Seal or No Seal? A Bayesian (FRUITS) Modeling of Hunter-gatherer Diet in the Little Sea Micro-Region of Lake Baikal.

by

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Abstract

The non-specific nature of stable isotope analysis limits interpretive assessments of diet to relative contributions of food sources. In an attempt to address this issue, scholars have focused on mixing models as a potential avenue to provide quantifiable measurements of dietary source contribution. FRUITS is currently a leading model on the market for the application of dietary questions in an archaeological context. The ability of FRUITS to consider non-isotopic priors is paramount to precise estimations in the field of archaeology. Previous work in the Baikal region of Russia has provided an excellent basis for more specific and targeted analyses such as this, which is primarily concerned with characterizing the diets of Early Bronze Age hunter-gatherers within the Little Sea micro-region. This analysis is guided by a set of four dietary hypotheses derived from the current state of literature in the Baikal region. Priors to constrain the model were created through assessment of physiological processes, ethnographic information, and zooarchaeological findings relevant to the subject. Results indicate that the Little Sea model provides estimations of the dietary contributions of the Game-Fish-Seal diet with moderate performance. As more GFS local individuals were rejected by the model than anticipated, further improvements to the parameters of the Little Sea model are evidently required. High plant and low fish contribution values to the overall diet contradict previous dietary conjectures. Game-Fish individuals responded as expected to the Little Sea model, as each individual was rejected or failed to produce results, indicating that they were not consuming Little Sea aquatic resources. Instead, the results suggest that the GF individuals were obtaining the aquatic element of their diet from elsewhere, likely from the Upper Lena micro-region. This suggests that the GFS and GF diet groups exploited foods originating from different ecological zones and ate variable amounts of similar resources despite their common burial location.

Preface

This thesis is an original work by Talisha Chaput. The Baikal Archaeological Project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "Holocene hunter-gatherers of Northeast Asia", No. Pro00021280, February 2, 2017. No part of this thesis has been previously published.

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Chapter 1: Introduction and Background

1.1 Introductory Remarks

The Baikal region, (Figure 1.1) located in Eastern Siberia, Russia, has been the subject of archaeological investigation since the 1850s. The work conducted here has been an invaluable resource for data on middle Holocene hunter-gatherer populations, especially given the presence of both stratified archaeological sites and formal cemeteries. The area became the focus of the Baikal-Hokkaido Archaeological Project through the partnership of local Russian archaeologists at Irkutsk Statw University, Irkutsk, Russia, and international researchers at the University of Alberta, Alberta, Canada in the early 1990s. The Baikal Archaeological Project (henceforth referred to as BAP) has over two decades of research that has focused on investigating population demography, migration, diet, health, subsistence strategies, and habitual activities of middle Holocene populations in the Cis-Baikal. The Baikal-Hokkaido Archaeological Project has continued to add to this wealth of information since 2011. BAP has focused on issues pertaining to the documentation of cultural and environmental phenomena, the identification of patterns and variability within and between cultural complexes; and, the application of theories that aim to explain these patterns and variability (Weber and Bettinger 2010). Another major objective of BAP is to gain a better understanding of past diet and dietary change, with stable isotope analyses playing an integral role since the mid-1990s (Katzenberg et al. 2012; Katzenberg and Weber 1999; Lam 1994; Weber et al. 2005; 2011; Weber, Link, and Katzenberg 2002).

While the reconstruction of diet of prehistoric individuals through stable isotope analysis provides substantial understanding to past ways of life, the non-specific nature of the data often limits analysis to relative assessments of diet and nutrition. This general description can cause over- or under-estimations of a resources place in individual or group diets, with no recourse to explore questions of dietary proportion or resource importance. This leads researchers to explore new techniques of data analysis to estimate the quantitative contributions of different food groups while accounting for the inherent uncertainty of data. This thesis will add to interdisciplinary research on the hunter-gatherers of the Cis-Baikal region conducted by BAP by using FRUITS modeling software to estimate the source contributions to the diet of Early Bronze Age (EBA) individuals from the Little Sea micro-region of Lake Baikal. The data used for this analysis include previously published carbon and nitrogen stable isotope values of faunal remains from the Little Sea and 30 humans from the cemetery Khuzhir-Nuge XIV (Katzenberg et al. 2012; Katzenberg, Goriunova, and Weber 2009; Weber, Link, and Katzenberg 2002; Weber et al. 2016a).

Chapter 1 provides an overview of the geography and middle Holocene culture-history of Cis-Baikal, as well as a review of the previous research conducted by BAP scholars. Chapter 2 reviews the literature on stable isotope analysis and Bayesian modeling software as a method for dietary reconstruction, as well as the limitations and prospects of said method. Chapter 3 reviews the methodology and materials used in this study and situates the data within the region's archaeological context. The research assumptions and hypotheses are also presented. Chapter 4 is an evaluation of the model's performance and the presentation of individual results, followed by the discussion of the results within the broader archaeological framework of the Cis-Baikal region in Chapter 5. Chapter 6 concludes the study with a summary of findings, a review of methods, and suggestions for future applications and research.

1.2 Geographic Context

The Baikal region is located approximately between 51°N and 58°N latitude and 99° and 112°E longitude in East Siberia, Russia (Atlas USSR 1984). Scholars distinguish between its two main areas the Cis-Baikal and the Trans-Baikal. The Cis-Baikal region includes four archaeological micro-regions:

the Southwest Baikal, the Angara, the Upper Lena, and the Little Sea micro-regions. The focus of this study is the Little Sea micro-region, which is located along the western shore of the center of Lake Baikal and includes Olkhon Island (Figure 1.1). The Trans-Baikal includes the eastern shore of Lake Baikal, the Selenga, and the Barguzin river valleys, along with their drainage basins and mountain ranges (Michael 1958; Weber 1995).

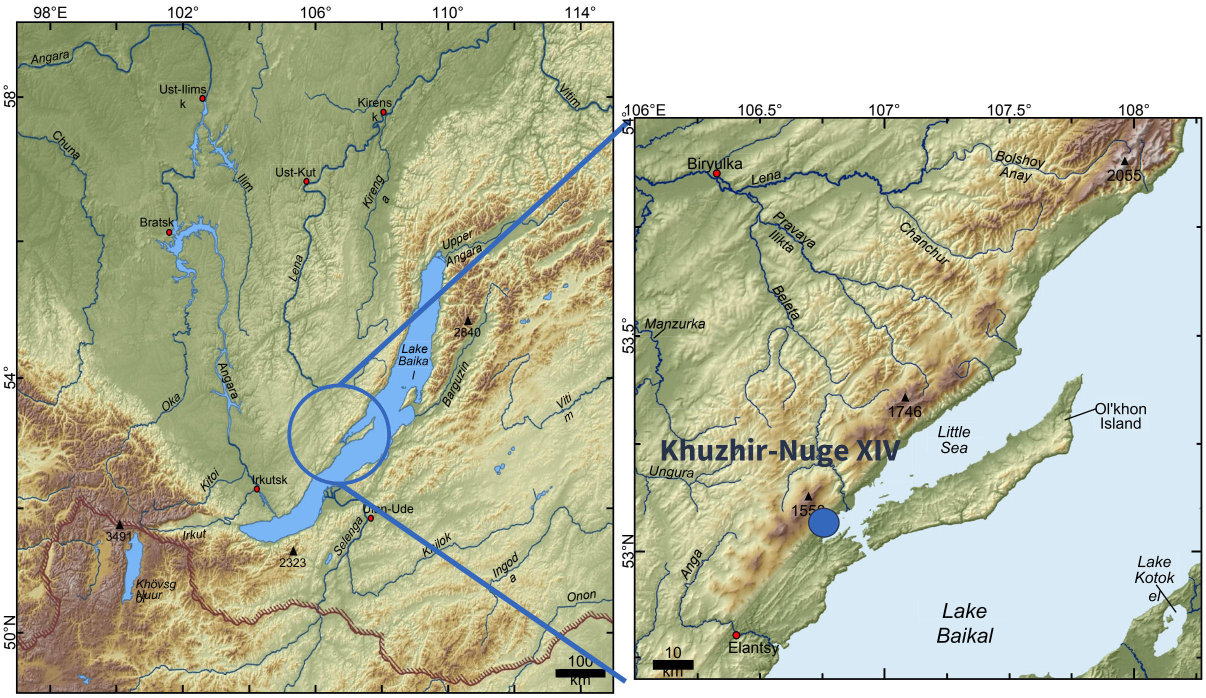


Figure 1.1 Map of Lake Baikal region, Russia, with inset map of the Little Sea micro-region with the location of Khuzhir-Nuge XIV shown.

At over 1,642m deep and 20–30 million years old, Lake Baikal is the oldest and deepest freshwater lake in the world (Karabanov et al. 2004). The lakes crescent shape extends approximately 636km long, and up to 80km wide, covering a total area of 31,500km^2 (Kozhov 1963, 5–7). The lake is bounded by a series of mountain ranges, including the Khamar-Daban range to the South, Ulan-Burgasy Range along the East coast— which changes into the Barguzinsky Range as it extends North— the Baikalskii Range to the northwest, and the Primorsky Range to the southwest (Kozhov 1963, 5–7). This mountain fence is interrupted by a number of rivers flowing into the lake such as those of the Upper Angara, Selenga, Barguzin, and Turka (Kozhov 1963, 5–7). During cold periods of the Pleistocene, the mountain ranges surrounding Lake Baikal were glaciated, and glacial tongues extended into the lake (Karabanov et al. 1998). As the glaciers receded, hilly plateaus, high ridges, valleys, and gorges were carved along mountain slopes to create a landscape rich in natural resources and fresh water (Weber et al. 2011).

The Baikal region is located within a southern taiga and transitional steppe-forest environment, producing dense boreal forest in the North, and open steppe-forest in the South (Khotinskii 1984; Kozhov 1963, 15–18). The vegetation is dominated by conifers and birch trees, in addition to shrubs, mosses, and steppe grasses. Today the climate is continental, featuring cold, long winters of up to five months, and dry two-month-long summers (Atlas USSR 1984; Weber, Link, and Katzenberg 2002). Average temperatures range from −26°C in January to 20°C in July (Kozhov 1963, 15–18). The growing season begins in mid-May when temperatures reach above 5°C and ends in late September. The waters of Lake Baikal greatly influence the climate of its shores, as average temperatures are approximately 10°C warmer during winter and cooler during summer along the coast compared to inland areas (Kozhov 1963, 15–18). The warmer shores mean that the area surrounding the lake is free from permafrost, though the ground freezes to depths of 120–220cm during the winter (Weber 1995). Annual precipitation in the area averages 300–400mm, with the majority of this falling during the growing season. Microclimate variation is common throughout the Baikal region; the southern Khamar-Daban mountains see as much as 1,200mm in annual precipitation, while Olkhon Island rarely exceeds 170mm (Kozhov 1963, 15–18).

Environmental reconstructions and model simulations of northern inland Asia suggest that the area of Lake Baikal oscillated between taiga and steppe-forest biomes during the Holocene. The environmental reconstruction also identified an increasing trend of warming and decreasing precipitation, beginning between c. 7,500 and 6,500 yrs. BP (White and Bush 2010; Mackay et al. 2013). This abrupt change in environmental conditions coincides with changes in mortuary practices and cultural discontinuity seen in the archaeological record during the Middle Neolithic (7000/6800–6000/5800 yrs. BP), indicating that perhaps the patterns seen in the archaeological record were influenced by environmental fluctuations, though the mechanisms and nuances of these changes are still unknown.

1.3 Flora and Fauna

The flora of Lake Baikal consists largely of larch (*Larix*), pine (*Pinus*), fir (*Abies*), spruce *(Picea),* and cedar *(Cedrus)* (Khotinskii 1984). Shrubs, mosses, and lichens are also present on the mountains alongside edible plants such as strawberries, blueberries, cloudberries, a variety of mushrooms, and pine nuts, which would all be seasonally available (Kozhov 1963, 17–18; Weber et al. 2011). In addition to terrestrial flora, there are approximately 20 species of flowering water plants living in the waters of Lake Baikal, and over 500 species of algae that are often responsible for the "blooms" that occur along the coast and in estuaries during the summer (Kozhov 1963, 150–151).

Terrestrial fauna is diverse due to the intersection of three separate faunal complexes, which include the European/Siberian, Central Asiatic, and Eastern Asiatic families (Kozhov 1963, 158–159). Despite this faunal diversity, terrestrial herbivore remains at habitation sites often include only red deer (*Cervus elaphus*), moose (*Alces alces*), musk deer (*Moschus moschiferus*), reindeer (*Rangifer tarandus*), roe deer (*Capreolus capreolus pygargus*), and the Siberian Mountain Goat (*Capra sibirica*). Carnivores and omnivores are generally represented by the brown bear (*Ursus arctos*), lynx (*Felis lynx*), wolf (*Lupus lupus*), and bobcat (*Gulo gulo*). Fur-bearing species that may have also been important resources include the fox *(Vulpes vulpes),* squirrel *(Sciurus vulgaris)*, hare (*Lepus timidus)*, ermine (*Martes ermine)*, chipmunk *(Eutamias sibiricus)*, sable (*Martes zibellina)*, marmot (*Sciuridae marmota*) and Siberian polecat *(Martes sibiricus)* (Shvetsov, Smirnov, and Monakhov 1984).

There are over 50 species of fish belonging to 9 families that live in the region's rivers and lakes, though the most productive and important for commercial fishing include the Baikal omul' (*Coregonus autumnalis migratorius)*, whitefish *(Coregonus lavaretus)*, grayling *(Thymallus arcticus)*, pike *(Esox lucius)* burbot *(Lota lota),* and sturgeon *(Acipenser baeri)* (Kozhov 1963, 139–145; Losey, Nomokonova, and White 2012; Sorokin and Sorokina 1988). The only mammalian species that lives in Lake Baikal is the freshwater seal (*Phoca sibirica*), or *nerpa*, whose closest relative is the ringed arctic seal (Kozhov 1963, 145; Losey, Nomokonova, and White 2012).

1.4 Culture History of Cis-Baikal

The cultural periods of the Holocene in Cis-Baikal are defined by major technological innovations and changes in the mortuary practices of the populations (Bazaliiskii 2010; Chlachula 2001; Weber and Bettinger 2010; Weber, Link, and Katzenberg 2002; Weber et al. 2016). The cultural sequence of the Baikal region has been debated since Okladnikov (1950; 1955a; 1955b; 1971) published his original sequence based on similarities in material culture and mortuary protocols. Okladnikov placed the Isakovo group at the beginning of his cultural progression, followed by the Serovo, Kitoi, and the Glazkovo, based upon the perceived complexity and richness of the graves (Okladnikov 1971: 12–30). Later research overturned his original developmental series by applying radiocarbon dating to individuals associated with specific cultural periods. This ultimately placed the Kitoi at the beginning of the cultural sequence in the Early Neolithic and demonstrated the documented hiatus in burial activity during the Middle Neolithic (Mamonova and Sulerzhitski 1986; Mamonova and Sulerzhitski 1989, Weber et al. 2002). Recent research into the freshwater reservoir effect on radiocarbon dating in the Baikal region has subsequently provided a series of corrections that outline the chronological sequence of each cultural complex (Weber et al. 2016b). Therefore, the current culture history model used by BAP scholars is based on the corrected radiocarbon dates. The following section will provide a brief overview of the cultural periods in the Baikal region, with a focus on the Neolithic and Early Bronze Age (Table 1.1).

Table 1.1 Culture history of the Cis-Baikal adapted from Weber and colleagues. (2016b).

Period	**Mortuary tradition(s)**	**Cal BP years**
Late Mesolithic (LM)	Small, scattered graves dispersed throughout region	*8277 ± 176* to *7503 ± 14* mean HPD cal BP
Early Neolithic (EN)	Kitoi and other micro-regionally specific traditions	*7503 ± 14* to *7027 ± 33* mean HPD cal BP
Middle Neolithic (MN)	Lack of archaeologically visible mortuary sites	*7027 ± 33* to *5571 ± 88* mean HPD cal BP
Late Neolithic (LN)	Isakovo and Serovo	*5571 ± 88* to *4597 ± 76* mean HPD cal BP
Early Bronze Age (EBA)	Glazkovo	*4597 ± 76* to *3726 ± 34* mean HPD cal BP

1.4.1 *Palaeolithic*

The Baikal region of Siberia has been occupied from at least the Middle Pleistocene with over 200 documented Palaeolithic sites, often located along the valleys of large rivers (Chlachula 2001; Okladnikov 1971: 1–11). This period broadly dates between 200,000–10,000 yrs. BP. Early and Middle Palaeolithic complexes are represented by simple stone tools fashioned via direct percussion techniques from quartz or quartzite pebbles. These are typically formed into choppers, bifaces, and scrapers that are similar to the European Early and Middle Palaeolithic toolkit (Chlachula 2001; Derev'anko et al. 1998: 1–2). The Late Palaeolithic sees the intensification of advanced blade technologies, with a focus on processing a variety of lithic raw materials that are superior in quality compared to the previous quartz pebble materials (silex, radiolarite, argillite, diorite). These materials were worked to produce long, thin blades that are lightweight, economical, and portable. Often these were retouched bifacially or fashioned into burins, end scrapers or notched/denticulate tools. This period also produced sculptures and Palaeolithic artworks carved into mammoth ivory and bone, indicating cultural as well as technological development (Chlachula 2001; Derev'anko et al. 1998: 27–32).

1.4.2 *Mesolithic*

The Mesolithic dates between 10,000–7,500 yrs. BP in the Baikal region. Mesolithic habitation sites of the Early Holocene are largely congruent in their lithic technologies when compared to the microblade traditions of the Late Palaeolithic. Most often Mesolithic sites are identified through the presence of taxonomically modern faunal species, pottery, and radiocarbon dating rather than their tool technologies which remains similar to Palaeolithic technologies (Chlachula 2001; Derev'anko et al. 1998: 122-124). Not much is known about the Late Mesolithic peoples, as graves in this period are quite rare but appear scattered around the entire region. The cemeteries are small, if at all present, and there appears to be no set mortuary pattern (Weber et al. 2016b). Based on the available archaeological evidence, they appear to be small, dispersed, and mobile populations moving through the landscape, with subsistence based on hunting, non-intensive fishing, and sealing (Weber and Bettinger 2010).

1.4.3 *Neolithic*

While the Neolithic can be identified as the beginnings of agriculture in other parts of the world, in the Cis-Baikal the hunter-gatherer lifestyle persisted until the Iron Age, when domesticated crops and animals were introduced to the area (Weber and Bettinger 2010). The Early Neolithic (*7503* ± *14* to *7027* ± *33* mean HPD cal BP) is the best represented archaeological period in the BAP dataset, with dates from over a dozen cemeteries from two micro-regions in Cis-Baikal (Weber et al. 2016a). This archaeological period is defined by the introduction of the bow and arrow, ground stone tools, and ceramic technologies (Okladnikov 1971: 12–21; Weber and Bettinger 2010; Weber, Link, and Katzenberg 2002). The Kitoi established centers of relatively high population density in areas where resources were plentiful, particularly in the Angara valley and southwest Baikal (Katzenberg and Weber 1999). The mortuary tradition of this period resulted in large, formal cemeteries where multiple generations were interred. The complex social arrangements of the Kitoi are visible in the mortuary record. Extensive variation in mortuary artifacts, especially those associated with subadults, indicate substantial social differentiation. Likewise, the presence of communal graves with occasional skeletal evidence of violence suggest that these groups were perhaps not always stable or peaceful (Bazaliiskii 2003; Bazaliiskiy and Savelyev 2003; Weber and Bettinger 2010).

The Middle Neolithic (*7027* ± *33* to *5571* ± *88* mean HPD cal BP) refers to the period where there is a distinct lack of formal cemeteries or other archaeologically visible burial practices. However, it is important to note that while there is currently no evidence of Middle Neolithic burials, there are habitation sites with archaeological materials dating to the Middle Neolithic across the Cis-Baikal during this period (Weber and Bettinger 2010; Weber, Link, and Katzenberg 2002). It is clear that there was a major change in cultural practices during this period as compared to the Early Neolithic Kitoi groups, which can be seen in the discontinuation of formal cemetery use. While research has indicated that the Baikal region experienced climate change during this transitional period, the change was evidently not significant enough to shift distributions of flora and fauna, which would have caused people to leave the region entirely (Bush 2005; White 2006). It is much more likely that the documented climatic change was a contributing factor to the redefinition of local hunter-gatherer adaptive strategies and should be considered alongside other cultural pressures such as changes in population, availability of important dietary resources, or inter- or intra-group conflict.

