas 13C, with an

extra neutron, comprises approximately 1.11% of the earth’s carbon. When atmospheric carbon (CO₂), dissolved CO₂, or marine bicarbonates (HCO₃⁻) are incorporated into plant tissues, physical and metabolic processes alter or fractionate the ratio of ¹³C to ¹²C depleting it relative to the substrate from which it was taken. This ratio is expressed in delta (δ¹³C) notation as parts per mil (‰) difference from an internationally recognized PDB standard [22].

\[
\delta^{13}C = \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \times 1000\%
\]

(1)

where \( R=^{13}C/^{12}C \).

The degree of discrimination against ¹³CO₂ during photosynthesis covaries with photosynthetic pathway type [31]. Lichens, cool season grasses, trees and most bushy plants employ C₃ photosynthetic mechanisms that discriminate heavily against ¹³C. Thus modern C₃ plants express a mean δ¹³C value of −26.7 ± 2.7‰ (n = 370) [11]. Alternatively, warm-season grasses, those in regions where daytime growing-season temperature exceeds 22 °C and precipitation exceeds 25 mm [28], use a C₄ pathway resulting in less discrimination against ¹³C and an average δ¹³C value of −12.5 ± 1.1‰ (n = 455) [11]. Plants grown before fossil fuel depletion of atmospheric CO₂ are enriched 1–2‰ relative to these averages [130]. Arctic terrestrial flora employ C₃ photosynthesis but exhibit a wider range of δ¹³C values than expected due to temperature and moisture extremes.

Kinetic processes governing bicarbonate (HCO₃⁻) formation in seawater fractionate marine bicarbonates approximately 7‰ relative to atmosphere, placing seawater δ¹³C values near 0‰ [12,125]. Submerged marine plants employ a C₃ photosynthetic pathway, with its associated heavy discrimination against ¹³C, yielding mean δ¹³C values of −16 to −18‰, approximately 7‰ more positive than terrestrial C₃ plants. However, mean values mask a wide range of variation. Significant differences in δ¹³C can exist from one season to another, within and between species, within a single population of the same species and within leaves of the same plant.

Sources of variation are not fully understood but may be a function of boundary layer diffusion rates [37,94].

In Arctic marine environments, additional factors contribute to variation in plant δ¹³C. Ocean upwelling recycles old carbon depleted in ¹³C [109], and eroding peat enters the marine food web at the deltas of large drainage systems [10,78,80,89]. Accordingly, zooplankton from bowhead whale summer feeding grounds off the MacKenzie River delta produced δ¹³C values 8‰ more negative than zooplankton collected in the Bering–Chukchi Seas, the whales’ winter range [89,109]. However, sections of baleen laid down during summer versus winter feeding episodes exhibit merely a 3‰ difference, illustrating that the isotope chemistry of baleen is a weighted average of intraspecific variation in lower-order diets. The δ¹³C values of Arctic foragers will represent a further averaging of intraspecific variation since carbon in ingested prey tissues is subject to continuous turnover unlike baleen, a keratinous protein metabolically inactive after formation.

δ¹³C values are passed up the food chain leaving a diagnostic signature in the tissue of consumers that does not co-vari with the skeletal element analyzed or sex of the sample independent of differences in feeding ecology [43,56]. Fractionation between primary producers and consumers approximates 5‰ and enrichment at higher trophic levels approaches 1‰ [48]. Adult bone collagen δ¹³C values represent a weighted average of long-term dietary intake since the carbon in bone collagen turns over slowly, requiring ca. 30 years to replace existing carbon with an equivalent amount of carbon [39,55,118,119].

