ARTICLE IN PRESS

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

Abstract

We obtained stable isotope signatures (δ^{13}C, δ^{15}N) 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.
© 2003 Published by Elsevier Ltd.

Keywords: Stable carbon isotope ratio (δ^{13}C); Stable nitrogen isotope ratio (δ^{15}N); 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 Silumiut on northwest 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.

* Corresponding author. Tel.: +1-801-581-8366;
fax: +1-801-581-6252.
E-mail address: coltrain@anthro.utah.edu (J.B. Coltrain).

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,

Fig. 1. Map of study area showing sites from which human samples were recovered.

161 fresh-water drainages flowing off the tundra at the bay's
162 southern margin [34]. In the southern bay, surface water
163 is warmer and fresher than bottom water preventing
164 upwelling and constraining productivity, but along the
165 northwestern shore and through Roes Welcome Sound
166 upwelling creates rich feeding grounds and the influx of
167 water from Hudson Strait leads to favorable winter/
168 spring whaling conditions, reducing the winter ice
169 mantle and increasing shore leads.
170 Despite vastly depleted stock, bowhead whales con-
171 tinue to occupy much of their traditional range [98].
172 Historic whaling accounts indicate that the Davis Strait/
173 Hudson Bay stock entered Hudson Strait from winter
174 feeding grounds off the coast of northeast Labrador or
175 southwest Greenland early in spring, crossed Hudson
176 Bay and appeared in southern Roes Welcome Sound by
177 early summer [32]. Most kills in Hudson Bay and Foxe
178 Basin were made north of Chesterfield Inlet, and Roes
179 Welcome Sound was a center of whaling activity [98].
180 Based on these accounts, Kamarvik and Silumiut were

181 ideally located to facilitate late spring/early summer
182 whaling and their artifact assemblages attest to whaling
183 activity with toggling-head harpoons, seal bladder drag-
184 floats to tire harpooned animals and seaworthy, drift-
185 wood and seal-skin open boats (*umiaks*), which held
186 four- to eight-man crews [62,105].
187 The Thule are thought to have preferred bowhead
188 whales over other baleen species because they feed and
189 sleep near the surface, swim at slow speeds, stay afloat
190 when harpooned due to thick layers of blubber and tend
191 not to use their enormous tail flukes as weapons.
192 Whereas "minimally one might guess that food from
193 bowheads equaled the food from all other animals
194 combined" ([65]:42), bowheads are often disregarded in
195 prey species counts due to confounding factors unique
196 to their size and skeletal anatomy. Faunal assemblages
197 are biased towards small prey easily transported
198 from procurement to consumption sites or by "culling"
199 activities that result in selective transport of skins or
200 skeletal elements not readily field processed [103].

201 Table 1
Eastern Arctic burials by site with preservation criteria, stable isotope and radiocarbon meassurements

	Museum no.	Field no.	Sex	Grave goods	Atomic C:N	Wt% collagen	δ^{13}C ‰	δ^{15}N ‰	Date BP	Cal intercept date AD[c]	Cal 2σ range AD	AA number
203	Sadlermiut											
204	XIV-C:145/263	NP B53	F		3.14	26.3	−13.5	20.5	875 ± 38	1485	1436–1573	AA38603
205	XIV-C:147/288	NP B10	F		3.14	24.8	−13.8	21.0	728 ± 41	1628	1488–1673	AA38604
206	XIV-C:247	NP B157	F		3.15	24.6	−13.1	20.6	760 ± 50	1667	1532–1807	AA35669
207	XIV-C:764	B36	F		3.13	25.6	−13.7	20.4	977 ± 54	1415	1308–1476	AA38607
208	XIV-C:098	NPB 46	F	y	3.17	24.6	−13.0	20.8	822 ± 32	1641	1521–1683	AA40086
209	XIV-C:112	NP B172	F		3.13	27.6	−13.5	21.1	791 ± 33	1557	1485–1661	AA40087
210	XIV-C:178	NP B48	F		3.09	25.4	−13.7	20.4	714 ± 44	1644	1510–1688	AA40090
211	XIV-C:752	B24	F	y	3.14	25.1	−13.1	21.2	682 ± 42	1704	1656–1890	AA40094
212	XIV-C:148	NP B175A	F	y	3.13	24.8	−13.2	21.4	806 ± 37	1632	1503–1679	AA41533
213	XIV-C:169[a]	PP 3	F	y	3.21	25.6	−13.3	21.3	915 ± 40	1480	1429–1555	AA38608
214	XIV-C:117	NP B101	M		3.15	26.7	−13.4	21.2	690 ± 55	1677	1548–1836	AA35667
215	XIV-C:126	NP B114	M		3.02	27.9	−13.1	20.4	836 ± 59	1613	1466–1691	AA38602
216	XIV-C:174	NP B9A	M	y	3.26	27.5	−13.3	20.3	725 ± 50	1669	1536–1811	AA35668
217	XIV-C:199	NP B 13	M	y	3.25	26.3	−13.6	20.8	817 ± 38	1518	1454–1644	AA38605
218	XIV-C:167	NP B61	M		3.10	24.2	−13.2	20.7	714 ± 42	1680	1627–1817	AA40089
219	XIV-C:190	NP B77	M	y	3.19	25.1	−13.2	21.3	781 ± 43	1648	1517–1695	AA40091
220	XIV-C:230	NP B73	M		3.14	29.4	−13.3	21.6	684 ± 40	1687	1642–1826	AA40092
221	XIV-C:737	B4	M	y	3.23	32.8	−13.1	22.2	772 ± 50	1661	1525–1723	AA40093
222	XIV-C:153	NP B159	unkn	unkn	3.13	24.7	−12.8	20.3	856 ± 41	1577	1484–1675	AA40088
223	XIV-C:299-1	none	unkn	unkn	3.19	26.9	−15.9	14.5	333 ± 51	1665	1531–1946	AA42324
224	XIV-C:302	House 34	unkn	unkn	3.19	21.2	−17.8	4.3	221 ± 34	1784[c]	1643–1948	AA42325
225	XIV-C:304-1	House 34	unkn	unkn	3.14	24.1	−16.3	14.0	261 ± 41	1668	1641–1946	AA42326
226	Kamarvik											
227	XIV-C:536	KA6	F		3.33	29.2	−14.3	18.7	1095 ± 50	1274	1173–1316	AA35670
228	XIV-C:587	KA56	F	y	3.25	27.8	−14.9	16.7	736 ± 40	1440	1404–1489	AA38610
229	XIV-C:621	KA90	F	y	3.32	31.1	−14.1	17.7	761 ± 40	1498	1444–1636	AA38611
230	XIV-C:644	KA113	F		3.17	22.1	−15.4	14.4	610 ± 39	1460	1427–1530	AA38612
231	XIV-C:650	KA119	F		3.37	28.9	−14.6	17.0	700 ± 50	1486	1431–1639	AA35674
232	XIV-C:532	KA2	F		3.19	30.9	−14.5	17.6	836 ± 42	1425	1327–1475	AA38619
233	XIV-C:584	KA53	F		3.22	24.4	−14.4	17.3	768 ± 49	1461	1411–1577	AA40097
234	XIV-C:637	KA106	F		3.24	30.6	−14.0	18.4	792 ± 38	1488	1439–1623	AA40101
235	XIV-C:531	KA1	F	y	3.17	19.8	−14.1	18.5	594 ± 41	1671	1630–1809	AA41545
236	XIV-C:537	KA7	F	y	3.20	26.6	−14.2	18.0	699 ± 48	1534	1459–1664	AA41547
237	XIV-C:582	KA51	F		3.09	25.9	−14.5	18.9	747 ± 38	1466	1426–1526	AA41549
238	XIV-C:605	KA74	F	y	3.21	24.1	−14.5	18.9	731 ± 43	1477	1430–1622	AA41551
239	XIV-C:623	KA92	F	y	3.12	26.7	−14.4	19.0	716 ± 51	1497	1436–1646	AA41553
240	XIV-C:577	KA46	M		3.18	25.5	−14.3	19.0	1120 ± 50	1256	1158–1304	AA35671
241	XIV-C:607	KA76	M		3.31	29.6	−13.9	18.3	785 ± 45	1506	1443–1644	AA35672
242	XIV-C:628	KA97	M		3.27	24.9	−14.4	17.7	705 ± 50	1510	1441–1650	AA35673
243	XIV-C:544	KA14	M		3.22	28.7	−13.9	19.5	931 ± 44	1423	1327–1473	AA38620
244	XIV-C:567	KA37	M		3.21	28.1	−14.1	18.9	763 ± 39	1497	1444–1634	AA40096
245	XIV-C:611	KA80	M	y	3.13	28.6	−14.4	19.2	720 ± 39	1494	1454–1539	AA40099
246	XIV-C:624	KA93	M		3.19	27.9	−13.6	20.5	918 ± 36	1449	1408–1504	AA40100
247	XIV-C:648	KA117	M		3.19	29.6	−13.8	20.0	1047 ± 49	1326	1278–1427	AA40102
248	XIV-C:533	KA3	M		3.17	24.9	−14.3	19.1	852 ± 38	1432	1393–1476	AA41546
249	XIV-C:545	KA15	M	y	3.16	23.5	−13.9	19.7	774 ± 42	1516	1449–1646	AA41548
250	XIV-C:583	KA52	M		3.15	25.5	−14.3	13.5	991 ± 43	1314	1277–1411	AA41550
251	XIV-C:613	KA82	M	y	3.20	24.4	−14.7	18.2	651 ± 45	1516	1447–1649	AA41552
252	XIV-C:646	KA115	M	y	3.07	28.1	−14.2	19.0	772 ± 43	1481	1431–1623	AA41554
253	XIV-C:647	KA116	M	y	3.06	25.1	−14.0	18.9	824 ± 41	1467	1422–1531	AA41555
254	XIV-C:560	KA30	unkn	y	3.05	26.4	−14.4	17.7	846 ± 43	1428	1334–1475	AA38609
255	XIV-C:600	KA69	unkn		3.21	27.5	−13.6	19.6	952 ± 38	1435	1382–1491	AA40098
256	XIV-C:653	KA122	unkn		3.17	26.9	−15.2	16.4	932 ± 47	1287	1219–1384	AA40103
257	Silumiut											
258	XIV-C:388	SIL47	F		3.23	26.7	−14.9	15.5	672 ± 39	1475	1432–1619	AA38614
259	XIV-C:412	SIL71	F		3.27	27.8	−14.4	17.8	730 ± 55	1487	1427–1643	AA35676
260	XIV-C:429	SIL88	F	y	3.16	26.4	−14.0	18.5	1105 ± 48	1288	1212–1383	AA38615

