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Thule dog diets in the Hudson Bay reflect human dietary variability: Implications for palaeodietary studies and past human–dog relationships in the Canadian Arctic

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ABSTRACT

The stable isotopic compositions of domestic dogs have frequently been used to investigate questions related to ancient human subsistence, leading to the development of analogical frameworks such as the Canine Surrogacy Approach (CSA). In this paper, we compared the stable carbon and nitrogen isotope ratios from canid (dogs and wolves) bone and dentine collagen with previously published human and dog stable isotope ratios at the Silumiut site (KkJg-1; northwestern Hudson Bay, Canada). We found a clear dietary relationship between humans and dogs at Silumiut, suggesting that dogs were heavily influenced by human provisioning. Despite their isotopic similarities, mixing models (MixSIAR) estimated that the dogs consumed a greater proportion of terrestrial resources than humans, particularly a juvenile dog at the site, which we interpreted as reflecting a seasonal dietary signal. The isotopic variability observed among the adult dogs reflected that of humans, despite the much smaller number of dogs. This may reflect small-scale differences in the care and provisioning of dogs at this site. Based on these results, we suggest that dogs are best served as a source of indirect information about human subsistence and human–dog relationships, rather than as direct dietary proxies for humans in palaeodietary studies in this region.

1. Introduction

Dogs played and continue to play an important role in Inuit culture by providing sled traction, carrying loads, aiding in hunting, and serving as a food or raw material source (Hill, 2018; Laugrand and Oosten, 2002; Morey and Aaris-Sørensen, 2001). Beyond their economic utility, dogs and humans share a close social relationship relative to other animals and were historically the only domesticated species in Inuit Nunangat. Following European arrival, significant changes to traditional Inuit lifeways occurred, but dogs remained focus, particularly among groups involved in the fur trade (Cummings, 2002). The reliance on dogs for hunting, trapping, and transportation by Inuit was dramatically affected in the 20th century with the introduction of new technologies (e.g., snowmobiles), Inuit relocation into permanent communities, and the killing of Inuit dogs by Royal Canadian Mounted Police (RCMP) officers (Carpenter, 1976; Laugrand and Oosten, 2002; Smith, 1991). Despite these events, dogs remain an important part of Inuit culture, highlighting the long-standing relationship between humans and dogs in this region.

Dogs first appeared in Inuit Nunangat and Greenland with the earliest Paleo-Inuit groups, roughly 2500 BCE (Milne and Park, 2016; Savelle and Dyke, 2009). It was not until the arrival of Inuit groups around 1200 CE, however, that dogs became common (Morey and Aaris-Sørensen, 2001). The dog sled also appeared in the archaeological record at this time. Beginning around 1400 CE, regional diversification and increasing reliance on locally available resources led to the *in-situ* development of distinct Inuit groups, such as the Inuvialuit, Kivallirmiut, Inughuit, and others (Friesen, 2013; Maxwell, 1985; McCullough, 1989). Ultimately, use of the dog sled helped facilitate the rapid colonization of Inuit Nunangat by ancestral Inuit groups and played a specialized role in long-range transportation and Inuit subsistence economies (e.g., Ameen et al., 2019; Maxwell, 1985).

Pulling sleds requires substantial amounts of energy, and dogs would have had to rely on humans to provide enough food to meet these energy demands (Lévesque, 2019; Lupo, 2019), particularly during the winter months when Inuit dogs are most active (Gerth et al., 2010; Morey and

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Aaris-Sørensen, 2001). Such resource demands are likely to have played a significant role in food procurement by humans (e.g., Smith, 1991). Feeding dogs could, at times, take precedence over the feeding of people because of their economic indispensability in sled traction and hunting (Laugrand and Oosten, 2002). However, human–dog interactions are highly context-specific; cultural, economic, and environmental factors can influence how humans treat and feed dogs (Guiry, 2012; Wishart, 2018). The close social and economic relationship between humans and dogs in modern and historic Inuit societies suggests that dogs in this region have great potential for providing information about ancient human subsistence.

In this study, we investigate human–dog relationships and subsistence economies using stable carbon and nitrogen isotope analysis of canid remains from the Silumiut (KkJg-1) site, located in the Kivalliq Region of Nunavut. Silumiut provides a unique opportunity to directly compare canid isotopic data (particularly domestic dogs) with humans from the same site to test their validity as proxies for human diet. Previous studies of human subsistence practices in other areas of the North American Arctic, including Alaska and Labrador, have provided important insights into human–dog relationships and human subsistence both directly and indirectly (e.g., Cannon et al., 1999; Harris et al., 2020; Hillis et al., 2020; McManus-Fry et al., 2018). To our knowledge, however, there is a lack of similar studies characterizing the isotopic compositions of dogs and humans in other areas of Inuit Nunangat. This research addresses this regional gap by evaluating whether dogs can be used as both direct dietary analogues (i.e., reflecting human diet) and indirect analogues (i.e., reflecting human provisioning and subsistence economies more broadly).

Stable isotope analysis of biological tissues provides a direct measure of an individual's diet and environment over their lifetime and can provide insight into how humans and animals may have lived and interacted with one another (Szpak, 2022). The stable carbon (δ^{13}C) and nitrogen (δ^{15}N) isotope composition of collagen reflects the δ^{13}C and δ^{15}N values at the base of the food web and an individual's trophic position, respectively (DeNiro and Epstein, 1978, 1981; Schoeninger and DeNiro, 1984). In Arctic environments, where all plant species use the C_3 photosynthetic pathway (Tiezen and Boutton, 1989), δ^{13}C values are used to determine the relative contributions of marine and terrestrial foods to diets (Chisholm et al., 1982; Schoeninger and DeNiro, 1984), based on differences in the primary carbon source used by primary producers in each environment. Marine consumers have consistently more positive δ^{13}C values than terrestrial consumers (Chisholm et al., 1982; Craig, 1953). Unlike δ^{13}C values which are conservatively fractionated along trophic levels, δ^{15}N values exhibit a stepwise enrichment of 3 to 5 ‰ with each trophic level (DeNiro and Epstein, 1981; Minagawa and Wada, 1984; Post, 2002). Because marine food webs are generally longer and more complex than terrestrial ones, marine consumers typically exhibit much higher δ^{15}N values than terrestrial consumers (Bocherens et al., 2016; Hobson and Welch, 1992; Schoeninger et al., 1983).

In many cases, ethical and practical limitations preclude the destructive sampling of human remains from archaeological sites. As such, researchers often turn to using animal remains from domestic and commensal species as supplementary or alternative materials to human remains for stable isotope analysis (e.g., Allitt et al., 2009; Cannon et al., 1999; Rick et al., 2011; Tankersley and Koster, 2009). Dogs are particularly appealing for studying human diets because they are assumed to be heavily influenced by human subsistence behaviors and share a close relationship relative to other domesticates. Guiry (2012) outlined in detail the use of dogs as isotopic proxies for humans, which he referred to as the Canine Surrogacy Approach (CSA). Dog diets have been used as a direct dietary analogue for humans in many CSA applications (e.g., Cannon et al., 1999), while other applications employ dogs as an indirect analogue for human subsistence activities more broadly (e.g., Burleigh and Brothwell, 1978; White et al., 2001).

Using dogs as dietary proxies requires consideration of many factors, including physiological differences with humans. It is generally assumed that dogs and humans metabolize and incorporate isotopes derived from dietary macronutrients in the same way, resulting in directly comparable δ^{13}C and δ^{15}N values (Guiry, 2012). However, human and dog stable isotope ratios may differ due to differences in their respective lifespans, tissue formation, and turnover rates (Guiry, 2012; Guiry and Grimes, 2013; NOE-Nygaard, 1988). Dog bone exhibits intra-skeletal turnover rate variability like that of humans, but the turnover rate is much faster in dogs (Fahy et al., 2017; Huja et al., 2006; Marotti, 1963). In adult dogs, the isotopic composition of bone represents a period anywhere from 6 months to 3 years (Martin et al., 1998), while in adult humans, the period represented by a bone sample can span multiple years or even decades depending on the bone being analyzed (Fahy et al., 2017; Hall, 2024). Despite the differences in adult human and dog bone collagen turnover rates, the isotopic composition should reflect their diet over multiple seasons and act to obscure any short-term dietary changes related to differential tissue growth and remodeling rates. As actively growing and remodeling rates of juvenile dog bones are elevated compared to those in adult dogs, particularly in post-cranial elements such as the femur (Huja and Beck, 2007), they may be more sensitive to short-term dietary changes. Only bone collagen from adult dogs should be used for direct dietary comparisons with humans, particularly in contexts with strong seasonal differences in subsistence economies.

