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SPECIAL ISSUE
ALEUTIANS

Ancient canids of the Aleutian Islands (new archaeological discoveries from the Islands of Four Mountains)

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Abstract

We discuss the cultural roles of dog and red fox recovered from Carlisle Island, Islands of Four Mountains, Alaska, within the context of Aleutian ethnographic and zooarchaeological records. Three dog bones were recovered from the Ulyagan archaeological site, Unit 5, in levels that date to AD 1450–1645. Three red fox bones come from the Ulyagan site, Unit 4, in levels that date 460 BC–AD 95. Our analyses show that both red fox and domestic dog date earlier than the contact with Russians and that these canids do not extend west of the Islands of Four Mountains archipelago. Given the rich history of human intervention on the Aleutians ecosystems over the last 250 years, we argue that indigenous red fox inhabited the Islands of the Four Mountains region prior to western contact; however, foxes did not have a pronounced cultural role for prehistoric Aleuts. Domestic dogs accompanied humans in the Aleutians after AD 950, suggesting that these canids might be linked with the Neo-Aleut culture. In the light of Arctic and oceanic cases of human use of dogs considered in the paper, we suggest that dogs might have served as reserve food sources during long trips for people migrating west.

Keywords: Aleutian Islands; The Islands of Four Mountains; Aleuts; Dogs; Foxes; Zooarchaeology

INTRODUCTION

With respect to the peopling of and adaptation to the Arctic and subarctic environments, Aleutian prehistory has great potential for understanding adaptations to a changing environment over the course of the last millennia. Ancient Aleuts crossed the Bering Land Bridge in the Terminal Pleistocene (Coutouly and Holmes, 2018) and probably reached the Aleutian archipelago around 11,000 yr (Black, 1976). The oldest archaeological sites found on the Fox Islands date to 7000 BC (Laughlin, 1975; Davis and Knecht, 2010; Davis et al., 2016); the subsequent expansion of Aleuts through the Aleutian chain westward is documented through radiocarbon-dated archaeological sites (West et al., 1999; O'Leary, 2001; Corbett et al., 2010; Savinetsky et al., 2012). Hrdlička (1945) first noted two skull morphologies in Aleutian burials that he believed represented two distinct groups, which subsequently have been called Paleo-Aleuts and Neo-Aleuts (Laughlin, 1974, 1975). Recent studies have shown that Neo-Aleuts were genetically divergent from Paleo-Aleuts and relied on a higher trophic diet (Coltrain et al., 2006; Smith et al., 2009; Coltrain, 2010). The Neo to Paleo-Aleut transition occurred sometime between AD 1150 and AD 1250 (West et al., 2019). Misarti and Maschner (2015) proposed that this transition resulted from increasing social complexity accompanied with intensified interactions with Kodiak people, and these authors argue that genetic change was due to an influx of Kodiak women.

Zooarchaeological investigations are not only valuable to archaeological investigations, but also to conservation ecology and biogeography (Wolverton and Lyman, 2010). In zooarchaeological studies, often rare taxa are underestimated until cumulative data indicate they may be significant. Compared with sea mammals, canids rarely appear in Aleutian archaeological sites and only include the domestic dog (Denniston, 1972; Turner and Turner, 1974; Knecht and Davis, 2003), arctic fox (Crockford et al., 2004), and red fox (Denniston, 1972; Turner and Turner, 1974; Yesner, 1977; Davis, 2001; Knecht and Davis, 2003). It remains

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unclear, however, whether canids really were uncommon and what specific roles they played in prehistoric Aleut culture. The Aleutian histories of these three canid species are quite unique.

Both red (*Vulpes vulpes*) and arctic foxes (*Vulpes lagopus*) played important roles in the past 250 yr of Aleutian history, but their ecology and distribution during the pre-contact period remains largely unexplored. After Russians discovered and claimed Alaska in 1741, they intensively harvested Aleutian sea otters, fur seals, seals, and foxes for their furs. Seeing a wealth of ground nesting Aleutian birds as a ready food supply, Russians introduced foxes as early as 1750 to the Near, Rat, Andreanof, and Islands of the Four Mountains island groups (Fig. 1). Fox "farming" escalated after the United States purchased Alaska in 1867. In 1913, the United States government established the Alaska Maritime National Wildlife Refuge. Although American wildlife managers regulated hunting of the endangered sea otter, refuge officials initially promoted fox farming. Fox trappers released and trapped foxes in the Aleutians between 1900 and 1920. By the 1930s, arctic or red foxes had been introduced on more than 450 islands (Black, 1984; Bailey, 1993). In the mid-twentieth century, foxes comprised the most widespread invasive species in the Aleutian Islands and the U.S. Fish and Wildlife Service introduced a program to eradicate them from all islands (Bailey, 1993). Ethnographic and archaeological records, however, suggest that foxes were native to some of the Aleutian Islands. If proven indigenous to particular islands, foxes should not be eradicated there. Thus, it is important to determine where foxes prehistorically lived. The archaeological record can provide valuable information on this important wildlife management topic.

The term "unexpected fauna" (Holland, 2004) is commonly used when dog bones are recovered from Aleutian archaeological sites. Dog remains are rare in Aleutian archaeological sites (Denniston, 1972; Turner and Turner, 1974; Knecht and Davis, 2003) and thus have warranted little attention. Ethnographic accounts of dogs are also sparse. Veniaminov (1984) mentioned nothing about dogs in his descriptions of domestic animals in the Aleutians. Ransom (1946) stated that, by the middle of the twentieth century, wild dogs inhabited Aleut villages, except on Umnak and Unalaska. Khlebnikov (1979) mentioned that locals used numerous Kodiak dogs for hunting. The presence of historic Kodiak dogs, however, does not indicate dogs existed on this island during the pre-contact period. Their absence in the ethnographic literature could indicate that dogs, if prehistorically present, did not play an important role in Aleutian lifeways. Meanwhile, Holland and Turner (1987) emphasize that the presence of dogs, even in small numbers, helped differentiate Neo-Aleut village sites from those occupied by Paleo-Aleuts.

In this paper, we discuss fox and dog remains recovered from two units of the Ulyagan archaeological site (Carlisle Island) and compare our data with other published zooarchaeological information for the Aleutian Islands. Beyond osteological analyses, we use stable isotope techniques to reveal the trophic position of dog and foxes in Aleutian prehistory.

MATERIALS AND METHODS

The bones of red fox (*Vulpes vulpes*) and dog (*Canis lupus familiaris*) came from Units 4 and 5 of the Ulyagan site (AMK-0003), located on Carlisle Island (Fig. 1). A detailed description of the site can be found in Hatfield et al. (2019) and Krylovich et al. (2019). Accelerator mass spectrometry (AMS) radiocarbon dates indicate that Unit 4 dates to 460 BC–AD 95 and Unit 5 to AD 1450–1645 (Krylovich et al., 2019).

We identified three fox bones recovered in two layers of the Ulyagan Site Unit 4. A left distal fragment of a tibia and a left astragalus were recovered from the 84–89 cm level and one left ulna fragment, missing the proximal epiphysis, was found in the 84–78 cm level (Fig. 2a). We recovered three skeletal elements of dog in 500-yr-old Unit 5 deposits: two teeth belonging to young and subadult dogs (Fig. 2c) including a deciduous premolar from the right mandible, recovered in the 70–80 cm level, and an incisor, found in 40–50-cm level, and a humerus (Fig. 2b), representing a subadult individual recovered from the adjacent profile exposure that is associated with the 70–80 cm level of Unit 5. The dog humerus was subjected to radiocarbon dating by AMS at the Center for Chronological Research at Nagoya University (laboratory code prefix NUTA2). Sample preparation for AMS (graphitization) was performed in the Radiocarbon Laboratory of the Institute of Geography Russian Academy of Sciences (RAS) using an AGE-3 graphitization system (Ionplus). Calibration of conventional radiocarbon date was conducted in Oxcal 4.3 using Marine13 calibration curve (Reimer et al., 2013) with $\Delta R = 495 \pm 20$ (West et al., 2019). The date is reported below in the "Results" section.

Stable isotope analysis

Stable isotopes of carbon and nitrogen are frequently used to determine an animal's trophic position, which is strongly linked to its diet (DeNiro and Epstein, 1978, 1981). If we know the average isotopic signature of the animal's tissue, we can compare it with stable isotopes of available local resources to determine the animal's food sources. We have conducted stable isotope analyses only on Pacific cod, red fox, and dog remains from the Ulyagan site on Carlisle Island so far. The other faunal remains from the site have not yet been analyzed; for this reason, we used Byers et al. (2011) isotopic data for various animals from the Chaluka archaeological site (Umnak Island) to compare dog and fox isotopic signatures with the isotopic signatures of other Aleutian fauna.

Stable isotope analyses on the dog humerus and fox tibia and ulna were conducted in the Severtsov Institute of Ecology and Evolution, RAS. Collagen extraction was carried out using a modified Longin (1971) method. Samples of cleaned bone (0.3 g) were soaked in 1 M HCl until complete demineralization. The sample was rinsed to neutrality with distilled water and the insoluble collagen was placed in a slightly acidic solution (pH ~2.5) and heated in plastic

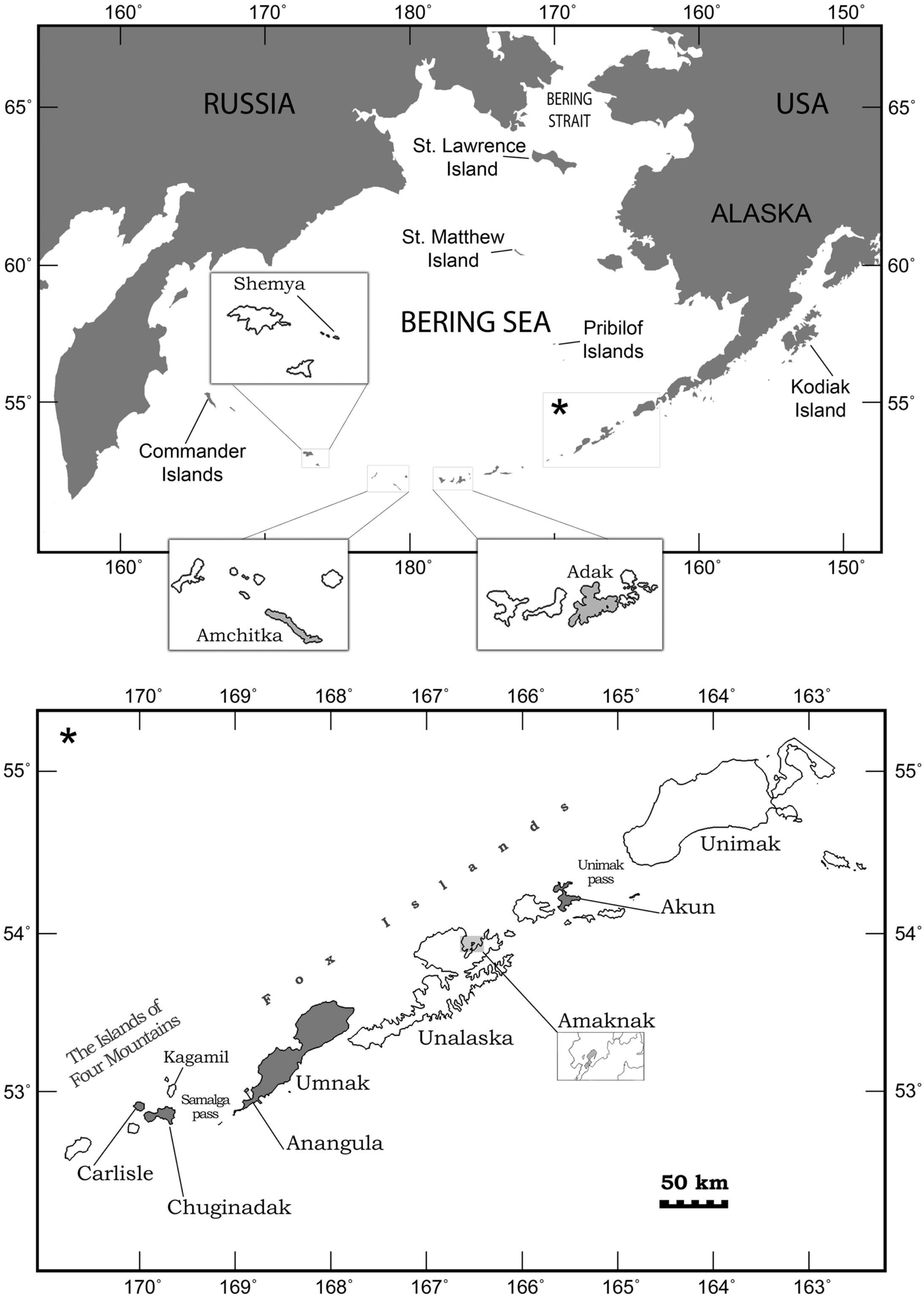

Figure 1. Map of Aleutian Islands showing geographical names mentioned in text. *Enlarged region of the eastern Aleutians.