The Late Neolithic (*5571* ± *88* to *4597* ± *76* mean HPD cal BP) is identified with the Isakovo-Serovo cultural complex, a biologically and culturally distinct population from earlier groups in the Cis-Baikal. While the EN Kitoi linked to a genetic lineage dating back to the Palaeolithic, the LN and EBA groups appear to be part of a more recent lineage that also includes modern native Siberian populations (Mooder et al. 2005; Mooder et al. 2006; Mooder et al. 2010; Weber and Bettinger 2010; Weber, Link, and Katzenberg 2002). The factors and processes that lead to the perceived increase in social complexity during this period are not well understood, though the outcomes are clearly visible in the archaeological record. This period sees the return of formal cemeteries, an increase in population, and more uniform population distribution across the entire Cis-Baikal. Most of the cemeteries are small, rarely containing more than ten individuals, and have only a few types of grave goods (Weber et al. 2008). Isakovo graves are known primarily from the Angara valley and feature stone structures, grave orientation parallel to the Angara River, and extended supine single internments, though multiple internments are not uncommon. The Serovo tradition is known from the Angara, Little Sea, and Upper Lena micro-regions, and are set apart from the Isakovo burials through their position relative to major rivers. Serovo graves are generally in an extended supine position, perpendicular to the major river in the area, with the head pointing away from it. They have stone architecture on the surface and inside the grave pits and use red ochre in some of their graves (Weber et al. 2016a). Hunting, fishing, and sealing continued to be an important aspect of subsistence activities, though fishing appears to be less extensive compared to the earlier Kitoi (Weber and Bettinger 2010).

1.4.4 *Early Bronze Age*

The Glazkovo cultural complex marks the beginning of the Early Bronze Age (*4597* ± *76* to *3726* ±

34 mean HPD cal BP) and is considered genetically continuous with the Isakovo-Serovo tradition (Mooder et al. 2005; Mooder et al. 2006; Mooder et al. 2010; Kılınç et al. 2018; Weber et al. 2016b; Weber and Bettinger 2010). Both the Isakovo-Serovo and the Glazkovo traditions have centers in the Angara valley, which was previously exploited by the Kitoi, though the Glazkovo complex is currently the only mortuary tradition found within all four micro-regions of the Cis-Baikal (Weber et al. 2002; Weber et al. 2008; Weber et al. 2016a). Formal cemetery use continued in this period, along with hunting, fishing, and sealing activities. Most cemeteries remained small, though some grow to be quite large for this period. There are similarities in mortuary protocol between the Late Neolithic and the Early Bronze Age cemeteries including grave architecture, body position, and the number of internments per grave; though, seated burials are entirely new in this period. Grave inclusions are also more diverse than in the Late Neolithic— though not as extensive as Kitoi grave inclusions— with nephrite artifacts, stone tools, pottery, fishing fear, and metal objects appearing with variable frequency (Weber et al. 2008; Weber et al. 2016a). While there appear to be no large-scale changes in population composition in this period, the Early Bronze Age does see the introduction of copper and/or bronze artifacts into the material culture (Weber and Bettinger 2010; Weber, Link, and Katzenberg 2002).

1.5 Previous Research

In the past 170 years, the Cis-Baikal region has seen numerous large-scale construction projects including the construction of the Trans-Siberian Railway– which began in 1897– and city expansion due to an increase in population, industry, and trade. These large-scale projects were one of the driving forces for archaeological fieldwork, as more artifacts were uncovered with every project. The primary concern was the preservation and recovery of artifacts uncovered or threatened by development. Early work focused on the classification and division of archaeological material into sequential chronological periods, while subsequent work aimed to increase the archaeological material available for study, though both were slow to publish any results. Work conducted in more recent years has focused on a comprehensive review and analysis of archaeological material, with an emphasis on publication and dissemination of results. The following section provides a review of previous archaeological work in the Baikal region, beginning with the advent of Siberian archaeology, up to the present day.

1.5.1 *Stage I: (1850–1959)*

Archaeological investigations in the Baikal region began with the founding of Siberian archaeology in general, which gained ground with the establishment of The Siberian Branch of the Imperial Russian Geographical Society in 1851. The organization placed a strong emphasis on scientific exploration in the region and aimed to comprehensively study the native land. This led to the discovery and documentation of petroglyphs in the Sagan-Zaba and Aia coves on Lake Baikal by N. N. Agapitov (1882). In the following years, N. I. Vitkovskii (1880; 1881; 1882; 1889) headed one of the first archaeological recovery projects in the 19th century, directing excavations at the mouth of the Kitoi River. At the turn of the century, M. P. Ovchinnikov discovered the first prehistoric graves containing copper artifacts during the construction of the Trans-Siberian Railway. He believed the metal artifacts he recovered were locally manufactured and identified these graves as the Irkutsk culture (Ovchinnikov 1904). Petri (1926; 1928) conducted subsequent archaeological work in the early 1910s at Ulan-Khada on Lake Baikal, which was the first stratified archaeological site to undergo extensive excavation in Siberia, with approximately 12 cultural layers. He later attempted to construct a chronological sequence for the area, which was endorsed and altered by a few of his students. During the 1930s A. P. Okladnikov began to survey the Angara valley in response to a series of planned hydropower plants along the river. By the 1940s the Angara River had been surveyed from its source to its confluence with the Yenisei (Goriunova and Novikov 2010). Okladnikov later published a series of monographs on the Neolithic and Bronze Age of the Baikal region (1950; 1955b), which justified the Bronze Age of Baikal as a distinct cultural-historical unit based on the archaeological materials and comparative ethnographic data.

1.5.2 *Stage II: (1959–1994)*

Okladnikov continued to investigate the prehistory of Baikal, aiming to create a sequential model based in unilineal cultural evolutionist thinking. He constructed the original culture model for the Baikal region based on archaeological material accumulated from the second half of the 19th century up until the Second World War, based primarily on his excavations of cemeteries (Okladnikov 1971). He paid special attention to describing the subsistence economy, social relations, and world views of these early peoples, detailing aspects of manufacturing processes and types of activities. The cultural chronology he constructed was, at the time, the most comprehensive review of Baikal prehistory, and defined the chronological boundaries that many scholars would later use as a standard. However, more recent reviews of Okladnikov's model have since proven it to be an inaccurate representation of Lake Baikal's cultural history, along with a number of other models proposed (Weber 1995).

During the 1950s–1990s, archaeological fieldwork in the region significantly increased, with Weber (1995) counting approximately 150 excavation projects occurring between 1950 and 1994. Long-term fieldwork projects focused on the Neolithic and Bronze Age were conducted by the Complex Archaeological Expedition of Irkutsk State University, the North Asiatic Expedition of the Institute of History, Philology, and Philosophy of the Siberian Branch of the USSR Academy of Science, and expeditions of the Irkutsk State Pedagogical University and Irkutsk Natural History Museum during the 1970s and 1980s (Goriunova and Novikov 2010). These projects provided substantial primary data from which many studies were produced. However, few of these studies were comprehensive in nature and were slow to be published (Goriunova and Novikov 2010; Weber 1995). This created a bottleneck in archaeological science in the Baikal region, as there was a greater focus on excavation than on analysis and publication of results, meaning that little information was available on the region and what was available was difficult to access.

1.5.3 *Stage III: (1994–Present)*

As previously mentioned, The Baikal Archaeological Project was established in partnership with local Russian archaeologists in the mid-1990s. Over the course of two decades, colleagues and researchers affiliated with the project have published papers and presented on a wide range of topics regarding the middle Holocene hunter-gatherers of Lake Baikal, with a substantial focus on the EN, LN, and EBA. These populations are well studied in contrast to the LM and MN due to the use of formal cemeteries— defined here as areas repeatedly and more or less exclusively used for the disposal of a group's dead (Goldstein 1981)— by the EN, LN, and EBA groups (Weber and Bettinger 2010). In contrast, MN groups most likely used informal cemeteries, which involve the disposal of the dead over the landscape in a scattered manner, or mortuary practices that do not leave archaeologically visible traces. While the following review does not aim to discuss the entirety of published research produced by BAP in the last two decades, it does outline a number of studies concerning topics of importance related to the BAP project.

Mortuary ritual and cemetery internal organization allow researchers to categorize and classify the archaeological remains of people, while simultaneously gaining insight into the ritualistic lives of different cultural groups. Bazaliiskii (2003; 2010) and McKenzie (2006), provided overviews of the variation seen in burial practices both within and between cemeteries over the middle Holocene.

Analysis of EN burials shows these graves generally lack stone structures, and individuals are interred in a predominately extended body position with the head oriented to the North. Mortuary artifacts are varied, with between 60–65 categories of grave goods recorded (Bazaliiskii 2010; McKenzie 2006; Weber et al. 2016b). After the MN hiatus of formal cemetery use, the LN sees the development of two mortuary traditions— the Isakovo and Serovo. The Isakovo is known only in the Angara, with surface stone structures, predominantly single inhumations parallel to the Angara river, with the head oriented to the South. Grave inclusions here are less varied than the Kitoi, and often include mitre-shaped clay vessels with net impressions. Serovo graves have between 30–35 categories of grave goods associated with single internments that are oriented perpendicular to the major river in the area (Bazaliiskii 2010; Weber et al. 2016b). The Upper Lena and Little Sea micro-regions see some variation in the regional patterns associated with each culture complex. However, water referencing in these micro-regions often results in variable orientation of burials, as the placement of the head away from the water conflicts with the standard northern orientation of the head. Glazkovo burials, found in all four micro-regions of the Cis-Baikal, display slight variation in mortuary characteristics. Grave architecture, body position, and the number of individuals per internment are similar to the Isakovo and Serovo groups, but it is primarily the burial orientation that sets Glazkovo inhumations apart. Along the Angara, Glazkovo graves are oriented parallel to the river, but with the heads downstream— that is, the opposite direction of Isakovo burials. In areas where water referencing is more complicated due to the presence of many important waterbodies, such as the Little Sea, it appears that graves are oriented N–S or NW–SW. The Southwest Baikal micro-region is the only area where it appears water referencing does not apply (Weber et al. 2012; Weber et al. 2016b).

Studies relating to demography and migration provide insights into the nature and distribution of human activities across a landscape, and how different cultural groups may have interacted and influenced each other. In Cis-Baikal, changes to the demographic profile of living populations, inferred from the archaeological record, changed throughout the middle Holocene. EN populations consisted of a few somewhat large cultural centers associated with a major cemetery, concentrated in the upper Angara valley and in the Southwest Baikal micro-region (Weber and Bettinger 2010; Weber and Goriunova 2013). However, during the LN and EBA, there was an increase in population, evidenced by the expansion into the Little Sea micro-region, while the upper Angara population remained relatively stable compared to early periods. This population consisted of a large number of smaller groups that were more evenly distributed across the landscape. Mortuary practices also experienced a change in this period, as these smaller groups buried their dead more often in single internments, rather than the multiple internments seen in the EN (Weber and Bettinger 2010; Weber and Goriunova 2013). Weber and Bettinger (2010) suggest that this change in mortuary tradition is a reflection of less internal differentiation within and between LN and EBA communities, compared to the larger EN communities, which displays evidence of distinct subunits associated with social, economic, or political status. Recent archaeogenomic studies have sequenced mitochondrial DNA and haplogroup data of 41 individuals in North Asia during the Holocene including samples from Lake Baikal. The results suggest some level of continuity between ancient groups and the present-day population, with genetic differences observed between 7,000 BP and 3,000 BP. These differences were inconsistent with genetic drift alone, suggesting gene flow into the region from distant gene pools was a factor (Kılınç et al. 2018).

Population studies in the Cis-Baikal region suggest that the EN Kitoi groups differed in their adaptive strategies from the LN and EBA Isakovo, Serovo, and Glazkovo groups. It is suggested that both the Kitoi and Isakovo-Serovo-Glazkovo cultural complexes may have been relatively sedentary during the summer months to take advantage of the abundant resources and in order to have sufficient workforce to harvest fish (Haverkort, Bazaliiskii, and Savel’ev 2010; Haverkort et al. 2008). However, due to the larger EN populations and high population density along the Angara River, it is thought Kitoi groups were less mobile than the LN and EBA populations and practiced logistical foraging expeditions for locally available resources (Weber, Link, and Katzenberg 2002; Weber et al. 2011). Weber and colleagues (2011) analysis of forager diets from each micro-region of Cis-Baikal shows that the food foraging ranges are smaller than expected for hunter-gatherer populations, especially for the more mobile LN and EBA populations. Individuals from each micro-region have stable isotope values that suggest foraging occurred almost exclusively within their particular micro-regions, showing little overlap with other micro-regions despite their relative geographic proximity. The study also showed evidence for an asymmetrical exchange network between micro-regions for the migration of peoples. In particular, the Little Sea consistently received migrants from the Upper Lena from the EN to the EBA such that it is estimated that nearly 65% of the entire Little Sea EBA population was of non-local birth (Haverkort et al. 2008; Weber et al. 2011).

A significant proportion of work has been conducted through bioanthropological analysis on osteological remains in the Cis-Baikal. Many of these studies focus on estimations of skeletal health through the identification of pathological lesions (Link 1999*:* Lieverse et al. 2007; Lieverse 2010; Macintosh 2011). Dental hypoplasia is a specific form of pathological lesion that occurs during enamel formation, which preserves in the dental record of an individual and can be examined as a proxy for health in a population. In the Cis-Baikal region, enamel hypoplasia is more prevalent in Early Neolithic Kitoi populations when compared to Late Neolithic-Bronze Age groups, suggesting higher levels of physiological stress among the Kitoi (Lieverse 2005; Lieverse 2007a; Lieverse 2007b; Lieverse 2010). Other osteological investigations including entheseal changes, post-cranial non-metric traits, and skeletal morphology have attempted to reconstruct potential activity levels among these populations (Lieverse et al. 2009; Lieverse et al. 2013). These studies have proposed that EN Kitoi males were engaged in higher levels of activity and terrestrial mobility when compared to their contemporary females, as well as the LN and EBA populations, both male and female (Lieverse et al. 2009; Lieverse et al. 2013; Macintosh 2011). Upper limb entheseal changes and post-cranial robusticity present on all analyzed individuals from the EN, LN, and EBA were consistent with watercraft use; though, to date, there has been no definitive archaeological evidence for watercraft in the Cis-Baikal (Lieverse et al. 2011; Lieverse et al. 2007). Lieverse and colleagues (2007) explored the prevalence of osteoarthritis in the Cis-Baikal in addition to examining activity level markers. Results show that average physical activity levels were fairly consistent throughout the middle Holocene, with only marginal differences between males and females from all populations. Distribution and prevalence of osteoarthritis in specific joints suggest that knee osteoarthritis was most prevalent among EN males. Activities associated with the development of knee osteoarthritis include squatting, kneeling, and walking over variable terrain while load-bearing (Lieverse et al. 2007). Osteoarthritic prevalence in the vertebral column— indicative of load-bearing stress— was lower in EN females compared to contemporary males and the LN and EBA females. Lieverse and colleagues (2007) study did not find sex-based differences in osteoarthritis in the LN and EBA populations, though it was noted for the EN Kitoi.

Investigations into the subsistence and diet of middle Holocene hunter-gatherers has also been an important aspect of BAP research since its establishment. Faunal analysis has attempted to reconstruct subsistence activities at habitation sites in the Cis-Baikal region, with a particular focus on seal hunting practices reconstructed from the season of death (Weber et al. 1998; Nomokonova et al. 2013; Nomokonova et al. 2015). Other analyses have attempted to identify fishing technologies through the size distribution and presence/absence of fish species (Losey, Nomokonova, and Goriunova 2008; Losey, Nomokonova, and White 2012; Losey, Nomokonova, and Savel'ev 2016; Nomokonova et al. 2011), and explore human-animal relationships through ritualistic burials of animals (Losey et al. 2013;

Bazaliiskiy and Savelyev 2003; Losey et al. 2011). These analyses have been used to inform broader investigations of diet, culture, and ecological change throughout the middle Holocene, supplemented by stable isotope analysis (Ezzo et al. 2003; Weber et al. 1998; Weber and Bettinger 2010).

Lam's (1994) study was the first application of dietary stable isotope analysis in the Baikal region. Though only a small sample of carbon and nitrogen values were published, the results clearly indicated that Kitoi, Isakovo-Serovo, and Glazkovo complexes relied significantly on aquatic foods. These results disagreed with the cultural and economic associations of Okladnikov's culture history model, further supporting the necessary re-evaluation of Cis-Baikal's cultural model. More recent stable carbon and nitrogen isotopic data have shown that both the Kitoi and the Isakovo-Serovo-Glazkovo populations had a diet consisting mainly of local game and fish in addition to seasonally available plant foods such as mushrooms and pine nuts (Katzenberg and Weber 1999; Katzenberg, Goriunova, and Weber 2009; Katzenberg et al. 2012; Weber et al. 2011). Inter-regional variation was noted in the proportions of fish, seal, and ungulates in the diet, indicating a dependence on locally available resources (Weber et al. 2011). However, intra-regional variation also existed, with substantially different diets present in the same population, as evidenced by the Game-Fish (GF) and Game-Fish-Seal (GFS) diets of Khuzhir-Nuge XIV and Kurma XI in the Little Sea micro-region (Katzenberg, Goriunova, and Weber 2009; Katzenberg et al. 2012; Weber and Goriunova 2013). Stable isotope values from Lokomotiv and Ust'-Ida I cemeteries located along the Angara River show that the EN Kitoi populations at Lokomotiv relied more heavily on fish resources than the Isakovo and Glazkovo peoples from Ust'-Ida I, who relied more on ungulate species, while neither consumed seal (Weber et al. 2011). More recent stable isotope analysis from the Shamanka II cemetery identified two phases of cemetery use with a chronological dietary trend towards a greater reliance on aquatic foods (Weber et al. 2016a). This is a similar pattern to

Early Neolithic groups along the Angara valley (Weber et al. 2016b), though the Shamanka II population is much more diverse in dietary variability than their northeastern neighbours.

The isotope data gathered for diet were also analyzed for weaning patterns and inter-birth intervals at Shamanka II and Lokomotiv in the EN and at Ust'-Ida I in the LN. The results indicate that infants from Ust'-Ida I were weaned at an earlier age than children from Shamanka II or Lokomotiv. While the EN children were weaned around 3.5 to 4 years of age, LN children were weaned at 3 years. This would allow for a shorter birth interval and could potentially facilitate population growth during the perceived increase in population during the LN and EBA, though there are many cultural and environmental factors also at work that influence population growth (Waters-Rist et al. 2011). Additionally, infant deaths during breastfeeding were more common among the EN sample, suggesting EN populations experienced significantly more stress than the LN and EBA samples. This observation offers complimentary evidence to earlier studies on dental enamel hypoplasia that also suggest regular high-intensity episodes of stress among the Kitoi, which were not observed in the LN and EBA groups (Lieverse 2010; Lieverse et al. 2007). A more detailed review of the stable isotope work within the Little Sea micro-region is provided in Chapter 3.

Stable isotope analysis is not restricted to investigating diet, mobility, or cultural practices, as paired stable isotope tests between human and terrestrial fauna remains are able to identify freshwater reservoir effects in the radiocarbon values of faunal and human remains. A series of studies showed that values from aquatic animals were continually being dated older than their terrestrial counterparts despite being deposited at the same time (Prokopenko et al. 1999; Nomokonova et al. 2013). While freshwater reservoir effects have been seen in other archaeological contexts, prior to these studies the issue remained unaddressed in the Baikal region. Subsequently, chronological models and reanalysis of radiocarbon dates accounting for the FRE were conducted in the areas of Lake Baikal (Schulting et al.

2014), the Angara River (Nomokonova et al. 2013; Prokopenko et al. 1999) and more recently the Upper Lena (Schulting et al. 2015). An overview of these chronological changes and corrections was compiled in Weber and colleagues (2016b) article, which used these radiocarbon dates to identify a trend towards a greater reliance on aquatic foods during the EN in the Angara and Southwest micro-regions and other chronological trends of diet and cemetery use in the Cis-Baikal. Important to the current topic, reanalysis of radiocarbon dates given the freshwater offset helped to clarify the posited migratory relationship seen in the Early Bronze Age cemeteries such as Khuzhir-Nuge XIV.

1.6 Summary

Lake Baikal is the largest and deepest freshwater lake in the world, with a varied steppe-forest environment that hosts an array of diverse flora and fauna. The Baikal region also boasts an extensive cultural history, dating back to the Middle Pleistocene, which preserved a hunter-gatherer lifestyle until the Iron Age. As a result, the Baikal region has been the locus of over 150 years of scientific inquiry and academic research. This analysis aims to contribute to the discourse of human settlement and lifeways in the Cis-Baikal by attempting to quantify the source food contributions to group and individual diet of Early Bronze Age populations in the Little Sea micro-region. A more detailed overview of the hypotheses guiding this research and the data used is provided Chapter 3.