2. Materials and methods

2.1. Silumiut (KkJg-1)

Silumiut (KkJg-1) is a Thule winter village site just off the coast of northwestern Hudson Bay, Nunavut (Fig. 1). Silumiut's location took advantage of both marine and terrestrial resources, particularly bowhead whales during the summer (Coltrain, 2009). A focus on whaling by the site's inhabitants is further supported by the presence of artifacts related to whaling and large whale bones (McCartney, 1977). Given the presumed importance of whaling at Silumiut as well as the presence of several semi-subterranean winter houses, the site was thought to date to the Classic Thule period (McCartney, 1977). Radiocarbon dates on human remains from burial cairns at Silumiut as well as on wood and caribou bone provide a calibrated two sigma range of 1100 – 1700 CE but largely post-date 1400 CE, suggesting Silumiut was in use during and after the Classic Thule period in this region (Ameen et al., 2019; Coltrain et al., 2004; Coltrain, 2009; Dyke et al., 2018). Ringed seal and caribou dominated Silumiut's faunal assemblage, with minor representations of other species including walrus, dog, muskox, fish, birds, wolverine,

Fig. 1. Map of the study area (northwestern Hudson Bay, Nunavut, Canada) with the location of the Silumiut site indicated.

Arctic hare, and Arctic fox (Staab, 1979). Numerous implements related to large marine mammal hunting were recovered, such as harpoon and lance heads, as well as arrowheads principally used in hunting caribou (McCartney, 1977).

Previous stable isotope analyses conducted on human bone collagen at Silumiut found a high dietary reliance on marine mammals in line with many traditional subsistence economies in this region, further supported by the site's zooarchaeological and artifactual evidence. Overall, human diets at Silumiut are isotopically similar to one another, with some inter-individual variations in δ^{15}N values interpreted as differences in consumption of various marine taxa (e.g., ringed seal, bowhead whale) that occupy different trophic levels (Coltrain et al., 2004; Coltrain, 2009). As one of the few sites in the North American Arctic with both human and dog stable isotope data, Silumiut provides a unique opportunity to test the suitability of using dogs as proxies for human subsistence research in Arctic contexts.

2.2. Sample information

Canid bone ($n = 7$) and tooth ($n = 1$) samples from Silumiut were collected for an ancient DNA study, and thus the species of canid were identified (see Ameen et al., 2019). Of the samples that underwent aDNA analysis, three were identified as domestic dogs (*Canis l. familiaris*), and two were identified as probable wolf (*Canis l. lupus*). However, the probable wolf samples derive from the same individual. In addition to the baseline faunal samples from Coltrain et al. (2004), previously published (Dyke et al., 2018; Szpak and Buckley, 2020) and unpublished bone collagen data from the site representing potential dietary resources include bearded seal ($n = 9$), bowhead whale ($n = 6$), caribou ($n = 4$), harbour seal ($n = 10$), polar bear ($n = 9$), ringed seal ($n = 27$), and walrus ($n = 13$). Isotopic and elemental data of baseline fauna are presented in the supplementary material (Table S1).

2.3. Collagen extraction

Collagen samples were prepared at Trent University in the Trent Environmental Archaeology Lab (TEAL), following a modified version of the Longin (1971) method. For bone collagen sample preparation, external debris was removed from samples before 100–150 mg of cortical bone was removed with an NSK dental drill. Samples were demineralized using 0.5 M HCl for ~12–24 h. Once demineralized, many samples were subjected to humic extraction based on visual observations of bone discoloration. Samples requiring humic extraction were placed in a 0.1 M NaOH solution and agitated on an oscillating table for 30 min intervals. This step was repeated until the NaOH solution showed no discoloration. All samples were then refluxed in an oven in 3.5 mL of 0.01 M HCl solution at a temperature of 66 °C for 36 h. The samples were frozen before being placed in a freeze dryer for 36 h. Once dried, 0.50 ± 0.05 mg of collagen was weighed into tin capsules to be analyzed.

For the tooth sample, the external surface was first cleaned by dry brushing and sonication in ultrapure water. The tooth was left to dry overnight before removing the enamel using an NSK dental drill with a diamond bit to expose the dentine. Dentine collagen was then extracted from the tooth sample following the same procedure as for bone collagen, with an additional step for incremental sampling. The whole tooth (minus the enamel) was demineralized and then cut using a razor blade into five even horizontal sections (~5 mm) perpendicular to the tooth's growth axis, to obtain a temporal sequence of isotopic change over the course of the tooth's development (Balasse, 2003).

2.4. Stable isotope analysis

Stable carbon and nitrogen isotopic compositions were determined using a Nu Horizon isotope ratio mass spectrometer coupled to a EuroVector 3000 elemental analyzer in the Water Quality Center at Trent University, Peterborough. δ^{13}C and δ^{15}N values were calibrated relative to VPDB and AIR, respectively, using calibration standards USGS40, USGS63 or USGS66 (Qi et al., 2003). In-house check standards with well-known stable carbon and nitrogen isotopic compositions were used to monitor internal analytical uncertainty and are available in the supplemental material (Table S2). The means and standard deviations of the calibration and check standards from all analytical sessions are presented in the supplementary material (Table S3).

Based on repeated measurements of all standards and sample replicates, precision was determined to be ±0.10 ‰ for δ^{13}C and ±0.25 ‰ for δ^{15}N values. Accuracy, based on comparisons of the difference between known and observed δ values and their long-term standard deviations was ±0.08 ‰ for δ^{13}C and ±0.26 ‰ for δ^{15}N values. Following the methods outlined in Szpak et al. (2017) the total analytical uncertainty for all analyzed samples and standards was estimated to be ±0.13 ‰ for δ^{13}C and ±0.36 ‰ for δ^{15}N values. For additional details see the supplementary materials.

2.5. Data analysis

Statistical analyses were conducted using PAST 4.11 (Hammer et al., 2001). To compare the δ^{13}C and δ^{15}N values between groups a Welch's *t*-test was used. The isotopic niches of dogs and humans were quantified and compared using multivariate ellipse-based metrics and standard ellipses using the R package SIBER (Jackson et al., 2011).

There were some differences in the preparation of the collagen extracted in this study relative to the data generated by Coltrain et al. (2004). Interlaboratory comparisons (Jørkov et al., 2007; Pestle et al., 2014; Sealy et al., 2014) and more specific tests of different methodological variants (Guiry et al., 2016; Wilson and Szpak, 2022) have not yielded any significant isotopic differences, so we have no reason to suspect that the data from these different studies would not be directly comparable. To equate the dietary compositions of humans and dogs at the site, and to test the assumption that dogs can function as a direct dietary proxy for humans, the dietary contributions of caribou, ringed seal, and bowhead whale were estimated and compared using the Bayesian mixing model MixSIAR (Stock et al., 2018). These taxa were selected to facilitate comparisons with Coltrain's (2009) original human dietary reconstruction using IsoSource 1.3.1 (Phillips and Gregg, 2003), based on their presumed economic importance and high relative abundance in Silumiut's faunal assemblage. Relative to simple probabilistic models like IsoSource, MixSIAR offers the advantage of incorporating uncertainties related to variability in source contributions, fractionation, and consumers (Moore and Semmens, 2008). Human and dog dietary estimates were run separately rather than treating them as subgroups of the same population, accounting for residual errors, following recommendations for modelling archaeological contexts by Cheung and Szpak (2021). The estimated magnitude of diet-tissue trophic fractionation (TDF) between each source and consumer's bone collagen was approximated as +1.0 ± 1.0 ‰ for δ^{13}C and +4.0 ± 1.0 ‰ for δ^{15}N (Bocherens and Drucker, 2003). The R code used in this analysis is presented in the supplementary material.

3. Results

The bulk isotopic and elemental compositions of the analyzed canids (dog, wolf, and unidentified *Canis* sp.) are presented in Table 1. All samples fell above the recommended minima for quality control indicators (collagen yields >1 %, wt%C >13 %, and wt%N >4.5 %) and had C:N ratios falling within the traditionally acceptable range of 2.9–3.6 for ancient bone collagen (Ambrose, 1990; DeNiro, 1985), as well as the most conservative QC criteria for ancient collagen proposed by Guiry and Szpak (2021). The δ^{13}C and δ^{15}N values of all canids, humans, and local baseline fauna are shown in Fig. 2.

Bone and dentine collagen from all canid samples analyzed in this study ($n = 8$) ranged from –17.91 to –13.57 ‰ for δ^{13}C values (mean

Table 1
Stable isotopic and elemental data from canid bone collagen and bulk dentine (the mean and standard deviation of the incremental dentine sections) at Silumiut analyzed for this study. Sample IDs in boldface indicate samples were run in duplicate, and the values listed represent the average of the duplicates.

Sample ID	Feature	Context	Taxon	Element	Age	δ^{13}C$_{VDPB}$ (‰)	δ^{15}N$_{AIR}$ (‰)	wt%C	wt%N	C:N	Collagen Yield (%)
17906	House 3	Midden	*Canis* sp.	Tibia	Adult	–14.57	+16.15	38.2	14.2	3.13	25.2
17919	House 14	Midden	*Canis* sp.	Mandible	Adult	–13.57	+18.77	36.3	13.2	3.21	16.3
17921	House 4	Sg-S	*Canis* sp.	Scapula	Adult	–14.16	+16.90	43.9	15.7	3.25	26.7
17924	House 14	Midden	*Canis l. familiaris*	Mandible	Juvenile	–17.91	+9.22	41.5	15.1	3.20	22.2
17992	House 8	S-D	*Canis l. familiaris*	Mandible	Adult	–13.89	+15.72	38.8	14.4	3.14	19.4
17993	House 14	Midden	*Canis l. lupus*	Mandible	Adult	–16.31	+7.97	39.7	14.6	3.17	16.0
18001	House 13	Midden	*Canis l. familiaris*	Mandible	Adult	–15.38	+11.77	40.5	14.9	3.18	13.9
18267	House 14	Midden	*Canis l. lupus*[*]	Mandibular PM4		–16.33 ± 0.26	+9.00 ± 0.15				

[*] sample from a probable wolf adult, but its dentine isotopic composition reflects its juvenile diet.