4.2. Stable nitrogen isotopes

When nitrogen isotope ratios (δ¹⁵N substituted for C in Equation (1)) are used in conjunction with carbon, the relative contribution of specific marine resources can be estimated by monitoring the trophic level of sampled diets. Stable nitrogen isotope analysis follows from the understanding that ¹⁵N/¹⁴N increases by approximately 2–4‰ with each increase in trophic level associated with discrimination against isotopically heavy urea at renal membrane boundaries, enriching the isotope signature of nitrogen available for protein synthesis [3]. Most terrestrial plant taxa obtain nitrogen from soil ammonium (NH₄⁺) or nitrate (NO₃⁻) and those in temperate ecosystems have mean δ¹⁵N values of 3–6‰ with a 0–9‰ range contingent upon digestive physiology, temperature and water stress [20,88]. Accordingly, herbivores in such ecosystems typically exhibit δ¹⁵N values of 6–9‰, while arid-land species and non-obligate drinkers, those that recycle urea, reflect their water-conservation strategies in more positive δ¹⁵N values [2,41,112]. Conversely, plants that fix atmospheric nitrogen, many legumes, mosses and lichens, have mean δ¹⁵N values of approximately 1‰, with a −2 to 2‰ range [30,88]. Phytoplankton, primary producers in marine ecosystems, exhibit nitrogen isotope ratios in the 4–8‰ range with a mean of approximately 6‰.

5. Procedures

One gram of cortical bone was cleaned of surface contaminants then soaked 24 h in 2:1 toluene:methanol, followed by 24 h of soxhlet extraction, to remove sea mammal oil contaminants. Samples were demineralized whole in 0.6 N HCl at 4 °C and progress recorded daily. After demineralization the collagen pseudomorph was rinsed to neutrality then treated with 5% KOH to
remove organic contaminants. The acid and base
extracted collagen pseudomorph was again rinsed to
neutrality then lyophilized and weighed to obtain a
collagen yield. Approximately 100 mg of lyophilized
collagen was gelatinized in 5 ml of acidified water (pH 3)
for 24 h at 120 °C. Water-soluble and -insoluble phases
were separated by filtration and the water-soluble phase
lyophilized.

Collagen δ13C and δ15N were determined by flash
combustion to produced CO2 and N2 and measured
against the appropriate reference gas on a Finnigan
Delta Plus mass spectrometer coupled to a Carlo Erba
EA118 CHN elemental analyzer at the Stable Isotope
Ratio Facility for Environmental Research (SIRFER)
at the University of Utah. Both stable isotope
measurements and sample weight percent carbon and
nitrogen were obtained from a single sample com-
bustion. Analytic precision is 0.2% for carbon and 0.3%
for nitrogen. Approximately 10 mg of purified collagen
were forwarded to the NSF-Arizona AMS Facility,
Tucson, for dating. Dates were normalized using
measured δ13C values.  

6. Results  
6.1. Stable isotope ratios by site  
Average Sadlermiut δ13C and δ15N values are
-13.3 ±0.3‰ and 20.9±0.5‰ respectively (n=19),
excluding three individuals whose stable isotope read-
ings fall well outside the Sadlermiut range and are
modern or near modern in age (XIV-C:299-1, XIV-
C:302, XIV-C:304-1) (Table 1). Thule burials from
Kamarvik (n=30) and Silumiut (n=32) exhibit average
δ13C and δ15N readings of -14.3 ±0.4‰ and
19.6 ±1.5‰, -14.5 ±0.3‰ and 14.5 ±1.1‰ respectively.
Although Kamarvik and Silumiut δ13C values are
discrepantly different given their low variances (0.1 and
0.2 respectively) (Table 2), an absolute difference of
0.2‰ is difficult to interpret and unlikely to be meaning-
ful in this context relative to the analytical precision of
the technique. Average isotope readings for Thule versus
Sadlermiut burials are also significantly different and
represent divergent economic regimes (Table 2). How-
ever, among both the Thule and Sadlermiut, no signifi-
cant differences exist between males and females or
between individuals recovered with grave goods versus
those without, when analyzed by site. Results for
Silumiut faunal remains (n=35) [117] and bowhead
whale (n=6) from sites in the eastern and central
Canadian Arctic are reported in Table 3. The atomic
C:N ratios and collagen yields of both human and
faunal data sets indicate protein preservation was near
modern [1].