Chapter 2: Literature Review

2.1 Introduction to Stable Isotopes

Stable isotope analysis can be used to identify the relative abundance of certain stable isotopes, isotopic signature, or chemical elements within organic and inorganic compounds. These values are able to track and represent an elements journey through physical processes and chemical reactions within a global cycle. The method has a wide range of applicability in the sciences, including the fields of chemistry, geology, forensics, ecology, hydrology, paleoclimatology, and archaeology. In archaeology, stable isotope analysis is most often used to infer ancient diet, where values of carbon and nitrogen stable isotopes represent a weighted average of an individual's dietary intake (Lee-Thorp 2003; Price 2015). That is to say, the old adage "you are what you eat", has some scientific bearing. Though there are many isotopic elements that can be exploited for a variety of research interests, here I will focus on carbon and nitrogen stable isotope values, as they are pertinent to research on diet reconstruction. This section will address the principles of stable isotope analysis, its place as a dietary tracer in the food web, and the target tissues archaeologists analyze.

2.2 Principles of Stable Isotope Analysis

Isotopes are the result of differences in the number of neutrons, and therefore nuclear mass, of an element. Most elements in the periodic table have at least one or two naturally occurring stable or radioactive isotopes, though elements like fluorine are monoisotopic (Sharp 2007, 23). Carbon has three naturally occurring isotopes— ^{12}C, ^{13}C, and ^{14}C— that contain 6 protons and 6, 7, or 8 neutrons in the nucleus, respectively (Figure 2.1). The stable isotopes of carbon are ^{12}C and ^{13}C, while ^{14}C is radioactive. Nitrogen has two naturally occurring stable isotopes— ^{14}N and ^{15}N— that contain 7 and 8 neutrons, respectively (Figure 2.2). An isotope is considered stable if it does not undergo radioactive decay, while an unstable isotope emits excess nuclear energy at a rate proportional to its current value. In naturally occurring isotopes, it is common to have one abundant and one scarce stable isotope. For example, ^{12}C comprises approximately 98.89% of available carbon, with the remaining 1.11% available as ^{13}C. Nitrogen is similar, with 99.64% of atmospheric nitrogen represented by ^{14}N, and only 0.36% consisting of ^{15}N (Chisholm 1989). The slight differences in mass affect the strength of bonds to other elements and cause variable thermodynamic and kinetic behaviours, but do not affect the chemical properties of an element or its compound (Sharp 2007, 5–6). For example, heavier isotopes tend to collect in liquid rather than gaseous states, as liquid states are more thermodynamically stable and are slower to react than lighter isotopes in mass-dependent kinetic reactions (Sharp 2007, 5–6). This means that while the chemical composition of an element remains the same, a particular isotope may be disproportionately retained or processed depending on the reaction. When in a state of equilibrium (either neutral, stable, or unstable), fractionation or partitioning of isotopes occurs through unidirectional or multidirectional physical processes due to the slight differences in bond strength between elements (Lee-Thorp 2008). Biochemical reactions are most often unidirectional processes, and therefore variation in fractionation values provides a means of tracking an element's pathway through the food web.

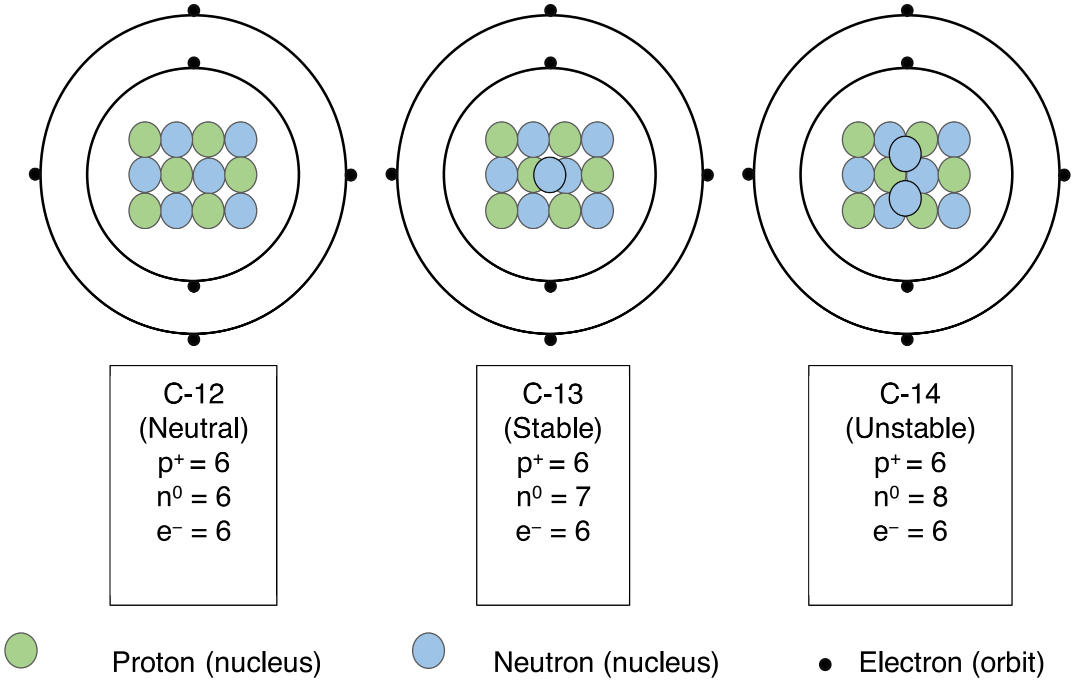


Figure 2.1 Differences in the atomic weights of carbon isotopes.

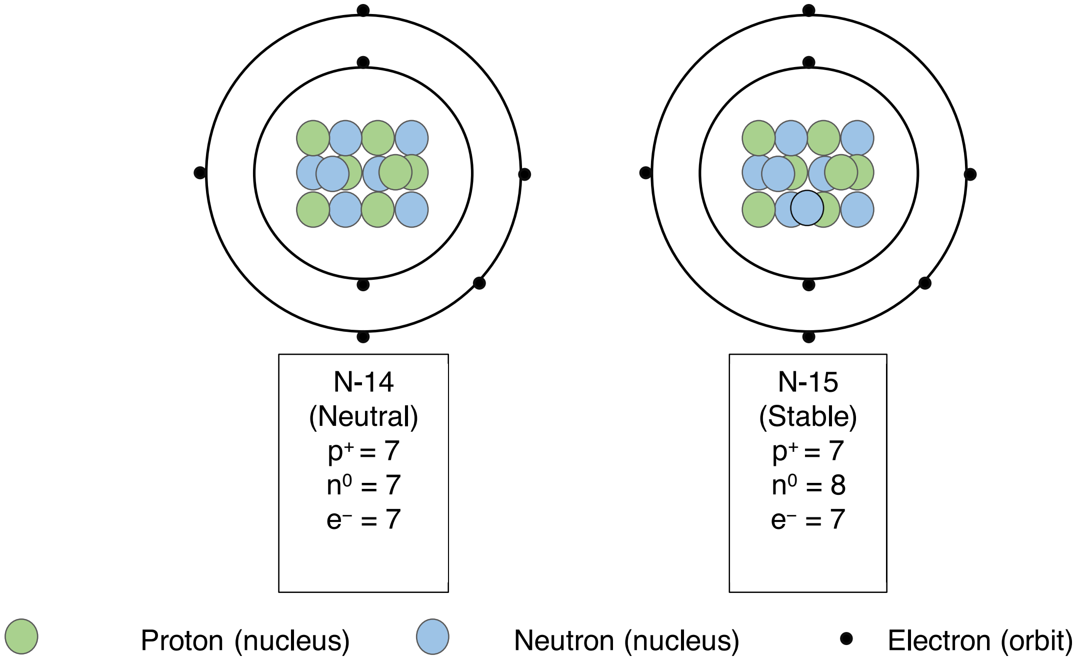


Figure 2.2 Differences in the atomic weights of nitrogen isotopes.

2.2.1 *Notation and Standards*

Stable isotope analysis measures the ratio of stable isotopes with different atomic weights preserved in various tissues and compares the measured ratio to the ratio of a standard, reported as "delta" values (δ) (Price 2015). The delta value is given by:

Equation 2.1

$$\delta = \left(\frac{R_x - R_{std}}{R_{std}}\right) \times 1000$$

Where *R* is the ratio of the abundance of the heavy to light isotope, *x* is the measured sample, and *std* is an abbreviation for the standard. Delta values represent the relative difference between the measured ratio and the standard, which is then reported in parts per thousand or parts per mil (‰) (Price 2015). Reference standards were set up beginning in the 1970s by geochemists meeting in Vienna to select material and establish protocols for the calibration of mass spectrometer analyses (Coplen and Clayton 1973; Coplen et al. 1983; Hut 1987; Coplen 1996). Early reports of $\delta^{13}C$ values were presented relative to a powdered specimen of *Belemnilella americana* from the Upper Cretaceous PeeDee formation in South Carolina, calling the standard PDB (PeeDee Belemnite) (Sharp 2007, 34). Due to depletion of PDB, current stable carbon isotope ratios are reported relative to a new standard of VPDB (Vienna Pee Dee Belemnite). However, PDB and VPDB are isotopically similar in content, such that results can be compared between the two standards (Coplen 1996; Hut 1987). Atmospheric nitrogen is the reference standard for stable nitrogen isotope analyses and is called AIR. The $\delta^{15}N$ value of atmospheric nitrogen is nearly constant around the world and is 0‰ by definition (Mariotti 1983). Therefore, a positive δ value means that the ratio of the heavy to light isotope in the measured sample is higher than in the standard, and a negative δ value means the heavy to light isotope ratio in the sample is lower than in the standard (Sharp 2007, 25).

2.2.2 *Carbon Isotopes in Food Webs*

Carbon can be traced through the food web due to the partitioning of organic carbon in plants that occurs during photosynthesis. There are three known photosynthetic pathways that terrestrial plants utilize for energy production, which discriminate either for or against the heavier isotope of carbon. Plants with a C_4 (also known as the Hatch-Slack cycle) photosynthetic pathway are able to create energy more efficiently in hot, dry climates by converting carbon dioxide into a 4-carbon compound that incorporates more ^{13}C into the plant tissues (Slack and Hatch 1967, van der Merwe 1982). This is because all of the atmospheric CO_2 is concentrated into bundle-sheath cells prior to their conversion into glucose by the enzyme ribulose-1.5-bisphosphate carboxylase/oxygenase, or RuBisCo for short (Lee-Thorp 2008). Because there is no discrimination of which isotope is preferred, C_4 plants will retain more of the heavier isotope, resulting in higher $\delta^{13}C$ values. Plants utilizing a C_3 pathway (also known as the Calvin cycle) produce a 3-carbon compound and are more common in temperate areas. In this case, strong discrimination against ^{13}C during carbon fixation by the RuBisCo enzyme produces more negative $\delta^{13}C$ values in nearly all herbs, trees, shade-loving grasses, and leafy vegetables (Calvin and Benson 1948, Lee-Thorp 2008). The differences in photosynthetic pathways mean that C_4 plants such as millet, sorghum, maize, and sugarcane have more positive $\delta^{13}C$ values compared to C_3 plants like rice, wheat, barley, and leafy greens; and the isotopic variation will be reflected in the $\delta^{13}C$ values of consumers (Finucane et al. 2006). Globally, C_4 plant $\delta^{13}C$ averages out to −12.5‰ whereas C_3 plant $\delta^{13}C$ varies more widely between −25 to −36‰ with a mean of −26.5‰ (O'Leary 1981; Farquhar et al. 1989; van der Merwe and Medina 1991; Lee-Thorp 2008). There is also a third photosynthetic pathway known as CAM (crassulacean acid metabolism), seen in plants such as succulents or cacti, that enables a plant to switch between the C_3 and C_4 pathways to produce energy most efficiently depending on environmental conditions (Hatch and Slack 1966). These plants often have intermediate values between those that have pure C_3 or C_4 photosynthetic pathways. The fractionation values of plants derived from photosynthesis are passed along through the food chain due to unidirectional biological processes. Consumers store the $\delta^{13}C$ values from the ingested food sources in their own tissues, resulting in a $\delta^{13}C$ value that reflects the averaged $\delta^{13}C$ of their diet. Therefore, humans eating exclusively C_4 rich plant food, such as maize, will have a more positive $\delta^{13}C$ value than an individual eating an exclusively C_3 diet.

2.2.3 *Nitrogen Isotopes in Food Webs*

The presence of nitrogen isotopes in the food web reflects the balance between biological nitrogen fixation by plants or marine primary producers, and the recycling of nitrogen within the biosphere, ending with the eventual release of N_2 for recirculation (Robinson 2001). Nitrogen mainly enters the food chain through plant uptake of terrestrial soil nutrients. The $\delta^{15}N$ levels of soil are typically between +1–4‰ depending on environmental factors such as aridity, soil leaching, anoxia, and salinity (Shearer et al. 1978; Heaton 1987; Handley and Raven 1992; Finucane et al. 2006). Nitrogen-fixing plants, such as legumes, are exceptions as they source their nitrogen from the atmosphere, resulting in $\delta^{15}N$ values closer to 0‰ (Price 2015). Depending on the role of nitrogen-fixing plants in the diet, shifts towards lower $\delta^{15}N$ levels may be seen. Similar to carbon, consumers store the $\delta^{15}N$ of ingested food sources in their own tissues and pass these values along the food chain. In one sense, $\delta^{15}N$ values reflect the proportion of animal protein in the diet, as $\delta^{15}N$ enrichment begins with plants, and increases with each trophic level (Price 2015). A stepwise trophic level shift of $\delta^{15}N$ between +2–6‰ has been widely documented in food web studies (DeNiro and Epstein 1981; Minagawa and Wada 1984; Schoeninger and DeNiro 1984; Sealy et al. 1987). The trophic shift seen in stable nitrogen isotope values is likely the result of excretion of ^{15}N-depleted waste like urea, but due to the significant amount of variability in physiological processes, the nuances of the relationship between trophic level and stable nitrogen isotopes are not yet well understood (Ambrose 1991; Lee-Thorp 2008). Because of the relationship between trophic level and $\delta^{15}N$ values, nitrogen stable isotopes are frequently used in conjunction with carbon stable isotopes to address research questions related to protein sources and trophic levels.

2.2.4 *Marine and Freshwater Ecosystems*

Marine food chains are significantly longer than their terrestrial counterparts, the effect of which is an increasing stepwise $\delta^{15}N$ enrichment that ultimately ends in distinctly high $\delta^{15}N$ values not seen in terrestrial food webs (Minagawa and Wada 1984; Schoeninger and DeNiro 1984). Aquatic primary producers also typically have an elevated $\delta^{15}N$ of approximately +5–6‰ because their source of nitrogen is recycled nitrate in contrast to N_2 from the atmosphere or within soils (Liu and Kaplan 1989; Finucane et al. 2006). Schoeninger and DeNiro (1984) examined this with an analysis of the stable isotope signatures of 66 birds, fish, and mammals. It was shown that animals feeding exclusively from a marine environment exhibited more positive $\delta^{15}N$ values, as compared to animals feeding on terrestrial sources, by a mean of +9‰. In addition, marine mammals displayed $\delta^{15}N$ values of +13.3‰ for those that fed on invertebrates, while marine mammals feeding on fish have mean $\delta^{15}N$ values of +16.5‰. Therefore, it is possible to determine whether the animal protein was sourced from marine or terrestrial environments. It is also possible to distinguish between plant and animal protein sources in the diet because of these separated values. This is mainly because marine environments have more trophic levels, and primary producers are already enriched in ^{15}N, meaning that animals living in a marine ecosystem will generally exhibit more positive $\delta^{15}N$ values than a terrestrial ecosystem, as well as enriched $\delta^{13}C$ values due to the high concentration of dissolved carbon in ocean water (Finucane et al.

2006, Price 2015). Marine ecosystems differ in δ^{13}C values primarily because the main source of carbon is bicarbonate dissolved in seawater, rather than atmospheric carbon, as bicarbonate has higher concentrations of ^{13}C than atmospheric carbon (Lee-Thorp 2008). Phytoplankton, diatoms and other marine primary producers preferentially uptake ^{12}C during photosynthesis, leaving ^{13}C rich waters behind in the water columns. As productivity increases, aqueous ^{13}C also increases. Therefore, at the most general level, it can be said that higher aqueous ^{13}C values are associated with rapid growth in primary producers and lower values are associated with slow growth (Goericke and Fry 1994, Popp et al. 1998). However, marine primary producers are already enriched in ^{13}C and ^{15}N when compared to terrestrial ecosystems, and these enriched values are then passed along through the food web. In the northern hemisphere, marine primary producers typically have a δ^{13}C of −18‰ to −22‰ (Boutton 1991; Fry and Sherr 1989; Mizutani and Wada 1988; Mizutani et al. 1990; Sydeman et al. 1997). Because the ocean's surface waters do not remain in a constant state and continuously circulate, δ^{13}C values from marine animals can be considered a local measurement. Recent research supports this, as an analysis of existing literature showed that marine habitats such as the open ocean, nearshore, seagrass, and kelp forests have distinct δ^{13}C values across the globe (Clements and Koch 2001).

Freshwater ecosystems also have long food chains similar to marine systems, resulting in a similar range of δ^{15}N values (Dufour et al. 1999). While nitrogen behaves in a similar manner in both marine and freshwater environments, carbon behaviour in freshwater ecosystems is much more variable than in marine ecosystems. Variability in δ^{13}C patterns is caused by different carbon sources and mixing of water in riverine systems. While terrestrial sources incorporate carbon solely from the atmosphere, aquatic environments use both atmospheric and dissolved carbon (Dodds 2002, 232). In freshwater habitats, dissolved carbon can be found in four forms, depending on water pH, including carbon dioxide, carbonic acid, bicarbonate, and carbonate (Dodds 2002, 232; Zohary et al. 1994). The pH level of freshwater determines what proportion of each form of carbon is present in the water. When photosynthesis or aerobic respiration occurs, carbon is removed from the water and incorporated into the food web. This causes a chemical reaction to maintain the bicarbonate equilibrium, which buffers water bodies from changes in pH when carbon is removed and CO_2 is made available for photosynthesis (Dodds 2002, 232). In rivers, these values form a gradient that reflects changes in water pH caused by the merging of streams, or the increase or reduction of organic materials (Dodds 2002, 457–59). In lakes, the water is more settled, and nutrients are regulated by the in-flow and outflow of riverine systems. Deep lakes, such as Lake Baikal, express stratification resulting from differences in temperature or salinity (Dodds and Whiles 2010, 156). This causes variable amounts of carbon to be held within each stratum, with ^{12}C rich waters occupying the lowest strata as decomposing or decaying organic matter on the lake bottom release ^{12}C into the lake. This means fish living in a deep-water lake can exhibit variable $\delta^{13}C$ values depending on the strata of the habitat they occupy within a lake system. In the case of Lake Baikal, this range is documented to be between −12.9‰ to −24.6‰ (Katzenberg and Weber, 1999). Mixing of the waters releases ^{12}C rich waters from the benthic (deepest) part of the lake, which is then preferentially taken up by primary producers, or released into the atmosphere, increasing the amount of ^{13}C in the lake (Dodds and Whiles 2010, 156–64). Rivers are simpler, as the constant mixing and preservation of the bicarbonate equilibrium maintains $\delta^{13}C$ values that change gradually from source to outlet.

2.2.5 *Target Tissues*

Through the first controlled feeding experiment DeNiro and Epstein (1978) showed that while the $\delta^{13}C$ of an animal is similar to its diet, there are differences in how isotopes are stored or retrieved from tissues through biochemical reactions. The fractionation that occurs between different tissues is often expressed as Δ (difference) or ε (enrichment factor) and can vary between values measured from collagen and bioapatite. The enrichment factor for $\delta^{13}C$ between diet and bone collagen is approximately +5‰, which was first observed by van der Merwe and Vogel (1978) and supported by later work by Sullivan and Krueger (1981) as well as Lee-Thorp and colleagues (1989). For each subsequent step in the trophic level, an increase of around +1–2‰ in $\delta^{13}C$ enrichment values can also be observed for omnivores and carnivores (Lee-Thorp 2008). Later, two other controlled dietary experiments showed that this relationship between diet and bone collagen is largely defined by dietary protein and collagen, rather than the whole diet because dietary amino acids are preferentially chosen for the construction of collagen tissues (Ambrose and Norr 1993; Tieszen and Fagre 1993, 152). This preferential selection means that the $\delta^{13}C$ of collagen is more representative of the $\delta^{13}C$ values of dietary protein, rather than of the whole diet.