275 Table 1 (*continued*)

Museum no.	Field no.	Sex	Grave goods	Atomic C:N	Wt% collagen	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	Date BP	Cal intercept date AD[c]	Cal 2σ range AD	AA number
XIV-C:473	SIL128	F	y	3.20	26.2	−14.8	17.2	815 ± 47	1413	1313–1454	AA38616
XIV-C:372	SIL32	F		3.10	29.8	−14.5	18.1	790 ± 37	1443	1407–1492	AA40105
XIV-C:384	SIL43	F		3.26	29.6	−15.0	16.0	628 ± 37	1492	1444–1634	AA40106
XIV-C:436	SIL95	F	y	3.27	28.3	−14.6	17.9	752 ± 42	1451	1413–1519	AA40108
XIV-C:490	SIL145	F		3.17	31.5	−14.9	17.1	584 ± 39	1548[e]	1476–1660	AA40110
XIV-C:514	SIL169	F	y	3.28	26.7	−14.4	16.9	608 ± 38	1646	1520–1679	AA40111
XIV-C:519	SIL174	F		3.11	29.2	−14.3	16.5	768 ± 45	1474	1424–1618	AA40112
XIV-C:341	SIL1A	F		3.26	26.0	−14.8	18.5	664 ± 37	1489	1442–1631	AA41534
XIV-C:404	SIL63	F	y	3.20	24.2	−14.5	19.1	809 ± 44	1436	1395–1488	AA41536
XIV-C:452	SIL117	F	y	3.11	26.2	−14.5	17.4	753 ± 82	1460	1337–1649	AA41539
XIV-C:480	SIL135	F	y	3.18	25.5	−14.6	18.5	895 ± 66	1393	1282–1449	AA41541
XIV-C:357	SIL17	M		3.31	24.0	−14.9	14.7	649 ± 43	1488	1438–1636	AA38613
XIV-C:443	SIL102	M		3.11	25.0	−14.6	17.4	920 ± 50	1366c	1284–1429	AA35677
XIV-C:499	SIL154	M	y	3.26	27.2	−13.5	18.6	774 ± 41	1624	1488–1675	AA38617
XIV-C:513	SIL168	M		3.24	27.2	−14.6	16.6	710 ± 45	1481	1431–1630	AA35679
XIV-C:345	SIL5	M	y	3.16	28.5	−14.7	17.1	736 ± 38	1451	1417–1514	AA40104
XIV-C:419	SIL78	M	y	3.14	29.1	−14.3	17.7	709 ± 40	1518	1452–1646	AA40107
XIV-C:462/451	SIL114	M	y	3.32	28.2	−14.8	16.5	648 ± 37	1502	1447–1638	AA40109
XIV-C:356	SIL16	M	y	3.23	25.2	−14.7	17.2	716 ± 44	1465	1422–1612	AA41535
XIV-C:415	SIL74	M	y	3.23	21.9	−14.3	18.5	854 ± 42	1431	1389–1479	AA41537
XIV-C:439	SIL98	M		3.14	21.1	−13.9	20.6	976 ± 37	1402	1309–1442	AA41538
XIV-C:476	SIL131	M	y	3.09	25.3	−14.7	17.0	676 ± 45	1491	1438–1639	AA41540
XIV-C:485	SIL140	M		3.21	23.2	−14.2	17.6	794 ± 33	1466	1429–1522	AA41542
XIV-C:501	SIL156	M	y	3.09	22.6	−14.3	17.8	703 ± 78	1522	1426–1679	AA41543
XIV-C:518	SIL173	M	y	3.13	26.9	−14.8	16.7	571 ± 40	1637	1493–1671	AA41544
XIV-C:740N[b]	SN3	M		3.20	25.7	−14.3	18.1	747 ± 40	1486	1437–1627	AA41532
XIV-C:741N[b]	SN4	F		3.24	26.0	−14.6	18.3	744 ± 54	1456	1407–1617	AA38618
XIV-C:376	SIL36	unkn		3.17	27.9	−14.5	18.2	1130 ± 50	1219	1063–1291	AA35675
XIV-C:487	SIL142	unkn		3.38	27.4	−14.5	17.5	750 ± 45	1463	1419–1532	AA35678
Other											
T-1 Dorset	B21	F		3.13	24.8	−13.9	20.3	1992 ± 41	423	325–539	AA38606
Tyara Dorset	none	unkn		3.31	28.3	−12.9	20.8	2260 ± 50	245	99–390	AA34764
Imaha	Burial 1	M	y	3.26	29.7	−14.0	18.5	800 ± 45	1461	1414–1533	AA34766
Mansel Island	none	F		3.20	27.9	−13.4	20.3	653 ± 39	1696	1654–1869	AA40095
Angekok	J1GU-2:61	unkn	y	3.37	27.4	−14.5	18.1	1216 ± 35	1248	1165–1297	Pooled[d]

[c] Multiple intercepts: XIV-C:302: AD 1661, 1784, 1789; XIV-C:490: AD 1540, 1548, 1623; XIV-C:433: AD 1327, 1366, 1382.
[a] Pirarie Point.
[b] Silumiut North.
[d] AA35683, AA34765.

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 mandible and rib fragments. Based on similar artifact assemblages from dated contexts, Taylor concluded that the site was early Dorset in age (ca. 800–300 BC).

Imaha (JaEj-1), on the eastern end of Pamiok Island, consisted of "two burial vaults, destroyed food caches, and house structures of two kinds", tent rings and a single, semi-subterranean dwelling ([52]:2). Faunal material was poorly preserved, comprised of seal, walrus and unidentified bone fragments. The burial was recovered from an intact stone cairn adjacent to

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 collection (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. McCartney [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 geographic 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 C_4 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. ^{12}C is the most common making up approximately 98.89% of global carbon; whereas ^{13}C, with an

extra neutron, comprises approximately 1.11% of the earth's carbon. When atmospheric carbon (CO_2), dissolved CO_2, or marine bicarbonates (HCO_3^-) are incorporated into plant tissues, physical and metabolic processes alter or fractionate the ratio of ^{13}C to ^{12}C depleting it relative to the substrate from which it was taken. This ratio is expressed in delta ($\delta^{13}C$) notation as parts per mil (‰) difference from an internationally recognized PDB standard [22].

$$\delta 13C = \frac{R_{sample} - R_{standard}}{R_{standard}} \times 1000\% \quad (1)$$

where $R = {}^{13}C/{}^{12}C$.

The degree of discrimination against $^{13}CO_2$ during photosynthesis covaries with photosynthetic pathway type [31]. Lichens, cool season grasses, trees and most bushy plants employ C_3 photosynthetic mechanisms that discriminate heavily against ^{13}C. Thus modern C_3 plants express a mean $\delta^{13}C$ 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 C_4 pathway resulting in less discrimination against ^{13}C and an average $\delta^{13}C$ value of -12.5 ± 1.1‰ ($n=455$) [11]. Plants grown before fossil fuel depletion of atmospheric CO_2 are enriched 1–2‰ relative to these averages [130]. Arctic terrestrial flora employ C_3 photosynthesis but exhibit a wider range of $\delta^{13}C$ values than expected due to temperature and moisture extremes.

Kinetic processes governing bicarbonate (HCO_3^-) formation in seawater fractionate marine bicarbonates approximately 7‰ relative to atmosphere, placing seawater $\delta^{13}C$ values near 0‰ [12,125]. Submerged marine plants employ a C_3 photosynthetic pathway, with its associated heavy discrimination against ^{13}C, yielding mean $\delta^{13}C$ values of -16 to -18‰, approximately 7‰ more positive than terrestrial C_3 plants. However, mean values mask a wide range of variation. Significant differences in $\delta^{13}C$ 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 $\delta^{13}C$. Ocean upwelling recycles old carbon depleted in ^{13}C [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 $\delta^{13}C$ values 8‰ more negative then 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 $\delta^{13}C$ 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.