tubes at 70°C for 24–36 h to gelatinize the collagen. The gelatinized fraction of collagen was transferred into glass vials and placed in a drying chamber at 80°C until the sample was totally dried. The extracted, dried collagen was then transferred into a tin cup for isotopic analysis (~500 µg). The stable isotope composition of the bone collagen was determined using a Thermo-Finnigan Delta V Plus continuous flow isotope-ratio mass spectrometry coupled with an elemental analyzer (Thermo Flash 1112) in the Joint Usage Center at the Institute of Ecology and Evolution, RAS. The

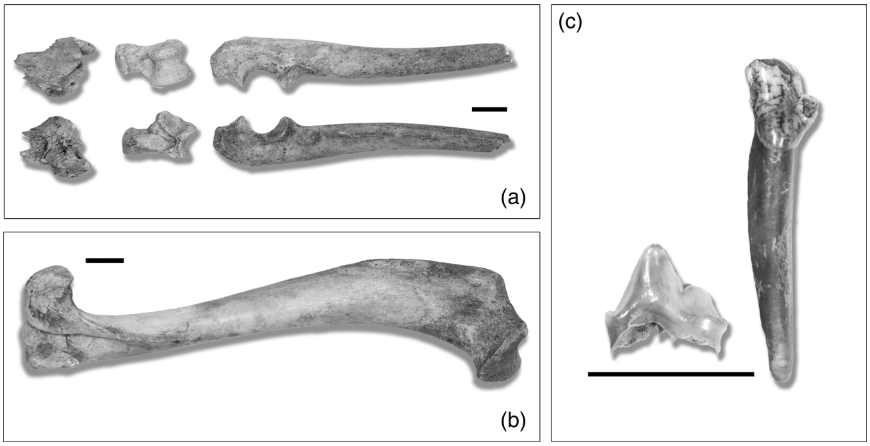

Figure 2. Canid remains found in Ulyagan site of Carlisle Island. Bold lines are equal to 1 cm. (a) Red fox bones found in Unit 4. From left to right: distal tibia fragment, astragalus, and ulna fragment. The bottom images display the opposite sides of same specimens. (b) Dog humerus and (c) teeth found in Unit 5.

isotopic composition of N and C was expressed in the δ-notation relative to the international standard (atmospheric nitrogen or VPDB): $\delta X\ (‰) = [(R_{sample} / R_{standard}) - 1] \times 1000$, where R is the ratio of the heavier isotope to the lighter isotope. Samples were analyzed with reference gas calibrated against International Atomic Energy Agency (IAEA) reference materials USGS 40 and USGS 41 (glutamic acid). The drift was corrected using an internal laboratory standard (acetanilide and casein). The standard deviation of $\delta^{13}C$ and $\delta^{15}N$ values in reference materials (n = 4–8) was less than 0.2‰.

Comparative archaeological data

The main goal of this study was to compare all published zooarchaeological data for the Aleutian Islands in order to evaluate spatial and temporal distribution of canids. The dataset of mammal bone identifications (Table 1) was created using Lippold (1966), Desaultes et al. (1971), Denniston (1972), Turner and Turner (1974), Yesner (1977), Holland and Turner (1987, 1988), Davis (2001), Knecht and Davis (2003), Crockford et al. (2004), Lefèvre et al. (2010, 2011), Byers et al. (2011), Crockford (2012), and Savinetsky et al. (2012) as sources.

All statistics and plotting were carried out in R v.3.4.4 (R Core Team, 2018), and all bone measurements were taken using techniques developed by von den Driesch (1976).

RESULTS

Osteological analysis

Fox remains

As previously noted, we recovered three fox bones in two levels of Unit 4: a distal fragment of a tibia, an astragalus, and an ulna fragment. All bones represent the left side. Comparison of these three bone fragments with red and arctic fox skeletons in our osteological collection at the IPEE RAS suggest they represent red fox (*Vulpes vulpes*). Both the tibia fragment and ulna possessed cut marks. All the cut marks were located near the joints, which reflects skinning rather than butchering for meat (Monchot and Gendron, 2011).

The tibia fragment and astragalus originated from the same archaeological layer; joint surfaces of these two bones articulate well with each other and highly likely represent a single individual. The distal breadth of the tibia fragment is 16.5 mm. This is 2 mm larger than the mean values of both adult red and arctic foxes sampled in Canada and the northwestern USA (Monchot and Gendron, 2010). However, the Carlisle tibia measurement appears within the range (16–18 mm) of red foxes sampled in Russia. The distal tibia breadth of Russian arctic foxes ranges from 12–16 mm (Gromova, 1950). The astragalus and tibia exhibited slight porosity, suggesting a subadult individual. Although the ulna possessed the same articular size as an adult individual, it was porous, especially at the distal, broken end. The ulna exhibited an unfused proximal epiphysis and possessed a relative robustness characteristic of juveniles (Sullivan and Haugen, 1956). According to Harris (1978), the proximal ulnar epiphysis fuses at 16–18 weeks, which approximately corresponds to July–August fusion time for foxes today; on the other hand, the distal epiphysis of the tibia fuses with the shaft at 23–25 weeks (September). Therefore, despite the close stratigraphic positions of the ulna and heel fragments, these two subadult bones represent two individuals that died at different times.

A χ^2 test is often used in zooarchaeological studies (Grayson, 1984; Lyman, 2008) to show whether the actual frequency of a variable(s) diverges from the expected one in which the estimate is based on the variable distribution in the sample. It can be used for intersite comparisons of species frequencies or for estimating whether the single species frequency deviates somewhere in the sample group based on stratigraphic levels or time periods. In order to test whether the observed frequencies of red fox in the Ulyagan Site Unit 4 excavation were linked to the sample size (i.e., due

Table 1. Zooarchaeological records of mammal remains recovered from Aleutian Islands sites. The sites are ordered from west to east. *, 2 bones are likely from a single individual (see text for details); **, 11 bones are likely from a single adult individual (see Crockford et al., 2004 for details); ***, 2 dog remains are of prehistoric context, 1 from historic layer and 1 of unknown origin (see Holland and Turner, 1987 for details)

Island	Site	Year (AD/BC)	*C. familiaris*	*Canis* sp.	*V. vulpes* (%)	*V. lagopus*	Ursidae	*E. lutris*	Odobenidae	Phocidae	Otariidae	Cetacea	Cervidae	Mammals (NISP)	Reference(s)
Shemya	ATU-061 (all units)	730–400 BC	–	–	–	–	–	1	–	2	390	9	–	402	Lefèvre et al., 2010
Shemya	ATU-022	180 BC–AD 85	–	–	–	–	–	15	–	9	162	35	–	221	
Shemya	ATU-003 (all pits)	150 BC – AD 395	–	–	–	–	–	2	–	–	15	20	–	37	
Shemya	ATU-021	50 BC–AD 410	–	–	–	–	–	1	–	4	27	24	–	56	
Amchitka	RAT-31	550 BC–AD 950	–	–	–	–	–	740	–	418	105	–	–	1263	Desautels et al., 1971
Adak	Tutiakoff (ADK-171)	5200 BC–AD 4830	–	–	–	–	–	41	–	22	73	2	–	138	Savinetsky et al., 2012
Adak	Sweeper Cove Site (ADK-009)	130 BC–AD 980	–	–	–	–	–	18	–	15	7	–	–	40	
Adak	Dozered (ADK-012)	AD 85–435	–	–	–	–	–	88	–	31	13	4	4	141	Crockford, 2012
Adak	Zeto point (ADK-011) (all units)	AD 1535–1780	–	–	–	–	–	12	–	20	19	6	–	57	Lefèvre et al., 2011
Carlisle	Ulyagan, Unit 4	950–750 BC	–	–	–	–	–	3	–	1	13	–	–	17	Krylovich et al., 2019
		750 BC–AD 50	–	–	2 (10.5)*	–	–	3	–	5	9	–	–	19	
		AD 50–100	–	–	1 (2.3)	–	–	10	–	9	22	–	–	42	
Carlisle	Ulyagan, Unit 5	AD 1450–1645	3	–	–	–	–	–	–	1	9	–	–	12	
Carlisle	Ulyagan, Unit 2	AD 1800	–	–	–	–	–	2	–	21	259	–	–	282	
Anangula	Anangula village site	–	–	–	3 (1.4)	–	–	35	–	45	126	–	–	209	Yesner, 1977
Umnak	Chaluka	1700 BC–AD 1550	–	2	5 (–)	–	–	2355	–	1372	1787	–	–	5521	Lippold, 1966; Yesner, 1977; Byers et al., 2011
Umnak	Oglodax`	410 BC–AD 1450	–	–		–	–	20	–	59	235	–	–	314	Yesner, 1977
		AD 1450–1650	–	–	14 (2.5)	–	–	26	–	71	441	–	–	552	
		AD 1650–1850	–	–	19 (1.9)	–	–	31	–	95	818	–	–	963	
Umnak	Ashishik Point	AD 600–900	–	–	1 (4.8)	–	–	–	–	3	13	3	–	20	Denniston, 1972
		AD 1500–1750 (pre-contact)	1	–	2 (4.7)	–	–	–	–	6	25	7	–	41	
Umnak	Sheep Creek	–	–	–	25 (5.1)	–	–	105	–	154	174	3	–	461	Yesner, 1977
Amaknak	Margaret bay (UNL-048)	2750–2150 BC	–	5	5 (0.1)		113	92	11	3257	782	1115	5	5385	Davis, 2001
Amaknak	Amaknak bridge (UNL-050)	1550–550 BC	–	–	–	14**	8	6	6	2463	2822	1047	7	6363	Crockford et al., 2004
Amaknak	Tanaxtaxak (UNL-055), Block A	AD 1310–1660	4	–	7 (0.2)	–		53	–	245	3756	242	–	4307	Knecht and Davis, 2003
Akun	Chulka	AD 780–1880	4***	–	5 (4.5)	–	2	2	–	13	71	4	4	105	Turner and Turner, 1974; Holland and Turner, 1987

Table 2. The archaeological levels of Ulyagan Site Unit 4, showing the relative abundance of fox remains.

Level	Red Fox NISP	Total Mammal NISP
10	0	6
11	0	8
12	1	28
13	2	11
14	0	8
15	0	9
16	0	3

to chance) in specific levels (Table 2), we used the Pearson's χ^2 test. The relative abundance of the red fox bones in seven layers of Unit 4 (Table 2) occurred by chance ($\chi^2 = 5.9014$, $P = 0.4343$). Although archaeological layers 12 and 13 both contain fox remains and are in close proximity, our statistics could suggest multiple episodes of fox harvesting and not a single event. Increasing the size of the excavation area and obtaining more faunal samples could increase our chances of finding more fox bones in other stratigraphic levels.