In archaeology, it is often only calcified tissues that are recovered such as bones and teeth. Consequently, bones and teeth are often the primary tissues used in stable isotope analysis. Collagen is the main protein in both bone and dentine and is composed of spiral-shaped fibrils with mineral acting as cement binding them together (Lee-Thorp 2008). Bone collagen and dentine provide sources for organic carbon ($^{13}C/^{12}C$), nitrogen ($^{15}N/^{14}N$), and other isotope measurements not discussed here (Lee-Thorp 2008). Bone mineral and tooth enamel are biological calcium phosphates, also known as hydroxyapatite (Lee-Thorp 2008). These apatites are prone to substitution with other minerals such as carbonates and can determine isotopic ratios of organic carbon ($^{13}C/^{12}C$) from the substituted carbonate (Lee-Thorp 2008). These tissues measure different periods of an individuals' life due to the rates at which the tissue remodels. Bone, which regenerates and turns over regularly throughout life, measures long-term averages that can vary from a few years to decades (Lee-Thorp 2008). This is because the rate of bone growth and remodeling vary according to age and bone element, with younger individuals or smaller elements experiencing faster bone growth and remodeling, whereas older individuals and larger bones have much slower rates of turn-over (Lee-Thorp 2008). Tooth enamel and dentine are unlike bone in that they grow in incremental structures accumulated during a limited period of growth (Lee-Thorp 2008). As a result of this, measurements from dentine and enamel correspond to specific periods (mostly juvenile) of time in an individuals' life (Table 2.1). However, these temporal periods are not discrete and are regulated by physiological processes of amelogenesis and mineralization of dental tissues (Lee-Thorp 2008).

Table 2.1 Summary of common materials for stable isotope analysis and targeted information.

	Collagen	*Apatite*
Teeth	Targets incremental temporally-limited protein in dentine	Targets incremental temporally-limited mineral in enamel
Bone	Targets age-related long-term averages of protein	Targets age-related long-term averages of mineral

2.3 Stable Isotopes in Archaeology

Scholars pioneered the application of stable isotope analysis to an archaeological framework over 40 years ago. The initial publications built on a series of discoveries beginning with the relationship between plant photosynthesis and carbon isotope pathways (Smith and Epstein 1971) and observations of the behaviour of radiocarbon under different experimental circumstances (Berger et al. 1964; Tamers and Pearson 1965; Bender 1968; Longin 1971; Hassan and Ortner 1977). Initial observations found that radiocarbon dating of C_4 plants provided consistently younger dates than C_3 plants of the same age (Bender 1968). This led to subsequent controlled diet experiments that capitalized on carbon stable isotopes as dietary tracers (DeNiro and Epstein 1978), especially when controlled feeding experiments supplied the necessary foundation for information regarding dietary offsets and isotopic transfer of carbon between diet and tissue in animals (Vogel 1978). Nitrogen stable isotopes were soon incorporated into dietary studies as an additional proxy documenting trophic level effects within food chains (DeNiro and Epstein 1981).

Following the insights from the initial carbon isotope studies, scientists were able to apply stable isotope analyses to questions of dietary intake in archaeological circumstances, with the first publications reconstructing the consumption of maize of prehistoric Woodland Americans (Vogel and van der Merwe 1977; van der Merwe and Vogel 1978). Importantly, carbon and nitrogen isotope analysis inherently reflects the dietary sources consumed by an individual in contrast to indirect methods of dietary estimation such as zooarchaeological analyses, which focus on waste materials and overlook organic foods with poor survival rates. A consequence of this in the North American case is that the unexpected results of the carbon isotope analysis inspired re-examination of earlier archaeological evidence regarding the introduction of maize agriculture and the development of complex societies (Lee-Thorp 2008). It also prompted a longstanding debate about the quantity of maize that was reflected in the collagen isotope values, causing scholars to ponder the broader question of how and if it is possible to measure the number of dietary sources seen in stable isotope values.

Another key question raised by early work concerns the degree to which the data and results were accurate, as there were no standards of practice in the field at the time. Questions raised by researchers included, “how is it possible to identify contaminated samples” and, “in what ways is it possible to deal with diagenesis in archaeological samples?” These questions sparked researchers to examine bone preservation, and how bone diagenesis might influence the preservation of biogenic isotope signatures in bone and teeth (Krueger 1991; Lee-Thorp and van der Merwe 1987; Masters 1987; Nelson et al. 1986; Schoeninger and DeNiro 1982, 1983; Sullivan and Krueger 1981, 1983; Tuross et al. 1988). The work contributed by these scholars during the 1980s and 1990s developed protocols and procedures aimed at identifying diagenesis in archaeological samples, such as the C/N ratio, which provided confidence in results taken from poorly preserved or very old samples.

Technical improvements within mass spectrometry and theoretical developments in anthropological archaeology also contributed to the growth and convenience of stable isotope analysis. Continuous-flow mass spectrometry, developed in the 1990s, greatly improved the accessibility of stable isotope analysis to archaeologists by decreasing cost and sample volume (Brenna et al. 1997). This technical improvement allowed archaeologists to process larger numbers of samples within the same budget, which in turn provided the means to increase sample sizes for better data analysis. Concurrent theoretical changes in the field of archaeology, namely the development of the post-processual movement, changed the theoretical framework within which data were analyzed. Processual archaeology views human behaviours as adaptations to environments and is interested in questions of human subsistence and economy, systems interaction, and taphonomic processes (Binford 1962, 1967; Clarke 2015; Trigger 2006). Alternatively, post-processual archaeology emphasizes the importance of agency, social practice, and identity in society, resulting in a focus on the roles of ideologies and symbols in shaping cultural worldview, and how cultural change is influenced by the manipulation of social rules (Brumfiel 1983; Earle and Preucel 1987; Hodder 1982; Miller and Tilley 1984; Shanks and Hodder 1995; Trigger 2006). Within different theoretical frameworks, archaeologists are able to approach research questions from multiple perspectives and address how social dynamics could be investigated through stable isotope analysis. After the popularization of post-processual archaeology, research was focused on examining questions of peoples identities (see Cox and Sealy 1997), or how class, age, and sex factor into the foods available to individuals (see White, Healy and Schwarcz 1993). Through this theoretical shift, stable isotope analysis transitioned into a field that integrates data from multiple sources to investigate human dietary and mobility decisions, including social or political influences (Makarewicz and Sealy 2015).

2.4 Mixing Models and Diet Reconstruction

The reconstruction of prehistoric diet presents interesting challenges. While zooarchaeological remains and food processing sites provide qualitative insights into how food resources were procured and processed, various taphonomic factors and site formation processes affect preservation to such a degree that reconstructing the total diet from recovered artifacts is nearly impossible (Makarewicz and Sealy 2015). Faunal analyses are indirect methods at best, as these reflect group activity rather than individual consumption. It is difficult to determine if food distribution was equal or unequal, or if the recovered artifacts represent the whole diet. This issue was apparent even in the first application of stable isotope-based dietary reconstruction in Woodland North America (Van der Merwe and Vogel 1978; Vogel and Van der Merwe 1977). While carbonized plant remains found at earlier sites pointed to the use of maize at many Woodland settlements, whether or not maize had become a dietary staple was debated, leading scholars to explore direct methods of dietary reconstruction (Stallar et al. 2006). Though stable isotope analysis addresses this issue by providing measures of dietary intake on an individual scale, this method is semi-quantitative and can only report the contribution of food sources in a relative manner. Vogel and Van der Merwe's (1977) North American study had suggested a substantial reliance on maize as a dietary staple; however, it was unclear how much maize was consumed as part of the total diet. This raised a number of questions about the nature of the relationship between diet and stable isotope values. As a result of this study, scholars questioned whether it was possible to determine the proportions of food sources from δ^{13}C values, as isotope results can only report dietary source consumption on a relative scale. Precise estimations of food source contributions remain an issue in all dietary reconstructions.

The development of stable isotope mixing models has substantially increased our understanding of how dietary sources contribute to and influence stable isotope signatures. Mixing models are probabilistic tools that allow the user to analyze a sample of observed data extracted from the population, without having to identify where the sample fits within the overall population. Such tools are best used to estimate values of properties of a population, given only a sample of the population, making them popular tools in archaeology. When applied to dietary questions, mixing models use the same underlying principles as stable isotope analysis in a statistical modeling framework in order to provide more precise measurements of source food contributions to total diet. Since the first attempt at modeling diet in the 1970s (see Haines 1976), a number of statistical methods for dietary modeling have been developed, with each subsequent development increasing their utility. The following sections review these techniques including one of the most recent approaches— the Bayesian mixing model FRUITS.

2.4.1 *Classic versus Bayesian Statistics*

Classic approaches to probability rely on maximum likelihood estimation (ML), which focuses on the parameter values that maximize the likelihood function for the sample data. The model then produces point values of the estimates standard errors. The hypothesized value is then subtracted from the ML estimate and is divided by the estimates standard error to produce a standardized estimate under the hypothesized value (Lynch 2007, 77). Because the Central Limit Theorem, to which classic statistics adheres, states that the sampling distribution for a sample statistic or parameter estimate will be a normal distribution, it is possible to apply the *z*- or *t*-test to the sample in order to evaluate the probability of our observation, under the assumption that the hypothesized value is true. Within a sufficiently acceptable p-value, we can accept the hypothesized estimate (Lynch 2007, 77–78). The classic approach to probability analysis allows the user to create standard likelihood functions that can be used successively across different research scenarios, such that the same model can be used for unrelated research samples or contexts.

In contrast, Bayesian statistics represents a different perception of probability and informed research. The basic ethos of Bayesian statistics suggests all research begins with some prior probability for an event. The prior probability is updated each time new information is produced to obtain a posterior probability. The information generated by the posterior probability can then be incorporated into a subsequent prior probability. From a Bayesian perspective, this strategy is an extension of the scientific process. Scott Lynch portrays this well when he said, "[as researchers] we continue to gather data to evaluate a particular scientific hypothesis; we do not begin anew (ignorant) each time we attempt to answer a hypothesis, because previous research provides us with *a priori* information concerning the merit of the hypothesis" (2007, 49). The information we have gathered prior to our current hypothesis should inform our decisions about variables, parameters, and expected values. This is known as Bayes' Theorem, and the Bayesian approach incorporates this philosophy into the process of generating statistics.

The probability formulas associated with Bayes' theorem originally applied to point probabilities, where the basic formula states: (Lynch 2007, 47)

Equation 2.2

$$p(B|A) = \frac{p(A|B)p(B)}{p(A)},$$

Written out, the above states that a conditional probability for event *B* given event *A* is equal to the probability of event *A* given event *B*, multiplied by the marginal probability for event *B* and divided by the marginal probability for event A. When Bayes' Theorem is applied to probability distributions, the formula looks similar: (Lynch 2007, 47)

Equation 2.3

$$f(\theta|\text{data}) = \frac{f(\text{data}|\theta)f(\theta)}{f(\text{data})},$$

Here, $f(\theta|\text{data})$ is the posterior distribution for the parameter θ, and $f\ (\text{data}|\theta)$ is the sampling density for the data— a value that is proportional to the likelihood function— with the addition of a constant that makes it a proper density function. The prior distribution of the parameter is f (θ), and f (data) is the marginal probability of the observed data. The marginal probability is calculated for a continuous sample space as follows: (Lynch 2007, 47)

Equation 2.4

$$f(\text{data}) = \int f(\text{data}|\theta)f(\theta)d\theta,$$

This formula calculates the marginal probability by multiplying the integral of the sampling density by the prior over the sample space for the parameter θ. It represents the additional constant in equation (2.3) that makes the sampling density a proper density function. Because the nature of the denominator is to make the posterior density a proper density function, and therefore the sampling density is proportional to the likelihood function, Bayes Theorem is often reduced to: (Lynch 2007, 50-51)

Equation 2.5

$$\text{Posterior} \propto \text{Likelihood} \times \text{Prior},$$

Which states that the posterior distribution is proportional to the likelihood function multiplied by the prior distribution. In essence, the data produced by the model (posterior distribution) is a ratio of the model (likelihood function) multiplied by the information fed into the model (prior distribution), where the prior information is the constant.

While ML models are able to use the same standard function across scenarios, Bayesian models require the model to be tailored for each specific case for accurate estimation. Bayesian statistics also differs from classic statistics by seeking to summarize the entire distribution after it derives the posterior distribution for a parameter. The focus here is not on point estimation, but the integrals (the mean, median, variance, and quantiles) of a distribution. By analyzing the entire posterior distribution for a parameter, there is no need to assume normality for the distribution, as in classic approaches, because the user can directly assess whether it is or not. This also increases the number of statistical tests and summaries that can be applied to the distribution, allowing more flexibility in data representation than ML applications. While Bayesian models require more effort than classic approaches, they also provide much more information and are more flexible. Last, and most relevant to this study, is that distributions for the parameters analyzed in a Bayesian model can be easily transformed into distributions of quantities that may be of interest but may not be directly estimated as part of the original model (such as proportions of dietary source contribution) (Lynch 2007, 77–78).

2.4.2 *An Overview of Mixing Models*

The most basic linear stable isotope mixing models use two food sources with clearly separated isotopic values to ascertain their relative contributions to a target stable isotope data. Haines (1976) pioneered one of the first applications of a dietary mixing model to a question of dietary source importance. His work focused on a simple linear model to identify the relative importance of C_4 marsh grass and other C_3 plants to the diet of Atlantic fiddler crab (*Uca pugnax*) (Haines 1976). Since this first work, there has been a steady increase in the number of applications of dietary mixing models to examine animal and human trophic relations in a number of academic fields, with a marked increase in popularity in the last decade (Figure 2.3). While mixing models have become more common, a number of theoretical and technological advancements have vastly improved the capabilities of dietary mixing models. The earliest mixing models were based on classical approaches to probability statistics, and more recent Bayesian approaches have made breakthroughs in dietary estimation. Today, researchers have the ability to choose from a suite of mixing model platforms to address dietary problems, though there are pros and cons of each system (Table 2.2).

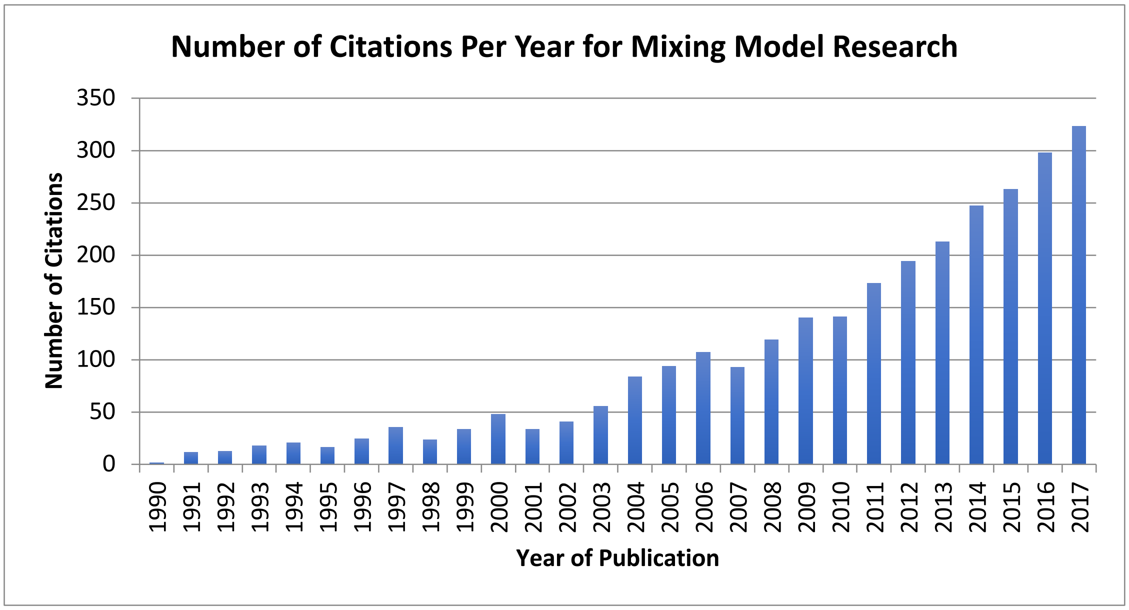


Figure 2.3 Number of citations per year from 1990 to 2017 for papers matching the search terms (a) “stable isotopes” and “mixing model” or (b) “stable isotopes” and “mixing models” from ISI Web of Knowledge. Search conducted Feb 2018.

Some early studies attempted to use Euclidian distance formulas in order to estimate dietary contributions from known food sources (Kline et al. 1993; Ben-David et al. 1997a; Ben-David et al. 1997b; Whitledge and Rabeni 1997; Szepanski, Ben-David, and Van Ballenberghe 1999). These methods were ultimately deemed unreliable, as they produced incorrect solutions for both observed and simulated data (Phillips 2001; Schwarcz 1991). A large part of the critique of the Euclidian distance method is that they failed to consider variation in the ratio of carbon to nitrogen, and the model did not preserve mass balance. Mass balance is an application of the law of conservation of mass, which states that dietary contributions from sources must sum to one when assimilated into a consumer (Hopkins and Ferguson 2012). This led to the development of mass-balance models, which ensure dietary contributions sum up to one, though some early iterations still could not address variations in C/N ratios (Phillips 2001). While these linear models allowed some measure of accuracy and reliability in simple ecological systems, they lacked the capability to cope with isotopic variability in source foods and could not accommodate the complexity and diversity of the human diet (Makarewicz and Sealy 2015). It was also of concern that early mixing models could only provide point estimates for dietary contributions (e.g. 24% A, 36% B, and 40% C), with no consideration for levels of uncertainty (Phillips et al. 2014).

Most stable isotope mixing models use the same methodology for estimating the contribution of source foods to a consumers diet. It is based on a set of mathematical equations that considers the number of dietary proxies, the number of sources, and accounts for mass-balance (Schwarcz 1991; Hopkins and Ferguson 2012). When the values of X and Y are known for both targets and sources, with the latter corrected for discrimination factors, these three equations (Equation 2.6) produce three proportional source contributions (f_1, f_2, f_3), for the mixture (m). The equations for a two proxy, three-source, mass-balanced, simple linear mixing model is shown below:

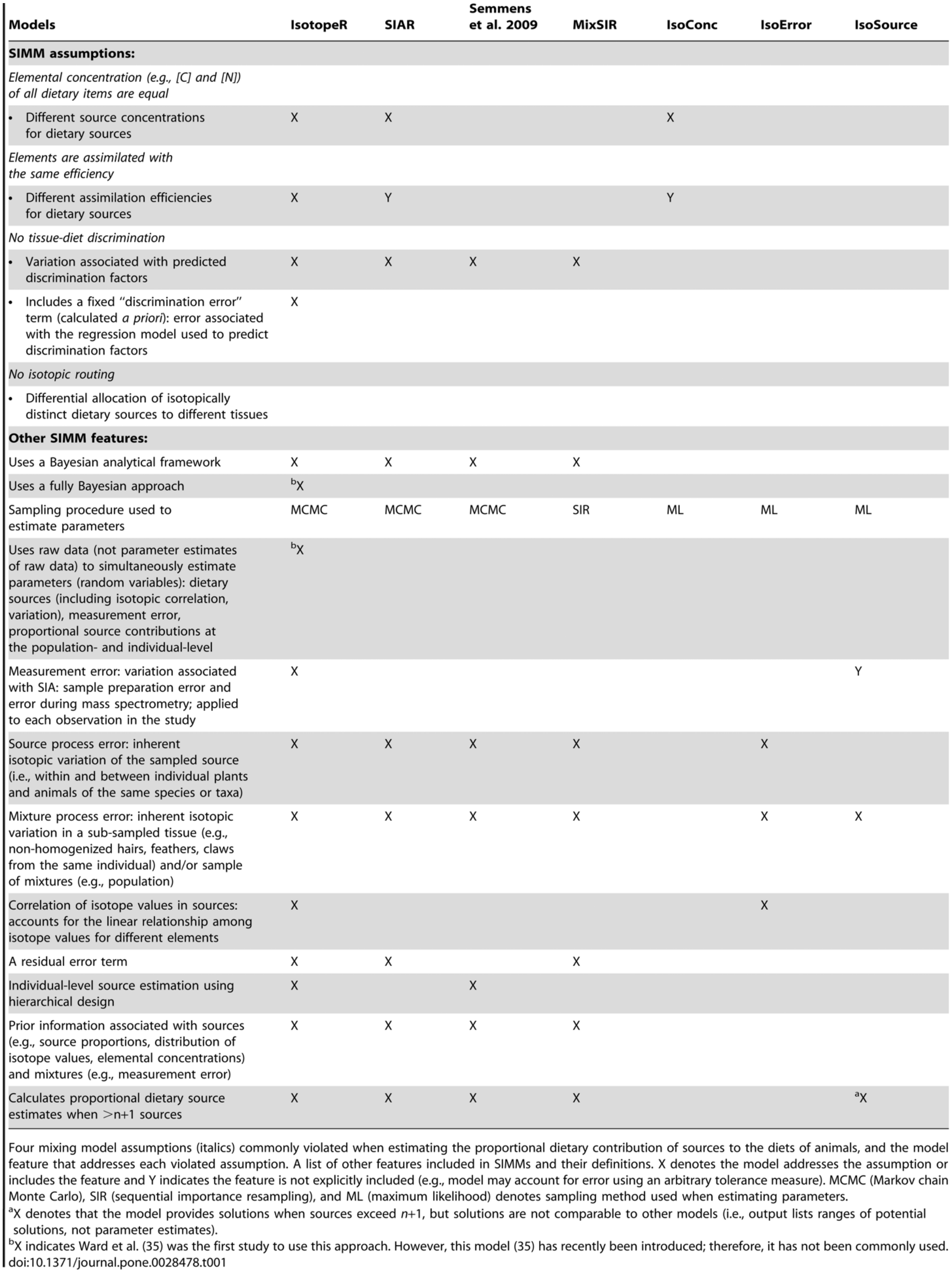
Equation 2.6

$$\delta X_m = f_1 \delta X_1 + f_2 \delta X_2 + f_3 \delta X_3,$$

$$\delta Y_m = f_1 \delta Y_1 + f_2 \delta Y_2 + f_3 \delta Y_3,$$

$$1 = f_1 + f_2 + f_3,$$

Table 2.2 A comparison of assumptions and features among commonly used SIMMs (Hopkings and Fergusan, 2012: Table 2).