$\delta^{13}C$ values are passed up the food chain leaving a diagnostic signature in the tissue of consumers that does not covary 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 $\delta^{13}C$ 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 ($\delta^{15}N$ 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 $^{15}N/^{14}N$ 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 (NH_4^+) or nitrate (NO_3^-) and those in temperate ecosystems have mean $\delta^{15}N$ 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 $\delta^{15}N$ values of 6–9‰, while arid-land species and non-obligate drinkers, those that recycle urea, reflect their water-conservation strategies in more positive $\delta^{15}N$ values [2,41,112]. Conversely, plants that fix atmospheric nitrogen, many legumes, mosses and lichens, have mean $\delta^{15}N$ 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

Table 2
Site means and two sample *t*-tests assuming unequal variance

Sites	Mean $\delta^{13}C$ ‰	*t*-value	df	*P* value	Mean $\delta^{15}N$ ‰	*t*-value	df	*P* value
Sadlermiut: Kamarvik	−13.31: −14.30	10.2325	47	1.517E-13	20.92: 18.21	9.0534	39	3.956E-11
Sadlermiut: Silumiut	−13.31: −14.51	14.4313	44	2.7074E-18	20.92: 17.53	14.7871	47	2.6708E-19
Kamarvik: Silumiut	−14.30: −14.51	2.3071	55	0.0248	18.21: 17.53	1.9981	53	0.0508

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 $\delta^{13}C$ and $\delta^{15}N$ were determined by flash combustion to produced CO_2 and N_2 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 $\delta^{13}C$ values.

6. Results

6.1. Stable isotope ratios by site

Average Sadlermiut $\delta^{13}C$ and $\delta^{15}N$ values are −13.3 ± 0.3‰ and 20.9 ± 0.5‰ respectively (*n*=19), excluding three individuals whose stable isotope readings 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 $\delta^{13}C$ and $\delta^{15}N$ readings of −14.3 ± 0.4‰ and 18.2 ± 1.5‰, −14.5 ± 0.3‰ and 17.5 ± 1.1‰ respectively. Although Kamarvik and Silimiut $\delta^{13}C$ values are significantly 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 meaningful 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). However, among both the Thule and Sadlermiut, no significant 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 $\delta^{15}N$ against $\delta^{13}C$ 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 Point individual with a $\delta^{15}N$ 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 isotope 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 $\delta^{15}N$ against $\delta^{13}C$ 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 $\delta^{15}N$ within a given range of $\delta^{13}C$ 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 $\delta^{15}N$ values against $\delta^{13}C$ (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 $\delta^{15}N$ values, are deleted (Fig. 4b). Fig. 5 performs the same exercise for seal, caribou and common eider ducks (*Somateria mollissima*) individually. The increase in seal and eider $\delta^{13}C$ values accounts for a significant proportion of the covariance in $\delta^{15}N$, similar to aggregate faunal and human data sets; however this relationship is not evident in the caribou sample.

Table 3
Silumiut fauna with preservation criteria and stable isotope measurements

	Sample	Species	Common name	Atomic C:N	Weight % collagen	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰
649	143	*R. tarandus*	caribou	3.2	13.3	−17.1	2.7
650	144	*R. tarandus*	caribou	3.1	23.5	−16.9	2.9
651	145	*R. tarandus*	caribou	3.3	21.8	−17.6	2.2
652	146	*R. tarandus*	caribou	3.2	21.3	−16.9	2.5
653	147	*R. tarandus*	caribou	3.3	19.6	−16.6	3.2
654	148	*R. tarandus*	caribou	3.3	22.2	−17.6	3.2
655	149	*R. tarandus*	caribou	3.2	23.8	−16.8	2.4
656	150	*R. tarandus*	caribou		19.9	−17.5	2.8
657	151	*R. tarandus*	caribou	3.2	21.8	−17.2	2.8
658	152	*R. tarandus*	caribou	3.2	21.7	−17.1	3.3
659	154	*C. familiaris*	dog	3.2	20.0	−14.3	14.2
660	155	*C. familiaris*	dog	3.2	22.5	−13.2	17.0
661	156	*C. familiaris*	dog	3.3	22.3	−16.0	8.0
662	157	*C. familiaris*	dog	3.2	25.5	−14.7	13.1
663	158	*O. moschatus*	muskoxen	3.1	26.1	−18.9	4.6
664	159	*O. moschatus*	muskoxen	3.2	23.1	−18.9	4.2
665	160	*O. moschatus*	muskoxen	3.2	22.9	−18.5	4.0
666	161	*O. moschatus*	muskoxen	3.3	18.5	−17.0	1.8
667	165	*S. mollissima*	common eider duck	3.2	18.1	−13.4	16.0
668	166	*S. mollissima*	common eider duck	3.2	21.2	−13.0	15.8
669	167	*S. mollissima*	common eider duck		15.0	−12.2	17.0
670	172	*E. barbatus*	bearded seal	3.2	15.8	−13.9	16.0
671	173	*E. barbatus*	bearded seal	3.2	14.3	−13.8	16.8
672	174	*E. barbatus*	bearded seal	3.2	11.9	−14.6	15.5
673	175	*E. barbatus*	bearded seal		12.0	−14.6	14.9
674	176	*E. barbatus*	bearded seal	3.2	11.7	−14.3	16.1
675	181	*P. hispida*	ringed seal	3.2	19.7	−13.2	18.5
676	182	*P. hispida*	ringed seal	3.1	16.1	−13.8	17.2
677	183	*P. hispida*	ringed seal	3.2	17.6	−13.4	17.9
678	184	*P. hispida*	ringed seal	3.2	17.5	−14.7	16.1
679	185	*P. hispida*	ringed seal	3.2	10.4	−14.5	16.2
680	177	*O. rosmarus*	walrus	3.2	20.4	−13.9	17.2
681	178	*O. rosmarus*	walrus	3.2	16.8	−13.9	11.9
682	179	*O. rosmarus*	walrus	3.2	23.8	−13.8	13.2
683	180	*O. rosmarus*	walrus	3.2	24.7	−14.3	13.1
684	482	*B. mysticetus*	bowhead whale	3.4	23.2	−14.6	14.8
685	483	*B. mysticetus*	bowhead whale	3.4	24.1	−14.9	14.5
686	485	*B. mysticetus*	bowhead whale	3.5	26.2	−15.3	15.8
687	486	*B. mysticetus*	bowhead whale	3.4	27.1	−14.6	15.0
688	487	*B. mysticetus*	bowhead whale	3.5	26.3	−14.5	16.4
689	488	*B. mysticetus*	bowhead whale	3.5	22.0	−15.1	14.1

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 [*Erignathus 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
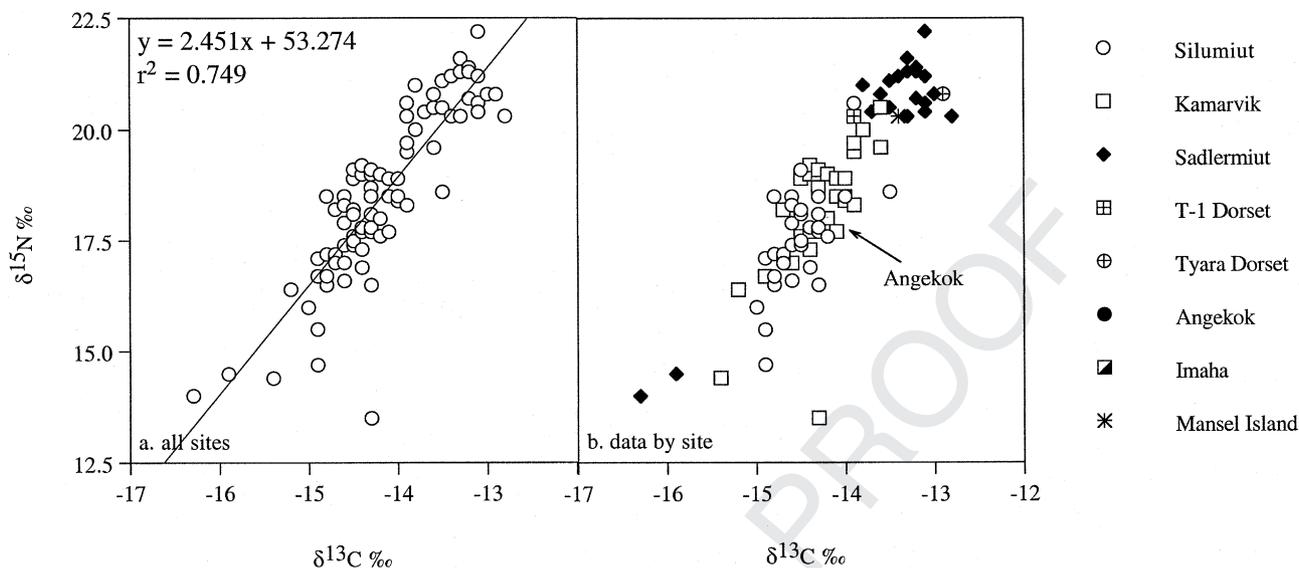
Fig. 2. a. δ^{15}N regressed against δ^{13}C with correlation coefficient for human remains from all sites; b. δ^{15}N regressed against δ^{13}C for human remains plotted by site, excluding Sadlermiut burial XIV-C:302.
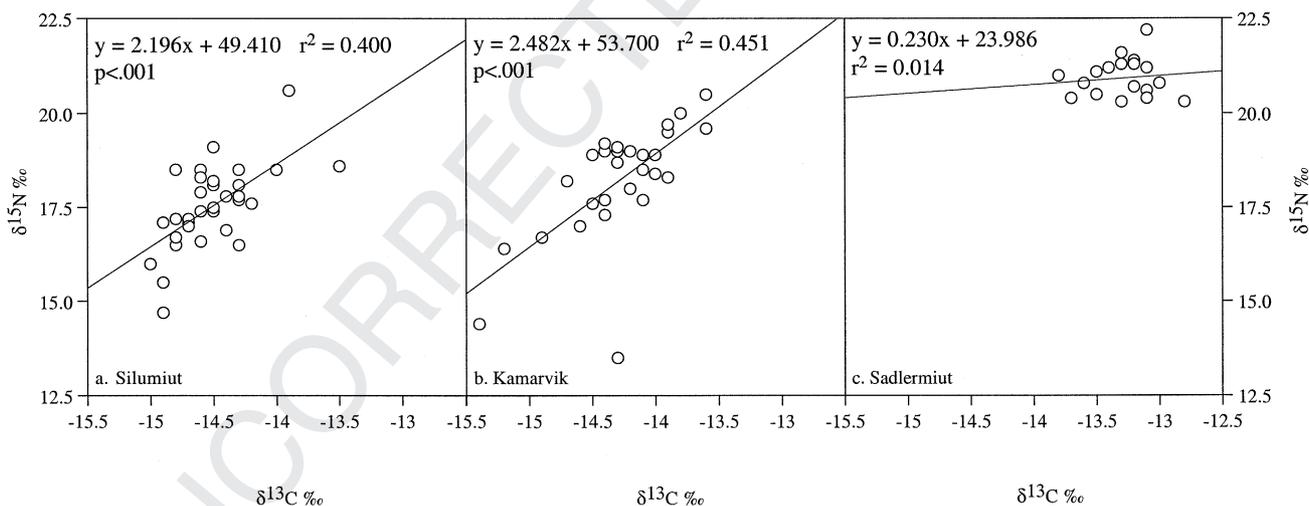

