Examination of Ancient Animal Management Practices in Siberia and the Russian Far East through Dietary Stable Isotope Analyses

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

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Abstract

This study examines diverse animal management practices through the application of δ^{13}C and δ^{15}N analyses to collagen extracted from faunal skeletal remains. The faunal remains analyzed were recovered from eight archaeological sites in three distinct ecological settings in Siberia and the Russian Far East. The archaeological record of these sites recorded thousands of years of human-animal interactions, from the hunter-fisher-gatherer societies of the Neolithic along the coast of southern Primorye, to Iron Age dog sledding groups at the Arctic Circle in the Lower Ob, to the agricultural peoples of Transbaiikal and Primorye during the medieval period. Samples were selected to reflect the suite of taxa represented at each site and include both domestic and wild animal species, as well as aquatic and terrestrial fauna. The values reported in this study are among the first faunal stable isotope data for these areas. In addition to the faunal samples, human skeletal samples from two sites were also available, providing an opportunity to explore the utility of animal dietary stable isotope values as proxies for human ones.

The results of this study demonstrate local strategies to animal management in each of the three regions and highlight the human use of locally available resources to provision domestic animals. At Ust'-Polui, Iron Age peoples likely relied upon the abundant fishery provided by the Ob River to feed sled dogs, which require massive quantities of dietary resources to perform labour in extreme temperatures. Inferences from the medieval Proezzhaia I hillfort in Transbaikal suggest dogs, pigs, and caprines provisioned themselves, while horses and cattle may have been provided with supplemental fodder or given access to pasture. In southern Primorye, human dietary stable isotope data indicate Late Neolithic and Early Iron Age peoples relied on high trophic level marine resources, at odds with the abundance of shellfish remains at Boisman II and Pospelovo I. Additional data from other coastal shell midden sites and the inland Cherniatino II show no dietary isotopic separation of suids over thousands of years, suggesting the local environment provided adequate accommodation for the management of

domestic pigs with natural resources. However, the dietary stable isotope data from Cherniatino II show extensive use of cultivated millet among other domestic species, particularly during medieval occupation of the site.

The dietary stable isotope data generated by this study provide some support for the use of animal $\delta^{13}C$ and $\delta^{15}N$ values as proxy information for contemporaneous human diets, particularly those of domestic dogs. Though humans and dogs from Ust'-Polui, Boisman II, and Pospelovo I broadly shared dietary inputs from aquatic resources, consistent $\delta^{13}C$ and $\delta^{15}N$ value offsets between the two hint at more specific provisioning practices.

Preface

This thesis is an original work by Lacey Fleming. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Ethics Board, Holocene Hunter-Gatherers of Northeast Asia, No. 21280, 30 July 2015.

For Jessica Aubé

Acknowledgements

I owe an enormous debt of gratitude to my supervisors, Dr. Rob Losey and Dr. Sandra Garvie-Lok. I appreciate your patience and honesty beyond what I am able to express with words. This project has challenged me in ways I didn't think possible, but I am grateful for your belief in my capacity to learn and grow from this experience and for helping me see it through to the end.

I'd like to recognize the University of Alberta faculty members who took part in my doctoral candidacy examination committee, Dr. Connie Varnhagen of the Department of Psychology, and Dr. Kisha Supernant, Dr. Lesley Harrington, and Dr. Joe Hill, all of the Department of Anthropology. I also wish to thank the members of my final examination committee, Dr. Robert Park of the University of Waterloo, and Dr. Kisha Supernant, Dr. Jack Ives, and Dr. Lesley Harrington of the Department of Anthropology.

I owe major thanks to Dr. Tatiana Nomokonova of the University of Saskatchewan for her assistance with sample selection and identification. She also located and summarized relevant Russian-language literature that was crucial to the completion of this project. I also appreciate the work of her brother, Mr. Sergei Cheremisin, who acquired the modern fish skeletal samples from the Shilka River in Transbaikal.

Dr. Alexander Popov and staff of Far Eastern Federal University were our gracious hosts when we visited Vladivostok in March 2015. In addition to granting access to the Primorye samples analyzed in this study, he arranged for his staff to take us on a driving tour of Russkiy Island to visit several of the sites examined in this project. Visiting these locations was an incredibly meaningful experience and very deeply appreciated.

From ordering supplies, to helping me with ethics clearance, to knowing precisely which specimens and artifacts to recommend for lab activities, to gentle reminders about overdue paperwork, to many excellent afternoon conversations, I sincerely appreciate the support and general good humour of Department of Anthropology staff. My heartfelt appreciation goes to Heather Cook, Gayeung Doan, Harvey Friebe, Shirley Harpham, Andrea Hiob, Pamela Mayne Correia, and Ruby Sutton.

I was fortunate to have access to the equipment and expertise of Dr. Mingsha Ma and Alvin Kwan of the University of Alberta Biogeochemical Analytical Services Laboratory. They provided excellent service and support in the processing of my samples. Additionally, Dr. Hugh McKenzie of Grant MacEwan University granted access to fourteen human bone specimens from Boisman II and Pospelovo I. The data obtained from these samples were vital to the study, and I am thankful I had the opportunity to analyze them.

What would a rite of passage be without amazing friends with whom to share it? To Stephanie Brown, Dr. Megan Caldwell, Aaron Coons, Dr. Victoria van der Haas, Dr. Emily Hull, Kate Latham, Dr. Ligang Zhou, Dr. Jennifer Miller, Dr. Ben Osipov, Dyan Semple, Dr. Daniel Sims, Dr. Hillary Sparkes, Ruth Urlacher, Dr. Katie Waterhouse, and Christopher White, thank you for all the memories and your years of camaraderie, commiseration, and support. I am excited to see where our paths will cross again. To Jessica Aubé, Ed Hunt, and Amy Zacharias, I can't tell you how much levity and light the three of you have brought to my life. Thank you. (Jess: I finally have Chapter 5 finished if you'd like to read it.)

I was the fortunate recipient of several awards during my time as a doctoral candidate at the University of Alberta. The Department of Anthropology generously provided four years of funding, which covered the cost of international tuition, and I also received a Graduate Students' Association Academic Travel Award, a Department of Anthropology Doctoral Completion Award, a Faculty of Graduate Studies and Research Bursary, and the University of Alberta Graduate International Bursary. These awards made pursuit of my education possible—thank you!

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1 Introduction

Increasingly, animals from archaeological contexts are recognized as social and biological entities in their own right, rather than just residue of economic activities left behind by ancient human societies. As a result, the remains of animals are often now analyzed using multidisciplinary techniques and methods previously employed mostly for the examination of human remains. This dissertation explores the lives of ancient animals in Siberia and the Russian Far East through $\delta^{13}C$ and $\delta^{15}N$ analyses. Dietary stable isotope values from animal samples permit archaeologists to assess what individuals consumed in their lifetime, allowing reconstructions of their dietary relationships with other organisms, including how humans intervened in or managed their diets. Such insights help us to assess the active roles taken by animals in past societies and the efforts humans took to maintain and modify these roles through time.

1.1 Overview

The primary goal of this dissertation is to explore ancient animal management practices through the lens of dietary stable isotope analysis. Inspired by recent publications where these techniques are used to make inferences about animal experiences in the past, in this dissertation I examine isotopic correlates for human-animal relationships at eight archaeological sites in three ecologically distinct regions: the Lower Ob River and Transbaikal in Siberia, and southern Primorye in the Russian Far East. Together, these sites represent human and animal activities over thousands of years and in a variety of settings, from the Neolithic shell middens of the Pacific coast, to an Iron Age sacrificial site on the Ob River, to inland medieval towns in Primorye and Transbaikal.

Secondary but crucial to my investigation of human-animal relationships is the generation of faunal comparative $\delta^{13}C$ and $\delta^{15}N$ data for the sites of the Lower Ob, Transbaikal, and southern Primorye. Dietary stable isotope values from many different animal taxa—in addition to the taxon of interest—are required to establish a site-appropriate isotopic context. Prior to the commencement of this project in 2014, human collagen stable isotope values had been reported from only one of the eight sites examined here, Boisman II (Kuzmin et al. 2002). Even for Boisman II, comparative isotope data from regional fauna was lacking, which precluded solid inferences about past dietary patterning. In addition to providing the much-needed isotopic context for interpretations of human diets, I pursue insights into animal lives through these faunal data.

At Ust'-Polui, a ceremonial site situated near the Arctic Circle, humans and dogs appear to have engaged in a complex social relationship involving dog sacrifice and intentional burial, but also dog breeding for sledding activities (Losey et al. 2018b). Here dog diets were rich in fish, indicating that these animals were intentionally provisioned by their human cohabitants. Much further south, faunal remains from Proezzhaia I, a medieval hill fort in the Transbaikal region, suggest differential provisioning of domestic animals, as well as a possible ceremonial role for dogs (Fleming et al. 2018; Kovychev 2009). My research at this site constitutes the first archaeological stable isotope study in the entire Transbaikal region. Moving eastward, along the heavily forested coasts and islands of southern Primorye, humans in the Late Neolithic and Early Iron Age created extensive marine shell middens, may have practiced pig husbandry, and clearly kept domestic dogs. The middens at Boisman II, Boiarin VI, Russkiy I, Pospelovo I, and Nazimova in Primorye were once thought to represent domestic subsistence waste but are now more frequently regarded as at least partially ceremonial in nature (Popov and Tabarev 2010; Tabarev 2007). Further, human cultivation of oysters may have been practiced in portions of this coastal region as early as the Middle Holocene (Brodianski and Rakov 1992; Rakov and Brodianski 2007, 2010). Cherniatino II, the eighth site in this study, is situated in inland Primorye and features three cultural components, one from the Early Iron Age and two associated with medieval use of the site. The faunal remains from this site indicate relations with a suite of domestic animals, some of which may have been raised exclusively for human consumption, including dogs (Nikitin and Chzhun 2008).

1.2 Research questions

In addition to the general goals stated in section 1.1, the initial design of this dissertation called for a specific examination of ancient human-dog relationship in Siberian and the Russian Far East. As data were collected and laboratory results became available, it was evident that dogs were but one managed taxon in the company of others. Dietary stable isotope values from other taxa, among them horses, cattle, sheep, goats, and suids, presented an opportunity to extend my research and encompass a wider variety of domestic animals and their interactions with humans. To provide structure to the discussion of results and interpretations, I have organized this broad line of questioning into two further areas of inquiry, as follows:

1. *How did people in different environments manage or provision animals?* For example, do samples from a specific taxon at a site have consistent or highly variable dietary stable isotope values? Consistent dietary stable isotope values within a taxon might suggest a distinct animal provisioning strategy was employed by a community, while highly variable values may indicate little human control over domestic animal diets. Additionally, differences in animal diets attributable to spatial or temporal phenomena could provide further insights into shifts in provisioning practices through time or show differently structured diets for sacrificed animals. Further, different roles for a taxon, or for certain individuals, may be gleaned from archaeological context and dietary stable isotope values. Animals engaged in transport activities, such as sled dogs or draft horses, may have different dietary requirements than other members of their domestic conspecifics due to higher levels of strenuous activity.
2. *Can animal dietary stable isotope values be used as proxy data for other archaeological phenomena?* Animals that live in close physical proximity to humans often have dietary stable isotope signatures that differ from those who do not, reflecting either some degree of commensality (e.g., Finucane et al. 2006; Hu et al. 2014) or direct human influence on their diets

(e.g., Dai et al. 2016; Makarewicz and Tuross 2006). Some researchers have suggested that companion species, such as dogs, might provide proxy dietary information for human populations where human stable isotope data are unattainable (Guiry 2012, 2013). However, in the Cis-Baikal region of Siberia, previous scholarship has indicated a small but consistent dietary stable isotope value offset between humans and dogs (Losey et al. 2011). Additionally, stable isotopic work with other animal taxa, such as domestic pigs, sometimes indicates that their dietary signatures are characteristic of human management and distinct from those of wild and/or unmanaged populations (Hu et al. 2014; Kuzmin et al. 2018). Dietary stable isotope data thus can potentially speak to the status of an animal as wild or domestic, or reveal whether humans provisioned animals in isotopically similar ways to themselves.

1.3 Organization of dissertation

In Chapter 2, I provide a comprehensive examination of dietary stable isotope theory, how stable isotopes are incorporated into the tissues of animals and move through ecosystems, and the sampling, tissue extraction, and analytical techniques employed in this project. In Chapter 3, I describe the ecological settings and culture histories of each of the three regions examined in this study and give detailed information for all eight sites. Chapter 4 provides an in-depth description and analysis of the dietary stable isotope data, as well as the inferences I have made from these data. In Chapter 5, I conclude the dissertation with a review of analytical and interpretive highlights with respect to the research questions stated in section 1.2 and give recommendations for future research.

1.4 Definitions and conventions

Individual researchers do not always possess identical understandings of what seem like straightforward concepts, so here I provide clarification on my use of terms which have multiple meanings. First, I employ the term “animal” only as shorthand to collectively refer to other-than-human animals when not making reference to a taxonomic unit. Humans are animals, and this differentiation is not intended to uphold the primacy of humans, or to assume the false dichotomy of human = culture/animal = nature.

Second, humans make distinctions among the groups to which they and other-than-human animals belong on the basis of behavioural, morphological, spatial, historical, and even cosmological differences. For the purposes of explication, it is necessary to adhere to a system that acknowledges these differences between animals in meaningful ways, yet it is impossible to apprehend how ancient peoples with few or no written records organized animals into groups. Presently, many documented ethnotaxonomies classify animals differently from the standard of western biological science, the Linnean taxonomic system (e.g., Souza and Begossi 2007; Naves and Zeller 2017). Following standard scientific practice, I use the Linnaean system as the basis of organization for the animal communities examined in this dissertation because it is the most widely known classification system and is routinely employed in zooarchaeological and stable isotope ecology analyses.

Finally, though I use the term ‘domestic’ in the coming chapters to refer to animals specifically whose breeding habits, diets, and movements were likely controlled to some extent by humans, I am sensitive to the logical inconsistencies that present themselves in doing so. Broadly defined, domestication is a model for human-animal interaction whereby wild animals undergo a process of human-mediated evolution that results in intergenerational behavioural and physiological changes. Some scholars base their definitions on more specific criteria that characterize it as a human cultural event, but I assert that these are more correctly identified as narratives added to the framework of what is, essentially, an evolutionary process. For example, some definitions of domestication assume human domination and control of animal and plant species, generally expressed as interventions in breeding habits, diets, and restriction of movement across landscapes (e.g., Bökönyi 1989; Clutton-Brock 1994). Others have maintained that domestication is simply an example of symbiosis between different species of animals, and domestication is not *always* one-sided in favour of humans (e.g., O'Connor 1997; Zeuner 1963). Acknowledging both sides of this debate, Pierre Ducos (1978:56) and Tim Ingold (1980:2) long ago called for a conceptual distinction between the biological and social aspects of domestication. These approaches still implied that domestication is a set of intentional processes initiated and maintained by humans, however commonly acknowledged as an ongoing genetic process (Clutton-Brock 1992; Frantz and Larson 2018). At the same time, some studies have pointed to the likelihood that there are multiple loci of initial domestication, and even these initial phases span millennia, in effect underscoring domestication's emergent qualities (Axelsson et al. 2013; Larson et al. 2005; Larson et al. 2012).

In light of these debates, I favour a model of domestication that acknowledges the agency of both humans and animals. I envision domestication as a process that is not necessarily intentional or directional, and that is ongoing. Niche construction is a biological concept whereby an organism alters its niche and may also impact the niches of other organisms living in it, resulting in evolutionary change as they adapt to the newly created environment (Vandermeer 2008). In niche construction, it is understood that organisms create changes in their environment and therefore co-direct evolution (Laland and O'Brien 2011). Niche construction also results in long-term ecological change that may continue to exist long after the selective pressure was initiated (Cuddington 2011; Hastings et al. 2007). Under the model of niche construction theory, myriad human-animal entanglements may have evolutionary implications that eventually result in domestication (Zeder 2016). This approach encompasses both consequential and intentional human efforts that lead to behavioural and morphological changes in animals, and it allows for animal-driven and co-domestication narratives (e.g., Coppinger and Coppinger 2001; Hu et al. 2014; Istomin and Dwyer 2010).

2 Stable Isotope Ecology, Key Concepts, and Methods

In this chapter, I review the characteristics of stable carbon and nitrogen isotopes, and how they are analyzed and interpreted. I explain the process of isotopic fractionation and how $\delta^{13}C$ and $\delta^{15}N$ are patterned in each type of ecological setting from which the samples in this study came. Further, I explore the incorporation of stable carbon and nitrogen isotopes into the structural tissues of plants and animals, and how these isotopes are assessed in animal bone collagen to make inferences about human and animal behavior. I conclude the chapter by explaining the methods used to prepare and analyze the samples in this study, and I report on the collagen quality of the samples used in this study.

2.1 Applications of stable isotope ecology to archaeological questions

Historically, standard zooarchaeological analyses included the collection, identification, and quantification of skeletal animal remains from archaeological sites. Additional data generated from such analyses might include a count of the minimum number of individuals (MNI), documentation of unfused epiphyses or visible lines of fusion (indicating a skeletally immature individual), identification of the presence of any sex-specific skeletal traits, incidence of trauma or disease, natural and cultural modifications to each specimen, and additional secondary data that can be gleaned from measurements (Reitz and Wing 2008:153-250). From this information, inferences about human subsistence practices, and even some management techniques, were made, as it was generally accepted that faunal remains represented individual animals who had been used in some fashion by humans.

Used singularly, these techniques restrict the scope of inference because they force zooarchaeologists to rely only on directly observable data—e.g., which context, which species, which bones, how were they modified and how often?—to answer a limited set of questions. In this approach, interpretations are necessarily biased toward organisms with robust structural tissues that can survive in the archaeological record (Lee-Thorp 2008:925). Similarly, the specificity of faunal data tends to limit archaeological inquiry to a bounded set of questions focused on how humans consumed or used animal bodies to suit their own purposes, with little consideration of relationships from the animal perspective (e.g., Russell 2012:3). More recently, the affirmation of and interest in the lives of other-than-human animals have been implicated in the theoretical and methodological shifts that have occurred in anthropology (e.g.,Fijn 2010; K. Lightfoot et al. 2013; Istomin and Dwyer 2010; Makarewicz and Sealy 2015; Ogden et al. 2013), including the integration of zooarchaeological and stable isotope techniques within archaeology.

Cheryl Makarewicz and Judith Sealy (2015) provide an excellent historical review of the use of stable isotope analyses in archaeology and identify three dominant chronological trends. Stable isotope analyses are rooted in earth and plant science geochemistry (Hoefs 2009) and were first used to track the flow of carbon isotopes in food webs (DeNiro and Epstein 1978; Vogel 1978), followed by investigations of the patterning of δ^{15}N values in animal tissues (DeNiro and Epstein 1981; Minagawa and Wada 1984; Schoeninger and DeNiro 1984). Thus, early applications of stable isotope techniques to archaeological questions focused on their ability to examine broad questions about human dietary trends in antiquity, including the origin and spread of maize agriculture in North America (van der Merwe and Vogel 1978; Vogel and van der Merwe 1977) and the shift from aquatic resource-based diets to agricultural products during the European Neolithic (Tauber 1981). Following this work, concerns regarding bone preservation and contamination came to the fore, and in the 1980s and 1990s, research was carried out to establish parameters for the chemical integrity of samples, and effective pretreatments for mitigating contamination were identified (Makarewicz and Sealy 2015:147). Meanwhile, advances in mass spectrometry significantly decreased the amount of sample needed for analysis and reduced overall costs, improving the techniques' accessibility for archaeological studies (Makarewicz and Sealy 2015:147). While questions about human diet have always been important to zooarchaeological analysis, criticism targeted at the shortcomings of processual archaeology in the

1980s gave rise to an array of interdisciplinary projects that applied stable isotope analyses to explorations of social phenomena beyond subsistence (Makarewicz and Sealy 2015:148). Increasingly, zooarchaeologists focus their inquiry on the lived experiences and social relationships of the animals whose remains are recovered from archaeological sites (e.g., Makarewicz and Sealy 2015; Russell 2012). Stable isotope ecology is one such means to examine ancient animal lives, predicated on the observation that the chemical composition of an organism's tissues is a reflection of the environment in which it lived and consumed resources (White 2004). As will be explored in this chapter, stable isotope data yield information about the origin of and dietary inputs to an organism, give researchers indications of the environmental conditions under which it lived, and can be used archaeologically to examine ancient dietary relationships between humans and animals.

2.2 Isotopes

Structurally, an atom consists of a nucleus containing positively charged protons and chargless neutrons, which is surrounded by a cloud of negatively charged electrons (Ellam 2016; Sharp 2007). All atoms of a given element have the same number of protons in their nuclei (Sharp 2007).

Atoms of an element with different numbers of neutrons are called isotopes. These different numbers of neutrons cause modest differences in an atom's mass (Sharp 2007), ultimately resulting in different chemical and physical properties (Hoefs 2009) which affect its ability to form bonds to atoms in molecules and the speed with which it participates in physical processes such as diffusion (Hoefs 2009). This leads to slight but measurable changes in the proportion of isotopes present—isotopic fractionation—the phenomenon that makes stable isotope analysis possible (Sharp 2007).

Isotopes can be either radioactive or stable. The number of known stable isotopes on Earth is approximately 300, while over 1200 radioactive isotopes have been identified (Hoefs 2009). Radioactive isotopes decay over time into other species (Ellam 2016; Hoefs 2009).

In contrast, stable isotopes do not decay into other isotopes over time because their nuclei are in equilibrium (Hoefs 2009). Upon the death of an organism, the uptake and incorporation of elements into bodily tissues ceases, and under conditions of adequate organic preservation, these isotopes can be detected in archaeological tissues.

This research focuses on isotopes of carbon and nitrogen, expressed as $\delta^{13}C$ and $\delta^{15}N$ values, which reveal information not only about an organism's dietary inputs during life, but also may permit contextual insights about the ecosystem in which it lived. Further, $\delta^{13}C$ and $\delta^{15}N$ values allow archaeologists to make inferences about animal and plant management strategies that otherwise would be inaccessible through material evidence in the archaeological record.

2.2.1 Values and notation

Stable isotopes from a single chemical element do not occur with the same frequency, and some stable isotopes naturally are far more abundant than others. The respective abundances of stable isotopes on Earth has been demonstrated statistically and substantiated experimentally (Hoefs 2009). The comparison of the abundance of an isotope to that of a correspondingly rare one is a key component of stable isotope analysis and forms the basis for the calculation of values (Fry 2006). Stable isotope values are expressed as a comparison of the abundance of one isotope to another from the same element in a sample. This, in turn, is expressed in comparison to the same ratio between the two isotopes within a reference sample. The formula is typically expressed as

$\delta = [(R_{\text{SAMPLE}}/R_{\text{STANDARD}}\text{-}1)]*1000$

where

$R = {}^{H}F/{}^{L}F$

and

F = fractional abundance of the heavy (${}^{H}F$) or light (${}^{L}F$) isotope (from Fry 2006)

Thus, δ^{13}C values are the result of the measurement of ^{13}C to ^{12}C isotopes in a given sample, divided by the ratio of ^{13}C to ^{12}C isotopes in a standard reference sample. The international reference standard is Vienna Pee Dee Belemnite (VPDB) (Hoefs 2009), whose value is based on the earlier PDB standard, a fossilized marine cephalopod dating to the Cretaceous Period, originating from the Pee Dee formation in South Carolina, United States (Ellam 2016). Its δ^{13}C value is defined as 0‰, and because most organisms are depleted in ^{13}C compared to this standard, the tissues of nearly all organisms on Earth will express negative δ^{13}C values. Correspondingly, δ^{15}N values are reported as the ratio of ^{15}N to ^{14}N in a given sample, divided by the ratio of ^{15}N to ^{14}N in the standard reference sample, the ambient inhalable reservoir (AIR). Positive δ^{15}N values denote that the ratio of the heavy to the light isotope is higher in a sample than in the reference standard, and negative δ^{15}N values show the ratio of the heavy to the light isotope is greater in the reference standard than in the sample (Sharp 2007). In part, because the differences in mass caused by fractionation processes are so small, stable isotope delta values are reported in per mil (‰) notation in order to more easily illustrate and communicate the different values (Fry 2006).

2.2.2 Mass spectrometry

To measure the relative abundance of one isotope to another in a sample, a mass spectrometer is employed. The isotope ratio mass spectrometers commonly used in ecological and archaeological stable isotope research separates charged atoms and molecules based on their mass. The following steps described by Fry (2006) occur during the process: 1) gasses are introduced into a chamber where a heat source produces electrons; 2) when the gases meet the electrons, they are ionized and forced to release electrons of their own, often breaking down into smaller molecules in the process; 3) having lost electrons, the ionized molecules now have a positive charge and are pushed, or accelerated, through a flight tube maintained under vacuum; 4) a magnetic field separates the charged ions based on their inertia, pushing them toward collectors where they are counted by computers. It is the difference in mass imparted by their isotopic composition that affect the ions' inertia, so ions containing heavier isotopes will require more force in order to be displaced. Raw values usually are fed into software to produce the delta values used by archaeologists and researchers in other disciplines to assess isotopic relationships.

2.3 Stable carbon isotope fractionation

^{12}C and ^{13}C are the two stable isotopes of carbon. As components of atmospheric carbon (CO_2), they are freely available in the Earth's biosphere. ^{13}C makes up approximately 1.1% of carbon available in atmospheric CO_2 in comparison to ^{12}C which comprises approximately 98.9% (O'Leary 1988; Rosman and Taylor 1998). Both stable isotopes of carbon are incorporated into tissues via several routes during an organism's life, but these processes cease when the organism dies.

As discussed in the previous section, stable isotope fractionation is the segregation of isotopes during a physical or chemical processs, altering the abundance of isotopes in the products of the process relative to the starting substances (Ellam 2016; Hoefs 2009). This process generally is due to heavier isotopes being discriminated against as they move through reactions or phase changes, though some mass-independent factors are known to exist (Hoefs 2009). In the case of carbon, kinetic isotope effects that take place during photosynthesis cause the lighter ^{12}C to become concentrated in the resulting organic material (Sharp 2007).

2.3.1 Carbon isotopes in plants

The entrance of carbon into food webs begins with photosynthesis. Photosynthesis is the chemical process through which autotrophs (plants) convert sunlight and CO_2 into sugars for their sustenance and growth, a complex series of operations involving light absorption, energy conversion, electron transfer, and reactions catalyzed by enzymes (Malkin and Niyogi 2000). There are three different ways in which plants carry out this process: C_3 (the Calvin-Benson pathway), C_4 (the Hatch-Slack pathway), and Crassulacean Acid Metabolism (CAM). The following explanation will focus on the C_3 and C_4 pathways, as the overwhelming majority of plant life uses the C_3 pathway, and many important agricultural products, such as maize and millet, use the C_4 pathway. CAM plants are rarer still than C_4 plants, and none is currently known to exist in any of the study regions.

In C_3 photosynthesis, a plant takes up carbon dioxide (CO_2) through its leaves and transports it to the internal gas space, where the sugar ribulose biphosphate and the CO_2 undergo a chemical reaction known as carboxylation, catalyzed by the enzyme ribulose-1,5-biphosphate carboxylase-oxygenase (RuBisCO) (Malkin and Niyogi 2000). The carboxylation produces two molecules of 3-phosphoglyceric acid, which are in turn used to create more complex sugars that plants can consume (Hall and Rao 1999). Under conditions of elevated CO_2 or at cool temperatures, C_3 photosynthesis is the most efficient pathway for a plant to fix carbon (Ehleringer and Cerling 2002).

C_4 photosynthesis is thought to have evolved because it allows for more efficient carbon fixation under drier, hotter conditions, and the occurrence of closely-related C_3 and C_4 plants suggests this pathway has evolved independently in different plant taxa as a response to localized climatic conditions (Björkman and Berry 1973). In the first step of C_4 carbon fixation, the enzyme phosphoenolpyruvate (PEP) carboxylase converts phosphoenolpyruvate into oxaloacetate, an intermediate acid. The oxaloacetate undergoes carboxylation and is converted into one of several acids comprised of four carbon molecules (O'Leary 1988). This acid is transported to the specialized bundle sheath cells and in turn is decarboxylated, releasing additional CO_2 (Malkin and Niyogi 2000). From this step, the CO_2 that results from decarboxylation is fixed by RuBisCO in the same manner as C_3 plants (Ehleringer and Cerling 2002). The Kranz leaf anatomy of C_4 plants, which features mesophyll cells and additional specialized structures known as bundle sheath cells, prevents direct fixation of CO_2. This arrangement effectively prevents photorespiration (the loss of fixed CO_2 from plants) while the leaf stomata are closed, allowing the plant to minimize water loss by limiting the amount of time leaf stomata are open (Malkin and

Niyogi 2000). C_4 plants are most efficient in full sunlight and at temperatures of 35 to 40° C (Ambrose 1986; Ehleringer and Cerling 2002).

Plants that employ the third form of carbon fixation, CAM, use both the C_3 and C_4 pathways; these include plants such as cacti, pineapple, and bromeliads (O'Leary 1981). Like C_4 plants, these also are adapted to hot and arid conditions, and as such, are not found in Siberia or the Russian Far East (Ivanova et al. 2018). They are not believed to have had any impact on the stable isotope values examined for this project.

The different types of carbon fixation can be distinguished isotopically as the result of differing discrimination against ^{13}C. This permits a plant species to be assigned to one of the three groups based on its $\delta^{13}C$ values (O'Leary 1988). During carbon fixation, all plants discriminate against the heavier ^{13}C, but each of the three forms of carbon fixation discriminates differentially, yielding distinctive $\delta^{13}C$ value ranges that reveal the group to which the plant belongs. Plants using the Hatch-Slack (C_4) pathway discriminate less against ^{13}C and have higher $\delta^{13}C$ values; these range from -9 to –21‰, with an average of -13‰ (Ambrose 1986; Bender 1971; Katzenberg et al. 1995). Among plants using the Calvin-Benson (C_3) pathway, $\delta^{13}C$ values range from -22 to -34‰, with an average of -26‰ (Ambrose 1986; Bender 1971; O'Leary 1988; Rao et al. 2017). CAM plant $\delta^{13}C$ values are intermediate between those of C_3 and C_4 plants, -10 to -20‰ (O'Leary 1988).

While the process of photosynthesis causes most of the $\delta^{13}C$ variation seen in plants, other natural processes that take place in the plant may cause further variation. For example, many plants show seasonal fluctuations in their $\delta^{13}C$ values due to differential environmental conditions, and some plant tissues favoured by consumers, like leaves and nuts, have distinctive tissue $\delta^{13}C$ values and are present only at certain times of the year (Ehleringer et al. 1992; Tieszen and Boutton 1989).

Despite significant ecological differences in each of the three study areas, C_3 plants dominate in all regions, particularly in the heavily forested coasts of Primorye. However, an important C_4 cultivar, millet, is present in archaeological contexts in Transbaikal and Primorye during several temporal periods under consideration (described in Chapters 3 and 4). Because all animals, irrespective of their trophic position, receive direct or indirect dietary inputs from plants, $\delta^{13}C$ values can be used to examine the presence of such plants in environments where they would not naturally occur and could not grow without human intervention (Vogel and van der Merwe 1977).

While the majority of isotopic fractionation in plants is the result of carbon fixation, other factors may impact their $\delta^{13}C$ values. Reviewed in part by O'Leary (1981), these include natural variations among and within species, the nutritional status of an individual plant and whether it has been fertilized, natural variations among the different organs of the plant, rainfall, temperature, soil salinity, CO_2 concentration in the canopy and impacts from the release of respired CO_2 by other plants, and light intensity and humidity. Several of these will be discussed in the following section.

Another significant impact on $\delta^{13}C$ values is anthropogenic activity that has resulted in a stable isotopic phenomenon known as the Suess effect. Since the Industrial Revolution, humans have released a much higher than natural amount of CO_2 into the atmosphere. Because fossil fuels are comprised of organic plant material that preferentially took up ^{12}C during the carbon fixation step of photosynthesis, the CO_2 that results from the combustion of fossil fuels is further depleted in ^{13}C when it is released into the atmosphere (Keeling 1979). Similarly, extensive deforestation of the planet has resulted in the release of additional ^{13}C-depleted CO_2 into the atmosphere (Houghton et al. 1983). This ^{13}C-depleted CO_2 is understood to be absorbed by the biosphere through several mechanisms and ultimately results in the lower $\delta^{13}C$ values of organic materials (Gruber et al. 1999). The mean preindustrial $\delta^{13}C$ value of atmospheric CO_2 was ca. -6.8‰ (Francey et al. 1999), but the mean postindustrial ratio is ca. -7.8‰ (Keeling et al. 1995), meaning modern collagen values used to make inferences about archaeological materials must have a correction applied. In archaeology, a standard +1.5‰ is added to modern sample $\delta^{13}C$ values when comparing them to those of preindustrial archaeological specimens (Keeling 1979).

2.3.2 Carbon isotopes in terrestrial environments

The elaborate isotopic interactions that take place in forest, steppe, and tundra environments which impact plant $\delta^{13}C$ values are dependent on several phenomena, many reflecting the context in which a plant developed and lived. The availability of water has a significant impact on leaf $\delta^{13}C$ values. Under conditions of adequate water supply, the stomata of C_3 plants will discriminate against ^{13}C, yielding lower $\delta^{13}C$ values, but such conditions increase the $\delta^{13}C$ values of plants that already use water efficiently (Farquahar and Richards 1984). When groups of plant $\delta^{13}C$ values are examined spatially, their distribution generally follows a rainfall gradient (Li et al. 2017; Stewart et al. 1995).

In forests, the location of a plant in the canopy affects the $\delta^{13}C$ values of its leaves. Foliar $\delta^{13}C$ values decrease from the top of the canopy to the forest floor (Medina and Minchin 1980; Vogel 1978). This decrease is the result of light availability, humidity, and CO_2 concentrations at different heights in the canopy. Additionally, in temperate deciduous forests, foliar $\delta^{13}C$ values reflect the seasonally mediated light and humidity conditions under which the leaves formed; lower $\delta^{13}C$ values are associated with higher humidity levels and less light, corresponding to the openness of the canopy (Graham et al. 2014). The 'canopy effect' results in decreasing leaf $\delta^{13}C$ values closer to the forest floor, the result of differential access to light, varying levels of humidity, and the composition and concentration of atmospheric CO_2 (Medina and Minchin 1980; Vogel 1978). The canopy effect is observed in forests of all types (Buchmann et al. 1997; Graham et al. 2014). Where animals are assumed to have eaten non-cultivated, locally available plant materials, slight differences in their sample $\delta^{13}C$ values permit researchers to make inferences about the settings in which animals were consuming plant material, for example, under a forest canopy or in an open field (Drucker et al. 2008; Fahy et al. 2013; Oelze et al. 2011; Schoeninger et al. 1999). While some studies have documented the expected differential $\delta^{13}C$ values between groups of African elephants feeding in canopy-covered forest and open savanna settings, possible causes of the observed effects might also be the more significant inclusion of C_4

grasses in savanna diets and/or plant water stress in drier areas, such as steppe ecosystems (van der Merwe et al. 1990; Vogel et al. 1990).

In comparison to forests, less information exists on the $\delta^{13}C$ ecology of steppe environments (but see Auerswald et al. 2009; Ivanova et al. 2018; Ventresca Miller et al. 2018). Plants growing in steppe ecosystems have $\delta^{13}C$ values that reflect the openness and aridity of the local environment (Farquhar et al. 1982). On the Eurasian steppe, floral communities are comprised of both C_3 and C_4 plants (Malyschev and Peschkova 2001); some areas are dominated by C_3 plants (Ventresca Miller et al. 2018), while more easterly steppe ecosystems exhibit a more equitable distribution of C_3 and C_4 taxa (Makarewicz and Tuross 2006). The higher levels of soil salinity on the steppe reduce the ability of plants to take up water and may raise some tissues' $\delta^{13}C$ values to 3‰ (Farquhar et al. 1982). Additionally, the generally drier conditions result in increased water-use efficiency of C_3 plants, serving to raise foliar $\delta^{13}C$ values (Farquhar et al. 1989).

The biological and archaeological literature on the $\delta^{13}C$ ecology of tundra settings is limited. General isotopic patterns indicate organism $\delta^{13}C$ values decrease with latitude (Hobson 1999; Kelly 2000), and plant $\delta^{13}C$ values decrease with latitude (Körner et al. 1991). Floral communities in tundra ecosystems are much smaller in comparison to those in forest and steppes and are dominated by mosses and short shrubs (Chapin et al. 1995; Nifontova 1995). Tundra vegetation is sensitive to changes in the water table because it impacts decomposition and the availability of nutrients, causing detectable shifts in the carbon balance (Billings et al. 1983).

2.3.3 Carbon isotopes in marine and freshwater environments

In addition to examining the types of plants and environmental conditions found in terrestrial ecosystems, $\delta^{13}C$ values can be used to assess aquatic carbon sources, which take on the greatest significance at the consumer level (discussed below). In marine ecosystems, carbon is derived from dissolved carbonate in the water, which has a $\delta^{13}C$ value of 0‰. Therefore, the $\delta^{13}C$ values of marine plants tend to be higher than those of terrestrial plants (Ambrose et al. 1997). Bodies of freshwater typically have many sources of carbon, which may carry a wide range of $\delta^{13}C$ values (Katzenberg et al. 2012).

The $\delta^{13}C$ values of aquatic plants reflect their living conditions much the same as terrestrial plants, but other considerations, such as the pH value of water, cell size, and growth rate, also may impact them (Hoefs 2009). The depth of the water where an aquatic plant resides also affects its $\delta^{13}C$ values; deep, near-bottom benthic settings are more enriched in ^{13}C than pelagic, nearshore ones, resulting in plants with higher $\delta^{13}C$ values (Kelly 2000). Further, northern oceans are enriched in ^{13}C compared to those at more southerly latitudes (Kelly 2000). Freshwater plant $\delta^{13}C$ values show the greatest range of variation due to the complexity of their carbon inputs and may be within the $\delta^{13}C$ ranges of either C_3 or C_4 plants (Katzenberg 2008).

Of concern for many data in this study is the structure of estuarine food webs, which, with numerous terrestrial and aquatic isotopic inputs, are notoriously complex—yet each estuary is isotopically distinguishable from its adjacent riverine and marine settings (Herzka 2005). In a model proposed by Fry (2002), freshwater and seawater carbon, each with a distinct stable isotope signature, becomes mixed in an estuarine setting and is picked up by bacteria and algae comprising the base of the food web, then passed on to shellfish and other consumers at higher trophic levels.

2.3.4 Carbon isotopes in skeletal tissues

When a plant part is consumed by an animal (a primary consumer), chemical components of the plant are broken down by the metabolic processes that take place in the animal's body, which fuel its growth and maintain its cellular structures. This process continues at higher levels of the food chain, wherein animals eat plants and other animals (characterized as omnivores), or almost exclusively other animals (tertiary consumers, typically carnivores). Because metabolic processes break down and recombine plant-derived chemicals in the tissues of secondary and tertiary consumers, further fractionation of the dietary carbon isotopes occurs (Chisholm et al. 1982; Lee-Thorp et al. 1989).

While all bodily tissues contain carbon, it has been experimentally demonstrated that collagen, a structural molecule present in bone and other bodily tissues, is primarily derived from an animal's dietary protein intake (Ambrose and Norr 1993; Froehle et al. 2010; Krueger and Sullivan 1984). As herbivores overwhelmingly consume plant tissues, their bone collagen $\delta^{13}C$ values reflect the $\delta^{13}C$ values of the plants they consumed because this is the primary source of their dietary protein. Lipids and carbohydrates are additional macronutrients that provide energy to the body to fuel its processes, and herbivores also acquire these compounds through the plants they consume. However, they are derived from different plant metabolic pathways and are routed differentially to the animal's bodily tissues. Dietary lipid and carbohydrate inputs are most closely reflected in the $\delta^{13}C$ values of hydroxyapatite, the mineral component of bone (a tissue not analyzed in this study) (Ambrose and Norr 1993; Froehle et al. 2010; Krueger and Sullivan 1984). Carnivore bone collagen and hydroxyapatite $\delta^{13}C$ values tend to be similar to those of their prey, with a small trophic fractionation effect elevating their tissue values by an additional 0‰ to 2.0‰ (Bender et al. 1981; Bocherens and Drucker 2003; DeNiro and Epstein 1978; McConnaughey and McRoy 1979; Schoeninger 1985; Tieszen et al. 1983). This range has been used in the interpretation of $\delta^{13}C$ values in the present study.

In their pioneering study establishing that the $\delta^{13}C$ values of animals reflect the isotopic inputs of their diets, DeNiro and Epstein (1978), showed that the whole body $\delta^{13}C$ values of most terrestrial animals are elevated approximately +1‰ over their diets. In isolation from other tissues, the $\delta^{13}C$ value of bone collagen of herbivores is enriched about +5‰ over that of their diets (Chisholm et al. 1982; Lee-Thorp et al. 1989; van der Merwe 1982). Among herbivores with monoisotopic diets, the $\delta^{13}C$ value ranges for C_3 and C_4 plants remain distinct even with the +5‰ enrichment factor (Chisholm et al. 1982). This +5‰ collagen enrichment over the diet also is observed in carnivores' bone collagen $\delta^{13}C$ values.

However, fractionation can be obscured somewhat by non-monoisotopic diets with protein derived from a variety of sources, such as mixed C_3-C_4 diets and those of omnivores, which show that the magnitude of the diet-bone collagen $\delta^{13}C$ offset is dependent on the proportion and composition (protein, lipid, and carbohydrate) of dietary inputs (Froehle et al. 2010).

Examination of bird diet and tissues, including bone collagen, has revealed a more modest fractionation effect than for mammals. Hobson and Clark (1992b) experimentally observed smaller diet-bone collagen $\delta^{13}C$ offsets in piscivorous, carnivorous, and granivorous avian taxa than those published for mammals, up to +2.7 ± 0.4‰. Bone collagen from grain-fed birds generally yielded smaller $\delta^{13}C$ offsets than those with fish-based diets, and their results suggest that bone collagen $\delta^{13}C$ values in birds also are protein source-dependent and that C_3/C_4 $\delta^{13}C$ value ranges are reflected in consumers' diets (Hobson and Clark 1992b).

An analysis of a global sample of marine consumers conducted by Schoeninger and DeNiro (1984) revealed marine consumers' $\delta^{13}C$ values are, on average, 5‰ higher than those of terrestrial consumers, the result of longer food chains in marine environments. The study further showed a high level of variation in $\delta^{13}C$ values among marine resources, as well as an 8‰ overlap between marine and terrestrial resources, mainly due to regional variations (Schoeninger and DeNiro 1984). Among freshwater animal taxa, $\delta^{13}C$ values are highly variable because of habitat-specific factors such as the CO_2 available to aquatic plants (France 1995). Values for the same freshwater taxon in different bodies of water likely will vary due to local conditions (Katzenberg et al. 2012). Because freshwater and marine fish diets often are highly variable based on the age and size of an individual fish, the enrichment effect between diet and bone collagen also is variable, though preferential routing of ^{13}C from dietary protein to collagenous structures has been established in fish (McMahon et al. 2010). Sholto-Douglas et al. (1991) cite a bone collagen $\delta^{13}C$ enrichment of +3.2 to +3.9‰ over diet in two species of small, schooled marine fish that feed on zooplankton, though larger aquatic organisms tend to be carnivorous (Knochel and Holtby 1979), which could result in a larger δ^{13}C enrichment.

2.4 Stable nitrogen isotope fractionation

The ^{15}N isotope makes up less than 1% of naturally available nitrogen, in contrast to ^{14}N, which comprises at minimum 99.8% of the nitrogen in Earth's biosphere (Rosman and Taylor 1998). As with ^{12}C and ^{13}C, ^{14}N and ^{15}N both are taken up by organisms and become incorporated in their tissues, with a cessation of uptake upon the organism's death.

2.4.1 Nitrogen isotopes in plants

Nitrogen enters food webs through fixation, wherein through various processes, it is converted from an inorganic form to an organic one as nitrogen must form compounds with hydrogen before it can be used by plants (Shin et al. 2016). ^{15}N fractionation begins when atmospheric nitrogen (N_2) is converted to either NO_{3-} (nitrate) or NH_{4+} (ammonium) and taken up by plants. This process, fixation, is done either indirectly by microorganisms in the soil that convert the nitrogen into plant-ready nitrate or ammonium, or directly within the tissues of some types of plants that have symbiotic relationships with nitrogen-fixing bacteria.

Diazotrophs are prokaryotic microorganisms that contain the nitrogenase enzyme complex, necessary for fixing N_2 (Ramos and Biselling 2004). Most diazotrophs live freely in soil (Touraine 2004), though some exist in loose association among certain types of plants, and some directly on plant roots (Unkovich 2013). The legumes and other symbiotic plants feature specialized root nodules which are home to bacteria; these bacteria, rhizobia, fix nitrogen in response to signals sent by the plant (Meeks and Elhai 2002). Almost no discernible isotopic discrimination takes place in symbiotic legume-rhizobia relationships, so this process results in δ^{15}N values of 0‰ (Ambrose 1986; Unkovich 2013). A fractionation of -3 to -1‰ occurs in plants that use the nitrogen compounds produced by soil-dwelling diazotrophs (Hoefs 2009). However, because non-symbiotic plants derive their nitrogen compounds from the soil matrix, their $\delta^{15}N$ values will reflect other sources of nitrogen present (Högberg 1997; Shearer et al. 1978). Generally, warmer temperatures are associated with higher plant $\delta^{15}N$ values (Amundson et al. 2003; Craine et al. 2009). Additional soil-level impacts on plant $\delta^{15}N$ values include precipitation, the depth in the soil at which nitrogen is taken up, whether nitrate or ammonium is the compound taken up by a plant, and the fractionation effects of mycorrhizal symbioses (Högberg 1997). Mycorrhizal fungi provide nitrogen to plants, and in return, receive sugars generated from photosynthesis (Read 1991); offsets between these fungi and plant roots may be as great as +8‰ (Högberg 1997).

Different plant tissues have been shown to carry different $\delta^{15}N$ signatures even within the same plant (Kolb and Evans 2002). For example, a tree's developing leaves may reabsorb nitrogen from root turnover just prior to their emergence (Bausenwein et al. 2001), and the seasonal development of other tissues, like fruit and nuts, may reflect the isotopic signature of the N pool from which the plant was drawing at the time of their development (Kolb and Evans 2002). Because herbivores and omnivores tend to consume certain plant tissues preferentially over others, regular ingestion of specific plant parts can have implications for an individual animal's dietary stable isotope values.

Urea excretion is likely the mechanism responsible for the trophic enrichment of herbivores over plants (Minagawa and Wada 1984). Urea production in an herbivore preferentially uses ^{14}N, serving to increase $\delta^{15}N$ values of its tissues over that of the plants it consumes. At each trophic level after that, the same process continues to increase $\delta^{15}N$ values (Ambrose 1986; Schoeninger and DeNiro 1984).