Dog remains

We identified one humerus and two teeth of dog in Unit 5 of the Ulyagan site. The humerus exhibited no cuts or chew marks. The distal epiphysis showed an indistinct fusion line; the proximal epiphysis was absent (Fig. 2b). The maximum length minus the proximal epiphysis is 130 mm, minimal diaphysis width is 10.1 mm, and the distal breadth is 26.7 mm. Harcourt's (1974) formulae let us calculate the withers height of a dog by substituting the total lengths of long bones. Thus, if we add 0.5 cm to the humerus bone length (the approximate height of the proximal epiphysis) and substitute this 135 mm into the corresponding formula, we obtain 43.7 cm — the approximate withers height of the dog from Carlisle Island. The distal humerus epiphysis of a medium sized dog fuses between 5–8 months and the proximal epiphysis fuses around 10–12 months (von Pfeil and DeCamp, 2009). The nearly invisible fusion line at the distal epiphysis indicates that the dog was 8–12 months old at time of death.

In canids, deciduous teeth are smaller and slightly differently shaped than permanent teeth. Using Baryshnikov and Averyanov (1993) and comparative analysis, we differentiated the archaeological canid dPM_3 from a fox deciduous tooth. Deciduous premolar teeth are usually shed between 1.5 and 2 months (Miller et al., 1964) or up to 3 months (Dmitry Vasyukov, personal observation). The probability of finding the deciduous teeth of an 8–12 month old individual represented by the humerus bone seems highly unlikely. Although found in the same stratigraphic level as the humerus, this tooth probably represents a second dog. We also identified the incisor of a juvenile or subadult dog; the occlusal surface was sharp, indicating very little tooth wear (Crockford, 2009).

Radiocarbon dating and stable isotope analysis

The calibration of the dog humerus conventional date (1417 ± 27 ^{14}C yr BP, NUTA2-24994) matches the Unit 5 occupation dates of AD 1340–1470 (2-sigma range).

Collagen yield (15–17%) and atomic C/N ratio (3.3) both indicate adequate preservation of collagen in both dog and fox bone remains. The $\delta^{15}N$ is $+16.72‰$ and $\delta^{13}C$ is $-13.94‰$ for the dog humerus. Stable isotope composition of the two fox samples showed dissimilarity both in $\delta^{15}N$ and $\delta^{13}C$: ulna, $\delta^{15}N + 18.69‰$, $\delta^{13}C$ -11.93‰; tibia, $\delta^{15}N + 16.26‰$, $\delta^{13}C$ -13.35‰. Both fox and dog samples indicate that these canids consumed a maritime diet.

We plotted the obtained isotopic values with: (1) 53 samples of Pacific cod from archaeological sites on Carlisle Island (Krylovich et al., 2019); (2) various groups of fauna from the Chaluka archaeological site (1700 BC–AD 1550; Byers et al., 2011) because Chaluka is the closest site with isotopic data on animals harvested by Aleuts; and (3) Neo-Aleut human remains from Kagamil Island (Fig. 3; Byers et al., 2011). Given the pronounced trend both in $\delta^{15}N$ and $\delta^{13}C$ plankton across the Aleutian Islands (Schell et al., 1998) along with the strong discontinuity in maritime ecosystems which Samalga Pass exhibits (Fig. 1; Hunt and Stabeno, 2005), the direct comparison of animal diets is complex, even from neighboring islands like Umnak and the Islands of Four Mountains. It is likely that the $\delta^{13}C$ shift in both cod and *Canis* sp. samples between Umnak and Carlisle could be explained by such ecological complexity.

The different isotopic signatures in the two fox samples appear to agree with the osteological analysis suggesting that these bones came from different individuals of different ages. The higher values of ulna $\delta^{15}N$ collagen might be the consequence of the "nursing effect," when a nursing offspring appears to have a higher trophic position than its mother (Jenkins et al., 2001). Although there are no direct investigations of when the nursing effect disappears from fox bone collagen, some studies suggest that the difference should be near 1‰ (Roth and Hobson, 2000; Jenkins et al., 2001).

The measured Carlisle dog sample shows the same isotopic signature as the mean isotopic value of Stellar's sea lion from Unmak and is close to Pacific cod from Carlisle. One *Canis* sp. from the Chaluka archaeological site has a similar trophic level to the Carlisle dog, while another *Canis* sp. specimen is significantly lower.

The increase of $\delta^{15}N$ and $\delta^{13}C$ at each trophic level in respect to the prey's isotopic composition is commonly known and frequently used to establish trophic interactions between predators and prey species (DeNiro and Epstein, 1978, 1981). In this respect, it is worth noting the relative trophic positions of humans, dogs, and foxes. Regardless of the similarity between human and dog diets, the distance between their $\delta^{15}N$ is common for many ancient cultures and comprises around 3‰ in various maritime hunter-gatherer sites (Guiry and Grimes, 2013), which is similar to the distance between Neo-Aleuts and the Carlisle dog in Figure 3. Modern

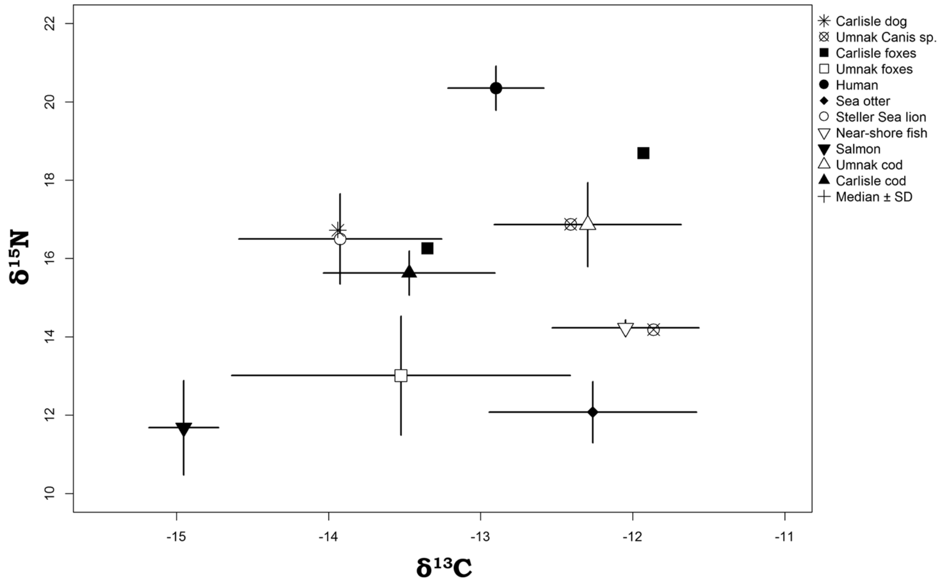

Figure 3. Stable nitrogen and carbon isotopes composition of the dog found in Ulyagan site of Carlisle Island in the space of isotopic signatures of Neo-Aleuts from Kagamil and various groups of animals from Chaluka archaeological site (Umnak Island). All the data, except Carlisle dog, foxes, and Carlisle cod from Byers et al. (2011).

Aleutian foxes feed on both marine and terrestrially derived foods (Murie, 1959); however, maritime input of the Carlisle fox diet is higher than in Umnak fox diets. Although this could be explained by the nursing effect in these particularly young individuals, it is important to remember that no rodents live on the Islands of Four Mountains. However, rodents do live on Chaluka and foxes there may have had access to more terrestrial food on Umnak Island.

The stable isotope signature might indicate that the Carlisle dog and foxes ate seabirds. The stable C and N isotope composition of seabird collagen from Aleutian archaeological sites is not well-studied. The average δ^{13}C and δ^{15}N of muscle tissues from modern Aleutian seabirds are -20 and + 10‰, respectively (Ricca et al., 2007). The contribution of seabirds in the Carlisle dog and fox diets could explain their isotopic position. However, multiple corrections should be considered for this comparison including: (1) muscle-bone isotopic composition differences, (2) the geographical position of the analyzed birds, and (3) age of birds. Additional stable isotopic investigations for Islands of Four Mountains fauna are required to clarify the interspecies isotopic landscape.

DISCUSSION

Foxes

Prior to our discovery of the Carlisle red fox, this species was identified in seven archaeological sites on four eastern Aleutian Islands: Anangula, Umnak, Amaknak, and Akun (Table 1). The ages of all eastern Aleutian archaeological layers containing red fox bones spanned from 2750–2150 BC to Russian contact. Prior to our research, no prehistoric red foxes had been recorded west of Carlisle Island. Currently, the Islands of Four Mountains should be considered the westernmost islands where red fox are indigenous. Veniaminov (1984) mentioned that red fox existed on Chuginadak Island in the Four Mountains in 1840; however, it remains unclear ethnographically whether foxes were indigenous or introduced.

Arctic fox was identified in only one site (UNL-050) on Amaknak Island (Crockford et al., 2004). The Fox Islands (Umnak, Unalaska, Amaknak, Akutan, Akun, and other smaller islands) were named "Lees'iy ostrova" by Glotov and Ponomaryov in 1759–1762 (Makarova, 1968). In the Russian language, "leessa" means red fox and "pessetz" means arctic fox. Thus, the Fox Islands were named for the presence and assumed abundance of red foxes living there at Russian contact. In his memoirs, Khlebnikov (1979, p. 125) writes: "The Headquarters ordered the breeding of arctic foxes on the Fox Islands, and in 1810 two pairs were delivered from Pavel to Unalaska and released there, but they were never seen after that. They think that they were exterminated by red foxes. However, on the Fox Islands, they should not be raised at all, because if they mixed with the red foxes, the quality of their furs would deteriorate from their breeding. For arctic foxes, besides the Fox Islands, there are still groups of Andreanof, Rat, and Near Islands, where there are no red foxes at all. And therefore, there should be paid attention on reproduction of " (translation by the authors).

The large number of red fox pelts harvested confirms the abundance of red foxes in the Fox Islands during the eighteenth century (Murie, 1959; Khlebnikov, 1979). Zooarchaeological data indicate that red fox, if not abundant, was at least prehistorically present in the Fox Islands, but has never been found in the central and western Aleutians

(Table 1). Red foxes are detrimental to arctic foxes (Hersteinsson and MacDonald, 1992). Currently, red foxes are used as biological control agents to eradicate arctic foxes in the Aleutian Islands (West and Rudd, 1983; Bailey, 1992). Three archaeological site components on Amaknak Island —UNL-048 (2750–2150 BC), UNL-055 (AD 1310–1660), and UNL-050 (1550–550 BC; Davis, 2001; Knecht and Davis, 2003; Crockford et al., 2004)—have red foxes (UNL-048 and UNL-055) and arctic fox (UNL-050). If the identification of these fox species and the supposition that red fox and arctic fox cannot cohabitate are correct, then evidence suggests that red foxes did not live on Amaknak Island during 1550–550 BC. Crockford and Frederick (2007) suggest that the occurrence of arctic fox on Amaknak might be a consequence of the Neoglacial period (1050–50 BC). If true, the habitat of red foxes may have substantially decreased while that of arctic foxes expanded during the Neoglacial. We cannot test this hypothesis because UNL-050 on Amaknak Island is the only site with bones representing the Neoglacial time period.

Arctic foxes were introduced on Carlisle Island in 1929 (Bailey, 1993) and fox-trapper cabins on Carlisle date to the early twentieth century (Cooper, 1991). Although there was historic introduction of fox farming, we emphasize that the red fox bones we recovered were *in situ* within prehistoric deposits from well-stratified excavation Unit 4 (Hatfield et al., 2019; Krylovich et al., 2019). The thick volcanic ash layer above the midden level containing fox bones was undisturbed, indicating that the fox remains were not intrusive and that the bones do not represent historically introduced fox. The origin of those prehistoric fox remains, however, is still under question. Were red foxes local or were these animals or their bones transported by prehistoric Aleuts from elsewhere (e.g., from the Fox Islands)? It is currently impossible to ascertain the origins of the Carlisle fox; however, herein, we try to: (1) explain how the red foxes could naturally occur in the Islands of Four Mountains and on Carlisle Island specifically and (2) estimate the value of foxes for Four Mountain Aleuts as well as for Aleuts in general.