Fig. 3. a. δ^{15}N regressed against δ^{13}C with correlation coefficient and *P*-value for human remains from Silumiut; b. Kamarvik; c. Native Point (Sadlermiut).

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 δ^{13}C value of -17.7‰, the average for Silimiut caribou and muskoxen, and a marine end-member δ^{13}C value of -14.0‰, the average value for seals, and corrected for a 1‰ offset between diet and collagen δ^{13}C [48]. In addition to the global reservoir effect correct, a regional correction of $+132 \pm 26$ 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 $+89 \pm 30$ 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
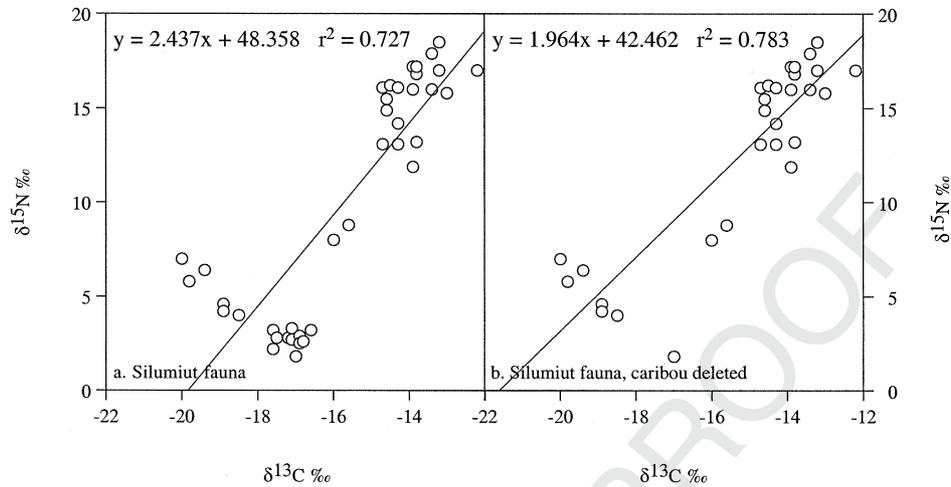
Fig. 4. a. δ^{15}N regressed against δ^{13}C with correlation coefficient for Silumiut fauna; b. Silumiut fauna, caribou deleted.
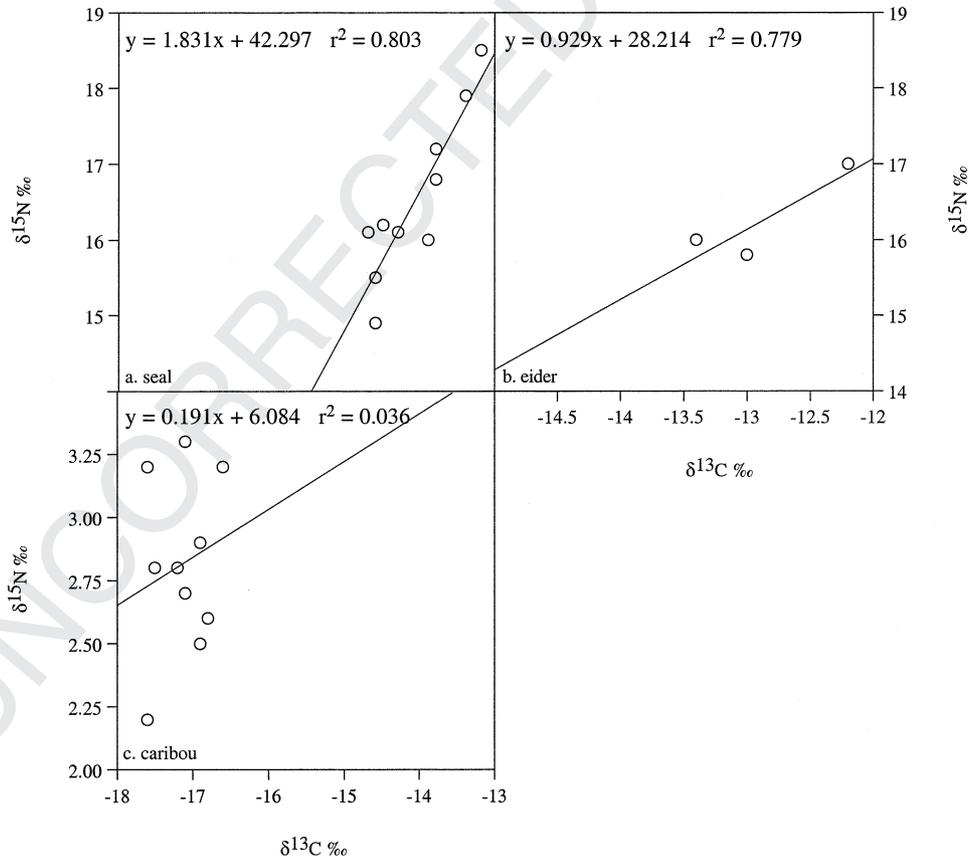
Fig. 5. a. δ^{15}N regressed against δ^{13}C with correlation coefficient for ringed seal (*P. hispida*) and bearded seal (*E. barbatus*); b. common eider duck (*S. mollissima*); c. caribou (*R. tarandus*).

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
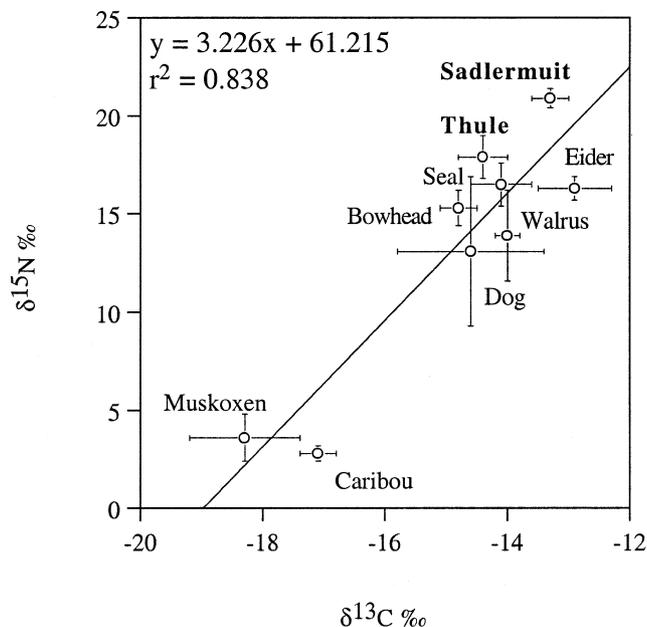
Fig. 6. Average δ^{15}N regressed against δ^{13}C for human and faunal samples shown at one standard deviation, with correlation coefficient and *P*-value.

742 range of AD 1165–1297 and intercept of AD 1248,
743 placing Angekok late in the Dorset sequence as Taylor
744 [129] suggested. Our mitochondrial DNA haplogroup
745 assignment also suggests the Angekok burial is Dorset in
746 origin [40]. The second Mansel Island burial is proto-
747 historic in age with a calibrated intercept date of AD
748 1696.
749   Figs. 7 and 8 plot calibrated intercept dates and
750 two-sigma ranges against δ^{13}C and δ^{15}N values respect-
751 ively. The earliest Silumiut burials are enriched in δ^{15}N,
752 while early Kamarvik burials exhibit a wider range
753 of variation than later individuals. Sadlermiut burials
754 cluster tightly.