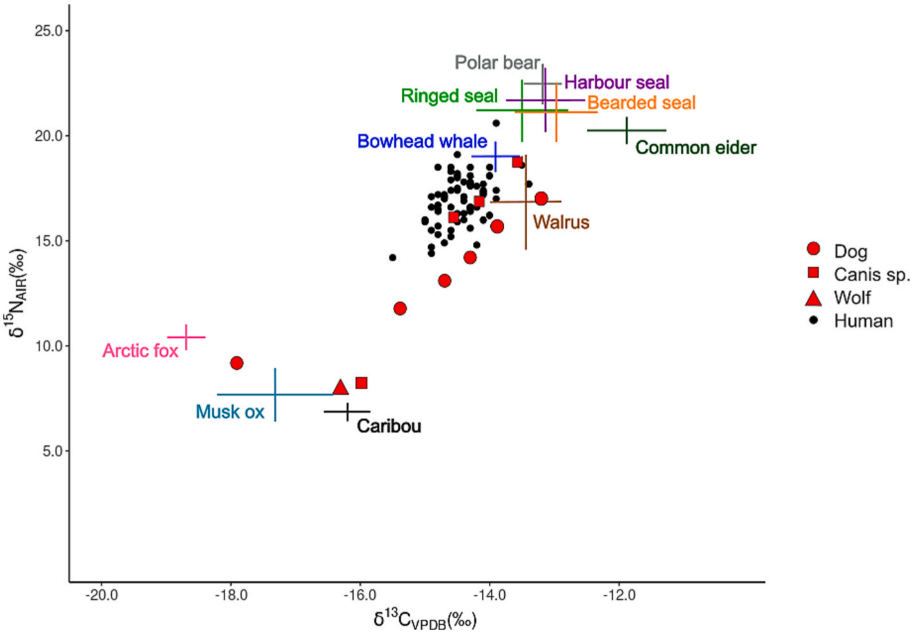

Fig. 2. Stable carbon and nitrogen isotopic compositions for human and canid bone collagen samples at the Silumiut site in comparison to archaeological faunal baseline data (mean ± 1σ), adjusted for trophic level effects (+1 ‰ for δ^{13}C and +3 ‰ for δ^{15}N, following Bocherens and Drucker, 2003).

–15.26 ± 1.50 ‰), and from +7.97 to +18.77 ‰ for δ^{15}N values (mean +13.19 ± 4.19 ‰). Based on the isotopic similarity in the adult bone collagen of the dogs and *Canis* specimens at this site as well as morphological observations (see Ameen et al., 2019), it was assumed that the *Canis* samples also came from domesticated dogs rather than from wolves. Considering this, the dog and *Canis* specimens (hereafter 'dogs') along with four dogs previously analyzed by Coltrain et al. (2004) had δ^{13}C values ranging from –17.91 to –13.20 ‰ (mean –14.77 ± 1.38 ‰), and δ^{15}N values ranging from +8.00 to +18.77 ‰ (mean +14.08 ± 3.53 ‰).

The juvenile dog's (17924) bone collagen was characterized by lower δ^{13}C and δ^{15}N values compared to adult dogs. The difference in this individual is not surprising given that the bone collagen of juveniles have isotopic compositions reflecting much shorter periods of time than in adults due to age-related differences in bone turnover rates (Huja and Beck, 2007) and therefore are more sensitive to short-term dietary changes. It was assumed that the bone collagen was not affected by a nursing signature given that dogs are weaned 5–10 weeks post-birth (Lord et al., 2013) and large breeds like the Inuit sled dog would undergo rapid bone growth and turnover, quickly replacing any collagen formed during the weaning period. Omitting the juvenile dog's bone collagen stable isotope values, the adult dogs at Silumiut had a mean δ^{13}C value of –14.42 ± 0.87 ‰ and a mean δ^{15}N value of +14.62 ± 3.28 ‰.

The probable wolf sample (17993) had lower δ^{13}C and δ^{15}N values compared to the dogs' bone collagen samples in general, consistent with a reliance on terrestrial prey (Bocherens et al., 2016; Treu et al., 2022; Losey et al., 2022) and was similar to the isotopic compositions of the bulk dentine collagen subsamples (18267.1 to 18267.5) derived from the same individual (Table 2), supporting the species identification for this individual. The isotopic compositions of the dentine increments had little variation in δ^{13}C values, ranging 0.52 ‰ (from –16.55 to –16.03 ‰) and δ^{15}N values, ranging 0.40 ‰ (from +8.82 to +9.22 ‰). This suggests that the individual's diet was isotopically homogeneous during tooth formation (Fig. 3). Taken together, the dentine and bone collagen from the wolf show a diet dominated by caribou, which is possible to interpret relative to other prey sources given caribou's uniquely high δ^{13}C values among terrestrial herbivores due to their dietary focus on lichen (Drucker, 2022) and the conservative fractionation of carbon isotopes across trophic levels. This agrees well with other studies of wolf

Table 2
Stable carbon and nitrogen isotope values and elemental data from tooth dentine increments.

Sample ID	δ^{13}C$_{VPDB}$ (‰)	δ^{15}N$_{AIR}$ (‰)	wt%C	wt%N	C:N
18267.1	–16.55	+8.94	39.8	14.5	3.20
18267.2	–16.52	+8.82	40.4	14.8	3.19
18267.3	–16.48	+8.95	40.9	14.9	3.20
18267.4	–16.06	+9.06	40.9	15.0	3.17
18267.5	–16.03	+9.22	40.9	15.1	3.17

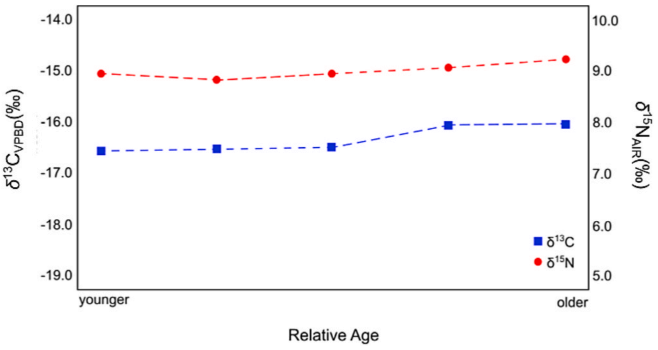

Fig. 3. Stable carbon and nitrogen isotope values of dentine collagen from a probable wolf's incrementally sampled tooth at the Silumiut site.

diets in the central Canadian Arctic that have found wolves will preferentially feed on large terrestrial ungulates, particularly migratory barren-ground caribou (Musiani et al., 2007), with minor, but variable, contributions of hares, lemmings, and seabirds (Dalerum et al., 2018; Newsome et al., 2016; Treu et al., 2022). Marine foods are typically less commonly available to wolves, although they are known to scavenge marine resources if available (e.g., Darimont and Reimchen, 2002).

Statistical comparisons found no significant differences with respect to human and adult dog δ^{13}C values (Welch's *t*-test; $t = 0.10$, $p = 0.92$) or δ^{15}N values (Welch's *t*-test; $t = 2.11$, $p = 0.07$). Although not significantly different, the δ^{15}N values of humans tended to be higher than those of dogs. Despite the much smaller sample size of dogs at this site compared to humans, the dogs had a wide range of δ^{13}C and δ^{15}N values quantified using multivariate ellipse-based metrics (Table 3). This range is greatly reduced, however, when omitting the juvenile bone collagen sample from this comparison, particularly the CHA, an extreme value metric which is strongly influenced by unique or outlying data points. For comparative purposes, the SEA_c and SEA_b values are more appropriate comparative metrics given the low number of dogs relative to humans (Jackson et al., 2011). The standard ellipses of adult dogs and humans as shown in Fig. 4 also exhibited limited overlap (1.3 %) suggesting that they had different isotopic niches.