2.4.2 Nitrogen isotopes in terrestrial environments

The $\delta^{15}N$ values of plants are impacted not only by the fractionation that takes place during nitrogen fixation but also climatic phenomena. In an analysis of $\delta^{15}N$ values from habitats in South Africa and Namibia, Heaton (1987) noted a slight elevation in values associated with arid environmental conditions, but the aridity signature was not significant until the consumer level of the food web. Many studies have documented that the $\delta^{15}N$ signatures of herbivore tissues are negatively correlated with rainfall in the regions whence they live, and hot and dry conditions seem to result in elevated $\delta^{15}N$ values (e.g., Cormie and Schwartz 1996; Sealy et al. 1987). The process by which herbivores in arid environments come to exhibit higher $\delta^{15}N$ values than their counterparts in wetter or more humid areas is not fully understood. There is much scholarship to indicate this phenomenon is an isotopic artifact of the elevated $\delta^{15}N$ signatures of the plants growing in such regions (Hartman 2011; Murphy and Bowman 2006). Other studies indicate this is not the case in all locations and that several complex, animal-specific mechanisms might be responsible for elevated animal $\delta^{15}N$ signatures, including the differential $\delta^{15}N$ values of amino acids in foods consumed by individual animals (Styring et al. 2010) and sustained nutritional stress of animals resulting in higher-than-expected $\delta^{15}N$ values as they are metabolically consuming their own tissues (Sealy et al. 1987).

Heaton (1987) also examined a possible correlation between elevated $\delta^{15}N$ values and a plant's proximity to the coast; values from plants on geographically disparate coasts were variable, but consistently high, suggesting oceanic nitrate from sea spray can affect these values. Further, it was observed that high plant $\delta^{15}N$ values are associated with saline soils, indicating coastal plants' $\delta^{15}N$ values are indeed affected by sea spray.

Controlled experiments have shown that manuring, a widespread agricultural practice, may raise soil $\delta^{15}N$ values (Bogaard et al. 2013; Fraser et al. 2011; Treasure et al. 2015). Other agricultural activities, such as the corralling and pasturing of animals, permit dung to accumulate in areas as herds feed in confined or restricted areas (Makarewicz 2014), which may result in the alteration of a soil's isotopic profile and affect nitrogen cycling processes within it (Szpak 2014). Enriched soils and the plants that grow in them show different isotopic signatures than those that have not been fertilized. Animal dung is enriched in ^{15}N due to ammonia volatilization, wherein ammonium is converted to ammonia gas. During this process, ^{14}N is preferentially lost with the ammonia gas, causing the remainder of ammonium in the waste to become comparatively enriched in ^{15}N (Kerley and Jarvis 1994). Nitrogen-rich additions to the growing medium of plants, whether wild or cultivated, enrich the soil, thereby increasing the $\delta^{15}N$ values of plants sown and grown in them (Bogaard et al. 2007; Bol et al. 2005). The addition of a nitrogen source initiates biogeochemical soil processes, which result in further preferential loss of ^{14}N, leaving behind ammonium and nitrate enriched in ^{15}N (Kahman et al. 2008). Whereas $\delta^{15}N$ values generally are used to assess dietary protein contributions and the assumed trophic level occupied by certain organisms in food webs, Bogaard et al. (2007) suggested a manuring effect might serve to raise tissue $\delta^{15}N$ values of animals that consume plants grown in an enriched medium. Correspondingly, this would raise the tissue $\delta^{15}N$ values of secondary consumers of those animals (Makarewicz 2014). Experimental animal dung manuring projects carried out in England and Germany for over one hundred years provide a line of evidence to support this argument, revealing that manured cereal grains consistently produce $\delta^{15}N$ values higher than those raised in non-manured control plots, on the order of ca. +3‰—equivalent to approximately one trophic level (Bogaard et al. 2007).

Indirectly, isotopic soil enrichment effects can be achieved by concentrating animals in a specific location and allowing their dung to accumulate in that area, such as in a corral or pasture. However, indirect manuring may be a component of a management strategy in which animal waste is incorporated into the upper layers of soil to improve forage quality in subsequent years (Morrison 1959). Additionally, in regularly used pastures, piles of dung should be broken up because cattle and horses avoid consuming plants that grow on or near their waste (Morrison 1959). The isotopic impacts of indirect manuring on enclosure and pasture soils have been given less consideration than intentional manuring, though examinations of abandoned livestock enclosures in Kenya have indicated their upper soil levels are enriched in ^{15}N (Shahack-Gross et al. 2008; Macharia et al. 2012) and demonstrated soil $\delta^{15}N$ values decrease with increasing depth, suggesting the same phenomenon is at work even when manure is not purposely applied. Soils appear to remain enriched for some time after manuring activities or dung accumulation has ceased, still creating isotopic implications for fields and/or enclosures used on a rotational basis.

Tundra vegetation is sensitive and responds to environmental changes more rapidly than plants at lower latitudes, particularly when nutrients are introduced, increasing local nitrogen pools (Chapin et al. 1995). A study by Nadelhoffer et al. (1996) examining δ^{15}N values in arctic tundra plants in central and coastal Alaska showed they are the greatest among sedges (1 to 3‰) and lowest among woody shrubs (-7 to -4‰); lichens, mosses, and deciduous willows exhibited intermediate values between the two (-3 to -2‰).

2.4.3 Nitrogen isotopes in aquatic environments

In clean freshwater systems, water carries a dissolved inorganic δ^{15}N value of 0‰ (Fry 1991), and in marine systems, these δ^{15}N values increase to 5‰ (Liu and Kaplan 1989). As with terrestrial plants, aquatic plant δ^{15}N values show a wide range of variability (Pomerleau et al. 2014; Schoeninger and DeNiro 1984). δ^{15}N values tend to be higher among marine and freshwater organisms than in terrestrial ones because aquatic food chains are longer (Schoeninger and DeNiro 1984). These values, therefore, can be used to assess the contribution of marine or terrestrial resources being consumed by animals at higher trophic levels (Schoeninger et al. 1983; Schoeninger and DeNiro 1984).

In pelagic food webs, trophic relationships appear to be based on organism size (Azam et al. 1983; Cousins 1980, 1985). Relationships in estuarine food webs are not as well understood. While often characterized as nurseries for larval and juvenile fish and as homes to estuary-dependent species, the use of estuaries by fish is highly variable. Able (2005) argues that the poorly understood or unknown but likely complex life histories and behaviours of many taxa present in estuaries, particularly fish, complicate our understanding of trophic relationships in these ecotones.

In addition to fractionation effects, extreme seasonal events such as winter freeze-up and spring floods may have substantial impacts on riverine ecology at more northerly latitudes. However, studies of these effects have focused on larger organisms such as fish (e.g., Weber et al. 2013), and their effects on phytoplankton and plant communities are understudied.

2.4.4 Nitrogen isotopes in skeletal tissues

Because carbohydrates and lipids do not contain nitrogen, the nitrogen in all consumers' tissues is derived from dietary protein (Ambrose et al. 1997). Beginning with plants, reliable, stepwise increases in $\delta^{15}N$ values resulting from isotopic fractionation occur at each trophic level. It has been demonstrated experimentally that animals consuming high-protein diets have higher diet-tissue fractionation values (DeNiro and Epstein 1978, 1981; Sponheimer et al. 2003), such that an animal consuming plants would show a smaller trophic level enrichment between its diet and bone collagen $\delta^{15}N$ values. Correspondingly, several studies have demonstrated variable ranges of this increase at different trophic levels among mammals, ranging between +1.6 and +6.9‰ (Bocherens and Drucker 2003; Hedges and Reynard 2007; Szpak et al. 2012). Most archaeological dietary stable isotope studies use a range of approximately +3 to +5‰ between each trophic level. Likewise, I interpret the data in this study using this narrower range. Hobson and Clark (1992b) determined that several avian species exhibited comparable $\delta^{15}N$ trophic level enrichment values to those of mammals and were consistent with the 2.4 to 4.0‰ range reported by DeNiro and Epstein (1981). In their study, however, the bone collagen $\delta^{15}N$ enrichment factor was higher among birds with plant-based diets than those with piscivorous diets. They suggested this may be related to birds' production of waste nitrogen in the form of uric acid rather than urea like many other animals (Owens 1987). Laboratory and field experiments reporting fish diet and bone collagen $\delta^{15}N$ values and enrichment factors are limited. Among schools of sampled marine fish [Cape anchovy (*Engraulis capensis*) and roundherring (*Etrumeus whiteheadi*)], Sholto-Douglas and colleagues (1991) report trophic level $\delta^{15}N$ enrichments of 2.0‰ and 2.5‰, respectively.

2.5 Bone collagen turnover

In bodily tissues, isotopic turnover is directly linked to growth (the addition of tissue) or remodeling (the replacement of tissue) processes. Even after an organism has reached biological maturity, metabolic activities maintain the structure and functioning of the entire body by replacing tissues, including collagen in the bones of vertebrate animals. Bone collagen is a favoured material for dietary stable isotope analysis because it tends to preserve in quantities that permit extraction and analysis even after hundreds of thousands of years (Jones et al. 2001). However, bone turns over more slowly than most tissues and is not as sensitive to seasonal and short-term variations in diet as highly metabolically active tissues, like blood, muscle, and organs (Tieszen et al. 1983; Stenhouse and Baxter 1979), or tissues not subject to remodelling, like tooth dentine. Most dietary stable isotope studies using bone collagen assume that the individuals whence samples came were in equilibrium with their diets—i.e., that the isotopic composition of bone collagen is consistent with what the individuals consumed (Vander Zanden et al. 2015), but as suggested above, this rate can also be impacted by dietary shifts (Fry and Arnold 1982; Phillips and Eldridge 2006). Turnover rate is typically expressed as a half-life measurement, the rate being the amount of time it takes an animal's tissues to reach 50% equilibrium with its diet (Fry and Arnold 1982).

Half-life values vary by tissue type and mechanism of heat regulation. In their comprehensive literature synthesis of ectothermic and endothermic animals, Vander Zanden et al. (2015) determined the isotopic half-life of *some* tissues increases with body mass and found consistent relationships between mass, taxon, tissue type, and isotopic half-life. While bone collagen was intentionally excluded from their review, the implication of their results is that the isotopic composition of tissues routinely eaten by secondary consumers, including muscle, blood, and internal organs, can vary due to the differential half-lives of these tissues, and also may vary with the overall body mass of the taxa whose tissues were consumed.

On an individual scale, an animal's age, different skeletal elements, and different types of bone may undergo different rates of turnover. Cortical (or compact) bone forms the hard, smooth surfaces of most vertebrate bone. In mammalian long bones, cortical bone is thickest and densest at the midshaft. The avian skeleton also is composed primarily of cortical bone (Bonser 1995). Though the particulars of bone tissue turnover are complex and vary from element to element and among specific locations therein (Parfitt 2002), collagen in most cortical bone takes longer to isotopically turn over than lightweight, porous, and highly vascularized trabecular bone (also known as spongy or cancellous bone). Until recently, Hedges et al. (2007) had carried out the most directed study of bone collagen turnover in humans. They reported that bone collagen in adult human females turns over more quickly than in adult males, that juvenile bone collagen experiences faster rates of turnover than that of adults, and that femoral bone collagen reflects a period longer than ten years. They also suggested that the rate of bone collagen turnover can vary in different locations on the same cortical bone belonging to the same individual (Hedges et al. 2007). A recent study published by Matsubayashi and Tayasu (2019) found that collagen extracted from the cortical bone of the femoral midshaft of four terrestrial mammalian species largely reflected their diets in adolescence, not the average of their more recent dietary inputs. The authors firmly established that the isotopic turnover of collagen does not take place evenly in cortical bone, with layers corresponding to different periods in an animal's life, and that the femoral midshaft is not extensively remodeled. However, δ^{13}C and δ^{15}N values acquired for each sample for each individual do not show a wide range of variation, suggesting these animals' diets changed little throughout their lives (Matsubayashi and Tayasu 2019). For skeletally mature animals that lived and ate in the same ecosystem until death, it is reasonable to infer that the isotopic composition of their bone collagen generally was in equilibrium with their diets. However, among animals that complete seasonal migrations between different types of ecosystems (particularly some types of birds and fish) or which may have been transported long distances through human activities (such as domestic livestock), it cannot be assumed that the $\delta^{13}C$ and $\delta^{15}N$ values of their bone collagen reflect equilibrium with diet.

Turnover of bone collagen in non-mammalian taxa may be linked to additional phenomena. Bird tissues undergo the most rapid rates of isotopic turnover of all animals (Vander Zanden et al. 2015). In an experiment to assess the isotopic half-life of tissues in exercising and non-exercising rosy starlings (*Pastor roseus*), Hobson and Yohannes (2007) observed no difference between the two groups, suggesting turnover rates are not linked to higher energy expenditures, such as those associated with flight. Among fish, in a controlled feeding experiment using winter flounder (*Pseudopleuronectes americanus*), rates of dietary whole-body isotopic turnover in fish tissues appear to be dependent on water temperature, with shorter half-lives of both ^{13}C and ^{15}N in fish tissues documented in warmer water (Bosley et al. 2002). In another study reported by Hesselein et al. (1993), the growth of a species of whitefish (*Coregonus nasus*) more immediately and significantly impacted the $\delta^{13}C$ and $\delta^{15}N$ signatures of its tissues. In more slowly developing individuals, the rate of remodelling appears to be much slower; Hesselein et al. (1993) propose it could take years for the tissues of a slow-growing fish to reach isotopic equilibrium with its diet.

2.6 Diagenetic processes in bone

Of all vertebrate skeletal elements, bones and teeth are the likeliest to maintain their structural integrity, and often are recognizable thousands of years after an organism has died. Further, bone collagen is an ideal tissue for use in paleodietary and ecological applications because it is abundant in the skeleton and is easy to isolate from hydroxyapatite (Hedges and Law 1989). However, as an organic material embedded in a crystalline structure, bone collagen is subject to degradation, and chemical impacts to hydroxyapatite can make bone collagen even more vulnerable. These highly variable mechanisms are collectively referred to as diagenesis, the postmortem chemical alteration of bone tissue following its deposition in soil (Sandford and Weaver 2000). Collins and colleagues (2002) identify three broad means by which bone is altered after death: 1) chemical deterioration of organic collagen; 2) chemical deterioration of mineral hydroxyapatite; and 3) biological attack of both components. The specific forms of diagenesis are mostly dependent on the passage of time and the context of deposition. Examinations of depositional conditions often include soil characteristics and chemical interactions (Sillen 1989), temperature (Roberts et al. 2002), and the effects of precipitation and groundwater (Hedges and Millard 1995), though the extent to which these variables affect skeletal tissues is itself variable.

Another significant impact on the quality and quantity of bone collagen is attack by biological agents. Microorganisms present in soil at the site of deposition may be introduced to bone collagen as hydroxyapatite degrades (Grupe et al. 1993), though more recent work by Jans et al. (2014) demonstrates that the condition of a corpse also may affect the later integrity of bones. Of all archaeological human and animal samples examined in that study, human skeletal remains show the highest incidence of bacterial attack, and those effects are observed most markedly in the abdominal area, suggesting bacterial activity during putrefaction plays an early and significant role in the preservation of human skeletal tissues and renders them susceptible to other kinds of diagenetic changes (Jans et al. 2014). Conversely, because animal skeletal remains from archaeological sites are reasonably assumed to have come from individuals butchered soon after death, they tend to lack the bacterial attack pattern seen in human skeletal remains; Jans and colleagues (2014) determined animal bone was generally better preserved than that of humans for this reason.

2.7 Animals as dietary analogues

Stable isotope studies have shown that animals feeding in proximity to humans have distinctive $\delta^{13}C$ and $\delta^{15}N$ values that reflect anthropogenic influences on their diets. This is true of both managed domestic and captive animals (e.g., Finucane et al. 2006; Sugiyama et al. 2015; White et al. 2001), and wild or unmanaged populations (e.g., Monagle et al. 2018; Murray et al. 2015; Penick et al. 2015). Some animals are attracted to human disturbance on landscapes, such as garbage dumps and areas cleared for agricultural activities (e.g., Cormie and Schwarcz 1994; Liu et al. 2012:288; Tankersley and Koster 2009:369), and where food is stored or prepared (Hu et al. 2014: Pechenkina et al. 2005; Sheng et al. 2020). Indeed, feeding in areas disturbed by humans has been suggested as one of several vehicles for the behavioural changes associated with domestication, including that of dogs (Coppinger and Coppinger 2001:57-68). Stable isotope values for fauna thus potentially inform not only about these animals' diets, but also can be used to make inferences about the diets of humans sharing their environments. Three sites in the present study—Ust'-Polui, Boisman II, and Pospelovo I—have yielded both human and dog skeletal remains that have been analyzed using stable isotope techniques and provide a foundation on which to explore the dietary similarities between the two species.

Dog skeletal remains have been a subject of archaeological dietary stable isotope analyses due to their close association with humans worldwide. Whether they were intentionally provisioned by humans or were permitted to scavenge on human subsistence waste, it is argued that their dietary inputs reflect human dietary inputs to some extent, which can be accessed through stable isotope analysis (Allitt et al. 2008; Hogue 2003; Katzenberg 1989; White and Schwarcz 1989; White et al. 2001). In a 2012 publication, Eric Guiry synthesizes data from archaeological stable isotope studies that report the analysis of both human and dog skeletal remains, citing the consistency of a +2 to +3‰ offset in $\delta^{13}C$ values between humans and dogs. He uses this figure to provide support for the "Canine Surrogacy Approach" (CSA), a technique by which dog stable isotope data can be used to make inferences about human diets.

A number of studies reviewed by Guiry (2012:355) used dog stable isotope samples to examine the timing, spread, and intensification of C_4 plant agriculture in the Americas (maize, *Zea mays*) and Asia (millets, *Panicum miliaceum* and *Setaria italica*). As explained in section 3.2, high $\delta^{13}C$ values are associated with plants that use the C_4 photosynthetic pathway. Some researchers have argued that human and faunal archaeological stable isotope samples with a high $\delta^{13}C$ value are the result of significant quantities of C_4 plants in individual diets, which generally are characterized as being possible only through cultivation of a C_4 plant (e.g., Finucane et al. 2006; Liu et al. 2012; Pechenkina et al. 2005). However, $\delta^{13}C$ values cannot resolve whether a C_4 plant resource was consumed directly, used to provision animals that were later consumed by humans and dogs, or accessed by unmanaged animals that were later consumed by humans and dogs.

Broomcorn millet (*P. miliaceum*) and foxtail millet (*S. italica*) were first cultivated in Neolithic China, and like maize in the Americas, are used to examine the spread of agriculture in Asia (Li et al. 2020; Lu et al. 2009; Yang et al. 2012). Stable isotope studies have demonstrated that millet appears to have been used as either a human food or fodder for animals destined for human consumption (Atahan et al. 2014; Barton et al. 2009; Hu et al. 2008; Liu et al. 2012; Pechenkina et al. 2005). Though Asia has some naturally-occurring C_4 plant taxa that could raise $\delta^{13}C$ values in both wild and domestic animals (Pechenkina et al. 2005:1182), it has been suggested that a significant quantity of this type of resource would need to be consumed to be reflected isotopically, perhaps beyond the capacity of a local ecosystem to provide (Barton et al. 2009:5524; Pechenkina et al. 2005). For example, Barton et al. (2009) report a bimodal distribution of dog $\delta^{13}C$ values from the Neolithic Dadiwan site in China, which indicates that some dogs consumed significantly more millet or millet-fed resources than other dogs.

Some archaeological pigs (*Sus scrofa*) also show dietary isotopic similarities to contemporaneous humans whose diets featured millet or millet-fed resources (Hu et al. 2008; Liu et al. 2012; Pechenkina et al. 2005). At sites where both domestic pigs and wild boar have been identified, there exists a range of $\delta^{13}C$ and $\delta^{15}N$ values between individual suids, suggesting that some were members of a managed population while others were not (Hu et al. 2008; Kuzmin et al. 2018). As both dogs and pigs are known to scavenge on human refuse, such differences also may be the result of some individuals accessing that resource (Hu et al. 2008:2963; Pechenkina et al. 2005:1184).

Guiry's (2012) review also includes studies that examine the applicability of the CSA to coastal diets. Early work with dog stable isotopes in Europe demonstrated that dog dietary trends closely followed those of humans as the latter shifted focus from high $\delta^{13}C$ value marine resources to lower $\delta^{13}C$ terrestrial ones (e.g., Clutton-Brock and Noe-Nygaard 1990). In North America, Cannon et al. (1999) used dog samples to fill in gaps in the human dietary record at the coastal Namu site in British Columbia, corroborating the shift from salmon to shellfish remains observed in the site's midden deposits. Though earlier stable isotope scholarship suggested the presence of human-procured foods in dog diets, Cannon et al.'s study was the first explicit example of dog stable isotope data employed as proxies for human dietary information.

Earlier scholarship in Siberia has provided some support for the applicability of the CSA. In the Cis-Baikal region of eastern Siberia, archaeological canid-focused research carried out by Losey et al. (2011, 2013) has included dietary stable isotope studies and is supplemented by a host of human stable isotope data from the same sites (Katzenberg and Weber 1999; Katzenberg et al. 2010; Katzenberg et al. 2011). Dog dietary stable isotope trends mirror those of humans and show a ca. +2‰ offset between human and dog $\delta^{13}C$ values (Losey et al. 2013). $\delta^{15}N$ values tend to be lower than those of humans, perhaps indicative of dogs' consumption of greater quantities of bone collagen, or among aquatic resource-based diets, fish of a smaller size (Losey et al. 2013).

2.8 Samples and selection

All archaeological samples collected for this project were obtained from assemblages housed in curation facilities across the Russian Federation and were collected by Dr. Robert Losey, Dr. Tatiana Nomokonova, and myself, under the supervision of and with the express consent of Russian archaeologists responsible for the materials. The collection of present-day fish bone specimens from the Shilka River was conducted by Mr. Sergei Cheremisin, a sport fisherman.

The primary objective when sampling was to acquire specimens from all animal taxa represented at each site to the greatest extent possible. This was done to examine isotopic differences between animals and gain perspective on food web relationships, as well as to assess isotopic similarities revealing ecological conditions. Certain taxa were so abundant at some sites that we were able to sample a variety of individuals within a single taxon. To avoid sampling the same individual multiple times, efforts were made to sample the same element (e.g., all right mandibles) across the taxon. Further, we intentionally avoided juvenile individuals whenever possible, as well as specimens exhibiting signs of skeletal trauma or disease, as each of these has isotopic implications this study was not designed to assess. Situations in which it was not possible to avoid taking samples from juvenile individuals are discussed in Chapter 5.

2.7 Analytical methods

The stable isotope analysis was conducted using a modified version of the Oxford sample preparation method (Bronk Ramsey et al. 2004). All samples were surface cleaned with a soft brush and distilled water, and outer bone surfaces were burred off. Samples were then sonicated in several changes of distilled water. After allowing the samples to air dry, they were ground to a powder consistency in a liquid nitrogen mill. Approximately 500 mg of powder from each sample was placed in a vial with 12 mL of 1% hydrochloric acid (HCl), shaken, and allowed to demineralize. The solution was changed several times during the demineralization process, and complete demineralization of each sample was assessed visually. After demineralization, samples were centrifuged and rinsed in double-distilled water until they reached neutrality. After the demineralization process, 12 mL of .01M sodium hydroxide (NaOH) solution was added to each sample to remove humates. The vials were allowed to react, then were centrifuged and rinsed in changes of double-distilled water until they reached neutrality. Immediately following this step, another 12 mL of 1% HCl was added to sample vials. Vials were shaken and left to react, then centrifuged and rinsed with double-distilled water until neutrality.

Six mL of acidulated water (pH 3) was added to each vial and shaken. The samples were then placed in a 75°C water bath and left undisturbed for 20 hours to allow the collagen to gelatinize into solution. The supranatant was filtered through a glass fiber filter paper using a 40 mm Büchner filter. Approximately 6 mL of filtrate from each sample was poured into a dual-chambered ultrafiltration vial and centrifuged until 1 mL remained in the upper chamber. This amount was pipetted into a centrifuge vial, frozen, lyophilized, then analyzed at the University of Alberta's Biogeochemical Analytical Services Laboratory. Samples were analyzed for $\delta^{13}C$ and $\delta^{15}N$ values using a EuroVector EuroEA3028-HT elemental analyzer coupled to a GV Instruments IsoPrime continuous-flow isotope ratio mass spectrometer.

2.8 Bone collagen sample quality

Each sample in this study was determined to be of adequate quality upon visual inspection, and generally high levels of organic preservation for all materials were reported for each site. It is useful here to make a distinction between two phenomena which may impact a collagen sample's quality. Degradation of collagen refers to its diagenetic breakdown, the splitting of bonds between amino acids that ultimately decreases the amount of analyzable collagen in a sample (van Klinken 1999). In this scenario, a sample retains its isotopic integrity even with small yields, but the initial amount of bone needed to acquire an adequate amount of collagen is increased, and in doing so, the potential for contamination to affect isotope results is heightened (van Klinken 1999). Contamination is caused when external substances bind to collagen and alter its chemical composition (van Klinken 1999). Humic acids derived from plants and found in soil and peat, are a significant source of archaeological collagen sample contamination.

To some extent, different extraction techniques and treatments can address these issues. For example, ultrafiltration is employed to improve yields from degraded samples by retaining collagen with higher molecular weight (Sealy et al. 2014), and NaOH treatment is used to remove humic contaminants from collagen (Liden et al. 1995). However, before stable isotope analysis is performed, it can be difficult to assess whether diagenetic effects or contamination are likely to impact collagen yields or quality. Building on earlier research executed by Ambrose (1990), van Klinken (1999) explored more deeply the use of elemental data acquired during stable isotope analysis to develop “alternative screening parameters” in the assessment of collagen quality, suggesting that several types of elemental data including sample collagen yield expressed as a percentage of the original whole bone sample, %C and %N content of collagen combusted during mass spectrometry, and sample C:N ratio. Using the guidelines recommended by van Klinken (1999), any collagen sample with a yield of less than 1% of its original weight has been excluded from discussion here, though in some instances the sample was analyzed if there was ~1 mg of collagen. Generally, the collagen yields acquired for all sites in this study were low, which may in part be due to the NaOH treatment performed on each sample. However, humic acid contamination was expected to have a considerable impact on the stable isotope values and was deemed necessary. Samples for which the associated C:N ratio falls outside the 3.1 to 3.6 range are thought to show evidence of contamination (DeNiro 1985; van Klinken 1999), and any such sample has been omitted from further consideration. Samples subject to instrument error at any stage of analysis also have been omitted. The results for all samples may be reviewed in Appendix A.

3 Ecological Setting and Archaeological Context

In this chapter, I describe the archaeological contexts of the sites analyzed in the Lower Ob, Transbaikal, and Primorye regions. In these descriptions, I explore the culture history model of each region, and present the excavation history and current interpretations of each site in the study. To contextualize the stable isotope data to the greatest extent possible, I also provide an overview of the geographic and ecological setting of each site in this study. Unless otherwise stated, radiocarbon dates reported in the text were obtained through AMS dating and calibrated using Oxcal 4.2, and the IntCal 13 calibration curve (Bronk Ramsey 2009, 2014; Reimer et al. 2013). In many cases, radiocarbon dates for sites were obtained for the first time as part of this dissertation. In all cases where dates are not previously published, they are provided here.

3.1 The West Siberian Plain and Lower Ob Region

The West Siberian Plain is a vast expanse of low-lying territory bounded by the Ural Mountains to the west, the Yenisei River to the east, and the Altai Mountains to the southeast (Figure 3.1), comprising approximately one-third of Siberia. Though the region is drained by the Ob-Irtysh River system, actual drainage in the area is poor. For this reason, the West Siberian Plain features some of the world's largest swamps, floodplains, and peatlands (Tishkov 2002). Extreme seasonal variations characterize the West Siberian Plain, particularly in the more northerly reaches. In the present-day city of Salekhard on the Arctic Circle, summer temperature averages +14°C, with an average winter temperature of -24°C (Kukarskih et al. 2018). Paleoclimatic data indicate the region was variously glaciated during much of the Pleistocene, but by ca. 9000 years ago, the region was covered by northern taiga vegetation (Besprozvanny et al. 2017). Today, the area around Salekhard lies in the convergence zone between taiga (to the south) and shrubby tundra (to the north). While the boundaries of these biomes are sensitive to climatic changes and have shifted over the millennia, since the end of glaciation the area has lain in close proximity to both (Kukarskih et al. 2018).

Figure 3.1 Location of the Ust'-Polui site in the Lower Ob region. Inset: area shown in larger map. Map produced with data from Natural Earth.

The region's position at the tundra and forest ecotone is reflected in its flora and fauna. Tree canopies are low in height and largely open, dominated by Siberian spruce (*Picea obovata*), larch (*Larix sibirica*), or both, with many dwarf shrubs and mosses in the understory (Tishkov 2002). Archaeological and present-day data indicate the presence of Eurasian beaver (*Castor fiber*), mountain hare (*Lepus timidus*), sable (*Martes zibellina*), Eurasian otter (*Lutra lutra*), stoat (*Mustela erminea*) and least weasel (*Mustela nivalis*), wolf (*Canis lupus*), Arctic and red foxes (*Vulpes lagopus, Vulpes vulpes*), brown bear (*Ursa arctos*), wolverine (*Gulo gulo*), moose (*Alces alces*), and reindeer (*Rangifer tarandus*) (Bachura et al. 2019). Additionally, many different types of birds, including migratory and resident species, are found here.

The Ob is 3676 kilometers long and is the world's seventh-longest river. Along with its tributaries, its watershed measures approximately 2,975,000 square kilometers (Zhang et al. 1999). The river's formal origin is at the confluence of the Biya and Katun Rivers near the city of Biysk, north of the Altai Mountains. From Biysk, the river takes a northwesterly route across the West Siberian Plain. At the Ob-Irtysh confluence near the city of Khanty-Mansiysk, it flows generally northward, but makes a hard turn to the east at Salekhard before discharging into the Gulf of Ob (also referred to as Ob Bay or Obskaya Inlet), which forms an estuary with the Kara Sea (Denisenko et al. 1999). In the lower reaches of the Ob, where the Ust'-Polui site is located, the river measures from four to ten meters in depth. The incremental elevation change along its length has resulted in numerous meanders and oxbow lakes (Papa et al. 2007:11).

The river's flow is entirely dependent on season. In winter, the river is bound up in ice, resulting in substantial spring and summer flooding following break up (Suslov 1961). Each autumn, a remarkable ecological event takes place in the middle reaches of the Ob. Known as the winter hypoxia event (*zamora*, in Russian), rapidly decreasing oxygen concentrations in the river force fish of all sizes and species to seek more oxygenated waters, which they achieve by moving downriver to the Gulf of Ob

(Ruban 2018). Fifty-five species of fish are found in the Ob River and the Gulf of Ob, as well as many mollusk and insect taxa, which provide a source of nutrition for larger fish taxa, including sturgeon, sterlet, inconnu, whitefish, and burbot (Bogdanov and Bogdanova 2016; Koporikov and Bogdanov 2011). A study examining productivity levels in the Gulf of Ob compared to the adjacent Kara Sea has demonstrated that the high productivity of the river is linked to its phytoplankton biomass, which is enriched by living and dead organic matter carried along the river's length (Makarevich et al. 2003).

3.1.1 Lower Ob archaeological contexts

The knowledge of the prehistoric archaeological contexts of the lower Ob River is somewhat limited. The northern portion of the West Siberian Plain was glaciated during the Pleistocene, effectively preventing human settlement and activity on the lower Ob. In the Late Pleistocene, palynological data indicate the landscape of the lower Ob was periglacial, with sagebrush-grass steppe to the south of the river and glaciers to the north of it (Besprovzanny et al. 2017). Evidence for a human presence on the West Siberian Plain during the Late Pleistocene is scarce and limited to the more southerly areas of the region. Reviewed by Besprovzanny et al. (2017), a human bone, a variety of lithic implements, and several suspected mammoth kill or scavenging sites have been assigned to the Late Paleolithic, primarily on the basis of direct or contextual radiocarbon dates. There is no evidence of human occupation of the Arctic areas of the West Siberian Plain until the Holocene, and it has been suggested there was no permanent habitation of this part of the plain prior to 4000 to 3000 years BP (Pitul'ko 1999).

During the Holocene, coniferous boreal forests began to dominate the Lower Ob region (Besprovzanny et al. 2017), and sites confidently associated with Neolithic peoples in this region are numerous, suggesting the environment had become favourable for human habitation. As with the rest of Siberia and the Russian Far East, the Neolithic in the Lower Ob is not associated with the onset of agriculture, but rather with the widespread use of ceramics and ground-stone tool technologies. Neolithic habitation sites—residential areas with rectangular pit houses—have been described, and strata from structure floors yielded bird and mammal bone, fish scales, remnants of charcoal and ash features, ceramic vessel fragments, and stone implements (Chernetsov and Moszyńska 1974). Human groups living along the Arctic coast likely engaged in marine-focused fishing and mammal hunting (Golovnev 1992; Chernetsov and Moszyńska 1974; Vizgalov et al. 2013), while those inhabiting taiga regions along the Ob River and the Gulf of Ob probably focused on hunting terrestrial mammals and the resources provided by the abundant riverine fishery (Pitul'ko 1999).

Despite the latitudinal expanse of the West Siberian Plain and its various ecosystems, the Bronze Age material culture in this region shares similarities with contemporaneous Andronovo styles further to the south, perhaps due to the general north-south orientation of the Ob-Irtysh River system and their many east-west tributaries (Chernetsov and Moszyńska 1974).

The focus of my research in the Lower Ob region is the Iron Age site of Ust'-Polui. By the Iron Age, fortified settlements, campsites, cemeteries, and prescribed locations where sacrifices were conducted (*svatilische*, in Russian) are diffuse, particularly in forested regions (Chernetsov and Moszyńska 1974). Widespread occupation of the tundra region to the north appears somewhat later, probably around the eleventh century CE (Nomokonova et al. 2018). Materials recovered from Iron Age sites in the Lower Ob show a diverse subsistence strategy. Specialized projectile points and composite bow pieces indicate a reliance on terrestrial mammal and bird hunting, though the presence of harpoons suggests marine mammals may have been taken on occasion if drawn into the Gulf or into the Ob River (Chernetsov and Moszyńska 1974; Vizgalov et al. 2013). The presence of other implements like fish spears and hooks, along with the abundance of fish bone and scales observed at Iron Age sites, attest to the significance of fishing on the Lower Ob (Chernetsov and Moszyńska 1974). Fish remains are generally rare in the region's collections due to a lack of site sieving (Vizgalov et al. 2013).

The skeletal remains of dogs also are frequently encountered at prehistoric archaeological sites in the Lower Ob region (reviewed in Losey et al. 2018b). The contexts of their deposition indicate dogs were an important part of human societies but likely had variable roles, as both complete dog burials and disarticulated remains have been recovered from sites in this region (Chernetsov and Moszyńska 1974; Vizgalov et al. 2013). According to historical documents and ethnographic studies of human groups who inhabit the Lower Ob, dogs have been employed in the hunting of birds and terrestrial mammals, and the use of dogs as reindeer herding partners and for pulling sleds also have been reported (Davydov and Klokov 2018; Losey et al. 2018b). At the Ust'-Polui site, small carved bone harness pieces and the well-preserved remains of several wooden sled runners suggest dog team-powered traction was practiced here in the Iron Age (Losey et al. 2018b). These sources also indicate the dog was used as a sacrificial animal, a source of fur, and occasionally, a source of food for humans (Davydov and Klokov 2018; Losey et al. 2018b).

Climatic data has shown that the Lower Ob region is subject to regular environmental fluctuations, and that its ecosystems experience greater short-term impacts than other areas of the planet (Forbes 1999). Such shifts may alter the length and intensity of the seasons, affect ice cover, and cause forests to advance north or retreat south. In the assessment of Krupnik (1993), these shifts are a hallmark of Arctic ecosystems, and have from time to time resulted in the radical restructuring of subsistence and resource management activities of their human inhabitants. A recent publication by Bachura et al. (2019) compared the incidence of terrestrial mammalian fauna skeletal remains recovered from sites in the central and southern forest-tundra. The presence of beaver, mountain hare, Arctic and red foxes, sable, moose, domestic dog, and reindeer skeletal remains indicates that such animals were consistently available from the Neolithic until the twelfth century and highlights the importance of terrestrial resources to the human inhabitants of the interior. After the twelfth century, the number of mountain hare, Arctic fox, and reindeer bones increases sharply and is roughly coincident with the Little Ice Age, though it is not clear how many individual animals these remains represent (Bachura et al. 2019). It is thought that the climatic changes that occurred during the Little Ice Age allowed for the rise of large-scale, intensive reindeer pastoralism across the European and Siberian Arctic (Krupnik 1993; Stépanoff 2017). Reindeer pastoralism is a relatively recent innovation that emerged over several centuries and is considered one of the most obvious and well-documented transformations from a hunter-fisher-gatherer subsistence economy to that of an intensive focus on a single species of livestock (Krupnik 1993; Losey et al. 2020; Stépanoff 2017). Reindeer pastoralism is a system characterized by large domestic herds that are accompanied by human herders as they make their seasonal migrations across the landscape. In the summer, many reindeer herds in Northwest Siberia move north, where they take advantage of tundra areas with winds that keep temperatures and biting insects at the greatest possible minimum (Skogland 1989; Stammler 2010:217). At the onset of cooler temperatures in the autumn, such herds begin their southward sojourn for the winter, toward shelter provided by the tree line. Some groups, however, remain on the northern tundra year-round, while others migrate from lowland areas to the slopes of the Ural Mountains.

Despite the relatively recent innovation of reindeer pastoralism, it appears the process of reindeer *domestication* began sometime in the Late Holocene, and they are understood as related yet distinct processes (Anderson et al. 2019; Stépanoff 2017). The keeping of reindeer in small, managed herds likely began many centuries before the emergence of large-scale reindeer pastoralism (Anderson et al. 2019; Nomokonova et al. 2018; Stépanoff 2017). Whereas most domestication narratives focus on the human control of animals, Indigenous oral traditions that explain the history of the reindeer-human relationship focus primarily on the mutually beneficial partnership between the two (Stépanoff 2017), and Istomin and Dwyer (2010) have demonstrated that reindeer herds and humans have adapted their behaviours in different parts of Eurasia. It is possible the Indigenous inhabitants of Siberia employed partially tamed or domesticated reindeer as hunting decoys or pack animals deep in antiquity (Anderson et al. 2019;

Krupnik 1993), and there is much historical and ethnographic documentation to support the view that they were used primarily in support of hunting and fishing activities (Stépanoff 2017). Material culture from the Ust'-Polui site, primarily in the form of harness and tack elements, supports the use of tame or domestic reindeer by at least the Iron Age, around 2200 BCE (Fedorova 2003; Chernetsov and Moszyńska 1974).

3.1.2 Ust'-Polui

The Iron Age site of Ust'-Polui is within the limits of the present-day city of Salekhard, Russian Federation, situated on a finger of land created by the northeast bank of the Polui River at its confluence with the much larger Ob River (Figure 3.2). Here, the Ob meanders dramatically and measures almost five kilometers across, which in warmer seasons gives rise to expansive wetlands that provide fishing opportunities and access to waterfowl (Losey et al. 2018b). The site is situated in a forest-tundra ecotone, with taiga to the south, and shrubby tundra to the north, and is approximately 60 kilometers east of the polar Ural Mountains foothills (Losey et al. 2018b). Across the Ob and immediately to the northwest of Ust'-Polui is the Kamen Portage, which permits passage through the Polar Urals (Figure 3.1). Additionally, Ust'-Polui is situated four kilometers southeast of Angalskiy Cape, which juts into the Ob River (Chernetsov and Moszyńska 1974).

The site was discovered in 1932, and its first excavation was directed by V.S. Andrianov in 1935-36, at which time approximately 10% of the site was excavated (Potapova and Panteleyev 1999). V.N. Chernetsov and W. Mosyńska visited the site in 1946, digging several test pits. From 1993-95, excavations were conducted jointly by the Yamal Archaeological Expedition of the Ural Branch of the Institute of History and Archaeology and Ural University under the direction of N.V. Fedorova, and since 2006 have been led by A.V. Gusev (Losey et al. 2018b).

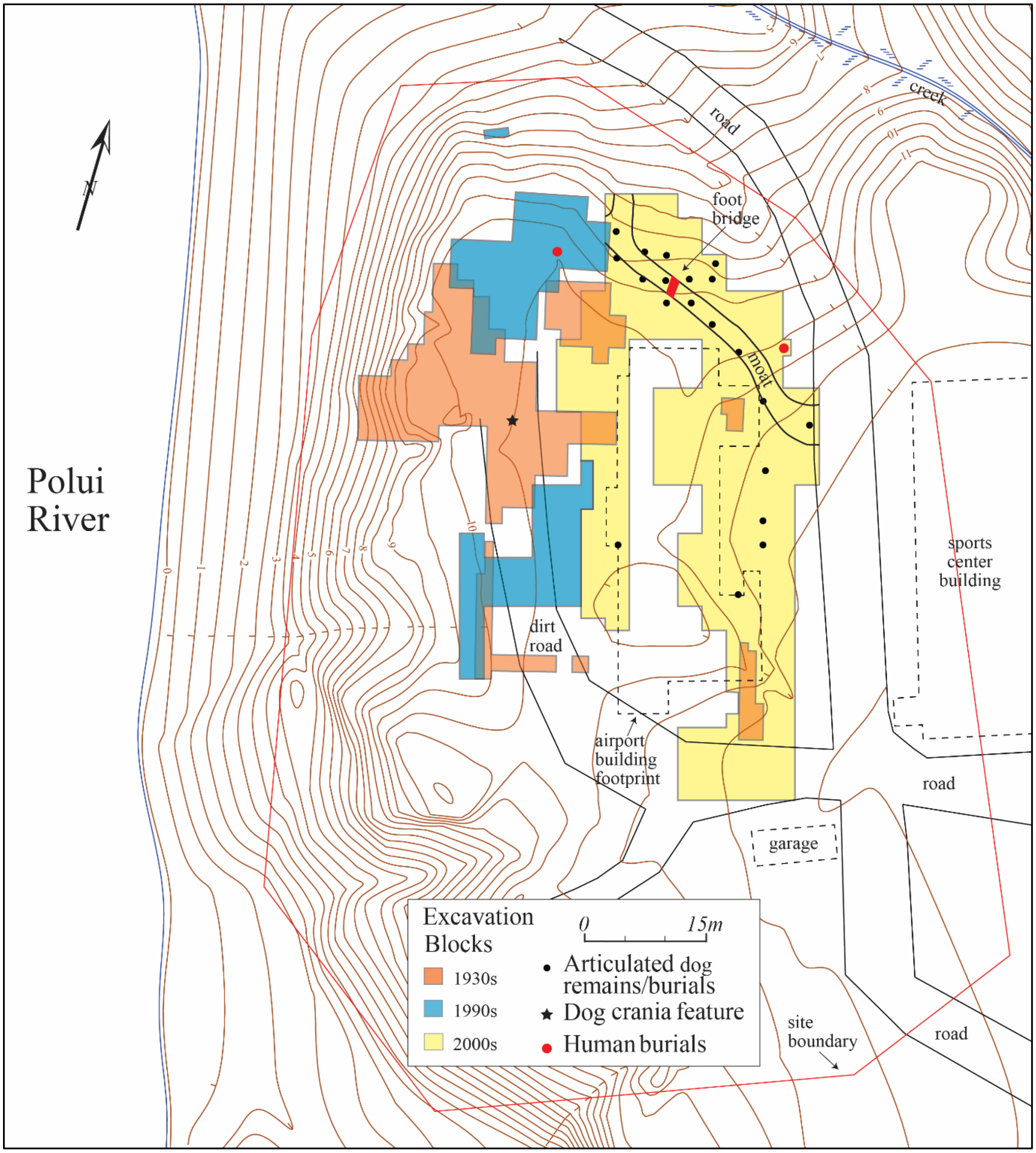

Figure 3.2 *Plan view of the Ust'-Polui site showing excavation blocks and key finds. Map courtesy of R. Losey and A. Gusev.*

Though Ust’-Polui was disturbed and partially destroyed by construction projects, some physical features of the site noted during excavations have strengthened its interpretation as a ceremonial location. The site is enclosed by a moat to the north and east, which possibly once enclosed the entire area. The moat or ditch is 1.2 to 1.6 meters deep and 1.3 to 1.6 meters wide and was traversable by a wooden footbridge oriented due north. The moat was unlikely effective as a defensive feature but may have served to conceptually separate the space from the surrounding landscape (Losey et al. 2018b).

Ust’-Polui was first identified as a probable dog sacrificial site by Moszyńska (1974) based on the preponderance of disarticulated dog skeletal remains. Carved antler swivel pieces and a decorative carved bone knife handle that may represent a harnessed sled dog have been recovered from Ust’-Polui, indicating that dog sledding was practiced. A feature containing 15 dog crania with similar traumatic injuries further points to ritualized killing, underscoring its probable significance as a sacrificial deposit. Losey et al. (2018b) analyzed the dog remains from the site, identifying a minimum of 128 individuals, making it one of the largest assemblages of dog remains from the entire Arctic. However, the site’s analyzed mammalian assemblage is dominated by reindeer remains, which account for ~63% of the mammal assemblage by NISP, followed by dog remains at only 21% (Bachura et al. 2017). The majority of recovered reindeer bones came from the postcranial skeleton of mature individuals and show signs of butchery (Vizaglov et al. 2013). Other mammals whose remains were recovered from the site include hare, beaver, seal (*Phoca* sp.), and walrus (*Odobenus rosmarus*), as well as sable, Arctic fox, wolf, and moose.

Potapova and Panteleyev (1999) report that the incidence of healed traumatic injuries to golden (*Aquila chrysaetos*) and white-tailed eagle (*Haliaeetus albicilla*) skeletal remains recovered from Ust’-Polui are indicative of having kept raptorial birds in captivity, and they may have been sacrificed in addition to dogs. Further, more recent excavations of the site have documented what appear to be several formal burials of diurnal raptors at the site (Nomokonova et al. *in press*). To date, the skeletal remains of thirty-nine avian taxa have been recovered from Ust’-Polui, including resident species and many migratory waterfowl/nearshore birds. The bones of the willow (*Lagopus lagopus*) and rock (*Lagopus muta*) ptarmigan, resident grouses, are particularly abundant; the majority came from skeletally mature individuals and some exhibit cut marks (Losey et al. 2017; Potapova and Panteleyev 1999; Vizaglov et al. 2013).

Fish skeletal remains were abundant at Ust’-Polui, likely due to the site’s location on the Ob River. While most of these remains are unidentifiable to species, over half of specimens from representative samples taken during the 2006 excavation were identified as burbot (*Lota lota*), whereas nearly half the samples from the 2009 excavations have been attributed to undifferentiated whitefish (*Coregonus* spp.) (Vizaglov et al.2013). Differences in the abundance of particular species across the site may be the result of natural or cultural shifts, though it appears fish under 1 meter in length were preferentially taken throughout the period of site occupation (Vizaglov et al. 2013).

In addition to faunal remains, a considerable quantity of plant remains point to the significance of these resources, which may have been used for food, medicines, dyes, and fibres. Seed and fruit remains from cloudberry (*Rubus chamaemorus*), crowberry (*Empetrum nigrum*), and dead-nettles (*Lamium* sp.) have been recovered from the site (Vizaglov et al. 2013).

As the site’s primary function was that of a sanctuary or sacrificial location, habitation and human burial features are uncommon. However, two complete human burials and several isolated skeletal elements have been excavated at Ust’-Polui (Fedorova 2003; Losey et al. 2018b). One complete burial was discovered outside the moat; its biological sex was determined as female, and a radiocarbon date obtained from a hide garment the individual appeared to have worn correspond to the period of the site’s use. The other complete burial was the skeleton of a biological male whose remains were directly dated and predate the main use of the site; the remains were poorly preserved, but had been placed in a grave structure consisting of a possible wooden frame with birch bark below and twigs on top.