7. Discussion

756   Our primarily objective was to estimate the contribu-
757 tion 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 impli-
768 cation other marine fauna, is closer to +200 years than
769 the 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
780 reasons. (1) Phytoplankton, at the base of marine food
781 webs, takes up photosynthetic carbon from marine
782 bicarbonates (HCO_3^-) and dissolved CO_2[93,95,96] and
783 transmits enriched stable carbon and depleted radiocar-
784 bon isotope signals to higher trophic level consumers in
785 marine ecosystems. It is the presence of inorganic source
786 carbon in marine foods that allows researchers to esti-
787 mate the importance of these foods in the diets of human
788 foragers [4,12,56,72,86,87,99,113–116,133]. (2) Although
789 a subset of wood samples from Silumiut residential
790 contexts have intercept dates older than the majority of
791 our data set [75], radiocarbon dates on wood record
792 when the wood was felled not the occupation date of
793 structures associated with wood artifacts or structural
794 members. This discrepancy is especially problematic at
795 high latitudes where driftwood is the sole source of
796 structural and artifactual wood, preserves well and is
797 reused. (3) Thule-era radiocarbon dates on wood from
798 Silumiut cover a calibrated two-sigma range of AD
799 1000–1636 [75], very similar to the calibrated two sigma
800 range of sampled Thule burials, AD 1063–1679. Given
801 the temporal distribution of these burials, any estimate
802 of reliance on bowhead whale will better characterizes
803 the Modified Thule period than earlier Thule subsistence
804 strategies.
805   Simple linear mixing models are useful for calculating
806 the percentage of foods in isotopically measured diets if
807 each food has approximately the same concentration of
808 carbon to nitrogen, characteristic of diets comprised
809 largely of animal protein [7,90,91,111]. The model is
810 formulated from the following set of mass balance
811 equations [90]:

$$\delta J_D = f_A \delta J_A + f_B \delta J_B + f_C \delta J_C \qquad 812$$

$$\delta K_D = f_A \delta K_A + f_B \delta K_B + f_C \delta K_C \qquad 813$$

$$1 = f_A + f_B + f_C \qquad 814$$

815 where: δJ and δK are isotope ratios for two elements,
816 A, B, C and D subscripts are three food sources and
817 the consumer respectively and f is the fractional
818 contribution of each food source.
819   Thus, the model should allow us to estimate the
820 relative importance of any three resources for which we
821 have data (i.e., seal, caribou and bowhead whale in
822 Thule diets or seal, caribou, and sea birds in Sadlermiut
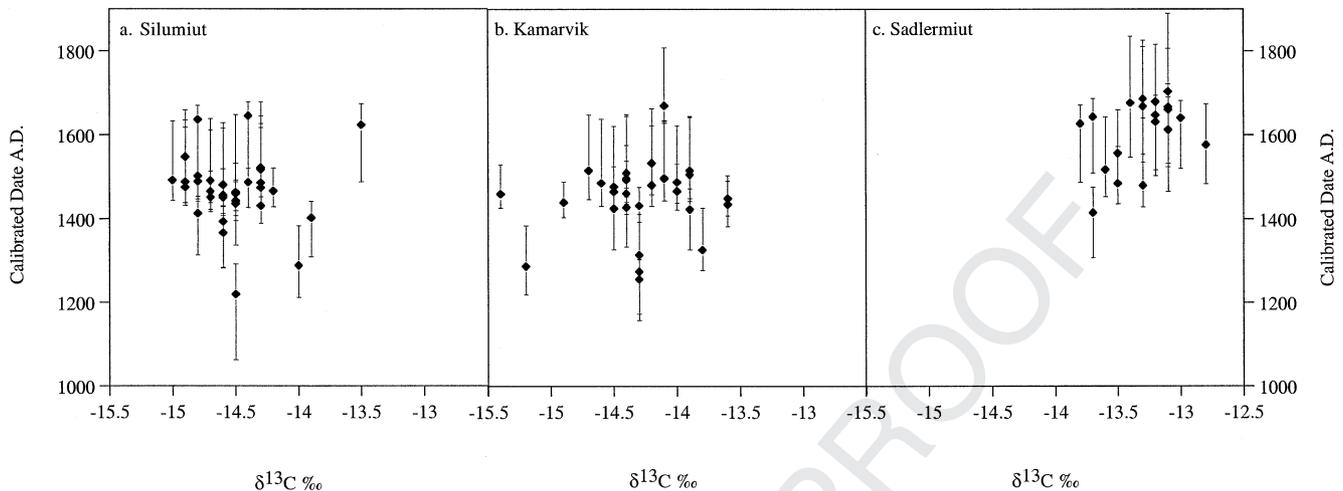
Fig. 7. a, b, c. Variation in δ^{13}C values over time plotted by site.
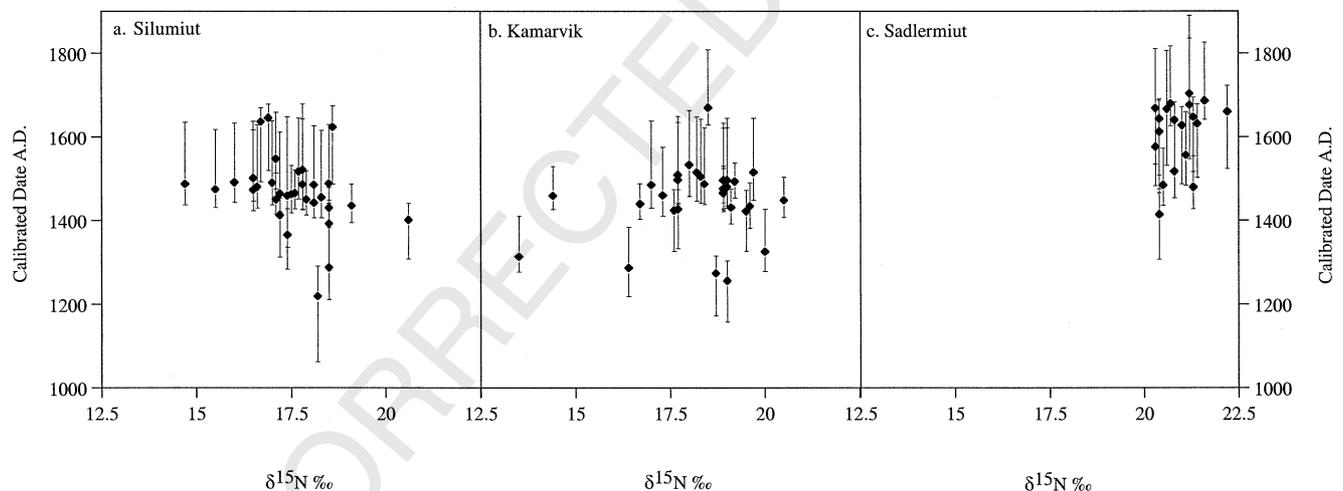
Fig. 8. a, b, c. Variation in δ^{15}N values over time plotted by site.

823 diets). However, initial attempts to do so proved prob-
824 lematic. Barren ground caribou are heavily reliant on
825 lichens, which are fungal/algal symbionts. The algal
826 component, commonly a blue-green algae, fixes atmos-
827 pheric nitrogen, which exhibits a δ^{15}N value of 0‰.
828 Accordingly, the average δ^{15}N value for Silumiut
829 caribou is 2.8 ± 0.4‰, approximately 3‰ more positive
830 than atmospheric source nitrogen; whereas herbivores in
831 terrestrial ecosystems derive source nitrogen from soil
832 ammonium or nitrate and commonly express δ^{15}N
833 values in the 6–9‰ range [19,20,112]. Substituting the
834 average measured δ^{15}N value for caribou into the above
835 model creates a significant positive bias in reliance on
836 caribou inconsistent with measured δ^{13}C values for any
837 human sample in the data set. To circumvent this
838 problem, we used the regression equation in Fig. 4b,
839 (i.e., Silumiut fauna, caribou deleted) to calculate
840 a modeled, average δ^{15}N value for caribou (8.88‰).

841 Results are shown in Table 4and are constrained by
842 percent marine intake. For example, using measured
843 δ^{13}C and δ^{15}N values for sea birds and seal and
844 measured δ^{13}C but calculated δ^{15}N for caribou results in
845 a diet of 5.0% sea birds, 86.6% seal and 8.4% caribou
846 with a calculated δ^{13}C value of -13.31‰ and δ^{15}N value
847 of 19.85‰. The former is virtually identical to the
848 average measured δ^{13}C value for Sadlermiut burials
849 while the latter is within a per mil of the measured value.
850 The same exercise for Kamarvik diets, using measured
851 δ^{13}C and δ^{15}N for seal and bowhead whale and
852 measured δ^{13}C but calculated δ^{15}N for caribou, results in
853 a diet of 54% seal, 11% whale and 35% caribou. Again
854 the former is virtually identical to the average δ^{13}C value
855 for Kamarvik burials while the latter is within half a per
856 mil (0.5‰). The same conditions and results apply to the
857 Silumiut, resulting in an average diet of 47% seal, 12%
858 whale and 41% caribou.