Models	**IsotopeR**	**SIAR**	**Semmens et al. 2009**	**MixSIR**	**IsoConc**	**IsoError**	**IsoSource**
SIMM assumptions:							
Elemental concentration (e.g., [C] and [N]) of all dietary items are equal							
• Different source concentrations for dietary sources	X	X			X		
Elements are assimilated with the same efficiency							
• Different assimilation efficiencies for dietary sources	X	Y			Y		
No tissue-diet discrimination							
• Variation associated with predicted discrimination factors	X	X	X	X			
• Includes a fixed "discrimination error" term (calculated *a priori*): error associated with the regression model used to predict discrimination factors	X						
No isotopic routing							
• Differential allocation of isotopically distinct dietary sources to different tissues							
Other SIMM features:							
Uses a Bayesian analytical framework	X	X	X	X			
Uses a fully Bayesian approach	[b]X						
Sampling procedure used to estimate parameters	MCMC	MCMC	MCMC	SIR	ML	ML	ML
Uses raw data (not parameter estimates of raw data) to simultaneously estimate parameters (random variables): dietary sources (including isotopic correlation, variation), measurement error, proportional source contributions at the population- and individual-level	[b]X						
Measurement error: variation associated with SIA: sample preparation error and error during mass spectrometry; applied to each observation in the study	X						Y
Source process error: inherent isotopic variation of the sampled source (i.e., within and between individual plants and animals of the same species or taxa)	X	X	X	X		X	
Mixture process error: inherent isotopic variation in a sub-sampled tissue (e.g., non-homogenized hairs, feathers, claws from the same individual) and/or sample of mixtures (e.g., population)	X	X	X	X		X	X
Correlation of isotope values in sources: accounts for the linear relationship among isotope values for different elements	X					X	
A residual error term	X	X		X			
Individual-level source estimation using hierarchical design	X		X				
Prior information associated with sources (e.g., source proportions, distribution of isotope values, elemental concentrations) and mixtures (e.g., measurement error)	X	X	X	X			
Calculates proportional dietary source estimates when >n+1 sources	X	X	X	X			[a]X

Four mixing model assumptions (italics) commonly violated when estimating the proportional dietary contribution of sources to the diets of animals, and the model feature that addresses each violated assumption. A list of other features included in SIMMs and their definitions. X denotes the model addresses the assumption or includes the feature and Y indicates the feature is not explicitly included (e.g., model may account for error using an arbitrary tolerance measure). MCMC (Markov chain Monte Carlo), SIR (sequential importance resampling), and ML (maximum likelihood) denotes sampling method used when estimating parameters.

[a]X denotes that the model provides solutions when sources exceed *n*+1, but solutions are not comparable to other models (i.e., output lists ranges of potential solutions, not parameter estimates).

[b]X indicates Ward et al. (35) was the first study to use this approach. However, this model (35) has recently been introduced; therefore, it has not been commonly used.

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The equation can be expanded to accommodate additional proxies and sources, though the general principle remains the same. While more complex Bayesian mixing models use modified variations of these equations, both ML and Bayesian methods use these equations as the backbone to their estimations of dietary contributions (Hopkins and Ferguson 2012).

Phillips and Gregg (2001a, 2001b) addressed issues of uncertainty and variation inherent in previous linear mixing models with the development of the IsoError mixing model. IsoError allows the user to incorporate process error— which refers to variation in the true population size due to biotic or abiotic drivers— and isotopic correlations between sources and mixtures into the calculations. However, these linear models are only applicable in exactly determined systems, where the number of food groups is not greater than the number of dietary proxies minus one (Phillips 2001). This is rarely the case in food webs of particular interest to archaeologist and ecologists, and therefore limits the usefulness of the method to specific scenarios. When the condition is not met, the equations become underdetermined and the model loses any statistical meaning. Also, IsoError is not constrained to produce proportionate source contributions, such that when important food sources are missed or when data are incorrectly entered, the model produces illogical negative values (Phillips and Koch 2002). In addition, many of the assumptions about estimating diets using mixing models that could invalidate outputs are not addressed in IsoError (Phillips 2001; Wolf et al. 2009; Martínez del Rio, Wolf, and Gannes, 2009).

IsoConc was the next model developed to address some of the difficulties experienced by previous models. It was developed to account for the variations in elemental concentrations of dietary sources. While nitrogen stable isotopes are dictated by dietary protein, dietary carbon can exist as protein, lipid, or carbohydrate, which can then be preferentially routed by physiological processes (Schoeller et al. 1986). Previous models assumed the elemental concentrations remained constant between food sources, which can be an acceptable assumption for herbivore and carnivore diets. Omnivorous animals are exceptions as they consume sources from multiple trophic levels, causing the premise, and therefore the output, to be invalid (Phillips and Koch 2002). Instead of assuming that elemental composition remains constant across sources, IsoConc presumes the contribution of the source is proportional to the sources assimilated biomass multiplied by the sources elemental concentration (Phillips and Koch 2002). The acknowledgement of variation in elemental composition of dietary sources by Phillips and Koch (2002) caused Robbins and colleagues (2002) to point out that digestibility should also be considered when determining the elemental composition of dietary sources. In response, Koch and Phillips (2002) calculated and incorporated the corrected elemental contributions, accounting for both variation and digestibility, into their existing model. This development was a significant improvement for stable isotope mixing models, increasing the accuracy and reliability of outputs. This improvement was not without compromise, however, and IsoConc lost the ability of IsoError to account for and incorporate various sources of error (Hopkins and Ferguson 2012).

The next development for stable isotope mixing models was the introduction of IsoSource. IsoSource combines standard linear mixing model equations with incremental changes to possible source contribution combinations that sum to one (Phillips and Gregg 2003). In this way, IsoSource is able to calculate both the frequency and range of potential source combinations, even when the number of sources exceeds the allowable limit (n+1, where n is the number of dietary proxies) (Phillips and Gregg 2003). The model then predicts the feasibility of each produced combination using the means of source stable isotope values. The combination is considered feasible if the values predicted by the model fall within a designated mass balance tolerance that accounts for measurement error and source value variability (Phillips and Gregg 2003). While IsoSource is helpful in situations where a unique solution cannot be calculated, as in cases where there are too many sources for other models, the results can be difficult to interpret. While isotopic constraints can be incorporated into the model, IsoSource still relies on an ML approach to probability statistics. This means that large spreads of probability produce numerous possible scenarios without providing integrals. As each solution generated by IsoSource is equally likely in probabilistic terms, there is potential to be left with a dizzying array of equally likely solutions, with little to discuss in terms of conclusive results (Hopkins and Ferguson 2012).

Prior to the development of the first Bayesian model, MixSIR (v. 1.0.4) (Moore and Semmens 2008), all mixing models used ML approaches to probability statistics, which, as previously discussed, have theoretical pitfalls and limitations in estimating distributions of data. The advent of Bayesian mixing models allowed scholars to fit the models better to their data and estimate a larger number of parameters while simultaneously avoiding the calculation of multidimensional derivatives, as in likelihood models (Hopkins and Ferguson 2012). In addition to circumventing these tedious calculations, Bayesian models are able to include various sources of uncertainty, handle greater than n+1 sources (with some considerations), incorporate prior information, and establish ranked processes within a flexible and intuitive structure (Hopkins and Ferguson 2012). Early applications of Bayesian models showed that dietary estimations could also be completed at the individual- (Semmens et al. 2009) and population-level (Moore and Semmens 2008; Parnell et al. 2010).

MixSIR uses importance sampling to estimate the joint posterior of probability food sources for a target, where sources are reported as marginal distributions for each dietary source. Importance sampling estimates properties of a particular distribution, while only having samples generated from a different distribution other than the distribution of interest. MixSIR is also able to include relevant isotopic information into the model including tissue-diet discrimination factor means and standard deviations, single or sample population data, as well as the source means and standard deviations (Moore and Semmens 2008). Later versions of MixSIR incorporated a Dirichlet prior as recommended by Jackson and colleagues (2009). Dirichlet priors allow users to specify mean proportions that sum to one for each source, as well as a standard deviation for the first of these proportions. However, the sampling method originally used by MixSIR is less efficient than other forms and though the Dirichlet prior allows additional information to be incorporated into the model, it does not allow the user to express the uncertainties associated with the values. These issues result in variable performance, where in some cases the model performs well, and in others, the credible intervals are too narrow for acceptance (Hopkins and Ferguson 2012).

SIAR, another Bayesian method created around the same time as MixSIR, was originally developed as an extension for use in R (Parnell and Jackson, 2013). This model improved upon previous techniques by allowing the user to incorporate unequal elemental concentrations of sources into the dietary estimations. However, both SIAR and MixSIR still lacked the ability to use a concentration-dependent model for analysis at an individual level.

In response to the need to run a concentration-dependent model on an individual scale, Hopkins and Ferguson (2012) developed IsotopeR. This method incorporates the features of previous mixing models and uses a hierarchical model structure with a concentration dependence formula developed by Semmens and colleagues (2009). A hierarchical structure allows the program to make statistical inferences on only one observation per individual, while still allowing for repeated observations in order to increase the accuracy of individual-level estimates. IsotopeR also employs a joint estimation approach in contrast to MixSIR and SIAR, which allows the model to account for uncertainty inherent in the process when estimating multiple dependent quantities in a concentration-dependent model (Hopkins and Ferguson 2012).

Since the inception of dietary mixing models in the 1970s, each successive model has considered and incorporated an increasing number of variables and features that continue to increase their applicability and utility. The advent of Bayesian approaches to dietary mixing problems opened a productive avenue for development and progress in which accurate and reliable estimates of dietary source contributions could be established. However, improvements can still be made. Some critiques of the most recent mixing models include the lack of comparability between outputs of different model systems and the relative complexity of these models for the user (Bond and Diamond 2011; Fernandes et al. 2014). Recent research in stable isotope analysis has also demonstrated the importance of dietary macronutrient routing in stable isotope estimation, a feature not currently incorporated into existing methods (Fernandes et al. 2012). Additionally, these techniques do not allow diverse priors from other avenues of research (including archaeological, ecological, biochemical, or physiological data) to be incorporated into the model. However, a newly developed Bayesian mixing model FRUITS (Food Reconstruction Using Isotopic Transferred Signals) has been developed to specifically address these concerns within a user-friendly framework (Fernandes et al. 2014).

2.5 FRUITS (Food Reconstruction Using Isotopic Transferred Signals)

Fernandes and colleagues (2014) developed FRUITS to account for dietary routing of food fractions while preserving existing functions of other Bayesian dietary mixing models. Depending on the mixing problem, FRUITS is able to consider concentration dependence, dietary routing, and population or individual-level analyses, making it a flexible program to accommodate a wide range of dietary and isotopic variation. The model also provides a platform to incorporate *a priori* information from sources not directly linked to stable isotopes. These sources can include archaeological or ethnographic data to influence the percentages of animal food sources or purely physiological priors to limit the protein allowance for dietary estimates (Fernandes et al. 2014). These priors establish relationships between food fractions or sources and limit the acceptable ranges of the variables calculated by the model. FRUITS was initially tested through a case study relying on previously published data from a controlled feeding experiment. FRUITS proved capable of accurately reporting the distributions of source contributions to the overall diet in different scenarios, especially when expert prior knowledge was incorporated into the model (Fernandes et al. 2014). Three dietary scenarios were explored, and while all three managed to predict accurately that corn and gluten were the major constituents of the diet, the precision of the estimated values increased with the addition of priors. Scenario (a) was not constrained with any priors and produced the widest confidence intervals, such that the contributions of corn and gluten could not be distinguished. With the addition of a prior that states corn must be greater than gluten, scenario (b) was able to distinguish the contributions of corn and gluten to the diet, with the measured values sitting within the 68% confidence interval. However, scenario (c) produced the most precise results with the addition of a prior limiting the amount of protein that could be consumed for healthy function. The actual values of the diet were still within the estimated ranges, though the gluten value was now in the 97.5% percentile (Fernandes et al. 2014). A later application of FRUITS was able to estimate the diets of Neolithic individuals from Ostrof, Germany based on priors derived from archaeological sources (Fernandes et. al 2015). Four dietary scenarios were tested, where the plant $\delta^{15}N$ values were changed to reflect the possible use of manure as fertilizer, and $\delta^{34}S$ values were either included or excluded from the analysis. All scenarios resulted in similar dietary source contribution estimates, with an increase in uncertainty seen in scenarios that excluded the additional proxy ($\delta^{34}S$). This suggests the model is robust (i.e. not sensitive to user changes in input data). The accuracy of the model was ascertained by comparison to human dietary radiocarbon reservoir effect (RRE) values with the Lake Ostorf RRE value as a reference. RRE values measure the carbon contribution from freshwater fish to human bone collagen, the values of which correspond to the fish contribution estimations towards the $\delta^{13}C$ values of human bone collagen produced by FRUITS (Fernandez et al. 2015).

FRUITS is a combination of a graphical interface that generates a model and script which is then analyzed by BUGS (Bayesian inference Using Gibbs Sampling) software (http://www.openbugs.net/w/FrontPage), a well-establish likelihood function framework for Bayesian probability models (Lunn et al. 2000). This system determines an appropriate Markov Chain Monte Carlo (MCMC) scheme based on the Gibbs sampler to analyze the prior distribution as defined by the user, which yields a posterior distribution upon convergence of the model (Spiegelhalter et al. 1998: 29–31). FRUITS then analyzes the output generated by BUGS sampling software to generate summary statistics and graphical representations of the results. A user-friendly version of FRUITS (version 3.0) for MAC or Windows is available to download from https://sourceforge.net/projects/fruits/ as Open Source software. Basic technical support, installation troubleshooting, and introduction to the software can currently be found on the FRUITS YouTube channel: https://www.youtube.com/channel/UCxNWBKevwf4QprY7orl0q1Q.

FRUITS is based on a modified diet reconstruction equation (2.7) similar to existing models, which is summarized below from Fernandes and colleagues (2014). The introduction of the weight contribution (W_{jk}) of variable food fractions towards the signal of the consumer allows for the use of dietary proxies in which dietary routing is considered, an improvement from previous models (Fernandes et al. 2014). The main goal of dietary reconstruction is to determine the relative contribution ($\propto_i$) to a consumer's diet of each defined i-th food group. Isotopic elemental signals of consumers (H_k) are measured in tissues such as bone collagen or bioapatite, which result from the mixing of k-th food sources isotopic signal (I_{ijk}) such as protein, carbohydrates, amino acids, or lipids. Concentration dependence (C_{ij}) is factored into the dietary signal by including the j-th food fraction (or macronutrients) found in the i-th food group (e.g. plants, animals, fish). The model also considers the diet-tissue offsets (T_k) that occur during isotope fractionation. In the case of a routed model, the weight parameter (W_{jk}) is able to establish the contribution of the *j*-th food fraction towards the *k*-the consumer signal (Fernandes et al. 2014).

Equation 2.7

$$H_k = \frac{\sum_j (W_{jk} \sum_i \propto_i C_{ij} (I_{ijk} + T_k)}{\sum_j (W_{jk} \sum_i \propto_i C_{ij})},$$

Here the *k*-th dietary proxy signal (H_k) that is measured in the consumer is modeled as a normal distribution following the equation, $H_k \sim N\ (\mu_{H,k}, \sigma^2_{H,k})$ where the average value is $\mu_{H,k}$ and the associated variance is $\sigma^2_{H,k}$. The dietary proportions ($\propto_i$) of the *i*-th food group are unknowns, and their estimation is the goal of the model. Restrictions on the proportions apply where the proportion of a food group must be between 0 and 1 ($0 \leq \propto_i \leq 1$ for $i\ = 1, \ldots, n$) such that the sum of each proportion included in the analysis (*n*) sum to 1 ($\sum_{i=1}^{n} \propto_i = 1$). The isotope values ($I_{ijk}$) for the *i*-th food groups, the *j*-th food fraction, and *k*-th dietary proxy are assumed to behave as a random variable, and is modeled by a normal distribution, $I_{ijk} \sim N\ (\mu_{I,ijk}, \sigma^2_{I,ijk})$. The diet-tissue offset (T_k) for the *k*-th dietary proxy is also modeled as a normal variable, $T_k \sim N\ (\mu_{T,k}, \sigma^2_{T,k})$. The weight contribution (W_{jk}) of the *j*-th food fraction that helps to form the *k*-th target signal is also modeled as a normal variable, $W_{jk} \sim N\ (\mu_{W,jk}, \sigma^2_{W,jk})$. Lastly the concentration of the *j*-th fraction within the *i*-th food group (C_{ij}) is modeled by a normal distribution, $C_{ij} \sim N\ (\mu_{C,ij}, \sigma^2_{C,ij})$ (Fernandes et al. 2014).

The model also provides estimates of quantities other than the dietary proportions ($\propto_i$). These estimates can help the user to assess model performance, and even help to inform the user on whether or not additional prior information in needed. These estimates are the relative contributions of the *i*-th food group towards the *k*-th dietary proxy signal (θ_{ik}) and the *j*-th food fraction towards the entire diet (β_j)(Fernandes et al. 2014). The following equation calculates the relative contribution of each *j*-th food fraction to the total diet by a simple weighted averaged using the fraction concentration (C_{ij}) of the dietary proportions ($\propto_i$) (Fernandes et al. 2014):

Equation 2.8

$$\beta_j = \frac{\sum_i \propto_i C_{ij}}{\sum_j \sum_i \propto_i C_{ij}}$$

It is possible to constrain the estimations of food fractions to the entire diet (β_j) through the application of physiological and metabolic priors. These types of priors should increase the overall precision of model estimates, even when these outputs are not the main focus of the research question.

FRUITS can also determine the relative contributions of the i-th food group towards the k-th dietary proxy signal (θ_{ik}) using the following equation (Fernandes et al. 2014)

Equation 2.9

$$\theta_{jk} = \frac{\sum_i \propto_i C_{ij} W_{jk}}{\sum_i \sum_j \propto_i C_{ij} W_{jk}}$$

These estimates can help in cases where reservoir effects are observed in radiocarbon dates on human bone collagen, which often date older than expected. This can be due to the inclusion of aquatic foods in the diet, as dietary carbon is assimilated into the human body. Radiocarbon reservoir effects can be corrected by estimating the amount of carbon originating from aquatic food groups, since aquatic sources are often depleted in $\delta^{14}C$, resulting in more accurate radiocarbon dates for individuals (see Fernandes et al. 2016).

While FRUITS is capable of producing accurate, reliable, and precise estimations of dietary contributions, the output is only as good as the input. The user must be careful to ensure the proposed dietary scenarios are realistic, that the number of food groups and dietary proxies is not too far apart, and that the food groups have sufficiently different stable isotope values. If there are many food sources, aggregation prior to analysis is suggested to reduce the food sources to a manageable amount (e.g. instead of using maize, wheat, cows, pigs, trout, and perch as different food groups, aggregate them into plants, terrestrial animals, and freshwater fish). Accurate estimation does require some knowledge of the concentrations and isotopic values of sources. Often in archaeological cases, these values are measured on bone collagen in recovered remains, which does not reflect the edible portion of the source. However, by using conservative offset values between edible and recovered food remains, food fraction estimations can still be produced with relative accuracy (Fernandes et al. 2014).