Numerous disarticulated human skeletal elements also have been recovered. The presence of three large fireplaces with associated ceramic fragments, carved wood, antler, shale molds (for casting bronze objects), and bronze casts themselves indicate iron and bronze smelting were taking place at Ust'-Polui (Fedorova 2014).

The chronology of Ust'-Polui has been analyzed by Losey et al. (2017). These analyses were based on 64 radiocarbon dates, including 42 on wood charcoal, 20 on human and faunal remains, and 2 on objects found in human graves. The faunal dates include seven dates made on dog remains. Four dendrochronology dates also are available for the site. Analyses of the dates revealed a significant old carbon reservoir effect in the human and dog radiocarbon dates, which is an isotopic artifact of diets based on riverine fish taxa, as discussed in Chapter 5. Bayesian modelling of the reliable radiocarbon dates from Ust'-Polui suggests a maximum period of occupation between ~260 BCE to 140 CE (Losey et al. 2017).

3.2 The Transbaikal region

Transbaikal (Figure 3.3) is a sparsely populated region southeast of the area immediately surrounding Lake Baikal. In total, it encompasses nearly one million square kilometers. The region is ecologically diverse, with its southern regions being characterized by patches of steppe, forest-steppe, and taiga (boreal forest), while its northern portions are largely comprised of taiga. Transbaikal is bordered by Manchuria to the east-southeast and Mongolia to its south. It is bisected by the Yablonovoy Mountains, which geographically divide it into eastern and western portions (Kradin 2005). This range is a significant geographic boundary, as basins to its west drain to the Arctic Ocean, and basins to its east drain to the Pacific Ocean (Suslov 1961:288).

Proezzhaia I, the focus of my research, is an archaeological site located on a terrace above the southeastern bank of the Shilka River, in a forested region just north of the Russia-China border in eastern Transbaikal (Figure 3.3). This part of the region is predominantly forest-steppe and is situated at the convergence of three floral and faunal regions (Mongolian steppe, Siberian taiga, and the Amur-Ussuri river basin) (Suslov 1961). Forests southeast of the Yablonovoy Mountains are dominated by Siberian taiga flora but give way to larch and pine forests to the east. These forests feature tree species unique to the Amur Basin and Primorye regions, including Mongolian oak (*Quercus mongolica*), elm (*Ulmus pumila*), filbert (*Corylus avallana*), and Asian black birch (*Betula dahurica*) (Suslov 1961). Diverse steppe, taiga, and high-mountain species characterize the fauna of Transbaikal, including sables, susliks (*Spermophilus* sp.), badgers (*Meles meles),* foxes, wolves, boar (*Sus scrofa*), roe deer (*Capreolus* sp.), and red deer (*Cervus elaphus*), and there is a seasonal presence of migratory birds such as ducks and cranes (Suslov 1961). To the south, forests give way to patches of steppe with aridity-adapted xerophytic plants on slopes and high-mountain alpine species at higher elevations (Suslov 1961), with the nearest large stretches of steppe found about 160 kilometers to the southwest of Proezzhaia I.

In the present day, Transbaikal experiences extreme fluctuations in temperature, but receives scant precipitation, most of which falls during the warm, short summer (Suslov 1961). Winters are windy and extremely cold, but relatively snowless (Nogina 1976). Historically, the insignificant winter melt resulted in springtime droughts, and forest fires were common (Nogina 1976). However, in the present day, the deforestation of regions adjacent to Transbaikal is causing significant seasonal flooding issues along the Shilka River (Solokova et al. 2019).

The Shilka River is the northern source of the Amur River. At 506 kilometers long, it drains a watershed of 206,000 square kilometers (Simonov and Dahmer 2008). Its bottom is generally comprised of large pebbles and some boulders (Simonov and Dahmer 2008). As part of the Amur watershed, the Shilka is home to the famed Kaluga sturgeon (*Huso dauricus*), which can grow to 5.6 meters long and weigh over 1000 kilograms (Krykhtin and Svirskii 1997).

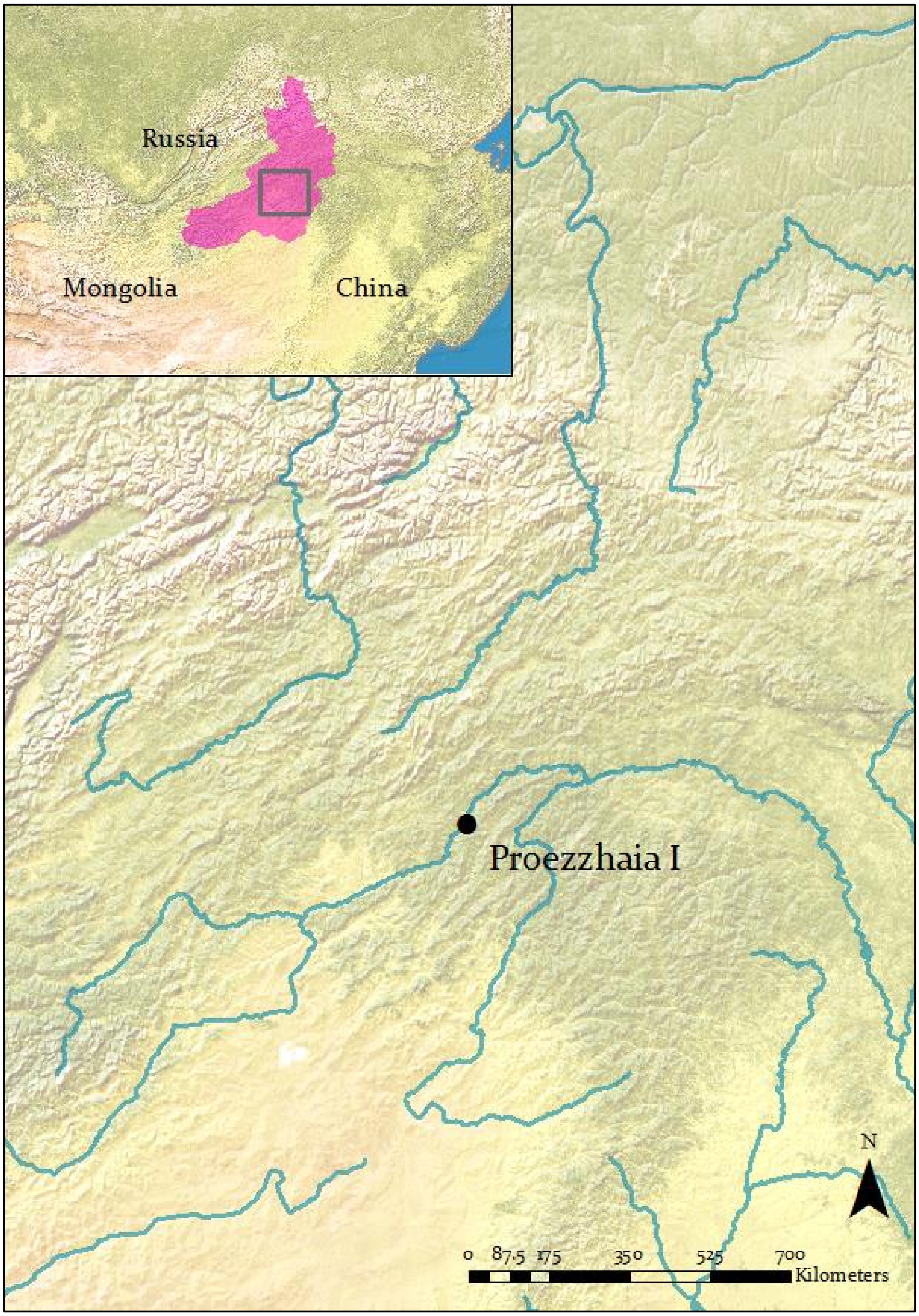

Figure 3.3 Location of the Proezzhaia I site. Inset: Transbaikal region shaded in pink, with grey box outlining approximate area of larger map. Map produced with data from Natural Earth.

It also is a habitat for much smaller benthopelagic fish such as the Amur ide (*Leuciscus waleckii*), Prussian carp (*Carassius gibelio*), redfin (*Pseudaspius leptocephalus*), yellow catfish (*Tachysurus fulvidraco*), and common carp (*Cyprinus carpio*), none of which typically reaches greater than 30 centimeters long (Froese and Pauly 2018).

3.2.1 Transbaikal culture history

Many of the archaeological investigations in Transbaikal have been conducted in support of prospective damming projects (Valchenko 2018). Though some archaeological evidence suggests Transbaikal was inhabited during the Lower Paleolithic, (Konstantinov 2016), there is undisputed evidence of regular human occupation by at least the early Upper Paleolithic (Buvit et al. 2016; Graf and Buvit 2017). The absence of identifiable archaeological materials at Transbaikal sites between ca. 24,800 and 22,700 years BP, coincident with particularly cold periods during the Last Glacial Maximum, has led some archaeologists to argue that the region was ephemerally occupied or abandoned by humans at this time (Buvit et al. 2016; Graf and Buvit 2017).

Archaeological research on the Siberian Neolithic is relatively limited in Transbaikal, especially compared to areas to the west of Lake Baikal. In addition to its diverse flora and fauna, Transbaikal has extensive tin and copper ore deposits (Sainsbury 1969; Seltmann et al. 2010). These deposits may have drawn more humans to the region with the expansion of metallurgy in the Early Bronze Age (Konstantinov 2016). By the Late Bronze Age, domestic animal husbandry had spread to parts of the Transbaikalian taiga, and its human inhabitants raised pigs, sheep, goats, and cattle (Konstantinov 2016) in addition to hunting and fishing (Kovychev 2009). As the region’s climate and soils are poorly suited to large-scale, intensive crop agriculture, it is not thought to have played a significant role in human subsistence economies (Konstantinov 2016), though the discovery of charred millet remains at the medieval village of Ust’-Chërninsk indicates domesticated plants were at least available to the region’s inhabitants, if not cultivated on a limited scale (Alkin and Sergusheva 2013). Among the faunal specimens recovered from medieval Transbaikal sites are the remains of domestic dogs, cattle, horses, sheep/goats, and pigs, consistent with those reported at earlier Bronze Age sites in Transbaikal.

The medieval period in Transbaikal was marked by relatively frequent shifts in socioeconomic and political organization (Kim 2011), due in part to the ethnically diverse makeup of its inhabitants (Akhmetov and Alkin 2018; Konstantinov 2016; Kovychev 2006). Markedly different subsistence and settlement patterns existed at this time, ranging from mobile reindeer herding and hunting among the region's Tungusic-speaking peoples of the taiga, to seemingly sedentary forms of agriculture among the Mohe, a group of people who originated in regions to the east-southeast and who colonized parts of Transbaikal (Alkin and Nesterenko 2010). Pastoral Mongolic and Turkic groups inhabited areas to the south and west (Konstantinov 2016).

In the medieval period, eastern Transbaikal was culturally and economically tied to Outer Manchuria, located immediately to the east (Janhunen 1996). Examination of ceramics from several Medieval settlements in eastern Transbaikal has shown strong stylistic similarities to those of the Mohe (Valchenko 2018), while evidence from other contemporaneous sites links their ceramic styles to the Mongolic Shivei (Kovychev and Piskareva 2016).

3.2.2 Proezzhaia I

Proezzhaia I is a fortified Medieval settlement located at the confluence of Proezzhaia Creek and the Shilka River, on the right bank of the river (Figure 3.4). At present, the site is surrounded by overgrown mixed forest, and nearby there is an oxbow lake surrounded by thicket (Kovychev et al. 2018). The site sits on a terrace 2 to 4 meters above the Shilka River, and unlike contemporaneous sites in the area, Proezzhaia I is not situated atop a hill (Kovychev et al. 2018). The site was first identified and described in the 1950s by esteemed Russian archaeologist A.P. Okladnikov, who then called the site "Pad' Katonga." The materials analyzed in this study were obtained during excavations by the Verkhneamursk archaeological expedition from Trans-Baikal State Pedagogical Institute in 2007-08 (Kovychev 2009). Though two distinct periods of occupation were identified during these excavations, samples used in the present work were recovered from deposits associated with the earlier episode of site use. During this period of occupation, a series of embankments and trenches was created along the north and south margins of the main habitation area (Figure 3.4). These are almost certainly the remains of fortifications (Kovychev et al. 2018), likely originally flanked by the Shilka River to the west and Proezzhaia Creek to the east. Though a substantial portion of the western section of the site was lost to erosion caused by the Shilka River, within these fortifications are the remains of numerous probable pit houses and other features. Several of these pits were excavated in 2007-08, revealing the presence of preserved wooden planks and poles (Kovychev et al. 2018). These finds suggested dwellings were square in shape, with wooden platforms along the interior walls and centrally located hearths. Storage pits were also identified, containing numerous artifacts and scattered faunal remains. Around the site, numerous potsherds, metal objects, and pieces of birch bark were recovered, along with gaming pieces fashioned from animal astragali (Kovychev et al. 2018). Crucible fragments were identified among the potsherds, and pieces of slag were recovered, suggesting metallurgical activities took place at Proezzhaia I (Kovychev et al. 2018).

Notably, within the floors of two dwellings, #s 28 and 32, were pits containing intentionally placed but not fully articulated skeletons of individual dogs. These deposits, which may be secondary burials of dogs that were consumed by humans, have been interpreted as expressions of ceremonial behaviour at Proezzhaia I (Losey et al. 2018b), as have similar features at other Medieval sites in the region (Akhmetov and Alkin 2018). Other faunal remains were found disarticulated and scattered in trash pits, including domestic pigs, cattle, horses, and sheep/goats, along with wild cervids, squirrels, hare, sable, and fox, indicating a diverse subsistence strategy that focused on both animal husbandry and hunting.

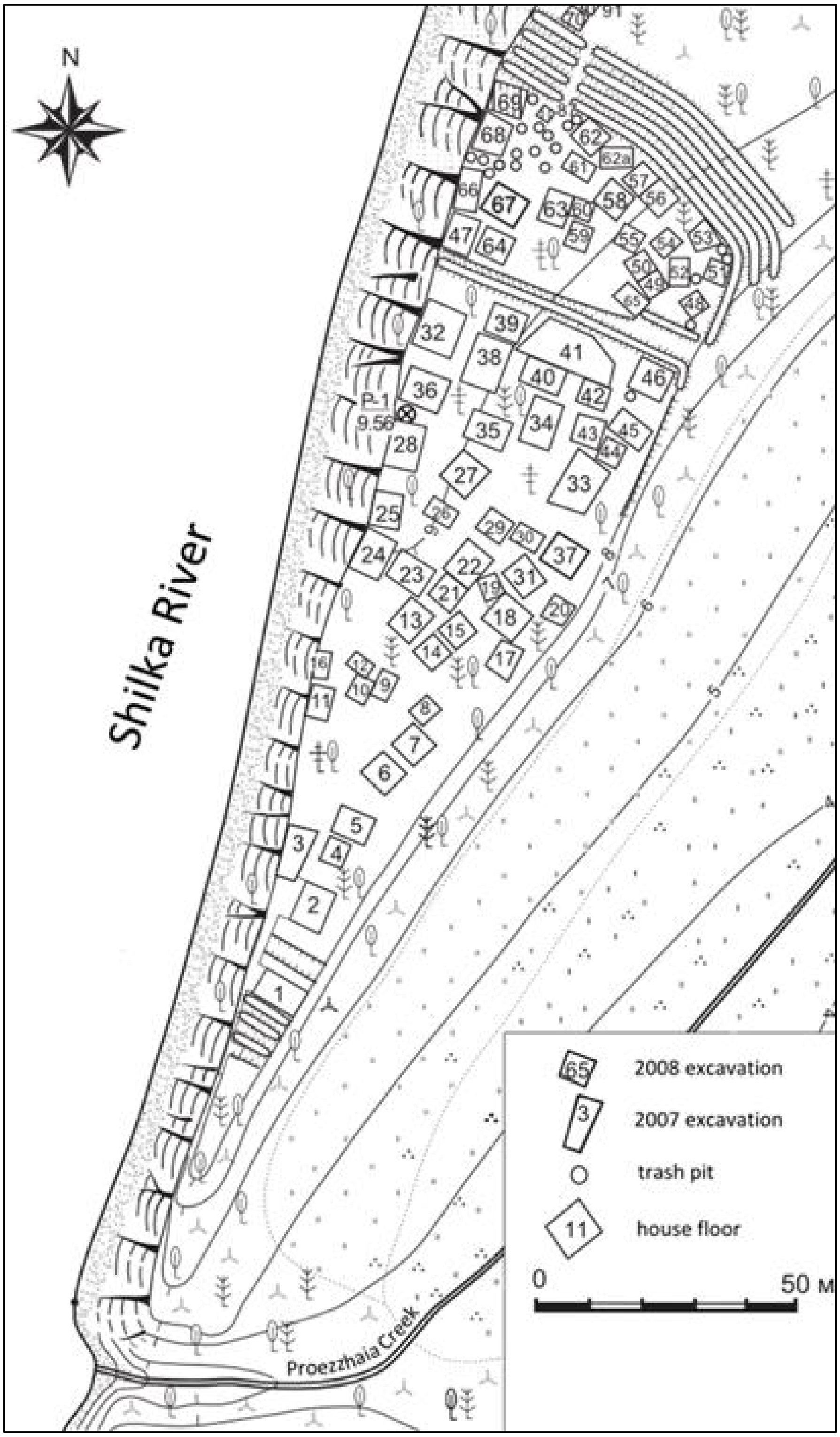

Figure 3.4 Plan view of the Proezzhaia I site. Site map courtesy of E.V. Kovychev.

A concentration of freshwater mussel shells and the presence of fish bones, along with the site's riverine setting, suggest some use of aquatic resources.

Six faunal bones were dated for this project, including three dog remains, and one each from an artiodactyl, *Bos* sp., and Caprinae (Fleming et al. 2018). These dates were entered into a single phase model in Oxcal 4.2, and the IntCal 13 calibration curve was used (Bronk Ramsey 2009, 2014; Reimer et al. 2013). The modeled starting age for the dates spans from 884 to 1025 CE (at 2 sigma), with the mean date for the starting period being 973 CE ± 44. The end date for the phase (at 2 sigma) spans from 1023 CE to 1201, with the mean being 1093 CE ± 58. Kovychev and Piskareva (2016), who led the most recent excavations of the site, suggest on the basis of ceramic typologies that members of the Shivei ethnic group occupied Proezzhaia I.

3.3 Primorye

Primorye, or the Maritime Province, is a vast, densely forested region of the Russian Far East. The Russian Far East itself is distinguished from Siberia by its watershed, which drains to the Pacific Ocean, whereas Siberia drains to the Arctic Ocean (Kuzmin 2006). It is bordered by the Amur River to the north, the Sea of Japan (also known as the East Sea) to the east, the Korean peninsula to the south, and the Manchurian steppe-lowlands to the west (Zhushchikhovskaya and Nikitin 2014). The northeast-southwest oriented Sikhote-Alin mountain range dominates the interior of Primorye, but as one nears its southeastern terminus at the port city of Vladivostok, the range gives way to lower mountains that define the coastal landscape of the southerly areas of this region (Suslov 1961). As with much of the continental landmasses surrounding the Pacific Rim, Primorye is subject to earthquakes. Earthquakes usually are triggered by movement along the Tan-Lu fault zone, which diagonally bisects Primorye in a northeast-southwest direction (Stepashko 2011). The Tan-Lu fault is one of the largest continental strike-slip faults in the world (Jiawei and Guang 1994); this specific type of seismic activity causes the block on one side of the fault to slip horizontally against the other.

Primorye lies on the Peter the Great Gulf, an inlet of the East Sea approximately 80 kilometers long and 200 kilometers across at its widest point (Figure 3.5). The city of Vladivostok, the largest population centre in the province, is situated at the tip of the Muravyov-Amurskiy Peninsula. This peninsula separates the gulf into the Amurskiy Bay to the west, and the Ussuriyskiy Bay to the east. Russkiy Island, on which several sites in this study are situated, is separated from Vladivostok to the north by a narrow strait of Peter the Great Bay. The larger East Sea is bounded by the Japanese Islands to the east and is connected to the Pacific Ocean only through four shallow straits (Kim et al. 2016).

Being almost entirely shielded from the Pacific Ocean, the East Sea experiences only slight changes in tidal height (Ivanova et al. 2009; Suslov 1961). Several currents of both warm and cold temperatures impact the waters of Peter the Great Gulf (Kalchugin et al. 2015; Kuzmin et al. 2001; Suslov 1961). Boreal-arctic, boreal, low-boreal, subtropical, and tropical fish taxa all have been observed in Peter the Great Gulf (Kalchugin et al. 2015), and the East Sea is home to a number of migratory and year-round marine mammals, including whales, dolphins, sea lions, and seals (Aikens 1992; Burkanov and Loughlin 2005; Katin and Nesterenko 2010). Today, as in centuries past, Peter the Great Gulf and the wider East Sea support an abundant fishery (Suslov 1961).

Primorye’s landscape and adjacent sea have a high diversity of plant and animal life. Here, as in the in the Lower Ob Region and Transbaikal, flora and fauna from separate biogeographic provinces, both terrestrial and marine, converge to create a complex ecosystem (Kuzmin 2006; Suslov 1961). Forests feature both broadleaf and coniferous tree species and represent an unusual combination of taiga and subtropical species (Ivanov 2002).

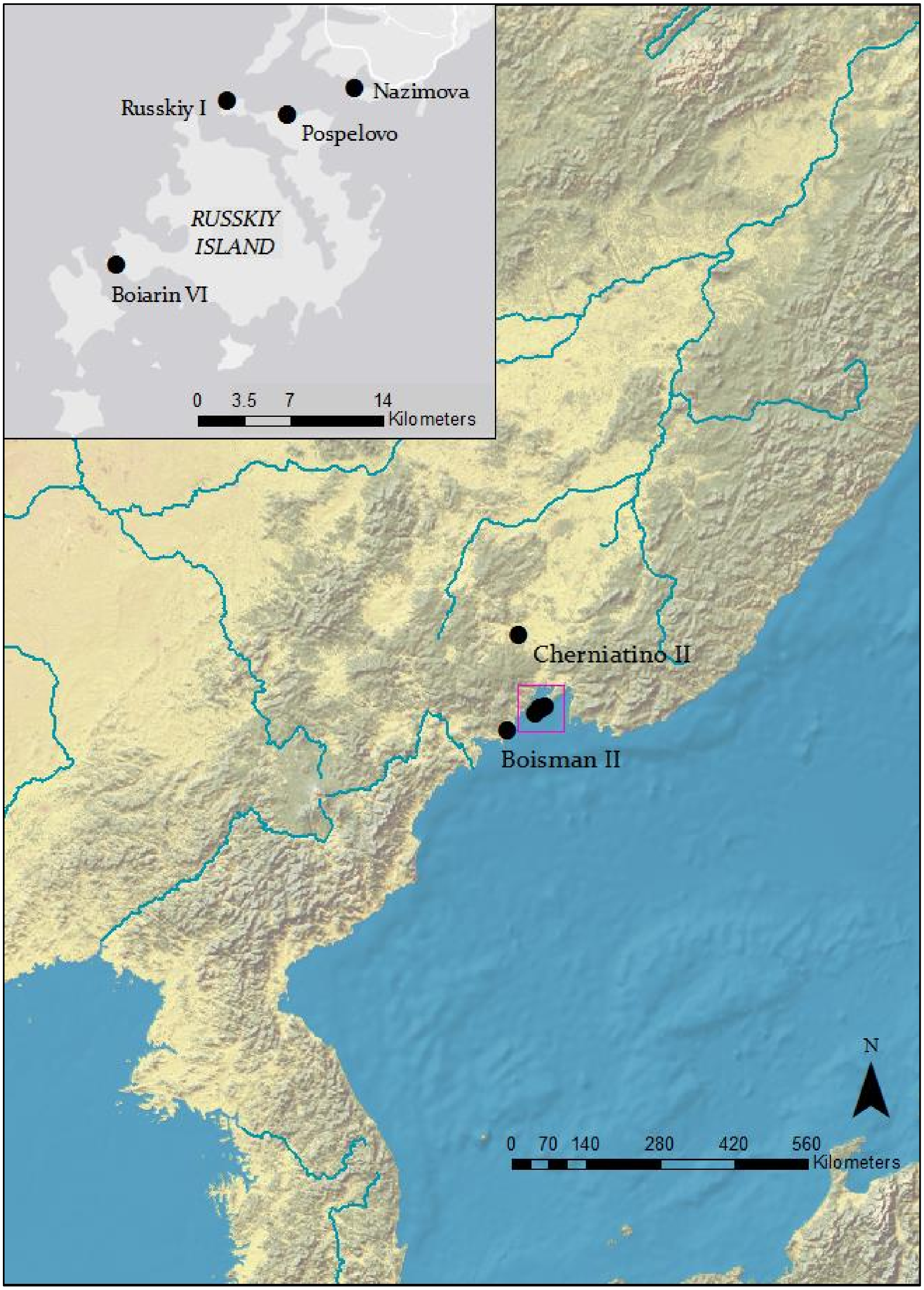

Figure 3.5 Map showing location of Primorye archaeological sites discussed in this study. Inset: location of sites on or near Russkiy Island. Map produced with data from Natural Earth and ESRI.

These forests arose in areas that were not glaciated during the Pleistocene, allowing for greater abundance and more complexity than forests further north (Krestov 2003). Among the dominant taxa in these forests are significant numbers of nut-bearing trees, including the Korean pine (*Pinus koraiensis*), Manchurian walnut (*Juglans mandshurica*), and Mongolian oak (*Quercus mongolica*), but also smaller species, such as the Manchurian hazel (*Corylus mandshurica*) (Krestov 2003). They also feature a rich diversity of understory trees and plants, such as Manchurian linden and maple (*Tilia mandshurica*, *Acer manshuricum*), wild jasmine (*Philadelphus tenuifolius*), barberry (*Barberis amurensis*), and vines with edible and desirable fruit like the Amur grape (*Vitis amurensis*) (Suslov 1961). Its forests are home to a host of animal taxa, including squirrels (*Sciurus vulgaris mandshuricus*), hares (*Lepus timidus mordeni* and *Allolagus mandshuricus*), larger herbivores such as musk deer (*Moschus moschiferus*) and roe deer (*Capreolus pygargus*), the antelope-like goral (*Naemorhedus caudatus*), omnivorous raccoon dogs (*Nyctereutes procyonoides*) and wild boar, small carnivores such as foxes, weasels, and otters, and large predators such as the Amur tiger (*Panthera tigris tigris*) and Amur leopard (*Felis pardus orientalis*), Manchurian bear (*Ursus mandchuricus*), and dhole (*Canis alpinus*) (Suslov 1961). As for avian taxa, the Manchurian pheasant (*Phasianus mongolicus*) is a common sight in Primorye, drawn to human settlements by stores of grain (Suslov 1961). Additionally, great numbers of migratory geese, swans, and ducks nest in the area's coastal lagoons during the spring and summer (Vostretsov et al. 2015).

Southern Primorye, where the sites in this study are situated, at present experiences a monsoon climate, with up to 85% of its annual precipitation falling in the summer months (Ganzei 2016). As a result, winter snows are rare and only reach a depth of 50 centimeters (Razjigaeva et al. 2019). As so little snow falls in Primorye, spring melts generally do not lead to flooding, though summer downpours may cause flash floods (Suslov 1961). Average high temperatures of +20 to +21°C typically occur in August, with mean winter lows in January of -13.5° to -16.5°C (Razijigaeva et al. 2017). Peter the Great Gulf, on which the coastal sites included in this study lie (Figure 3.5), typically freezes over in winter

(Suslov 1961), though mollusk shells and fish remains recovered from archaeological sites along the coast of Primorye provide evidence that the East Sea experienced milder temperatures in the past (Besenov 2015).

3.3.1 Primorye Culture History

Unlike some areas within the Russian Federation, Primorye has been intensively studied by archaeologists, and a wealth of information has been produced and published by Russian, Chinese, Korean, and Japanese researchers, much of it available in English. Archaeological investigations of Primorye began in the 1800s, but these expanded considerably in the 1950s and 60s (Popov et al. 2014b). The present-day geopolitical boundaries of Russia, Korea, China, and Mongolia do not correspond to the prehistoric and historic culture areas of Primorye. Different cultures have met and mixed in this region since at least historic times (Dyakova 2014; Kim and Kyounghoun 2015), and many northeastern Asian cultural groups identify Primorye as their ancient homeland (Sasaki 1998). These peoples have been subject to colonizing forces, first from the east, then from the west, and as a result, much of Primorye has been under the control of political regimes thrust upon it by external groups (Kim and Kyounghyoun 2015). Correspondingly, archaeological studies conducted in the region have been subject to variable interpretations depending on the perspective of the researcher (e.g., Dyakova 2014; Kim 2016), and teasing out the common thread that binds together competing views is not an easy task.

The earliest traces of human life in Primorye have been found in coastal and inland sites associated with the Late Paleolithic (Table 3.1) (Kuzmin 1992). The most significant of these is the Ustinovka site, a location thought to be ice-free since ca. 13,000 years ago; here, blades and other specialized tools have been recovered (Vasil'evskiy 1987). However, little more than human presence is established by the lithic implements found there (Derevianko and Tabarev 2006).

Evidence for human habitation in Primorye during the subsequent Neolithic period is much more extensive. As described earlier, the beginning of the Neolithic is associated with the first evidence for ceramic technology among hunter-gatherers in much of northern Asia (Table 3.1) (Popov et al. 2014b). Using ceramic technology as its defining characteristic, the Neolithic of the Russian Far East was a much longer period than nearly anywhere else in the world (Popov et al. 2014b:250). In Primorye, the *earliest* radiocarbon date obtained from the organic temper of potsherds is about 10,700 BP (Popov et al. 2014b). These materials are not attributable to a clearly defined material culture tradition and may constitute a hitherto unknown archaeological complex (Popov and Tabarev 2008).

Cultural Horizon	**Archaeological Culture**	**Radiocarbon Date and/or Historical Dates**
Ustinovka/Final Paleolithic	Paleolithic	13,500 ± 200 to 7840 ± 60 BP (Kuzmin 1992)
Rudnaia	Middle Neolithic	8380 ± 60 to 6710 ± 105 BP (Popov et al. 2014b)
Boisman	Middle-Late Neolithic	7500 to 4500 BP (Popov and Tabarev 2008)
Vetka	Late Neolithic	6000 to 5500 BP (Popov and Tabarev 2008; Popov et al. 2014b)
Zaisanovka	Late Neolithic	5370 to 3500 BP (Popov et al. 2014b)
Yankovskaia	Paleometal/Early Iron Age	3000 to 2000 BP (Kuzmin and Rakov 2011) or 10th/9th century BC to 3rd/2nd century BC (Zhushchikhovskaya and Nikitin 2014)
Krounovskaia	Bronze Age	4th to 5th century AD (Zhushchikhovskaya and Nikitin 2014)
Mohe (pre-state)	Iron Age	4th to 8th century AD (Zhushchikhovskaya and Nikitin 2014)
Mohe (under Koguryŏ)	Medieval	37 BC to AD 668 (Kim 2011)
Mohe (under Balhae)	Medieval	AD 698 to 926 (Zhushchikhovskaya and Nikitin 2014)

Table 3.1 Culture history model for the Primorye region. Radiocarbon dates generally have not been calibrated for earlier sites (e.g., those predating the Mohe). Additional chronological information based on historical documents also are available for more recent sites.

The appearance of ceramics in Primorye archaeological contexts is the first step in what many Russian scholars refer to as “Neolithization,” a gradual process wherein hunter-fisher-gatherers engaged in more varied subsistence economies and adopted new social and ritual structures, rather than its caricature as a singular, revolutionary event (Popov et al. 2014b). Archaeologically speaking, no evidence for agriculture appears in the region until ca. 5000 to 4500 BP (Popov et al. 2014b). Further, the production of crops for human consumption was probably done on a small scale until near the time of the arrival of Russian colonizers in the sixteenth and seventeenth centuries (Naumov 2006).

Throughout the Primorye Neolithic, there is abundant evidence for the exploitation of both terrestrial and marine resources. The toolkit consists of both lithic and bone implements for taking and processing animals from both the land and sea—projectile points, knives, fishhooks, net sinkers, harpoons, scrapers, needles, and awls (Popov et al. 2011), and items crafted from bone and wood point to uses for other implements such as drills (Popov et al. 2014b). Preserved mat, net, and cordage fragments (Kuzmin et al. 2012), as well as considerable numbers of nutshell fragments from Neolithic strata (Kuzmin and Rakov 2011; Vostretsov et al. 2015), attest to the gathering and processing of plant-based resources.

The Rudnaia culture (Table 3.1) is the earliest *consistently* identifiable cultural tradition in the middle Neolithic of Primorye, though, as suggested previously, there may exist earlier Neolithic cultures which are not yet well defined. Materials from the Rudnaia Pristan site have been recovered from contexts dating from 7700 to 7400 BP (Zhushchikovskaya 2006). The Rudnaia culture is characterized by square pit houses ranging in size from 10 to 100 m^2 and which feature centrally located wood- and clay-lined hearths (Popov and Tabarev 2008; Popov et al. 2014b). Decorative items such as beads, pendants, and bracelets have been recovered (Popov et al. 2014b). Excavation of several human interments from Devil Gate Cave has been carried out, but no formal cemetery has yet been identified (Popov et al. 2014b;

Zhushchikhovskaya 2006). Faunal remains from the cave suggest a subsistence strategy focused on terrestrial and sea mammal hunting, fishing, and gathering (Popov et al. 2014b)

Conceptually, the Rudnaia culture is followed by the Boisman culture (Table 3.1), yet in some parts of Primorye, radiocarbon dates indicate a temporal overlap between the two. While Soviet-era interpretations of the Neolithic drew heavily from the timeline of human cultural evolution as presented by Karl Marx and V. Gordon Childe (Popov et al. 2014b), the concept of linear technological innovation is somewhat flawed, and at this point in the ancient past, such “advances” may be more representative of external environmental or cultural influences that led to the development or adoption of certain technologies before others (e.g., Popov et al. 2014b), not simply that technologies emerge in the same, predictable sequence across the world during the Neolithic (Popov et al. 2014b). Despite these issues, Boisman sites indicate a reliance on marine and estuarine resources. One of the hallmarks of Boisman sites is the distinctive lenses and middens comprised of mollusk remains, predominantly Pacific oyster (*Crassostrea gigas*) shells. The midden matrix also contains many fish bones, predominantly those of so-iuy mullet or haarder (*Planiliza haematocheilus*), but also Pacific cod (*Gadus macrocephalus*), sea bass (*Lateolabrax* sp.), and flounders (Pleuronectidae) (Popov et al. 2011). Additionally, the clear association of much of the Boisman toolkit with marine-based subsistence activities, along with abundant marine mammal skeletal remains in these sites, indicate resources from the East Sea made substantial contributions to Boisman subsistence.

During the Boisman period, conditions were warmer and more humid than either before or after, and rising sea levels are believed to have given rise to lagoons in which extensive oyster beds flourished (Popov et al. 2014b). A provocative hypothesis advanced by Brodianski and Rakov (1992) argues that the ancient inhabitants of Primorye were among the first humans to adopt a system of aquaculture based on oyster production. This proposal has been heavily critiqued by other archaeologists working in the region, but few efforts have been made to address it (e.g., Tabarev 2007).

Boisman sites also show considerable use of terrestrial plants and animals. Nutshells are the most frequently recovered plant tissue at Boisman sites, though assessing their dietary significance is difficult because, like shellfish, they represent a resource with much more processing waste relative to their nutritional yield (Gremillion 2002). Situated in a naturally productive environment, the Boisman peoples of Primorye likely took advantage of the region's many fruit-bearing shrubs, trees, and vines when they were in season (Vostretsov 2015), which typically leave few to no material traces in the archaeological record. Among terrestrial fauna, wild boar and/or domestic pigs (*Sus scrofa*) skeletal remains are relatively common finds at Boisman sites, though high levels of individual and geographic variation make it difficult to assess to which group a skeletal element should be assigned based on morphology and size (cf. Albarella et al. 2009). Some dog remains also have been recovered from Boisman contexts, but these remain unanalyzed, except as part of this dissertation, and in one recent genetics study (Ameen et al. 2019).

The earliest clear signature of agriculture in southern Primorye comes from the Zaisanovka Late Neolithic component of the Krounovka I site. Direct evidence comes in the form of domestic millet seeds (broomcorn, *Panicum miliaceum*, and foxtail, *Setaria italica*) from dwelling floors at Krounovka I, which returned a radiocarbon date of 4640 to 4670 BP (Kuzmin 2013). The seeds from these strains of millet, a particularly important cultivar in Asia, also have been identified at other Zaisanovka-affiliated sites (Kuzmin 2013). Further analysis of Krounovka I's paleoethnobotanical assemblage revealed the presence of wild plant resources, including naturally occurring grass seeds and shells from nut-bearing trees (Sergusheva 2007; Sergusheva and Moreva 2017). Additional, indirect evidence of plant cultivation includes implements recovered from the archaeological record that allow researchers to infer certain activities. In Zaisanovka contexts, agricultural tools such as hoes and quernstones speak to the cultivation and processing of plant products, respectively (Kuzmin 2013). Other forms of indirect evidence include the seed-impressed ceramic vessels from the Zaisanovka VII site; morphologically, these impressions appear to have been made by broomcorn millet seeds (Vostretsov et al. 2015).

Though obvious signs of agricultural practices emerged in the Zaisanovka period, hunting and gathering terrestrial and aquatic resources were the primary focus of their economic activities. In their study of seasonal resource availability at Zaisanovka VII, Vostretsov et al. (2015) demonstrated that the various skeletal and pollen remains from fish, shellfish, terrestrial mammals, berries, and nuts recovered at the site would have been available or most abundant at specific times of the year, ensuring an annual cycle of nutrition for the site's inhabitants, who did not yet rely on agriculture to meet their subsistence needs.

In a departure from previous culture periods, when fishing seems to have been carried out in warmer months of the year, Popov et al. (2011) note the Early Iron Age Yankovskaia peoples fished year-round; this assessment was based on seasonal fish otolith (ear stone) growth rings and the appearance of larger, more specialized equipment in archaeological contexts. Based on the types of fish skeletal remains recovered from Yankovskaia sites, Popov et al. (2011) further indicate these new technologies allowed Yankovskaia peoples to shift to open-water fishing.

The skeletal remains of domestic dogs have been recovered from Yankovskaia contexts, though debate continues about the identification of suid remains as either wild boar or domestic pig (Kuzmin et al. 2018; Momot et al. 2016; Rowley-Conwy et al. 2012). These assemblages also show great diversity in wild fauna, including wolf, fox, weasels (*Mustela* sp.), badger, Steller sea lion (*Eumetopias jubatus*), spotted (larga) seal (*Phoca largha*), moose (*Alces alces*), wild boar, roe, red, and musk deer (*Moschus moschiferus*), hares and rabbits (Family Leporidae), and birds like goldeneye ducks (*Bucephala* sp.) and cormorants (*Phalacrocorax* sp.) (Kuzmin 1997). Again, this suggests that Yankovskaia lifeways were predominantly focused on foraging rather than on food production.

Information on the Bronze Age Krounovskaia culture (Table 3.1) is extremely limited. In Kuzmin's 1997 review of faunal remains from Primorye archaeological sites with Krounovskaia components, wild mammalian taxa are limited to wild boar, roe, red, and sika deer (*Cervus nippon*), and the presence of domestic pigs, dogs, and horse (*Equus* sp.) is noted. Zhuskchikhovskaya and Nikitin (2014) comment that two main ceramic vessel styles are identifiable in Krounovskaia pottery assemblages, including one for storage or cooking, and another likely for serving.

Medieval archaeological sites in Primorye (Table 3.1) are significantly different from those of previous cultural periods, owing to the complexity of Mohe-Balhae society, its status as a state, and its multiethnic composition (Dyakova 2014; Kim and Kyounghoun 2015; Wei 2007). Historical documents that mention the Mohe variously characterize them as a distinct cultural entity, or a combination of Tungusic Mohe (or Malgal), Koguryŏ (one of the three Medieval kingdoms of Korea), and Chinese ethnic groups (Dyakova 2014; Kim 2011). A thorough review of previous Mohe-Balhae research conducted by Sloane (2014) underscores the highly political nature of claims made by researchers from Russia, North and South Korea, China, and Japan. These arguments about interpretations of Mohe-Balhae material culture focus on its affiliation to present-day countries as attempts to establish an argument for a particular country's right to control the former state's territory. Russian and Chinese archaeologists tend to describe Balhae as a unified nation comprised of Indigenous Mohe/Malgal peoples from Manchuria, whereas Korean and some Japanese archaeologists characterize it as a Korean state founded by Koguryŏ descendants (the elite class) ruling over a Mohe ethnic majority (Kim 2011). In AD 926, Khitan (Liao) forces invaded Mohe-Balhae territory from the south and assumed control but were violently resisted by the Mohe-Balhae people; eventually, the Khitan removed some 94,000 Mohe-Balhae families to other locations (Kradin and Ivliev 2008).

Brodianski et al. (1993) define Mohe-Balhae territory as the area bounded by the western slopes of the Sikhote-Alin range and along the Ussuri River, to its confluence with the Sungachen River in present-day China. As a stratified state with at least some of its members engaged in specialized labour, Mohe-Balhae had a complex social organization, reflected in part by its variety of archaeological sites, including fortified and unfortified settlements, hunting and fishing camps, administrative buildings, mineral extraction areas, roads, temples, and cemeteries (Brodianski et al. 1993; Song 1990). Excavations have yielded evidence for agricultural and cattle breeding activities, hunting and fishing, and specialists who produced metal implements, pottery, bone carving and woodworking, and masonry (Brodianski et al. 1993; Kim et al. 2017; Sergusheva 2012).

Many of Primorye's prehistoric archaeological sites are situated at or near the coast, as are the ones included in this study: the Late Neolithic Boisman II and Boiarin VI sites and the Early Iron Age Russkiy I, Pospelovo I, and Nazimova sites. The sole inland site in Primorye, Cherniatino II, features three components, the earliest examined here dating to the Early Iron Age, followed by two Medieval occupations—the early Mohe state and the later Balhae state.

3.3.2 Boisman II

Boisman II is situated atop a hill on the right bank of the Riazanovka River, 500 meters from the coast of Peter the Great Gulf (Figure 3.5) (Popov et al. 2011). In addition to the Boisman cultural strata, Rudnaia (Middle Neolithic) (Kuzmin et al. 2002), Zaisanovka (Late Neolithic) and Yankovskaia (Early Iron Age) components also have been identified (Popov and Tabarev 2008). The total area of the site is estimated to be 600 square meters (Popov et al. 2011). The site contains six distinct shell middens with three separate mounds; to date, middens 1 and 2 have been excavated (Popov et al. 2014b). Due to the massive volume of the shell midden layers, it has been suggested shellfish were extensively exploited by the site's inhabitants, who likely made use of the resources provided by the nearby lagoon, river estuary, and gulf (Zhushchikhovskaya 2006). The artifacts recovered from Boisman II further point to aquatic resource-based subsistence activities using a variety of techniques, evidenced by net sinkers, harpoons, fishhooks, and carved bone spinners (Popov and Tabarev 2010; Popov et al. 2011). However, the presence of numerous terrestrial mammal skeletal remains indicates hunting played an important role as well (Zhushchikhovskaya 2006).

While the site was initially identified as a shell midden composed of subsistence waste, among the more unusual features of Boisman II was the presence of a human cemetery (Popov and Tabarev 2008). Two concentrations of burials containing the partially commingled remains of multiple individuals and accompanying grave goods have been reported. Popov and et al. (2011) note individuals identified as males seem to have been interred with fishing and marine hunting implements, while biological females' remains were associated with items used for processing food and raw materials. Female burials also featured marine shell bracelets in the vicinity of their wrists. Osteological analysis has revealed several Boisman II individuals experienced unusual or violent deaths, while some showed signs of intentional cranial modification (McKenzie and Popov 2016; Popov et al. 2011). McKenzie and Popov (2016) note that cranial modification has been linked to differential status in other parts of the world, and because modification typically begins with the shaping of an infant's skull, and that this may be indicative of ascribed status that the individuals retained throughout their lifetimes.

Boisman II has been repeatedly radiocarbon dated. These dates indicate a maximum period of occupation between ~8500 and 5000 cal. BP (Popov et al. 2014b). For this study, effort was focused on dating the site's dog skeletal remains (Table 3.2). Six samples were submitted for dating, five of which produced sufficient collagen for dating. When calibrated, the dates range between 6895 and 5925 BP, at two sigma, confirming that the dated samples clearly were deposited at the site during the Neolithic period. However, as will be shown in Chapter 4, the dogs at Boisman had diets rich in marine fauna. Their radiocarbon dates surely carry some marine reservoir effect. A systematic effort to assess the extent and variation in marine reservoir effect in this area of Primorye is ongoing (Kuzmin et al. 2001, 2002).

Sample ID	**Provenience**	**Lab number**	**^{14}C age**	**δ^{13}C (‰)**	**Calibrated Age BP, 2 sigma**
BOIS #1	1998, Layer 2, square В-Г 23	Ua-51192	5251 ± 39	-16.8	6180 to 5925 BP
BOIS #5	2001, Layer 1, burial area, square Ж 28-29	Ua-51193	5780 ± 33	-16.5	6660 to 6495 BP
BOIS #7	2001, black--brown sandy gravel (contact with shell heap), square Ж 28	Ua-51194	5710 ± 32	-14.3	6625 to 6410 BP
BOIS #9	1997, fauna № 7786, 7770, 7769, 7781	Ua-51195	5511 ± 45	-14.6	6405 to 6215 BP
BOIS #10	2001, upper shell layers in the trench	Ua-51196	5954 ± 47	-15.2	6895 to 6670 BP

Table 3.2 Radiocarbon dates obtained from dog bone samples from the Boisman II site.

3.3.3 Boiarin VI

Boiarin VI is a multicomponent site situated on the southwest coast of Russkiy Island (Figure 3.5). It was partially excavated in 2013 by a team from Far Eastern Federal University, under the direction of A.N. Popov. Two components, Boisman and Zaisanovka, were identified, though the former component comprised the larger of the two and was associated with a shell midden layer (Brodianski et al. 2013). However, the faunal remains analyzed for this study were recovered from Zaisanovka-associated contexts. For this study, one ^{14}C sample (Ua-51202) taken from dog bone from square C24, layer 4, returned a date of 3840 ± 39 BP, which calibrates to 4410 to 4150 cal. BP. Other radiocarbon dates for the Zaisanovka component of this site are not known. Again, given that the site is located on the coastline and contains evidence suggesting the consumption of marine foods (described below), this date may carry a marine reservoir effect of a few centuries.

An eight meter by eight meter excavation area was opened on the northern edge of the midden at Boiarin VI, which contained the remains of a probable surface-level dwelling (Popov et al. 2014a). The house was semicircular and featured a hearth. In this area, stamped and incised potsherds of both the Boisman and Zaisanovka styles, as well as lithic implements (projectile points, end scrapers, retouched drill blanks, and flakes), and bone and horn implements (including harpoon pieces) were recovered (Popov et al. 2014a).