Table 4
Estimated reliance on major components of Eastern Arctic diets

Isotope values estimated by linear mixing model	Calculated δ values	Measured δ values	% Seal	% Whale	% Caribou	% Sea birds
Mean Sadlermiut $\delta^{13}C$ (91.6% marine)	−13.31	−13.3	86.6		8.4	5.0
Mean Sadlermiut $\delta^{15}N$ w/caribou as measured	+19.34	+20.9				
Mean Sadlermiut $\delta^{15}N$ w/caribou as calculated	+19.85					
Mean Kamarvik $\delta^{13}C$ (65.0% marine)	−14.27	−14.3	54.0	11.0	35.0	
Mean Kamarvik $\delta^{15}N$ w/caribou as measured	+15.57	+18.2				
Mean Kamarvik $\delta^{15}N$ w/caribou as calculated	+17.71					
Mean Silumiut $\delta^{13}C$ (59.1% marine)	−14.46	−14.5	47.0	12.0	41.0	
Mean Silumiut $\delta^{15}N$ w/caribou as measured	+14.73	+17.5				
Mean Silumiut $\delta^{15}N$ w/caribou as calculated	+17.24					

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 Silimiut 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 given 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, $\delta^{15}N$ values vary randomly over a virtually identical 6‰ 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

[67]

Carlyle, Allison Freedman, Henry Harpending, Duncan Metcalfe, James O'Connell, Alan Rogers and Thomas Stafford for highly useful discussions. Finally, we thank two anonymous reviewers for valuable comments that measurably improved the manuscript.

References

[1] S.H. Ambrose, Preparation and characterization of bone and tooth collagen for isotopic analysis, Journal of Archaeological Science 17 (1990) 431–451.

[2] S.H. Ambrose, Effects of diet, climate and physiology on nitrogen isotope abundance in terrestrial foodwebs, Journal of Archaeological Science 18 (1991) 293–317.

[3] S.H. Ambrose, M.J. DeNiro, Reconstruction of African human diet using bone collagen carbon and nitrogen isotope ratios, Nature 319 (1986) 321–324.

[4] S.H. Ambrose, B.M. Butler, D.B. Hanson, R.L. Hunter-Anderson, H.L. Krueger, Stable isotope analysis of human diets in the Marianas Archipelago, western Pacific, American Journal of Physical Anthropology 104 (1997) 343–361.

[5] W.H. Arundale, Radiocarbon dating in Eastern Arctic archaeology: A flexible approach, American Antiquity 46 (1981) 244–271.

[6] D.C. Barber, A. Dyke, C. Hillaire-Marcel, A.E. Jennings, J.T. Andrews, M.W. Kerwin, G. Bilodeau, R. McNeely, J. Southon, M.D. Morehead, J.M. Gagnon, Forcing of the cold event of 8,200 years ago by catastrophic drainage of Laurentide lakes, Nature 400 (1999) 344–348.

[7] M. Ben-David, D.M. Schell, Mixing models in analyses of diet using multiple stable isotopes: A response, Oecologia 127 (2001) 180–184.

[8] A. Berta, J.L. Sumich, Marine Mammals Evolutionary Biology, Academic Press, Orlando, 1999.

[9] W.S. Broecker, Was the Medieval Warm Period global, Science 291 (2001) 1497–1499.

[10] S.T. Bunn, D.R. Barton, H.B.N. Hynes, G. Power, M.A. Pope, Stable isotope analysis of carbon flow in a tundra river system, Canadian Journal of Fish and Aquatic Science 46 (1989) 1769–1775.

[11] T.E. Cerling, J.R. Ehleringer, J.M. Harris, Carbon dioxide starvation, the development of C_4 ecosystems, and mammalian evolution, Philosophical Transactions of the Royal Society of London B353 (1998) 159–171.

[12] B.S. Chisholm, E.D. Nelson, H.P. Schwarcz, Stable-carbon isotope ratios as a measure of marine versus terrestrial protein in ancient diets, Science 216 (1982) 1131–1132.

[13] B. Clark, The Lake site (KkHh-2) Southampton Island, NWT, and its position in Sadlermiut prehistory, Canadian Journal of Archaeology 4 (1980) 53–81.

[14] H.B. Collins, Archaeology of St. Lawrence Island, Alaska, Smithsonian Miscellaneous Collections 96, Smithsonian Institution, Washington DC, 1937.

[15] H.B. Collins, Excavations at Frobisher Bay, Baffin Island, NWT, Annual Report of the National Museum of Canada, Bulletin 118, Ottawa, 1950, pp. 18–43.

[16] H.B. Collins, Manuscript No. 1970, Unpublished manuscript on file at the Canadian Museum of Civilization, Ottawa, 1955.

[17] H.B. Collins, The T-1 site at Native Point, Southampton Island, NWT, Anthropological Papers of the University of Alaska 4(2), Fairbanks, 1956, pp. 63–89.

[18] H.B. Collins, Archaeological investigations on Southampton and Walrus Islands, NWT, Annual Report of the National Museum of Canada, Bulletin 147, Ottawa, 1957, pp. 22–61.

[19] J.B. Coltrain, S.W. Leavitt, Climate and diet in Fremont prehistory: Economic variability and abandonment of maize agriculture in the Great Salt Lake Basin, American Antiquity 67 (2002) 1–33.

[20] J.B. Coltrain, J.M. Harris, T.E. Cerling, J.R. Ehleringer, M. Dearing, J. Ward, J. Allen, Trophic level relationships among Rancho La Brea fauna and their implications for the paleoecology of the late Pleistocene based on bone collagen stable carbon and nitrogen isotope chemistry, Palaeogeography, Palaeoclimatology, Palaeoecology (2003), in review.

[21] S.L. Cox, A. Spiess, Dorset settlement and subsistence in northern Labrador, Arctic 33 (1980) 659–669.

[22] H. Craig, Isotopic standards for carbon and oxygen and correction factors for mass spectrometer analysis of carbon dioxide, Geochimica et Cosmochimica Acta 12 (1957) 133–149.

[23] D. Dahl-Jensen, K Mosegaard, N. Gundestrup, G.D. Clow, S.J. Johnsen, A.W. Hansen, N. Balling, Past temperatures directly from the Greenland ice sheet, Science 282 (1998) 268–271.

[24] F. de Laguna, The Prehistory of Northern North American as Seen from the Yukon, Society for American Archaeology Memoir 3, Menasha, 1947.

[25] D.E. Dumond, D.G. Griffin, Measurements of the marine reservoir effect on radiocarbon ages in the eastern Bering Sea, Arctic 55 (2002) 77–86.

[26] A.S. Dyke, J. Hooper, J.M. Savelle, A history of sea ice in the Canadian Arctic Archipelago based on postglacial remains of the bowhead whale (*Balaena mysticetus*), Arctic 49 (1996) 235–255.

[27] A.S. Dyke, R.N. McNeely, J. Hooper, Marine reservoir correction for bowhead whale radiocarbon age determinations, Canadian Journal of Earth Science 33 (1996) 1628–1637.

[28] J.R. Ehleringer, T.E. Cerling, B.R. Helliker, C_4 photosynthesis, atmospheric CO_2, and climate, Oecologia 112 (1997) 285–299.

[29] J. Esper, E.R. Cook, F.H. Schweingruber, Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability, Science 295 (2002) 2250–2253.

[30] R.D. Evans, J.R. Ehleringer, Water and nitrogen dynamics in an arid woodland, Oecologia 99 (1994) 233–242.

[31] G.D. Farquhar, J.R. Ehleringer, K.T. Hubick, Carbon isotope discrimination and photosynthesis, Annual Review of Plant Physiology and Molecular Biology 40 (1989) 503–537.

[32] K.J. Finley, Natural history and conservation of the Greenland whale, or bowhead in the northwest Atlantic, Arctic 54 (2001) 55–76.

[33] K.J. Finley, L.M. Darling, Historical data sources on the morphometry and oil yield of the bowhead whale, Arctic 43 (1990) 153–156.

[34] W.W. Fitzhugh, Environmental factors in the evolution of Dorset culture: A marginal proposal for Hudson Bay, in: M.S. Maxwell (Ed.), Eastern Arctic Prehistory: Paleoeskimo Problems, Memoirs of the Society for American Archaeology 31, Washington, DC, 1976, pp. 139–149.

[35] W.W. Fitzhugh, E.I. Ward (Eds.), Vikings: The North Atlantic Saga, Smithsonian Institution Press, Washington, DC, 2000.

[36] B. Fry, Food web structure on Georges Bank from stable C, N, and S isotopic compositions, Limnology and Oceanography 33 (1988) 1182–1190.

[37] B. Fry, E.B. Sherr, $\delta^{13}C$ measurements as indicators of carbon flow in marine and freshwater ecosystems, in: P.W. Rundel, J.R. Ehleringer, K.A. Nagy (Eds.), Stable Isotopes in Ecological Research, Springer-Verlag, New York, 1988, pp. 196–229.

[38] C. Grier, J.M. Savelle, Intrasite spatial patterning and Thule social organization, Arctic Anthropology 31 (1994) 95–107.

[39] D.D. Harkness, A. Walton, Further investigation on the transfer of bomb ^{14}C to men, Nature 240 (1972) 302–303.

[40] M.G. Hayes, J.B. Coltrain, D.H. O'Rourke, Molecular archaeology of the Dorset, Thule, and Sadlermiut: Ancestor descendant relationships in eastern North America Arctic prehistory, in: P. Sutherland, R. McGhee (Eds), The Dorset Culture—75 Years

after Jenness, Canadian Museum of Civilization Mercury Series, Archaeological Survey of Canada, Hull, 2003, in press.