Interpretations of the Silumiut human and canid stable isotope ratios were contextualized in part by stable isotope data from other fauna at the site. These baseline faunas are intended to provide an interpretative foundation representative of potentially important dietary resources that were available at Silumiut (Cheung and Szpak, 2022). Terrestrial taxa had much lower δ^{13}C and δ^{15}N values than marine taxa, reflecting the large isotopic differences between these environments. Polar bears had the highest δ^{15}N values, reflecting their position as a top-level marine consumer (Hobson and Welch, 1992; Ramsay and Hobson, 1991), although the magnitude of difference between polar bears and other high-trophic-level consumers like seals was not as large as in other regional contexts (Routledge et al., 2023). Seals showed high δ^{15}N values but variable δ^{13}C values depending on the species, reflecting variable consumption of pelagic (upper ocean layers) and benthic (deep water) or sympagic (sea ice) resources. Lower trophic level marine consumers included bowhead whale and walrus. Both had lower δ^{15}N values than seals, consistent with their reliance on lower-trophic-level prey (Hobson and Welch, 1992). The caribou possessed δ^{13}C values associated with lichen-dominated diets, which are ^{13}C-enriched relative to most other terrestrial C_3 plants (Ben-David et al., 2001; Britton et al., 2023; Drucker et al., 2010). Muskox had similar δ^{15}N values but lower δ^{13}C values than the caribou, reflecting either a lower reliance on lichen (Drucker et al., 2010), lower marine macroalgae consumption (Hansen and Aanes, 2012), or some combination of both. Although Arctic foxes are known to be opportunistic scavengers and will prey on other terrestrial resources including caribou carcasses or marine resources in coastal tundra ecosystems (Ehrich et al., 2015), the low δ^{13}C values of the Arctic foxes relative to caribou and marine prey items indicate that dietary contributions from such sources were limited; instead, the foxes' isotopic compositions are indicative of a completely terrestrially-derived diet, most likely small rodents like lemmings which are known to dominate Arctic fox diets in other contexts (Elmhagen et al., 2000; Ims et al., 2017; Roth, 2002).

Table 3
SIBER metrics for human and dogs at Silumiut.

Group	n	CHA	SEA	SEA_c	SEA_b
Humans	66	6.90	1.22	1.24	1.20
Dogs (all ages)	10	15.91	7.64	8.59	8.99
Dogs (adults only)	9	6.51	3.63	4.15	4.82

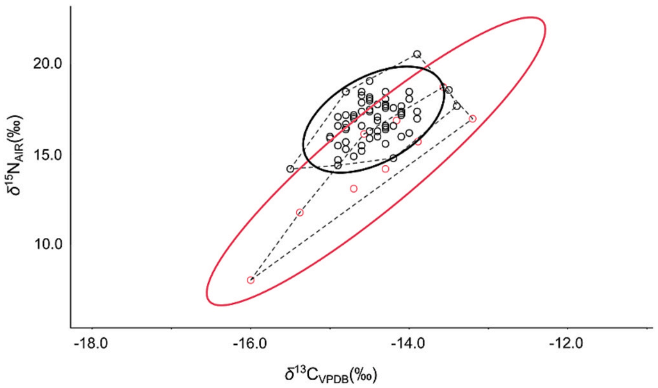

Fig. 4. Stable carbon and nitrogen isotope values, convex hull areas (CHA) and standard ellipses of adult dogs and humans at Silumiut. Red symbols and ellipses show dogs, and black symbols and ellipses show humans.

Dietary compositions of humans and adult dogs were estimated using updated source data and the Bayesian mixing model, MixSIAR (Table 4). Results of the models estimated greater dietary contributions of caribou for dogs than humans. The updated human dietary reconstruction produced a similar range of estimations (95 % confidence interval) to Coltrain's (2009: 770) IsoSource model, which estimated dietary contributions ranging from 5–20 % for caribou, 15–80 % ringed seal, and 0–80 % bowhead whale (median diet: 15 % caribou, 55 % ringed seal, 25 % bowhead whale), but suggested a greater contribution of bowhead whale relative to ringed seal for humans. The 3-source models produced large confidence interval ranges, particularly for marine sources, reflecting the isotopic similarity of these food sources and the limitations of mixing models for discriminating among certain resources (Brett, 2014). Combined with the narrow resource polygon produced by these sources, the models may not reliably differentiate ringed seal and bowhead whale with high precision and could be over- or underrepresenting these resources relative to one another. *A posteriori* aggregation into two source groups (marine protein and terrestrial protein) was therefore applied to the MixSIAR models (Table 5). Model outputs following source aggregation showed much smaller confidence intervals for marine protein and indicated that dogs and humans did not consume the same proportions of terrestrial and marine protein. Although both groups consumed proportionally more marine protein than terrestrial,

Table 4
Summary statistics of MixSIAR models estimated dietary source contributions for humans and adult dogs at Silumiut.

Group	Dietary source	95 % CI	Median	Mean ± 1σ
Humans	Caribou	7.9–25.0 %	13.0 %	14.8 ± 5.2 %
	Ringed seal	0.4–75.2 %	10.8 %	24.7 ± 26.7 %
	Bowhead whale	1.5–90.5 %	76.7 %	60.4 ± 31.6 %
Dogs	Caribou	12.3–49.6 %	32.5 %	32.1 ± 9.6 %
	Ringed seal	1.7–65.8 %	30.9 %	31.6 ± 18.6 %
	Bowhead whale	1.9–76.5 %	36.0 %	36.3 ± 21.9 %

Table 5
Summary statistics of MixSIAR models following *a posteriori* source aggregation.

Group	Dietary source group	95 % CI	Median	Mean ± 1σ
Humans	Terrestrial protein	7.9–25.0 %	13.0 %	14.8 ± 5.2 %
	Marine protein	75.0–92.1 %	87.0 %	85.2 ± 5.2 %
Dogs	Terrestrial protein	12.3–49.6 %	32.5 %	32.1 ± 9.6 %
	Marine protein	50.4–87.7 %	67.5 %	67.9 ± 9.6 %

dogs were more reliant on terrestrial protein relative to humans.

4. Discussion

Dogs at Silumiut clearly share a dietary relationship with humans given their isotopic similarities with one another and differences from both foxes and wolves. Higher δ^{13}C and δ^{15}N values among the dogs reflect greater access to marine resources, either from being directly provisioned with these foods by humans or indirectly from scavenging human food by-products. This dietary reliance on marine mammals is consistent with the diets of sled dogs in other regions of Inuit Nunangat (e.g., Harris et al., 2020). Dog dietary needs were likely strongly influenced by economic factors: sled traction and breathing-hole sealing are labor-intensive and involve close cooperation between humans and dogs (Gerth et al., 2010) necessitating provisioning of the dogs with calorie-rich foods, particularly marine mammals (e.g., Jenness, 1922; Pryde, 1972).

Interestingly, differences in the diets of individual dogs are consistent with the variability observed among humans. Given that the dog remains derive from different house contexts, the few dogs' remains present at this site overall, and the low numbers of dogs kept by Inuit groups in this region historically (Damas, 1984), these inter-individual differences may reflect differences in dog ownership and provisioning by individual hunters or families. Differences in Inuit attitudes towards dogs in general or even towards individual dogs have been described for various communities (Laugrand and Oosten, 2002), which could affect a dog's diet. Other culturally mediated dietary relationships could have impacted the dogs isotopic compositions. Food sharing practices, for example, are often formalized among Inuit groups as a means of reducing food stress and strengthening social ties (Damas, 1972; Nuttall, 2000). It is not unreasonable to suggest that the distribution of food among dogs could have been structured similarly to human food sharing practices, leading to the similar variability observed in both humans and dogs at Silumiut.

Changes to Silumiut's subsistence economy over time could have also impacted dog provisioning. Previously, Coltrain (2009) argued that the diets of humans at Silumiut showed a decreased reliance on high trophic level marine taxa through time. Uncertainties in the contemporaneity of humans and dogs at the site limits interpretation. If earlier, dogs and humans may have had more distinctive diets than if the dogs were from a later period. The dogs at Silumiut are from separate contexts to the human remains, but direct radiocarbon dating was not undertaken because of their variable marine-food consumption, which are associated with a great amount of marine reservoir uncertainty and would make such dates difficult to calibrate. Rather, radiocarbon dates on caribou bones from some of the same midden and house contexts as the dogs, as reported in Ameen et al. (2019) and Dyke et al. (2018), provide a rough, albeit tentative, estimate of the dogs' ages. The caribou bones largely post-date 1400 CE, suggesting that, like humans, dogs were reliant on lower-trophic level marine taxa for their diets, and that the observed isotopic variation among the dogs is not a result of a changing subsistence economy.