The capabilities of FRUITS outlined above means the software is particularly suited for use in archaeological contexts. Providing distribution parameters for the estimations allows researchers to more critically analyze results and determine the spread of data. Additionally, archaeological scenarios often have non-isotopic information from diverse sources that can be used to constrain models. Previous iterations of mixing models for which priors could be incorporated focused on isotopic limitations, whereas FRUITS allows information from multiple avenues to be considered when applying model constraints. Likewise, the ability to apply conservative offsets allows the user to account for the inherent uncertainty associated with archaeological contexts and materials, especially in cases where there is an unknown amount isotopic variation in the parts of a resource consumed, or changes to the isotopic values of food change when cooked or processed. The goal of this work is to apply the Bayesian framework FRUITS to estimate the dietary contributions of food sources in a Middle Holocene hunter-gatherer population in the Little Sea of Lake Baikal. The next chapter discusses the method and materials used during the creation of the model.

Chapter 3: Materials and Method

3.1 Introduction

The Little Sea is an area of Lake Baikal that provides access to shallow bays, small rivers, steppe, and forested areas. This variable geography is what made the Little Sea a likely gathering place for Neolithic and Early Bronze Age hunter-gatherers. Previous isotopic studies of the Little Sea have shown the micro-region has a continuous bimodal distribution of $\delta^{15}N$ signatures representing two distinct isotopic groups. In addition, neither the carbon nor nitrogen stable isotope values correlate with each other, indicating a diet of mixed terrestrial and aquatic sources (Katzenberg et al. 2012; Weber and Bettinger 2010; Weber and Goriunova 2013). These groups, referred to as the Game-Fish and Game-Fish-Seal diets, reflect differences in consumption of Baikal seal, cove-and-lagoon fishes, and ungulates. It is thought the lack of correlation between carbon and nitrogen values for the Little Sea EBA hunter-gatherers is due to the interaction of the stable isotope signatures of consumed Baikal seal and cove-and-lagoon fish, which represent carbon-light and carbon-heavy resources, respectively (Weber et al. 2011). Similarly, the values of the GF diet seem to suggest these individuals included aquatic food resources from regions other than Lake Baikal and did not rely equally on seal consumption, in contrast to the local GFS signatures (Weber et al. 2011). It is suggested that the aquatic resources reflected in the stable isotope signatures of the GF diet are more representative of the Upper Lena, or a similar ecosystem, where local fishes are light in carbon values (Weber et al. 2011).

This chapter provides an overview of the data included in the study sample and the methodology associated with the diet reconstruction of Little Sea individuals in order to answer questions of dietary mixing and food resource contributions. This will include a discussion of relevant archaeological information, current stable isotope work, and previous IsoSource modeling. Methods and materials used in the analysis are detailed including the target and source samples, model parameters, and prior information to address this mixing problem.

3.2 Zooarchaeological and Archaeological Dietary Information

Russian archaeological excavations have produced abundant evidence for seal hunting, primarily from sites along the open coastline of the central portion of Lake Baikal, excluding the Little Sea shoreline (Losey, Nomokonova, and White 2012). Weber and colleagues (1998) and more recently Nomokonova and colleagues (2010; 2015) work on seasonality and age at death of seal canines suggests seal hunting occurred in winter and early spring. Seals would be most vulnerable to human predation during spring when they bask on the ice, and the season also corresponds to a lean time for terrestrial mammals. Seasonality estimations for Baikal seal from Nomokonova and colleagues (2015) work suggest spring to early summer procurement for seals, which is in agreement with earlier publications (Weber et al. 1998; Nomokonova et al. 2010). Seal hunting activities can be reconstructed from remains recovered from two trenches at Sagan-Zaba II, located along the western shore of Lake Baikal just South of Ol'khon Island, where 16,283 (NISP) Baikal seal remains were identified. The majority of the seal bones were recovered from strata dating between 6750 cal B.P. and 4870 cal B.P. indicating a peak in hunting frequency at this locality. The next most plentiful species found at Sagan-Zaba II is the *salmonidae* taxon (whitefish, grayling, or omul') with 851 (NISP) remains recovered. Shallow water fishes such as roach, perch, and pike are found in relatively small frequencies, with 5, 55, and 15 total NISP recovered from all strata, respectively. Other faunal remains include various species of mollusks, fish, terrestrial mammals, and birds that are native to the area.

Losey and colleagues (2008) and Nomokonova and colleagues (2009) also analyzed the faunal remains recovered from the Ityrkhei habitation site located near Khuzhir-Nuge XIV. Ityrkhei seems to have been used throughout the Holocene, with a peak between 8000 and 4300 cal BP. Faunal analysis of early excavations resulted in the recovery of 8,400 (NISP) specimens from ~290m^3 of sediment, 97% of which were fish, despite that excavations occurred without the use of sieves (Losey et al. 2008). Excavations in 2005 employed 2mm sieves, and subsequently produced 11,300 (NISP) faunal remains from ~7m^3 of sediment, of which 99% were fish bones. This high density indicates that Ityrkhei was a site focused on fish procurement and processing. Other animals recovered include small amounts of waterfowl, moose, red deer, dog, and Baikal seal bones (Losey et al. 2008). Losey and colleagues (2008) also argue that the disproportionate representation of size categories in fish species represent selective fishing focusing on adult specimens through the use of large-gauge nets and traps to catch fish around or over 20cm in length.

The fishing equipment available to EBA hunter-gatherers in the Cis-Baikal include hooks, harpoons, and nets all of which are confirmed from archaeological investigations (Okladnikov 1971). Weirs, traps, and fences, though not identified in the archaeological record, could have been used in the rivers, lagoons, and the lake itself (when covered in ice) with varying success (Novikov and Goriunova 2005; Weber and Bettinger 2010). While direct archaeological evidence of watercraft use is missing from the archaeological record, studies on human bone morphology (Stock et al. 2010) and musculoskeletal stress markers (Lieverse et al. 2009; Lieverse et al. 2011) show skeletal evidence consistent with watercraft use. Cultural markers of intensive watercraft use such as storage, larger camps, and sturdier housing, are absent suggesting that if watercraft were in use in the Cis-Baikal region, it had not yet reached a point of significant economic impact (Weber et al. 2011). Considered as a whole, the fishing technology of the Middle Holocene would have allowed individuals access to all species of fish in the Angara and Lena Rivers, but variable access to Lake Baikal resources, where the fishes sort themselves into habitats where some (mainly cove and lagoon, and to some extent open coast littoral) are much easier to access than others (gulf and pelagic).

Waterfowl and their eggs may be another predictable and easily accessible food that drew prehistoric people together to particular regions, a behaviour that is documented in ethnographic accounts of northern hunter-gatherers (Alekseenko 1999; Anderson 1999; Feit 1999; Asch and Smith 1999; Ziker 2002). The source of the Angara River South of the Little Sea remains ice-free year-round, offering a suitable nesting site for waterfowl. Overall, the data suggest a seasonal round of food availability, during which individuals ate what was available. According to faunal evidence, fish, seal, and ungulates were the most frequently hunted species, and should comprise the majority of the diet of Little Sea hunter-gatherers. While faunal remains indicate presence and absence of dietary resource, they are at best an indirect measure of diet contribution, as only records the remains of resource processing in one particular area. These analyses cannot directly reflect the actual rates at which dietary sources have been consumed by individuals or groups and can only speak to what has been preserved in the archaeological record.

3.3 Stable Isotopes at Khuzhir-Nuge XIV

The dietary adaptations of individuals in the Cis-Baikal region can be considered comparable to patterns seen in other coastal populations in other parts of the world, as they combine both aquatic and terrestrial resources in their diet. Previous studies of stable isotopes in human and animal bones have shown that ungulates, freshwater fish, and seal meat played significant roles in the Middle Holocene hunter-gatherer diet in Cis-Baikal (Katzenberg and Weber, 1999; Katzenberg, Goriunova, and Weber 2009; Katzenberg et al. 2010; Katzenberg et al. 2012; Weber et al. 2002; Weber et al. 2011). These data are in approximate agreement with the archaeological, zooarchaeological, and ethnographic data for the region. However, the relative contributions of each of these sources are difficult to discern due to the contribution of isotope values from two food webs with substantially different ranges to the diet.

In contrast to other micro-regions such as the Angara, individuals within the Little Sea show a large amount of variability in stable isotope signatures. Neither the carbon nor the nitrogen values are correlated with one another, and the $\delta^{13}C$ values are shifted c. 3–5‰ towards the lighter end of the axis for the whole population when compared to the Angara pattern (Weber et al. 2011). Previous analysis has suggested that this variability is a result of the interaction between the Baikal seal and cove-and-lagoon fish, the former carbon light and the latter carbon heavy. A diet consisting of these two isotopically distinct sources in addition to ungulates would result in individuals' being placed between the seal and fish values, with a wider spread in $\delta^{13}C$ values than otherwise expected (Weber et al. 2013). This pattern is well-documented in the Little Sea, and additional variation is noted through the existence of two distinct diets, GF and GFS (Weber and Goriunova 2013). These values are different enough to suggest individuals were drawing on different food groups, and perhaps on different ecosystems, resulting in a bimodal distribution seen strongly in $\delta^{15}N$ values. The GFS diet is present in all Little Sea cemeteries, and throughout the Late Neolithic and Early Bronze Age, while the valleys of the Angara and Upper Lena show only individuals with little to no seal contribution throughout the Late Neolithic and Early Bronze Age as indicated by their $\delta^{15}N$ values (Weber et al. 2011). Further, other research has shown that EBA populations in the Little Sea were heterogeneous in diet and place of birth (Haverkort et al. 2008; Katzenberg, Goriunova, and Weber 2009; Weber et al. 2011; Weber and Goriunova 2013). Strontium values in first molars of 22 Little Sea individuals have shown that all individuals with a GFS diet are identified as local (n=11), while the non-locals born outside of the Little Sea exhibited the GF (n=7) and GFS (n=6) diet in roughly the same proportions (Weber and Goriunova 2013). Thus, it can be said that the GFS diet is local to the Little Sea, while the GF diet is non-local. While it seems the GF diet is a relatively good predictor of non-local birth, it should be cautioned that the sample size is small and there are non-locals that show the GFS diet.

At Khuzhir-Nuge XIV, both carbon and nitrogen values exhibit variation between individuals indicating some variability in food consumption was common (Katzenberg, Goriunova, and Weber 2009; Weber et al. 2011). This variability is also reflected in mortuary practices, as grave placement in the cemetery can be linked to $\delta^{15}N$ values and diet group membership. The West Sector of Khuzhir-Nuge XIV exclusively contained individuals with the GFS diet, while the East and Centre Sector included a mixture of individuals with GFS and GF diets forming distinct spatial clusters (Weber et al. 2011). Katzenberg, Goriunova, and Weber (2009) suggest this may indicate social complexity, often seen in groups subsisting on abundant and reliable aquatic resources (Binford 2001: 368). A total of 45 individuals were found to belong to the GFS dietary group, with mean $\delta^{15}N$ and $\delta^{13}C$ values of 14.8 ±0.8‰ and −18.1 ±0.7‰, respectively. The GF diet was found in 26 individuals, who displayed $\delta^{15}N$ values averaging 11.9 ±0.66‰, and a mean $\delta^{13}C$ value of −19.4 ±0.3‰ (Weber and Goriunova 2013). These dietary groups were found to be significantly different from one another, even when subadults were removed from the sample (Weber and Goriunova 2013). Comparisons between the $\delta^{13}C$ of bone collagen and carbonate revealed a lack of correlation in the data, which has been attributed to the consumption of a diet with mixed terrestrial and aquatic resources (Prowse et al. 2005; Keenleyside et al. 2009; Hard and Katzenberg 2011). The $\delta^{13}C_{collagen}$ and $\delta^{13}C_{carbonate}$ spacing should be around 4‰ when individuals are consuming mainly animal foods (Krueger and Sullivan 1984; Lee-Thorp et al. 1989). However, the values at Khuzhir-Nuge XIV range from 3.2‰ to 9.3‰ (Katzenberg, Goriunova, and Weber 2009). Katzenberg, Goriunova, and Weber (2009) suggest these measurements are the result of variation in isotope values from fat and protein of food sources, coupled with the use of two distinct food webs, which further complicates the interpretation of results. This discrepancy between food web isotope signatures is also noted in later publications (Katzenberg et al. 2010; Katzenberg et al. 2012). The high $\delta^{15}N$ values seen in Cis-Baikal populations make clear that no groups relied solely on terrestrial resources; however, it is the same high $\delta^{15}N$ values that mask contributions of terrestrial game to the overall diet (Katzenberg et al. 2010). This issue is also seen in $\delta^{13}C$, as the stable isotopes signatures only indicate whether fish enriched in $\delta^{13}C$ were included in the diet and not the degree of reliance on these foods (Katzenberg et al. 2010).

Overall, the stable isotope values of the GFS diet group at Khuzhir-Nuge XIV are best explained by considering a diet composed of ungulates, seal, and cove-and-lagoon fishes. Weber and colleagues (2011) note that the Baikal seal drives the distribution up the nitrogen scale, and down the carbon scale, while cove-and-lagoon fishes drive the distribution up the carbon scale. Therefore, human diets that contain variable amounts of each of these sources would result in patterns seen in Khuzhir-Nuge XIV — a distribution of isotope values that are not correlated and are scattered across the axes. While the naming conventions of the GF dietary group suggest a simple removal of seal from the GFS diet, the isotopic variation seen in the GF group cannot be accounted for with just a lack of seal. If this were the case, the omission of seal would move carbon values toward the heavy end of the axis, rather than the lighter carbon values seen in the GF group (Weber et al. 2011). Rather, the values are more indicative of a non-Lake Baikal aquatic food source. Given the variable bathymetry of the Little Sea gulf and the subsequent variation in carbon values of the fish located there, a diet based on these sources would exhibit a wide range of carbon values. This is contrary to the GF group data, which display a narrow range of carbon isotope values (spread of 1.2‰). It is much more likely that the fish component of the GF diet is sourced from areas with light carbon fish, the likes of which has been documented in the Upper Lena river valley (Weber et al. 2011).

The stable isotope values of Khuzhir-Nuge XIV present an interesting and challenging case study. The patterns of dietary variability and emphasis on ungulate, fish, and seal meat are prevalent throughout all periods of continuous cemetery use at Khuzhir-Nuge XIV (Katzenberg, Goriunova, and Weber 2009). Individual variation in consumption patterns of the same sources is reflected in their isotope values, which can then be divided into GF and GFS diets. These diets correlate to local or non-local membership, though both non-locals and local exhibit a GFS diet. The complexity of the mixing problem is evident with the variation seen in aquatic stable isotope values, which further muddles the meaning of human values. As a result of the variation and patterns seen in the stable isotope values, four hypotheses have been constructed to provide clarity in the dietary strategies of the GFS and GF diet groups at Khuzir-Nuge XIV.

3.4 Research Hypotheses

The continued research of BAP provides a coherent framework within which it is possible to investigate multiple aspects of the region's culture history and integrate this information within . The substantial dataset of published and unpublished stable isotope values for both faunal and human samples provides the basis for the current project. These values are integral to mixing model research, such that this project would be impossible without them. The patterns already seen in the isotope values provide general expectations and hypotheses that guide the conjectures within this work, namely the distinction between a GF and GFS diet. While inclusion and exclusion of certain dietary sources are suspected in these diets, FRUITS allows the testing of the likelihood of these hypotheses. Not only does this project exploit the broad and extensive body of research available in the Cis-Baikal, but it also challenges the utility of FRUITS as a mixing model. The conjectures guiding this research are built from the existing knowledge base of colleagues who have worked to define important features of these early peoples.

This work will focus on the quantification of source food contributions to the group and individual diets of Early Bronze Age populations of the Little Sea micro-region in Cis-Baikal. The data used for this analysis include new, still unpublished, carbon and nitrogen stable isotope values for source foods generated recently by BAP, as well as those published previously (Katzenberg et al. 2012; Weber, Link, and Katzenberg 2002). These will be used in addition to values acquired for individuals from the Little Sea cemetery Khuzhir-Nuge XIV, which have been previously published (Katzenberg, Goriunova, and Weber 2009; Katzenberg et al. 2012; Weber, Link, and Katzenberg 2002). Additional information from the fields of physiology, ethnography, and zooarchaeology will also be incorporated into priors during the model construction. A more detailed overview of the data used is provided in Section 3.5. This research is guided by the following hypotheses:

Hypothesis 1: If the GFS Locals are largely accepted by the model and produce precise estimates, it can be posited that the Little Sea FRUITS model adequately represents the dietary landscape of the Little Sea.

Hypothesis 2: If Hypothesis 1 is accepted, the GFS Non-Local group will show a mix of accepted and rejected individuals, where the accepted individuals represent long-term migrants, whose dietary signatures reflect a local diet, and the rejected individuals represent either:

a. recent migrants whose dietary signatures have not yet transitioned to a completely local values, or
b. migrants who continue to obtain dietary resources from two distinct isotopic food webs.

Hypothesis 3: If Hypothesis 1 is accepted, and the model predicts a high contribution from the Fish 1 and Fish 2 groups and a low or near zero contribution from the Baikal seal for GF individuals, it can be posited that they are obtaining the aquatic portion of their diet from Lake Baikal.

Hypothesis 4: If Hypothesis 1 is accepted, and all individuals belonging to the GF dietary group are rejected by the Little Sea FRUITS model, it can be posited that the aquatic portion of their diet is a source other than Lake Baikal.

   a. If Hypothesis 4 is accepted, it is possible that these individuals reflect migrants from the Upper Lena, or other isotopically similar ecosystems.

3.5 IsoSource Modelling

Previous attempts at quantifying potential food contributions for Baikal hunter-gatherers used IsoSource as the mixing model of choice (Katzenberg et al. 2012). As discussed in Chapter 2, IsoSource combines standard linear mixing model equations with small adjustments in source contributions that sum to one, allowing the model to calculate the frequency, range, and feasibility of potential combinations (Phillip and Gregg 2003). But as it is not set within a Bayesian framework the results can be difficult to interpret when there are too many possible solutions. Katzenberg and colleagues (2012) calculated mean stable isotope values from faunal bone data that were adjusted for offsets between diet and tissue. Birds were excluded from the analysis due to the small sample size (n=2) and distinct isotope signatures. Plants were also excluded from the analysis as they were expected to be a small, though constant, dietary contribution (Katzenberg et al. 2012). The results showed that the largest dietary contribution for all groups was whitefish, and other fish with similar isotope ratios, closely followed by seals. Terrestrial mammals made up a smaller proportion of the diet, with the exception of the East Sector of graves from Khuzhir-Nuge XIV, with the individuals belonging to the GF dietary group (Katzenberg et al. 2012). While Katzenberg and colleagues (2012) were able to identify possible ranges of dietary contributions, the model produced an extremely large number of potential solutions to the dietary mixing problem.

This application of dietary mixing modeling was not conducted with enough thought regarding the complex food web of the Cis-Baikal; and, even though IsoSource allows constraints to be applied to a mixing scenario, they were not employed. As a result, the analysis is without merit. Katzenberg and colleagues (2012) model produced an average of 92,290 feasible solutions for each group analyzed. Because the model produced such a copious number of possible solutions, the conclusions lacked specificity and were only able to convey a broad comparison of proportional representation; therefore, this study has little application to the current study. Additionally, the analysis was done by group, and not by individual, which averaged out their isotopic signatures and effectively ignored the variation seen between GF and GFS dietary groups at Khuzhir-Nuge XIV. Due to these inconsistencies and errors, the results from IsoSource modeling were quite meaningless for interpreting the contributions of dietary sources to Little Sea individuals. The following analysis aims to shed more light on the dietary contributions of individuals in the Little Sea by applying the Bayesian framework FRUITS, which offers more flexibility for this complicated mixing problem. The advantages of FRUITS relative to other frameworks have been presented in Chapter 2. The next few sections will discuss how the model for this study was created, including target and source sample information, the process of source aggregation, and which prior information was incorporated in the analysis. Discussion regarding prior information will also contain discussions on the values of macronutrient composition, concentration dependence, and diet-to-tissue offsets.

3.6 Samples

3.6.1 *Target Sample (Khuzhir-Nuge XIV)*

Target data are derived from carbon and nitrogen stable isotope analysis of 30 individuals from the cemetery of Khuzhir-Nuge XIV, reported in Katzenberg, Goriunova, and Weber's (2009) article. The 22 individuals for which strontium stable isotope data (reported in Haverkort et al. 2008) are available were preferentially selected in order to see if it is possible to identify local and nonlocal individuals displaying a GFS diet based on the proportion of seal they include in their diet. The other eight individuals were selected to balance out sex differences and represent different age groups (Table 3.1). The cemetery is the largest EBA cemetery located along the West coast of the Little Sea micro-region and is just North of the southern tip of Ol'khon Island. The cemetery overlooks the lake with the graves located on a hill between two bedrock outcrops. Graves were located quite close to the surface (30–60 cm below the surface) with bedrock composed of schist lining the bottom of each grave. The cemetery of Khuzhir-Nuge XIV produced 89 individuals from 79 graves over the course of six excavation seasons by the Baikal Archaeological Project under the direction of Dr. Olga Goriunova and Dr. Andrzej Weber.