Fig. 2a regresses δ15N against δ13C for all burials. A
highly correlated relationship exists indicating that
reliance on marine resources is a robust predictor of
trophic level. Fig. 2b plots isotope ratios by site or
cultural affiliation, excluding one modern Native
individual with a δ15N value far below the plotted range
(XIV-C:302), discussed below. With the exception of
two additional data points in the lower left quadrant of
the plot, as noted (XIV-C:299-1, XIV-C:304-1), the
Sadlermiut exhibit very positive or enriched stable iso-
tope ratios indicating they were uniformly reliant on
high trophic level marine foods. In contrast, Thule diets
show greater reliance on terrestrial foods and more
variation in the trophic level of marine intake. The T-1
and Tyara Dorset burials plot with the Sadlermiut
isotopically, as does the Mansel Island burial, while the
Angekok and Imaha burials plot with the Thule.

Fig. 3 regresses δ15N against δ13C by site. The stable
isotope ratios of Thule burials from Silumiut (Fig. 3a)
and Kamarvik (Fig. 3b) are significantly correlated
although the correlation is not as robust as exhibited
by the data set as a whole, showing more variation in
δ15N within a given range of δ13C values. In contrast,
Sadlermiut isotope ratios vary randomly within a
narrow range characteristic of a living population (Fig.
3c), excluding the anomalous individuals noted.

6.2. Stable isotope ratios for Silumiut fauna  
Fig. 4 regresses Silumiut faunal δ15N values against
δ13C (Table 3). The positive relationship (Fig. 4a) is
approximately as robust as that of the human data set
(Fig. 2a) but improves when caribou, with extremely
depleted δ15N values, are deleted (Fig. 4b). Fig. 5
performs the same exercise for seal, caribou and com-
mon eider ducks (Somateria mollissima) individually.
The increase in seal and eider δ13C values accounts for a
significant proportion of the covariance in δ15N, similar
to aggregate faunal and human data sets; however this
relationship is not evident in the caribou sample.
Table 3  Silumit fauna with preservation criteria and stable isotope measurements

<table>
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<tr>
<th>Sample</th>
<th>Species</th>
<th>Common name</th>
<th>Atomic C:N</th>
<th>Weight % collagen</th>
<th>$\delta^{13}C$‰</th>
<th>$\delta^{15}N$‰</th>
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<td>3.3</td>
<td>21.8</td>
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<td>2.2</td>
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<tr>
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<td>bowhead whale</td>
<td>3.5</td>
<td>22.0</td>
<td>-15.1</td>
<td>14.1</td>
</tr>
</tbody>
</table>

Fig. 6 regresses average human and faunal $\delta^{15}N$ values against $\delta^{13}C$ at one standard deviation. The relationship is again robust with marine species expressing $\delta^{13}C$ values between $-14.8‰$ and $-12.9‰$ and terrestrial herbivores in the $-17‰$ to $-18‰$ range. $\delta^{15}N$ values for marine species vary from $13.0‰$ to $16.5‰$, with walrus showing depleted readings in keeping with their reliance on mollusks [8], while seals (ringed and bearded seal [Eriognathus barbatus]), marine carnivores, are at the opposite end of the range. Eider ducks also subsisted high on the marine food web but show more variation in $\delta^{13}C$, possibly attributable to individual migratory histories. Variation in walrus $\delta^{15}N$ is more than twice that of seal or bowhead whale reflecting occasional predation on seals by adult male walrus [8]. Two dogs ($Canis\ familiaris$) (154, 157; Table 3) have isotope ratios consistent with a winter diet of walrus in keeping with ethnographic accounts [77], while one of the remaining samples (155) subsisted primarily on seal and the other on terrestrial prey (156). Three of four muskoxen relied on a customary diet of grasses and shrubs [54], while the fourth (161; Table 3) foraged primarily on lichens, enriched in $\delta^{13}C$ and depleted in $\delta^{15}N$. Similarly, all caribou have relatively uniform stable isotope ratios consistent with heavy reliance on lichens [54].