Despite their overall isotopic similarities, comparisons of dog and human isotopic niches and estimated diets indicated dietary differences, either from consuming different resources, or the same resources but in different proportions. An important caveat to consider is that the models only included the contributions of three sources to facilitate direct human–dog comparisons due to their abundance in Silumiut's faunal assemblage and presumed economic importance. Assuming that dogs consumed the same resources as humans, they were not consuming the same proportions of these resources. Food sources such as small terrestrial mammals that might have been consumed by dogs are likely to be underrepresented or even absent in the site's faunal assemblage, particularly if dogs were provisioning themselves through hunting and scavenging. It is also possible that the dogs were consuming large amounts of blubber instead of protein from marine mammals (e.g., Harris et al., 2020), which would be underrepresented in their δ^{13}C and δ^{15}N values and in the dietary reconstructions because collagen primarily reflects the protein component of the diet (Ambrose and Norr, 1993; Tiezen and Fagre, 1993). Dogs require high-fat diets to meet the energy demands associated with sled traction (Lupo, 2019), and there are ethnographic notes about blubber being fed to dogs (Rasmussen, 1929). Walrus is also mentioned as a food source for dogs during winter months by Inuit hunters (Nelson, 1969; Smith, 1991). Further stable isotope analyses on both dogs and humans at Silumiut would help characterize their isotopic relationship in a way that is not heavily biased towards dietary protein. Compound-specific isotope analysis of individual amino acids (Newsome et al., 2014), fatty acids (Howland et al., 2003), or bulk analysis of bioapatite δ^{13}C values (Ambrose and Norr, 1993; Jim et al., 2006; Tiezen and Fagre, 1993) would be useful for investigating the dietary contributions of lipids to the dogs' subsistence, particularly those of large marine mammals like bowhead whale and walrus which may be underrepresented in the dogs' bone collagen. This approach would be useful for similar studies in high-latitude contexts where marine resources are likely an important dietary component.

At first glance, the isotopic composition of adult dogs appears to provide a relatively accurate direct dietary proxy for humans, recognizing that humans tend to produce slightly higher δ^{15}N values. The generally elevated human δ^{15}N values at Silumiut agree with a trend observed in many other studies comparing human and dog isotope data (e.g., Glencross et al., 2022; Guiry and Grimes, 2013; Katzenberg, 1989 ; Losey et al., 2011), with some exceptions (e.g., Perri et al., 2019; Tankersley and Koster, 2009). Behaviorally, some researchers have suggested that the practice of cacaeotrophy by dogs is the reason for this ^{15}N-depletion (e.g., Cannon et al., 1999); however, feces can be roughly equivalent to or even enriched in ^{15}N, relative to an animal's diet (Sponheimer et al., 2003), which makes this an unlikely explanation. Human consumption of dogs could result in higher δ^{15}N values due to trophic level effects (e.g., McManus-Fry et al., 2018; Richards et al., 2009). Dogs may have been consumed occasionally by humans during periods of food stress but the lack of higher δ^{13}C values in humans compared to dogs, the limited numbers of dogs at the site, and a paucity of evidence for direct butchering suggests that the consumption of dog meat was not a key dietary component (Guiry and Grimes, 2013; Staab, 1979).

Given the challenges related to applying dogs as direct dietary proxies for humans, even at Silumiut where human diets are relatively well-characterized, dogs may better serve as an indirect application of the CSA. That is, dietary information from dogs is most informative when focusing on aspects of human dietary practices and human–dog relationships more generally rather than as direct analogs for human diet (Guiry, 2012). The juvenile dog in this study serves as an example; although its isotopic composition is distinct from humans and adult dogs, and therefore not a reliable direct dietary proxy, this individual can provide insight into seasonal variations in Silumiut's subsistence economy and dog provisioning that would be obscured in adult bone collagen.

The dietary focus of the juvenile dog was terrestrially oriented, with little if any marine protein in its diet. The slightly elevated δ^{15}N value, and more negative δ^{13}C value compared to the wolf samples indicates that caribou was not being consumed in great proportions by this dog, suggesting that it derived the bulk of its dietary protein from other terrestrial prey. This is somewhat unexpected, given the site's faunal assemblage, composed primarily of caribou for terrestrial prey species (Staab, 1979). Instead, the isotopic composition of this dog is more in line with self-provisioning of small terrestrial prey, likely lemmings or hares given its isotopic similarity to the Arctic foxes with an average δ^{13}C value of −19.7 ± 0.3 ‰ and δ^{15}N value of +6.4 ± 0.6 ‰. Alternatively, this individual may have had a diet focusing on musk ox, in which case it would have been more reliant on human provisioning, given that dogs, unlike wolves, tend not to hunt animals larger than themselves (Losey et al., 2022). Dogs were typically less active in subsistence-related activities outside of the winter months (Gerth et al., 2010), leading to a decreased need to directly provision them during warmer seasons. Although the winter diets of humans and dogs were likely similar, with both species consuming large amounts of marine foods and some terrestrial foods, their warm season diets were likely more distinct. Ethnographic accounts describe Inuit groups leaving their dogs to fend for themselves the summer or stranding them on islands (Boas, 1888; Freuchen, 1935; Weyer, 1932). Humans at Silumiut likely had much greater access to marine foods throughout the year than dogs, particularly in warmer months considering the juvenile dog's isotopic compositions. An analysis of tissues from dogs and humans at the site that document short-term dietary information, including incremental sampling of dentine collagen, would be extremely useful in providing additional lines of evidence of seasonal dietary practices beyond the single juvenile bone collagen sample analyzed in this project. Such information would help characterize human and dog diets at different times of the year, and how seasonality may have affected dog provisioning.

5. Conclusions

In Inuit Nunangat, dogs played an important role in Inuit economies, even if only for part of the year, and their diets are closely related to human subsistence practices, supporting their usefulness in human palaeodietary research in this region. At Silumiut, dogs clearly show a dietary relationship with humans, both based on their isotopic similarities to humans and the differences between wild and domestic canids. Adult dogs appear to serve as an appropriate dietary analogue for humans for the purpose of CSA applications, with the caveat that humans should be expected to produce higher δ^{15}N values than dogs, for as of yet unknown reasons. It is still necessary, however, to remain cautious of uncritical applications of dog diets as a direct analog for human palaeodiets. Dietary reconstructions indicated that despite their general isotopic congruence, dogs were consuming proportionally more terrestrial resources than humans at the site. On the other hand, the isotopic compositions of the Silumiut canids are still extremely useful for other lines of evidence regarding human subsistence practices. Differences between the adult and juvenile dogs' stable isotope ratios revealed seasonal variation in dog diet and provisioning, which could be related to the economic role of dogs at different times of the year. Given the often-limited sample sizes associated with archaeological data, the range of isotopic variation in the diets of a handful of individuals may not be reflective of the full dietary range across a larger canid population. At Silumiut, however, the limited number of dogs showed a considerable isotopic range—one that is comparable to the variation observed in humans at the site—indicating dietary differences among the dogs. Beyond Silumiut, more studies from different regions of Inuit Nunangat and adjacent Greenland on the isotopic compositions of dogs are needed to shed light on regional variations in human–dog relationships before considering the wide-spread applications of dogs as human palaeodietary proxies in this area.

CRediT authorship contribution statement

Brooke Driscoll: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Christyann M. Darwent:** Writing – review & editing, Resources, Funding acquisition, Conceptualization. **Paul Szpak:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2025.105233.

Data availability

All data and code are provided in the manuscript or supplementary materials.

References

Allitt, S., Stewart, R.M., Messner, T., 2009. The utility of dog bone (*Canis familiaris*) in stable isotope studies for investigating the presence of prehistoric maize (*Zea mays ssp. mays*): A preliminary study. N. Am. Archaeol. 29 (3), 343–367. https://doi.org/10.2190/NA.29.3-4.h.

Ambrose, S.H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. J. Archaeol. Sci. 17, 431–451.

Ambrose, S.H., Norr, L., 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: Lambert, J.B., Grupe, G. (Eds.), Prehistoric Human Bone: Archaeology at the Molecular Level. Springer-Verlag, pp. 1–37. https://doi.org/10.1007/978-3-662-02894-0_1.

Ameen, C., Feuerborn, T.R., Brown, S.K., Linderholm, A., Hulme-Beaman, A., Lebrasseur, O., Sinding, M.S., Lounsberry, Z.T., Lin, A.T., Appelt, M., Bachmann, L., Betts, M., Britton, K., Darwent, J., Dietz, R., Fredholm, M., Gopalakrishnan, S., Goriunova, O.I., Grønnow, B., Evin, A., 2019. Specialized sledge dogs accompanied Inuit dispersal across the North American Arctic. Proc. r. Soc. b. 286, 20191929. https://doi.org/10.1098/rspb.2019.1929.

Balasse, M., 2003. Potential biases in sampling design and interpretation of intra-tooth isotope analysis. Int. J. Osteoarchaeol. 13, 3–10. https://doi.org/10.1002/oa.656.

Ben-David, M., Shochat, E., Adams, L.G., 2001. Utility of stable isotope analysis in studying foraging ecology of herbivores: Examples from moose and caribou. Alces 37, 421–434.

Boas, F., 1888. The Central Eskimo: Sixth Annual Report of the Bureau of Ethnology to the Secretary of the Smithsonian Institution, 1884-1885. Government Printing Office, Washington, D.C., pp. 399–669

Bocherens, H., Drucker, D., 2003. Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. Int. J. Osteoachaeol. 13 (1–2), 46–53. https://doi.org/10.1002/oa.662.

Bocherens, H., Drucker, D.G., Haidle, M.N., Müller-Beck, H., Münzel, S.C., Naito, Y.I., 2016. Isotopic evidence (C, N, S) for a high aquatic dietary contribution for a Pre-Dorset muskox hunter from Umingmak (Banks Island, Canada). J. Archaeol. Sci. Rep. 6, 700–708. https://doi.org/10.1016/j.jasrep.2015.08.021.