The analysis of faunal remains from Boiarin VI is ongoing. Popov et al.'s (2014) initial assessment of the Boiarin VI assemblage includes 25 molluscan taxa (15 bivalves, 10 gastropods) and various species of *Balanus* (barnacles in the Crustacea subphylum). Of these, Pacific oysters and sea mussels (*Crenomytilus grayanus*) amounted to over 97% of the molluscan taxa recovered from the site. Four hundred thirty-six mammal, bird, fish, and amphibian bones also were recovered; Popov et al. (2014) reported these skeletal remains were highly fragmented and of moderate preservation, and it was possible to positively identify only 47% of the total assemblage. Among these, most numerous were the skeletal remains of terrestrial mammals. Cervids, including sika, red, and roe deer, formed the largest group (NISP = 115), followed in incidence by wild boar (NISP = 65), said to be distinguishable from domestic pigs on the basis of bone morphology. Additionally, skeletal remains attributed to undifferentiated pinnipeds (NISP = 6) and the spotted (largha) seal (NISP = 5) were identified. Only two dog specimens have been recovered from the analyzed portion of the faunal assemblage.

3.3.4 Russkiy I

Russkiy I is a Yankovskaia-affiliated shell midden site located on Russkiy Island (Figure 3.5). It sits two to four meters above the shoreline on a gentle east-west slope (Brodianski et al. 2012). Emergency excavations were conducted at the site in 2011 under the direction of A.N. Popov of Far Eastern Federal University (Brodianski et al. 2012). While several strata were identified at the site, two in particular—a shell lens and a sandy loam--yielded archaeological materials dating to the Early Iron Age. Unfortunately, the site has only been described in a single seven-page report (Brodianski et al. 2012). Six radiocarbon dates were obtained on bones from six different dogs at the site (Table 3.3). When calibrated, they range in age from 3205 to 2750 cal. BP. Given that the site is a shell midden with ample evidence of consumption of marine foods, some level of marine reservoir effect is likely present in these dog dates.

Material culture from Russkiy I suggests some ceremonial function for the site. The midden stratum yielded a large scallop shell mask, stone animal figurines, and a ceramic spindle whorl incised with an elaborate design that is said to represent a sea star (Brodianski et al. 2012). The site's faunal assemblage, which has not been published, contains numerous fish and bird skeletal remains, in addition to the midden matrix's near-total composition of Pacific oyster valves (Brodianski et al. 2012). Additionally, dog, cervid, fox, suid, and phocid skeletal remains were identified.

Sample ID	**Provenience**	**Lab number**	**^{14}C age**	**δ^{13}C (‰)**	**Calibrated Age BP, 2 sigma**
Dog 4	Mixed layers, Ж/15, bone 9974(8)	Ua-51203	2765 ± 36	-13.5	2950 to 2780
Dog 5	PK, P2, formation 2 E/3, bone 9161 (7)	Ua-51204	2702 ± 37	-13.3	2865 to 2750
Dog 6	PK, parsing, P2 3/2, bone 9505(1)	Ua-51205	2933 ± 37	-14.4	3205 to 2965
Dog 8	Mixed layers, Ж/1, bone 9801(19)	Ua-51206	2853 ± 37	-13.5	3075 to 2860
Dog 10	PK, edge, P2, E/7, bone 9650 (16)	Ua-51207	2935 ± 37	-14.4	3205 to 2965
Dog 13	displaced cultural layer, bone 218	Ua-51208	2835 ± 36	-14.8	3060 to 2855

Table 3.3 Radiocarbon dates obtained from dog bone samples from the Russkiy I site.

3.3.5 Pospelovo I

Posepelovo I is a Yankovskaia period shell midden situated on Peter the Great Bay, on a strait across from the city of Vladivostok, approximately 40 meters from the shore of Russkiy Island (Figure 3.5). Emergency excavations were conducted at Pospelovo I in 2008, concurrent with similarly urgent investigations at several other locations on Russkiy Island; for this reason, specific contextual information is limited (Popov and Tabarev 2010). Popov and Tabarev (2010) report that Pospelovo I is a series of eight separate shell middens; the largest of these heaps lies at the centre of the site and has been interpreted as a platform. On the site's eastern periphery, a flexed human burial was discovered. The individual, tentatively identified as young adult female, was interred with a ceramic vessel filled with fish bones, as well as a dog mandible, a fishhook, scallop shells, two bone implements, and two pebble net sinkers (Popov and Tabarev 2010). Other archaeological evidence, such as the identification of large ash spots, may indicate the use of ceremonial fire (Popov and Tabarev 2010).

Five dog bone samples were submitted for radiocarbon dates for this project (Table 3.4). When calibrated, these dates range in age from 3020 to 2750 cal. BP. Again, some level of marine reservoir effect is likely present in these dates (Kuzmin et al. 2001). Other radiocarbon dates from Pospelovo I are not known.

Sample ID	Provenience	Lab number	14C age	δ^{13}C (‰)	Calibrated Age BP, 2 sigma
Dog 2	Trench 2, line 39/е-т PK №1, 1373	Ua-51197	2803 ± 37	-13.8	3000 to 2795
Dog 5	Trench 2, square 44/К PK 1, 1571	Ua-51198	2812 ± 36	-14.5	3020 to 2795
Dog 8	Shell layer, trench 2, line 1/Ж-И, PK 3	Ua-51199	2740 ± 36	-14.5	2925 to 2780
Dog 12	Trench 2, square 43/Л, PK 1, 1541	Ua-51200	2698 ± 42	-15.0	2870 to 2750
Dog 20	Shell layer, trench 2, line 22, M-O, PK 2	Ua-51201	2805 ± 36	-13.5	3000 to 2795

Table 3.4 Radiocarbon dates obtained from dog bone samples from the Pospelovo I site.

According to Rakov et al. (2011), the site's faunal assemblage suggests year-round use. Mollusks, cervids, suids, fish, and birds all have been identified, and Pospelovo I is the first Yankovskaia site from which the remains of a raccoon dog (*Nyctereutes procyonoides*) have been recovered. The assemblage consisted mostly of mammalian skeletal remains; within the mammals, suid remains were most numerous, followed by dog and deer (Rakov et al. 2009). Fish bones comprised the next largest identifiable faunal class, being primarily herring (*Clupea pallasii*), yellowfin pufferfish (*Takifugu xanthopterus*), and Pacific cod (Rakov et al. 2009).

3.3.6 Nazimova I

Nazimova I is a Yankovskaia-associated shell midden site first recorded by A.N. Popov in 2007, who also directed emergency excavations on the site in 2008 (Figure 3.5). No evidence for dwellings was identified during excavation, though over 27,000 artifacts were recovered, including ceramic, lithic, and bone objects (Popov et al. 2011). The shell midden was largely composed of Pacific oyster valves, though ten additional bivalve taxa and ten gastropod taxa also were identified (Rakov et al. 2009). The site also yielded 409 fish skeletal remains, 189 of which were identifiable to genus and/or species. Yellowfin pufferfish bones made up approximately 65% of the identified fish specimens, with Pleuronectidae (flounder) bones form an additional 20% (Rakov et al. 2009). The remainder of the faunal assemblage includes the skeletal remains of terrestrial mammals, predominantly suids and cervids, with younger boar/pig remains particularly numerous (Rakov et al. 2009). Carnivores, mostly dogs, also were identified, though some bear and orca teeth were also recovered (Rakov et al. 2009).

For this study, three dog remains were directly dated (Table 3.5). When calibrated, these dates range from 2950 to 2750 cal. BP. Some marine reservoir effect is likely to be present.

Sample ID	**Provenience**	**Lab number**	**14C age**	**$\delta^{13}C$ (‰)**	**Calibrated Age BP, 2 sigma**
Dog 2	Turf layer	Ua-51209	2765 ± 37	-12.4	2950 to 2780
Dog 3	Layer II, PK, square Y/4	Ua-51210	2694 ± 37	-13.2	2860 to 2750
Dog 5	PK, square T/4	Ua-51211	2685 ± 37	-13.9	2855 to 2750

Table 3.5 Radiocarbon dates obtained from dog bone samples from the Nazimova I site.

3.3.7 Cherniatino II

Cherniatino II is a multicomponent habitation site two kilometers southwest of the Cherniatino settlement, on the floodplain of the right bank of the Razdolnaia River near its confluence with the Orlikha River (Nikitin et al. 2016) (Figure 3.5). It was discovered in 1997 by Yuri G. Nikitin, who directed excavations there in 1998 and again in 2007 (Nikitin et al. 2016). These excavations revealed three periods of site use. The earliest strata are associated with the Krounovka (Bronze Age) culture (investigated in 2007), followed by an Early Iron Age component (also investigated in 2007), and finally, early medieval Mohe-Balhae strata (investigated in 1998 and 2007). The medieval occupation of the site caused extensive destruction to the archaeological record of earlier periods of use, particularly the Krounovskaia strata (Nikitin et al. 2016). Materials used in this study come from the site’s Early Iron Age and medieval contexts.

Cherniatino II has been interpreted as a habitation site, though the identification of a kiln area suggests ceramics were also produced at the site (Zhushchikhovskaya and Nikitin 2017). The excavation of Mohe-Balhae household trash pits have yielded numerous potsherds, shell buttons, bone and metal projectile points and knives, awls, and glass ornaments (Nikitin and Chzhun 2008). Nearly all trash pits contained the disarticulated skeletal remains of dogs which exhibited cut marks, suggesting butchery and consumption by humans (Nikitin and Chzhun 2008). Other domestic animals have been identified in the Cherniatino II assemblage, including pig, horse, and cattle. The faunal assemblage from the site’s excavation in 2007 consisted primarily of pig skeletal remains, followed by those of the dog (Nikitin and

Chzhun 2008). The consistent size of dog remains, and the apparent slaughter of pigs at two to three years of age, point to animal management practices carried out by the site's inhabitants (Nikitin and Chzhun 2008). Further, the remains of several domestic plants from Mohe-Balhae contexts have been identified, including broomcorn and foxtail millet, wheat (*Triticum aestivum*), barley (*Hordeum* sp.), adzuki bean (*Phaseolus angularis*), and soybean (*Glycine* sp.) (Sergusheva 2010, 2012). Sergusheva (2010) reports that foxtail millet and barley remains were the dominant species identified in the site's paleobotanical assemblage. However, hunting, fishing, and gathering also appear to have played roles in Cherniatino II subsistence. The remains of wild cervids, hares, birds (pheasants, ducks, geese, and eagles), and freshwater mollusks have been identified (Nikitin and Chzhun 2008), and the presence of pine nuts and hazelnuts, as well as elderberry (*Sambucus* sp.), Amur grape, and apple (*Malus* sp.) seeds, have been noted (Sergusheva 2010, 2012).

Eight dog bones were radiocarbon dated for this study, including five from the Mohe deposits, and three from the Balhae deposits (Table 3.6). While there is some overlap in the calibrated age ranges of the samples from the Mohe and Balhae layers, the Balhae dogs all slightly postdate those of the Mohe period. The Mohe dates, when calibrated, range from 1395 to 1180 cal. BP, and the Balhae dates from 1285 to 800 cal. BP. Cherniatino II is located away from the coast, and there is little or no marine reservoir effect in the dated samples.

Sample ID	Provenience	Lab number	^{14}C age	$\delta^{13}C$ (‰)	Calibrated Age BP, 2 sigma
Dog 2	Early Iron Age layer, mixed, trench 3	Ua-51212	1304 ± 29	-10.6	1290 to 1180
Dog 2b	Mohe layer, C. AB KOT. 3, trench 3	Ua-51213	1456 ± 29	-13.1	1395 to 1300
Dog 8	Mohe layer, trench 3 П2	Ua-51214	1414 ± 29	-11.5	1360 to 1290
Dog 12	Mohe layer, Бр.меж. АВ-СД, trench 3/П3	Ua-51215	1322 ± 30	-11.8	1300 to 1180
Dog 14	Mohe layer, object 8, trench 4	Ua-51216	1294 ± 33	-11.1	1290 to 1180
Dog 18	Balhae layer, trench 2/П2, С1, 3Пр	Ua-51217	962 ± 28	-10.2	930 to 800
Dog 22	Balhae layer, object 9, trench 4	Ua-51218	1182 ± 30	-11.2	1225 to 1000
Dog 26	Balhae layer, trench 4, П2, СА	Ua-51219	1266 ± 30	-10.7	1285 to 1090

Table 3.6 Radiocarbon dates obtained from dog bone samples from the Cherniatino II site.

4 Results of Analysis and Discussion

In this chapter, I present results of the dietary stable isotope analysis and discuss the data from each site and region. For each site, I describe the δ^{13}C and δ^{15}N values by taxon, followed by a summary of the data. Following these descriptions, I discuss the dietary scenarios presented by these data. I conclude the chapter with a review of the most significant patterns observed in the Ust'-Polui, Proezzhaia I, and Primorye datasets, along with a commentary on the research goals specified in Chapter 1.

4.1 Ust'-Polui

A total of 63 Ust'-Polui faunal samples were taken for stable isotope analysis. Thirteen taxa, representing terrestrial and marine mammals, riverine fish, and migratory waterfowl, were processed for analysis. However, dogs and reindeer from the site were of particular interest given interpretations of previously excavated archaeological material, and these comprise the majority of samples (dogs, *n* = 44; reindeer, *n* = 5). The relative paucity of human remains at Ust'-Polui indicated those recovered from the site might also be of interest, and samples from two recently excavated individuals and an isolated find were included in this study.

Of the 63 samples, 71.4% (45 samples) representing ten taxa met the accepted collagen quality standards discussed in the previous chapter and were deemed suitable for inclusion in discussion and interpretation. The dietary stable isotope results for the baseline fauna are presented first, followed by the results for dogs, reindeer, and humans, and a discussion of results for the three latter taxa.

Moose (<u>Alces</u> <u>alces</u>)

A lone moose sample (Figure 4.1) yielded adequate collagen for analysis and met quality criteria; its δ^{13}C value was -21.8‰ and δ^{15}N, 3.9‰. Though herbivorous, moose have a variety of dietary inputs because they consume both terrestrial and aquatic plants; further, they consume various plant parts (leaves, stems, twigs, bark, roots, and flowers), and are known to eat lichens and fungi (Baskin and Danell 2003). This sample's δ^{13}C and δ^{15}N values are consistent with consumption of these types of resources.

Mountain hare (Lepus timidus)

A single mountain hare (*L. timidus*) sample was taken from a lumbar vertebra, but it did not yield an adequate amount of collagen for analysis (Appendix A).

Medium-sized terrestrial omnivores, fox (Vulpes sp.) and sable (Martes zibellina)

One sample each for the Arctic fox (*A. lagopus*, MNI = 1) and sable (*M. zibellina*, MNI = 1) were taken from the Ust'-Polui faunal assemblage (Figure 5.1); both met collagen quality criteria (Appendix A). The discovery of skeletal remains from both species at Ust'-Polui underscores the site's position at the transition between arctic tundra and forest tundra. Both species' δ^{13}C (Arctic fox -22.6‰; sable -22.0‰) and δ^{15}N values (Arctic fox 9.1‰; sable 8.7‰) are similar. Arctic foxes are opportunistic omnivores whose travel between and occupation of different biomes (coastal or inland areas, for example) is well-documented (Angerbjörn et al. 1994). Sables also are classed as omnivores, and they generally remain in wooded areas (Monakhov 2001). Both species have extremely variable seasonal diets, and field observation of scat and dens suggests they take advantage of certain resources when natural abundances, such as lemming population peaks, occur (Angerbjörn et al. 1994; Ben-David et al. 1997; Dubinin 2010; Elmhagen et al. 2000).

Birds, willow ptarmigan (Lagopus lagopus) and undifferentiated duck (Anas sp.)

Samples from two migratory bird taxa, the willow ptarmigan (*L. lagopus*) (*n* = 2, MNI = 1) and an undifferentiated duck (*Anas* sp., *n* = 1, MNI= 1) were prepared for analysis. One ptarmigan sample and the duck sample met collagen quality standards (Appendix A). In this part of western Siberia, willow ptarmigan remain in the region year-round (Vartapetov et al. 2005).

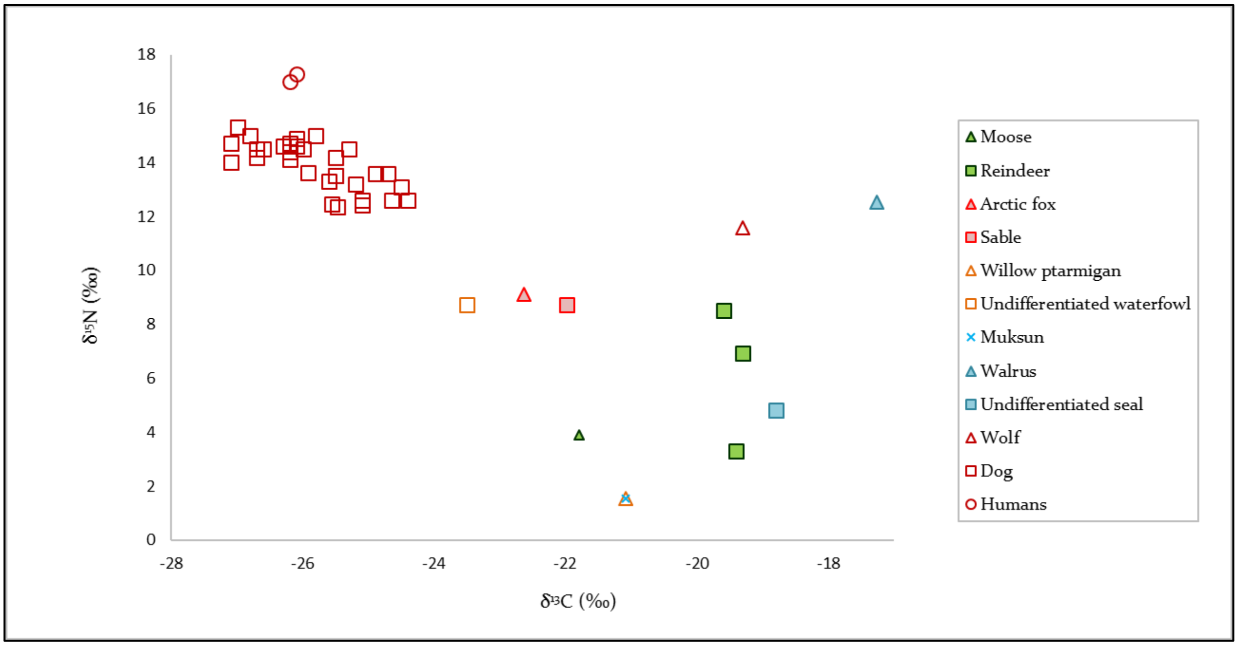

Figure 4.1 Biplot of Ust'-Polui faunal sample δ^{13}C and δ^{15}N values by taxon.

The ptarmigan's δ^{13}C (-21.1‰) and δ^{15}N (1.5‰) values were consistent with reported values for this bird's tissues elsewhere in the Arctic (Ehrich et al. 2015; Feige et al. 2012; Ricca et al. 2006; Roth 2002) (Figure 4.1). Ducks, particularly those found at northerly latitudes, are migratory and travel to nest and brood in the vast wetlands characteristic of the Arctic tundra in warmer months. Bone collagen turnover in birds can be rapid (Hobson and Clark 1992a), but this sample's stable isotope values still likely reflect more than one season, and thus feeding in more than one location—overwintering locations, points along its migratory path, and summer nesting grounds (Hobson 1999; Yerkes et al. 2008). While identification of this specimen to the species level was not possible, its δ^{13}C and δ^{15}N values, -23.5‰ and 8.7‰, respectively, are consistent with expected values for feathers and muscle of piscivorous migratory ducks in other parts of the Arctic (Yerkes et al. 2008).

Marine mammals, walrus (Odobenus rosmarus) and seal (Phoca sp.)

One sample each of walrus (*O. rosmarus*, MNI = 1) and seal (*Phoca* sp., MNI = 1) was available for analysis, and both met collagen sample quality criteria (Appendix A). The walrus's δ^{13}C and δ^{15}N values, -

17.3‰ and 12.5‰, respectively, are characteristic of a marine-based diet and reflect its preference for prey at lower trophic levels, such as mollusks (Dehn et al. 2007; Gjertz and Wiig 1992) (Figure 4.1).

The seal sample could be identified only to the genus level, and while its δ^{13}C value (-18.8‰) is consistent with a marine resource-based diet, its δ^{15}N value (4.8‰) is low given most Arctic seal species' reliance on crustaceans in spring and summer and pelagic fishes in fall and winter (Belikov and Boltunov 1998; Renouf et al. 1998) (Figure 4.1). It is possible the specimen was misidentified as its signature is more typical of a large terrestrial mammal.

Anadromous fish, muksun/whitefish (Coregonus muskun) and inconnu (Stenodus leucichthys nelma)

Considerable quantities of fish skeletal remains were encountered during excavations at Ust'-Polui, but few were retained and made available for laboratory analyses. Only a single vertebra (LPO-o1F) identified as muksun (a type of whitefish, *C. muksun*, MNI = 1) was taken for analysis and met collagen quality standards (Appendix A). Its δ^{13}C value, -21.1‰, is typical for a semi-anadromous fish that spends the majority of its life in the sea but returns to freshwater to spawn (Borvinskaya et al. 2016; Fuller et al. 2012). Muksun are unusual fish in that they can be fully anadromous, semi-anadromous, lacustrine, lacustrine-riverine, or riverine (Pauly and Froese 2019). The specific setting in which a muksun is feeding will have isotopic implications, as seen here with this sample's δ^{13}C value. However, its δ^{15}N value, 1.5‰, is unexpectedly low for a secondary consumer that generally feeds on invertebrates and zooplankton (Borvinskaya et al. 2016). An error in identification is unlikely here, so it is possible the sample came from a young individual with a differently structured diet than larger, mature fish, or perhaps it originated in a different habitat (Knoechel and Holtby 1986; Scharf et al. 2000).

Domestic dog (Canis lupus familiaris) and wolf (Canis lupus)

Dog skeletal samples were taken from formal burials and the cranium cache mentioned above, and many isolated elements also were analyzed. Ten of the 15 crania from the cache were sampled specifically for this study. For the remainder of the dog specimens, care was taken to select samples from only right scapulae, ensuring the same individual was not sampled more than once. In all, 44 samples were available for analysis, and of these, 32 (72.7%) met collagen sample quality criteria (Appendix A). Nine of these samples were from the cranium cache. A single wolf (*C. lupus*) specimen also met collagen sample quality criteria.

For clarity, the Ust'-Polui cranium cache samples and all other dog samples from the site will be treated separately. The samples taken from the cranium cache had δ^{13}C values ranging from -25.9‰ to -24.7‰ (mean -25.3 ± 0.4‰), and δ^{15}N values from 12.4‰ to 13.6‰ (mean 12.9 ± 0.5‰). The remainder of the Ust'-Polui dog samples' δ^{13}C values ranged from -27.1‰ to -24.4‰ (mean -26.0 ± 0.8‰), and δ^{15}N values from 12.6‰ to 15.3‰ (mean 14.3 ± 0.7‰). These data can be viewed in context to other fauna in Figure 4.1 and as a single taxon in Figure 4.2.

When the dog isotope values are observed in a biplot (Figure 4.2), two nearly distinct clusters emerge. To assess the statistical significance of the seemingly different isotopic signatures, a two-tailed independent t-test was performed for each group's mean δ^{13}C and δ^{15}N values.

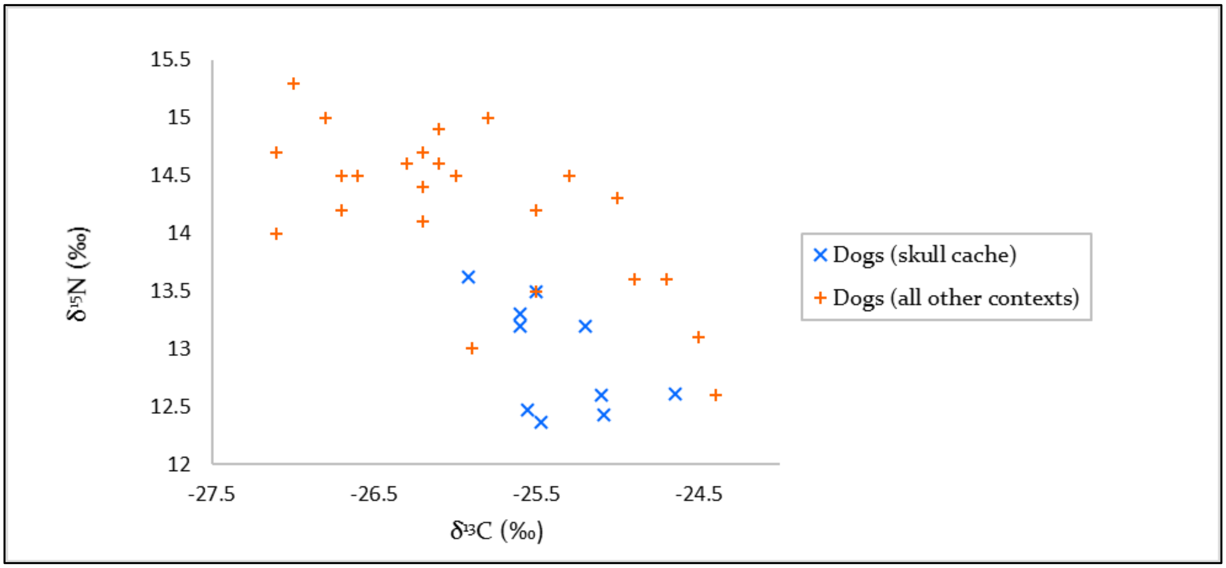

Figure 4.2 Biplot of δ^{13}C and δ^{15}N values of Ust'-Polui dogs from the skull cache and other intrasite contexts.

The resulting $\delta^{13}C$ p-value ($p < 0.019791$) is statistically significant at the 95% confidence level, and the $\delta^{15}N$ p-value ($p < 0.00001$) is statistically significant at the 99% confidence level. These results are discussed in further detail below.

The wolf sample yielded lower $\delta^{13}C$ and $\delta^{15}N$ values than either group of dogs: -19.3‰ and 11.6‰, respectively. It is clearly isotopically distinct from the domestic dog samples from Ust'-Polui (Figure 4.1).

Reindeer (<u>Rangifer</u> <u>tarandus</u>)

Among the mammalian skeletal remains from Ust'-Polui, reindeer are the most numerous, but nearly all were recovered only as disarticulated elements. Stable isotope samples were selected from different contexts in efforts to avoid analyzing the same individual more than once, as the disarticulated state of the reindeer remains made it difficult to select the same skeletal element from the same side of the body in each instance. Therefore, a minimum of only one reindeer can be calculated confidently for this study; however, it is likely up to four individuals are represented. The range of $\delta^{13}C$ values exhibited by Ust'-Polui reindeer is very small, -19.3‰ to -19.6‰. Their $\delta^{15}N$ values show a greater range of values, from 3.3‰ to 8.5‰ (Figure 4.1), which may be explained by wider $\delta^{15}N$ variation among dietary inputs. A range of 3.4 to 7.2‰ is observed among Ust'-Polui reindeer sample $\delta^{15}N$ values reported by Losey et al. (2018b).

Reindeer are an herbivorous species. Their diets are comprised mainly of leaves, stems, or twigs from trees, shrubs, herbs, grasses, and horsetails, though they also consume mosses, lichens, and fungi (Baskin and Danell 2003). It has been noted that reindeer seek out some nutrients in unusual resources, such as gnawing on shed antler and bone (Hutson et al. 2013). Many Indigenous groups across Eurasia are pastoralists who keep domestic reindeer herds. While these animals vary from their wild counterparts primarily in terms of behaviour and coloration, they are highly similar in the sense that their regional and ecological differences are constrained by local environmental conditions (Baskin 1986). As most reindeer herders in Yamal are pastoralists, domestic reindeer are mostly permitted to maintain their seasonal migrations across the landscape, and foraging habits remain largely unchanged between domestic and wild reindeer so long as they are in their indigenous habitat (Baskin 1986; Golovnev et al. 2016; Stammler 2005). There is some suggestion that reindeer inhabiting forested regions have access to a wider range of plants, mosses/lichens, and fungi (Baskin 1986), each with different $\delta^{15}N$ values from plant to plant and tissue to tissue (Ta and Weiland 1992; Wilhelm et al. 2002). Furthermore, reindeer have been observed consuming seaweed in coastal settings when weather events have prevented access to inland feeding areas (Bartsch et al. 2010; Hansen and Aanes 2012). A reindeer herd feeding in a distinct ecological setting—or even in different areas in different seasons—would result in samples featuring a wide range of collagen $\delta^{15}N$ values.

Humans (Homo sapiens)

Three human skeletal samples representing three individuals were collected in Russia after the initial sampling of the Ust'-Polui faunal assemblage. Despite the representation of three individuals, only one set of human remains, a flexed skeleton belonging to a 35- to 40-year-old female discovered outside the site's ditch, appeared to be well-preserved (Losey et al. 2017); this individual (LPO-86H) was sampled for this study. A poorly preserved inhumation thought to predate the main component at Ust'-Polui also was sampled (LPO-85H) but did not yield a sufficient amount of collagen for stable isotope analysis (Appendix A). The final human sample (LPO-84H) came from an adult tibia recovered from the central area of the site; other isolated, disarticulated human skeletal remains were found in the same locations during excavations in the 1930s and 1990s (Fedorova and Gusev 2008). Both humans' $\delta^{13}C$ values were very similar— -26.1‰ and -26.2‰—as were the individuals' $\delta^{15}N$ values, at 17‰ and 17.3‰ (Figure 4.1).

4.1.1 Discussion of Ust'-Polui dietary stable isotope data

The most compelling stable isotope data from the Ust'-Polui site centres on the $\delta^{13}C$ and $\delta^{15}N$ values yielded by reindeer, domestic dog, and human bone samples. Dog and human dietary signatures obtained for samples in this study follow the same pattern observed among several other Ust'-Polui samples analyzed by Losey et al. (2017), exhibiting low δ^{13}C values and high δ^{15}N values. Both datasets point to freshwater fauna-based diets, likely fish from the Ob' River (Losey et al. 2018b). The inclusion of fish in dog and human diets is implicated in two significant observations. Firstly, dog and human radiocarbon samples appear to be far older than other dated organic material from the same depositional contexts. Secondly, despite clear similarities in the structure of Ust'-Polui dog and human diets, there remains a ca. +2.0‰ offset between the species' δ^{13}N values, an observation made for dog and human samples in other parts of the world (Guiry 2012, 2013; Losey et al. 2013).

The stable isotope data in this study were used in concert with Losey et al.'s (2018) radiocarbon dates from bone, hide, and charcoal to examine the presence of a freshwater reservoir effect (FRE) for archaeological dogs and humans in the Lower Ob region. While terrestrial plants assimilate CO_2-derived carbon from the atmosphere, dissolved organic carbon is the most significant carbon source used by aquatic plants during photosynthesis (Philippsen 2013). Dissolved organic carbon is comprised of carbon from a variety of sources (e.g., limestone, permafrost), many of which have lower ^{14}C levels than the atmosphere, such that when organic materials from aquatic contexts—or from organisms that fed on aquatic resources—are radiocarbon dated, they generally appear older than they are (Philippsen 2013). In an aquatic resource-based food web, the ^{14}C reservoir effect is passed up to higher trophic levels, meaning even samples from secondary terrestrial consumers have the potential to carry a more ancient ^{14}C date if their dietary inputs originated in this context.

Losey et al. (2017) note the Ust'-Polui FRE was investigated due to the publication of several recent archaeological papers concerning a possible FRE in other parts of Siberia where humans and dogs appear to have relied heavily on lacustrine and riverine fish species (e.g., Nomokonova et al. 2013; Schulting et al. 2014, 2015; Svyatko et al. 2015).

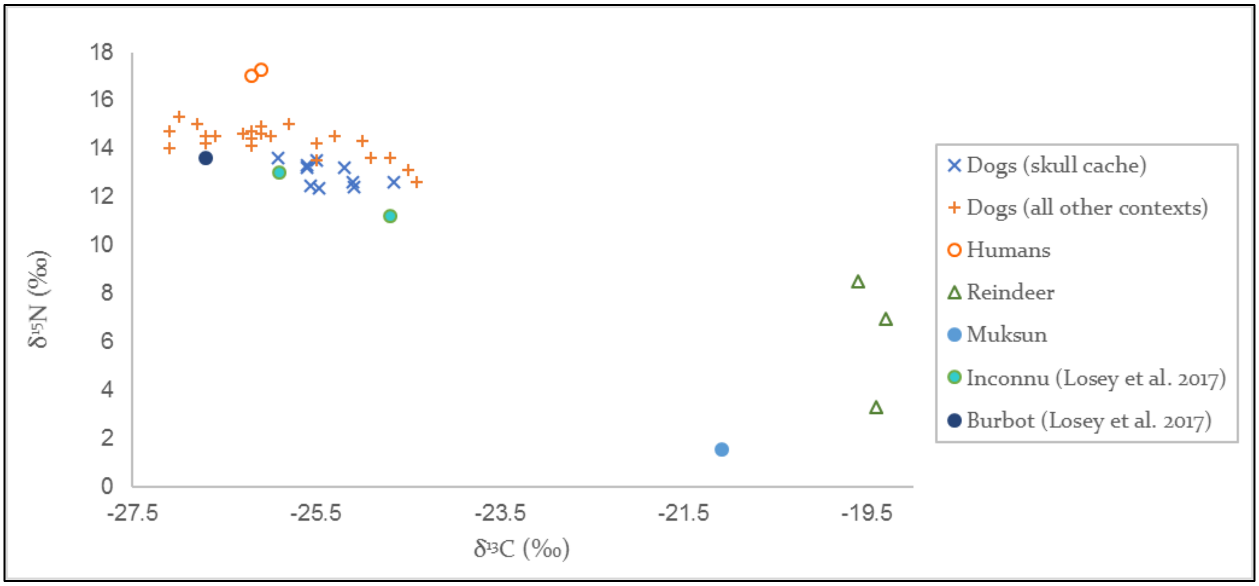

Figure 4.3 Biplot of Ust'-Polui dog, human, reindeer, and fish δ^{13}C and δ^{15}N values.

Fish were suspected to be significant dietary contributors to Ust'-Polui dogs, an assertion supported by the preliminary dietary stable isotope data I generated for this project. These data pointed to two isotopically distinct diets: for the reindeer, a terrestrial, plant-based diet, and for dogs and humans, an aquatic, freshwater resource-based diet (Figure 4.3). If freshwater fish comprised the bulk of dog and human diets, a possible FRE would skew their radiocarbon dates, causing materials to appear much older than their true ages. Due to the generally excellent organic preservation at the site, paired radiocarbon date samples were taken from the two human interments with associated hide and bark materials, as well as reindeer and fish bones in direct contextual association; dog skeletal remains and the isolated human tibia were among non-paired materials also dated (Losey et al. 2018b). The paired samples revealed a clear pattern of human, dog, and fish bones yielding much earlier radiocarbon dates, an average of 784.25 years older than the other organic materials with which they had been found in close association (Losey et al. 2018b).

Exercising dogs, and particularly those carrying out strenuous activities in winter Arctic conditions, have extraordinary dietary needs (Loftus et al. 2014). Presently, sled dog teams in many parts of Siberia are provisioned with the most bountiful and locally available source of protein: riverine fish. Each fall, humans undertake fishing projects to ensure sled dog teams are suitably provisioned throughout the winter (R. Losey, personal communication, 2018). In their ethnographic survey of dog sledge-using human groups in Siberia, Davydov and Klokov (2018) observed a significant spatial relationship: the use of dogs for traction occurs in parts of Siberia where humans have the means to provision their dogs with abundant aquatic resources. In Siberia, the shores of the Pacific and Arctic Oceans, as well as large rivers with substantial populations of spawning or migratory fish, provide the best environments for such practices. As a single ten-dog team can consume up to four tons of fish in a single sledding season (Chikachev 2004, quoted in Davydov and Klokov 2018), adequate stores of fish must be acquired, salted, and frozen for use throughout the winter. In the summer, however, sled dogs do not perform heavy labour, and typically are left to forage and hunt on their own. Today on the Yamal tundra, lemmings are a favourite food of dogs when they are plentiful at warmer times of the year (R. Losey, personal communication, 2018).

The long-term relationships dogs have had with humans are, to some extent, evident in their diets and feeding practices. While the specific mechanisms for wolf domestication remain unknown—though they likely varied across location and time (Larson et al. 2012; Ovodov et al. 2011; Peng et al. 2011; Savolainen et al. 2012; Thalmann et al. 2013; Wayne and von Holdt 2012)—Coppinger and Coppinger's (2001) "self-domestication" model suggests wolves were drawn to accumulations of human trash. Those wolves less likely to perceive an approaching human as a threat became increasingly tolerant of them, and humans became tolerant of the wolves' presence. Over time, a complex, mutually beneficial relationship emerged as wolf behaviours and bodies became significantly altered. In this domestication narrative, it is possible some of these canids, as a result of scavenging on human trash, had similar dietary inputs to humans and consequently acquired a similar isotopic signature. This dietary similarity would increase with the widening genetic gulf between wild wolves and domestic dogs as the latter were integrated into human social structures—at least until human subsistence or economic activities changed course and the relationships between dogs and humans began to vary and became more complex.

The isotopic proximity of human and dog diets, particularly among hunter-gatherer groups, has been well established. In recent years, the use of dogs as dietary isotopic proxies for humans has been championed by Guiry (2012, 2013) as the Canine Surrogacy Approach (CSA). He acknowledges a consistent $\delta^{15}N$ offset that places humans just slightly above dogs, which other researchers have suggested is an isotopic consequence of some human consumption of dog meat, dogs' tendency to consume scat, or a metabolic difference between the two species (Cannon et al. 1999; Losey et al. 2013). Guiry comments that, depending on research aims and interpretations afforded by dietary stable isotope data, this difference may be significant or of little importance. Generally, the human and dog $\delta^{15}N$ values from Ust'-Polui uphold the pattern documented by Guiry (Table 4.1). Guiry notes that the number of human samples in archaeological stable isotope work tends to be larger than those of dogs from the same sites. This is not the case for Ust'-Polui, where dog samples significantly outnumber those of humans. Given the complex nature of stable isotope ecology, no archaeological stable isotope study involving both humans and dogs can point to a single explanation for such an offset in all datasets. However, it appears that both cultural and non-cultural factors are potential mechanisms responsible for the offset between Ust'-Polui humans and dogs, and possibly the dietary offsets observed at other locations. While the scenarios outlined below are presented as discrete interpretations of the $\delta^{15}N$ offset between the Ust'-Polui dog and human dietary stable isotope data, two or more of them working in concert may be responsible for the patterns seen here.

The $\delta^{15}N$ value offset demonstrated by the Ust'-Polui dog and human samples echoes a phenomenon seen in other parts of Siberia. Losey et al. (2013) suggest the slight $\delta^{15}N$ value offset between humans and dogs at several prehistoric archaeological sites in Cis-Baikal, a region in southern Siberia, could be the result of preferential human consumption of larger freshwater fish with correspondingly higher $\delta^{15}N$ values, while smaller ones may have been retained for consumption by dogs. This possibility takes on even more significance when interpreting the dietary stable isotope results of the Ust'-Polui dogs, where a similar isotopic pattern to that of ancient Cis-Baikal is observed.

The Ob River experiences an annual winter hypoxia event at the onset of river freeze-up, lowering oxygen levels as liquid water becomes bound up in ice (Miranda 2014). Fish must seek out more oxygenated water or they will suffocate. This event affects fish of all species and sizes, pushing them into the lower reaches of the Ob, or the Gulf of Ob, each fall just before the onset of sledding season.

Freshwater fish diets are complex and based on many variables (Borvinskaya et al. 2016; Koporikov and Bogdanov 2011), but fish age and size play important roles. Field observations of fish feeding habits and gut content analyses, as well as experimental feeding projects, have revealed younger and/or smaller secondary consumer fish select smaller prey than older, larger individuals, primarily as a function of their size and ability (Graeb et al. 2011; Scharf et al. 2000). It also has been suggested that a fish's growth rate, not its metabolic tissue replacement rate, impacts its $\delta^{34}S$, $\delta^{13}C$, and $\delta^{15}N$ muscle tissue values. Hesselein et al. (1993) demonstrated in a controlled feeding experiment that the slow turnover rate in young members of a coregonid species was a feature of its slow growth rate; over a year passed before their muscle tissues' isotopic signatures began to reflect dietary inputs. Further controlled feeding experiments with other larval and juvenile fish have shown their muscle $\delta^{15}N$ values are dependent on growth rates (MacAvoy et al. 2001). If humans and dogs differentially and consistently consumed fish of a specific age, size, or growth rate, it is reasonable to expect their dietary isotopic signatures would reflect this difference.

$\delta^{13}C$	*n*	Mean	Lowest Value	Highest Value
Dog (cache)	9	-25.3 ± 0.4‰	-25.9‰	-24.7‰
Dog (non-cache)	23	-26.0 ± 0.8 ‰	-27.1‰	-24.4‰
Human	2	-26.2 ± 0.07‰	-26.2‰	-26.1‰

$\delta^{15}N$	*n*	Mean	Lowest Value	Highest Value
Dog (cache)	9	12.9 ± 0.5‰	12.5‰	13.6‰
Dog (non-cache)	23	14.3 ± 0.7‰	12.6‰	15.3‰
Human	2	17.2 ± 0.2‰	17.0‰	17.3‰

Table 4.1 Count, mean, and range of Ust'-Polui dog and human $\delta^{13}C$ and $\delta^{15}N$ values.

In a similar vein, it is possible differential consumption of specific fish parts by humans and dogs could result in the offset observed among these data. As reviewed in Chapter 2, ^{13}C and ^{15}N fractionation varies not only by species and environmental conditions, but also between different tissues within a single individual. While this phenomenon among tissues of individual plants has been intensively studied and is relatively well-understood, animal metabolic processes are more complex, and dietary stable isotope research may target the same species but different tissue types. To address these concerns in the analysis of fish, Pinnegar and Polunin (1999) sampled different tissues from the same individuals in two cohorts of rainbow trout (*Oncorhynchus mykiss*). Their results indicate that all tissues are enriched in ^{15}N, but white muscle is particularly so. While all fish possess white and red muscle, the proportion of each varies by species (Greek-Walker and Pull 1975). Red muscle is limited to thin bands along the lateral line--meaning white muscle comprises the bulk of muscle tissue in most fish taxa (Kiessling et al. 2006). The ^{15}N enrichment of fish white muscle over other their tissues is suggestive of similar processes that could be at work in the Ust'-Polui human-dog $\delta^{15}N$ offset. Though human perceptions of edibility, consumption, and use of specific fish parts (e.g., muscle, skin/scales, and eggs) are to a great extent culturally determined, humans tend to avoid large bones and certain types of organs (Losey et al. 2013). Dogs feeding on whole fish and offal from fish processing would necessarily consume more of the ^{15}N-depleted tissues, while humans preferentially would consume greater quantities of the ^{15}N-enriched white muscle. Among present-day dogsledding peoples in Kamchatka, filleting fish and leaving the bones and heads to dogs is a noted practice (Strecker 2018). In addition to fish muscle, the eggs of some fish species are particularly prized by humans, though there are scant examinations of the isotopic value of this type of tissue. Among anadromous Coho salmon of the Pacific Northwest, δ^{15}N values from eggs are elevated ca. 2‰ over muscle (Bilby et al. 1996). Such isotopic differences might also contribute to the human-dog offset observed among the Ust'-Polui data.

A third scenario that could explain the δ^{15}N offset between the Ust'-Polui humans and dogs is seasonal resource availability and different provisioning practices between winter and summer. As noted previously, recent ethnographic observations suggest dogsledding humans generally leave their dogs to self-provision during the warmer months of the year. If this occurred in Yamal, it could be assumed dogs' diets partially shifted to lemmings and other small rodents at this time. Lemmings are small, non-hibernating rodents present year-round in the Arctic forest-tundra and tundra but most readily available in the summer (Dunaeva 1948; Oksanen et al. 2013); they experience huge summer population peaks in three- to five-year cycles (Korpimäki et al. 2004). In the Western Siberian Lowlands, lemming species include the brown lemming (*Lemmus sibiricus*) and the collared lemming (*Dicrostonyx torquatus*) (Solomesch 2005). Lemmings are primary consumers that feed on C_3 plant material in terrestrial ecosystems and have correspondingly low dietary δ^{15}N values. If these animals comprised a significant portion of sled dog diets during the short Arctic summers, their isotopic input could result in lower dog δ^{15}N values relative to those of humans.

Here I explored three plausible and distinctive provisioning schemes that may explain the observed dietary isotopic offsets between Ust'-Polui humans and dogs. Returning to the precepts of the Canine

Surrogacy Approach, I argue that in the case of Ust'-Polui, dog dietary stable isotope data are suitable proxies only for the purpose of establishing the aquatic source of dog and human dietary inputs. The δ^{15}N value offset between the two species at Ust'-Polui is similar to those observed among other prehistoric datasets in Siberia, and within this small space lie several cogent possibilities to explain why their values are not precisely equivalent. In other words, while the Ust'-Polui human-dog δ^{13}C and δ^{15}N offsets are not large, the consistency of these offsets is notable and merits deeper investigation.

4.1.2 Differential dietary stable isotope values between intrasite contexts

Examination of the Ust'-Polui dietary stable isotope data revealed another interesting pattern. Upon inspection of the isotope data with respect to their depositional contexts, samples from the skull cache and those recovered from elsewhere on site formed two somewhat distinctive clusters (Figure 4.2). While both groups of dog samples yielded δ^{13}C and δ^{15}N values consistent with significant freshwater resource dietary inputs, the samples taken from the skull cache carry higher δ^{13}C and lower δ^{15}N values. Due to the relatively large sample of dogs from Ust'-Polui, I performed two-tailed independent *t*-tests in Excel to examine the statistical significance between the δ^{13}C and δ^{15}N values of the groups (Ruxton 2006). The differences in the groups' δ^{13}C data yielded a value of $p = .019791$, making the difference between the two significant at the 95% confidence level. The significance increased to the 99% confidence level when I compared the groups' δ^{15}N values, which yielded a result of $p < .00001$.

Several possibilities may explain these differences. Other dietary stable isotope studies have made convincing arguments in favour of the special status of sacrificial animals on the basis of differential δ^{13}C and δ^{15}N values and their depositional contexts (e.g., White et al. 2001). However, in the absence of more explicit contextual information for the non-cache dog remains from which these samples came, it is impossible to say for certain that the skull cache dogs represent a special cohort of the dog population. The context of the skull cache—the same element with nearly the same traumatic injury—is highly suggestive of ceremonial killing and could represent a single event wherein fifteen dogs were sacrificed. The dietary inputs for dog remains recovered from other locations within the site were more varied, indicating they represent dogs from a wider window of time and may have come from a range of ecological contexts. The non-cache dogs could represent individuals from a variety of communities whose diets were based on slightly different types of aquatic resources (different fish populations, for example).