The natural occurrence of the red foxes on the Islands of Four Mountains

Red and arctic foxes are very similar species in ecological terms; the arctic fox is a “small red fox in white clothing” (Hersteinsson and MacDonald, 1982, p. 512). Both species are well adapted to the Arctic climate; however, the low primary and secondary production in the Arctic allows only the arctic fox to live there (Hersteinsson and MacDonald, 1992). Therefore the arctic fox area is largely restricted to the Arctic and subarctic zones (Monchot and Gendron, 2010) and is bordered on the south by red fox, the larger species that dominates in direct competition (Hersteinsson and MacDonald, 1992).

Both red and arctic foxes are the most frequent carnivorous species in Holocene subfossil assemblages (Sommer and Benecke, 2005) and exhibit an incredible ability to enlarge their range. For example, due to the permanent foraging migrations (Chesemore, 1975), arctic fox shows almost no genetic variation within its circumpolar area (Carmichael et al., 2007); however, its spread significantly depends on the presence of ice corridors (Geffen et al., 2007). Arctic fox was seen arriving on ice floe to the Commander Islands (Iljina, 1950). Evidently, this is a common method for fox colonization of islands located far from the continental seashore and was recently used by red foxes to colonize St. Matthew Island in the Bering Sea, 400 km distant from the Alaska mainland (Colson et al., 2017). Arctic foxes colonized the Pribiloff Islands in the same way (Veltre et al., 2008). These data demonstrate the great potential for foxes to expand their territory via seasonal sea ice or rafting on ice floes or logs. Several obvious conditions are necessary for a species to successfully establish an insular population; these include (1) at least two individuals of different sexes, (2) the island must have an adequate food supply, and (3) for foxes in particular, the island (especially a small one) should be free of predators or stronger competitors. These conditions were met for the colonization of the Commander Island by the arctic fox (*Vulpes lagopus beringensis* [syn. *semenovi*]; Dzhikiya et al., 2008) and for the Channel Islands of California by the island fox (*Urocyon littoralis*; Wayne et al., 1991). However, taking into account the fox burials found on the Channel Islands (Raab et al., 1994), researchers argue that foxes were introduced on these islands by humans (Rick et al., 2008a). Once on these islands, foxes that are able to establish viable populations evolve in isolation. Although no genetic research exists for Aleutian red foxes, a high percentage of black and cross-color phases (up to 84%) of red foxes harvested in the Fox Islands (Murie, 1959) was noted in the 1760s and 1770s. In 1912 in Alaska, however, red color foxes comprised 91% of 8,624 pelts (Evermann, 1913). Murie proposed this to be a consequence of economic selection for the more valuable black (silver) or cross-color phases of fox fur. In the Quebec region of Canada selective killing did not significantly affect the color phase composition ratio in the harvested population of red fox (Haldane, 1942); however, it might have had consequences for the insular population. It is still unknown which factors determine the ratio of color phases in natural populations of red foxes (Anderson, 2009), whether the contribution of heredity (particularly gene flow effect) is greater than the potential adaptive advantages of some phase in specific region. Until genetic studies are conducted, it is impossible to estimate the degree of isolation of red foxes in the Fox Islands.

Red foxes colonized North America at the end of the middle Pleistocene (Péwé and Hopkins, 1967; Aubry et al., 2009), it remains unknown when red foxes first appeared in the Aleutian Islands. Sea level was approximately 100 m lower during the Pleistocene than today (Lambeck, 1990), making the Aleutians more accessible. However, the northern border for the range of red fox was then further south. Sea level rise, beginning 18,000 yr, reached its current level circa 5000 yr BP (Lamb, 1995). The Alaska Peninsula and the eastern seashore of the Bering Sea were likely the centers for the dispersal of red fox into the Aleutian Islands. This idea is based on the proximity of these areas to the Alaskan stream, which originates near Kodiak and flows west-southwest along the south side of the Aleutian Island arc (Stabeno et al., 2005). To reach the Four Mountains from Alaska during the Holocene, the red fox had to cross two deep passes: Unimak Pass, separating Unimak Island from the Fox Islands, and Samalga Pass, separating Umnak from the Islands of Four Mountains (Fig. 1). The Alaskan stream prevents ice floes from the north from landing on Aleutian shores; however, extreme ice conditions in 1973–1978 along with the strong northern winds resulted in advection of sea ice floes to Unimak Pass (Hood, 1981; Stabeno et al., 2010). Once advected or even stacked in the pass, it could have served as a bridge between Unimak and the Fox Islands. This likely occurred during the late Pleistocene and early Holocene with similar or colder/windier climatic conditions.

Samalga Pass (Fig. 1) shows a strong discontinuity in marine ecosystems (Hunt and Stabeno, 2005). Much deeper than Unimak Pass, this pass probably never served as a land bridge when sea level was lower (Aigner, 1977). No rodents inhabit the Aleutian Islands west from Samalga Pass (Murie, 1959), except ground squirrels introduced as fox fodder and synanthropic (dependent upon humans) rats. Samalga Pass functioned as a natural barrier restricting the migration of terrestrial animals from the Fox Islands westward. This has been confirming by zooarchaeological investigations on either sides of Samalga Pass. Until the current study, rodents, wild canids, caribou, and bears—species whose bones have been recovered in Fox Island archaeological sites (e.g., Davis, 2001; Crockford et al., 2004)—have never been found in prehistoric archaeological sites west of Samalga Pass (e.g., Desautels et al., 1971; Lefèvre et al., 2010).

The absence of rodents on the Aleutian Islands west of Samalga Pass begs the question regarding the availability of food resources for foxes. Rodents are valuable resource for foxes, specifically noted in the Fox Islands (Murie, 1959). Other resources for Aleutians fox would include sea bird colonies, sea mammal rookeries, invertebrates and other resources in the littoral zone, and resources washed ashore. The Islands of Four Mountains are circular and lack littoral zones or bays, significantly decreasing the resources available for the red fox. Similarly, the Commander Islands also were never naturally inhabited by rodents (Barabash-Nikiforov, 1938) and arctic fox population date to the late Pleistocene (Dzhikiya et al., 2008). However, the Commander Islands feature large, undulating shores and pronounced littoral zones that provide a rich resource for foxes. Thus, the natural occurrence of red foxes on Carlisle Island is not an obvious explanation for their occurrence in the archaeological deposits.

Foxes can substantially enlarge their home range depending on landscape productivity (Walton et al., 2017). This species possesses both natural affinity and capability to migrate (Gritsenko et al., 1983). If mainland Alaska was the dispersal center of red foxes, then the prehistoric rodent populations, bays, and littoral zones of the Fox Islands provided suitable colonization conditions but we would expect to see the trend of fox density decline from east to west as ocean passes became wider and deeper. Variations in climatic conditions may have opened corridors, which allowed foxes to migrate westward. Given an insufficient resource base on the Islands of Four Mountains, it is possible that the foxes that once occurred on those islands and having had no ability to escape could not establish a viable, long-lived population or were immediately killed by humans. It is possible that red foxes spread west, even beyond the Four Mountain Islands; however, the probability of recovering such remains is very low.

The value of foxes for Aleuts

Archaeological material usually represents common everyday items associated with ancient people and only occasionally reveals something rare or unknown. Most materials left behind by ancient people were not deposited or were lost/destroyed or dropped in the other unexcavated areas of the site (Dinesman et al., 1999; Lyman, 2008). We generally assume that a single animal bone represents several or many of the same species and is not an isolated example. If we assume that these three fox bones from Unit 4 on Carlisle Island were transported there by Aleuts from elsewhere, then this behavior was likely a common action; in other words, Aleuts regularly brought foxes (as pets, pelts, or skeletons) to their villages. No ethnographic evidence supports the use of fox pelts by Aleuts (Unangax̂) for clothing or meat (Khlebnikov, 1979; Veniaminov, 1984). There is some ethnographic evidence to suggest that Aleuts did not value fox fur and only hunted foxes during the Russian period for their value to the Russians. This idea is suggested by this quote that indicates Aleuts were not selective of the fur quality, just the quantity: “The prohibition to harvest animals in spring- and summertime cannot stop the Aleuts, though the animal furs are very thin in those seasons and are half-valued” (Khlebnikov, 1979, p. 39, translation by the authors).

The majority of tools Aleuts manufactured were made of bird or sea mammal bones; no tools made of fox bone have been documented in Aleutian archaeological contexts (McCartney, 1967; Holland, 1982; Turner, 2008; Margaris, 2009). The Fox Islands and Kodiak never saw the introduction of foxes by Russians, because red foxes already inhabited these islands. Tools made of fox have never been recovered on the Fox Islands or on Kodiak, where the natural occurrence of red foxes is unquestionable. Thousands of red fox pelts were harvested annually in the Fox Islands at the beginning of eighteenth century (Khlebnikov, 1979). Kodiak Island saw a similar annual exploitation of red fox (Khlebnikov, 1979). Although we cannot directly compare modern harvesting data with prehistoric activities, this evidence suggests a high carrying capacity for foxes at the time of Russian contact. Yet, there are very small numbers of prehistoric fox remains recovered from Fox Islands middens (Table 1); on Kodiak, the percentage of fox remains is significantly higher

(Etneir et al., 2016), which probably correlates with other cultural variables between these two island societies.

The small numbers of fox remains in prehistoric Aleutian archaeological sites indicate that Aleuts only occasionally harvested canids. On Carlisle, foxes could have naturally migrated and established a viable population in the absence of humans. Given the small size of the Islands of Four Mountains and limited resources, however, both competition with human predation and direct human predation may have limited their population size or ability to maintain a viable population. Given the cultural similarities between the Four Mountains and Fox Island prehistoric Aleuts (Hatfield et al., 2016), we assume that if red foxes were not valued by prehistoric peoples of the Fox Islands, foxes would also not be valued in the Four Mountains. Thus, the red fox remains from Ulyagan Unit 4 on Carlisle were probably not brought to Carlisle by ancient Aleuts.

Dogs

Besides the dog materials recovered on Carlisle Island there are at least three documented records of prehistoric dogs in Aleutian archaeological sites: Ashishik Point on Umnak (Denniston, 1972), Tanaxtaxak on Amaknak (Knecht and Davis, 2003), and Chulka at Akun (Table 1; Holland and Turner, 1987). Dog bones, identified as historic, were reported at the Akun Chulka site (Holland and Turner, 1987). Currently, Carlisle Island represents the westernmost point in the Aleutian Islands for pre-contact dog.

Prehistoric dogs from Carlisle, Umnak, and Amaknak (Unalaska) Islands date later than the fourteenth century AD (Table 1). Archaeological and human biological evidence from the Chulka site, the oldest village site where dog bones have been identified (AD 1000), suggests this site was a Neo-Aleut settlement lacking any Paleo-Aleut components (Holland and Turner, 1987, 1988).

Davis (2001) reported four *Canis* sp. bones from levels dated 2750–2150 BC on Amaknak Island. Byers et al. (2001) reported two *Canis* sp. bones, which are possibly wolf, at Chaluka from levels dated 1700 BC–AD 1550; however, wolf has never been described west of Akun Island (Murie, 1959; Veniamonov, 1984).