Brett, M.T., 2014. Resource polygon geometry predicts Bayesian stable isotope mixing model bias. Mar. Ecol. Prog. Ser. 514, 1–12. https://doi.org/10.3354/meps11017.

Britton, K., Jimenez, E.L., Le Corre, M., Renou, S., Rendu, W., Richards, M.P., Hublin, J. J., Soressi, M., 2023. Multi-isotope analysis of bone collagen of Late Pleistocene ungulates reveals niche partitioning and behavioural plasticity of reindeer during MIS 3. Sci. Rep. 13, 15722. https://doi.org/10.1038/s41598-023-42199-7.

Burleigh, R., Brothwell, D., 1978. Studies of Amerindian dogs: carbon isotopes in relation to maize in the diet of domestic dogs from early Peru and Ecuador. J. Archaeol. Sci. 5 (4), 3550362. https://doi.org/10.1016/0305-4403(78)90054-7.

Cannon, A., Schwarcz, H.P., Knyf, M., 1999. Marine-based subsistence trends and the stable isotope analysis of dog bones from Namu. British Columbia. J. Archaeol. Sci. 26 (4), 399–407. https://doi.org/10.1006/jasc.1998.0341.

Carpenter, W.J., 1976. Canada's own Eskimo dog on the brink of extinction. North/nord 2–7.

Cheung, C., Szpak, P., 2021. Interpreting past human diets using stable isotope mixing models. J.archaeol. Method Theory 28, 1106–1142. https://doi.org/10.1007/s10816-020-09492-5.

Cheung, C., Szpak, P., 2022. Interpreting past human diets using stable isotope mixing models- Best practices for data acquisition. J. Archaeol. Method Theory 29, 138–161. https://doi.org/10.1007/s10816-021-09514-w.

Chisholm, B.S., Nelson, D.E., Schwarcz, H.P., 1982. Stable-carbon isotope ratios as a measure of marine versus terrestrial protein in ancient diets. Science 216 (4550), 1131–1132.

Coltrain, J.B., 2009. Sealing, whaling and caribou revisited: Additional insights from the skeletal isotope chemistry of eastern Arctic foragers. J. Archaeol. Sci. 36 (3), 764–775. https://doi.org/10.1016/j.jas.2008.10.022.

Coltrain, J.B., Hayes, M.G., O'Rourke, D.H., 2004. Sealing, whaling and caribou: the skeletal isotope chemistry of eastern Arctic foragers. J. Archaeol. Sci. 31, 39–57. https://doi.org/10.1016/S0305-4403(03)00091-8.

Craig, H., 1953. The geochemistry of the stable carbon isotopes. Geochim. Cosmochim. Acta 3 (2–3), 53–92. https://doi.org/10.1016/0016-7037(53)90001-5.

Cummings, B.D., 2002. First Nations, First Dogs: Canadian Aboriginal Ethnocynology. Brush Education, Calgary.

Dalerum, F., Freire, S., Angerbjörn, A., 2018. Exploring the diet of Arctic wolves (*Canis lupus arctos*) at their northern range limit. Can. J. Zool. 96 (3), 277–281. https://doi.org/10.1139/cjz-2017-0054.

Damas, D., 1972. The structure of Central Eskimo associations. In: Guemple, L. (Ed.), Alliance in Eskimo Society. University of Washington Press, Seattle, pp. 40–55.

Damas, D., 1984. Copper Eskimo. In: Damas, D., Sturtevant, W.C. (Eds.), Handbook of North American Indians. Vol. 5: Arctic. Smithsonian Institution Press, Washington, D.C., pp. 397–414.

Darimont, C.T., Reimchen, T.E., 2002. Intra-hair stable isotope analysis implies seasonal shift to salmon in gray wolf diet. Can. J. Zool. 80, 1638–1642. https://doi.org/10.1186/1472-6785-8-14.

DeNiro, M.J., 1985. Postmortem preservation and alteration of *in vivo* bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature 317, 806–809.

DeNiro, M.J., Epstein, S., 1978. Influence of diet on the distribution of carbon isotopes in animals. Geochim. Cosmochim. Acta 42, 495–506. https://doi.org/10.1016/0016-7037(78)90199-0.

DeNiro, M.J., Epstein, S., 1981. Influence of diet on the distribution of nitrogen isotopes in animals. Geochim. Cosmochim. Acta 45, 341–351. https://doi.org/10.1016/0016-7037(81)90244-1.

Drucker, D.G., 2022. The isotopic ecology of the Mammoth Steppe. Annu. Rev. Earth Planet. Sci. 50, 395–418. https://doi.org/10.1146/annurev-earth-100821-081832.

Drucker, D.G., Hobson, K.A., Ouellet, J.P., Courtois, R., 2010. Influence of forage preferences and habitat use on 13C and 15N abundance in wild caribou (*Rangifer tarandus caribou*) and moose (*Alces alces*) from Canada. Isotopes Environ. Health Stud. 46 (1), 107–121. https://doi.org/10.1080/10256010903388410.

Dyke, A.S., Savelle, J.M., Szpak, P., Southon, J.R., Howse, L., Desrosiers, P.M., Kotar, K., 2018. An assessment of marine reservoir corrections for radiocarbon dates on walrus from the Foxe Basin region of Arctic Canada. Radiocarbon 61, 67–81. https://doi.org/10.1017/RDC.2018.50.

Ehrich, D., Ims, R.A., Yoccoz, N.G., Lecomte, N., Killengreen, S.T., Fuglei, E., Rodnikova, A.Y., Ebbinge, B.S., Menyushina, I.E., Nolet, B.A., Pokrovsky, I.G., Popov, I.Y., Schmidt, N.M., Sokolov, A.A., Sokolova, N.A., Sokolov, V.A., 2015. What can stable isotope analysis of top predator tissues contribute to monitoring of tundra ecosystems? Ecosystems 18, 404–416. https://doi.org/10.1007/s10021-014-9834-9.

Elmhagen, B., Tannerfeldt, M., Verucci, P., Angerbjörn, A., 2000. The arctic fox (*Alopex lagopus*): an opportunistic specialist. J. Zool. Lond. 251, 139–149. https://doi.org/10.1111/j.1469-7998.2000.tb00599.x.

Fahy, G.E., Deter, C., Pitfield, R., Miszkiewicz, J.J., Mahoney, P., 2017. Bone deep: Variation in stable isotope ratios and histomorphometric measurements of bone remodelling within adult humans. J. Archaeol. Sci. 87, 10–16. https://doi.org/10.1016/j.jas.2017.09.009.

Freuchen, P., 1935. Mammals. Part II. Field Notes and Biological Observations. Report of the Fifth Thule Expedition 1921–24, Vol. II. No. 4–5. Gyldendalske Boghandel, Copenhagen, pp. 69–278.

Friesen, M.T., 2013. When Worlds Collide: Hunter-Gatherer World-System Change in the 19th Century Canadian Arctic. University of Arizona Press, Tucson.

Gerth, N., Redman, P., Speakman, J., Jackson, S., Starck, J.M., 2010. Energy metabolism of Inuit sled dogs. J. Comp. Physiol. b. 180 (4), 577–589. https://doi.org/10.1007/s00360-009-0432-7.

Glencross, B., Warrick, G., Smith, T., Prowse, T.L., 2022. Estimating ancient Huron-Wendat diet in southern Ontario using stable isotopes from dogs. J. Archaeol. Sci. Rep. 41. https://doi.org/10.1016/j.jasrep.2021.103324.

Guiry, E.J., 2012. Dogs as analogs in stable isotope-based human paleodietary reconstructions: A review and considerations for future use. J. Archaeol. Method Theory 19 (3), 351–376. https://doi.org/10.1007/s10816-011-9118-z.

Guiry, E.J., Grimes, V., 2013. Domestic dog (*Canis familiaris*) diets among coastal Late Archaic groups of northeastern North America: A case study for the canine surrogacy approach. J. Anthropol. Archaeol. 32 (4), 732–745. https://doi.org/10.1016/j.jaa.2013.04.005.

Guiry, E.J., Szpak, P., 2021. Improved quality control criteria for stable carbon and nitrogen isotope measurements of ancient bone collagen. J. Archaeol. Sci. 132, 105416. https://doi.org/10.1016/j.jas.2021.105416.

Guiry, E.J., Szpak, P., Richards, M.P., 2016. Effects of lipid extraction and ultrafiltration on stable carbon and nitrogen isotopic compositions of fish bone collagen. Rapid Commun. Mass Spectrom. 30 (13), 1591–1600. https://doi.org/10.1002/rcm.7590.

Hall, O.R., 2024. Assessing human bone collagen turnover rate (Order No. 31336568) [Master's Thesis, Trent University]. ProQuest Dissertations & Theses Global. https://www.proquest.com/dissertations-theses/assessing-human-bone-collagen-turnover-rate/docview/3078226732/se-2.

Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4 (1), 9. https://www.nhm.uio.no/english/research/infrastructure/past.

Hansen, B., Aanes, R., 2012. Kelp and seaweed feeding by High-Arctic wild reindeer under extreme winter conditions. Polar Res. 31, 17258. https://doi.org/10.3402/polar.v31i0.17258.