The stable isotopic similarities of the samples taken from the skull cache suggest these dogs acquired their food from the same resources and were members of same population, but rather than forming a distinctive group within the larger Ust'-Polui dog community, it is possible the skulls (or living dogs) were brought to Ust'-Polui from another location and had different dietary inputs. If the skull cache dogs were from the same community and sacrificed at the same time, this also suggests they represent a population who lived (and ate) within the same period of time, minimizing year-to-year variations in diets. The dog's shorter lifespan compared to that of humans means their bone collagen reflects a much shorter period of dietary isotopic inputs and is more sensitive to changes in diet (Cannon et al. 1999), though the combined effects of lifespan, metabolic rate, and isotopic half-life on stable isotope values remain poorly understood. Because Ust'-Polui has been interpreted as a multi-community ritual location, one should expect regional dietary and ecological patterns to be expressed in the dogs' stable isotope values. Future efforts to assess the geographic origin(s) of these dogs may shed further light on the issue.

4.2 Proezzhaia I

A total of 47 Proezzhaia I faunal specimens was available for stable isotope analysis (Appendix A). Fourteen terrestrial taxa are represented among the samples and include herbivorous, omnivorous, and carnivorous mammals. As this is a medieval site, several important domestic animals were present in the assemblage and sampled for this study, including dog (*Canis lupus familiaris*), cattle (*Bos* sp.), horse (*Equus* sp.), sheep/goat (*Ovis*/*Capra* sp.), and pig (*Sus scrofa*). Fish remains are rare in the Proezzhaia I faunal assemblage; their scarcity is likely linked to the intermittent use of sieves during excavation. However, the use of aquatic resources by the inhabitants of the site is reasonable based on its location above the Shilka River. For this reason, seven modern fish samples from seven taxa present in the Shilka River also were analyzed. All specimens analyzed were identifiable to at least the family level. In all, thirty-five archaeological samples (74.5%) and five modern fish samples (71.4%) met the accepted standards of collagen yield and quality.

No human remains have been recovered from the site to date, consistent with its previous interpretations as a habitation site. While juvenile specimens from all sites in this study generally were avoided, several Proezzhaia I samples, including four boar/pigs (*Sus scrofa*) and one cattle (*Bos* sp.), exhibited visible lines of fusion. This suggests these animals had not reached skeletal maturity at the time of their death, but the size and overall maturity of the elements indicated the individuals had passed the weaning stage.

Faunal samples were taken across the assemblage to reflect the breadth of taxa represented by the site. The wild taxa of Proezzhaia I—particularly the cervids and carnivores—provide a useful ecological baseline for interpreting the isotopic dietary inputs of the domestic taxa. Furthermore, these data represent the first archaeological dietary stable isotope baseline for the entire Transbaikal region, from any time period.

Cervids, undifferentiated Cervidae, moose (Alces alces), deer (Cervus sp.), roe deer (Capreolus sp.), and musk deer (Moschus moschiferus)

A total of six cervid samples were prepared for analysis. Collagen yield for one sample (LPZ-12F, a moose calcaneus) could not be calculated due to instrument error and was excluded from further analysis. Additionally, the *Cervus* sp. sample was excluded as its C:N ratio exceeded the accepted figure for collagen quality (≥ 3.6). Two undifferentiated cervid samples (MNI = 1) yielded comparable δ^{13}C values (-21.3‰ and -21.4‰), but somewhat different δ^{15}N values (2.5‰ and 5.4‰). The moose (*Alces alces*) sample (MNI = 1) yielded a δ^{13}C value of -21.4‰ and a δ^{15}N value of 2.7‰. Two roe deer (*Capreolus* sp.) samples (MNI = 1), likely belonging to the Siberian roe deer (*C. pygargus*) species given the site's location yielded δ^{13}C values of -19.6‰ and -22.4‰ and δ^{15}N values of 3.8‰ and 5.7‰. Lastly, a single musk deer (*M. moschiferus*) sample (MNI = 1) yielded δ^{13}C a value of -23.3‰ and a δ^{15}N value of 4.9‰. The mean δ^{13}C value for all Proezzhaia cervid taxa is -21.2 ± .09‰, and the mean δ^{15}N value is 4.2 ± 1.3‰.

The values obtained from the Proezzhaia I cervids are consistent with terrestrial, C_3 plant-based diets and are similar to those obtained from cervid samples at earlier sites in Cis-Baikal (Katzenberg et al. 2012).

Long-tailed ground squirrel (Citellus undulatus) and hare (Lepus sp.)

Samples from an additional two wild herbivore taxa, the long-tailed ground squirrel (*C. undulatus*; *n* = 1; MNI = 1) and a species of hare (*Lepus* sp.; *n* = 3; MNI = 1), were available for analysis and met collagen quality criteria (Figure 4.4; Appendix A). The ground squirrel's δ^{13}C value (-18.9‰) and δ^{15}N value (6.5‰) were slightly higher than those of other terrestrial herbivores from Proezzhaia I. Mean δ^{13}C and δ^{15}N values for the hare samples were -22.0 ± 1.2‰ and 3.8 ± 1.7‰, respectively.

Medium-sized carnivores, sable (Martes zibellina) and fox (Vulpes sp.)

Three sable (*M. zibellina*, MNI = 2) and two fox (*Vulpes* sp., MNI = 1) samples were available for analysis and met collagen quality standards (Appendix A). Sable δ^{13}C values ranged from -19.9‰ to -19.6‰ (mean -19.7 ± 0.2‰), and δ^{15}N values ranged from 7.8‰ to 8.3‰ (mean 8.1 ± 0.3‰). Fox δ^{13}C values were slightly lower, at -20.5‰ and -20.0‰, though their δ^{15}N values, 8.3‰ and 8.5‰, were very similar. These data show sables and foxes had access to isotopically similar foods to those accessed by domestic dogs (Figure 4.4). Though both sable and foxes are known to scavenge on human refuse when it is available (Herr 2008; Lanzski et al. 2009), in the absence of human dietary stable isotope values, it is impossible to favour such an interpretation over their natural hunting and foraging activities.

Modern freshwater fish

Given the important isotopic contributions of aquatic resources to human and animal diets elsewhere in Siberia, and Proezzhaia I's location on the Shilka River, freshwater shellfish and fish sample stable isotope values have the potential to illuminate interpretations of animal management practices at the site. Freshwater bivalve shells were encountered during excavation, and several examples were retained; however, as mollusk shell lacks collagen, the shells were not analyzed for this study. Due to the previously mentioned dearth of archaeological fish remains from Proezzhaia I, seven modern fish samples from the Shilka River, each comprising several ribs, were made available for analysis by sport fisherman Sergei Cheremisin. Five samples were taken from benthopelagic cyprinids (Cyprinidae, the minnow and carp family) including the Crucian or Prussian carp (*Carassius gibelio*), redfin (*Pseudaspius leptocephalus*), Amur ide (*Leuciscus waleckii*), common carp (*Cyprinus carpio*), and an undifferentiated cyprinid (*Hemibarbus* sp.). The remaining two samples represent two species of bottom-feeding (demersal) catfish, yellow catfish (*Tachysurus fulvidraco*) and Amur catfish (*Silurus asotus*).

As addressed in the section on the Ust'-Polui fish samples, the complex ecological interactions among biota in freshwater settings, and even among individual fish of the same species in the same body of water, may result in widely variable dietary stable isotope values. Benthopelagic freshwater fish occupy the part of the water column just above demersal taxa, which rest at or very near the bottom of the water column. The benthopelagic taxa analyzed in this study feed on a variety of aquatic resources, including planktons, plant materials from aquatic vegetation, larval stage and fully mature insects, other invertebrate taxa such as mollusks, small fish, and even detritus (Froese and Pauly 2019).

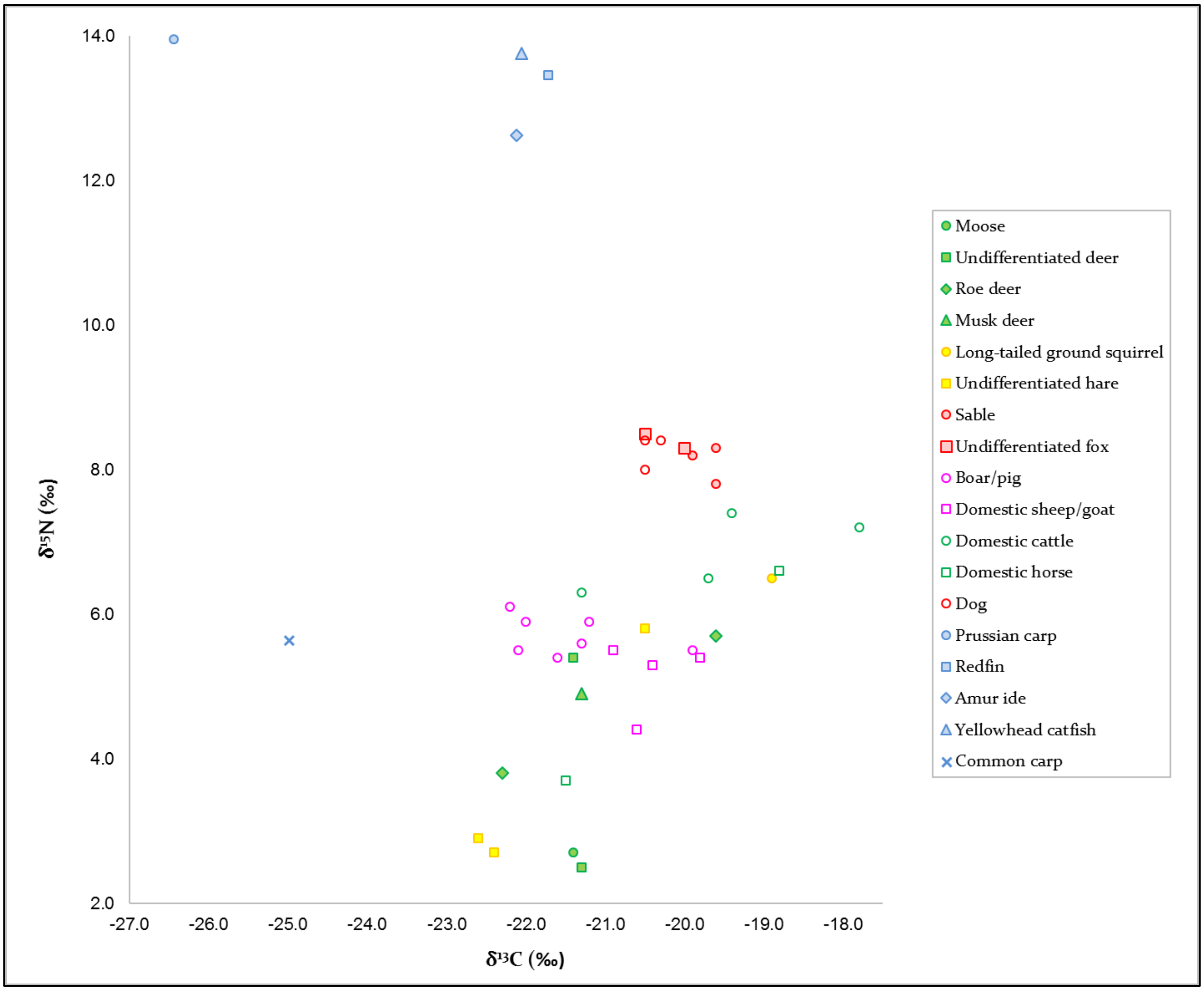

Figure 4.4 Biplot of Proezzhaia I faunal sample δ^{13}C and δ^{15}N values by taxon.

The demersal catfish taxa analyzed feed at the bottom, but also consume insects and larvae, mollusks, and other fish (Froese and Pauly 2019). The Shilka fish samples' low δ^{13}C values are characteristic of freshwater fish taxa (mean -23.5 ± 2.1‰), and the generally high δ^{15}N values (mean 11.9 ± 3.5‰) corroborate these taxa's high trophic position in the aquatic food web. Given the complexity of fish populations in rivers, and the inherent variation in diet with respect to an individual's age and size, it is not unusual that one Shilka fish sample, that from the common carp (*C. carpio*), showed a markedly lower δ^{15}N value than the other fish samples (5.6‰ compared to 12.6‰ to 14.0‰). In its natural setting, field observations have shown the common carp is particularly fond of detritus (Garcìa-Berthou et al. 2001), the consumption of which is consistent with lower δ^{15}N values (Fry 1991).

Sheep/goat (<u>Ovis/Capra</u> sp.)

Four sheep or goat (*Ovis/Capra* sp., hereafter referred to as 'caprines'; MNI = 1) samples were taken for analysis, and all met collagen quality standards (Appendix A). Three samples were taken from fully fused skeletal elements, but a fourth was obtained from an ulna on which a line of fusion was visible. The ulna is among the last bones of the caprine skeleton to complete the process of epiphyseal fusion (Zeder 2006), and this sample's values are similar to that of other samples from this taxon, precluding the possibility this sample represents an individual who had not yet been weaned. Though very unlikely given the careful selection of samples from different intrasite contexts, all caprine samples in the present study are possibly from a single individual. Mean caprine δ^{13}C and δ^{15}N values are -20.4 ± 0.5‰ and 5.2 ± 0.5‰, respectively, and are similar to the ranges of the wild Proezzhaia I cervids, suggesting they consumed similar, C_3 plant-based diets.

Suids (<u>Sus</u> <u>scrofa</u>)

Eight suid (*S. scrofa*) samples were prepared for analysis, though one did not meet collagen quality criteria (Appendix A). Among the remaining seven samples (MNI = 3), four were taken from unfused skeletal elements; however, the absence of a trophic level effect among their δ^{15}N values suggests these individuals had been weaned before death (Figure 4.4). While differentiating between domestic pigs and wild boar on basic skeletal morphology is equivocal at best, it is assumed given the medieval context that these samples represent domestic pigs, which by this time were husbanded by humans in Transbaikal. Pig δ^{13}C values ranged from -22.2 to -19.9‰ (mean -21.5 ± 0.8‰), and δ^{15}N values ranged from 5.4 to 6.1‰ (mean 5.7 ± 0.3‰).

Domestic cattle (Bos sp.) and horse (Equus sp.)

A total of seven cattle skeletal samples were taken for analysis (MNI = 1); however, only four met the accepted standards of collagen quality (Appendix A). δ^{13}C values were variable (Figure 4.4), ranging from -17.8 to -21.3‰. δ ^{15}N values were more tightly grouped, from 6.3 to 7.4‰. Six horse bone samples also were prepared for analysis (MNI = 1), though only two met collagen quality standards (Appendix A). One of two horse samples yielded a δ^{13}C value of -18.8‰ and a δ^{15}N value of 6.6‰, while the other had a δ^{13}C value of -21.5‰ and a δ^{15}N value of 3.7‰ (Figure 4.4).

Domestic dog (Canis lupus familiaris)

A total of five dog samples (MNI = 2) were taken for analysis; of these, three met the accepted standards of collagen quality (Appendix A). Both δ^{13}C and δ^{15}N values were highly comparable among the three samples (Figure 4.4). δ^{13}C values ranged from -20.3 to 20.5‰ (mean -20.4 0.1‰), and δ^{15}N values ranged from 8.0 to 8.4‰ (mean 8.2 ± 0.1 ‰).

4.2.1 Discussion of Proezzhaia I dietary stable isotope data

Discussed in Fleming et al. (2018), the possible reasons for the inconsistency of the cattle and horse stable isotope values with those of the other Proezzhaia I fauna include small-scale crop cultivation, animal foddering practices, or exchange activities. Deeper examination of the archaeological and ethnohistorical literature suggests crop cultivation and animal foddering practices are very closely related aspects of an intensive animal management strategy (Bogaard 2012; Gurung and McVeigh 2002). Intensive animal management strategies often include small-scale plant cultivation and the husbandry of several domestic animals, while extensive management strategies tend to focus on a single species (Bogaard 2004; Briske and Heitschmidt 1991). The intensive animal management approach seeks to distribute risks and often supplements hunting, fishing, and gathering activities, with the eventual goal of consuming the domestic animals if needed (Bogaard 2004; Halstead 1996). Here, I examine the stable isotope values of domestic taxa from Proezzhaia I against the backdrop of data provided by the region's wild fauna. I argue that cattle and horses existed in a system managed directly by humans, while dogs, pigs, and caprines appear to have self-provisioned with infrequent or indirect human influence on their diets. Additionally, I present an alternative, or supplemental, scenario wherein cattle and horses were brought to Proezzhaia I from a distant location.

As reviewed in Chapter 2, dietary stable isotope values can be used to assess the location in which an herbivore regularly ate because the plants they consume will reflect the openness of the growing environment. Generally, C_3 plants growing under a closed canopy experience higher humidity levels, receive less light, and are more heavily impacted by CO_2 exchanges than plants in more open conditions, resulting in lower $\delta^{13}C$ values (Brooks et al. 1996; Graham et al. 2014). This effect is observed among understory plants in forests of all types, including those where coniferous evergreens are the dominant taxa, such as the forest-steppe typical of eastern Transbaikal, though experimental studies from western North America demonstrate the magnitude of the effect is less dramatic than in deciduous forests (Buchmann et al. 1997). As browsers, most cervids prefer to consume plants that grow in forested areas (Jiang et al. 2009), and the Proezzhaia I cervid sample $\delta^{13}C$ value mean (-21.2 ± 0.9‰) is consistent with the consumption of vegetation growing under a closed canopy. In comparison, the $\delta^{13}C$ values for the cattle samples (mean -19.6 ± 1.4‰) and one horse sample value (-18.8‰), would suggest these animals consumed plant matter which grew in an environment that was more open. Cattle and horses are grazers that prefer to consume grasses in open pastures (Bokdam et al. 2003; Menard et al. 2002). Sheep and goats (the caprines) are both ruminant animals (like cattle), but sheep are grazers that selectively consume grassy forage (Eadie 1969), while goats are generalist browsers that eat grasses as well as the shoots, leaves, and fruit of woody shrubs and trees (Russell 1988). Though very difficult to skeletally identify a domestic caprine as either a sheep or goat, the mean $\delta^{13}C$ value for the Proezzhaia I caprine samples, -20 ± 0.5‰, lies between those of the site's cervid and cattle/horse samples. Considered together, these data indicate wild cervids and domestic cattle, horses, and caprines were consuming plants under conditions consistent with their known feeding habits.

Noted in Chapter 1, human management of animal diet is a criterion of many definitions of domestication. Such strategies are extremely varied, but generally, domestic animal diets are either directly managed by humans or indirectly influenced by them, and dietary stable isotope data permit some inferences to be made on these points. The most striking data from the Proezzhaia I assemblage were the $\delta^{15}N$ values yielded by the four cattle samples (mean 6.9 ± 0.5‰) and one of the two horse samples (6.6‰). These values are unexpectedly high for herbivorous grazers. The majority of primary consumer $\delta^{15}N$ values from Proezzhaia I do not indicate that the locally available flora were similarly enriched in ^{15}N or could be responsible for the cattle and horse sample values observed here. These data further suggest that cattle and horses at Proezzhaia I were managed more closely than other domesticates at the site.

The $\delta^{13}C$ values for the Proezzhaia I cattle and horse samples are consistent with the consumption of plant matter growing in an open environment. As discussed, both species are grazers, and it is reasonable to suggest both domesticates accessed open areas where forage was available, such as a pasture. Pastures are managed landscapes where dung readily accumulates and fertilizes the soil, and in some management strategies, dung is incorporated into the soil to maintain the productivity of the pasture (Barretto de Figueiredo et al. 2017; Morrison 1959). Animals then consume the ^{15}N-enriched plants, resulting in their higher tissue $\delta^{15}N$ values. In some parts of the world, forage plants are cultivated by humans in field- or pasture-like settings. Animals may be allowed to enter such areas to graze on the growing plants after they have reached a certain stage, and in some instances the material may be harvested for use as fodder over the winter (Bogaard 2004). Considering the long, severe Transbaikal winter and its very short summer, the production of fodder may have been a strategy to ensure cattle and horses were adequately sustained in the non-growing seasons of the year when fresh plant material was not available.

It is possible a specific plant was cultivated for consumption by Proezzhaia I horses and cattle. However, no paleoethnobotanical study has been performed for Proezzhaia I to date, and the presence of any such plant at the site has not been established. Domestic millets have been used as livestock fodder in Asia since at least the Neolithic (Atahan et al. 2014; Dai et al. 2016). They are tolerant of poor soils and dry conditions and respond well to fertilization (Baltensperger 2002; Tadele 2016). The Ust'-Chërninsk fortified Medieval settlement, located five kilometers upriver from Proezzhaia I, has produced remains of a millet cultivar, either foxtail millet (*Setaria italica*) or broomcorn millet (*Panicum miliaceum*) (Alkin and Sergusheva 2013). Given the sites' proximity to one another and their contemporaneous occupation, it is likely the inhabitants of Proezzhaia I had access to this millet cultivar. I offer a circumstantial argument to suggest the plant was in use here based on long-tailed ground squirrel diet. The long-tailed ground squirrel sample, admittedly just a single sample, yielded δ^{13}C and δ^{15}N values (-18.9‰, 6.5‰) similar to those of the cattle samples (means -19.6 ± 1.4‰, 6.9 ± 0.5‰). A field rodent, the long-tailed ground squirrel is a documented pest on crops in northern China (Zhi and Cheng-Xin 1984), and because they hibernate in the winter (Galster and Morrison 1976), their dietary signatures are established in the warmer months of the year. Though the Shilka-Argun Floristic Region in which both Proezzhaia I and Ust'-Chërninsk are located is home to several species of wild plants that use the C_4 photosynthetic pathway (Malyschev and Peschkova 2001), the identification of a cultivated millet at Ust'-Chërninsk suggests its presence at Proezzhaia I.

In comparison to the Proezzhaia I cattle and horse dietary stable isotope sample values, the site's dog, pig, and caprine sample values do not suggest that these diets were managed directly by humans. Because fish bones and mollusk shells were encountered during the excavations at Proezzhaia I, and given the site's situation on the Shilka River, it was considered that these animals may have made isotopic contributions to human and animal diets. Unlike Ust'-Polui, where dogs were almost certainly provisioned with fish, a review of the Proezzhaia I dog sample $\delta^{13}C$ and $\delta^{15}N$ values (mean -20.4 ± 0.1‰, 8.2 ± 0.2‰) alongside the values obtained for several species of modern Shilka fish (Figure 4.4) do not show the inclusion of any aquatic resource in dog diets. Though pig sample $\delta^{13}C$ values (mean -21.5 ± 0.8‰) could indicate some access to riverine resources, their $\delta^{15}N$ values (mean 5.7 ± 0.3‰) are considerably lower than those of the modern Shilka fish. This could suggest their consumption of some other resource other animals at Proezzhaia did not eat, such as nuts.

Though compelling, the data do not speak unequivocally to the scenarios described above, and long-distance trade might also explain the dietary stable isotope patterns observed among the Proezzhaia I cattle and horse samples. In the absence of dietary stable isotope data from incremental structures such as teeth or horn, it cannot be ruled out that the variation observed among the Proezzhaia I cattle and horse sample values is due to a human-mediated activity that resulted in at least some of these animals being moved over long distances. Atahan et al. (2011) argue that the wide range of $\delta^{15}N$ values observed among domestic livestock samples from Bronze Age sites in northern China is consistent with a long-distance trade in animals.

To the south and west of Proezzhaia I, vast areas of arid steppe in what is now Mongolia are dominated by C_4 grasses (Auerswald et al. 2009; Pyankov et al. 2000; Wang 2003), and the $\delta^{13}C$ and $\delta^{15}N$ values of both C_3 and C_4 plant tissues appear to be higher in arid environments (Díaz et al. 2016; Hartman and Danin 2010; Heaton 1987). Then, as now, the dry Mongolian steppe was home to large-scale pastoralist societies engaged in cattle herding and horse breeding (Drobyshev and Syrtypova 2016;

Fijn 2011; Honeychurch 2015). Historical sources suggest the forested Transbaikal region was a source for highly valued luxury goods in medieval societies, including the richly scented musk glands from the musk deer (*Moschus moschiferus*) (King 2007). At this time, trade along the famed Silk Road moved goods between Asia and Europe and all points in between (Eisma 2012). As yet, no unequivocal archaeological evidence has been recovered from Proezzhaia I to link the site to an extensive trade network, but it is reasonable to suggest that its inhabitants were, at minimum, engaged in a down-the-line trade system. More detailed studies, including the sampling and analysis of animals' incremental structures, additional isotopic analyses to examine stable oxygen and strontium values, and a deeper examination of individual animals' life histories would provide additional information to assess whether the human inhabitants of Proezzhaia I were engaged in the trade of livestock or some other activity that would result in the isotopic variation observed here.

4.3 Primorye

The Primorye dataset, in contrast to those from the Lower Ob and Transbaikal, consists of faunal materials from six archaeological sites—Boisman II, Boiarin VI, Russkiy I, Pospelovo I, Nazimova I, and Cherniatino II. From spatial and temporal perspectives, samples from these sites offer a unique opportunity to examine human-animal relationships and subsistence economies in the Vladivostok area of the Russian Far East over thousands of years, from the coastal hunter-fisher-gatherers of the Neolithic to the stratified agricultural societies of the medieval period.

4.3.1 Boisman II

Seventy-seven samples from the Late Neolithic component of the Boisman II site, representing 24 taxa including humans, terrestrial mammals, marine mammals, birds, and marine fish, were made available for analysis (Appendix A). Of these, samples from 19 taxa yielded sufficient collagen and met accepted quality standards. These samples are included in the discussion, and their values are represented in Figure 4.5.

Undifferentiated deer (Cervidae), red deer (Cervus elaphus), roe deer (Capreolus capreolus), sika deer (Cervus nippon), and musk deer (Moschus moschiferus)

In all, 16 Boisman II cervid samples were taken for analysis. Nine of these samples yielded collagen and were deemed adequate for further analysis and interpretation (Appendix A), and include samples identified to four taxonomic levels: Cervidae (n = 1, MNI = 1), red deer (*C. elaphus*, n = 4, MNI = 3), roe deer (*C. capreolus*, n = 3, MNI = 2), and sika deer (*C. nippon*, n = 1, MNI = 1). A single musk deer (*M. moschiferus*) sample did not yield enough collagen for analysis. The single Cervidae sample yielded a δ^{13}C value of -23.2‰ and a δ^{15}N value of 3.1‰. The red deer sample δ^{13}C values ranged from -23.3 to -22.0‰ (mean -22.3 ± 0.7‰), with δ^{15}N values from 4.1 to 4.9‰ (mean 4.4 ± 0.4‰). Roe deer δ^{13}C value samples ranged from -23.5 to -22.5‰ (mean -19.9 ± 0.5‰) and δ^{15}N values ranged from 3.8 to 4.2‰ (mean 3.8 ± 0.2‰). Another solitary sample, the sika deer, had a δ^{13}C value of -22.4‰ and a δ^{15}N value of 3.1‰.

Hare (Lepus sp.)

A single innominate fragment identified as hare was taken for analysis (MNI =1). Unfortunately, the sample did not meet collagen quality standards (Appendix A).

Large felid (Panthera sp.)

Both the Siberian tiger (*Panthera tigris tigris*) and Amur leopard (*Panthera pardus orientalis*) are found in the Primorye province. This single sample, a humerus, was not complete and identifiable only to the genus level; however, its overall size suggested it belonged to the much larger Siberian tiger. It met all collagen quality criteria (Appendix A), and its δ^{13}C and δ^{15}N values were -21.0‰ and 8.0‰, respectively.

Raccoon dog (Nyctereutes procyonoides)

Two raccoon dog samples were available for analysis. However, one sample failed to yield an adequate amount of collagen for analysis (Appendix A). The remaining sample (MNI = 1) yielded $\delta^{13}C$ and $\delta^{15}N$ values of -21.0‰ and 10.1‰, respectively.

Eurasian badger (Meles meles)

Collagen was extracted from three Eurasian badger samples, but one of these samples did not yield a sufficient amount of collagen, and another did not meet collagen quality indictors (Appendix A). The lone sample (MNI = 1) deemed suitable for analysis had $\delta^{13}C$ and $\delta^{15}N$ values of -19.5‰ and 7.3‰, respectively.

Otter (Lutrinae)

The distal portion of a single humerus identified as Lutrinae was taken for analysis (MNI = 1). Unfortunately, the sample did not meet collagen quality standards (Appendix A).

Undifferentiated birds (Aves), duck (Anatidae), and cormorant (Phalacrocorax sp.)

Samples from three avian taxa (n = 12) were taken for analysis. Of the two samples identifiable only to class (Aves), one met collagen quality standards (Appendix A); its $\delta^{13}C$ and $\delta^{15}N$ values were -23.0‰ and 8.5‰, respectively. The duck family (Anatidae) was represented by six samples, five of which met collagen quality standards (MNI = 3) (Appendix A). Duck samples showed a $\delta^{13}C$ value range of -19.7‰ to -14.5‰, with $\delta^{15}N$ values ranging from 6.4‰ to 18.1‰. Lastly, of the three cormorant samples available for analysis, a single sample (MNI = 1) met collagen quality criteria (Appendix A). Its $\delta^{13}C$ and $\delta^{15}N$ values were -14.4‰ and 15.4‰, respectively.

Marine mammals, Delphinidae, Steller sea lion (Eumetopias jubatus), undifferentiated seal (Phoca sp.), spotted seal (Phoca larga), and ringed seal (Phoca hispida)

A total of ten marine mammal samples were taken for analysis. Of these, four samples were excluded for failing to yield an adequate amount of collagen, not meeting collagen quality standards, or instrument error, and the Delphinidae sample was not relocated among the samples when laboratory preparation began (Appendix A). Among the remaining samples, three taxa were represented: Steller sea lion (*E. jubatus*, n = 3, MNI = 3), spotted (or largha) seal (*P. larga*, n = 1, MNI = 1), and an undifferentiated seal (*Phoca* sp., n = 1, MNI = 1). Steller sea lion sample δ^{13}C values ranged from -15.3‰ to -14.4‰; δ^{15}N values ranged from 17.4‰ to 18.3‰. The spotted seal sample's δ^{13}C and δ^{15}N values were -17.6‰ and 16.7‰, respectively. The undifferentiated seal sample yielded a δ^{13}C value of -15.7‰ and a δ^{15}N value of 16.5‰.

Undifferentiated Salmonidae (salmonid, anadromous fish)

A single salmonid vertebra was taken for analysis (MNI =1). Unfortunately, the sample did not yield an adequate amount of collagen for analysis (Appendix A).

Undifferentiated cod (Gadidae, marine fish)

Seven Gadidae samples were taken for analysis, but only three of these met collagen quality criteria (Appendix A). The remaining three samples' (MNI = 3) δ^{13}C values showed a range of -16.3‰ to -14.9‰ (mean -15.5 ± 0.7‰), and δ^{15}N values ranged from 8.7‰ to 11.6‰ (mean 10.2 ± 1.5‰).

Undifferentiated Perciformes (perch-like marine fish)

Two samples identified as Perciformes were taken for analysis (MNI = 1). Of these, one sample failed to yield a sufficient amount of collagen (Appendix A). The remaining sample had a δ^{13}C value of -15.4‰ and a δ^{15}N value of 9.5‰.

Undifferentiated rockfish (<u>Sebastes</u> sp., marine fish)

A single vertebra later identified as belonging to a rockfish was taken for analysis. Unfortunately, the sample did not yield an adequate amount of collagen for analysis (Appendix A).

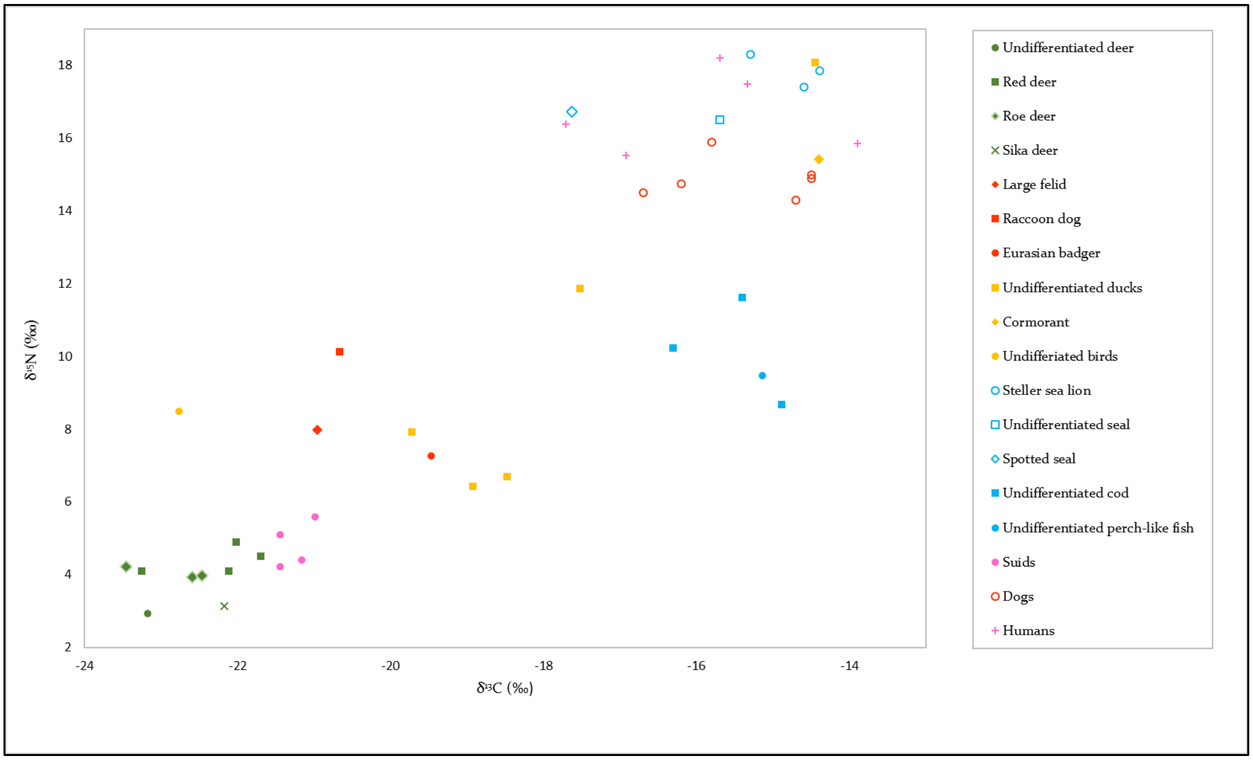

Figure 4.5 Biplot of Boisman II human and faunal sample δ^{13}C and δ^{15}N values by taxon.

Suids (Sus scrofa)

Five suid samples were taken for analysis; of these, four samples (MNI = 4) met collagen quality standards (Appendix A). The δ^{13}C values of these samples ranged from -21.4‰ to -21.0‰ (mean -21.3 ± 0.2‰), and their δ^{15}N values ranged from 4.2‰ to 5.6‰ (mean 4.8 ± 0.6‰). Due to the general difficulty in differentiating between wild boar and domestic pig skeletal remains through observation alone, it is not possible to determine which type of suid(s) these samples represent. As explained in Chapter 2, there is much debate about when domestic pigs were introduced to Primorye, and these samples may represent wild boar or pigs.

Domestic dog (Canis lupus familiaris)

Thirteen dog samples were made available for analysis, but approximately half of the samples did not meet collagen quality standards (*n* = 6) or did not yield an adequate amount of collagen (*n* = 1); a single sample did not yield a $\delta^{15}N$ value due to mass spectrometer instrument error and also was excluded (Appendix A). The six remaining samples (MNI = 6) are considered here. Their $\delta^{13}C$ values ranged from -16.7‰ to -14.5‰ (mean -15.4 ± 1.0‰), and their $\delta^{15}N$ values ranged from 14.3‰ to 15.9‰ (mean 14.9 ± 0.6‰).

Humans (<u>Homo</u> <u>sapiens</u>)

Samples from 13 humans interred in shell midden layers at Boisman II were taken by Dr. Hugh McKenzie for analysis. All were from skeletally mature individuals and exhibited no obvious signs of disease or trauma. Nine samples are not included in the discussion, the result of yielding collagen insufficient for further analysis or not meeting collagen quality criteria (Appendix A). The four samples included in this discussion (MNI = 4) had $\delta^{13}C$ values ranging from -17.7‰ to -15.3‰ (mean -16.4 ±1.1‰), and $\delta^{15}N$ values ranging from 15.5‰ to 18.2‰ (mean 16.9 ± 1.2‰).

4.3.2 Summary of Boisman II dietary stable isotope data

The data provided by the Late Neolithic Boisman II faunal samples establishes a needed context in which to evaluate contemporaneous human sample values as well as those obtained in previous investigations of the Early Neolithic inhabitants of the same site (Kuzmin et al. 2002). The human and dog data generated in this study point to similarities between their diets, which carry a strong marine signal. Marine resources are thought to have been an important part of Neolithic human diets on the Primorye coast. The marine mammal samples in this study, those from a Steller sea lion and an undifferentiated seal, yielded $\delta^{13}C$ and $\delta^{15}N$ values consistent with diets based on marine fish, as has been observed in modern field studies of these pinnipeds (Dehn et al. 2007; Sigler et al. 2009). Archaeological samples from gadids and a perciform fish suggest marine fish were indeed an important part of human, dog, and pinniped diets by the Late Neolithic. The cormorant sample from Boisman II also indicates an aquatic resource-based diet, likely marine fish. Among the remaining avian taxa, likely belonging to various waterfowl, the wide range of $\delta^{15}N$ values is in keeping with the variety of diets observed in different duck taxa; some are highly piscivorous (Solovyeva et al. 2016), and some consume large amounts of seaweed (Ganter 2000), though many have an omnivorous diet (Shuntov 2000; Yerkes et al. 2008).

In contrast to Late Neolithic Boisman II humans and dogs, suid sample values suggest a heavy reliance on terrestrial resources. These values are much closer to those of terrestrial herbivores, particularly the cervids.

4.3.3 Boiarin VI

Fifteen specimens from six taxa recovered from the Zaisanovka period (Late Neolithic) Boiarin VI site were taken for analysis; of these, three samples from three taxa (20%) met collagen sample quality standards (Figure 4.6). Samples from the red fox (*Vulpes vulpes*), Eurasian badger (*Meles meles*), Eurasian otter (*Lutra lutra*), undifferentiated seal (*Phoca* sp.), and an unidentified pinniped did not yield an adequate amount of collagen for analysis or otherwise did not meet collagen quality criteria. In the case where collagen yields were less than 1%, but a detectable amount of collagen was present in the post-lyophilization vial, samples were prepared and analyzed. While they have been excluded from discussion, it is important to note the rejected samples from the cervids and suids returned δ^{13}C and δ^{15}N values similar to those of non-rejected samples from the same taxon (Appendix A). These data can be viewed as a biplot in Figure 4.6.

Cervids, red deer (<u>Cervus</u> <u>elaphus</u>) and roe deer (<u>Capreolus</u> <u>capreolus</u>)

Collagen was extracted from eight cervid samples, including five red deer (*C. elapahus*) samples (MNI = 1) and three roe deer (*C. capreolus*) samples (MNI = 1); however, only one sample from each species met collagen quality criteria (Appendix A). The red deer sample yielded a δ^{13}C value of -22.8‰ and a δ^{15}N value of 6.4‰. The roe deer sample's δ^{13}C and δ^{15}N values were -23.2‰ and 5.2‰, respectively.

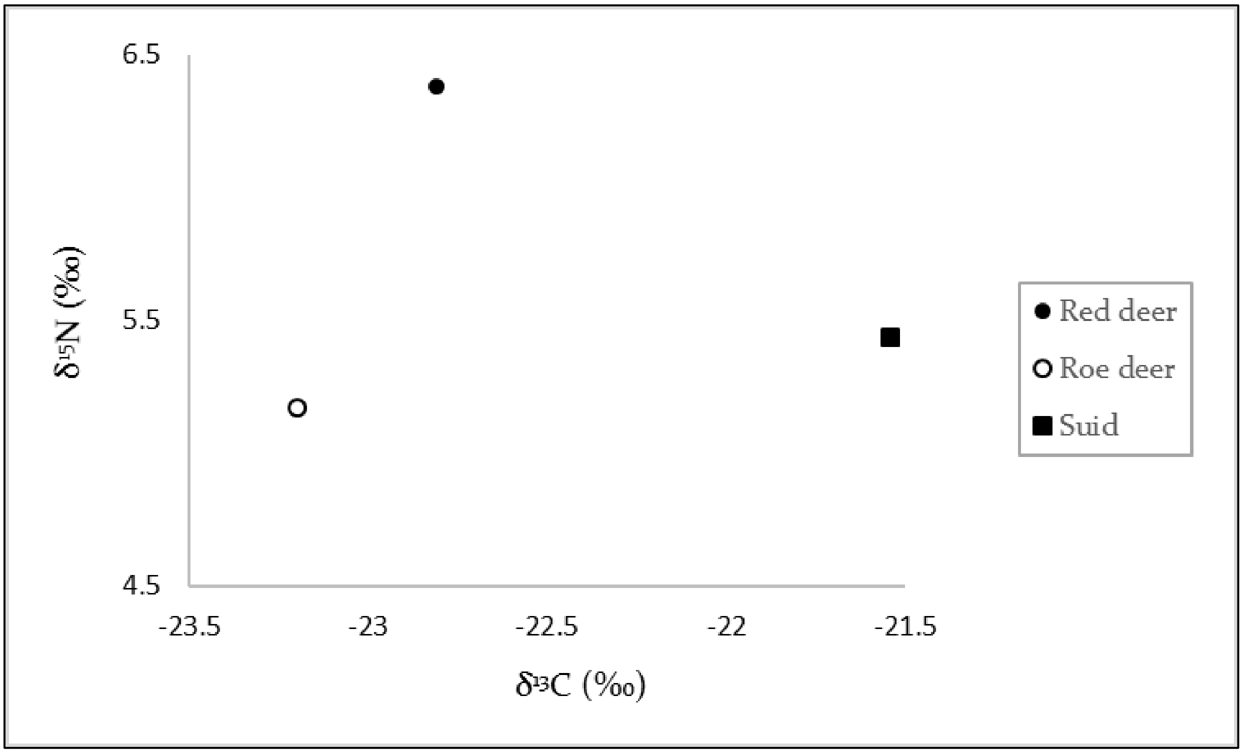

Figure 4.6 Biplot of Boiarin VI faunal sample δ^{13}C and δ^{15}N values by taxon.

Suid (Sus scrofa)

Six boar or pig samples representing at least two individuals were available for analysis, but only one sample (MNI = 1) met collagen quality standards (Appendix A). This sample, a fragmented maxilla, yielded a δ^{13}C value of -21.5‰ and a δ^{15}N value of 5.4‰.

4.3.4 Summary of Boiarin VI dietary stable isotope data

Though limited, the Boiarin VI dataset contributes baseline dietary stable isotope data from the Zaisanovka cultural period, the only such information for these periods in the current study. The cervid and suid δ^{13}C values indicate both had terrestrial resource-based diets.

4.3.5 Russkiy I

Thirty-seven archaeological faunal samples representing 15 taxa from the Russkiy I site on Russkiy Island, associated with the Yankovskaia (Early Iron Age) culture, were taken for analysis. Of these, 17 samples from eight taxa met collagen quality standards (46%); these values can be viewed as a biplot in Figure 4.7.

Undifferentiated cervids, red deer (Cervus elaphus) and roe deer (Capreolus capreolus)

Two red deer (MNI = 2) and one roe deer (MNI = 1) samples yielded collagen of a sufficient quality and amount for analysis. One red deer sample's δ^{13}C and δ^{15}N values were -22.3‰ and 2.9‰; the other sample's values were -21.2‰ and 6.8‰. The roe deer sample yielded δ^{13}C and δ^{15}N values of -20.5‰ and 6.0‰, respectively. Two samples, one identified as Cervidae and the other as roe deer, were misplaced before sample preparation began and were not analyzed (Appendix A).

Marine fishes, undifferentiated cod (Gadidae), undifferentiated flatfish (Pleuronectidae), undifferentiated shark (Selachimorpha), and undifferentiated tuna (Scombridae-Thunnini)

Five marine fish skeletal samples were available for analysis, but only one Gadidae sample met collagen quality criteria (Appendix A). This sample's δ^{13}C and δ^{15}N values were -15.8‰ and 8.6‰, respectively.

Suids *(Sus scrofa)*

Four suid samples from the Russkiy I site were available for analysis. Three of these samples (MNI = 1) yielded collagen of adequate quantity and quality (Appendix A). The samples' δ^{13}C values ranged from -21.5‰ to -20.4‰ (mean -21.1 ± 0.6‰), while δ^{15}N values ranged from 4.2‰ to 6.1‰ (mean 4.8 ± 1.1‰).

Domestic dogs (Canis lupus familiaris)

Samples from fifteen individual dogs recovered at Russkiy I were taken for analysis. Of these, 11 samples (MNI = 11) yielded collagen of an adequate amount and quality. These samples' δ^{13}C values ranged from -15.3‰ to -13.2‰ (mean -14.6 ± 0.6‰), with their δ^{15}N values ranging from 14.7‰ to 18.1‰ (mean 16.2 ± 1.1‰).

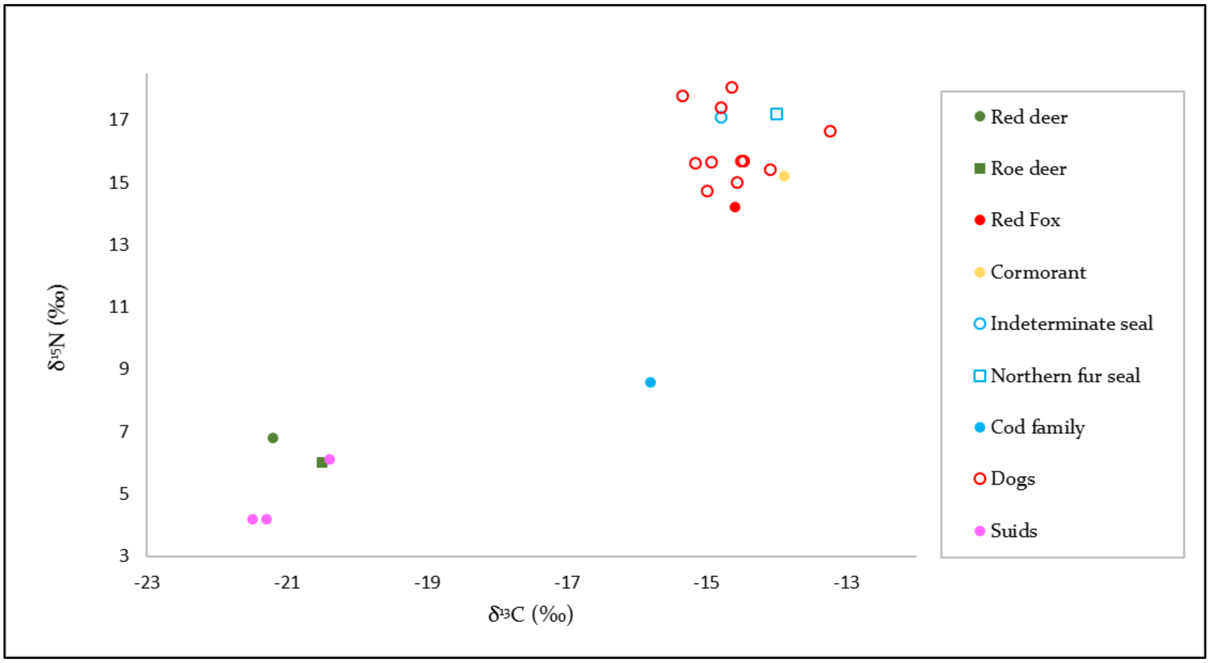

Figure 4.7 Biplot of Russkiy I faunal sample δ^{13}C and δ^{15}N values by taxon.