6.3. Accelerator radiocarbon dates

Calibrating radiocarbon dates on human or faunal study populations with a marine dietary component is widely recognized as problematic given the uncertainty in...
associated with marine reservoir effects [5,25,57,76, 81,125]. Dates reported herein were calibrated by Calib 4.2 [123], which weights global and regional marine reservoir effects (ΔR [122]) relative to the percentage of marine resources in sampled diets. This percentage was estimated using a terrestrial end-member δ13C value of −17.7‰, the average for Silimiut caribou and muskoxen, and a marine end-member δ13C value of −14.0‰, the average value for seals, and corrected for a 1‰ offset between diet and collagen δ13C [48]. In addition to the global reservoir effect correct, a regional correction of +132 ± 26 radiocarbon years was weighted and used in the calibration of AMS dates for all individuals except the Imaha burial and is based on the mean difference between measured and known age on prebomb shell collected in the west Hudson Strait, specifically from the southwest coast of Baffin Island, Coats Island and the southeastern peninsula of Southampton Island including Native Point [6,124]. A regional reservoir effect correction of +89 ± 30 radiocarbon years was used to calibrate the Imaha date, averaged from prebomb shell collected in the east Hudson Strait and Ungava Bay [6,124].

Silumiut burials date to a calibrated two sigma range of AD 1063–1679. Kamarvik covers a similar temporal range, AD 1158–1664 (Table 1; Figs. 7 and 8). With four
exceptions, Sadlermiut burials date to a calibrated two sigma range of AD 1308–1890 indicating this sample does not represent the historic population that succumbed to disease early in the twentieth century. The T-1 burial (XIV-C:749) is Dorset (AD 423) as noted above. Also three historic individuals are identified by modern, upper two-sigma ranges and European diets. The Tyara burial is clearly Dorset in age dating to AD 245; whereas the Imaha burial has a calibrated intercept date of AD 1461. We obtained a replicate date on the Angekok burial that yielded a pooled age of 1216 ± 35 BP in radiocarbon years, calibrating to a two-sigma

Fig. 4. a. δ¹⁵N regressed against δ¹³C with correlation coefficient for Silumiut fauna; b. Silumiut fauna, caribou deleted.

Fig. 5. a. δ¹⁵N regressed against δ¹³C with correlation coefficient for ringed seal (*P. hispida*) and bearded seal (*E. barbatus*); b. common eider duck (*S. mollissima*); c. caribou (*R. tarandus*).
742 range of AD 1165–1297 and intercept of AD 1248, placing Angekok late in the Dorset sequence as Taylor
743 [129] suggested. Our mitochondrial DNA haplogroup
744 assignment also suggests the Angekok burial is Dorset in origin [40]. The second Mansel Island burial is proto-
745 historic in age with a calibrated intercept date of AD
746 1696.

747 Figs. 7 and 8 plot calibrated intercept dates and
748 two-sigma ranges against $\delta^{13}C$ and $\delta^{15}N$ values respectively. The earliest Silumiut burials are enriched in $\delta^{15}N$,
749 while early Kamarvik burials exhibit a wider range
750 of variation than later individuals. Sadlermiut burials
751 cluster tightly.