Radiocarbon-dated human skeletons from Chaluka, Shiprock, and Kagamil indicate that Neo-Aleuts inhabited the eastern Aleutians at least by AD 1375 (West et al., 2019). It remains unclear how long Paleo-Aleuts and Neo-Aleuts interacted (communicated, traded, raided, or warred) prior to transition to the Neo-Aleut phase in the eastern Aleutians. Correct dates are critical for this important time in the prehistory of the eastern Aleutians. Nevertheless, all pre-contact dog remains identified in Aleutian archaeological sites are associated with Neo-Aleut aged layers; however, the unidentified canid remains from the Paleo-Aleutian context (e.g., Davis, 2001) leave place for uncertainty in postulating whether or not Paleo-Aleuts had dogs.

Why would Paleo-Aleuts not use dogs, while Neo-Aleuts did? Was it because Paleo-Aleuts were not acquainted with dogs or because they did not know that these animals could be useful? Why did Neo-Aleuts keep or obtain dogs? Where did they get them? Why did they want them? These questions lead to more general issues regarding use of dogs by ancient people (Morey, 2010). Dogs possess great antiquity with humans, and local (e.g., geographical and climatic) conditions played a crucial role for people when evaluating the profitability of dogs versus their maintenance. Maintenance primarily involves feeding; for island populations, however, transportation can become an issue. The amount of effort that goes into feeding dogs depends on their number, resource availability, and the abilities of the hunter/gatherers. Thus, when resources are scarce, dogs have a higher maintenance cost and their value may shift toward their use as a food resource. This theoretical situation can be and has been overridden by other cultural values, which will be mentioned further.

There are two important case studies with respect to the maintenance of dogs and their role in a society. One case is from the Arctic, where dogs strictly depend on humans due to the severe environment. In the Arctic, a dog requires 350–500 kg of food/yr (Foot, 1965; Saladin d'Anglure, 1984); a dog team consisting of 12 dogs consumes two times more food than a family of 4–7 people (Bogoras, 1901). In this situation, dog maintenance is very expensive; thus, their profit must be high. While travelling to the North Pole, Cook (1911) noted that the number of dogs and the number of children was a measure of wealth in Eskimo settlements because both are important for prosperity. However, dogs became widespread in the Arctic and played a vital role only in Thule culture by 1000 yr (Darwent, 2004; Morey, 2010). The Thule, ancestors of the modern Inuit, used dogs tied to sleds for transportation and this critical innovation allowed for the rapid expansion of ancient Arctic peoples across vast areas in a short time (Mathiassen, 1927; Jenness, 1940; Maxwell, 1985; McGhee, 1996; Morey and Aaris-Sørensen, 2002). They also used dogs for breathing-hole sealing (Cox and Spiess, 1980). Prior to this Arctic expansion, dogs, identified only in isolated patches and scarce in archaeological sites, were used far less intensively by Paleo-Eskimo populations for at least 3500 yr (Morey, 2010). Recent genetic studies showed that modern Inuit dogs likely derive from the Thule dog gene pool, not from Paleo-Eskimo dogs or the dogs of the first North American colonizers (Brown et al., 2013, 2015). It is important to note that in the Arctic: (1) despite the environmental severity, the Arctic seas are highly productive (e.g., Pabi et al., 2008) and provide the necessary food resources; (2) the region is environmentally conducive to dog sleds, with sea ice and snow cover for most of the year; and (3) dog sled technology was either invented late or was slow to be adopted by people, perhaps because it took a while for the profit margin to catch up to the cost of dog maintenance. Regarding this, the Aleutians lack most of the characteristics that made dogs so valuable for Neo-Eskimo people over the past millennium.

A second case derives from tropical and remote oceanic islands. With other domesticated plants and animals, ancient people transported dogs to Polynesia (Steadman, 1995; Burney et al., 2001), Micronesia (Intoh and Shigehara, 2004), California's Channel Islands (Raab et al., 1994; Rick et al., 2008b), and the Carribean (Lippold, 1991; Wing 1991; Newsom and Wing, 2004) to "provide the necessary means to survive over the long term" (Fitzpatrick et al., 2016, p. 6; see also Steadman et al., 2002; Anderson, 2009; Fitzpatrick and Callaghan, 2009). On the Channel Islands (Rick et al., 2008b), dogs were recovered from burials rather than in kitchen middens (Newsom and Wing, 2004), suggesting dogs played a different cultural or ritual purpose in those societies. Giovas (2006) demonstrated that island biogeography determined the survivorship for pigs that, like dogs, were introduced to many Polynesian sites. Although effects of island biogeography has not yet been shown for dogs, it is also likely applicable for them due to the close trophic and ecological position between dogs and pigs. According to the general biogeography statements, species home range depends on its size and trophic position: the higher these characteristics are, the larger the range that is needed, and this is how the island area impacts survivorship of any given species (Brown and Lomolino, 1998). Isolation is another factor in island biogeography predictions (MacArthur and Wilson, 1967; Brown and Lomolino, 1998) and has been used to explain the loss of domestic animals during human migrations to Polynesia, as well as the lack of pigs on Easter Island, Norfolk Island, the Chatham Islands, and New Zealand (Giovas, 2006). Dietary examinations of dog remains from Polynesia revealed that in many cases dogs ate maritime food or a mixed diet (maritime and terrestrial), likely fed to them by humans (Clark 1997a, 1997b; Leach et al., 2003; Valentin et al., 2006). On the Marquesas Islands (French Polynesia), researchers noted a descending trend of maritime food in dog's diet during the initial stages of island occupation (Richards et al., 2009). Richards et al. (2009) suppose that both pigs and dogs were part of the basic subsistence strategy for these islanders; however, others suggest that they were prestige foods, available only to elites and resulting from social complexity in these Polynesian societies (Rechtman, 1992; Leach, 2003; Valentin et al., 2006). Even if dogs and other transported animals were valuable as prestige food items, they also provided insurance for basic subsistence and this insurance role is very different from the role dogs played in Arctic. The mildness of tropical/subtropical climate in contrast to the Arctic suggests dog maintenance was easier in terms of human efforts where dogs could scavenge their own food. In the tropics, the cost of dog maintenance would be far less.

Given these two scenarios, the question regarding dog usage in Aleutian Islands can be refined. The people that colonized North America circa 14,000–12,000 yr (Starikovskaya et al., 1998; Fiedel, 2000) brought dogs into the New World (Leonard et al., 2002). Archaeological evidences from North American archaeological sites support that dogs were present elsewhere during the Paleo-Aleut occupation. Dog remains have been found in small numbers at several Paleo-Eskimo sites in Canada and Greenland (Morey and Aaris-Sørensen, 2002; Morey, 2010), St. Lawrence Island, and Alaska (Murie, 1936; Giddings and Anderson, 1986; Darwent, 2006). Dog burials, "the most obvious sign of a close prehistoric human-animal relationship" (Clark, 1996, p.34), were found in Newfoundland dating back 4000 yr (Tuck, 1976). Even if Paleo-Aleuts or their ancestors "got rid" of their dogs on the way to Aleutian Islands 9000–11,000 yr, dogs continued to be present on the mainland and interactions with or migrations back to the mainland would have re-introduced dogs to the Aleutians. Thus, Arctic peoples could have had periodic access to dogs (Morey and Aaris-Sørensen, 2002). However, there is no association between Paleo-Aleut populations and dogs. It is likely that both isolation and the high maintenance of dogs explain their absence in Paleo-Aleut contexts. The rugged terrain that precluded much overland travel (Lantis, 1984), and year-round ice-free seas negated the use of dogs for transportation (Clark, 1974). The isolation could also prevent the appearance of dogs in the Aleutian Islands prior the Neo-Aleut period. Isolation is obviously not as pronounced as in Polynesia, because many of the Aleutian Islands are relatively close to each other and can be observed from one another.

Misarti and Maschner (2015) suggested that the Paleo-Neo-Aleut transition could reflect increased social complexity accompanied with the appearance of elite groups with close ties to Kodiak people. They argue Neo-Aleuts married Kodiak women who imported their slate tool kits as they moved into the Aleutians. Kodiak Island is the closest place with abundant dog remains (Holland and Turner, 1987; West and Jarvis, 2015) and these animals may also have been imported with slate and other cultural materials. This could explain their sudden appearance in the eastern Aleutians associated with Neo-Aleut occupations. Koniag peoples might have imported dogs from Kodiak as insurance, like in Polynesia. Carlisle dogs were either juvenile or subadult. Allen (1939) suggested puppies were used as a food resource during migrations. Stable isotope analysis from one dog sample suggests that it had a maritime diet, as did the foxes found at the same location, thus demonstrating the same trophic position, which can be explained by the similar food source. Probably fed during seasons of plenty, dogs could serve as "walking larders" to be sacrificed and eaten during periods of starvation when migratory and other food sources were scant or entirely absent (Bogoras, 1904). It has generally been assumed that late winter and early spring constituted lean months for Aleuts. During these seasons, Aleuts relied on low calorie shellfish for sustenance (West et al., 2012). If this is correct, then it is easy to imagine that prehistoric Aleuts would have eaten dogs during famines, thus not giving them the chance to breed. However, it is also possible that the consumption of dogs was for the elites. No dog remains have been recovered west of the Islands of Four Mountains, which reflects a migration trend, declining further from the source of migration. For foxes, migration was probably natural, but for dogs, migration was undoubtedly cultural.

The ethnographic literature says nothing about Aleutian dogs (Holland and Turner, 1987; West and Jarvis, 2015).

This may be due to: (1) an actual absence of dogs in the regions of ethnographic studies, (2) imperfect ethnographic records on aboriginal dogs, or (3) the inability of ethnographers to distinguish pre-contact dogs from historic ones. In contrast, for many regions ethnographic literature mentions aboriginal dogs and their usage, presumably because of their abundance in the Arctic (Sarychev, 1802; Hooper, 1853; Nordenskiöld, 1881; Nelson, 1900; Bogoras, 1901, 1904; Cook, 1911, Malaurie, 1965) or Polynesia (Luomala, 1960). The only evidence concerning nineteenth-century dogs near the Aleutians comes from Khlebnikov's (1979, p. 39) memoirs, in which he describes the harvesting of ground squirrels and foxes by locals on Kodiak: "For ground squirrel trapping, hunters use up to 200 dogs, which, when running with them, sniff the holes and show where the critters hide", and "[f]oxes are much caught by dogs, which the Aleuts have bred everywhere" (translation by the authors). It is worth noting that the large number of dogs on Kodiak during the Russian era is demonstrated by the high relative frequency of dog remains (5–10% of identified mammals) in the kitchen middens dated to AD 1790–1830 (Etnier et al., 2016). It remains unclear, however, whether the local hunters bred dogs after contact with Russians, or before. Genetic studies are needed to discern these dynamics.

CONCLUSION

Ethnographic accounts provide little to no information about either Aleutian dogs or pre-contact foxes. Due to this absence of data, dog and red fox remains from Carlisle Island are valuable findings. One of the primary goals of this study was to consider the canid remains found in the Ulyagan archaeological site on Carlisle Island in the light of other canid discoveries in the Aleutian Islands. The understanding of the cultural role of particular species in ancient human societies, especially the domestic dog, often sheds a light on some aspect of human history of the region. Tracing the natural living areas of wild species in the past is also valuable for conservation and biogeography knowledge.

Red fox remains occur periodically in eastern Aleutian archaeological sites from 2750–2150 BC to historic times. Given the proximity of the most likely dispersal place (mainland Alaska) and the fox's ability to cross sea passes, our identification of red fox suggests that this species was sometimes indigenous to the Islands of Four Mountains. The great potential of foxes to migrate allows us to suggest the existence of a westward migration trend from Fox Island (eastern Aleutians) with its relatively rich food base to as far as the Four Mountains. However, it is likely that, if they *ever* existed, the fox populations west of the Fox Islands (e.g., on the Carlisle Island) were not permanent due to the small island area, poor food base, competition with humans for food resources, and/or direct predation by humans.