McKenzie (2006), McKenzie and colleagues (2008) and Weber and Goriunova (2013) identified the West, Central, and East Sectors of graves based on mortuary characteristics such as grave size, spatial distribution, demographic composition, grave goods distribution, and mortuary customs. There were seven double and two triple burials found in the Central Sector, an area that also produced evidence of fire activity in 17 of the burials, including fragments of birch charcoal (Lieverse 2007a; Weitzel 2007). Most graves were oriented West-East with the head towards the West; however, one grave (dated to the EN) was oriented North-South, with the head to the North (Weber et al. 2005). There is a distinct lack of infant remains under 2 years in the cemetery, with the youngest individual aged 2–3 years; however, there are 16 children aged between 2 and 12 years interred at Khuzhir-Nuge XIV, indicating only young infants were excluded from internment (Lieverse et al. 2007).

Initial radiocarbon dates for Khuzhir-Nuge XIV indicated that the cemetery was in use for approximately 700 years, between 2700 and 2000 cal. B. P. (Weber et al. 2005). However, a new examination of the chronology suggests a significant change in dates due to the freshwater reservoir effect. An average correction of 406 ^{14}C years for individuals belonging to the GFS dietary group and 200 ^{14}C years for those in the GF group was applied to the Khuzhir-Nuge XIV cemetery (Weber et al. 2016b). The full analysis of these corrected radiocarbon dates is forthcoming. The radiocarbon dating was conducted at the Oxford Radiocarbon Accelerator (ORAU) at the University of Oxford, UK, with stable carbon and nitrogen isotope ratios, collagen yields, and C/N ratios reported simultaneously. Samples were preferentially taken from long bones and some from ribs. In the case where the burials were only partially burnt, the samples were taken from the unburnt portion of the bone. As the stable isotope signatures were reported at the same time, the values taken from long bones and ribs represent long term averages over the last 7–10 years of life. The analytical precision for δ^{15}N was ±0.3 and ±0.2 for δ^{13}C (Weber et al. 2016b). After accounting for the FRE, all 89 burials date to between 3270 and 3864 ± 60 cal. B.P. during the Early Bronze Age (Weber et al. 2016b), including those within this analysis (Table 3.1). Lieverse (2005) and Lieverse and colleagues (2007) created osteobiographies for the individuals including sex, age at death, and any skeletal or dental pathology. The preservation of bones was affected by mortuary practices such as burning, grave disturbance, and by the bedrock upon which the graves rested (Lieverse 2007b).

A study number was assigned to each individual due to limitations of FRUITS in accepting special characters in name fields (Table 3.1). The study number lists the cemetery mnemonic name with the first three characters— ‘K14’— followed by a code of the dietary group they belong to, either GF or GFS.

The remaining digits reflect their assigned burial number as noted in the Master ID table field, with the leading ‘0’ removed for sake of brevity.

3.6.2 *Dietary Sources Sample*

Beginning in the 1990s, ancient and modern samples were obtained from various archaeological sites and local fishermen (Katzenberg and Weber 1999; Weber et al. 2002). Weber and colleagues (2002), and later Katzenberg and colleagues (2012) published carbon and nitrogen stable isotope results on the bone collagen of collected samples in order to contextualize the human stable isotope data. Further paired dating studies also increased the faunal data available from archaeological contexts, as carbon and nitrogen isotope values were produced as a by-product of radiocarbon dating. Due to the wealth of archaeological specimens now available, all results from modern samples were excluded from this study. Likewise, only specimens retrieved from the Little Sea area were considered for this analysis. The samples are sourced from the following sites: Little Sea, Tyshkine I and II, Berloga, Bugul’deika, Ityrkhei, Khuzhir-Nuge XIV, Kulara III, Kurma XI, Sagan-Zaba, Sagan-Nuge, Shamanskii Mys, Todakta I, Tudugu, and Ulan-Khada. A number of species for which stable isotope data are available were also excluded, as there is no archaeological or ethnographic basis for their consumption as food resources. These excluded species are bear, squirrel, dog, and unidentified specimens. These decisions filtered the data such that they represent the effective environment of the ancient isotopic landscape for groups living along the coastline of the Little Sea (Table 3.2). Most of these are unpublished BAP faunal data, though several have been previously published by Weber and colleagues (2002).

Table 3.1 Individuals included in the study sample, after Katzenberg et al. 2012.

Cemetery Name	Master ID	Study ID	Age	General Age	Sex	Sector	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
Khuzhir-Nuge XIV	K14_1993.002	K14GFS02	20+ y.	Adult	U	n/a	3683±62	−18.5	14.9	GFS	Non-local
Khuzhir-Nuge XIV	K14_1993.004	K14GF04	20+ y.	Adult	U	Centre	3532±61	−20.1	11.7	GF	Non-local
Khuzhir-Nuge XIV	K14_1993.005	K14GFS05	20+ y.	Adult	U	West	3864±61	−16.6	15.5	GFS	Non-local
Khuzhir-Nuge XIV	K14_1997.010	K14GFS10	20–25 y.	Adult	U	West	3759±61	−18.5	13.4	GFS	Non-local
Khuzhir-Nuge XIV	K14_1997.011	K14GFS11	35–50 y.	Adult	M	West	3518±61	−18.4	15.5	GFS	Local
Khuzhir-Nuge XIV	K14_1997.012	K14GFS12	25–35 y.	Adult	U	West	3523±61	−18.3	13.9	GFS	Local
Khuzhir-Nuge XIV	K14_1997.014	K14GFS14	35–50 y.	Adult	M?	West	3499±61	−18.4	14.5	GFS	Local
Khuzhir-Nuge XIV	K14_1997.015	K14GFS15	25–35 y.	Adult	M	West	3715±60	−17.4	15.0	GFS	Local
Khuzhir-Nuge XIV	K14_1997.016	K14GFS16	7–9 y.	Adult	U	West	3380±61	−17.6	16.2	GFS	Local
Khuzhir-Nuge XIV	K14_1997.019	K14GFS19	35–50 y.	Adult	F	West	3593±61	−16.7	15.7	GFS	Non-local
Khuzhir-Nuge XIV	K14_1998.027.01	K14GF2701	35–50 y.	Adult	M	Centre	3391±61	−19.3	12.7	GF	Non-local
Khuzhir-Nuge XIV	K14_1998.034	K14GF34	25–35 y.	Adult	M	Centre	3587±65	−19.6	12.0	GF	Non-local
Khuzhir-Nuge XIV	K14_1998.035.01	K14GF3501	18–20 y.	Adult	M?	Centre	3514±61	−19.0	12.6	GF	Non-local
Khuzhir-Nuge XIV	K14_1998.036.01	K14GF3601	35–50 y.	Adult	U	Centre	3582±60	−18.9	12.4	GF	Non-local
Khuzhir-Nuge XIV	K14_1998.036.02	K14GF3602	4–6 y.	Subadult	U	Centre	3660±38	−19.2	12.7	GF	Non-local

Cemetery Name	**Master ID**	**Study ID**	**Age**	**General Age**	**Sex**	**Sector**	**^{14}C Date**	**δ^{13}C**	**δ^{15}N**	**Diet**	**Birth**
Khuzhir-Nuge XIV	K14_1998.037.01	K14GF3701	15–20 y.	Adult	M?	Centre	3689±60	−19.0	11.1	GF	Non-local
Khuzhir-Nuge XIV	K14_1998.037.02	K14GF3702	15–20 y.	Adult	M?	Centre	3538±56	−19.2	11.7	GF	Non-local
Khuzhir-Nuge XIV	K14_1998.038	K14GFS38	35–50 y.	Adult	M	Centre	3618±60	−18.4	13.6	GFS	Non-local
Khuzhir-Nuge XIV	K14_1998.039	K14GFS39	9–11 y.	Adult	U	Centre	3509±61	−17.5	16.1	GFS	Local
Khuzhir-Nuge XIV	K14_1999.044	K14GFS44	35–50 y.	Adult	M	Centre	3392±61	−17.8	15.9	GFS	Local
Khuzhir-Nuge XIV	K14_1999.045	K14GFS45	8–10 y.	Adult	U	Centre	3540±59	−17.9	14.4	GFS	Local
Khuzhir-Nuge XIV	K14_1999.046	K14GFS46	25–35 y.	Adult	M	Centre	3527±61	−18.4	14.2	GFS	Non-local
Khuzhir-Nuge XIV	K14_1999.051	K14GFS51	18–20 y.	Adult	M	Centre	3645±61	−17.6	14.8	GFS	Non-local
Khuzhir-Nuge XIV	K14_1999.055	K14GFS55	35–50 y.	Adult	M?	Centre	3505±61	−17.7	15.4	GFS	Local
Khuzhir-Nuge XIV	K14_1999.057.02	K14GF5702	35–50 y.	Adult	M	Centre	3639±59	−16.6	16.6	GFS	Non-local
Khuzhir-Nuge XIV	K14_1999.058.01	K14GFS5801	25–35 y.	Adult	U	Centre	3710±61	−17.2	14.8	GFS	Non-local
Khuzhir-Nuge XIV	K14_1999.059.02	K14GFS5902	18–20 y.	Adult	M	Centre	3439 ±57	−18.6	13.6	GFS	Local
Khuzhir-Nuge XIV	K14_2000.063	K14GFS63	16–18 y.	Adult	U	Centre	3529±62	−17.1	15.6	GFS	Local
Khuzhir-Nuge XIV	K14_2000.064	K14GFS64	25–35 y.	Adult	M	Centre	3637±61	−17.4	14.8	GFS	Local
Khuzhir-Nuge XIV	K14_2000.077	K14GF77	12–15 y.	Adult	U	East	3776±56	−18.7	10.5	GF	Non-local

Table 3.2 Carbon and nitrogen stable isotope values of fauna included in the study sample.

ESAMP_ID	**BHAP No.**	**Micro-region**	**Site**	**Sample Age**	**Material**	**Species**	**Common Name**	**%Yld**	**%C**	**δ^{13}C**	**δ^{15}N**	**C:N**
E 2012.0101	2012-12	Little Sea	Sagan-Nuge III	prehistoric	bone	Lota lota	Burbot	10.2	43.5	−11.2	11.5	3.5
E 2012.0100	2012-12	Little Sea	Sagan-Nuge III	prehistoric	bone	Lota lota	Burbot	16.8	43.0	−16.1	12.7	3.3
E 2012.0089	2012-12	Little Sea	Ityrkhei	prehistoric	bone	Leuciscus leuciscus baicalensis	Dace	6.7	40.0	−13.1	9.5	3.5
E 2001.0799	2012-16	Little Sea	Little Sea	modern	bone	Thymallus arct. b.br	Grayling	100.0	42.4	−14.7	11.6	3.2
E 2001.0797	2012-16	Little Sea	Little Sea	modern	bone	Thymallus arct. b.br	Grayling	100.0	41.0	−10.0	9.2	3.2
E 2012.0104	2012-12	Little Sea	Sagan Zaba II	prehistoric	bone	Thymallus sp.	Grayling	6.7	42.1	−11.6	10.7	3.4
E 2012.0103	2012-12	Little Sea	Sagan Zaba II	prehistoric	bone	Thymallus sp.	Grayling	11.6	42.2	−14.2	10.2	3.3
E 2012.0083	2012-12	Little Sea	Ulan-Khada	prehistoric	bone	Salmonidae	Grayling	7.0	39.8	−17.8	10.2	3.5
E 2012.0078	2012-12	Little Sea	Ulan-Khada	prehistoric	bone	Salmonidae	Grayling	3.5	39.3	−17.2	10.2	3.9
E 2001.0796	2012-16	Little Sea	Little Sea	modern	bone	Perca fluviatilis	Perch	100.0	41.2	−11.3	10.8	3.3
E 2012.0092	2012-12	Little Sea	Ityrkhei	prehistoric	bone	Perca fluviatilis	Perch	9.9	41.2	−11.9	11.0	3.4
E 2012.0087	2012-12	Little Sea	Ityrkhei	prehistoric	bone	Perca fluviatilis	Perch	9.8	42.7	−11.9	13.0	3.4

ESAMP_ID	**BHAP No.**	**Micro-region**	**Site**	**Sample Age**	**Material**	**Species**	**Common Name**	**%Yld**	**%C**	**δ^{13}C**	**δ^{15}N**	**C:N**
E 2012.0085	2012-12	Little Sea	Ityrkhei	prehistoric	bone	Perca fluviatilis	Perch	9.2	40.4	−12.9	10.8	3.4
E 2012.0084	2012-12	Little Sea	Ityrkhei	prehistoric	bone	Perca fluviatilis	Perch	14.3	43.3	−14.1	11.4	3.2
E 2012.0079	2012-12	Little Sea	Ulan-Khada	prehistoric	bone	Perca fluviatilis	Perch	9.8	41.7	−14.7	10.4	3.4
E 2012.0076	2012-12	Little Sea	Ulan-Khada	prehistoric	bone	Perca fluviatilis	Perch	7.6	41.2	−13.7	10.6	3.5
E 2012.0006	2016-05	Little Sea	Berloga	prehistoric	bone	Cervus elaphus	Red Deer	6.5	43.8	−19.0	6.9	3.2
E 2010.0040	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Cervus elaphus	Red Deer	0.9	43.7	−19.4	6.1	3.3
E 2010.0040	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Cervus elaphus	Red Deer	1.6	43.0	−19.4	6.0	3.3
E 2010.0036	2010-04	Little Sea	Bugul'deika	prehistoric	tooth	Cervus elaphus	Red Deer	4.2	45.5	−19.2	7.3	3.2
E 2010.0019	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Cervus elaphus	Red Deer	5.3	45.7	−19.7	0.0	3.3
E 2010.0019	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Cervus elaphus	Red Deer	6.1	45.8	−19.5	4.3	3.3
E 2012.0015	2016-05	Little Sea	Ityrkhei	prehistoric	bone	Cervus elaphus	Red Deer	7.6	43.9	−18.9	5.5	3.2
E 2012.0012	2016-05	Little Sea	Ityrkhei	prehistoric	bone	Cervus elaphus	Red Deer	13.4	43.9	−21.3	5.1	3.2
E 2012.0043	2012-02	Little Sea	Khuzhir-Nuge XIV	prehistoric	tooth	Cervus elaphus	Red Deer	9.7	44.4	−20.0	6.1	3.1
E 2012.0042	2012-02	Little Sea	Khuzhir-Nuge XIV	prehistoric	tooth	Cervus elaphus	Red Deer	15.3	43.9	−20.0	7.9	3.2

ESAMP_ID	BHAP No.	Microregion	Site	Sample Age	Material	Species	Common Name	%Yld	%C	$\delta^{13}C$	$\delta^{15}N$	C:N
E 2012.0041	2012-02	Little Sea	Khuzhir-Nuge XIV	prehistoric	tooth	Cervus elaphus	Red Deer	8.0	43.8	−19.8	7.6	3.2
E 2012.0040	2012-02	Little Sea	Khuzhir-Nuge XIV	prehistoric	tooth	Cervus elaphus	Red Deer	7.0	42.8	−18.9	6.9	3.2
E 2012.0039	2012-02	Little Sea	Khuzhir-Nuge XIV	prehistoric	tooth	Cervus elaphus	Red Deer	4.4	44.1	−19.3	6.4	3.2
E 2012.0038	2012-02	Little Sea	Khuzhir-Nuge XIV	prehistoric	tooth	Cervus elaphus	Red Deer	6.4	43.2	−18.9	7.5	3.2
E 2012.0037	2012-02	Little Sea	Khuzhir-Nuge XIV	prehistoric	tooth	Cervus elaphus	Red Deer	2.4	44.0	−19.6	6.5	3.2
E 2012.0036	2012-02	Little Sea	Khuzhir-Nuge XIV	prehistoric	tooth	Cervus elaphus	Red Deer	6.9	43.0	−19.1	5.3	3.2
E 2012.0023	2016-05	Little Sea	Kulara III	prehistoric	bone	Cervus elaphus	Red Deer	8.7	44.5	−20.2	3.9	3.3
E 2012.0022	2016-05	Little Sea	Kulara III	prehistoric	bone	Cervus elaphus	Red Deer	6.5	44.7	−19.4	4.3	3.2
E 2012.0035	2012-02	Little Sea	Kurma XI	prehistoric	tooth	Cervus elaphus	Red Deer	7.8	43.2	−19.3	6.6	3.1
E 2012.0034	2012-02	Little Sea	Kurma XI	prehistoric	tooth	Cervus elaphus	Red Deer	5.9	43.8	−19.0	7.4	3.2
E 2012.0033	2012-02	Little Sea	Kurma XI	prehistoric	tooth	Cervus elaphus	Red Deer	9.0	43.6	−20.0	5.7	3.1
E 2012.0032	2012-02	Little Sea	Kurma XI	prehistoric	tooth	Cervus elaphus	Red Deer	10.6	43.6	−19.7	5.3	3.1
E 2012.0031	2012-02	Little Sea	Kurma XI	prehistoric	tooth	Cervus elaphus	Red Deer	7.5	43.3	−18.9	7.8	3.2
E 2012.0030	2012-02	Little Sea	Kurma XI	prehistoric	tooth	Cervus elaphus	Red Deer	10.2	45.3	−19.8	7.0	3.1

ESAMP_ID	BHAP No.	Micro-region	Site	Sample Age	Material	Species	Common Name	%Yld	%C	$\delta^{13}C$	$\delta^{15}N$	C:N
E 2012.0029	2012-02	Little Sea	Kurma XI	prehistoric	tooth	Cervus elaphus	Red Deer	8.5	44.5	−19.0	5.6	3.1
E 2012.0028	2012-02	Little Sea	Kurma XI	prehistoric	tooth	Cervus elaphus	Red Deer	14.0	44.2	−19.7	4.9	3.1
E 2012.0028	2012-02	Little Sea	Kurma XI	prehistoric	tooth	Cervus elaphus	Red Deer	11.2	43.2	−19.4	4.9	3.2
t4cf973	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Cervus elaphus	Red Deer	15.5	45.3	−20.7	4.0	3.2
t4b08f2220	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Cervus elaphus	Red Deer	10.4	45.5	−18.6	4.8	3.2
E 2012.0017	2016-05	Little Sea	Ulan Khada	prehistoric	bone	Cervus elaphus	Red Deer	15.4	43.6	−19.3	4.9	3.2
E 2012.0091	2012-12	Little Sea	Ityrkhei	prehistoric	bone	Rutilus rutilus lacustris	Roach	12.4	42.4	−13.3	9.8	3.4
E 2012.0088	2012-12	Little Sea	Ityrkhei	prehistoric	bone	Rutilus rutilus lacustris	Roach	7.8	43.0	−14.5	9.6	3.4
E 2012.0081	2012-12	Little Sea	Ulan-Khada	prehistoric	bone	Rutilus rutilus lacustris	Roach	9.3	41.0	−17.0	9.9	3.5
E 2001.0698	2012-16	Little Sea	Little Sea	modern	bone	Phoca sibirica	Seal	100.0	42.5	−22.5	6.2	3.5
E 2000.0551	2012-16	Little Sea	Tyshkine	modern	bone	Phoca sibirica	Seal	100.0	41.9	−17.9	9.4	3.3
t4cf42	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	10.9	49.3	−23.1	15.6	3.2
t4cf353	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	10.8	45.2	−19.8	13.5	3.1

ESAMP_ID	BHAP No.	Micro-region	Site	Sample Age	Material	Species	Common Name	%Yld	%C	δ^{13}C	δ^{15}N	C:N
t4cf2035	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	7.0	45.4	−22.5	16.5	3.3
t4cf1820	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	10.4	42.4	−23.4	14.2	3.1
t4cf1820	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	9.9	43.6	−23.5	13.5	3.1
t4cf1104	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	5.8	45.8	−22.4	16.4	3.3
t4c08f318	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	7.7	45.4	−19.2	13.9	3.2
t4c08f1764	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	4.8	45.7	−22.7	15.8	3.2
t4c08f1540	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	6.9	45.3	−22.2	15.2	3.2
t4c08f15	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	6.0	45.9	−18.3	13.7	3.2
t4c08f1396	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	7.0	45.4	−21.2	16.6	3.2
t4bf2816	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	10.5	43.9	−22.0	13.6	3.2
t4bf1826	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	18.4	41.5	−21.1	14.6	3.1
t4bf1224	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	15.9	45.0	−21.1	12.4	3.2
t4b08f629	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	9.9	43.0	−24.2	15.9	3.2
t4b08f2332	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	13.8	44.7	−23.4	14.8	3.1