Harris, A.J.T., Elliott, D.A., Guiry, E.J., Von Tersch, M., Rankin, L., Whitridge, P., Alexander, M., Eriksson, G., Grimes, V., 2020. Diversity in Labrador Inuit sled dog diets: Insights from δ^{13}C and δ^{15}N analysis of dog bone and dentine collagen. J. Archaeol. Sci. Rep. 32, 102424. https://doi.org/10.1016/j.jasrep.2020.102424.

Hill, E., 2018. The archaeology of human-dog relations in Northwest Alaska. In: Losey, R. J., Wishart, R.P., Laurens Loovers, J.P. (Eds.), Dogs in the North: Stories of Cooperation and Co-Domestication. Routledge, London, pp. 87–104.

Hillis, D., McKechnie, I., Guiry, E., St. Claire, D.E., Darimont, C.T., 2020. Ancient dog diets on the Pacific Northwest Coast: Zooarchaeological and stable isotope modelling evidence from Tseshaht territory and beyond. Sci. Rep. 10, 15630. https://doi.org/10.1038/s41598-020-71574-x.

Hobson, K.A., Welch, H.E., 1992. Determination of trophic relationships within a high Arctic marine food web using δ13C and δ15N analysis. Mar. Ecol. Prog. Ser. 84, 9–18. https://www.jstor.org/stable/24829721.

Howland, M.R., Corr, L.T., Young, S.M.M., Jones, V., Jim, S., Van Der Merwe, N.J., Mitchell, A.D., Evershed, R.P., 2003. Expression of the dietary isotope signal in the compound-specific δ^{13}C values of pig bone lipids and amino acids. Int. J. Osteoarchaeol. 13 (1–2), 54–65. https://doi.org/10.1002/oa.658.

Huja, S.S., Beck, F.M., 2007. Bone remodeling in maxilla, mandible, and femur of young dogs. Anat. Rec. 291 (1), 1–5. https://doi.org/10.1002/ar.20619.

Huja, S.S., Fernandes, S.A., Hill, K.J., Li, Y., 2006. Remodeling dynamics in the alveolar process in skeletally mature dogs. Anat. Rec. 288A (12), 1243–1249. https://doi.org/10.1002/ar.a.20396.

Ims, R.A., Killengreen, S.T., Ehrich, D., Flagstad, Ø., Hamel, S., Henden, J., Jensvoll, I., Yoccoz, N.G., 2017. Ecosystem drivers of an Arctic fox population at the western fringe of the Eurasian Arctic. Polar Res. 36. https://doi.org/10.1080/17518369.2017.1323621.

Jackson, A.L., Inger, R., Parnell, A.C., Bearhop, S., 2011. Comparing isotopic niche widths among and within communities: SIBER - Stable Isotope Bayesian Ellipses in R. J. Anim. Ecol. 80, 595–602. https://doi.org/10.1111/j.1365-2656.2011.01806.x.

Jenness, D., 1922. The life of the Copper Eskimos. In: Jenness, D. (Ed.), Report of the Canadian Arctic Expedition, 1913-1918, Vol. XII. F.A. Acland, Ottawa, pp. 5–277.

Jim, S., Jones, V., Ambrose, S.H., Evershed, R.P., 2006. Quantifying dietary macronutrient sources of carbon for bone collagen biosynthesis using natural abundance stable carbon isotope analysis. Br. J. Nutr. 95 (6), 1055–1062. https://doi.org/10.1079/BJN20051685.

Jørkov, M.L.S., Heinemeier, J., Lynnerup, N., 2007. Evaluating bone collagen extraction methods for stable isotope analysis in dietary studies. J. Archaeol. Sci. 34 (11), 1824–1829. https://doi.org/10.1016/j.jas.2006.12.020.

Katzenberg, M.A., 1989. Stable isotope analysis of archaeological faunal remains from southern Ontario. J. Archaeol. Sci. 16 (3), 319–329. https://doi.org/10.1016/0305-4403(89)90008-3.

Laugrand, F., Oosten, J., 2002. Canicide and healing: The position of the dog in the Inuit cultures of the Canadian Arctic. Anthropos 97, 89–105. https://www.jstor.org/stable/40465618.

Lévesque, F., 2019. Ni animal de campagnie, ni animal de travail: proximité et mise à l'écart du qimmiq (chien) dans les familles inuites de l'Arctique central canadien avant la sédentarisation. Enfances Fam. Gener. 32. https://doi.org/10.7202/1064508ar.

Longin, R., 1971. New method of collagen extraction for radiocarbon dating. Nature 230, 241–242. https://doi.org/10.1038/230241a0.

Lord, K., Feinstein, M., Smith, B., Coppinger, R., 2013. Variation in reproductive traits of members of the genus *Canis* with special attention to the domestic dog (*Canis familiaris*). Behav. Process. 92, 131–142. https://doi.org/10.1016/j.beproc.2012.10.009.

Losey, R.J., Bazaliiskii, V.I., Garvie-Lok, S., Germonpré, M., Leonard, J.A., Allen, A.L., Katzenberg, A.M., Sablin, M.V., 2011. Canids as persons: Early Neolithic dog and wolf burials, Cis-Baikal, Siberia. J. Anthropol. Archaeol. 30 (2), 174–189. https://doi.org/10.1016/j.jaa.2011.01.001.

Losey, R.J., Nomokonova, T., Guiry, E., Fleming, L.S., Garvie-Lok, S.J., Waters-Rist, A.L., Bieraugle, M., Szpak, P., Bachura, O.P., Bazaliiskii, V.I., Berdnikova, N.E., Diatchina, N.G., Frolov, I.V., Gorbunov, V.V., Goriunova, O.I., Grushin, S.P., Gusev, A.V., Iaroslavtseva, L.G., Ivanov, G.L., Tishkin, A.A., 2022. The evolution of dog diet and foraging: Insights from archaeological canids in Siberia. Sci. Adv. 8 (29), eabo6493. https://doi.org/10.1126/sciadv.abo6493.

Lupo, K.D., 2019. Hounds follow those who feed them: What can the ethnographic record of hunter-gatherers reveal about early human-canid partnerships? J. Anthropol. archaeol. 55, 101081. https://doi.org/10.1016/j.jaa.2019.101081.

Marotti, G., 1963. Quantitative studies on bone reconstruction. Acta Anat.5 52 (4), 291–333. https://doi.org/10.1159/000142367.

Martin, R.B., Burr, D.B., Sharkley, N.A., 1998. Skeletal Tissue Mechanics. Springer, New York.

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

McCartney, A.P., 1977. Thule Eskimo Prehistory along Northwestern Hudson Bay. Archaeological Survey of Canada, Mercury Series, Paper No. 70. National Museums of Canada, Ottawa.

McCullough, K.M., 1989. The Ruin Islanders: Early Thule Culture Pioneers in the Eastern High Arctic. Archaeological Survey of Canada, Mercury Series, Paper No.141. Canadian Museum of Civilization, Hull.

McManus-Fry, E., Knecht, R., Dobney, K., Richards, M.P., Britton, K., 2018. Dog-human dietary relationships in Yup'ik western Alaska: The stable isotope and zooarchaeological evidence from pre-contact Nunalleq. J. Archaeol. Sci. Rep. 17, 964–972. https://doi.org/10.1016/j.jasrep.2016.04.007.

Milne, S.B., Park, R.W., 2016. Pre-Dorset Culture. In: Friesen, M., Mason, O. (Eds.), The Oxford Handbook of the Prehistoric Arctic. Oxford University Press, Oxford, pp. 693–712.

Minagawa, M., Wada, E., 1984. Stepwise enrichment of 15N along food chains: Further evidence and the relationship between δ^{15}N and animal age. Geochim. Cosmochim. Acta 48 (5), 1135–1140. https://doi.org/10.1016/0016-7037(84)90204-7.

Moore, J.W., Semmens, B.X., 2008. Incorporating uncertainty and prior information into stable isotope mixing models. Ecol. Lett. 11, 470–480. https://doi.org/10.1111/j.1461-0248.2008.01163.x.

Morey, D.F., Aaris-Sørensen, K., 2001. Paleoeskimo dogs of the eastern Arctic. Arctic 55 (1), 44–56. https://www.jstor.org/stable/40512917.

Musiani, M., Leonard, J.A., Cluff, H.D., Gates, C.C., Mariani, S., Paquet, P.C., Vilà, C., Wayne, R.K., 2007. Differentiation of tundra/taiga and boreal coniferous forest wolves: Genetics, coat colour and association with migratory caribou. Mol. Ecol. 16 (19), 4149–4170. https://doi.org/10.1111/j.1365-294X.2007.03458.x.

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

Newsome, S.D., Wolf, N., Peters, J., Fogel, M.L., 2014. Amino acid δ^{13}C analysis shows flexibility in the routing of dietary protein and lipids to the tissue of an omnivore. Integr. Comp. Biol. 54 (5), 980. https://doi.org/10.1093/icb/icu106.