According to our zooarchaeological data, pre-contact domestic dogs as well as red fox occurred in the eastern Aleutians at least as far west as the Carlisle Island. The reasons for such a match remain unclear, but the similar trends could have taken a place. We consider two cases of dog uses reported from other part of the world to provide some comparison for the Aleutian case in the paper: (1) an Arctic case, where dogs were actively used for sledding for at least the last millennium, and (2) the set of cases from remote Oceania, where people transported dogs for food. Costs versus benefits must have played a key role in choice of dog ownership and use. Unlike foxes, dogs usually migrate with people. Dogs could not be effectively used for transportation in the Aleutians like in Arctic, but these domestic canids, possibly arising from Kodiak to the east, could serve as a food resource during long, westward trips. No cut marks or other butchering evidences have ever been noted on the dog bones from Aleutian Islands archaeological context, however, which is probably due to the small number of findings.

All Aleutian dog remains date from AD 950 to more recent times, falling within the "Neo-Aleut" period. Whether Neo-Aleuts came from elsewhere and/or instigated some social changes in Paleo-Aleut societies, we find dog remains associated only with the Neo-Aleut time period, which suggests cultural differences between Paleo- and Neo-Aleuts.

Excavations on Yunaska, Amukta, Amlia, and Atka islands, which lie between the Islands of the Four Mountains and Adak (central Aleutians), would clarify both dog and fox dispersal history and fill a large spatial zooarchaeological data gap for the North Pacific. Finally, continued analysis of fox remains from the Neoglacial period (1050–50 BC) of the Aleutian Islands could help us to understand: (1) whether this climatic period shifted both arctic and red fox distributions, and (2) Aleut interactions with these canids in relation to climate fluctuations and social changes in that interval.

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REFERENCES

Aigner, J.S., 1977. Anangula: an 8,500 B.P. *coastal occupation in the Aleutian Islands.* Sonderdruck aus Quartar 27, 65–102.

Allen, G.M., 1939. Dog skulls from Uyak Bay, Kodiak Island. *Journal of Mammalogy* 20, 336–340.

Anderson, A., 2009. The rat and the octopus: initial human colonization and the prehistoric introduction of domestic animals to Remote Oceania. *Biological Invasions* 11, 1503–1519.

Aubry, K.B., Statham, M.J., Sacks, B.N., Perrine, J.D., Wisely, S.M., 2009. Phylogeography of the North American red fox: vicariance in Pleistocene forest refugia. *Molecular Ecology* 18, 2668–2686.

Bailey, E.P., 1992. Red Foxes, *Vulpes vulpes*, as biological control agents for introduced Arctic Foxes, *Alopex lagopus*, on Alaskan lslands. *Canadian Field-Naturalist* 106, 200–205.

Bailey, E.P., 1993. *Introduction of Foxes to Alaskan Islands — History, Effects on Avifauna, and Eradication*. U.S. Fish and Wildlife Service (USA) Resource Publication 193, Washington, DC.

Barabash-Nikiforov, I., 1938. Mammals of the Commander Islands and the surrounding sea. *Journal of Mammalogy* 19, 423–429.

Baryshnikov, G.F., Averyanov, A.O., 1993. Deciduous teeth of carnivorous mammals (order Carnivora). Part IV. Families Amphicyonidae and Canidae. [In Russian.] In: Baryshnikov, G.F., Kuzmina, I.E. (Eds.), *Materials of Mezozoic and Cenozoic History of Terrestrial Vertebrates. Proceedings of the Zoological Institute. Vol. 249*, Zoological Institute of RAS, St.-Petersburg, pp. 158–197.

Black, L.T., 1984. *Atka: An Ethnohistory of the Western Aleutians*. Limestone Press, Kingston.

Black, R.F., 1976. Influence of Holocene climatic changes on Aleut expansion into the Aleutian Islands, Alaska. *Anthropological Papers of the University of Alaska* 18, 31–42.

Bogoras, W., 1901. The Chukchi of Northeastern Asia. *American Anthropologist* 3, 80–108.

Bogoras, W., 1904. Part I. – The Chukchee – Material culture. *Memoirs of the American Museum of Natural History, Vol. 11*. E. J. Brill, Leiden, pp. 1–279.

Brown, J.H., Lomolino, M.V., 1998. *Biogeography*. Sinauer Associates, Sunderland, Massachusetts.

Brown, S.K., Darwent, C.M., Sacks, B.N., 2013. Ancient DNA evidence for genetic continuity in Arctic dogs. *Journal of Archaeological Science* 40, 1279–1288.

Brown, S.K., Darwent, C.M., Wictum, E.J., Sacks, B.N., 2015. Using multiple markers to elucidate the ancient, historical and modern relationships among North American Arctic dog breeds. *Heredity* 115, 488.

Burney, D.A., James, H.F., Burney, L.P., Olson, S.L., Kikuchi, W., Wagner, W.L., Burney, M., *et al.*, 2001. Fossil evidence for a diverse biota from Kaua'i and its transformation since human arrival. *Ecological Monographs* 71, 615–641.

Byers, D.A., Yesner, D.R., Broughton, J.M., Coltrain, J.B., 2011. Stable isotope chemistry, population histories and Late Prehistoric subsistence change in the Aleutian Islands. *Journal of Archaeological Science* 38, 183–196.

Carmichael, L.E., Krizan, J., Nagy, J.A., Fuglei, E., Dumond, M., Johnson, D., Veitch, A., Berteaux, D., Strobeck, C., 2007. Historical and ecological determinants of genetic structure in Arctic canids. *Molecular Ecology* 16, 3466–3483.

Chesemore, D.L., 1975. Ecology of the Arctic fox (Alopex lagopus) in North America: a review. In: Fox, M.W. (Ed.), *The Wild Canids: Their Systematics, Behavioral Ecology and Evolution*. Van Nostrand Reinhold, New York, pp. 143–163.

Clark, D.W., 1974. *Koniag Prehistory: Archaeological Investigations at Late Prehistoric Sites on Kodiak Island, Alaska*. Verlag W. Kohlhammer, Stuttgart.

Clark, G., 1996. Animal burials from Polynesia. *Archaeology in New Zealand* 39, 30–38.

Clark, G.R., 1997a. Anthropogenic factors and prehistoric dog morphology: a case study from Polynesia. *Archaeology in Oceania* 32, 124–130.

Clark, G.R. 1997b. Maori subsistence change: zooarchaeological evidence from the prehistoric dog of New Zealand. *Asian Perspectives* 36, 200–219.

Colson, K.E., Smith, J.D., Hundertmark, K.J., 2017. St. Matthew Island colonized through multiple long-distance red fox (*Vulpes vulpes*) dispersal events. *Canadian Journal of Zoology* 95, 607–609.

Coltrain, J.B., 2010. Temporal and dietary reconstruction of past Aleut populations: stable- and radio-isotope evidence revisited. *Arctic* 63, 391–398.

Coltrain, J.B., Hayes, M.G., O'Rourke, D.H., 2006. Hrdlička's Aleutian population-replacement hypothesis: a radiometric evaluation. *Current Anthropology* 47, 537–548.

Cook, F.A., 1911. *My Attainment of the Pole*. Polar Publishing, New York.

Cooper, D.R., 1991. Report of investigation for site CR-2, 1991. The Aleut Corporation Bureau of Land Management AA-12203. On file at the U.S. Bureau of Indian Affairs, Alaska Native Claims Settlement Act Office, Anchorage, Alaska.

Corbett, D., Lefèvre, C., West, D., 2010. Chronology and settlement patterns: Shemya and the Semichi Islands. In: Corbett, D., West, D., Lefèvre, C. (Eds.), *The People at the End of the World: The Western Aleutians Project and the Archaeology of Shemya Island*. Aurora, Alaska Anthropological Association Monograph Series, No. 8, Alaska Anthropological Association, Anchorage, pp. 197–207.

Coutouly, Y.A.G., Holmes, C., 2018. The microblade industry from Swan Point cultural zone 4b: technological and cultural implications from the earliest human occupation in Alaska. *American Antiquity* 83, 735–752.

Cox, S.L., Spiess, A., 1980. Dorset settlement and subsistence in Northern Labrador. *Arctic* 33, 659–669.

Crockford, S., Frederick, G., Wigen, R., McKechnie, I., 2004. Analysis of the Vertebrate Fauna from Amaknak Bridge UNL-50, Unalaska, AK. In: *Unalaska South Channel Bridge Project # MGS-STP-BR-0310(S)/52930. Amaknak Bridge Site Data Recovery Final Report*, by Richard Knecht and Richard Davis, supplement. Alaska Department of Transportation and Public Facilities, Anchorage.

Crockford, S.J., 2009. *A Practical Guide to In Situ Dog Remains for the Field Archaeologist*. Pacific Identifications, Victoria.

Crockford, S.J., 2012. Archaeozoology of Adak Island: 6000 years of subsistence history in the central Aleutians. In: West, D., Hatfield, V., Wilmerding, E., Lefèvre, C., Gualtieri, L. (Eds.), *The People Before: The Geology, Paleoecology and Archaeology of Adak Island, Alaska*. BAR International Series 2322. Archaeopress, Oxford, pp. 107–143.

Crockford, S.J., Frederick, S.G., 2007. Sea ice expansion in the Bering Sea during the Neoglacial: evidence from archaeozoology. *The Holocene* 17, 699–706.

Darwent, C.M., 2004. The highs and lows of high Arctic mammals: temporal change and regional variability in Paleoeskimo subsistence. In: Mondini, M., Muñoz, S., Wickler, S. (Eds), *Colonisation, Migration and Marginal Areas: A Zooarchaeological Approach*. Proceedings of the 9th Conference of the International Council of Archaeozoology, Durham, August 2002. Oxbow Books, Oxford, pp. 62–73.

Darwent, C.M., 2006. Reassessing the Old Whaling Locality at Cape Krusenstern, Alaska. In: Arnebord, J., GrØnnow (Eds.), *Dynamics of Northern Societies Proceedings of the SILA/NABO Conference on Arctic and North Atlantic Archaeology, Copenhagen, May 10th–14th, 2004*. PNM, Copenhagen, pp. 95–101.

Davis, B., 2001. Sea mammals hunting and the Neoglacial: environmental change and subsistence technology at Margaret bay. Archaeology in the Aleut zone of Alaska: some recent research. *University of Oregon Anthropological Papers* 58, 71–85.

Davis, R., Rogers, J., Knecht, R., 2016. First maritime cultures of the Aleutians. In: Friesen, M., Mason, O. (Eds.), *The Oxford Handbook of the Prehistoric Arctic*. Oxford University Press, New York, pp. 279–302.

Davis, R.S., Knecht, R., 2010. Continuity and change in the eastern Aleutian archaeological sequence. *Human Biology* 82, 507–524.

DeNiro, M.J., Epstein, S., 1978. Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta* 42, 495–506.

DeNiro, M.J., Epstein, S., 1981. Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta* 45, 341–351.

Denniston, G.B., 1972. Ashishik Point: An Economic Analysis of a Prehistoric Aleutian Community. PhD dissertation, University of Wisconsin, Madison.

Desautels, R.J., McCurdy, A.J., Flynn, J.D., Ellis, R.R., 1971. *Archaeological report. Amchitka Island, Alaska 1969–1970*. Archaeological Research Inc., Costa Mesa, U.S. AEC report TID-25481.

Dinesman, L.G., Kiseleva, N.K., Savinetsky, A.B., Khassanov, B.F., 1999. *Secular Dynamics of Coastal Zone Ecosystems of the Northeastern Chukchi peninsula (Chukotka: Cultural Layers and Natural Depositions from the Last Millennia)*. Mo Vince, Tübingen.

Dzhikiya, E.L., Ploshnitsa, A.I., Kolesnikov, A.A., Goltsman, M.E., 2008. Genetic monomorphism of the second exon of the drb1 gene in the major histocompatibility complex of the arctic fox of Mednyi Island (*Alopex lagopus semenovi* Ognev, 1931). *Doklady Biological Sciences* 418, 37–38.