4.3.6 Summary of Russkiy I dietary stable isotope data

Though the generally small sample sizes from the Russkiy I faunal assemblage precludes much in the way of interpretation, these samples add to the growing body of dietary stable isotope data for the coast of Primorye and the wider East Sea area during the Early Iron Age, serving to contextualize information from other sites in the region. The primary animals of interest at the Russkiy I site are the dogs, which, as with dog samples from other coastal sites in this region, appear to have consumed a largely marine diet. In the absence of human and other domestic animal dietary stable isotope values, it is difficult to make conjectures on the provisioning of these dogs as they are capable intertidal foragers and scavengers (Carlton and Hodder 2003).

The cervid samples' $\delta^{13}C$ values are consistent with terrestrial diets; however, the $\delta^{15}N$ values of two samples—one each of red deer and roe deer--are rather high in comparison to the majority of Primorye cervid samples in this study.

4.3.7 Pospelovo I

Thirty-five faunal samples from ten taxa were recovered from the Yankovskaia period (Early Iron Age) Pospelovo I site on Russkiy Island were taken for analysis, of which 14 samples (40%) from five taxa met collagen quality standards (Figure 4.8; Appendix A). The pinniped (n = 4) and roe deer (n = 1) samples are in the former group and have been omitted from further discussion. Additionally, a single human sample (LBM-14H) was taken from the Pospelovo I assemblage. It, too, met collagen quality standards (Appendix A).

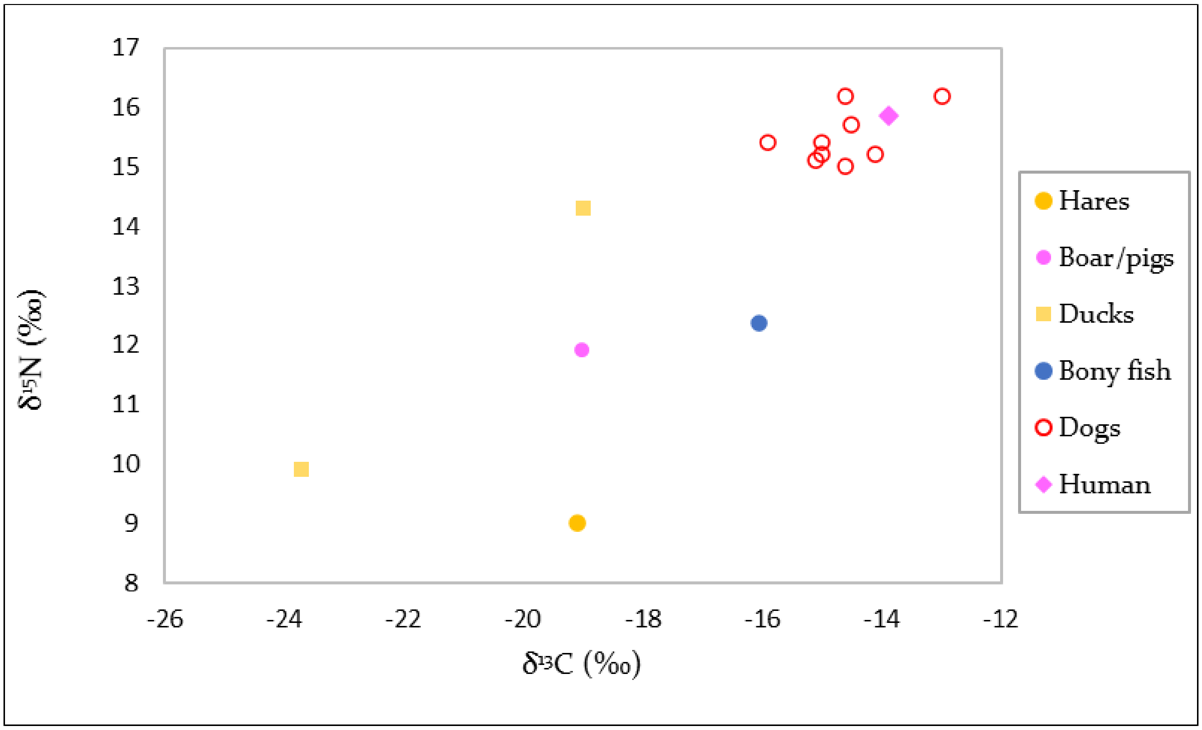

Figure 4.8 Biplot of Pospelovo I faunal sample $\delta^{13}C$ and $\delta^{15}N$ values by taxon.

Undifferentiated hare (Lepus sp.)

One hare sample was available for analysis, and it met all collagen quality criteria. Its $\delta^{13}C$ value was -19.1‰, similar compared to other Primorye leporid samples in this study but not inconsistent with an isotopic signature for a terrestrial herbivore; however, its $\delta^{15}N$ value, 9.0‰, is unexpectedly high for a small, herbivorous, terrestrial mammal.

Suids (Sus scrofa)

One of four suid samples from Pospelovo I met collagen quality standards (Appendix A). It yielded a $\delta^{13}C$ value of -19.0‰ and a $\delta^{15}N$ value of 11.9‰. This sample shows a unique value among suid samples from coastal Yankovskaia period sites in this study and will be discussed in comparison to the larger set of values in section 4.4.1.

Ducks (Anatidae)

Two samples from the duck family were taken for analysis; both met collagen quality criteria (Appendix A). The elements sampled, a humerus and a tibiotarsus, appeared to belong to species of the genus *Aythya* (MNI =1). One sample's $\delta^{13}C$ and $\delta^{15}N$ values were -23.7‰ and 10.0‰, while the other's were -19.0‰ and 14.3‰.

Actinopterygii (bony fish)

A single fish dentary identifiable only to the class of bony fishes met collagen quality standards. Its $\delta^{13}C$ and $\delta^{15}N$ values were -16.1‰ and 12.4‰.

Domestic dog (Canis lupus familiaris)

Twenty-one individual dogs from Pospelovo I were available for this study; of these, 12 either did not yield an adequate amount of collagen or did not meet quality standards (Appendix A). The remaining nine samples (MNI = 9) had $\delta^{13}C$ values ranging from -15.9‰ to -13.0‰ (mean -14.6 ± 0.8‰) and $\delta^{15}N$ values ranging from 15.0 to 16.2‰ (mean 15.5 ± 0.5‰).

Human (<u>Homo</u>* **sapiens*)

A single human sample recovered from the Pospelovo I site was taken by Dr. Hugh McKenzie for analysis. This sample was taken from the left femur of a skeletally mature individual and did not show visible signs of disease or trauma. It yielded a sufficient amount of collagen for analysis and met collagen quality criteria (Appendix A). Its $\delta^{13}C$ value was -13.9‰ and its $\delta^{15}N$ value was 15.9‰.

4.3.8 Summary of Pospelovo I dietary stable isotope data

Similar to Russkiy I, the small number of samples from the Pospelovo I site does not permit a deeper discussion on their own, though these data can be used to explore patterns among coastal Primorye sites during the Early Iron Age, and may help to contextualize data obtained in future archaeological stable isotope studies in the region. Domestic dog samples comprise the majority of the Pospelovo I assemblage and show similar values to dog samples from other Yankovskaia contexts. Though it is not possible to make deep inferences about coastal Yankovskaia human subsistence from the $\delta^{13}C$ and $\delta^{15}N$ values yielded by the sole human sample from Pospelovo I, this data point hints at a continued trend in the complementarity of human and dog diets during the Early Iron Age. Additional data are needed to make a more thorough assessment, but taken together the Pospelovo I human and dog samples show higher $\delta^{13}C$ values and lower $\delta^{15}N$ values than their Late Neolithic counterparts from Boisman II. The lone boar/pig sample is an outlier among its counterparts from other coastal Primorye sites, and the single hare sample exhibited an unusually high $\delta^{15}N$ value. However, Ugan and Coltrain (2011) and Somerville et al. (2018) have demonstrated that leporid bone collagen $\delta^{15}N$ values are highly variable, likely owing to their short lifespans, small home ranges, and generalist feeding habits, resulting in a bias toward the $\delta^{15}N$ values of plants growing in the microhabitats in which they live.

Two sets of values are available for aquatic fauna. While the duck samples were both identified as members of the genus *Aythya*, their $\delta^{13}C$ and $\delta^{15}N$ values are different enough to indicate the samples came from separate individuals eating in different isotopic niches. Members of the genus *Aythya* have diverse dietary preferences (Winfield and Winfield 1994), and these differences may simply reflect the highly seasonal nature of duck diets and could indicate the ducks were not taken in the same season. The undifferentiated bony fish sample's values indicate it came from a member of a marine species, entirely expected for the site's situation on the shore.

4.3.9 Nazimova I

Eighteen stable isotope samples from seven taxa recovered at the Yankovskaia period (Early Iron Age) Nazimova I site on Russkiy Island were taken for analysis. However, the majority of these samples (78%; *n* = 14) are not discussed here, the result of instrument error, having failed to yield a sufficient amount of collagen, or not passing collagen quality standards (Appendix A). The remaining samples, two each from boar/pig (MNI = 1) and domestic dog (MNI = 2) are described below; these values are represented as a biplot in Figure 4.9.

Boar or pig (Sus scrofa)

Two boar or pig samples from the Nazimova site yielded δ^{13}C values of -20.9‰ and -19.5‰, while their δ^{15}N values were 4.3‰ and 6.3‰.

Domestic dog (Canis lupus familiaris)

Of the Nazimova site's five individual dogs, only samples from two can be discussed here. The samples' δ^{13}C values were -15.9‰ and -14.3‰. Their δ^{15}N values were 14.9‰ and 16.4‰.

4.3.10 Summary of Nazimova dietary stable isotope data

The extremely small sample size from the Nazimova site limits interpretation beyond simple commentary that the boar/pig and dog stable isotope values are consistent with those from other Yankovskaia sites in the study (Russkiy I and Pospelovo I) and suggest these taxa's dietary inputs were relatively homogeneous across the region.

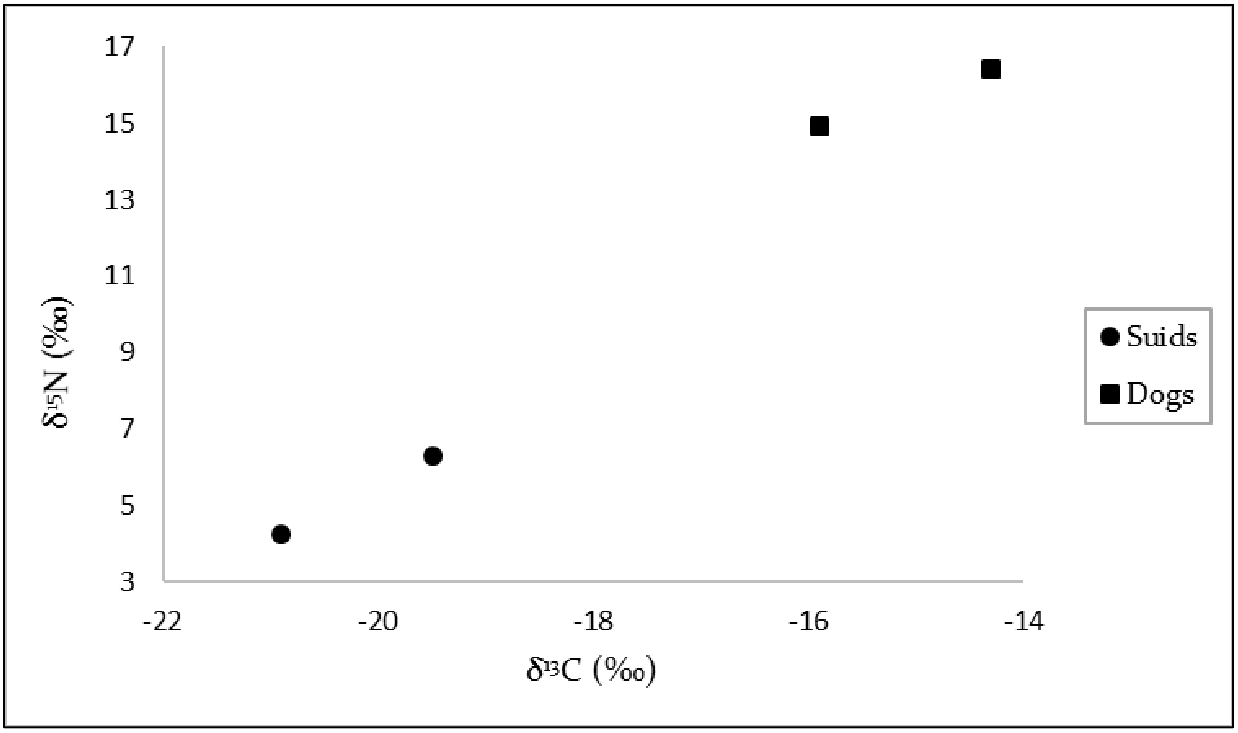

Figure 4.9 Biplot of Nazimova I faunal sample $\delta^{13}C$ and $\delta^{15}N$ values by taxon.

4.3.11 Cherniatino II

Sixty-six stable isotope samples from sixteen taxa excavated at the multicomponent (Early Iron Age and medieval Mohe-Balhae) Cherniatino II site were taken for analysis. Of these, 42 samples (64%) from ten taxa met collagen quality standards and are discussed below (Figure 4.10). The fish samples, including those identified as belonging to undifferentiated bony fishes (Actinopterygii, n = 3) and the carp/minnow family (Cyprinidae, *n* = 1) did not meet these standards, nor did a single sheep/goat (*Ovis/Capra* sp.) sample (Appendix A).

Red deer (<u>Cervus</u> <u>elaphus</u>) and roe deer (<u>Capreolus</u> <u>capreolus</u>)

Two red deer (*C. elaphus*) and six roe deer (*C. capreolus*) samples were selected for analysis; however, neither of the red deer samples and three roe deer samples failed to yield amounts of collagen sufficient for analysis (Appendix A). The three remaining roe deer (MNI = 2) samples of unknown cultural context had δ^{13}C values ranging from -20.9‰ to -20.5‰ (mean -20.8 ± 0.2‰), with δ^{15}N values ranging from 3.8‰ to 4.8‰ (mean 4.3 ± 0.5‰).

Undifferentiated hares (Lepus sp.)

Three hare samples were available for analysis; all met collagen quality standards. The samples' δ^{13}C values ranged from -23.7‰ to -14.7‰ (mean -19.2 ± 4.2‰), and their δ^{15}N values ranged from 1.1‰ to 9.1‰ (mean 4.2 ± 4.3‰). The highest δ^{13}C and δ^{15}N values are from the same sample, recovered from an Early Iron Age context; both values appear to be atypical of leporid stable isotope values for this site. However, as explained in section 4.3.8., leporid bone collagen is highly representative of the microhabitats in which hares live, and this individual may have come from a different setting. The other two samples came from Mohe and Balhae contexts, respectively, for a minimum of three individuals represented.

Undifferentiated squirrels (Sciuridae)

Three samples identified as belonging to members of the squirrel family were selected for analysis; two of these samples (MNI = 2), recovered from Balhae contexts, exceeded minimum collagen quality standards. Their δ^{13}C values were -17.6‰ and -15.6‰, and their δ^{15}N values were 7.3‰ and 9.1‰.

Undifferentiated turtle (Chelonii/Testudines) and snake (Serpentes)

One sample each from an unidentified turtle (Chelonii/Testudines) and snake (Serpentes), recovered from Mohe contexts, were discovered in the Cherniatino II faunal assemblage and taken for analysis; both met collagen quality standards. These taxa were unexpected finds in the assemblage and unique among the taxa of the Primorye dataset. Unidentifiable beyond the taxonomic level of Order, the dietary stable isotope values only hint at their dietary particularities and the habitats in which they lived. The turtle sample's δ^{13}C and δ^{15}N values were -12.7‰ and 11.5‰, respectively, suggesting a marine diet for this individual. The snake sample's δ^{13}C and δ^{15}N values were -19.3‰ and 8.7‰, respectively, indicating it likely fed in a terrestrial setting.

Undifferentiated Galliformes

Two tarsometatarsi featuring spurs, recovered from an unknown cultural context at Cherniatino II, were taken for analysis (MNI = 1). Identified as belonging to a member of the order Galliformes, both samples met collagen quality criteria. The tarsometatarsi were similar to each other in size and appearance and were consistent with those from a domestic rooster (*Gallus gallus*), but may represent another gallinaceous species. One samples' δ^{13}C and δ^{15}N values were -20.4‰ and 5.2‰; the other sample yielded values of -16.3‰ and 7.4‰.

Suids (Sus scrofa)

Nine suid samples were selected for analysis. Of these, seven (MNI = 5) met collagen quality standards (Appendix A). Samples were taken from each of the three cultural contexts (Early Iron Age, *n* = 2; Mohe, *n* = 2; Balhae, *n* = 3). No distinct temporal trend in their δ^{13}C and δ^{15}N values was observed, and so they are treated collectively here. The samples' δ^{13}C values ranged from -21.1‰ to -19.9‰ (mean -20.5 ± 0.5‰), and δ^{15}N values ranged from 3.4‰ to 5.1‰ (mean 4.3 ± 0.6‰).

Cattle (Bos sp.)

Three cattle samples were taken for analysis, and all met collagen quality standards (Appendix A). One sample was recovered from a Mohe context (MNI = 1), with the remaining two samples recovered from a Balhae context (MNI = 1). The Mohe sample's δ^{13}C and δ^{15}N values were -15.6‰ and 6.1‰, respectively. The Balhae samples' δ^{13}C values were -16.6‰ and -16.4‰, and their δ^{15}N values were 6.1‰ and 6.9‰.

Horse (Equus caballus)

Four horse samples were available for analysis; two of these samples, one each from the Early Iron Age and Mohe components (MNI = 2), met collagen quality criteria (Appendix A). The Early Iron Age sample's δ^{13}C and δ^{15}N values were -18‰ and 5.8‰, respectively, and the Mohe sample's δ^{13}C and δ^{15}N values were -21.1‰ and 3.6‰, respectively.

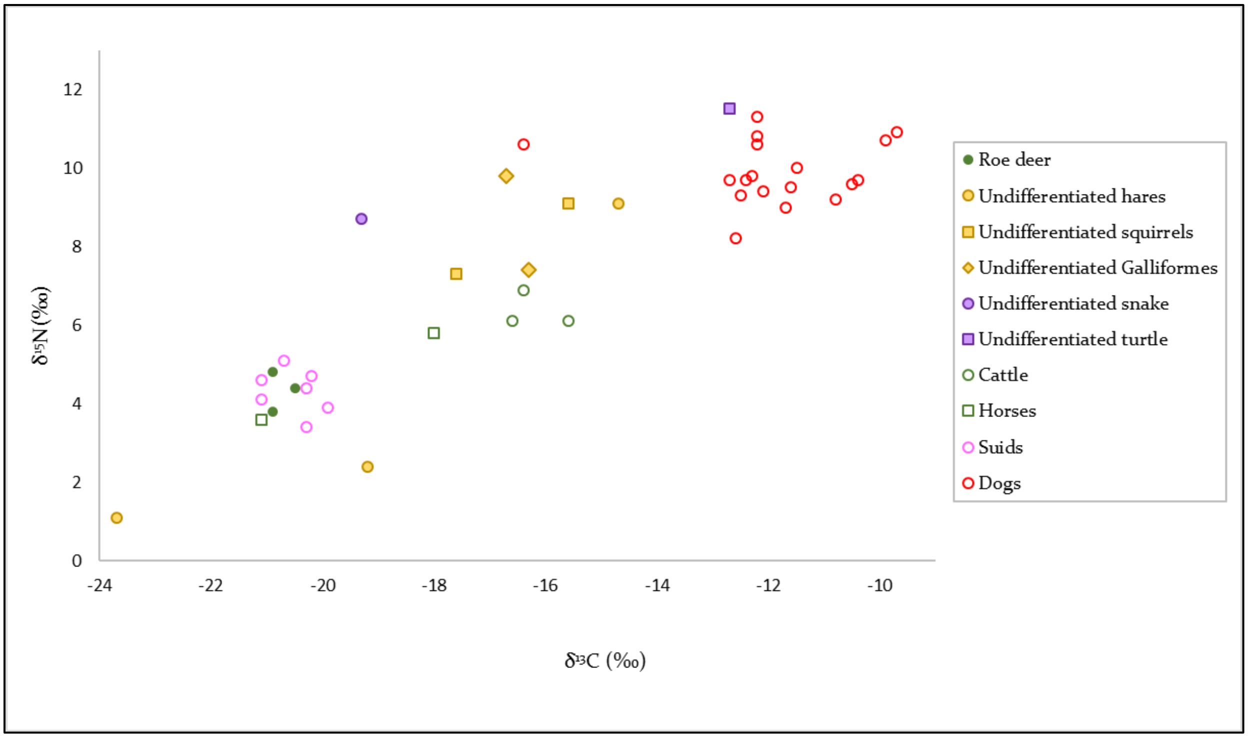

Figure 4.10 Biplot of Cherniatino II faunal sample δ^{13}C and δ^{15}N values by taxon.

Domestic dog (Canis lupus familiaris)

Samples from twenty-three individual dogs were selected for analysis. Of these, 18 from each of the three temporal contexts (Early Iron Age, *n* = 2; Mohe, *n* = 9; Balhae, *n* = 7) met collagen quality standards. The Early Iron Age dog samples' δ^{13}C values were -11.7‰ and -10.5‰, and their δ^{15}N values were 9.6‰ and 9.7‰. Mohe dog sample δ^{13}C values ranged from -12.5‰ to -9.9‰ (mean -11.9 ± 2.0‰), with δ^{15}N values ranging from 9.0‰ to 11.3‰ (mean 10.3 ± 0.8‰). One of the Mohe dog samples showed a δ^{13}C value of -16.4‰, the highest among all Primorye dog samples, though its δ^{15}N value (10.9‰) was consistent with that of other Mohe dogs at the site. Balhae samples' δ^{13}C values ranged from -12.6‰ to -10.4‰ (mean -11.9 ± 0.8‰), and δ^{15}N values ranged from 8.2‰ to 10.0‰ (mean 9.4 ± 0.6‰).

4.3.12 Summary of the Cherniatino II stable isotope data

The Cherniatino II stable isotope dataset allows for examination of domestic animal diets in three temporal and cultural contexts—the Early Iron Age, the Mohe period, and the Balhae period (the latter both Medieval). The animal taxa represented here are consistent with species encountered at other Mohe-Balhae sites in Primorye (Kim et al. 2017), but this site is unique among the Primorye sites analyzed here because it is located well away from the coast.

The Early Iron Age horse sample's $\delta^{13}C$ value is consistent with grazing on C_3 plants in an open area. Like Proezzhaia, the preparation of natural pastures and/or the foddering of horses with supplemental, purpose-grown plant material may have been a management strategy in place here as well, or this individual may have been traded into Primorye from a more arid region, helping to explain its elevated $\delta^{15}N$ value. The Mohe horse sample shows a distinctly different signature, more closely aligned with those of cervid and suid samples, both of which likely were feeding in forested areas.

In comparison to horses and suids, dogs from each of the three Cherniatino II temporal contexts show elevated $\delta^{13}C$ values that indicate the presence of a C_4 plant, or the consumption of another animal that had a C_4 plant-based diet. Further, cattle sample $\delta^{13}C$ values from both Mohe and Balhae contexts attest to a mixed C_4-C_3 diet, though they are markedly lower than that of the dog samples. Similarly, the site's squirrel sample $\delta^{13}C$ and $\delta^{15}N$ values, as well as those from one of three hare samples, are atypically high for small, herbivorous mammals, also hinting at access to a C_4 plant.

There appears to be no marine influence on dietary stable isotope signatures of samples obtained from the site in any period, with the exception of an undifferentiated turtle sample. Its $\delta^{13}C$ and $\delta^{15}N$ values suggest the individual could have originated in a marine setting. At Utesnoe IV, another inland Mohe-Balhae site further along the Razdolnaia River, Kim et al. (2017) report the identification of large crab remains in the zooarchaeological assemblage, the size of which point to marine specimens, and also suggest some marine resources may have found their way to points inland. Trade or exchange with the coast might explain the presence of the turtle analyzed in this study.

4.4 Discussion of the Primorye dietary stable isotope dataset

The Primorye dataset complements previous dietary stable isotope research carried out in the region, specifically human values from the Rudnaia (Early Neolithic) component at Boisman II (Kuzmin et al. 2002) and human and zooarchaeological values from Yankovskaia contexts at the Cherepakha XIII site (Kuzmin et al. 2018). In addition to providing greater ecological context for the interpretation of human subsistence activities, these data provide a view into animal diets from the Late Neolithic through the Medieval period. They also permit a unique opportunity to examine shifts in human-animal relationships in the same region, but in different cultural settings over thousands of years. In the sections that follow, I assess the Primorye dietary stable isotope data with respect to the management of three specific animal taxa: suids, dogs, and oysters.

4.4.1 Primorye suids

For thousands of years, the Russian Far East has been home to deciduous broadleaf forests. While the specific composition of tree taxa in these forests has changed over the period humans have inhabited the region (Razjigaeva et al. 2019), it has always featured a number of nut-bearing tree species. These constitute a rich resource for many animals, and particularly for suids, who possess the anatomy to crack open large nutshells with their powerful jaws. The first direct archaeological evidence of domestic pigs in Primorye supposedly dates to the Bronze Age, ca. 3000 years BP (Kuzmin 1997). By the Medieval period, the historic distribution of pigs elsewhere in Asia is sufficient to assume most archaeological suid samples from Primorye are domestic animals (Momot et al. 2006). However, the region is also an ideal habitat for the pig’s wild counterpart, the boar. In this section, I examine the dietary patterns of Primorye suid samples to make two arguments: that the nut-laden environment permitted suid diets to remain unchanged for thousands of years, and, because of this, that dietary stable isotope data from zooarchaeological remains cannot be used to reliably identify wild boar from pig in this region.

Because it is difficult to make distinctions between wild boar and domestic pig skeletal remains on the basis of gross morphology, some researchers have promoted more refined techniques to aid in suid sample identification. For example, Dobney and Ervynck (2000) have suggested the consistency of pathological features in some archaeological populations points to their having been domesticated. More relevant here, at two Primorye sites with large Yankovskaia components, Peschany I and Zaisanovka II, Rowley-Conwy and Vostretsov (2009) performed statistical analyses of suid molar measurements and concluded that these tests could identify a specimen as wild boar or domestic pig. Others have argued that $\delta^{13}C$ and $\delta^{15}N$ values can be used to categorize suid remains because, like dogs, domestic pigs' diets are thought to be heavily influenced by humans (Hu et al. 2008; Rowley-Conwy et al. 2012). However, pigs have adapted to a wide range of environments (Masetti 2007), and as opportunistic feeders they make use of an impressive variety of foods that other domestic and wild animals do not, including the aforementioned nut mast, as well as fungi, scavenged or foraged meat, and even marine vertebrates and invertebrates (Ascough et al. 2014; Baskin and Danell 2003; Masetti 2007). Due to pigs' ability to consume many different kinds of resources, management strategies where the animals received little to no human-derived dietary inputs are well-evidenced for some archaeological populations (Belkova and Rozkot 2017; Grigson 1982; Hamilton et al. 2009; Shaw 1940).

Woodland management strategies have been widely used with pigs for thousands of years. This strategy involves herding pigs into forests because their delicate skin is prone to sunburn (from which the canopy provides shelter), and because they seem to prefer nut mast over all other food items (Grigson 1982; Hamilton 2009). It is said that pigs finished on this resource yield meat with a desirable flavour (Brownlow 1994). Wild boar also prefer nut mast and are known to consume vast quantities of it (Kolchin 2018). In the Russian Far East, boar are particularly reliant on Mongolian oak acorns (Stephens et al. 2006). Nut mast quality and quantity vary dramatically from year to year within a species, with bumper production some years but next to no nuts in others. This phenomenon, known as mast pulsing, is widely studied but remains poorly understood. It may be directed by several mechanisms, including weather, internal and external resource availability, reproductive strategies, or combinations of all these factors (Pearse et al. 2016; Selva et al. 2012; Sork et al. 1993). However, mast pulsing in nut-bearing trees is limited to species within a geographically bounded area, and low mast production by one species does not mean all tree taxa in the region will experience a similar result in the same year (Shibata et al. 2002). This 'synchronous masting' trait ensures a reliable source of nutrition for animals each year, albeit from different species. Considering the breadth of nut-bearing tree taxa in the Russian Far East, it seems likely the forests of the region could have provided wild boar and domestic pigs with a readily available food resource.

Suid samples from each Primorye site were present in my dataset, and the δ^{13}C and δ^{15}N and values for all but one showed a distinctly terrestrial character, in stark contrast to the strong marine signal observed among the human and dog sample datasets. Evidence for differences between coastal and inland suid diets is meager, as the coastal Yankovskaia sites' mean suid δ^{15}N values are only ca. 2‰ higher than those from the Early Iron Age component at inland Cherniatino II (Figures 4.11, 4.12). Mean suid δ^{13}C values from these sites are nearly identical.

The suid sample data obtained for this project are interesting in comparison to those reported by Kuzmin et al. (2018) from Cherepakha XIII, a site also located on the coast of Primorye with a large Yankovskaia component (Figures 4.11, 4.12). Kuzmin et al. (2018) assigned samples with higher δ^{13}C (-20.1 to -18.4‰) and δ^{15}N (6.3 to 6.8‰) values to domestic pigs, and claimed those with lower δ^{13}C (-24.0 to -22.0‰) and δ^{15}N (5.1 to 5.9‰) values represent boar. The latter were identified as boar because their values are similar to those of other wild terrestrial herbivore samples taken from the site.

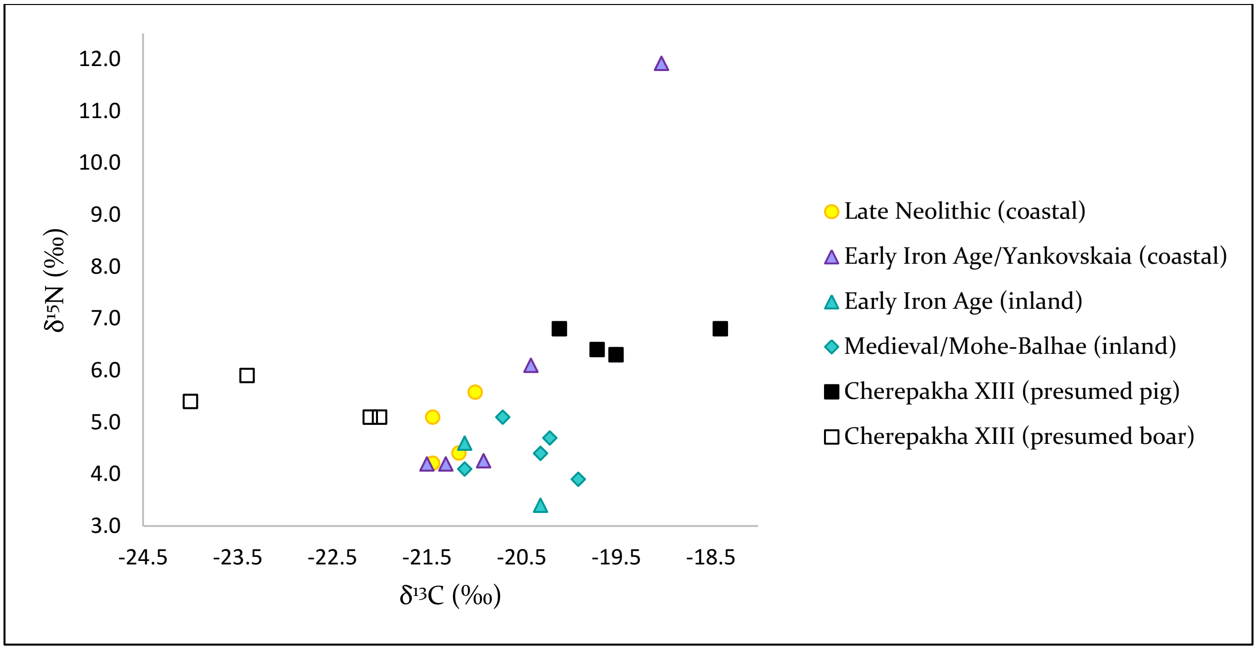

Figure 4.11 Biplot of suid δ^{13}C and δ^{15}N values from Late Neolithic through medieval contexts in Primorye. (Cherepakha XIII data from Kuzmin et al. 2018.)

My suid data do not follow such patterns. First, all data from the present study fall between the clusters Kuzmin et al. (2018) identified as wild boar and domestic pig (Figure 4.11). Note, however, that three of four coastal samples plot nearer Kuzmin and colleagues' wild boar cluster, and five of seven inland suid samples group nearer their domestic pig cluster (Figure 4.11). Second, there is a general trend toward lower δ^{15}N values for suid samples in the current study in comparison to those reported by Kuzmin et al. (2018) (Figure 4.11). Overall, these data indicate that suid diets and management practices at Cherepakha XIII were markedly different than those at sites included in my study.

Additional suid dietary variation in Primorye likely will be documented with the addition of more isotopic data. For example, among my Primorye suid samples, one from Pospelovo I is an outlier (Figure 4.11). The δ^{13}C value of the LPL-08F sample (-19.0‰) is consistent with other Primorye suids, but its δ^{15}N value, 11.9‰, is considerably higher, approximately one trophic level above that of other suid samples. Because intertidal foraging has been observed among suids, it is possible this sample represents an individual who fed in such habitats. However, because it is the only suid value from Pospelovo I, it is difficult to suggest this value represents yet another pig management strategy. Additional sampling of the suid remains at this site is needed to assess the implications of this single outlier.

Research on the suid samples from Peschany I and Zaisanovka II led Rowley-Conwy and Vostretsov (2009) to suggest that Yankovskaia peoples inhabiting areas on or near lagoons were less likely to have adopted pig husbandry because they lived in richer locations for hunting, fishing, and gathering. This conclusion was based on the observation that more ‘boar’ molars had been identified in the assemblage from the Zaisanovka II site, which is situated on an extant lagoon, and that more ‘pig’ molars were identified in the Peschany I assemblage, which lies on the coast, but is adjacent to the open water of Peter the Great Bay. Overall, isotope data from Yankovskaia and Early Iron Age suids obtained in this study fall outside of the range of the isotope values for wild and domestic populations identified in Kuzmin et al.’s (2018) samples regardless of the specific setting, as suggested by Rowley-Conwy and Vostretsov (2009) (Figure 4.12). In other words, the isotope data do not provide a clear indication as to the wild or domestic status of these suids. Correspondingly, the data from the current study obscure detection of a clear temporal shift in dietary values that would indicate when humans in Primorye adopted pig husbandry. Moreover, pigs and boar are known to interbreed even in the present day, and this has been suggested for medieval pig populations in Primorye (Momot et al. 2016). However, Rowley-Conwy and Vostretsov (2009) suggest this would not have been the case for managed Yankovskaia herds because wild boar would not have had access to domestic pigs, which were kept inside settlements. The data in this study demonstrate that nearly all suids were consuming isotopically similar diets, which appear to have come from terrestrial forest resources. In light of these dietary stable isotope data, it is difficult to claim that domestic pigs were always kept separate from wild boar, if indeed both populations coexisted in the Early Iron Age of Primorye.

4.4.2 Dog diets

In this section, I demonstrate the isotopic complementarity of Primorye human and dog diets to make a case for the applicability of the Canine Surrogacy Approach to Late Neolithic and Early Iron Age societies on the Primorye coast. Following this, I examine the distinct dog dietary stable isotope data from the Cherniatino II site, which connotes a significantly different management strategy than seen at the region's coastal sites.

While stable isotopic investigations of Primorye humans have been carried out on samples from Early Neolithic contexts at the coastal Boisman II and inland Chertovy Vorota sites (Kuzmin et al. 2002), the earliest comparative data for Primorye human *and* dog diets were generated in the current study, from Late Neolithic contexts at Boisman II. According to Kuzmin et al. (2002), coastal Early Neolithic diets were centred on high trophic level marine fauna such as seals and sea lions (Figure 4.13). My faunal data provide clear support for Kuzmin et al.'s (2002) argument that pinnipeds were a dietary stable for the Early Neolithic people of Boisman II.

For the Late Neolithic, both human and dog values are available. Compared to the Boisman II Early Neolithic human $\delta^{13}C$ and $\delta^{15}N$ values, the site's Late Neolithic human values generally are lower (Figure 4.13), suggesting a shift in dietary focus took place between the two periods. These data will be examined in detail in section 4.4.3. Compared to contemporaneous human values, Late Neolithic dog samples show lower $\delta^{13}C$ and $\delta^{15}N$ values. In this period, Boisman II peoples may have provisioned dogs directly with food items from their own meals, or they may have permitted dogs to access the waste generated by them, possibilities bolstered by the small but detectable and consistent $\delta^{13}C$ and $\delta^{15}N$ value offsets between the two species (Table 4.2), ca. 0.5‰ ($\delta^{13}C$) and 1.8‰ ($\delta^{15}N$). By comparison, Early Neolithic human samples show higher $\delta^{13}C$ and $\delta^{15}N$ values than Late Neolithic human and dog samples (Figure 4.13).

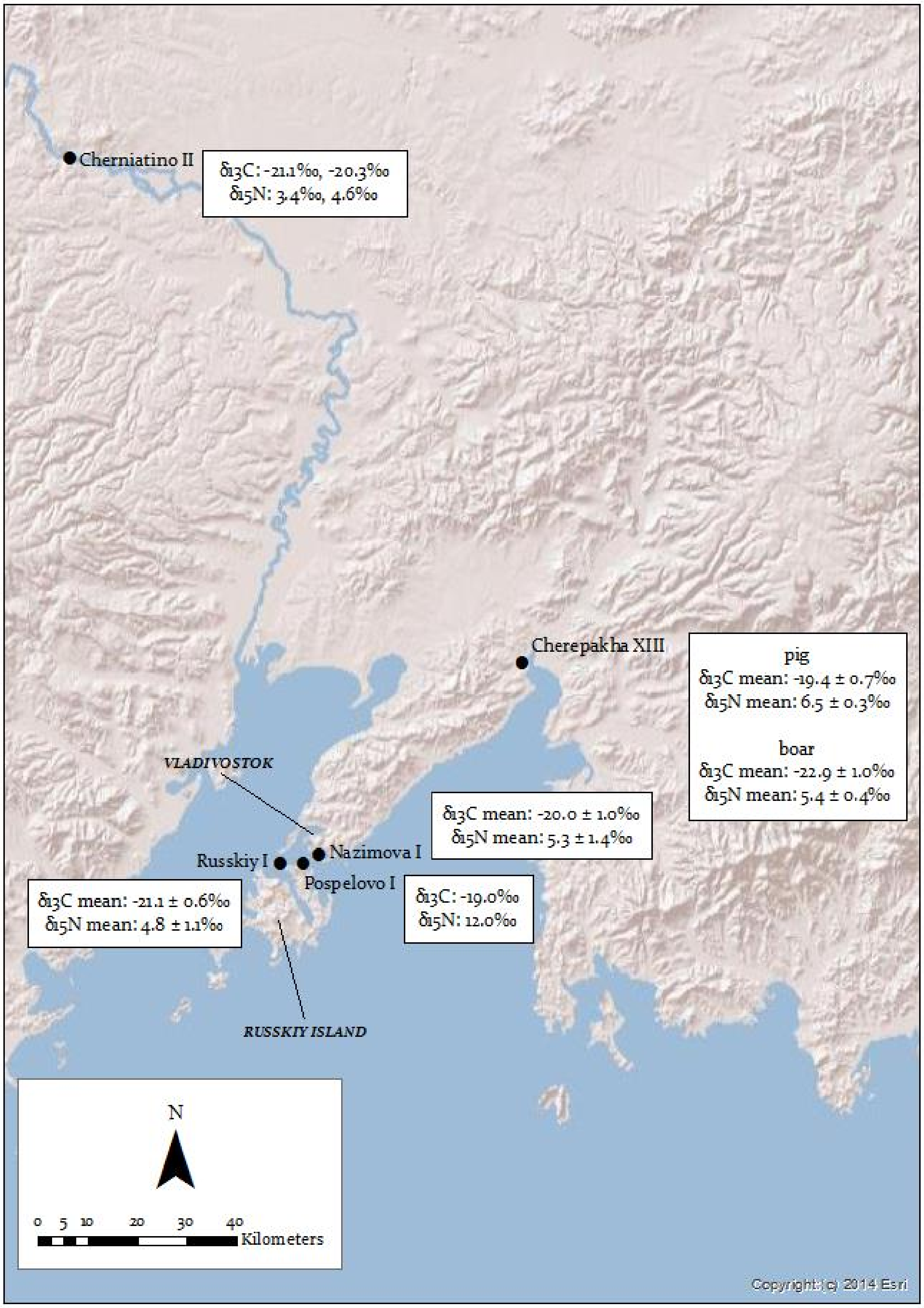

Figure 4.12 Map showing Primorye Early Iron Age suid sample δ^{13}C and δ^{15}N values by site. (Cherepakha XIII data from Kuzmin et al. 2018.) Map produced with data from ESRI.

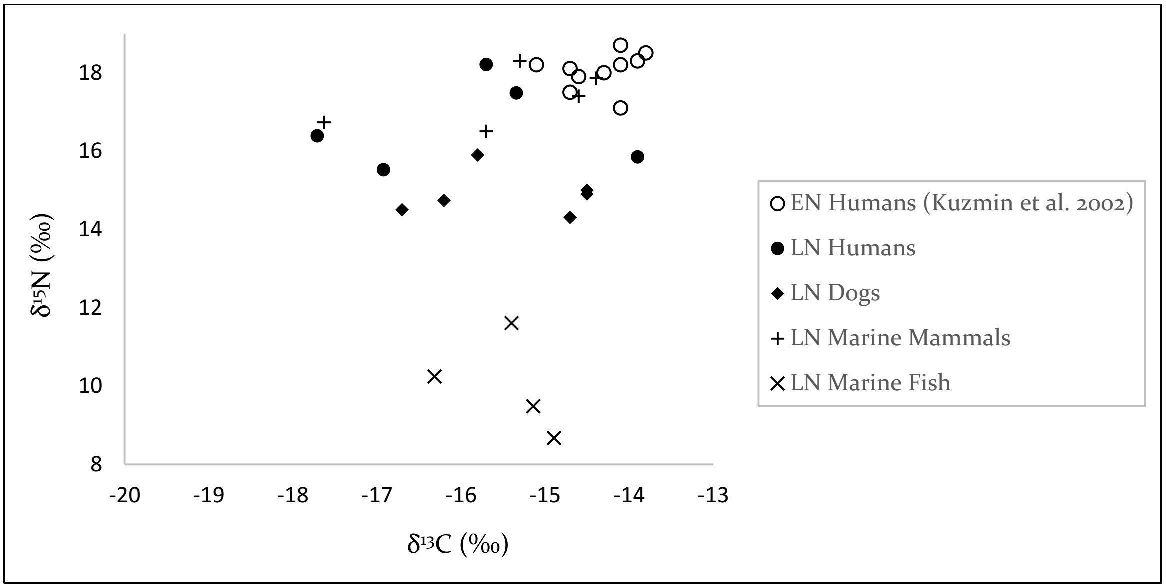

Figure 4.13 Biplot of Boisman II Early Neolithic humans and Late Neolithic humans, dogs, marine mammals, and fish. (Early Neolithic human data from Kuzmin et al. 2002.)

$\delta^{13}C$	***n***	**Mean**	**Lowest Value**	**Highest Value**
Dog	6	-15.4 ± 1.0‰	-16.7‰	-14.5‰
Human	5	-16.4 ± 1.1‰	-17.7‰	-15.3‰

$\delta^{15}N$	***n***	**Mean**	**Lowest Value**	**Highest Value**
Dog	6	14.9 ± 0.6‰	14.3‰	15.9‰
Human	5	16.9 ± 1.1‰	15.5‰	18.2‰

Table 4.2 Count, mean, and range of Late Neolithic Boisman II dog and human $\delta^{13}C$ and $\delta^{15}N$ values.

The Boisman II human-dog offset is smaller than that observed at Ust'-Polui and other archaeological sites in Siberia (Losey et al. 2013), but overall provides some support for Guiry's (2012, 2013) canine surrogacy argument. This is in some ways unsurprising, as like most of the examples used by Guiry (2013), marine resources were the basis of human and dog diets at Boisman II, and the number of dogs analyzed from that site is rather modest (*n* = 6), especially compared to Ust'-Polui. Regardless, a small dietary offset between the Late Neolithic humans and dogs at the site is clearly present. In place of, or in addition to, the direct provisioning of dogs with smaller fish, their ^{15}N-depleted tissues, or the indirect provisioning with their trash, it is possible the offset can be explained by the site's coastal setting. Dogs, like suids, are capable intertidal zone foragers, and they may have self-provisioned with marine resources of a slightly lower trophic level.

Among Yankovskaia (Early Iron Age) contexts along the Primorye coast near Vladivostok--Russkiy I, Pospelovo I, and Nazimova I--dog diets are isotopically consistent from site to site (Figures 4.14, 4.15). The slightly higher δ^{13}C and δ^{15}N values among the Russkiy I, Posepelovo I, and Nazimova dog samples than those from the Boisman II, Cherepakha XIIII, and Cherniatino II sites could indicate a greater reliance on open-water marine resources as the former sites are situated directly on the coast—Boisman II was situated on a lagoon, not directly on the coast. Values yielded by the single human sample from Pospelovo I (δ^{13}C -13.9‰, δ^{15}N 15.9‰) are similar to those of dogs from the same site and other coastal Yankovskaia contexts. Further north in the Yankovskaia culture area, Kuzmin et al. (2018) report human and dog values from the Cherepakha XIII site (Figures 4.14, 4.15, 4.16). These samples' δ^{15}N values also appear to have been the result of marine resource-based diets, albeit at a lower trophic level than the Yankovskaia human and dog samples in the present study. Kuzmin et al. (2018) suggest a focus on mollusks may explain their relatively high δ^{13}C values. The Cherepakha XIII human and dog samples show they had isotopically similar diets, as do the human and dog samples from Late Neolithic contexts at the Boisman II site and the Yankovskaia human and dog samples from the Pospelovo I site.