[41] T.H.E. Heaton, J.C. Vogel, G. von la Chevallerie, G. Collet, Climatic influence on the isotopic composition of bone nitrogen, Nature 322 (1986) 822–823.

[42] K.A. Hobson, Use of stable-carbon isotope analysis to estimate marine and terrestrial protein content in gull diets, Canadian Journal of Zoology 65 (1987) 1210–1213.

[43] K.A. Hobson, H.P. Schwarcz, The variation in $\delta^{13}C$ values in bone collagen for two wild herbivore populations: Implications for paleodiet studies, Journal of Archaeological Science 13 (1986) 101–106.

[44] K.A. Hobson, H.E. Welch, Cannibalism and trophic structure in a high Arctic lake: Insights from stable-isotope analysis, Canadian Journal of Fish and Aquatic Science 52 (1995) 1195–1201.

[45] F.S. Hu, E. Ito, T.A. Brown, B.B. Curry, D.R. Engstrom, Pronounced climatic variations in Alaska during the last two millennia, Proceedings of the National Academy of Science 98 (2001) 10552–10556.

[46] J.D. Jacobs, D.R. Stenton, Environment, resources and prehistoric settlement in Upper Frobisher Bay, Baffin Island, Arctic Anthropology 22 (1985) 59–76.

[47] R.H. Jordon, Inugsuk revisited: An alternative view on Neo-Eskimo chronology and culture change in Greenland, in: A.P. McCartney (Ed.), Thule Eskimo Culture: An Anthropological Retrospective, National Museum of Man Mercury Series, Archaeological Survey of Canada Paper 88, Ottawa, 1979, pp. 149–170.

[48] M.A. Katzenberg, Age differences and population variation in stable isotope values from Ontario, Canada, in: J.B. Lambert, P. Grupe (Eds.), Prehistoric Human Bone: Archaeology at the Molecular Level, Springer-Verlag, New York, 1993, pp. 39–62.

[49] G.W. Kling, B. Fry, W.J. O'Brien, Stable isotope and planktonic trophic structure in Arctic lakes, Ecology 73 (1992) 561–566.

[50] I.I. Krupnik, Prehistoric eskimo whaling in the Arctic: Slaughter of calves or fortuitous ecology, Arctic Anthropology 30 (1993) 1–12.

[51] C.M. Kurle, G.A.J. Worthy, Stable isotope assessment of temporal and geographic differences in feeding ecology of northern fur seals (*Callorhinus ursinus*) and their prey, Oecologia 126 (2001) 254–265.

[52] W.S. Laughlin, W.E. Taylor Jr, A Cape Dorset culture site on the west coast of Ungava Bay, Annual Report of the National Museum of Canada, Bulletin 167, Ottawa, 1960, pp. 1–28.

[53] J. Le Mouël, M.L. Le Mouël, Aspects of early Thule culture as seen in the architecture of a site on Victoria Island, Amundsen Gulf area, Arctic 55 (2002) 167–189.

[54] P.C. Lent, Muskoxen and Their Hunters, University of Oklahoma Press, Norman, 1999.

[55] W.F. Libby, R. Berger, J.F. Mead, G.V. Alexander, J.F. Ross, Replacement rates for human tissue from atmospheric radiocarbon, Science 146 (1964) 1170–1172.

[56] N.C. Lovell, D.E. Nelson, H.P. Schwarcz, Carbon isotope ratios in palaeodiets: Lack of age or sex effect, Archaeometry 28 (1986) 51–55.

[57] J. Mangerud, S. Gulliksen, Apparent radiocarbon ages of recent shell from Norway, Spitsbergen and Arctic Canada, Quaternary Research 5 (1975) 263–273.

[58] M.S. Maxwell, Archaeology of the Arctic and subarctic zones, Annual Review of Anthropology 9 (1980) 161–185.

[59] M.S. Maxwell, Pre-Dorset and Dorset prehistory of Canada, in: D. Damas (Ed.), Arctic, Smithsonian Institution, Handbook of North American Indians Vol. 5, Washington, DC, 1984, pp. 359–368.

[60] M.S. Maxwell, Prehistory of the Eastern Arctic, Academic Press, Orlando, 1985.

[61] A.P. McCartney, Thule Eskimo Prehistory along Northwestern Hudson Bay. National Museum of Man Mercury Series, Archaeological Survey of Canada Paper 70, Ottawa, 1977.

[62] A.P. McCartney, The nature of Thule eskimo whale use, Arctic 33 (1980) 517–541.

[63] A.P. McCartney, Canadian Arctic metal trade: Reflections of prehistoric to historic social networks, in: R.M. Ehrenreich (Ed.), Metals in Society: Theory beyond Analysis, University of Pennsylvania Museum, MASCA Research Papers in Science and Archaeology 8(2), Philadelphia, 1991.

[64] A.P. McCartney, Whale size selection by precontact hunters of the North American western Arctic and subarctic, in: A.P. McCartney (Ed.), Hunting the Largest Animals: Native Whaling in the Western Arctic and Subarctic, University of Alberta, Canadian Circumpolar Institute Occasional Publication No. 36, Alberta, 1995, pp. 83–108.

[65] A.P. McCartney, J.M. Savelle, Thule eskimo whaling in the central Canadian Arctic, Arctic Anthropology 22 (1985) 37–58.

[66] A.P. McCartney, J.M. Savelle, Bowhead whale bones and Thule eskimo subsistence-settlement patterns in the central Canadian Arctic, Polar Record 29 (1993) 1–12.

[67] R. McGhee, The timing of Thule migration, Polarforschung 54 (1984) 1–7.

[68] R. McGhee, The peopling of the Arctic islands, in: C.R. Harington (Ed.), Canada's Missing Dimension: Science and History in the Canadian Arctic Islands, Canadian Museum of Nature, Ottawa, 1990, pp. 666–676.

[69] R. McGhee, Disease and the development of Inuit culture, Current Anthropology 35 (1994) 565–594.

[70] T.H. McGovern, Climate, correlation and causation in Norse Greenland, Arctic Anthropology 28 (1991) 77–100.

[71] T.H. McGovern, T. Amorosi, S. Perdikaris, J. Woollett, Vertebrate zooarchaeology of Sandnes V51: Economic change at a chieftain's farm in west Greenland, Arctic Anthropology 33 (1996) 94–121.

[72] R. McGovern-Wilson, C. Quinn, Stable isotope analysis of ten individuals from Afetna, Saipan, Northern Mariana Islands, Journal of Archaeological Science 23 (1996) 59–66.

[73] C.F. Merbs, Human burials at Silumiut, a Thule culture site north of Chesterfield Inlet, Preliminary Report to the Archaeological Survey of Canada, National Museum of Man Manuscript No. 605, Ottawa, 1968.

[74] D.F. Morey, K. Aaris-Sørensen, Paleoeskimo dogs of the eastern Arctic, Arctic 55 (2002) 44–56.

[75] R.E. Morlan, Canadian Archaeological Radiocarbon Database, Canadian Archaeological Association, Ottawa, 2002.

[76] D.A. Morrison, Radiocarbon dating the Thule culture, Arctic Anthropology 26 (1989) 48–77.

[77] R.K. Nelson, Hunters of the Northern Ice, University of Chicago Press, Chicago, 1969.

[78] R.E. Nelson, L.D. Carter, S.W. Robinson, Anomalous radiocarbon ages from a Holocene detrital organic lens in Alaska and their implications for radiocarbon dating and paleoenviromental reconstructions in the Arctic, Quaternary Research 29 (1988) 66–71.

[79] D. Odess, The archaeology of interaction: Views from artifact style and material exchange in Dorset society, American Antiquity 63 (1998) 417–435.

[80] W.C. Oechel, S.J. Hastings, G. Vourlitis, M. Jenkins, G. Riechers, N. Grulke, Recent change in Arctic tundra ecosystems from a net carbon dioxide sink to a source, Nature 361 (1993) 520–523.

[81] I.U. Olsson, Content of ^{14}C in marine mammals from northern Europe, Radiocarbon 22 (1980) 662–675.

[82] L. Oschinski, Two recently discovered human mandibles from Cape Dorset sites on Sugluk and Mansel Islands, Anthropologica 2 (1960) 212–227.

[83] A.K. Outram, A comparison of paleo-eskimo and medieval Norse bone fat exploitation in western Greenland, Arctic Anthropology 36 (1999) 103–117.

[84] R.W. Park, The Dorset-Thule succession in Arctic North America: Assessing claims for culture contact, American Antiquity 58 (1993) 203–234.

[85] R.W. Park, Thule winter site demography in the high Arctic, American Antiquity 62 (1997) 273–284.

[86] J. Parkington, Holocene coastal settlement patterns in the western Cape, in: G. Bailey, J. Parkington (Eds.), The Archaeology of Prehistoric Coastlines, Cambridge University Press, Cambridge, 1988, pp. 22–41.

[87] J. Parkington, Approaches to dietary reconstruction in the western Cape: Are you what you have been eating, Journal of Archaeological Science 18 (1991) 331–342.

[88] F.D. Pate, Bone chemistry and paleodiet, Journal of Archaeological Method and Theory 1 (1994) 162–209.

[89] B.J. Peterson, J.E. Hobbie, T.L. Corliss, Carbon flow in a tundra stream ecosystem, Canadian Journal of Fish and Aquatic Science 43 (1986) 1259–1270.