Etnier, M.A., Partflow, M.A., Foster, N.R., 2016. Alutiq subsistence economy at Igvak, a Russian-American Artel in the Kodiak Archipelago. *Arctic Anthropology* 53, 52–68.

Evermann, B.W., 1913. Fishery and Fur Industries of Alaska in 1912. Bureau of Fisheries Document No. 780. Government Printing Office, Washington, DC.

Fiedel, S.J., 2000. The peopling of the New World: present evidence, new theories, and future directions. *Journal of Archaeological Research* 8, 39–103.

Fitzpatrick, S.M., Callaghan, R., 2009. Examining dispersal mechanisms for the translocation of chicken (*Gallus gallus*) from Polynesia to South America. *Journal Of Archaeological Science* 36, 214–223.

Fitzpatrick, S.M., Thompson, V.D., Poteate, A.S., Napolitano, M.F., Erlandson, J.M., 2016. Marginalization of the Margins: the importance of smaller islands in human prehistory. *The Journal of Island and Coastal Archaeology* 11, 155–170.

Foot, D.C., 1965. Exploration and resource utilization in Northwestern Arctic Alaska before 1855. PhD dissertation, McGill University, Montreal.

Geffen, E., Waidyaratne, S., Dalén, L., Angerbjörn, A., Vila, C., Hersteinsson, P., Fuglei, E., *et al*., 2007. Sea ice occurrence predicts genetic isolation in the Arctic fox. *Molecular Ecology* 16, 4241–4255.

Giddings, J.L., Anderson, D.D., 1986. Beach ridge archeology of Cape Krusenstern. Eskimo and Pre-Eskimo settlements around Kotzebue Sound, Alaska. U.S. Department of the Interior, National Park Service, Washington, DC.

Giovas, C.M., 2006. No Pig Atoll: island biogeography and the extirpation of a Polynesian domesticate. *Asian Perspectives* 45, 69–95.

Grayson, D.K., 1984. *Quantitative Zooarchaeology:Topics in the Analysis of Archaeological Faunas*. Academic Press, Orlando.

Gritsenko, V.V., Kreslavsky, A.G., Mikheev, A.V., Severtsov, A.S., Solomatin, V.M., 1983. *Species Concepts and Sympatric Speciation*. [In Russian.] Moscow State University, Moscow.

Gromova, V., 1950. The key for identifying skeletal elements of mammals of the USSR. [In Russian.] Gromov, V.I. (Ed), *Proceedings of the Commission for the Study of the Quaternary Period Vol. 9*. RAS, Moscow.

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. *Journal of Anthropological Archaeology* 32, 732–745.

Haldane, J.B.S., 1942. The selective elimination of silver foxes in Eastern Canada. Journal of Genetics 44, 296–304.

Harcourt, R.A., 1974. The dog in prehistoric and early historic Britain. *Journal of Archaeological Science* 1, 151–175.

Harris, S., 1978. Age determination in the Red fox (*Vulpes vulpes*) - an evaluation of technique efficiency as applied to a sample of suburban foxes. *Journal of Zoology* 184, 91–117.

Hatfield, V., Bruner, K., West, D., Savinetsky, A., Krylovich, O., Khasanov, B., Vasyukov, D., *et al*., 2016. At the foot of the Smoking Mountains: the 2014 scientific investigations in the Islands of the Four Mountains. *Arctic Anthropology* 53, 141–159.

Hatfield, V., West, D., Bruner, K., Savinetsky, A., Krylovich, O., Vasyukov, D., Khasanov, B., Nicolaysen, K., Okuno, M., 2019. Human resilience and resettlement among the Islands of Four Mountains, Aleutians, Alaska. *Quaternary Research*, this volume. https://doi.org/10.1017/qua.2018.149.

Hersteinsson, P., MacDonald, D.W., 1982. Some comparisons between red and Arctic foxes, *Vulpes vulpes* and *Aloapex lagopus*, as revealed by radio tracking. *Symposia of the Zoological Society of London* 49, 259–289.

Hersteinsson, P., Macdonald, D.W., 1992. Interspecific competition and the geographical distribution of red and Arctic foxes *Vulpes vulpes* and *Alopex lagopus*. *Oikos* 64, 505–515.

Holland, K., 1982. Chulka Bone Artifacts, Akun Island, Alaska: Analysis and Description. Master's thesis, Arizona State University, Tempe.

Holland, K.M., 2004. A brief note on the significance of prehistoric dogs from the eastern Aleutian Islands. *Arctic Anthropology* 41, 50–54.

Holland, K.M., Turner, C.G., II, 1987. Prehistoric Aleutian Dogs. Paper prepared for the 52nd Annual Meeting of the Society for American Archaeology, Toronto, Canada, May 6–10, 1987.

Holland, K.M., Turner, C.G., II, 1988. A 1,000 Year Akun - Kodiak Interaction Sphere. In: Shaw, R.D., Harritt, R.K., Dumond, D.E. (Eds), *The Late Prehistoric Development of Alaska's Native People*. Aurora: Alaska Anthropological Association Monograph Series No. 4, Anchorage, pp. 307–317.

Hood, D.W., 1981. Introduction. In: Hood, D.W., Calder, J.A. (Eds.), *The Eastern Bering Sea Shelf: Oceanography and Resources*, Vol. 1. University of Washington Press, Seattle, pp. xiii-xviii.

Hooper, R.N., 1853. *Ten Months among the Tents of the Tuski, with Incidents of an Arctic Boat Expedition in Search of Sir John Franklin, as Far as the Mackenzie river, and Cape Bathurst*. John Murray, London.

Hrdlička, A.,1945. *The Aleutian and Commander Islands and Their Inhabitants*. The Wistar Institute of Anatomy and Biology, Philadelphia.

Hunt, G.L., Stabeno, P.J., 2005. Oceanography and ecology of the Aleutian Archipelago: spatial and temporal variation. *Fisheries Oceanography* 14, 292–306.

Iljina, E.D., 1950. *Ostrovnoe Zverovodstvo (Island fur-farming)*. [In Russian.] Mezdunarodnaya kniga, Moscow.

Intoh, M., Shigehara, N., 2004. Prehistoric pig and dog remains from Fais Island, Micronesia. *Anthropological Science* 112, 257–267.

Jenkins, S.G., Partridge, S.T., Stephenson, T.R., Farley, S.D., Robbins, C.T., 2001. Nitrogen and carbon isotope fractionation between mothers, neonates, and nursing offspring. *Oecologia* 129, 336–341.

Jenness, D., 1940. Prehistoric culture waves from Asia to America. *Journal of the Washington Academy of Sciences* 30, 1–15.

Khlebnikov, K.T., 1979. *Russian America in unpublished notes of K.T. Khlebnikov*. [In Russian.] Nauka, Leningrad.

Knecht, R., Davis, R., 2003. Archaeological Evaluation of Tanaxtaxak, The Amaknak Spit Site (UNL-00055). Final Report. The Museum of the Aleutians, Unalaska, AK.

Krylovich, O., Vasyukov, D., Khasanov, B., Hatfield, V., West, D., Savinetsky, A., 2019. Hunter-gatherers subsistence and impact on fauna in the Islands of Four Mountains, Eastern Aleutians, Alaska, over 3000 yr. *Quaternary Research*, this volume. https://doi.org/10.1017/qua.2018.127.

Lamb, H.H., 1995. *Climate, History and the Modern World*. Routledge, London and New York.

Lambeck, K., 1990. Late Pleistocene, Holocene and present sealevels: constraints on future change. *Palaeogeography, Palaeoclimatology, Palaeoecology* 89, 205–217.

Lantis, M., 1984. Aleut. In: Sturtevant, W.C., Damas, D. (Eds.), *Arctic, Handbook of North American Indians*, Vol. 5. Smithsonian Institution, Washington, DC, pp. 161–184.

Laughlin, W.S., 1974. Holocene history of Nikolski Bay, Alaska, and Aleut evolution. *Folk* 16/17, 95–115.

Laughlin, W.S., 1975. Aleuts: ecosystem, Holocene history, and Siberian origin. *Science* 189, 507–515.

Leach, H., 2003. Did East Polynesians have a concept of luxury foods? *World Archaeology* 34, 442–457.

Leach, F., Quinn, C., Morrison, J., Lyon, G., 2003. The use of multiple isotope signatures in reconstructing prehistoric human diet from archaeological bone from the Pacific and New Zealand. *New Zealand Journal of Archaeology* 23, 31–98.

Lefèvre, C., Corbett, D., Crockford, S., Czederpilz, J., Partlow, M., West, D., 2010. Faunal Remains and Intersite Comparisons. In: Corbertt, D., West, D., Lefèvre, C. (Eds.), *The People at the End of the World: The Western Aleutians Project and the Archaeology of Shemya Island*. Aurora Alaska Anthropological Association Monograph Series, Vol. 3. Alaska Anthropological Association, Anchorage, pp. 133–158.

Lefèvre, C., West, D., Corbett, D.G., 2011. Zooarchaeological analysis at ADK-011, Adak Island, Central Aleutian Islands, Alaska. *Arctic Anthropology* 48, 69–82.

Leonard, J.A., Wayne, R.K., Wheeler, J., Valadez, R., Guillen, S., Vila, C., 2002. Ancient DNA evidence for Old World origin of New World dogs. *Science* 298, 1613–1616.

Lippold, L.K., 1991. Animal resources utilized by Saladoid People at Pearls, Grenada, West Indies. In: Ayubi, E.N., Haviser, J.B. (Eds.), *Proceedings of the Thirteenth International Congress for Caribbean Archaeology*. Reports of the Archaeological-Anthropological Institute of the Netherlands Antilles, Curaçao, pp. 264–268.

Lippold, L.K., 1966. Chaluka: the economic base. *Arctic Anthropology* 3, 125–131.

Longin, R., 1971. New method of collagen extraction for radiocarbon dating. *Nature* 230, 241–242.

Luomala, K., 1960. A History of the Binomial Classification of the Polynesian Native Dog. *Pacific Science* 14, 193–223.

Lyman, R.L., 2008. *Quantitative Paleozoology*. Cambridge University Press, New York.

MacArthur, R.H., Wilson, E.O., 1967. *The Theory of Island Biogeography*. Monographs in Population Biology, No. 1. Princeton University Press, Princeton.

Makarova, R.V., 1968. *Russians in the Pacific in the second half of the 18th century*. [In Russian.] Nauka, Moscow.

Malaurie, J., 1965. *Les derniers Rois de Thulé*. 10/18, Paris.

Margaris, A., 2009. The mechanical properties of marine and terrestrial skeletal materials. *Ethnoarchaeology* 1, 163–184.

Mathiassen, T., 1927. Archaeology of the Central Eskimos, the Thule Culture and Its Position within the Eskimo Culture. Report of the Fifth Thule Expedition 1921–1924, Vol. 4. Gyldendal, Copenhagen.

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

McCartney, A., 1967. An Analysis of the Bone Industry from Amaknak Island, Alaska. Master's Thesis. University of Wisconsin.

McGhee, R., 1996. *Ancient people of the Arctic*. University of British Columbia Press, Vancouver.

Miller, M., Christensen, G.C., Evans, H.E., 1964. *Anatomy of the Dog*. W.B. Saunders Company, London.

Misarti, N., Maschner, H.D.G., 2015. The Paleo-Aleut to Neo-Aleut transition revisited. *Journal of Anthropological Archaeology* 37, 67–84.

Monchot, H., Gendron, D., 2010. Disentangling long bones of foxes (*Vulpes vulpes* and *Alopex lagopus*) from arctic archaeological sites. *Journal of Archaeological Science* 37, 799–806.

Monchot, H., Gendron, D., 2011. Fox exploitation by the Paleoeskimo at the Tayara Site, Nunavik. *Arctic Anthropology* 48, 15–32.

Morey, D.F., 2010. *Domestication and the Development of a Social Bond*. Cambridge University Press, New York.