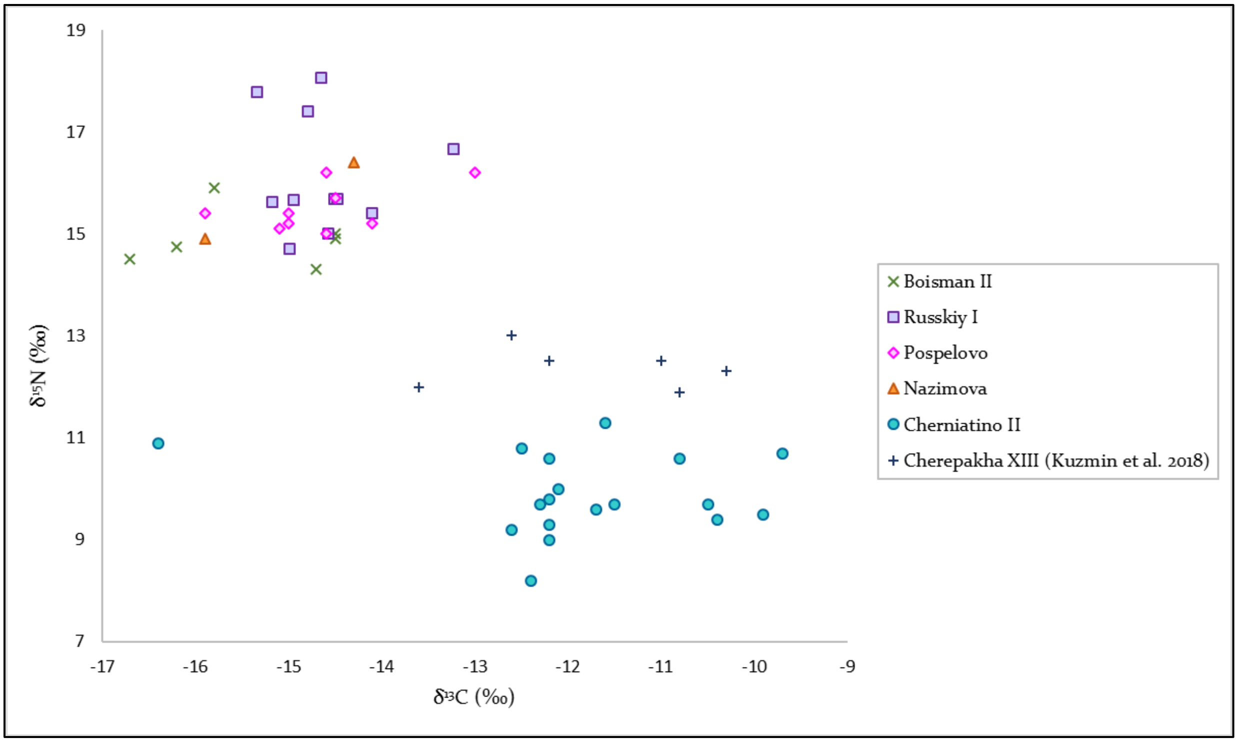

Figure 4.14 Biplot of dog $\delta^{13}C$ and $\delta^{15}N$ values from all Primorye sites. (Cherepakha XIII data from Kuzmin et al. 2018.)

While the Yankovskaia dog samples in the present study had diets more isotopically similar to Boisman II dogs than those from Cherepakha XIII, there remains a slight offset that could be explained by the specific ecological setting (i.e., open coast versus lagoon). Taken together, these dogs' differently structured diets suggest that inter-site comparisons of stable isotope data to support the Canine Surrogacy Approach, even among contemporaneous cultural contexts, may be misleading—at least for the Yankovskaia societies of the Primorye coast.

Another major issue to consider in the Primorye region is the incorporation of millets in dog diets. The earliest presence of domestic millet in the Russian Far East dates to the Neolithic and appears to have been introduced from China (Kuzmin et al. 1998; Kuzmin 2013; Li et al. 2020; Popov et al. 2014b). At Cherepakha XIII, paleoethnobotanical investigations have identified the presence of at least two domestic millets, foxtail and broomcorn (Sergusehva and Moreva 2017).

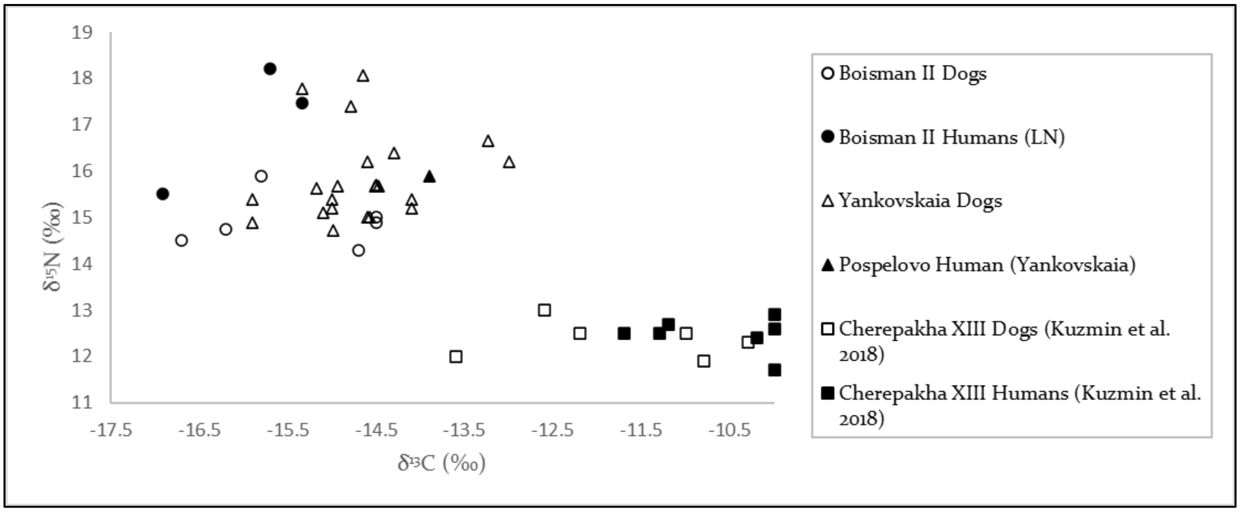

Figure 4.15 Biplot of dog and human δ^{13}C and δ^{15}N values from Late Neolithic and Yankovskaia contexts. (Cherepakha XIII data from Kuzmin et al. 2018.)

Kuzmin et al. (2018) suggest the unexpectedly high δ^{13}C values they obtained from the Cherepakha XIII dog samples (mean -11.8 ± 1.3‰) may be evidence of their having been provisioned with millet. Kuzmin et al. (2018) base this reasoning on the values from the Cherepakha XIII human samples, which yielded slightly higher δ^{13}C values (mean -10.2 ± 0.8‰) than those of dogs and within the range reported for C$_4$ plant-dominated human diets in mainland China.

The dog samples from Cherniatino II, the single inland Primorye site in the current study, show dietary signatures of a markedly different character than those on the coast. In the three cultural periods represented at Cherniatino II--the Early Iron Age, the Mohe state, and finally, the Balhae state--dog sample δ^{13}C values are consistently higher than seen in the coastal samples. Despite the site's location on the Razdolnaia River, it does not appear that aquatic resources played a significant role in dog diets. The two dog samples dating to the Early Iron Age had δ^{13}C values of -11.7‰ and -10.5‰, far higher than the -14.7 ± 0.7‰ mean of Yankovskaia samples from the coastal sites (Figure 4.14). Sixteen Mohe and Balhae dog samples yielded similarly high δ^{13}C values (mean -11.9 ± 1.5‰) (Figure 4.13). All of these values are well within the reported δ^{13}C value range for C$_4$ plants (-19.0 to -6.0‰, with a mean of ca. -14.0‰) (Bender 1971; Deines 1980; O'Leary 1988; Smith and Epstein 1971). Further, they are only slightly higher than archaeological charred millet $\delta^{13}C$ values from China, which average -9.1‰ (Chen et al. 2017).

However, among the Cherniatino II dogs, a Mohe-period sample had a $\delta^{13}C$ value of -16.4‰, unlike any other dog sample value from the site, and the lowest of all Primorye dog $\delta^{13}C$ values. Its $\delta^{15}N$ value (10.9‰), however, was similar to those of other dog samples from the site. This dog may have been a local animal with a differently structured diet than its counterparts at the site, or it may have been brought to Cherniatino II from another location. A diet consisting of primarily C_3 plants (or animals eating C_3 plants) with limited C_4 plant inputs might be responsible for producing a value in this range (Jim et al. 2004; White et al. 2001). Clearly, this individual had regular access to a food item that other dogs from the site did not.

The Cherniatino II dog samples had the lowest $\delta^{15}N$ values (9.9 ± 0.8‰) of all Primorye dog samples in this study, further suggesting they consumed a millet-based diet, or were the secondary consumers of animals that ate millet. Cultivated millet has been in Primorye since the Neolithic (Li et al. 2020). Among Neolithic agriculturalists in China, Pechenkina et al. (2005) determined that the $\delta^{13}C$ values of human, dog, and pig samples were consistent with a dietary reliance on C_4 plant resources. These plants were identified as various millets, the remains of which also were recovered at each of the sites. To explain the dog and pig samples' high $\delta^{15}N$ values, the authors offered several explanations, including the consumption of human refuse and feces, the feeding of millet in addition to eggs laid by C_4 plant-fed chickens, or the hunting of small rodents (Pechenkina et al. 2005). The inclusion of chicken eggs in dog diets or their hunting activities are inviting interpretations of the Cherniatino II stable isotope data. However, Kuzmin (1997) notes chickens were not commonly kept as livestock in Medieval Primorye, an observation corroborated by their poor representation in the Cherniatino II faunal assemblage. Only two chicken-sized tarsometatarsii identified to Order Galliformes were identified among the medieval specimens, indicating at least some gallinaceous birds were present. The specimens' $\delta^{13}C$ values (-16.3‰, -20.4‰) also are consistent with a predominantly C_3 plant diet with some C_4 input. Pechenkina et al. (2005) also suggest the Neolithic dogs in their study may have hunted small rodents. These animals are frequent pests on grain stores, and if Cherniatino II dogs were supplementing their managed diets with small mammals that also consumed some quantity of millet, the $\delta^{13}C$ and $\delta^{15}N$ values observed here would be expected.

The limited variability of the Cherniatino II dog diets is echoed by the supposed uniformity of the dog's skeletal dimensions and morphology, noted by excavators of the site. Managed animals tend to show a consistency of characteristics because they interbreed (e.g., Rege et al. 2001). Moreover, the discovery of disarticulated dog vertebrae and ribs in numerous household trash pits are suggestive of their consumption by humans (Nikitin and Chzhun 2008), and there is some indication that dog skin garments were popular during the Mohe and Balhae periods (Okladnikov 1965). Without archaeological samples of millet from which $\delta^{13}C$ and $\delta^{15}N$ values can be obtained, specific identification of its consumption by the Cherniatino II dogs is challenging.

Millet consumption is nonetheless strongly implied by the data in this study. A standardized diet may have yielded desirable, dependable results for dog-derived products, and millet may have been used to fatten the dogs, as has been suggested for some Neolithic sites in China (Atahan et al. 2011; Pechenkina et al. 2005).

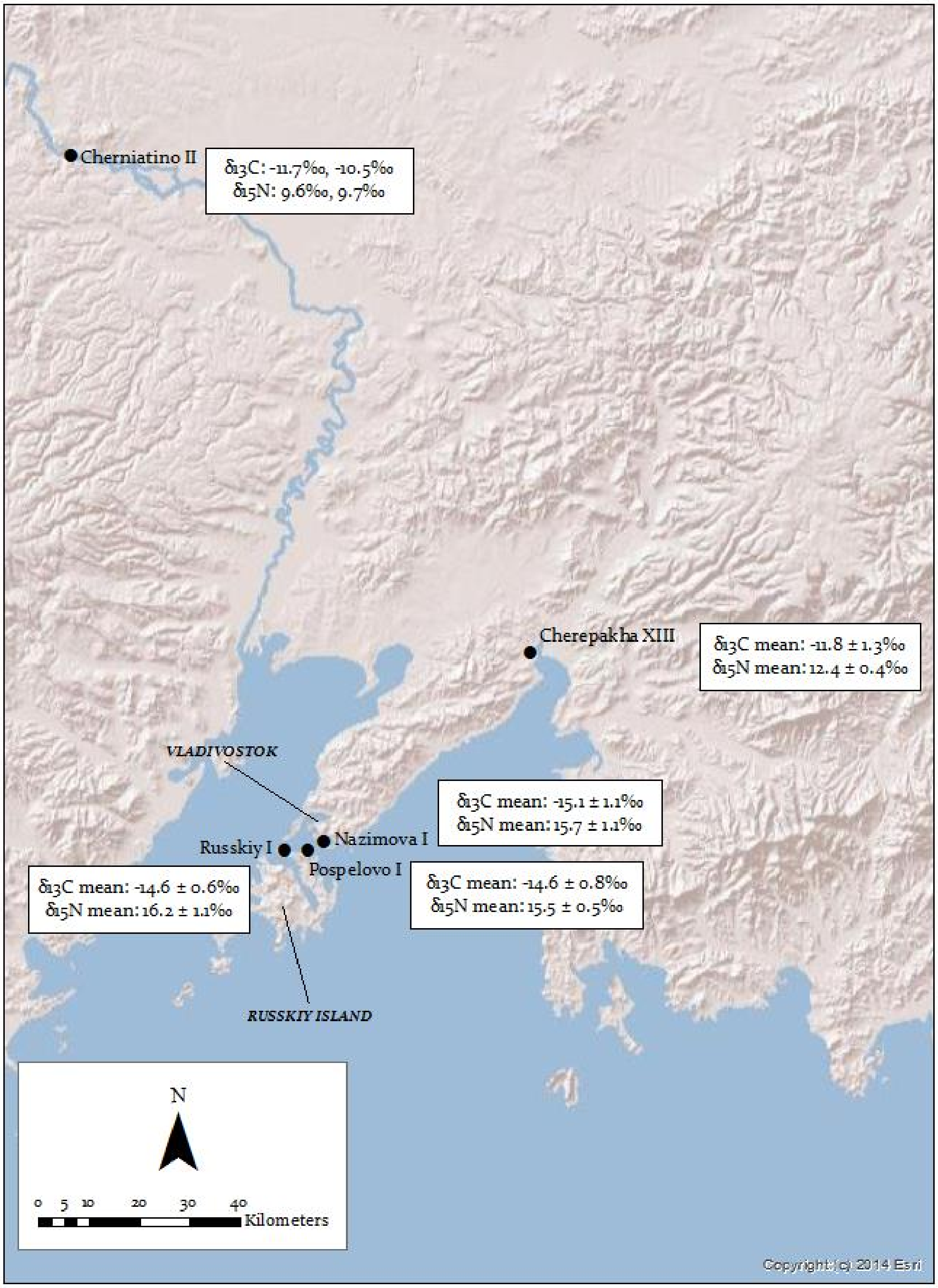

Figure 4.16 Map showing Primorye Early Iron Age dog sample δ^{13}C and δ^{15}N values by site. (Cherepakha XIII data from Kuzmin et al. 2018.) Map produced with data from ESRI.

4.4.2 Shellfish exploitation and management

Stable isotope analysis of human and dog bone collagen has confirmed the importance of marine resources to prehistoric diets in Primorye (Kuzmin et al. 2002; Kuzmin et al. 2018), and the recent stable isotope study performed on Boisman II potsherd residues (Kunikita et al. 2017) provides further support for the bone collagen results. However, until recently, these values lacked the isotopic context needed to assess *which* marine resources were consumed by these peoples, and how their diets may have varied over time. The preponderance of shellfish remains in many strata at Boisman II, and at later Yankovskaia sites, suggests that these animals made significant dietary contributions to the region's human inhabitants during the Neolithic (Jull et al. 1994; Kononenko 1998; Lutaenko and Artemieva 2017). Brodianski and Rakov (1992) have argued that the intensive exploitation and intentional cultivation of shellfish emerged on the Primorye coast in the Late Neolithic, and by the Early Iron Age was part of a broader food-producing economy. In their own words, these interactions constitute a form of aquaculture, which they conceptualize as a spectrum of human-mollusk interactions ranging from the improvement of the natural environment to the intentional sowing and selection of individuals for harvest. More recent—yet somewhat similar—human activities elsewhere in the world, such as the clam gardens and holding ponds of the Pacific Northwest coast of North America, have been demonstrated to improve shellfishing and fishing yields by making certain types of aquatic environments more attractive and habitable to desired species (Caldwell et al. 2012; Lepofsky and Caldwell 2013). Tabarev (2007) remarks that most archaeologists working in Primorye are dismissive of the concept but have not made formal attempts to disprove it and highlights the possible function of the shell middens as ceremonial sites where feasting may have taken place.

Both hypotheses may be reviewed in light of the dietary stable isotope data produced by this study and that of Kuzmin et al. (2018), along with paleoclimatic data reported by Razjigaeva et al. (2017, 2018, 2020). Razjigaeva and colleagues' data indicate the Early Iron Age was marked by the deterioration of lagoons along the coasts of Primorye and its islands. Multi-proxy paleoclimatic data from the Murav'ov Amurskiy Peninsula and the north and south coasts of Russkiy Island have indicated lagoons were at their greatest extent during the Late Neolithic, when high sea levels created brackish water conditions (Razjigaeva et al. 2018, 2019, 2020). Such lagoons were ideal habitats for the Pacific oyster (*Crassostrea gigas*) (Harris 2008), the predominant molluscan species in Yankovskaia shell midden assemblages. However, at about 4800 BP, sea levels began to drop (Razjigaeva et al. 2020), and ca. 3000 BP, during the Yankovskaia cultural period, the lagoons' connections to the sea were lost (Razjigaeva et al. 2020). Strong storms and tsunamis along the coast occasionally brought incursions of marine water into the former lagoons, but regular mixing of fresh and saltwater does not occur (Razjigaeva et al. 2020).

Coupled with paleoclimatic data, the stable isotope data reported by Kuzmin et al. (2018) for the Cherepakha XIII site and in the current study do not support assertions that shellfishing increased in dietary significance during the Early Iron Age. Indeed, Kuzmin et al. (2018) suggest that lower sea levels and a cooler climate are associated with the shift from aquatic resources to agriculture and livestock husbandry in Primorye, interpretations supported by human, dog, and suid data from the Cherepakha XIII site, and suggested by other researchers (e.g., Kononenko 1998). However, as shown by the Russkiy I, Pospelovo I, and Nazimova data from the current study, Early Iron Age subsistence trends across the region are not so easily characterized, and suggest there are temporal and spatial aspects to the structure of ancient coastal Primorye shell deposits. First, the Russkiy I, Pospelovo I, and Nazimova samples radiocarbon dated for this project appear to be contemporaneous with Cherepakha XIII. However, the Cherepakha XIII dates reported by Kuzmin et al. (2018:1612) were obtained from charcoal whereas the dates in the present study came from dog bone collagen, and likely carry a marine reservoir effect as a result of their aquatic resource-based diets. Further, millet was not detected in the diets of the Russkiy I, Pospelovo I, or Nazimova dog samples, unlike those from Cherepakha XIII (Kuzmin et al.

2018:1614), meaning the dogs in the current study represent individuals during or after the supposed shift to millet agriculture took place in the region.

Modern mollusk flesh δ^{15}N values from the East Sea are low in comparison to those of aquatic resources at higher trophic levels (Kharlamenko et al. 2008), and correspondingly, shellfish are not implicated in human or dog diets at any Yankovskaia site examined thus far. Some zooarchaeologists have challenged characterizations of shell midden as the residue of daily subsistence activities, pointing out that many such deposits appear to have been intentionally placed on the landscape and are structured with features of probable ceremonial significance, such as human and dog interments (Claassen 2010; McNiven and Wright 2008; Russo 1994), and may be representative of short-lived feasting events (Bourke 2004; Claassen 2010; Thompson and Andrus 2011).

In any event, the dissonance between the high visibility of mollusks at Early Iron Age midden sites, their apparent absence in human and dog diets, and the disappearance of their preferred habitats merits deeper investigation. More specific recommendations for this work are given in Chapter 5.

4.5 Conclusion

In this study, the dietary stable isotope analysis of faunal and human samples was performed to explore ancient human-animal relationships and the management of animal populations in three distinct ecological settings in Siberia and the Russian Far East. Specifically, I sought to assess how the inhabitants of these sites worked within local ecological conditions to manage animal populations. For some locations, prior archaeological studies had already defined these relationships, and in these instances, the data generated in this study complement and affirm those observations. At Ust'-Polui, the abundant Ob River fishery allowed humans to enter into a complex relationship with dogs, which provided labour in the form of sled traction. The overall complementarity of their dietary stable isotope data speaks to the proximity of dogs to humans, but minute differences on a smaller scale reveal the existence of human provisioning decisions indicative of a managed population. Dogsled traction would have allowed humans to travel longer distances to meet their own subsistence needs, though given the apparent dietary significance of fish to both dogs and humans at Ust'-Polui, it is possible these activities included other kinds of economic activities, such as long-distance trade.

Among the agriculturalist Early Iron Age and later medieval Mohe-Balhae peoples of Primorye, historical documents and previous archaeological work at Cherniatino II suggest dogs were valued as a source of meat and other products. These dogs also appear to have been a managed population, but their diets are isotopically consistent with the consumption of millet or the result of provisioning with products from animals that were fed on millet. This is a departure from the coast of Primorye, where hunter-fisher-gatherer groups likely had access to domestic millets but evidence for their cultivation and regular consumption by humans and domestic animals is equivocal at best.

Other intensively managed animal diets were suggested by the stable isotope data from the Medieval habitation Proezzhaia I. Here, cattle and horses appear to have consumed resources from open areas free of canopy cover, consistent with the grazing preferences of these animals. Further, the elevated $\delta^{15}N$ values of some samples suggest the animals ate plants grown in enriched soil, itself indicative of several management strategies, including pasturing and foddering. Long-distance trade also cannot be ruled out. While the interpretive possibilities for animal management strategies and individual life histories increase with dietary stable isotope analysis, such ambiguities highlight the need for sampling strategies that yield higher-resolution data.

In contrast to dogs, many of the cattle, horse, caprine, and suid diets analyzed here appear to have had little direct human influence. At Proezzhaia I, caprine and suid diets were isotopically similar to those of wild roe deer and musk deer and were distinct from other domesticates. Proezzhaia I suid sample $\delta^{13}C$ values are slightly lower than those of the caprines, suggesting differential access to some food or trash item, such as riverine fish. Kuzmin et al. (2018) demonstrated a slight isotopic separation between suids at the Cherepakha XIII site in Primorye, which they argue is evidence for wild and domestic populations. However, the suid $\delta^{13}C$ and $\delta^{15}N$ values acquired in this study did not permit such distinctions to be made. In all cases, it appears the suids were consuming resources from the forest, likely the abundant nut mast that would have been available in the region. These data show consistent values from coastal and inland sites from the Late Neolithic through the Medieval period, suggesting the local environment adequately satisfied suid dietary needs. Interestingly, the $\delta^{13}C$ and $\delta^{15}N$ values of Late Neolithic human and dog samples from the Boisman II site and Yankovskaia dog samples show strong marine signatures, indicating that suids were not consumed in significant quantities. Similarly, enormous quantities of mollusk shell at Primorye archaeological sites (particularly those situated on or near coastal lagoons), suggest the importance of shellfish to the region's inhabitants, but dietary stable isotope data do not identify these invertebrates as the focus of long-term diets. The absence of a predominant suid or shellfish signature in Late Neolithic and Early Iron Age human and dog diets could point to their value as feasting or ceremonial foods or use as an emergency food when other resources failed. Shell middens like Boisman II are likely representative of locations where such activities took place and may not reflect the day-to-day activities or subsistence-related trash of the humans who used these sites.

5 Conclusion

In this study, I have demonstrated the utility of dietary stable isotope analyses in answering questions about ancient animal management practices in different regions of Siberia and the Russian Far East. As suggested by Makarewicz (2016:190), the stable isotope methods I employed made otherwise inaccessible data available. When these data were paired with archaeological context information, I was able to make inferences about the lives of ancient animals and to explore possible human activities related to the animals' care. In this chapter, I summarize the most significant findings and interpretations in light of the questions stated in Chapter 1. To conclude, I provide recommendations for additional research that would complement or provide addition support for the stable isotope research presented in this dissertation.

5.1 Summary of results and interpretations

Ust'-Polui has been interpreted as an Iron Age ceremonial space on the landscape of the Lower Ob, and it is believed to have been visited regularly by members of different human-animal communities who performed animal sacrifices at the location, among other activities (Chernetsov and Moszyńska 1974; Losey et al. 2018b). Harness pieces, also recovered from Ust'-Polui, suggest some of these dogs pulled sleds, and dietary stable isotope analyses demonstrated that aquatic resources formed the bulk of their diets. The abundant resources provided by the Ob River, including riverine fish, almost certainly were made available to dogs by humans, and would have ensured an accessible, high-quality source of nutrition for them. This observation gives support to Davydov and Klokov's (2018:48) assertion that dog breeding and sledding were predominant among naturally productive rivers in Siberia, where humans could economically provision large numbers of working dogs.

In this study, each of the 15 dog crania recovered from the site's skull cache was sampled, along with dog skeletal remains from elsewhere at the site. Though all dog samples exhibited values consistent with consumption of freshwater resources, the skull cache samples formed a distinctive isotopic cluster, yielding significantly higher $\delta^{13}C$ and lower $\delta^{15}N$ values than other dog samples from Ust'-Polui. At a location used by multiple human and animal communities in the region, such differences were not unexpected. Likely, these dogs came from a single community that transported living dogs or the skulls to Ust'-Polui, where they were deposited in a small concentration. Though all dogs sampled yielded stable isotope data consistent with a riverine fish-based diet, how this community's feeding strategy varied from others requires further research.

This study also provided data to support the existence of the freshwater reservoir effect reported by Losey et al. (2018b) for the Lower Ob region. Similar age biases have been documented among archaeological dogs and humans in other parts of Siberia (Nomokonova et al. 2013; Schulting et al. 2014, 2015; Svyatko et al. 2015). At Ust'-Polui, dog and human skeletal samples yielded radiocarbon dates centuries older than other terrestrial mammals and organic materials, the result of their significant consumption of riverine fish. The source of this bias would remain unknown without the faunal stable isotope data generated by this research.

The $\delta^{13}C$ and $\delta^{15}N$ values from Proezzhaia I are the first archaeological stable isotope data reported for the Transbaikal region of Siberia, an area spanning over 400,000 square kilometers. Both domestic and wild animal skeletal remains were recovered from this fortified medieval town and provided an opportunity to explore provisioning of the site's domestic animals, some of which appear to have been managed more directly and intensively than others. Here, cattle and horses may have had diets directly influenced by human agricultural activities or limited foddering with a C_4 plant resource. Alternatively, some animals may have been brought in from a more arid location where floral $\delta^{13}C$ and $\delta^{15}N$ baseline values were higher. However, the observation of higher $\delta^{13}C$ values among samples belonging to the long-tailed ground squirrel, a noted agricultural pest, and the identification of charred millet remains from contemporaneous sites in the same region, provide additional lines of evidence for the inclusion of a C_4 plant in some cattle and horse diets. Additionally, these animals' dietary stable isotope values are distinct from those of other domestic taxa recovered from the site, including caprines, dogs, and pigs, all of which are consistent with consumption of C_3 plant or C_3 plant-fed resources. These latter domestic faunal have stable isotope values that are similar to those of wild terrestrial mammals living in the region. In sum, these differential practices may reflect an intensive, small-scale management strategy designed to distribute the risks associated with agricultural activities and animal husbandry.

The large dataset from southern Primorye allowed for exploration of animal management practices at six sites in different geographic settings, representing significant environmental and cultural shifts from the Late Neolithic through the medieval period. Human and dog samples from coastal Late Neolithic and Early Iron Age shell midden sites revealed diets rich in marine resources. Dogs were fed marine foods as part of their management strategy, or had access to these foods, likely through a combination of intertidal foraging or scavenging on human subsistence waste. However, these data do not suggest shellfish, which have higher $\delta^{13}C$ and lower $\delta^{15}N$ values than marine resources at higher trophic levels, made significant dietary contributions to either species despite the preponderance of shell in midden fill. Similarly, though suid skeletal remains were recovered from all coastal Primorye sites, these samples' strong terrestrial dietary signatures are not shared by humans or dogs, nor does it appear boar or pig were consumed in isotopically significant quantities during the Late Neolithic and Early Iron Age.

Further, suid samples from Primorye sites yielded low $\delta^{13}C$ values, suggesting they consumed locally available C_3 plant materials, perhaps pannage produced by the region's tree nut-rich forests. If these individuals were domestic pigs, their feeding strategy mimicked the natural dietary patterns of wild suids in the region. Further, the suid $\delta^{13}C$ and $\delta^{15}N$ values in the present study are at odds with the bimodal distribution of suid stable isotope data reported by Kuzmin et al. (2018) from the Cherepakha XIII site, another Early Iron Age site on the coast of southern Primorye. Here, Kuzmin et al. (2018) argue for the presence of both wild boar and domestic pigs, the former identified by the C_3 signature of their

$\delta^{13}C$ values, indicative of unmanaged populations of terrestrial animals. Conversely, domestic pigs were said to be characterized by high $\delta^{13}C$ and $\delta^{15}N$ values, argued to reflect the inclusion of a cultivated C_4 plant (likely millet) in their diets. When viewed as a biplot, the suid values from this study fall outside the $\delta^{13}C$ and $\delta^{15}N$ ranges for wild and domestic suids identified by Kuzmin and colleagues. This illustrates that stable isotopes alone may be insufficient to identify managed and unmanaged suid populations in Primorye, as has been suggested by Kuzmin et al. (2018).

At the inland Cherniatino II site, Early Iron Age and medieval peoples appear to have interacted with a suite of domestic animals, including cattle, horses, dogs, and pigs, and a lone undifferentiated turtle sample hints at exchange with coastal areas to the east. Cattle samples were available only from Mohe and Balhae (medieval) contexts and suggest they consumed a mixed C_3-C_4 plant diet. Horse sample values, one each from the Early Iron Age and the Mohe period, are indicative of different management strategies in the two periods, however both appear to have consumed primarily C_3 resources.

By the medieval period, dog samples exhibit high $\delta^{13}C$ and $\delta^{15}N$ values that indicate they frequently consumed a C_4 plant or C_4 plant-fed resource, and the consistency of this pattern is suggestive of a managed diet. The homogeneity of their diets, presence of cut marks on their disarticulated remains, consistently small skeletal dimensions, and anecdotal reports of Mohe-Balhae consumption of dog flesh and use of dog fur all suggest these dogs were a closely managed breed or type. Suid samples from the Early Iron Age and both medieval contexts also were analyzed, but yielded consistently low $\delta^{13}C$ and $\delta^{15}N$ values, giving no indication that their diets were supplemented by humans.

Suid samples from the Early Iron Age and both medieval contexts also were analyzed, but yielded consistently low $\delta^{13}C$ and $\delta^{15}N$ values, giving no indication that their diets were supplemented by humans. Further, these data indicate no significant shift in the management of their diets occurred in this period. Indeed, the values observed here are similar to those of the coastal Primorye suid samples. By the medieval period, suids in Primorye were almost certainly a mix of domestic pigs and wild boar.

The suid stable isotope data generated in this dissertation suggests a medieval management strategy wherein pigs were herded into woodlands to consume large quantities of nuts. This practice has been suggested for archaeological pig populations in other parts of the world, and is a noted practice for finishing pig flesh before slaughter even in the present day.

5.2 Animals as human dietary proxies

A primary goal of this research was to assess the applicability of the Canine Surrogacy Approach (CSA) to dietary stable isotope datasets in Siberia and the Russian Far East. This study established that dog $\delta^{13}C$ and $\delta^{15}N$ values can effectively be used as proxy data for human values in the Early Iron Age of the Lower Ob region and in Late Neolithic-Early Iron Age of Primorye. Guiry (2012) notes the slight but consistent offset between the dietary values of humans and dogs "may be significant, or not at all." His assertion that interpretive aims will necessarily dictate the complementarity of human and dog isotopic signatures is pertinent here. At the Ust'-Polui site, while human and dog sample $\delta^{13}C$ values suggest the two species had substantial dietary inputs from the same freshwater source, the small but detectable offset in $\delta^{15}N$ values points to some slight difference among those inputs, and the consistency of this isotopic relationship, especially across the Ust'-Polui dog sample dataset, indicates provisioning strategies in which dogs routinely consumed fish tissues slightly less enriched in ^{15}N than what humans ate. At Boisman II, the proximity of dog diet to that of humans provides another line of evidence to support a subsistence focus on high trophic level aquatic resources, and the offset, evident in this dataset as well, also may point to differential consumption of fish tissues between humans and dogs. These data demonstrate the scale at which interpretation is made may be the most important determination of the applicability of the CSA. However, most examples presented in defense of the CSA are from ancient hunter-gatherer groups, and the only way to confirm its veracity for any given context is to analyze both human and dog samples from the same temporal contexts.

Previously, human diets have been far more deeply studied by archaeologists than those of dogs. As human societies become more complex, so do their diets—in many cases manifesting in social constructs that dictate access to certain types of foods (e.g., Müldner and Richards 2005). Some researchers have demonstrated the ability of dietary stable isotope data to detect differential status among groups of dogs. For example, at the Colha site in Belize, White et al. (2001) showed that dietary stable isotope samples taken from dogs who had received special mortuary treatment—interment in caches with other dogs—had diets that were based increasingly on maize than those recovered from midden contexts (White et al. 2001).

Given that dogs, like humans, are subject to divisions of labour and status as they are more fully integrated into human social structures, it is reasonable to expect concomitant differences in access to certain dietary resources, and that these become more numerous and diverse as social complexity increases. Just as we would not suggest the dietary stable isotope signature of a single human was representative of all humans living in a stratified society, we should also not assume that all dogs at a given site had similarly structured diets, nor that all dogs will have similar diets to all humans at such sites. Thus, the complementarity of human and dog diets in the CSA always requires consideration of variability in human and dog social structure and its potential impacts on dietary variability among both species.

Other issues to consider in the CSA are the consumption of dogs by humans and dog consumption of human feces. Regular human consumption of dog flesh might account for some of the small isotopic offsets observed in humans and dogs from the same sites. Among some societies, the consumption of dog flesh is a strictly limited ceremonial activity (e.g., Oberholtzer 2002), but in other contexts may be far more frequent (e.g., Oh and Jackson 2011; Hutabarat et al. 2003). The frequency of cut marks on disarticulated dog bone is one indication of their butchery, and when such bone modifications are present, the consumption of dog meat by humans should be assessed and considered in stable isotope studies. Additionally, caecotrophy (the consumption of animal waste by other animals) is a commonly used in archaeological literature as one explanation why human and dog diets are slightly offset (Guiry 2012; Katzenberg et al. 2012; Losey et al. 2013). How caecotrophy affects dog (or other animal) dietary stable isotope patterns, however, is largely speculative and requires much additional research.

Finally, because dietary stable isotope analysis requires a comparatively small portion of bone for collagen extraction and analysis, some studies have shown that skeletal element selection has the potential to skew datasets. Eriksson and Zagorska (2003) surmised the dog tooth pendants sampled in their study of the inland Zvejniecki site in present-day Latvia did not originate from dogs raised in the area—or at the very least, that the dogs whose teeth were used had spent the early part of their lives (when their teeth were formed) much nearer to the coast. While the Cherniatino II dogs in this study have a distinctively higher $\delta^{13}C$ values than the earlier dogs from coastal sites, their $\delta^{15}N$ values do not support any argument for an origin on the Primorye coast, nor did any clear isotopic pattern on the basis of skeletal element emerge to support any such interpretation. Regardless, the potential for element selection to shape dietary isotope values should be considered when selecting samples and assessed after analysis has been carried out.

5.3 Future work

The zooarchaeological and stable isotope data generated for this study have illustrated the value of a multidisciplinary approach to make inferences about ancient human and animal diets and management practices. The results of this research underscore the necessity of further inquiry to provide essential, additional lines of evidence, but also highlight opportunities for new projects that might build upon the work presented in this dissertation. Broadly, these recommendations fall into two groups: the first concerns additional faunal and stable isotope analyses, and the second calls for an examination of paleobotanical remains and landscape use. A third recommendation deals specifically with an examination of shellfish management in Primorye and is discussed in its own section.

With only a few exceptions as noted, sampling was intentionally limited to skeletally mature individuals whose bones were free from visible pathology, at least insofar as could be determined from largely disarticulated remains. Because animal husbandry tends to include human decisions based on demography—greater dietary supplementation for pregnant and nursing females, or culling of immature males, for example—additional sampling across a population and a region's sites could net further insights into how groups of animals were managed (e.g., Finucane et al. 2006; Stevens et al. 2013). In a similar vein, incremental sampling of dentinal collagen would permit assessment of an individual's diet over the period of formation, providing a snapshot of dietary information in a bounded window of time (Balasse et al. 2006, 2012; Makarewicz 2014; Makarewicz and Tuross 2006). This approach might also allow researchers to make observations about seasonal provisioning when coupled with other stable isotope analyses, such as $\delta^{18}O$, which varies both on a seasonal basis and by geographic location (e.g., Frémondeau et al. 2012; Kirsanow et al. 2008).

Additionally, if skeletal pathologies are perceived as markers for experiences and events, rather than only as conditions that might confound dietary stable isotope analyses, deeper insights about animal populations and individual animal lives may be made. For example, a higher incidence of linear enamel hypoplasia, a dental pathology associated with physiological stress, has been identified in northern Chinese Neolithic domestic pig populations that appear to have been dependent on agricultural resources (Dobney et al. 2007). Wang et al. (2012) have already demonstrated the utility of a combined approach using dental pathology assessments and stable isotopes to examine dietary stress in different suid populations in northern China, and to examine differential husbandry practices in other parts of the world (e.g., Frémondeau et al. 2017). Such an approach could aid in making distinctions between domestic pigs and wild boar and would be useful in exploring varied management strategies in different ecological settings.

I also recommend more river- and taxon-specific isotopic analyses of fish, along with directed analysis of key tissues—namely, white and red muscle, bones, organs, and eggs. Such data would be highly useful for more fully understanding the interplay of taxon, fish size, and regular consumption of specific tissues, and their implications for the utility of collagen-derived stable isotope values in paleodietary modeling.

Several sites in this study have been interpreted as locations where ceremonial activities were performed, including sacrifice and feasting. Making inferences about population-level animal management from these sites may be biased. Several zooarchaeological stable isotope studies have demonstrated that sacrificial animals are sometimes provisioned with special diets in preparation for their death (e.g., Sugiyama et al. 2015; White et al. 2004). The use of ceremonial locations by multiple human-animal communities over long periods of time, as has been suggested for Ust'-Polui, may further confound interpretations. Additionally, faunal remains recovered from these sites likely represent the remains of feasting rather than day-to-day subsistence waste, and interpretations of human diet and animal management based on these assemblages may be deceiving. For example, midden fill at Boisman II and Pospelovo I is dominated by mollusk shell and contains suid skeletal remains, yet stable isotope values for human and dog samples taken from the same sites failed to identify those resources as significant dietary contributors. Analysis of more faunal skeletal remains from contemporaneous archaeological sites in these regions, preferably from habitation contexts, would help to establish the range of variation with respect to their dietary stable isotope values and enable researchers to more easily identify outliers and regional variability.

Stable isotope analysis of other forms of archaeological material might also shed light on human and animal diets and their variability within each study area. For example, analysis of ceramic vessel residues has provided a line of evidence underscoring the increasing significance of aquatic resources in human diets at Boisman II (Kunikita et al. 2017) and along the coast of the East Sea near Primorye (Gibbs et al. 2017; Shoda et al. 2017). Gibbs et al. (2017:1492) and Shoda et al. (2017:169) have asserted that residues' high $\delta^{15}N$ values are associated with a focus on marine resources, and further, that separation of residues from shellfish and fish at higher trophic levels may be possible with these techniques. Sampling and analysis of ceramic residues from multiple sites across all study regions could aid in better identification of the resources used at different sites, and perhaps provide an additional line of evidence for the presence of ceremonial or feasting foods at specific locations on the landscape.

The remains of both foxtail and broomcorn millet have been identified in samples from the Cherniatino II site, and, as reported by Sergusheva (2012), are the most numerous paleobotanical remains in Balhae contexts across Primorye, followed by soft wheat and naked barley. This information corroborates the patterns seen in the site's isotopic data, explaining the incidence of high $\delta^{13}C$ values among some taxa and the mixed C_3-C_4 diets indicated for others. Additional sites in this study, particularly Proezzhaia I, would benefit from directed paleobotanical research to address the presence of cultivated millets, confirmation of which will help to better contextualize faunal dietary stable isotope data and to direct future work on their cultivation and use. If such cultivated grains are not identified, this will permit researchers to explore alternative explanations for the high $\delta^{13}C$ values observed among some taxa at these sites. Additionally, soil chemistry analyses have been used in archaeological applications to identify human-modified soils thousands of years after they were cultivated or used as pasture (e.g., Benson 2012; Bull et al. 1999). If areas of possible ancient agricultural activity were identified near the sites in this study, coordinated efforts to assess floral remains and soil composition would augment the zooarchaeological and stable isotope data, illuminating ancient plant cultivation and animal husbandry practices.

5.3.1 Primorye shellfish use and management

The dietary stable isotope data generated for this study, along with the Cherepakha XIII data produced by Kuzmin et al. (2018), do not indicate that shellfish were a human and dog dietary mainstay at any point in the Late Neolithic or Early Iron Age. From these observations, Brodianski and Rakov's (1992) assertion that shellfish management was practiced on the Primorye coast and reached a peak in the Early Iron Age might be dismissed. However, the isotopic absence of a mollusk-based subsistence strategy in spite of physical presence of shells on the landscape calls for a directed assessment of the significance of shellfish in these societies. If shellfish held a particular non-dietary significance among the ancient peoples of the Primorye coast, it is reasonable to suggest that management of molluscan resources in these lagoons may have been even more important in the context of a changing landscape.

The Pacific oyster (*C. gigas*), whose shells predominate Primorye shell midden matrix, is the most frequently identified molluscan taxon in Early Iron Age faunal assemblages (Brodianski et al. 2012:109; Popov and Tabarev 2017:389). It is a hardy species that can adapt to a range of water temperatures and salinity levels (Harris 2008), and it may have been a candidate for management and experimentation at a time when naturally productive lagoon habitats transformed into freshwater lakes and swamps along the coasts of Primorye. While their shells remain intact for thousands of years, these portions of mollusk bodies are formed seasonally by different chemical mechanisms under the specific environmental conditions in which they live (Claassen 1998) and cannot be used for dietary isotope work. However, they can be used in sclerochronological studies due to the periodicity of shell formation and secretion of minerals as part of the precipitation process (Andrus 2011). There are several techniques for the assessment of incremental seasonal growth in mollusks, including microsampling across the shell for $\delta^{18}O$ analysis. While season of capture is the most typical application of sclerochronology in the study of archaeological midden assemblages (e.g., Harke et al. 2015), $\delta^{18}O$ analysis also has been used to assess salinity levels (Andrus 2011; Eerkens et al. 2013). If mollusk remains from Primorye's shell middens were examined using these techniques, information on when shellfish were harvested would give deeper insight into their ancient dietary role, if any, and might also provide an additional line of evidence to corroborate Razjigaeva and colleagues' (2017, 2018, 2020) multiproxy paleoenvironmental data that indicate lagoon water salinity decreased over time as their connections to the sea were lost.

5.4 Final remarks

Theoretical and methodological advances in the social sciences and ecology have led to increasingly complex questions about ancient human lives and their relationships with other-than-human organisms, as well as their interactions with the landscapes they shared. Such questions require robust multidisciplinary approaches with unique perspectives that provide multiple lines of evidence and strengthen archaeological inference (Makarewicz 2016). Through integration of zooarchaeological methods with dietary stable isotope analysis, in this study I have explored ancient animal management at various points in time in three ecologically distinct regions of Siberia and the Russian Far East. While this study concerns broad dietary trends and ancient animal management practices in these areas, the data reported here demonstrate the potential of an integrated approach to address more complex questions of archaeological interest, as well as to examine related phenomena, including an exploration of daily experiences and major events in animal lives, the modification of landscapes by humans and animals, and the variety of human-animal social relationships that have emerged over time.