755 7. Discussion

756 Our primarily objective was to estimate the contribution
757 whaling made to Classic Thule diets; however
758 calibrated intercept dates on all but seven individuals in
759 the Thule data set are more recent than the Medieval
760 Warm Period, most falling between AD 1400–1550. The
761 upper end of the Thule two-sigma range is, however,
762 consistent with an account by the explorer Thomas
763 Button who visited Silumiut and Kamarvik in late July
764 of 1613 and reported that Silumiut had been very
765 recently abandoned [73]. Alternatively, Dyke et al. [27]
766 have suggested that the reservoir effect correction for
767 eastern Canadian Arctic bowhead whale, and by implication
768 other marine fauna, is closer to +200 years than the
769 larger global (+400 yr) and regional corrections
770 usually applied. They argue that because carbon in the
771 bone collagen of marine mammals derives from organic
772 sources rather than marine bicarbonates, mammals are
773 less affected by the upwelling of old carbon than known-
774 age shell, routinely used to calculate reservoir effect. If a
775 +200 year reservoir correction was applied to the Thule
776 data set, burials would fall largely within the Medieval
777 Warm Period or date slightly earlier, allowing us to
778 examine our primary research objective. However, we
779 hesitate to make this correction for the following reasons. (1) Phytoplankton, at the base of marine food webs, takes up photosynthetic carbon from marine bicarbonates ($HCO_3^-$) and dissolved $CO_2$ [93,95,96] and transmits enriched stable carbon and depleted radiocarbon isotope signals to higher trophic level consumers in marine ecosystems. It is the presence of inorganic source carbon in marine foods that allows researchers to estimate the importance of these foods in the diets of human foragers [4,12,56,72,86,87,99,113–116,133]. (2) Although a subset of wood samples from Silumiut residential contexts have intercept dates older than the majority of our data set [75], radiocarbon dates on wood record when the wood was felled not the occupation date of structures associated with wood artifacts or structural members. This discrepancy is especially problematic at high latitudes where driftwood is the sole source of structural and artifactual wood, preserves well and is reused. (3) Thule-era radiocarbon dates on wood from Silumiut cover a calibrated two-sigma range of AD 1000–1636 [75], very similar to the calibrated two sigma range of sampled Thule burials, AD 1063–1679. Given the temporal distribution of these burials, any estimate of reliance on bowhead whale will better characterize the Modified Thule period than earlier Thule subsistence strategies.

Simple linear mixing models are useful for calculating the percentage of foods in isotopically measured diets if each food has approximately the same concentration of carbon to nitrogen, characteristic of diets comprised largely of animal protein [7,90,91,111]. The model is formulated from the following set of mass balance equations [90]:

$$
\delta J_D = f_A \delta J_A + f_B \delta J_B + f_C \delta J_C
$$

$$
\delta K_D = f_A \delta K_A + f_B \delta K_B + f_C \delta K_C
$$

where: $\delta J$ and $\delta K$ are isotope ratios for two elements, $A$, $B$, $C$ subscripts are three food sources and the consumer respectively and $f$ is the fractional contribution of each food source.

Thus, the model should allow us to estimate the relative importance of any three resources for which we have data (i.e., seal, caribou and bowhead whale in Thule diets or seal, caribou, and sea birds in Sadlermiut
diets). However, initial attempts to do so proved problematic. Barren ground caribou are heavily reliant on lichens, which are fungal/algal symbionts. The algal component, commonly a blue-green algae, fixes atmospheric nitrogen, which exhibits a $^{15}$N value of 0‰. Accordingly, the average $^{15}$N value for Silumiut caribou is $2.8 \pm 0.4$‰, approximately 3‰ more positive than atmospheric source nitrogen; whereas herbivores in terrestrial ecosystems derive source nitrogen from soil ammonium or nitrate and commonly express $^{15}$N values in the 6–9‰ range [19,20,112]. Substituting the average measured $^{15}$N value for caribou into the above model creates a significant positive bias in reliance on caribou inconsistent with measured $^{13}$C values for any human sample in the data set. To circumvent this problem, we used the regression equation in Fig. 4b, (i.e., Silumiut fauna, caribou deleted) to calculate a modeled, average $^{15}$N value for caribou (8.88‰). Results are shown in Table 4 and are constrained by percent marine intake. For example, using measured $^{13}$C and $^{15}$N values for sea birds and seal and measured $^{13}$C but calculated $^{15}$N for caribou results in a diet of 5.0% sea birds, 86.6% seal and 8.4% caribou with a calculated $^{13}$C value of $-13.31$‰ and $^{15}$N value of 19.85‰. The former is virtually identical to the average measured $^{13}$C value for Sadlermiut burials while the latter is within a per mil of the measured value. The same exercise for Kamarvik diets, using measured $^{13}$C and $^{15}$N for seal and bowhead whale and measured $^{13}$C but calculated $^{15}$N for caribou, results in a diet of 54% seal, 11% whale and 35% caribou. Again the former is virtually identical to the average $^{13}$C value for Kamarvik burials while the latter is within half a per mil (0.5‰). The same conditions and results apply to the Silumiut, resulting in an average diet of 47% seal, 12% whale and 41% caribou.