Newsome, T.M., Boitani, L., Chapron, G., Ciucci, P., Dickman, C.R., Dellinger, J.A., López-Bao, J.V., Peterson, R.O., Shores, C.R., Wirsing, A.J., Ripple, W.J., 2016. Food habits of the world's grey wolves. Mamm. Rev. 46 (4), 255–269. https://doi.org/10.1111/mam.12067.

Noe-Nygaard, N., 1988. δ^{13}C-values of dog bone reveal the nature of changes in man's food resources at the mesolithic-neolithic transition. Denmark. Chem. Geol. 73 (1), 87–96. https://doi.org/10.1016/0168-9622(88)90023-1.

Nuttall, M., 2000. Indigenous peoples, self-determination and the Arctic environment. In: Nuttall, M., Vallaghan, T.V. (Eds.), The Arctic: Environment, People, Policy. Harwood Academic Publishers, Australia, pp. 377–409.

Perri, A.R., Koster, J.M., Otárola-Castillo, E., Burns, J.L., Cooper, C.G., 2019. Dietary variation among indigenous Nicaraguan horticulturalists and their dogs: An ethnoarchaeological application of the Canine Surrogacy Approach. J. Anthropol. Archaeol. 55, 101066. https://doi.org/10.1016/j.jaa.2019.05.002.

Pestle, W.J., Crowley, B.E., Weirauch, M.T., 2014. Quantifying inter-laboratory variability in stable isotope analysis of ancient skeletal remains. PloS One 9 (7), e102844. https://doi.org/10.1371/journal.pone.0102844.

Phillips, D.L., Gregg, J.W., 2003. Source partitioning using stable isotopes: coping with too many sources. Oecologia 136, 261–269. https://doi.org/10.1007/s00442-003-1218-3.

Post, D.M., 2002. Using stable isotopes to estimate trophic position: models, methods, and assumptions. Ecol. 83 (3), 703–718. https://doi.org/10.1890/0012-9658(2002)083[0703:USITET]2.0.CO;2.

Pryde, D., 1972. Nunaga: My Land. My Country, Hurtig, Edmonton.

Qi, H., Coplen, T.B., Geilmann, H., Brand, W.A., Böhlke, J.K., 2003. Two new organic reference materials for δ^{13}C and δ^{15}N measurements and a new value for the δ^{13}C of NBS 22 oil. Rapid Commun. Mass Spectrom. 17, 2483–2487. https://doi.org/10.1002/rcm.1219.

Ramsay, M.A., Hobson, K.A., 1991. Polar bears make little use of terrestrial food webs: Evidence from stable-carbon isotope analysis. Oecologia 86, 598–600. https://doi.org/10.1007/BF00318328.

Rasmussen, K., 1929. Intellectual Culture of the Iglulik Eskimos. Report of the Fifth Thule Expedition 1921-24. Vol. VII. No. 1. Gylderndalske Boghandel, Copenhagen.

Richards, M.P., West, E., Rolett, B., Dobney, K., 2009. Isotope analysis of human and animal diets from the Hanamiai archaeological site (French Polynesia). Archaeol. Ocean. 44, 29–37. https://doi.org/10.1002/j.1834-4453.2009.tb00042.x.

Rick, T.C., Culleton, B.J., Smith, C.B., Johnson, J.R., Kennett, D.J., 2011. Stable isotope analysis of dog, fox, and human diets at a Late Holocene Chumash village (CA-SRI-2) on Santa Rosa Island, California. J. Archaeol. Sci. 38, 1385–1393.

Roth, J.D., 2002. Temporal variability in arctic fox diet as reflected in stable-carbon isotopes; the importance of sea ice. Oecologia 133, 70–77. https://doi.org/10.1007/s00442-002-1004-7.

Routledge, J., Sonne, C., Letcher, R.J., Dietz, R., Szpak, P., 2023. Unprecedented shift in Canadian High Arctic polar bear food web unsettles four millennia of stability. Anthropocene 43, 100397. https://doi.org/10.1016/j.ancene.2023.100397.

Savelle, J.M., Dyke, A.S., 2009. Paleoeskimo demography on western Boothia Peninsula, Arctic Canada. J. Field. Archaeol. 2, 43–58. https://doi.org/10.1179/009346909791070916.

Schoeninger, M.J., DeNiro, M.J., 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochim. Cosmochim. Acta 48, 625–639. https://doi.org/10.1016/0016-7037(84)90091-7.

Schoeninger, M.J., DeNiro, M.J., Tauber, H., 1983. Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. Science 220 (4604), 1381–1383. https://www.science.org/doi/10.1126/science.6344217.

Sealy, J., Johnson, M., Richards, M., Nehlich, O., 2014. Comparison of two methods of extracting bone collagen for stable carbon and nitrogen isotope analysis: comparing whole bone demineralization with gelatinization and ultrafiltration. J. Archaeol. Sci. 47, 64–69. https://doi.org/10.1016/j.jas.2014.04.011.

Smith, E.A., 1991. Inujjuamuit Foraging Strategies: Evolutionary Ecology of an Arctic Hunting Economy. Aldine De Gruyter, New York.

Sponheimer, M., Robinson, T., Ayliffe, L., Passey, B., Roeder, B., Shipley, L., Lopez, E., Cerling, T., Dearing, D., Ehleringer, J., 2003. An experimental study of carbon-isotope fractionation between diet, hair, and feces of mammalian herbivores. Can. J. Zool. 81 (5), 871–876. https://doi.org/10.1139/z03-066.

Staab, M.L., 1979. Analysis of faunal material recovered from a Thule Eskimo site on the island of Silumiut, N.W.T., Canada. In: McCartney, A.P. (Ed.), Thule Eskimo Culture: An Anthropological Retrospective. Archaeological Survey of Canada, Mercury Series, Paper No. 88. National Museums of Canada, Ottawa.

Stock, B.C., Jackson, A.L., Ward, E.J., Parnell, A.C., Phillips, D.L., Semmens, B.X., 2018. Analyzing mixing systems using a new generation of Bayesian tracer mixing models. PeerJ 6, e5096.

Szpak, P., 2022. Why zooarchaeology needs stable isotope analysis. In: Sharpe, A.E., Krigbaum, J. (Eds.), Applications of Isotope Research in Zooarchaeology. University Press of Florida, Gainesville, pp. 248–270.

Szpak, P., Buckley, M., 2020. Sulfur isotopes (δ^{34}S) in Arctic marine mammals: Indicators of benthic vs. pelagic foraging. Mar. Ecol. Prog. Ser. 653, 205–216. https://doi.org/10.3354/meps13493.

Szpak, P., Metcalfe, J.Z., Macdonald, R.A., 2017. Best practices for calibrating and reporting stable isotope measurements in archaeology. J. Archaeol. Sci. Rep. 13, 609–616. https://doi.org/10.1016/j.jasrep.2017.05.007.

Tankersley, K.B., Koster, J.M., 2009. Sources of stable isotope variation in archaeological dog remains. N. Am. Archaeol. 30 (4), 361–375. https://doi.org/10.2190/NA.30.4.b.

Tiezen, L.L., Boutton, T.W., 1989. Stable carbon isotopes in terrestrial ecosystems research. In: Rundel, P.W., Ehleringer, J.R., Nagy, K.A. (Eds.), Stable Carbon Isotopes in Ecological Research. Ecological Studies, Springer-Verlag, New York, pp. 167–195.

Tiezen, L.L., Fagre, T., 1993. Effect of diet quality and composition on the isotopic composition of respiratory CO_2, bone collagen, bioapatite, and soft tissues. In: Lambert, J.B., Grupe, G. (Eds.), Prehistoric Human Bone: Archaeology at the Molecular Level. Springer-Verlag, New York, pp. 121–155.

Treu, G., Sinding, M.S., Czirjak, G.A., Dietz, R., Graff, T., Krone, O., Marquard-Petersen, U., Mikkelsen, J.B., Schulz, R., Sonne, C., Sondergaard, J., Sun, J., Zubrod, J., Eulaers, I., 2022. An assessment of mercury and its dietary drivers in fur of Arctic wolves from Greenland and High Arctic Canada. Sci. Total Environ. 838, 156171. https://doi.org/10.1016/j.scitotenv.2022.156171.

Weyer, E.M., 1932. The Eskimos: Their Environment and Folkways. Yale University Press, New Haven.

White, C.D., Pohl, M.E.D., Schwarcz, H.P., Longstaffe, F.J., 2001. Isotopic evidence for Maya patterns of deer and dogs use at Preclassic Colha. J. Archaeol. Sci. 28 (1), 89–107. https://doi.org/10.1006/jasc.1999.0560.

Wilson, T., Szpak, P., 2022. Acidification does not alter the stable isotope composition of bone collagen. PeerJ 10, e13593. https://doi.org/10.7717/peerj.13593.

Wishart, R.P., 2018. Telling stories of co-domestication and cooperation: An introduction. In: Losey, R.J., Wishart, R.P., Laurens Loovers, J.P. (Eds.), Dogs in the North: Stories of Cooperation and Domestication. Routledge, London, pp. 1–7.