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Appendix A: Collagen sample δ^{13}C and δ^{15}N data

Ust'-Polui

Taxon	**Element (side if noted)**	**Lab ID**	**Collagen Yield (%)**	**δ13C (‰)**	**δ15N (‰)**	**C content (%)**	**N content (%)**	**C/N Mass**	**C/N Atomic**	**Notes**
^{14}C sample	humerus	LPO-23F	/	/	/	/	/	/	/	Collagen not extracted
^{14}C sample	phalanx 1	LPO-26F	/	/	/	/	/	/	/	Collagen not extracted
^{14}C sample	phalanx 1	LPO-27F	/	/	/	/	/	/	/	Collagen not extracted
Alces alces	phalanx 1	LPO-22F	1.2	-21.8	3.9	43.6	14.8	2.9	3.4	
Alopex lagopus	costa	LPO-18F	1.8	-22.6	9.1	43.2	14.4	3.0	3.5	
Alopex lagopus	tibia	LPO-19F	2.4	-22.4	5.7	43.8	12.6	3.5	4.1	C/N atomic >3.6; excluded
Alopex lagopus	vertebra thoracales	LPO-20F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Alopex lagopus	mandible	LPO-21F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Anas sp.	humerus	LPO-80F	2.5	-23.5	16.4	43.3	14.1	3.1	3.6	
Canis lupus	pelvis	LPO-17F	1.4	-19.3	11.6	44.3	14.5	3.0	3.6	
Canis lupus familiaris	scapula (R)	LPO-28F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Canis lupus familiaris	scapula (R)	LPO-29F	1.6	-26.0	14.5	46.0	16.3	2.8	3.3	

Canis lupus familiaris	scapula (R)	LPO-30F	1.2	-24.7	13.6	44.7	15.7	2.8	3.3	
Canis lupus familiaris	scapula (R)	LPO-31F	12.7	-24.4	12.6	46.0	16.1	2.9	3.3	
Canis lupus familiaris	scapula (R)	LPO-32F	1.0	-24.5	13.1	44.7	15.7	2.8	3.3	
Canis lupus familiaris	scapula (R)	LPO-33F	1.1	-26.3	14.6	43.9	15.1	2.9	3.4	
Canis lupus familiaris	scapula (R)	LPO-34F	1.2	-26.2	14.1	46.2	15.8	2.9	3.4	
Canis lupus familiaris	scapula (R)	LPO-35F	1.5	-26.2	14.4	44.3	15.2	2.9	3.4	
Canis lupus familiaris	scapula (R)	LPO-36F	1.0	-26.1	14.6	45.6	15.6	2.9	3.4	
Canis lupus familiaris	scapula (R)	LPO-37F	2.0	-26.7	14.2	45.5	16.2	2.8	3.3	
Canis lupus familiaris	scapula (R)	LPO-38F	1.1	-26.9	14.3	43.5	14.3	3.0	3.5	
Canis lupus familiaris	scapula (R)	LPO-39F	1.4	-25.3	14.5	46.0	15.9	2.9	3.4	
Canis lupus familiaris	scapula (R)	LPO-40F	0.8	-25.9	13.0	45.2	15.6	2.9	3.4	
Canis lupus familiaris	scapula (R)	LPO-41F	0.5	-25.7	13.8	46.2	16.4	2.8	3.3	
Canis lupus familiaris	scapula (R)	LPO-42F	1.7	-27.0	15.3	46.3	16.5	2.8	3.3	
Canis lupus familiaris	scapula (R)	LPO-43F	1.2	-25.9	13.8	44.9	15.9	2.8	3.3	
Canis lupus familiaris	scapula (R)	LPO-44F	1.7	-27.1	14.7	45.7	15.7	2.9	3.4	

Canis lupus familiaris	scapula (R)	LPO-45F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Canis lupus familiaris	scapula (R)	LPO-46F	0.7	-25.1	14.7	45.0	14.9	3.0	3.5	
Canis lupus familiaris	scapula (R)	LPO-47F	1.2	-26.6	14.5	45.3	16.0	2.8	3.3	
Canis lupus familiaris	scapula (R)	LPO-48F	0.2	-25.6	13.5	46.1	16.3	2.8	3.3	
Canis lupus familiaris	scapula (R)	LPO-49F	0.1	-26.4	13.8	40.8	13.3	3.1	3.6	
Canis lupus familiaris	scapula (R)	LPO-50F	1.8	-25.5	14.2	44.2	15.6	2.8	3.3	
Canis lupus familiaris	scapula (R)	LPO-51F	1.4	-25.8	15.0	45.7	16.3	2.8	3.3	
Canis lupus familiaris	scapula (R)	LPO-52F	1.4	-25.2	13.8	45.8	16.1	2.8	3.3	
Canis lupus familiaris	scapula (R)	LPO-53F	2.5	-26.8	15.0	44.6	15.7	2.8	3.3	
Canis lupus familiaris	scapula (R)	LPO-54F	2.2	-26.2	14.7	45.5	15.9	2.9	3.3	
Canis lupus familiaris	scapula (R)	LPO-55F	1.2	-27.0	15.3	43.5	15.1	2.9	3.4	
Canis lupus familiaris	scapula (R)	LPO-56F	1.1	-26.3	13.3	45.1	16.0	2.8	3.3	
Canis lupus familiaris	scapula (R)	LPO-57F	2.5	-24.9	13.6	44.6	15.6	2.9	3.3	
Canis lupus familiaris	scapula (R)	LPO-58F	1.3	-25.5	13.5	45.3	15.8	2.9	3.3	
Canis lupus familiaris	scapula (R)	LPO-59F	2.0	-26.7	14.5	43.6	15.4	2.8	3.3	

Canis lupus familiaris	scapula (R)	LPO-60F	1.3	-26.7	15.4	45.9	15.8	2.9	3.4	
Canis lupus familiaris	scapula (R)	LPO-61F	1.8	-25.0	14.3	43.3	14.7	2.9	3.4	
Canis lupus familiaris	scapula (R)	LPO-62F	1.1	-27.1	14.0	43.9	14.7	3.0	3.5	
Canis lupus familiaris	scapula (R)	LPO-63F	2.8	-26.1	14.9	42.7	15.1	2.8	3.3	
Canis lupus familiaris	parietal fragment	LPO-64F	1.0	-25.5	12.4	42.7	14.0	3.1	3.6	
Canis lupus familiaris	parietal fragment	LPO-65F	1.6	-24.7	12.6	44.0	15.9	2.8	3.2	
Canis lupus familiaris	parietal fragment	LPO-66F	1.9	-25.6	12.5	41.7	14.3	2.9	3.4	
Canis lupus familiaris	parietal fragment	LPO-67F	1.4	-25.9	13.6	44.4	15.4	2.9	3.4	
Canis lupus familiaris	parietal fragment	LPO-68F	1.6	-25.1	12.6	45.3	16.1	2.8	3.3	
Canis lupus familiaris	parietal fragment	LPO-69F	1.8	-25.6	13.2	45.7	16.2	2.8	3.3	
Canis lupus familiaris	parietal fragment	LPO-70F	1.4	-25.2	13.2	45.3	16.0	2.8	3.3	
Canis lupus familiaris	parietal fragment	LPO-71F	1.7	-25.6	13.3	45.1	16.0	2.8	3.3	
Canis lupus familiaris	parietal fragment	LPO-72F	1.5	-25.1	12.4	44.9	15.8	2.8	3.3	
Canis lupus familiaris	parietal fragment	LPO-73F	2.6	-25.5	13.5	44.3	15.3	2.9	3.4	
Castor fiber	scapula	LPO-15F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded

Castor fiber	vertebra caudales	LPO-16F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Coregonus muskun	vertebra	LPO-01F	1.1	-21.1	1.5	45.4	15.8	2.9	3.4	
Coregonus muskun	vertebra	LPO-02F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Homo sapiens sapiens		LPO-84F	2.0	-26.1	17.3	42.9	14.5	3.0	3.5	
Homo sapiens sapiens		LPO-85F	0.1	-23.5	16.4	43.3	14.1	3.1	3.6	Insufficient collagen in vial for analysis; excluded
Homo sapiens sapiens	tibia	LPO-86F	1.8	-26.2	17.0	44.2	15.1	2.9	3.4	
Lagopus lagopus	humerus	LPO-06F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Lagopus lagopus	scapula	LPO-07F	1.4	-21.3	3.2	47.3	15.8	3.0	3.5	
Lagopus lagopus	coracoid	LPO-08F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Lagopus lagopus	carpometacarpus	LPO-09F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Lagopus lagopus	coracoid	LPO-10F	1.5	-21.1	1.5	45.4	15.8	2.9	3.4	
Lepus timidus	vertebra lumbales	LPO-13F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Lepus timidus	vertebra lumbales	LPO-14F	1.7	-22.8	3.1	44.2	15.1	2.9	3.4	
Lota lota	vertebrae	LPO-82F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Lota lota	vertebrae	LPO-83F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded

Martes zibellina	tibia	LPO-79F	1.1	-26.1	17.3	42.9	14.5	3.0	3.5	
Milvus migrans	humerus	LPO-81F	1.0	-26.2	17.0	44.2	15.1	2.9	3.4	
Odobenus rosmarinus	phalanx 1	LPO-11F	1.5	-17.3	12.5	45.4	16.2	2.8	3.3	
Phoca sp.	costa	LPO-12F	1.4	-18.8	4.8	45.6	15.9	2.9	3.3	
Rangifer tarandus	humerus	LPO-24F	0.2	-19.8	7.6	44.8	15.0	3.0	3.5	
Rangifer tarandus	talus	LPO-25F	1.9	-19.3	6.9	43.0	15.2	2.8	3.3	
Rangifer tarandus	metacarpus	LPO-75F	1.8	-19.4	3.3	45.8	15.5	3.0	3.4	
Rangifer tarandus	tibia	LPO-76F	1.0	-19.3	6.2	44.4	14.8	3.0	3.5	
Rangifer tarandus	humerus	LPO-77F	0.4	-22.0	8.7	42.5	13.9	3.1	3.6	C/N atomic >3.6; excluded
Rangifer tarandus	metatarsus	LPO-78F	1.5	-23.5	8.7	39.1	12.8	3.1	3.6	C/N atomic >3.6; excluded
Sciurus vulgaris	tibia	LPO-74F	0.6	-19.6	8.5	45.9	15.9	2.9	3.4	Collagen yield too low; excluded
Stenodus leucichthys nelma	vertebra	LPO-03F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Stenodus leucichthys nelma	vertebra	LPO-04F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Stenodus leucichthys nelma	vertebra	LPO-05F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded

Proezzhaia

Taxon	Element (side if noted)	Lab ID	Collagen Yield (%)	δ13C (‰)	δ15N (‰)	C content (%)	N content (%)	C/N Mass	C/N Atomic	Notes
Alces alces	calcaneus	LPZ-12F	1.1	-19.4	7.4	49.5	17.2	2.9	3.4	
Alces alces	maxilla	LPZ-37F	1.0	-21.4	2.7	44.9	15.3	2.9	3.4	
Bos sp.	phalanx 2	LPZ-03F	1.2	-19.8	5.4	45.7	16.6	2.8	3.2	
Bos sp.	phalanx 2	LPZ-11F	0.5	-20.6	1.4	46.7	15.9	2.9	3.4	Collagen yield too low; excluded
Bos sp.	phalanx 1	LPZ-13F	5.2	-19.9	8.2	43.6	15.0	2.9	3.4	
Bos sp.	phalanx 2	LPZ-16F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Bos sp.	patella	LPZ-28F	1.5	-19.7	6.5	44.6	15.5	2.9	3.4	
Bos sp.	phalanx 3	LPZ-35F	1.1	-21.3	6.3	45.8	16.5	2.8	3.2	
Bos sp.	horn core	LPZ-38F	/	-17.1	8.0	45.7	15.4	3.0	3.5	instrument error; excluded
Canis lupus familiaris	ulna	LPZ-43F	/	-20.5	8.4	47.4	16.3	2.9	3.4	instrument error; excluded
Canis lupus familiaris	mandible	LPZ-44F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Canis lupus familiaris	vertebrae lumbales	LPZ-45F	1.2	-20.5	8.0	45.0	15.5	2.9	3.4	
Canis lupus familiaris	maxilla	LPZ-46F	3.4	-20.3	8.4	46.1	16.4	2.8	3.3	
Canis lupus familiaris	scapula	LPZ-47F	2.3	-21.4	8.2	43.4	14.5	3.0	3.5	

Capreolus sp.	tibia	LPZ-10F	5.2	-17.8	7.2	48.5	16.9	2.9	3.3	
Capreolus sp.	innominate	LPZ-06F	3.4	-20.0	8.3	43.6	15.2	2.9	3.3	
Caprinae	patella	LPZ-20F	1.7	-20.4	5.3	44.6	15.7	2.8	3.3	
Caprinae	mandible	LPZ-22F	3.4	-20.6	4.4	44.5	15.5	2.9	3.3	
Cervidae	astragalus	LPZ-26F	1.5	-21.4	5.4	44.6	15.3	2.9	3.4	
Cervidae	phalanx 2	LPZ-39F	4.7	-21.3	2.5	44.8	15.8	2.8	3.3	
Cervus sp.	calcaneus	LPZ-29F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Citellus undulatus	humerus	LPZ-40F	2.4	-18.9	6.5	42.1	13.5	3.1	3.6	
Equus sp.	patella	LPZ-21F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Equus sp.	phalanx 1	LPZ-01F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Equus sp.	metapodial	LPZ-09F	5.1	-21.5	3.7	48.5	16.5	2.9	3.4	
Equus sp.	phalanx 1	LPZ-17F	0.1	-19.9	5.5	48.8	16.5	3.0	3.4	Collagen yield too low; excluded
Equus sp.	ulna	LPZ-23F	5.6	-18.8	6.6	58.8	21.4	2.7	3.2	
Equus sp.	femur	LPZ-42F	0.0	-20.9	7.7	44.5	14.8	3.0	3.5	Collagen yield too low; excluded
Lepus sp.	innominate	LPZ-32F	3.6	-20.5	5.8	45.2	16.2	2.8	3.3	

Lepus sp.	mandible	LPZ-34F	2.0	-22.6	2.9	43.4	14.5	3.0	3.5	
Lepus sp.	metatarsal	LPZ-36F	3.8	-22.4	2.7	45.0	15.6	2.9	3.4	
Martes zibellina	innominate	LPZ-08F	0.1	-21.5	3.7	51.3	18.0	2.9	3.3	
Martes zibellina	tibia	LPZ-14F	3.0	-21.3	4.9	44.7	15.6	2.9	3.3	
Martes zibellina	tibia	LPZ-27F	3.1	-19.6	8.3	43.8	15.1	2.9	3.4	
Moschus moschiferus	maxilla	LPZ-15F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Ovis/Caprinus	ulna	LPZ-04F	2.3	-22.2	6.1	44.9	15.9	2.8	3.3	
Ovis/Caprinus	tibia	LPZ-30F	3.6	-20.9	5.5	46.0	16.6	2.8	3.2	
Sus scrofa	cranial fragments	LPZ-02F	2.4	-18.4	8.2	45.2	16.0	2.8	3.3	
Sus scrofa	atlas	LPZ-05F	4.3	-19.6	5.7	48.7	15.8	3.1	3.6	
Sus scrofa	radius	LPZ-18F	5.6	-19.9	5.5	48.8	16.5	3.0	3.4	
Sus scrofa	ulna	LPZ-19F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Sus scrofa	occipital	LPZ-24F	2.6	-21.6	5.4	43.7	14.8	3.0	3.4	
Sus scrofa	occipital	LPZ-25F	2.5	-22.1	5.5	49.6	16.6	3.0	3.5	
Sus scrofa	ulna	LPZ-31F	3.6	-21.3	5.6	45.0	15.3	2.9	3.4	

Sus scrofa	tibia	LPZ-33F	4.0	-21.2	5.9	45.0	15.6	2.9	3.4	
Vulpes sp.	scapula	LPZ-07F	4.1	-19.6	7.8	45.0	15.8	2.8	3.3	
Vulpes sp.	mandible	LPZ-41F	1.5	-20.5	8.5	45.2	15.7	2.9	3.4	
Hemibarbus sp.	ribs	LSH-01F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Silurus asotus	ribs	LSH-02F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Carassius gibelo	ribs	LSH-03F	3.9	-26.4	14.0	45.9	16.7	2.7	3.2	
Pseudaspius leptocephalus	ribs	LSH-04F	6.3	-21.7	13.5	46.0	17.4	2.6	3.1	
Leuciscus waleckii	ribs	LSH-05F	1.8	-22.1	12.6	45.1	16.7	2.7	3.1	
Tachysurus fulvidraco	ribs	LSH-06F	3.4	-22.1	13.8	45.1	16.7	2.7	3.1	
Cyprinus carpio	ribs	LSH-07F	1.8	-25.0	5.6	46.0	16.8	2.7	3.2	

Boisman II

Taxon	Element (side if noted)	Lab ID	Collagen Yield (%)	δ13C (‰)	δ15N (‰)	C content (%)	N content (%)	C/N Mass	C/N Atomic	Notes
Anatidae	coracoid	LBM-36F	1.5	-17.5	11.9	40.8	13.3	3.1	3.6	
Anatidae	coracoid	LBM-38F	1.5	-24.0	15.2	43.1	12.9	3.3	3.9	C/N atomic >3.6; excluded
Anatidae	humerus	LBM-39F	1.5	-19.7	7.9	45.8	15.9	2.9	3.4	
Anatidae	humerus	LBM-41F	2.6	-14.5	18.1	46.7	16.9	2.8	3.2	
Anatidae	femur, distal and diaphysis	LBM-42F	1.9	-18.5	6.7	46.5	16.3	2.9	3.3	
Anatidae	ulna	LBM-43F	3.8	-18.9	6.4	47.5	16.6	2.9	3.3	
Aves	humerus	LBM-40F	0.3	-24.6	7.2	43.3	12.3	3.5	4.1	C/N atomic >3.6; excluded
Aves	humerus	LBM-44F	1.2	-22.8	8.5	45.7	15.5	3.0	3.4	
Canis lupus familiaris	mandible	LBM-65F	1.2	-16.2	14.7	39.0	14.3	2.7	3.1	
Canis lupus familiaris	mandible	LBM-66F	1.1	-14.9	Inst. Error	42.7	Inst. Error	/	/	Instrument error; excluded
Canis lupus familiaris	mandible	LBM-67F	1.0	-14.5	14.9	44.0	14.2	3.1	3.6	
Canis lupus familiaris	mandible	LBM-68F	0.2	-16.9	14.8	43.0	12.1	3.6	4.1	C/N atomic >3.6; excluded
Canis lupus familiaris	mandible	LBM-69F	1.0	-14.5	15.0	41.6	14.2	2.9	3.4	

Canis lupus familiaris	mandible	LBM-70F	1.0	-14.7	14.3	41.7	13.7	3.1	3.6	
Canis lupus familiaris	mandible	LBM-71F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Canis lupus familiaris	mandible	LBM-72F	1.9	-17.4	15.7	41.9	12.2	3.4	4.0	C/N atomic >3.6; excluded
Canis lupus familiaris	mandible	LBM-73F	0.4	-18.5	14.0	41.2	10.8	3.8	4.4	C/N atomic >3.6; excluded
Canis lupus familiaris	mandible	LBM-74F	1.0	-16.7	14.5	38.7	14.0	2.8	3.2	
Canis lupus familiaris	mandible	LBM-75F	1.2	-15.8	15.9	42.6	14.2	3.0	3.5	
Canis lupus familiaris	mandible	LBM-76F	1.5	-15.7	18.1	43.3	13.6	3.1	3.7	C/N atomic >3.6; excluded
Canis lupus familiaris	mandible	LBM-77F	2.1	-14.3	17.7	42.8	13.6	3.1	3.6	C/N atomic >3.6; excluded
Canis lupus familiaris	mandible	LBM-78F	1.9	-18.3	14.6	43.1	13.6	3.2	3.7	C/N atomic >3.6; excluded
Capreolus capreolus	calcaneus	LBM-08F	2.5	-23.5	4.2	46.0	15.5	3.0	3.5	
Capreolus capreolus	calcaneus	LBM-09F	1.2	-24.1	4.9	42.6	13.2	3.2	3.8	C/N atomic >3.6; excluded
Capreolus capreolus	calcaneus	LBM-10F	1.7	-23.2	5.1	37.5	12.1	3.1	3.6	C/N atomic >3.6; excluded
Capreolus capreolus	astragalus	LBM-11F	0.9	-22.6	3.9	45.9	16.3	2.8	3.3	
Capreolus capreolus	mandible with teeth	LBM-12F	2.0	-22.5	4.0	46.8	16.2	2.9	3.4	
Capreolus capreolus	mandible with teeth	LBM-13F	0.1	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded

Cervidae	calcaneus	LBM-15F	1.8	-23.2	2.9	46.2	15.6	3.0	3.5	
Cervidae	astragalus	LBM-16F	2.0	-23.6	4.2	38.2	12.3	3.1	3.6	C/N atomic >3.6; excluded
Cervus elaphus	distal phalanx 4	LBM-01F	2.2	-22.0	4.9	47.1	16.8	2.8	3.3	
Cervus elaphus	magnum	LBM-02F	1.0	-22.1	4.1	45.2	16.1	2.8	3.3	
Cervus elaphus	distal phalanx 4	LBM-03F	1.0	-23.3	4.1	47.7	16.1	3.0	3.5	
Cervus elaphus	tibia	LBM-04F	2.0	-21.7	4.5	45.6	15.9	2.9	3.3	
Cervus elaphus	tibia	LBM-05F	1.7	-22.5	4.3	45.2	15.5	2.9	3.4	
Cervus elaphus	distal phalanx 4	LBM-06F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Cervus elaphus	astragalus	LBM-07F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Cervus nippon	scapula, fragment (area of glenoid fossa)	LBM-17F	1.0	-22.2	3.1	46.5	16.1	2.9	3.4	
Cervus nippon	vertebral body (fragment)	LBM-58F	/	/	/	/	/	/	/	Sample lost
Eumetopias jubatus	astragalus	LBM-25F	3.1	-14.4	17.9	46.1	16.7	2.8	3.2	
Eumetopias jubatus	metapodial	LBM-26F	1.0	-18.4	16.6	39.4	11.3	3.5	4.1	C/N atomic >3.6; excluded
Eumetopias jubatus	metapodial	LBM-27F	1.4	-15.3	18.3	39.3	13.1	2.0	2.3	
Eumetopias jubatus	metapodial	LBM-28F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded

Eumetopias jubatus	metapodial	LBM-29F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Eumetopias jubatus	calcaneus	LBM-31F	1.1	-14.6	17.4	41.7	14.0	3.0	3.5	
Gadidae	vertebrae, operculum	LBM-47F	1.5	-16.3	10.2	43.5	14.2	3.1	3.6	
Gadidae	vertebrae	LBM-48F	0.2	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Gadidae	vertebra, operculum (fragment)	LBM-49F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Gadidae	vertebrae, operculum	LBM-50F	2.2	-13.3	11.0	41.7	13.2	3.2	3.7	C/N atomic >3.6; excluded
Gadidae	vertebrae	LBM-51F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Gadidae	maxilla	LBM-52F	1.1	-15.4	11.6	40.1	13.2	3.0	3.5	
Gadidae	vertebra	LBM-63F	1.5	-14.9	8.7	43.3	14.0	3.1	3.6	
Homo sapiens	femur	LBM-01H	3.1	-17.5	16.7	43.9	13.2	3.3	3.9	C/N atomic >3.6; excluded
Homo sapiens	femur	LBM-02H	1.0	-16.9	15.5	40.7	13.4	3.0	3.6	
Homo sapiens	femur	LBM-03H	1.1	-17.7	16.4	41.8	13.6	3.1	3.6	
Homo sapiens	femur	LBM-04H	6.8	-15.3	17.5	46.0	16.5	2.8	3.2	
Homo sapiens	femur	LBM-05H	2.3	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Homo sapiens	femur	LBM-06H	2.8	-17.1	15.9	43.1	13.1	3.3	3.8	C/N atomic >3.6; excluded

Homo sapiens	clavicle	LBM-07H	1.5	-15.7	18.2	45.2	16.8	2.7	3.1	
Homo sapiens	femur	LBM-08H	2.9	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Homo sapiens	femur	LBM-09H	5.0	-17.2	17.1	40.4	12.3	3.3	3.8	C/N atomic >3.6; excluded
Homo sapiens	femur	LBM-10H	1.4	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Homo sapiens	femur	LBM-11H	2.4	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Homo sapiens	femur	LBM-12H	2.4	-17.3	17.1	42.4	13.1	3.2	3.8	C/N atomic >3.6; excluded
Homo sapiens	femur	LBM-13H	0.7	/	/	/	/	/	/	Collagen yield too low; excluded
Homo sapiens	femur	LBM-14H	9.9	-13.9	15.9	43.5	14.6	3.0	3.5	
Lepus sp.	innominate	LBM-57F	1.6	-24.3	2.1	42.8	12.7	3.4	3.9	C/N atomic >3.6; excluded
Lutrinae	humerus	LBM-23F	0.8	-21.4	6.9	60.2	11.9	5.0	5.8	C/N atomic >3.6; excluded
Meles meles	humerus	LBM-24F	2.3	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Meles meles	mandible	LBM-33F	1.0	-18.3	11.7	42.9	13.7	3.1	3.7	C/N atomic >3.6; excluded
Meles meles	mandible	LBM-34F	2.2	-19.5	7.3	46.6	16.7	2.8	3.3	
Moschus moschiferus	metapodial	LBM-14F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Nyctereutes procyonoides	scapula	LBM-60F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded

Nyctereutes procyonoides	maxilla	LBM-61F	1.0	-20.7	10.1	43.3	14.3	3.0	3.5	
Panthera sp.	humerus	LBM-54F	2.2	-21.0	8.0	44.7	15.6	2.9	3.3	
Perciformes	premaxilla	LBM-53F	1.0	-15.1	9.5	44.2	15.1	2.9	3.4	
Perciformes	vertebrae	LBM-62F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Phalacrocorax sp.	femur	LBM-35F	1.2	-17.2	15.0	42.6	13.3	3.2	3.7	C/N atomic >3.6; excluded
Phalacrocorax sp.	humerus	LBM-37F	2.0	-17.2	14.9	42.3	13.5	3.1	3.7	C/N atomic >3.6; excluded
Phalacrocorax sp.	coracoid	LBM-45F	1.0	-16.6	15.3	Inst. error	Inst. error	/	/	Excluded
Phalacrocorax sp.	maxilla, fragment	LBM-46F	1.3	-14.4	15.4	46.0	16.1	2.9	3.3	
Phoca hispida	auditory bulla	LBM-59F	1.9	-17.1	17.8	40.8	11.6	3.5	4.1	C/N atomic >3.6; excluded
Phoca larga	ulna	LBM-30F	1.0	-17.6	16.7	41.0	13.4	3.1	3.6	
Phoca sp.	femur	LBM-56F	1.4	-15.7	16.5	46.6	16.2	2.9	3.4	
Salmonidae	vertebrae	LBM-55F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Sebastes sp.	vertebra	LBM-64F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Sus scrofa	intermediate phalanx III (hind)	LBM-18F	1.0	-21.2	4.4	45.0	15.1	3.0	3.5	
Sus scrofa	intermediate phalanx IV (front)	LBM-19F	1.4	-21.0	5.6	45.5	15.9	2.9	3.3	

Sus scrofa	metapodial	LBM-20F	1.4	-21.4	4.2	46.1	16.2	2.9	3.3	
Sus scrofa	mandible	LBM-21F	2.4	-21.4	5.1	46.3	16.0	2.9	3.4	
Sus scrofa	mandible	LBM-22F	1.5	-20.9	5.2	44.0	14.2	3.1	3.6	C/N atomic >3.6; excluded
Ursidae	radius	LBM-32F	/	/	/	/	/	/		Inadvertently excluded

Boiarin VI

Taxon	Element (side if noted)	Lab ID	Collagen Yield (%)	δ13C (‰)	δ15N (‰)	C content (%)	N content (%)	C/N Mass	C/N Atomic	Notes
Capreolus capreolus	mandible	LBY-01F	1.0	-23.2	5.2	43.8	15.3	2.9	3.3	
Capreolus capreolus	calcaneus	LBY-02F	1.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Capreolus capreolus	femur	LBY-03F	0.5	-22.8	5.4	45.1	16.0	2.8	3.3	collagen yield >1%; excluded
Cervus elaphus	metapodial	LBY-04F	0.3	-23.9	5.8	36.7	10.7	3.4	4.0	C/N atomic >3.6; excluded
Cervus elaphus	distal phalanx IV	LBY-05F	2.3	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Cervus elaphus	tibia	LBY-06F	0.1	-22.5	5.4	45.3	16.4	2.8	3.2	collagen yield >1%; excluded
Cervus elaphus	tibia	LBY-07F	2.4	-22.8	6.4	43.5	14.1	3.1	3.6	
Cervus elaphus	calcaneus	LBY-08F	0.0	-21.6	6.2	42.6	14.1	3.0	3.5	collagen yield >1%; excluded
Lutra lutra	mandible	LBY-17F	1.5	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Meles meles	mandible	LBY-16F	2.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Phoca sp.	radius	LBY-18F	0.5	-15.7	18.1	42.8	14.8	2.9	3.4	collagen yield >1%; excluded
Phoca sp.	mandible	LBY-19F	2.0	Instr. Error	Instr. Error	Instr. Error	Instr. Error	/	/	Instrument error; excluded
Pinnipedae	metapodial	LBY-20F	0.4	-18.7	17.6	40.0	11.0	3.1	3.6	collagen yield >1%; excluded

Sus scrofa	scapula	LBY-09F	0.3	-21.3	6.5	44.5	15.9	2.8	3.3	collagen yield >1%; excluded
Sus scrofa	maxilla	LBY-10F	0.3	-22.0	6.5	43.2	14.0	3.1	3.6	C/N atomic >3.6; excluded
Sus scrofa	maxilla	LBY-11F	1.4	-21.5	5.4	45.7	16.2	2.8	3.3	
Sus scrofa	astragalus	LBY-12F	0.4	-21.6	6.8	42.8	14.8	2.9	3.4	
Sus scrofa	astragalus	LBY-13F	1.4	-22.6	5.9	43.5	14.1	3.1	3.6	C/N atomic >3.6; excluded
Sus scrofa	tibia	LBY-14F	0.7	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Vulpes vulpes	mandible	LBY-15F	0.2	-20.7	9.6	43.0	14.4	3.0	3.5	collagen yield >1%; excluded

Russkiy I

Taxon	**Element (side if noted)**	**Lab ID**	**Collagen Yield (%)**	**δ13C (‰)**	**δ15N (‰)**	**C content (%)**	**N content (%)**	**C/N Mass**	**C/N Atomic**	**Notes**
Accipitridae	coracoid	LRU-08F	1.9	-16.7	16.0	43.8	13.9	3.2	3.7	C/N atomic >3.6; excluded
Anatidae	humerus	LRU-07F	1.0	-23.2	8.0	42.3	12.5	3.4	3.9	C/N atomic >3.6; excluded
Anatidae	ulna	LRU-09F	2.3	-24.7	12.0	43.0	13.7	3.1	3.7	C/N atomic >3.6; excluded
Anatidae	ulna	LRU-10F	0.3	-21.7	9.3	43.7	12.0	3.7	4.3	C/N atomic >3.6; excluded
Bos sp.	calcaneus	LRU-18F	1.0	-23.8	6.3	43.1	13.7	3.2	3.7	C/N atomic >3.6; excluded
Callorhinus ursinus	mandible	LRU-20F	2.3	-14.0	17.2	43.9	15.6	2.8	3.3	
Canis lupus familiaris	mandible	LRU-25F	1.3	-15.2	15.5	43.8	14.1	3.1	3.6	C/N atomic >3.6; excluded
Canis lupus familiaris	innominate and calcaneus	LRU-26F	1.7	-15.3	15.1	41.8	13.3	3.2	3.7	C/N atomic >3.6; excluded
Canis lupus familiaris	innominate	LRU-27F	1.2	-14.1	15.4	43.2	14.7	2.9	3.4	
Canis lupus familiaris	ulna	LRU-28F	1.7	-14.5	15.7	46.1	16.7	2.8	3.2	
Canis lupus familiaris	ulna	LRU-29F	2.1	-15.0	14.7	45.1	15.9	2.8	3.3	
Canis lupus familiaris	humerus	LRU-30F	1.6	-14.9	15.7	45.7	16.5	2.8	3.2	
Canis lupus familiaris	maxilla	LRU-31F	0.6	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded

Canis lupus familiaris	ulna	LRU-32F	2.0	-14.5	15.7	45.4	16.2	2.8	3.3	
Canis lupus familiaris	mandible	LRU-33F	1.4	-14.6	15.0	46.0	16.7	2.8	3.2	
Canis lupus familiaris	tibia	LRU-34F	2.8	-15.2	15.6	46.6	16.8	2.8	3.2	
Canis lupus familiaris	humerus	LRU-35F	1.7	-16.1	15.0	42.8	13.7	3.1	3.6	C/N atomic >3.6; excluded
Canis lupus familiaris	tooth (unid)	LRU-36F	1.1	-15.3	17.8	45.3	16.1	2.8	3.3	
Canis lupus familiaris	tooth (unid)	LRU-37F	2.4	-13.2	16.7	45.5	16.7	2.7	3.2	
Canis lupus familiaris	tooth (unid)	LRU-38F	0.8	-14.8	17.4	45.6	16.4	2.8	3.2	
Canis lupus familiaris	tooth (unid)	LRU-39F	1.7	-14.7	18.1	45.5	16.2	2.8	3.3	
Capreolus capreolus	astragalus	LRU-14F	10.0	-21.6	6.5	43.9	13.8	3.2	3.7	C/N atomic >3.6; excluded
Capreolus capreolus	tibia	LRU-15F	0.0	/	/	/	/	/	/	Sample lost
Capreolus capreolus	calcaneus	LRU-16F	3.8	-20.5	6.0	44.3	15.5	2.9	3.3	
Cervidae	calcaneus	LRU-17F	0.0	/	/	/	/	/	/	Sample lost
Cervus elaphus	tibia	LRU-12F	2.6	-22.3	2.9	39.5	13.8	2.9	3.3	
Cervus elaphus	tibia	LRU-13F	4.7	-21.2	6.8	44.0	15.8	2.8	3.2	
Gadidae	vertebrae (n=3)	LRU-03F	1.0	-15.8	8.6	43.4	14.0	2.8	3.2	

Phalacrocorax sp.	carpometacarpus	LRU-06F	1.1	-13.9	15.2	40.8	15.1	2.7	3.2	
Phoca sp.	femur	LRU-19F	3.8	-14.8	17.1	43.9	15.4	2.9	3.3	
Pleuronectidae	vertebrae	LRU-04F	0.1	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Pleuronectidae	vertebrae	LRU-05F	1.8	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Scombridae/Thunnini	vertebra	LRU-02F	1.1	-15.9	13.2	43.3	12.3	3.5	4.1	C/N atomic >3.6; excluded
Selachimorpha	centrum	LRU-01F	1.2	-13.7	13.3	2.0	14.3	0.1	0.2	C/N atomic >3.6; excluded
Sus scrofa	mandible	LRU-21F	1.9	-21.6	5.1	43.9	13.4	3.3	3.8	C/N atomic >3.6; excluded
Sus scrofa	mandible	LRU-22F	1.5	-21.5	4.2	44.2	14.5	3.0	3.5	
Sus scrofa	astragalus	LRU-23F	3.7	-20.4	6.1	44.3	15.3	2.9	3.4	
Sus scrofa	ilium	LRU-24F	4.0	-21.3	4.2	43.9	15.5	2.8	3.3	
Vulpes vulpes	mandible	LRU-11F	4.0	-14.6	14.2	43.4	15.3	2.8	3.3	

Pospelovo I

Taxon	Element (side if noted)	Lab ID	Collagen Yield (%)	δ13C (‰)	δ15N (‰)	C content (%)	N content (%)	C/N Mass	C/N Atomic	Notes
Actinopterygii to ID	dentary	LPL-01F	1.6	-19.0	14.3	44.4	15.2	2.9	3.4	
Anatidae	humerus	LPL-02F	2.0	-23.7	9.9	44.2	14.8	3.0	3.5	
Anatidae	tibiotarsus	LPL-03F	3.4	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Canis lupus familiaris	humerus and maxilla	LPL-14F	1.5	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Canis lupus familiaris	tibia	LPL-15F	0.8	-16.2	15.0	42.2	13.0	3.2	3.8	C/N atomic >3.6; excluded
Canis lupus familiaris	tibia	LPL-16F	0.8	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Canis lupus familiaris	humerus	LPL-17F	2.7	-15.0	15.4	42.9	14.3	3.0	3.5	
Canis lupus familiaris	humerus	LPL-18F	1.7	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Canis lupus familiaris	humerus	LPL-19F	1.4	-15.9	15.4	43.1	14.1	3.1	3.6	
Canis lupus familiaris	maxilla	LPL-20F	1.2	-16.3	16.0	43.5	12.9	3.4	3.9	C/N atomic >3.6; excluded
Canis lupus familiaris	mandible	LPL-21F	1.9	16.9	16.0	42.6	11.5	3.7	4.3	C/N atomic >3.6; excluded
Canis lupus familiaris	humerus	LPL-22F	2.0	-14.5	15.7	43.5	15.0	2.9	3.4	
Canis lupus familiaris	mandible	LPL-23F	1.4	-15.1	15.1	42.9	14.4	3.0	3.5	

Canis lupus familiaris	tibia	LPL-24F	3.1	-15.3	15.8	42.5	13.7	3.1	3.6	C/N atomic >3.6; excluded
Canis lupus familiaris	tibia	LPL-25F	1.2	-15.9	15.9	43.3	14.0	3.1	3.6	C/N atomic >3.6; excluded
Canis lupus familiaris	tibia	LPL-26F	1.3	-15.0	15.2	43.7	15.2	2.9	3.4	
Canis lupus familiaris	maxilla	LPL-27F	1.9	-17.8	16.3	41.4	12.0	3.5	4.0	C/N atomic >3.6; excluded
Canis lupus familiaris	ulna	LPL-28F	5.6	-18.0	15.9	40.6	11.1	3.6	4.3	C/N atomic >3.6; excluded
Canis lupus familiaris	femur	LPL-29F	0.9	-15.1	15.9	42.0	13.5	3.1	3.6	C/N atomic >3.6; excluded
Canis lupus familiaris	tibia	LPL-30F	1.6	-14.1	15.2	43.2	14.8	2.9	3.4	
Canis lupus familiaris	maxilla	LPL-31F	1.2	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Canis lupus familiaris	mandible	LPL-32F	3.1	-14.6	15.0	43.4	14.5	3.0	3.5	
Canis lupus familiaris	mandible	LPL-33F	0.3	-13.0	16.2	43.7	14.8	3.0	3.4	
Canis lupus familiaris	tibia	LPL-34F	2.2	-14.6	15.0	43.4	14.5	3.0	3.5	
Canis lupus familiaris	tooth	LPL-35F	2.3	-13.0	16.2	43.7	14.8	3.0	3.4	
Capreolus capreolus	metapodial	LPL-04F	2.6	-20.6	5.3	44.1	14.3	3.1	3.6	C/N atomic >3.6; excluded
Lepus sp.	innominate	LPL-13F	1.0	-14.6	16.2	43.4	15.0	2.9	3.4	
Phoca larga	astragalus	LPL-09F	0.8	-17.7	15.9	46.8	13.8	3.4	4.0	C/N atomic >3.6; excluded

Phoca sp.	humerus	LPL-10F	2.7	-16.1	17.3	45.8	15.8	2.9	3.4	C/N atomic >3.6; excluded
Phoca sp.	radius	LPL-11F	0.3	-17.7	16.4	43.7	12.3	3.6	4.2	C/N atomic >3.6; excluded
Pinnipedae	metapodial	LPL-12F	2.0	-19.1	9.0	44.0	14.6	3.0	3.5	
Sus scrofa	astragalus	LPL-05F	2.0	-21.8	5.7	42.0	12.7	3.3	3.9	C/N atomic >3.6; excluded
Sus scrofa	mandible	LPL-06F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Sus scrofa	ulna	LPL-07F	1.0	-19.0	11.9	45.0	15.4	2.9	3.4	
Sus scrofa	atlas	LPL-08F	1.4	-17.6	17.7	43.3	14.0	3.1	3.6	C/N atomic >3.6; excluded

Nazimova I

Taxon	Element (side if noted)	Lab ID	Collagen Yield (%)	δ13C (‰)	δ15N (‰)	C content (%)	N content (%)	C/N Mass	C/N Atomic	Notes
Anatidae	scapula	LNZ-01F	3.6	-23.1	9.9	43.5	12.5	3.5	4.1	C/N atomic >3.6; excluded
Anatidae	coracoid	LNZ-02F	1.2	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Anatidae	ulna	LNZ-03F	5.7	-23.5	10.2	60.4	15.0	4.0	4.7	C/N atomic >3.6; excluded
Anatidae	tarsometatarsus	LNZ-04F	1.0	-16.6	18.1	43.6	12.5	3.5	4.1	C/N atomic >3.6; excluded
Eumetopias jubatus	phalanx	LNZ-05F	0.6	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Pinnipedia	phalanx	LNZ-06F	0.3	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Ovis aries	calcaneus	LNZ-07F	0.0	Inst. Error	Inst. Error	Inst. Error	Inst. Error	/	/	Instrument error; excluded
Cervidae	calcaneus	LNZ-08F	15.4	-19.5	6.3	40.9	13.5	3.0	3.5	
Cervidae	ulna, proximal	LNZ-09F	0.0	/	/	/	/	/	/	Sample lost
Sus scrofa	distal phalanx IV	LNZ-10F	5.6	-20.9	4.3	44.3	15.0	3.0	3.4	
Sus scrofa	astragalus	LNZ-11F	1.0	-21.7	4.9	42.9	12.0	3.6	4.2	C/N atomic >3.6; excluded
Sus scrofa	mandible	LNZ-12F	1.3	-24.3	4.7	35.9	9.9	3.6	4.2	C/N atomic >3.6; excluded
Sus scrofa	astragalus	LNZ-13F	0.4	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded

Canis lupus familiaris	mandible	LNZ-14F	5.8	Inst. Error	Inst. Error	Inst. Error	Inst. Error	/	/	Instrument error; excluded
Canis lupus familiaris	humerus	LNZ-15F	5.8	Inst. Error	Inst. Error	Inst. Error	Inst. Error	/	/	Instrument error; excluded
Canis lupus familiaris	radius	LNZ-16F	10.8	-16.7	14.2	77.4	11.8	6.6	7.7	C/N atomic >3.6; excluded
Canis lupus familiaris	calcaneus	LNZ-17F	6.1	-15.9	14.9	39.7	13.1	3.0	3.5	
Canis lupus familiaris	tooth (unid)	LNZ-18F	2.3	-14.3	16.4	42.4	14.6	2.9	3.4	

Cherniatino II

Taxon	Element (side if noted)	Lab ID	Collagen Yield (%)	δ13C (‰)	δ15N (‰)	C content (%)	N content (%)	C/N Mass	C/N Atomic	Notes
Actinopterygii	gillraker	LCH-02F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Actinopterygii	vertebra	LCH-03F	2.0	-20.1	7.6	40.7	12.2	3.3	3.9	C/N atomic >3.6; excluded
Actinopterygii	gillraker	LCH-10F	1.3	-16.7	9.8	42.3	15.1	2.8	3.3	
Anatidae	humerus	LCH-04F	1.3	-19.9	4.3	43.3	13.7	3.2	3.7	C/N atomic >3.6; excluded
Aves	carpometacarpus	LCH-05F	0.6	-18.8	6.0	41.2	12.0	3.4	4.0	C/N atomic >3.6; excluded
Aves	carpometacarpus	LCH-06F	0.1	-18.2	5.9	26.2	7.9	3.3	3.9	C/N atomic >3.6; excluded
Aves	carpometacarpus	LCH-07F	0.7	-18.6	6.0	43.9	13.4	3.3	3.8	C/N atomic >3.6; excluded
Bos sp.	radius	LCH-29F	7.5	-15.6	6.1	44.2	15.7	2.8	3.3	
Bos sp.	radius	LCH-30F	1.4	-16.6	6.1	44.2	15.7	2.8	3.3	
Bos sp.	humerus, distal (fragments)	LCH-31F	1.3	-16.4	6.9	40.8	13.9	2.9	3.4	
Canis lupus familiaris	mandible	LCH-44F	2.7	-10.5	9.7	43.4	14.9	2.9	3.4	
Canis lupus familiaris	atlas	LCH-45F	3.0	-11.7	9.6	43.8	15.0	2.9	3.4	
Canis lupus familiaris	mandible	LCH-46F	3.8	-12.2	9.0	43.7	14.7	3.0	3.5	

Canis lupus familiaris	mandible	LCH-47F	2.9	-12.5	10.8	43.6	15.3	2.9	3.3	
Canis lupus familiaris	zygomatic	LCH-48F	2.4	-12.2	9.3	43.3	15.1	2.9	3.3	
Canis lupus familiaris	cranium fragment (unid)	LCH-49F	0.5	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Canis lupus familiaris	mandible	LCH-50F	5.2	-11.6	11.3	44.9	15.4	2.9	3.4	
Canis lupus familiaris	occipital	LCH-51F	1.1	-13.5	8.7	42.4	13.7	3.1	3.6	C/N atomic >3.6; excluded
Canis lupus familiaris	mandible	LCH-52F	2.0	-12.4	9.5	43.1	13.8	3.1	3.6	C/N atomic >3.6; excluded
Canis lupus familiaris	cranium fragments (unid)	LCH-53F	5.1	-9.9	9.5	44.5	15.7	2.8	3.3	
Canis lupus familiaris	ulna	LCH-54F	2.7	-9.7	10.7	44.4	15.6	2.8	3.3	
Canis lupus familiaris	mandible	LCH-55F	4.1	-16.4	10.9	44.6	15.1	3.0	3.4	
Canis lupus familiaris	mandible	LCH-56F	3.7	-12.2	10.6	44.5	15.5	2.9	3.4	
Canis lupus familiaris	mandible	LCH-57F	3.3	-10.8	10.6	44.2	15.4	2.9	3.4	
Canis lupus familiaris	mandible	LCH-58F	0.9	-12.9	8.3	42.3	13.5	3.1	3.7	C/N atomic >3.6; excluded
Canis lupus familiaris	mandible	LCH-59F	3.3	-12.6	9.2	42.9	14.6	2.9	3.4	
Canis lupus familiaris	mandible	LCH-60F	2.4	-12.8	10.1	44.6	14.3	3.1	3.6	C/N atomic >3.6; excluded
Canis lupus familiaris	premaxilla	LCH-61F	1.7	-12.4	8.2	43.8	14.2	3.1	3.6	

Canis lupus familiaris	mandible	LCH-62F	2.5	-11.5	9.7	44.5	15.7	2.8	3.3	
Canis lupus familiaris	mandible	LCH-63F	1.6	-12.1	10.0	44.0	14.7	3.0	3.5	
Canis lupus familiaris	mandible	LCH-64F	4.6	-10.4	9.4	44.2	15.8	2.8	3.3	
Canis lupus familiaris	mandible	LCH-65F	1.4	-12.3	9.7	44.5	15.6	2.9	3.3	
Canis lupus familiaris	mandible	LCH-66F	3.0	-12.2	9.8	44.5	15.4	2.9	3.4	
Capreolus capreolus	mandible	LCH-11F	2.7	-20.5	4.4	43.4	15.4	2.8	3.3	
Capreolus capreolus	mandible	LCH-12F	3.1	-22.9	3.9	40.9	12.2	3.3	3.9	C/N atomic >3.6; excluded
Capreolus capreolus	mandible	LCH-13F	2.8	-20.9	3.8	43.9	15.1	2.9	3.4	
Capreolus capreolus	mandible	LCH-14F	1.3	-20.9	4.8	43.7	15.5	2.8	3.3	
Capreolus capreolus	mandible	LCH-15F	1.5	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Capreolus capreolus	astragalus	LCH-17F	2.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Cervus elaphus	calcaneus	LCH-16F	1.6	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Cervus elaphus	distal phalanx IV	LCH-18F	0.7	1.2	5.6	42.4	14.1	/	/	Collagen yield <1%; excluded
cf. Cyprinidae	pharyngeal plate	LCH-01F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Chelonii/Testudines	innominate	LCH-43F	2.5	-12.7	11.5	44.1	15.2	2.9	3.4	

Equus caballus	innominate	LCH-32F	0.4	Inst. Error	Inst. Error	Inst. Error	Inst. Error	/	/	Instrument error; excluded
Equus caballus	phalanx 1	LCH-33F	1.0	-18.0	5.8	43.5	14.6	3.0	3.5	
Equus caballus	metapodial	LCH-34F	2.9	-21.1	3.6	43.3	14.3	3.0	3.5	
Equus caballus	distal phalanx 3	LCH-35F	0.2							Insufficient collagen in vial for analysis; excluded
Galliformes	tarsometatarsus (with spur)	LCH-08F	1.0	-16.3	7.4	44.8	15.6	2.9	3.3	
Galliformes	tarsometatarsus (with spur)	LCH-09F	1.0	-20.4	5.2	44.2	14.8	3.0	3.5	
Lepus sp.	mandible	LCH-36F	4.6	-19.2	2.4	44.7	15.4	2.9	3.4	
Lepus sp.	mandible	LCH-37F	2.4	-23.7	1.1	43.8	14.5	3.0	3.5	
Lepus sp.	innominate	LCH-38F	2.7	-14.7	9.1	43.7	14.5	3.0	3.5	
Ovis/Capra sp.	astragalus	LCH-19F	4.9	23.3	4.7	39.2	11.7	3.3	3.9	C/N atomic >3.6; excluded
Sciuridae	femur	LCH-39F	0.6	-13.1	8.4	43.6	13.8	3.2	3.7	C/N atomic >3.6; excluded
Sciuridae	femur	LCH-40F	5.1	-17.6	7.3	43.9	14.8	3.0	3.5	
Sciuridae	femur	LCH-41F	2.5	-15.6	9.1	44.1	15.5	2.8	3.3	
Serpentes	vertebrae	LCH-42F	4.5	-19.3	8.7	43.7	15.5	2.8	3.3	
Sus scrofa	mandible	LCH-20F	0.1	/	/	/	/	/	/	Collagen yield <1%; excluded

Sus scrofa	mandible	LCH-21F	2.0	-19.9	3.9	38.0	12.9	3.0	3.4	
Sus scrofa	mandible	LCH-22F	1.6	-20.7	5.1	41.1	13.4	3.1	3.6	
Sus scrofa	mandible	LCH-23F	1.3	-20.3	4.4	43.9	14.3	3.1	3.6	
Sus scrofa	mandible	LCH-24F	2.1	-21.1	4.1	43.1	14.0	3.1	3.6	
Sus scrofa	mandible	LCH-25F	2.5	-21.1	4.6	44.2	15.0	2.9	3.4	
Sus scrofa	mandible	LCH-26F	1.3	-20.3	3.4	42.3	14.5	2.9	3.4	
Sus scrofa	ulna	LCH-27F	0.0	/	/	/	/	/	/	Insufficient collagen in vial for analysis; excluded
Sus scrofa	astragalus	LCH-28F	1.6	-20.2	4.7	44.2	14.3	3.1	3.6	