Morey, D.F., Aaris-Sørensen, K., 2002. Paleoeskimo dogs of the eastern Arctic. *Arctic* 55, 44–56.

Murie, O.S., 1936. Dog skulls from St. Lawrence Island, Alaska. In: Geist, O.W., Rainey, F.G. (Eds.), *Archaeological Excavations at Kukulik, St. Lawrence Island, Alaska*. University of Alaska Miscellaneous Publications. Government Printing Office, Washington, DC, pp. 347–357.

Murie, O.J., 1959. Fauna of the Aleutian Islands and Alaska Peninsula, with notes on invertebrates and fishes collected in the Aleutians, 1936–38. *North American Fauna* 61, 1–406.

Nelson, E.W., 1900. *The Eskimo about Bering Strait. Extract from the eighteenth annual report of the Bureau of American Ethnology*. Government Printing Office, Washington, DC.

Newsom, L.A., Wing, E.S., 2004. *On Land and Sea: Native American Uses of Biological Resources in the West Indies*. University of Alabama Press, Tuscaloosa and London.

Nordenskiöld, A.E., 1881. *The Voyage of the Vega around Asia and Europe, with a Historical Review of Previous Journeys along the North Coast of the Old World*. MacMillan, London.

O'Leary, M., 2001. Volcanic Ash Stratigraphy for Adak Island, Central Aleutian Archipelago. In: Dumond, D. (Ed.), *Archaeology in the Aleut Zone of Alaska, Some Recent Research*. University of Oregon Anthropological Papers, No. 58. University of Oregon Press, Eugene, pp. 215–234.

Pabi, S., van Dijken, G.L., Arrigo, K.R., 2008. Primary production in the Arctic Ocean, 1998–2006. *Journal Of Geophysical Research* 113, C08005.

Péwé, T.L., Hopkins, D.M., 1967. Mammal remains of pre-Wisconsin age in Alaska. In: Hopkins, D.M. (Ed.), *The Bering Land Bridge*. Stanford University Press, Palo Alto, pp. 266–287.

R Core Team, 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. URL https://www.R-project.org/

Raab, L.M., Bradford, K.G., Yatsko, A., 1994. Advances in Southern Channel Islands archaeology: 1983 to 1993. *Journal of California and Great Basin Anthropology* 16, 243–270.

Ransom, J.E., 1946. Aleut natural-food economy. *American Anthropologist* 48, 607–623.

Rechtman, R.B., 1992. The Evolution of Socio-Political Complexity in the Fiji Islands. PhD dissertation, University of California, Los Angeles.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Grootes, P.M., *et al*., 2013. IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. *Radiocarbon* 55, 1869–1887.

Ricca, M.A., Miles, A.K., Anthony, R.G., Deng, X., Hung, S.S.O., 2007. Effect of lipid extraction on analyses of stable carbon and stable nitrogen isotopes in coastal organisms of the Aleutian archipelago. *Canadian Journal of Zoology* 85, 40–48.

Richards, M.P., West, E., Rolett, B., Dobney, K., 2009. Isotope analysis of human and animal diets from the Hanamiai archaeological site (French Polynesia). *Archaeology in Oceania* 44, 169–187.

Rick, T.C., Erlandson, J.M., Vellanoweth, R.L., Braje, T.J., Collins, P.W., Guthrie, D.A., Stafford, T.W., 2008a. The origins and antiquity of the island fox (*Urocyon littoralis*): AMS ^{14}C evidence from California's Channel Islands. *Quaternary Research* 71, 93–98.

Rick, T.C., Walker, P.L., Willis, L.M., Noah, A.C., Erlandson, J.M., Vellanoweth, R.L., Braje, T.J., Kennet, D.J., 2008b. Dogs, humans and island ecosystems: the distribution, antiquity and ecology of domestic dogs (*Canis familiaris*) on California's Channel Islands, USA. *The Holocene* 18, 1077–1087.

Roth, J.D., Hobson, K.A., 2000. Stable carbon and nitrogen isotopic fractionation between diet and tissue of captive red fox: implications for dietary reconstruction. *Canadian Journal of Zoology* 78, 848–852.

Saladin d'Anglure, B., 1984. Inuit of Quebec. In: Sturtevant, W.C., Damas, D. (Eds.), *Arctic, Handbook of North American Indians*, Vol. 5. Smithsonian Institution, Washington, DC, pp. 476–507.

Sarychev, G.A., 1802. *The Voyage of Captain Sarychev's Fleet in the Northeastern Part of Siberia, the Arctic Ocean and the Eastern Ocean, for Eight Years, with the Geographic and Astronomical Marine Expedition, Commanded by the Fleet of Captain Billings from 1785 to 1793 yrs*. [In Russian.] Shnorr Typography, St. Petersburg.

Savinetsky, A.B., West, D.L., Antipushina, Z.A., Khassanov, B.F., Kiseleva, N.K., Krylovich, O.A., Pereladov, A.M., 2012. The reconstruction of ecosystems history of Adak Island (Aleutian Islands) during the Holocene. In: West, D., Hatfield, V., Wilmerding, E., Lefèvre, C., Gualtieri, L. (Eds.), *The People Before: The geology, paleoecology and archaeology of Adak Island, Alaska*. British Archaeological Reports International Series 2322. Archaeopress, Oxford, pp. 75–106.

Schell, D.M., Barnett, B.A., Vinette, K.A., 1998. Carbon and nitrogen isotope ratios in zooplankton of the Bering, Chukchi and Beaufort seas. *Marine Ecology Progress Series* 162, 11–23.

Smith, S.E., Hayes, M.G., Cabana, G.S., Huff, C., Coltrain, J.B., O'Rourke, D.H., 2009. Inferring population continuity versus replacement with aDNA: a cautionary tale from the Aleutian Islands. *Human Biology* 81, 407–426.

Sommer, R., Benecke, N., 2005. Late-Pleistocene and early Holocene history of the canid fauna of Europe (Canidae). *Mammalian Biology* 70, 227–241.

Stabeno, P.J., Kachel, D.G., Kachel, N.B., Sullivan, M.E., 2005. Observations from moorings in the Aleutian Passes: temperature, salinity and transport. *Fisheries Oceanography* 14, 39–54.

Stabeno, P.J., Napp, J., Mordy, C., Whitledge, T., 2010. Factors influencing physical structure and lower trophic levels of the eastern Bering Sea shelf in 2005: ice, tides and winds. *Progress in Oceanography* 85, 180–196.

Starikovskaya, Y.B., Sukernik, R.I., Schurr, T.G., Kogelnik, A.M., Wallace, D.C., 1998. mtDNA diversity in Chukchi and Siberian Eskimos: implications for the genetic history of ancient Beringia and the peopling of the New World. The American Journal of Human Genetics 63, 1473–1491.

Steadman, D.W., 1995. Prehistoric Extinctions of Pacific Island birds: biodiversity meets zooarchaeology. *Science, New Series* 267, 1123–1131.

Steadman, D.W., Plourde, A., Burley, D.V., 2002. Prehistoric butchery and consumption of birds in the kingdom of Tonga, South Pacific. *Journal of Archaeological Science* 29, 571–584.

Sullivan, E.G., Haugen, A.O., 1956. Age determination of foxes by x-ray of forefeet. *Journal of Wildlife Management* 20, 210–212.

Tuck, J.A., 1976. *Ancient People of Port au Choix – The Excavation of an Archaic Indian Cemetery in Newfoundland*. Institute of Social and Economic Research, Newfoundland Social and Economic Studies, No. 17. Memorial University of Newfoundland, St. John's.

Turner, C.G., Turner, J.A., 1974. Progress report on evolutionary anthropological study of Akun Strait District, Eastern Aleutians, Alaska, 1970–1971. *Anthropological Papers of the University of Alaska* 16, 27–57.

Turner, L., 2008. *An Aleutian Ethnography*. University of Alaska Press, Fairbanks.

Valentin, F., Bocherens, H., Gratuze, B., Sand, C., 2006. Dietary patterns during the late prehistoric/historic period in Cikobia island (Fiji): insights from stable isotopes and dental pathologies. *Journal of Archaeological Science* 33, 1396–1410.

Veltre, D.W., Yesner, D.R., Crossen, K.J., Graham, R.W., Coltrain, J.B., 2008. Patterns of faunal extinction and paleoclimatic change from mid-Holocene mammoth and polar bear remains, Pribilof Islands, Alaska. *Quaternary Research* 70, 40–50.

Veniaminov, I., 1984. Notes on the islands of the Unalaska district. Pierce, R.A. (Ed.) and Black, L., Geoghegan, R.H. (translators). *Elmer E. Rasmuson Library Translation Program*, University of Alaska, Fairbanks. Limestone Press, Kingston, Ontario.

von den Driesch, A., 1976. A guide to the measurement of animal bones from archaeological sites. *Peabody Museum Bulletin* 1, 1–136.

von Pfeil, D.J.F., DeCamp, C.E., 2009. The Epiphyseal Plate: Physiology, Anatomy, and Trauma. *Compendium: continuing education for veterinarians* 31, E1–11, quiz E12.

Walton, Z., Samelius, G., Odden, M., Willebrand, T., 2017. Variation in home range size of red foxes *Vulpes vulpes* along a gradient of productivity and human landscape alteration. *PLoS One* 12, e0175291.

Wayne, R.K., George, S.B., Gilbert, D., Collins, P.W., Kovach, S.D., Girman, D., Lehman, N., 1991. A morphological and genetic-study of the Island fox, *Urocyon littoralis*. *Evolution* 45, 1849–1868.

West, C.F., Jarvis, K.N., 2015. Osteometric variation in domestic dogs (*Canis familiaris*) from the Kodiak Archipelago, Alaska. *International Journal of Osteoarchaeology* 25, 289–298.

West, D., Coltrain, J.B., Hayes, M.G., O'Rourke, D.O., Lefèvre, C., Corbett, D., Bouchet, F., Savinetsky, A., 2012. A human burial from the Andreanof Islands, Alaska. In: West, D., Hatfield, V., Wilmerding, E., Lefèvre, C., Gualtieri, L. (Eds.), *The People Before: The geology, paleoecology and archaeology of Adak Island, Alaska*. British Archaeological Reports International Series 2322. Archaeopress, Oxford, pp. 303–316.

West, D., Khasanov, B., Krylovich, O., Hatfield, V., Khasanov, T., Vasyukov, D., Savinetsky, A., 2019. Refining the Paleo-Aleut to Neo-Aleut transition using a new ΔR for the eastern Aleutian Islands, Alaska. *Quaternary Research*, this volume. https://doi.org/10.1017/qua.2018.91.

West, D., Lefèvre, C., Corbett, D., and Savinetsky, A., 1999. Radiocarbon dates for the Near Islands, Aleutian Islands, Alaska. *Current Research in the Pleistocene* 16, 83–85.

West, E.W., Rudd, R.L., 1983. Biological control of Aleutian Island Arctic fox: a preliminary strategy. *International Journal for the Study of Animal Problems* 4, 305–311.

Wing, E.S., 1991. Dog Remains from the Sorcé Site on Vieques Island, Puerto Rico. In: Purdue, J.R., Klippel, W.E., Styles, B.W. (Eds.), *Beamers, Bobwhites, and Blue-Points: Tributes to the Career of Paul W. Parmalee*. Illinois State Museum Scientific Papers, Vol. 23. Illinois State Museum, Springfield, pp. 379–386.

Wolverton, S., Lyman, R.L., 2010. Introduction to Applied Zooarchaeology. In: Wolverton, S., Lyman, R.L. (Eds.), *Conservation Biology and Applied Zooarchaeology*. University of Arizona Press, Tucson.

Yesner, D.R. 1977. Prehistoric Subsistence and Settlement in the Aleutian Islands. PhD dissertation, University of Connecticut, Mansfield.