Fig. 7. a, b, c. Variation in $^{13}$C values over time plotted by site.

Fig. 8. a, b, c. Variation in $^{15}$N values over time plotted by site.
Although useful, simple linear mixing models do not generate absolute measures of reliance on all foods since they are limited to estimating the intake of \( n+1 \) resources, where \( n \) is the number of elemental isotopes measured. Thus by way of comparison, we briefly review the composition of a Silumiut faunal assemblage with a representative large mammal MNI (minimum number of individuals). We recognize that faunal assemblages are site specific, biased by culling for transport and temporally constrained reflections of past diet, whereas an individual’s skeletal isotope chemistry reflects long-term, often life-time, adult diet independent of his tenure at the burial site. However, it is not unreasonable to assume that a representative faunal assemblage from an intensively occupied site will be grossly similar in species abundance to the isotope chemistry of an individual recovered from the same site, particularly at high latitudes, and may further inform our interpretation of his isotope signature.

Large mammal remains from “House and Midden 14” are dominated by seal (58%) and caribou (37%), while walrus are sparsely represented (3%), with an MNI more than an order of magnitude less than that of seals [117]. Polar bear (Ursus maritimus) are absent and muskoxen rare (2%). Fish, shellfish and avifauna are also rare; and small mammals are sparsely represented by species used in the fabrication of clothing (e.g., wolverine [Gulo gulo], arctic hare [Lepus arcticus], and arctic fox [Alopex lagopus]). Our estimates are in keeping with the relative abundance of frequently exploited prey types, given that whales were not inventoried and culling for transport may have depressed caribou counts. These estimates indicate that the average Silumiut forager was heavily and nearly equally reliant on seal and caribou, while bowhead whale provided a smaller fraction of the diet, accounting for approximately 12% of measured isotopic enrichment. The average Kamarvik forager consumed a similar diet; however seals made a somewhat greater contribution than caribou. Among the Sadlermiut, seals account for 86% of measured isotopic enrichment, while sea birds and caribou are of minor importance (Table 4).

Both the Tyara and T-1 Dorset burials exhibit diets similar to the average Sadlermiut forager, heavily reliant on seal and sea birds. The Mansel Island burial also has a “Sadlermiut” diet and is proto-historic in age, fitting nicely into the Sadlermiut age range. Both the Imaha and Angekok burials exhibit diets similar to the average Thule forager. Imaha is also similar in age to the Modified Thule data set while the Angekok burial, Dorset in affiliation [40,82,84,129], dates within both the Thule and late Dorset occupation of the Labrador–Ungava peninsula.

Seven burials in the Thule data set have calibrated intercept dates before AD 1350; however they provide little insight into earlier diets. The isotope signatures of early Kamarvik burials (n=5) cover the range of variation present in the remaining Kamarvik data set, while the mean \( \delta^{13}C \) value of early Silumiut burials (XIV-C:376, XIV-C:429) is virtually identical to the remainder of the Silumiut population and the mean \( \delta^{15}N \) value is only slightly more positive. Neither Classic Thule subset is distinct from the Modified Thule; yet neither subset is adequate in size to assume isotope signatures are representative of an earlier population. All we can reasonably conclude is that Classic Thule foragers were at least as reliant on bowhead whale as estimates generated for the current Thule data set reported herein.