[90] D.L. Phillips, Mixing models in analyses of diet using multiple stable isotopes: A critique, Oecologia 127 (2001) 166–170.

[91] D.L. Phillips, J.W. Gregg, Uncertainty in source partitioning using stable isotopes, Oecologia 127 (2001) 171–179.

[92] H. Pringle, New respect for metal's role in ancient Arctic culture, Science 277 (1997) 766–767.

[93] J.A. Raven, Physiology of inorganic C acquisition and implications for resource use efficiency by marine phytoplankton: Relation to increased CO_2 and temperature, Plant, Cell and Environment 14 (1991) 779–794.

[94] J.A. Raven, Present and potential uses of the natural abundance of stable isotopes in plant science, with illustrations from the marine environment, Plant, Cell and Environment 15 (1992) 1083–1091.

[95] J.A. Raven, A.M. Johnston, Mechanisms of inorganic-carbon acquisition in marine phytoplankton and their implications for the use of other resources, Limnology and Oceanography 36 (1991) 1701–1714.

[96] J.A. Raven, A.M. Johnston, L.L. Handley, S.G. McInroy, Transport and assimilation of inorganic carbon by Lichina pygmaea under emersed and submersed conditions, New Phytologist 114 (1990) 407–417.

[97] R. Reeves, S. Leatherwood, Bowhead whale—Balaena mysticetus, in: S.H. Ridgway (Ed.), Handbook of Marine Mammals 3, Academic Press, New York, 1985, pp. 305–344.

[98] R. Reeves, E. Mitchell, A. Mansfield, M. McLaughlin, Distribution and migration of the bowhead whale, Balaena mysticetus, in the eastern North American Arctic, Arctic 36 (1983) 5–64.

[99] M.P. Richards, R.E.M. Hedges, Stable isotope evidence for similarities in the types of marine foods used by late Mesolithic humans at sites along the Atlantic coast of Europe, Journal of Archaeological Science 26 (1999) 717–722.

[100] W.G. Ross, Whaling and the decline of native populations, Arctic Anthropology XIV-2 (1977) 1–8.

[101] S. Rowley, The Sadlermiut: Mysterious or misunderstood, in: D. Morrison, J.-L. Pilon (Eds), Threads of Arctic Prehistory: Papers in Honour of William E. Taylor Jr, Canadian Museum of Civilization Mercury Series, Archaeological Survey of Canada Paper 149, Ottawa, 1994, pp. 361–384.

[102] G. Sabo III, J.D. Jacobs, Aspects of Thule culture adaptations in southern Baffin Island, Arctic 33 (1980) 487–504.

[103] J.M. Savelle, The role of architectural utility in the formation of zooarchaeological whale bone assemblages, Journal of Archaeological Science 24 (1997) 869–885.

[104] J.M. Savelle, A.P. McCartney, Geographical and temporal variation in Thule eskimo subsistence economies: A model, Research in Economic Anthropology 10 (1988) 21–72.

[105] J.M. Savelle, A.P. McCartney, Prehistoric Thule eskimo whaling in the Canadian Arctic Islands: Current knowledge and future research direction, in: C.R. Harington (Ed.), Canada's Missing Dimension: Science and History in the Canadian Arctic Islands, Canadian Museum of Nature, Ottawa, 1990, pp. 695–723.

[106] J.M. Savelle, A.P. McCartney, Thule Inuit bowhead whaling: A biometrical analysis, in: D. Morrison, J.-L. Pilon (Eds), Threads of Arctic Prehistory: Papers in Honour of William E. Taylor Jr, Canadian Museum of Civilization Mercury Series, Archaeological Survey of Canada Paper 149, Ottawa, 1994, pp. 281–310.

[107] J.M. Savelle, A.S. Dyke, A.P. McCartney, Holocene bowhead whale (Balaena mysticetus) mortality patterns in the Canadian Arctic Archipelago, Arctic 53 (2000) 414–421.

[108] D.M. Schell, Carbon-13 and carbon-14 abundances in Alaskan aquatic organisms: Delayed production from peat in Arctic food webs, Science 219 (1983) 1068–1071.

[109] D.M. Schell, S.M. Saupe, N. Haubenstock, Natural isotope abundances in bowhead whale (Balaena mysticetus) baleen: Markers of aging and habitat usage, in: P.W. Rundel, J.R. Ehleringer, K.A. Nagy (Eds.), Stable Isotopes in Ecological Research, Springer-Verlag, New York, 1988, pp. 261–269.

[110] P. Schledermann, K. McCullough, Western elements in the early Thule culture of the eastern high Arctic, Arctic 33 (1980) 833–841.

[111] H.P. Schwarcz, Some theoretical aspects of isotope paleodiet studies, Journal of Archaeological Science 18 (1991) 261–275.

[112] H.P. Schwarcz, T.L. Dupras, S.I. Fairgrieve, ^{15}N enrichment in the Sahara: In search of a global relationship, Journal of Archaeological Science 26 (1999) 629–636.

[113] J. Sealy, Stable carbon isotopes and prehistoric diets in the south-western Cape province, South Africa, British Archaeological Report No. 293, Oxford, 1986.

[114] J. Sealy, N. van der Merwe, Isotope assessment of Holocene human diets in the southwestern Cape, South Africa, Nature 315 (1985) 138–140.

[115] J. Sealy, N. van der Merwe, Isotope assessment and the seasonal mobility hypothesis in the southwestern Cape of South Africa, Current Anthropology 27 (1986) 135–150.

[116] J. Sealy, N. van der Merwe, Social, spatial and chronological patterning in marine food use as determined by δ^{13}C measurements of Holocene human skeletons from the southwestern Cape, South Africa, World Archaeology 20 (1988) 87–102.

[117] M.L. Staab, Analysis of faunal material recovered from a Thule eskimo site on the island of Silumiut, NWT, Canada, in: A.P. McCartney (Ed.), Thule Eskimo Culture: An Anthropological Retrospective, National Museum of Man Mercury Series, Archaeological Survey of Canada Paper 88, Ottawa, 1979, pp. 349–389.

[118] M.J. Stenhouse, M.S. Baxter, Bomb ^{14}C as a biological tracer, Nature 287 (1977) 828–832.

[119] M.J. Stenhouse, M.S. Baxter, The uptake of bomb ^{14}C in humans, in: R. Berger, H.E. Suess (Eds.), Radiocarbon Dating, Proceedings of the Ninth International Radiocarbon Congress, University of California Press, Berkeley, 1979, pp. 324–341.

[120] D.R. Stenton, Caribou population dynamics and Thule culture adaptations on southern Baffin Island, NWT, Arctic Anthropology 28 (1991) 15–43.

[121] S. Stine, Extreme and persistent drought in California and Patagonia during mediaeval time, Nature 369 (1994) 546–549.

[122] M. Struiver, T.F. Braziunas, Modeling atmospheric ^{14}C influences and ^{14}C ages of marine samples to 10,000 BC, Radiocarbon 35 (1993) 137–189.

[123] M. Struiver, P.J. Reimer, Extended ^{14}C database and revised Calib 3.0 ^{14}C age calibration program, Radiocarbon 35 (1993) 215–230.

[124] M. Struiver, P.J. Reimer, T.F. Braziunas, High-precision radiocarbon age calibration for terrestrial and marine samples, Radiocarbon 40 (1998) 1127–1151.

[125] H. Tauber, ^{14}C activity of Arctic marine mammals, in: R. Berger, H.E. Suess (Eds.), Radiocarbon Dating, Proceedings of the Ninth International Radiocarbon Congress, University of California Press, Berkeley, 1979, pp. 446–452.

[126] H. Tauber, ^{13}C evidence for dietary habits of prehistoric man in Denmark, Nature 292 (1981) 332–333.

[127] W.E. Taylor Jr, The mysterious Sadlermiut, The Beaver 290 (1959) 26–33.

[128] W.E. Taylor Jr, A description of Sadlermiut houses excavated at Native Point, Southampton Island, NWT, Annual Report of the National Museum of Canada, Bulletin 162, Ottawa, 1960, pp. 53–100.

[129] W.E. Taylor Jr, The Arnapik and Tyara Sites, Memoirs of the Society for American Archaeology No. 22, Salt Lake City, 1968.

[130] L.L. Tieszen, T. Fagre, Carbon isotope variability in modern and archaeological maize, Journal of Archaeological Science 20 (1993) 25–40.

[131] J.W. VanStone, Notes on the economy and population shifts of the eskimos of Southampton Island, Anthropological Papers of the University of Alaska, Vol. 8 (2), Fairbanks, 1960, pp. 80–87.

[132] E. Wada, H. Mizutani, M. Minagawa, The use of stable isotopes for food web analysis, Critical Reviews in Food Science and Nutrition 30 (1991) 361–371.

[133] P.L. Walker, M.J. DeNiro, Stable nitrogen and carbon isotope ratios in bone collagen as indices of prehistoric dietary dependence on marine and terrestrial resources in southern California, American Journal of Physical Anthropology 71 (1986) 51–61.

[134] P.J. Whitridge, The construction of social differences in prehistoric Inuit whaling, Unpublished Ph.D. dissertation, Department of Anthropology, Arizona State University, Tempe, 1999.

[135] P. Wiessner, Hunting, healing and *hxaro* exchange: A long term perspective on !Kung (Ju/'hoansi) large-game hunting, Evolution and Human Behavior 23 (2002) 407–436.