These results indicate that while whaling appears to have made a larger contribution to Modified Thule diets than hunting walrus or muskoxen, it did not make a contribution equal to that of seal or caribou. However, whaling may have served a more important social function, structuring male status hierarchies. Pringle [92] reports that Thule winter houses with whaling gear were also characterized by higher frequencies of trade metals. Whaling was likely a “high status” activity [134] with an
associated social currency underwritten by the skill required and danger associated with hunting a cetacean weighing three tons per linear meter \([33,60,97]\) from an open boat with hand-held harpoon. Moreover, the average adult provided 15,000 kg of usable meat and skin and 9000 kg of blubber as well as baleen and bone for a variety of uses [60]. Although yearling animals, 7–9 m in length, were taken in preference to mature adults \([50,66,106]\), whaling was clearly a high-risk, high-return foraging strategy [135].

Variation in the isotope chemistry of Thule diets can be read to support the presence of status differences. Both Silumiut and Kamarvik intercept dates cluster between AD 1400–1550 (Figs. 7 and 8) and give the resolution of radiocarbon dating, indicate that we may have sampled near-contemporaneous, site-specific populations. Within the narrow range of dates from both sites, \(\delta^{13}N\) values vary randomly over a virtually identical \(\delta^{15}N\) range (Fig. 8), while variation in \(\delta^{13}C\) is less than half that (Fig. 7). Fig. 3 shows that among Silumiut foragers in particular reliance on marine resources is relatively uniform, while the trophic level of marine foods varies more widely. Some individuals subsisted on diets comprised largely of seal, while others derived more of their marine intake from bowhead whale or perhaps walrus. Whaling captains, their crews and families may have had access to larger shares of each kill; and as the encounter rate of bowhead whale declined, an occasional kill may have become increasingly valuable in terms of status accruing to individuals capable of providing a highly prized but increasingly scarce resource. Conversely, Sadlermiut intercept dates cover an approximate 300 year range, twice the temporal range of most Thule burials; yet variation in the trophic level of sampled diets is minimal. Clearly Sadlermiut foragers had less access to or were less adept at taking both whales and walrus, and as a population consumed very similar diets.

Finally, the three historic individuals from Sadlermiut (XIV-C:299-1, XIV-C:302, XIV-C:304-1) are unlikely to have been indigenous to Native Point or the adjacent mainland. Burials XIV-C:299-1 and XIV-C:304-1 have diets low in marine foods, 21.6% and 10.8% respectively, and relatively low in trophic level and may have been European in origin or consumed adult diets largely comprised of European foods. Burial XIV-C:302 is clearly European in origin, with a diet virtually devoid of marine foods, low in animal protein and high in cereal grains and/or beans. All three were recovered by Taylor, the latter two from the interior of a standing house.

8. Summary

Our primary research objective was to estimate the importance of bowhead whale in Classic Thule diets. However, most Thule burials in our data set are younger in age, dating after the Medieval Warm Period when exploitation strategies are thought to have shifted to greater reliance on ringed seal. Those that date earlier are few in number and inconclusive with respect to Classic Thule diets. Modified Thule foragers relied primarily and relatively evenly on ringed seal and caribou with less than 15% of isotopic enrichment attributable to bowhead whale. It is reasonable to conclude that Classic Thule foragers were at least as reliant on bowhead whale; but data reported here provide no basis for making further estimates.

However, significant variation exists within the Thule data set with respect to the trophic level of marine intake. Some individuals relied heavily on high trophic level marine fauna, such as ringed seal, while others were more reliant on bowhead whale (and perhaps walrus) leading us to consider the possibility that status differences may have existed, based on whaling success. In contrast, Sadlermiut diets are uniformly high in high trophic level marine foods, varying randomly within a narrow range of \(\delta^{13}C\) and \(\delta^{15}N\) values. In addition, the Sadlermiut collection does not date to the early twentieth century but is proto-historic or early historic in age with four exceptions. One individual is Dorset in age; the remaining three are historic and exhibit European or European-like diets. The indigenous population that died en masse at Native Point during the winter of 1902–03 is not represented by individuals in our sample.

9. Uncited reference

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