ESAMP_ID	BHAP No.	Micro-region	Site	Sample Age	Material	Species	Common Name	%Yld	%C	$\delta^{13}C$	$\delta^{15}N$	C:N
t4b08f2307	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	6.6	44.2	−23.2	15.4	3.1
t4b08f2054	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	7.1	44.0	−22.1	14.8	3.1
t4b08f2029	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	12.1	45.7	−22.4	15.7	3.2
t4b08f1683	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	9.0	43.3	−21.4	14.5	3.1
E 2008.0168	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	17.7	43.0	−19.7	4.8	3.4
E 2008.0168	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	15.3	43.0	−19.6	4.9	3.4
E 2008.0167	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	10.0	44.0	−17.3	12.1	3.4
E 2008.0166	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	8.4	43.0	−21.2	13.3	3.4
E 2008.0164	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	13.0	43.0	−21.1	12.6	3.4
E 2008.0162	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	9.1	42.0	−21.7	13.2	3.5
E 2008.0157	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	10.3	44.0	−21.1	13.0	3.4
E 2008.0155	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	6.7	43.0	−21.7	14.2	3.4
E 2008.0149	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	9.6	45.0	−21.5	15.2	3.5
E 2008.0145	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	5.7	45.0	−22.3	13.6	3.4

ESAMP_ID	BHAP No.	Micro-region	Site	Sample Age	Material	Species	Common Name	%Yld	%C	δ^{13}C	δ^{15}N	C:N
E 2008.0144	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	6.9	46.0	−21.7	14.9	3.4
E 2008.0143	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	9.1	48.0	−20.9	15.6	3.4
E 2008.0140	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	7.2	44.0	−19.1	13.5	3.3
E 2008.0137	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	6.4	47.0	−22.7	14.0	3.3
E 2008.0135	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	4.8	42.0	−21.8	15.9	3.2
E 2008.0134	2008-01	Little Sea	Sagan-Zaba	prehistoric	bone	Phoca sibirica	Seal	6.2	43.0	−22.4	15.3	3.2
E 2012.0007	2016-05	Little Sea	Berloga	prehistoric	bone	Mammalia sp. (terrestrial	Ungulate	6.3	43.1	−19.3	2.4	3.3
E 2012.0005	2016-05	Little Sea	Berloga	prehistoric	antler	Artiodactyla sp.	Ungulate	9.8	43.2	−20.2	3.0	3.2
E 2012.0003	2016-05	Little Sea	Berloga	prehistoric	bone	Mammalia sp.	Ungulate	15.6	43.6	−20.3	4.0	3.2
E 2012.0002	2016-05	Little Sea	Berloga	prehistoric	bone	Mammalia sp. (terrestrial	Ungulate	7.7	43.7	−19.2	6.1	3.3
E 2010.0038	2010-04	Little Sea	Bugul'deika	prehistoric	tooth	C.f. Cervus elaphus	Ungulate	1.4	43.7	−18.8	8.8	3.3
E 2010.0037	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Terrestrial mammal	Ungulate	1.9	43.7	−19.1	4.9	3.3
E 2010.0035	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Terrestrial mammal	Ungulate	0.9	44.4	−20.0	4.6	3.3

ESAMP_ID	**BHAP No.**	**Micro-region**	**Site**	**Sample Age**	**Material**	**Species**	**Common Name**	**%Yld**	**%C**	**δ^{13}C**	**δ^{15}N**	**C:N**
E 2010.0033	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Artiodactyla, large	Ungulate	3.1	49.5	−20.5	3.6	3.3
E 2010.0032	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Capreolus pygargus	Ungulate	2.1	44.7	−21.1	5.7	3.3
E 2010.0031	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Bos sp.	Ungulate	4.9	46.1	−19.7	5.4	3.3
E 2010.0029	2010-04	Little Sea	Bugul'deika	prehistoric	tooth	Bos sp.	Ungulate	4.3	45.2	−18.8	6.3	3.3
E 2010.0028	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Bos sp.	Ungulate	3.5	45.1	−19.3	5.7	3.3
E 2010.0027	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Terrestrial mammal	Ungulate	6.2	46.0	−20.0	5.5	3.2
E 2010.0026	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Terrestrial mammal	Ungulate	2.5	45.7	−19.8	5.4	3.4
E 2010.0025	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Herbivore, large	Ungulate	7.1	45.3	−20.4	5.7	3.3
E 2010.0024	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Cervidae, large	Ungulate	5.2	46.3	−18.9	3.3	3.3
E 2010.0023	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Terrestrial mammal	Ungulate	4.8	46.4	−20.3	5.7	3.3
E 2010.0022	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Terrestrial mammal	Ungulate	4.4	46.0	−20.0	5.2	3.3
E 2010.0021	2010-04	Little Sea	Bugul'deika	prehistoric	bone	C.f. Cervus elaphus	Ungulate	4.5	46.7	−20.3	5.6	3.3
E 2010.0020	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Equus sp.	Ungulate	6.4	46.5	−20.5	3.7	3.3
E 2010.0018	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Cervidae, large	Ungulate	8.4	46.0	−19.9	5.7	3.2

ESAMP_ID	BHAP No.	Micro-region	Site	Sample Age	Material	Species	Common Name	%Yld	%C	$\delta^{13}C$	$\delta^{15}N$	C:N
E 2010.0017	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Capreolus pygargus	Ungulate	6.1	44.6	−20.0	3.6	3.2
E 2010.0016	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Rangifer sp.	Ungulate	8.3	45.7	−20.4	5.8	3.3
E 2010.0014	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Cervidae, large	Ungulate	4.3	46.3	−20.4	3.8	3.3
E 2010.0012	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Bos sp.	Ungulate	2.2	45.4	−20.6	6.2	3.4
E 2010.0011	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Rangifer sp.	Ungulate	3.8	45.6	−20.4	6.1	3.3
E 2010.0009	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Equus sp.	Ungulate	8.7	46.2	−21.1	4.4	3.3
E 2010.0008	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Capreolus pygargus	Ungulate	5.9	45.5	−19.4	5.1	3.3
E 2010.0007	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Capreolus pygargus	Ungulate	6.3	45.4	−19.3	6.0	3.3
E 2010.0005	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Ovicaprine	Ungulate	7.4	46.0	−19.8	8.5	3.3
E 2010.0004	2010-04	Little Sea	Bugul'deika	prehistoric	bone	Equus sp.	Ungulate	4.2	45.1	−21.0	4.5	3.3
E 2012.0016	2016-05	Little Sea	Ityrkhei	prehistoric	bone	Artiodactyla sp.	Ungulate	12.8	44.8	−19.4	2.5	3.2
E 2012.0014	2016-05	Little Sea	Ityrkhei	prehistoric	bone	Mammalia sp. (terrestrial)	Ungulate	10.5	43.9	−19.2	4.6	3.2
E 2012.0013	2016-05	Little Sea	Ityrkhei	prehistoric	bone	Mammalia sp. (terrestrial)	Ungulate	9.9	43.2	−19.6	4.4	3.3

ESAMP_ID	BHAP No.	Micro-region	Site	Sample Age	Material	Species	Common Name	%Yld	%C	$\delta^{13}C$	$\delta^{15}N$	C:N
E 2012.0024	2016-05	Little Sea	Kulara III	prehistoric	tooth	Capreolus pygargus	Ungulate	5.2	44.1	−20.1	5.0	3.3
E 2012.0021	2016-05	Little Sea	Sagan-Nuge	prehistoric	bone	Equus sp.	Ungulate	9.6	42.9	−20.7	2.8	3.2
E 2012.0020	2016-05	Little Sea	Sagan-Nuge	prehistoric	antler	Cervidae sp.	Ungulate	8.6	43.9	−19.9	5.1	3.2
E 2012.0019	2016-05	Little Sea	Sagan-Nuge	prehistoric	bone	Caprinae sp.	Ungulate	5.9	44.9	−20.2	4.8	3.2
E 2012.0018	2016-05	Little Sea	Sagan-Nuge	prehistoric	bone	Mammalia sp.	Ungulate	1.9	45.5	−21.1	3.6	3.3
E 2012.0027	2016-05	Little Sea	Sagan-Nuge III	prehistoric	bone	Equus sp.	Ungulate	15.4	43.8	−22.1	3.8	3.2
t4cf944	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Caprinae	Ungulate	18.2	45.9	−19.6	6.3	3.2
t4cf895	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Equus sp.	Ungulate	15.4	48.6	−21.1	3.2	3.2
t4cf86	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Bos sp.	Ungulate	14.6	42.9	−19.5	6.9	3.2
t4cf811	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Caprinae	Ungulate	9.0	46.5	−19.2	6.2	3.2
t4cf785	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Bos sp.	Ungulate	6.7	43.5	−19.1	7.0	3.2
t4cf445	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Caprinae	Ungulate	19.5	48.1	−17.2	8.2	3.2
t4c08f391	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Artiodactyla-large	Ungulate	13.4	46.3	−18.5	5.6	3.2
t4c08f1799	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Artiodactyla-small	Ungulate	9.8	42.6	−20.6	5.8	3.2

ESAMP_ID	BHAP No.	Micro-region	Site	Sample Age	Material	Species	Common Name	%Yld	%C	$\delta^{13}C$	$\delta^{15}N$	C:N
t4c08f1763	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Capreolus pygargus	Ungulate	6.3	49.1	−19.2	6.3	3.2
t4c08f1743	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Artiodactyla -small	Ungulate	9.4	43.0	−19.6	6.1	3.2
t4c08f1590	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Artiodactyla -large	Ungulate	8.0	43.3	−18.0	6.0	3.3
t4c08f147	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Cervidae-large	Ungulate	13.2	45.6	−19.9	5.5	3.2
t4c08f1468	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Large mammal	Ungulate	8.2	46.8	−18.6	5.5	3.2
t4c08f1393	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Cervidae-large	Ungulate	7.6	46.0	−18.8	5.2	3.2
t4bf91	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Caprinae	Ungulate	16.4	47.4	−18.7	5.4	3.2
t4bf857	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Bos sp.	Ungulate	8.9	44.5	−17.9	8.0	3.2
t4bf834	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Mammalia-unidentified	Ungulate	14.1	44.9	−19.6	7.2	3.2
t4bf2102	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Cervidae-large	Ungulate	10.8	46.4	−19.8	6.8	3.2
t4bf1797	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Caprinae	Ungulate	14.6	46.8	−18.7	6.5	3.1
t4bf1690	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Bos sp.	Ungulate	14.1	42.2	−20.5	5.7	3.2
t4bf1021	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Caprinae	Ungulate	10.6	49.8	−18.7	5.6	3.2
t4bf1021	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Caprinae	Ungulate	12.6	47.1	−19.2	5.6	3.2

ESAMP_ID	**BHAP No.**	**Micro-region**	**Site**	**Sample Age**	**Material**	**Species**	**Common Name**	**%Yld**	**%C**	**$\delta^{13}C$**	**$\delta^{15}N$**	**C:N**
t4b08f338	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Cervidae-large	Ungulate	4.7	45.6	−19.8	5.6	3.2
t4b08f2311	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Capreolus pygargus	Ungulate	4.7	43.1	−20.7	7.0	3.3
t4b08f2107	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Cervidae-large	Ungulate	7.9	45.5	−18.3	5.1	3.2
t4b08f1820	2009-02	Little Sea	Sagan-Zaba	prehistoric	bone	Cervidae-large	Ungulate	8.7	45.7	−18.9	5.4	3.2
E 2011.0078	2012-04	Little Sea	Sagan-Zaba	prehistoric	bone	Bos sp.	Ungulate	15.6	42.8	−20.1	6.5	3.2
E 2011.0077	2012-04	Little Sea	Sagan-Zaba	prehistoric	bone	Bos sp.	Ungulate	10.8	45.2	−18.8	6.7	3.2
E 2011.0076	2012-04	Little Sea	Sagan-Zaba	prehistoric	tooth	Bos sp.	Ungulate	6.3	41.6	−18.7	7.1	3.2
E 2011.0075	2012-04	Little Sea	Sagan-Zaba	prehistoric	bone	Bos sp.	Ungulate	11.8	39.7	−18.7	7.2	3.2
E 2011.0074	2012-04	Little Sea	Sagan-Zaba	prehistoric	bone	Bos sp.	Ungulate	15.3	47.3	−20.1	4.7	3.2
E 2011.0073	2012-04	Little Sea	Sagan-Zaba	prehistoric	bone	Bos sp.	Ungulate	12.1	44.6	−18.6	7.0	3.2
E 2011.0072	2012-04	Little Sea	Sagan-Zaba	prehistoric	tooth	Bos sp.	Ungulate	3.5	43.6	−19.3	8.3	3.2
E 2011.0071	2012-04	Little Sea	Sagan-Zaba	prehistoric	tooth	Bos sp.	Ungulate	4.9	40.5	−19.2	7.0	3.2
E 2011.0070	2012-04	Little Sea	Sagan-Zaba	prehistoric	bone	Bos sp.	Ungulate	7.4	45.9	−19.0	7.3	3.2
E 2011.0069	2012-04	Little Sea	Sagan-Zaba	prehistoric	bone	Bos sp.	Ungulate	10.8	46.8	−18.7	7.1	3.2

ESAMP_ID	BHAP No.	Micro-region	Site	Sample Age	Material	Species	Common Name	%Yld	%C	$\delta^{13}C$	$\delta^{15}N$	C:N
E 2012.0026	2016-05	Little Sea	Todakta 1	prehistoric	bone	Bos sp.	Ungulate	8.4	45.2	−19.0	8.5	3.2
E 2012.0025	2016-05	Little Sea	Tyshkine II	prehistoric	bone	Artiodactyla sp.	Ungulate	12.9	45.1	−19.6	4.6	3.2
E 2012.0011	2016-05	Little Sea	Ulan Khada	prehistoric	bone	Artiodactyla sp.	Ungulate	2.9	43.1	−20.8	3.3	3.3
E 2012.0010	2016-05	Little Sea	Ulan Khada	prehistoric	bone	Artiodactyla sp.	Ungulate	7.1	44.5	−20.7	2.9	3.2
E 2012.0009	2016-05	Little Sea	Ulan Khada	prehistoric	antler	Cervidae sp.	Ungulate	7.5	43.4	−19.2	2.5	3.3
E 2012.0008	2016-05	Little Sea	Ulan Khada	prehistoric	bone	Artiodactyla sp.	Ungulate	1.0	41.7	−20.4	2.9	3.3
E 2001.0789	2012-16	Little Sea	Little Sea	modern	bone	Coregonus l.b	White-fish	100.0	41.9	−20.8	11.1	3.4
E 2012.0080	2012-12	Little Sea	Ulan-Khada	prehistoric	bone	Coregonus sp.	White-fish	7.2	41.3	−22.5	9.4	3.3

3.7 Source Aggregation (*A Priori*)

The earliest stable isotope mixing models were restricted to considering only one additional source compared to the number of dietary proxies available and measured. Because models are statistically under-defined when more than n+1 (where n is the number of proxies) sources are considered, most mixing models use some form of aggregation to combine dietary sources into analytical categories (Phillips and Gregg 2003; Moore and Semmens 2008; Parnell et al. 2010). Phillips and colleagues (2005) suggested *a priori* and *a posteriori* approaches for the combination of dietary sources, to reduce the number of sources for a more statistically robust model. *A priori* approaches to source aggregation combine dietary sources if their stable isotope signatures are not significantly different after performing statistical tests for equality of means (Ben-David, Flynn, and Schell 1997; Ben-David et al. 1997). Biological relatedness (i.e. same taxon or trophic guild) should also be considered, such that results are easier to interpret, and have some biological meaning (Phillips, Newsome, and Gregg 2005).

In order to prepare the faunal data (Table 3.2) for use in the mixing model, stable isotope averages were calculated for every listed species. Within the sample used for this analysis, trophic level and analytical importance were considered in *a priori* aggregation. To ensure the faunal data reflected the effective environment for EBA hunter-gatherers, only prey animals that could be considered part of a staple diet were considered. Herring gull, though a possible dietary source, was also excluded as only three modern values are available for analysis. These modern values would not reflect the values of an archaeological specimen, as development in the area has changed the behaviour of herring gulls, which now feed on human refuse. This process left only ungulates such as roe deer, red deer, moose, and musk deer as possible terrestrial mammal food sources for analysis in the Little Sea micro-region. All ungulate species did not exhibit significantly different stable isotope values and were grouped together with a weighted average (Table 3.3).

Plant data are difficult to obtain from this region, and there is a paucity of published stable isotope values for plant materials in the Cis-Baikal both in palaeodietary and ecological fields. Okladnikov's (1950; 1955) summary of plant sources available in the Baikal region suggest that early hunter-gatherers would focus on pine nuts, inner tree bark, young shoots and buds, roots, bulbs (such as onion, garlic, Siberian lily, and martagon lily) berries, mushrooms, moss, and lichen. To account for the presence of these edible plant materials, delta values of carbon and nitrogen were inferred from stable isotope results available for mammalian herbivores; these were based upon observed diet to collagen enrichment factors for both carbon (+5‰*)* and nitrogen (+1–4‰) (Lee-Thorp 2008; Sullivan and Krueger 1981). The estimated mean value for $\delta^{13}C$ is −23‰ and 2‰ for $\delta^{15}N$. These were assigned higher uncertainty (±1 for $\delta^{15}N$, ±1.5 for $\delta^{13}C$) to account for variation in isotope values due to the circumstantial nature of the data. These values are analogous to the only published plant data available of pine nuts, which reported values of −22.7‰ for $\delta^{13}C$ and 1.3‰ for $\delta^{15}N$ (Lam 1994).

For aquatic food sources, fish and seal species were considered. Seals were kept as a separate analytical category with a mean value of −22.1‰ for $\delta^{13}C$ and 13.7‰ for $\delta^{15}N$. This was because their stable isotope values are unique as an aquatic apex predator, and their contribution towards target diets is of central concern to this study. A conservative uncertainty (±0.5) was included in the model calculations to account for any sources of error and variability in stable isotopes between flesh and bone in source animals. Fish species considered for this analysis include burbot, perch, grayling, roach, and dace. Fish specimens proved more difficult to aggregate, as values exhibited both inter-and intra-species variation. A k-means clustering test was applied to the means of each species to classify the values according to their distance from data centroids. This test allows the separation of *n* values into *k* clusters, in which each observation is grouped with the nearest mean. The resulting classifications (Fish1 and Fish2) group together grayling and roach into Fish1, and burbot, dace, and perch into Fish2 (Table 3.4).

Table 3.3 Averaged mammal stable isotope averages.

Ungulates	**$\delta^{13}C$**	**s.d of $\delta^{13}C$**	**$\delta^{15}N$**	**s.d of $\delta^{15}N$**	**N**
Moose	−19.2	-	3.7	-	1
Red Deer	−19.4	0.6	5.8	1.5	33
Roe deer	−19.7	0.3	5.2	1.5	3
Ungulate	−19.6	0.9	5.5	1.5	82
Aggregated Total	**−19.6**	**0.8**	**5.5**	**1.5**	**119**

Seal	**$\delta^{13}C$**	**s.d of $\delta^{13}C$**	**$\delta^{15}N$**	**s.d of $\delta^{15}N$**	**N**
Seal	−21.5	1.5	14	2.5	36
Aggregated Total	**−21.5**	**1.5**	**14**	**2.5**	**36**

Table 3.4 Averaged fish source stable isotope averages

Fish1	**$\delta^{13}C$**	**s.d of $\delta^{13}C$**	**$\delta^{15}N$**	**s.d of $\delta^{15}N$**	**N**
Grayling	−15.2	2.9	10.3	0.2	4
Roach	−14.9	1.9	9.8	0.2	3
Aggregated Total	**−15.1**	**2.3**	**10.1**	**0.4**	**7**

Fish2	**$\delta^{13}C$**	**s.d of $\delta^{13}C$**	**$\delta^{15}N$**	**s. d. of $\delta^{15}N$**	**N**
Burbot	−13.7	3.5	12.1	0.8	2
Dace	−13.1	-	9.5	-	1
Perch	−13.2	1.2	11.2	0.9	6
Aggregated Total	**−13.3**	**1.5**	**11.2**	**1.1**	**9**

3.8 Prior Information

The FRUITS model can be constrained to consider scenarios in which the prior information given to the model is true. In some cases, purely physiological priors are used (e.g. limiting the amount of protein in a concentration-dependent model to be physiologically realistic), in others ethnographic information can be incorporated (e.g. arctic groups whose plant consumption is less than 5–10% of their total dietary intake). These values can constrain the model to consider not only what is feasible statistically, but also what makes sense in any given scenario using existing data.

The first prior employed was a purely physiological one. Humans cannot subsist on diets containing more than 35–40% protein by energy. There are historical and ethnographic accounts of acute harmful health effects that occur when there is excess consumption of dietary protein from lean meat (Stefansson 1957, 233–34; 283–84; Speth and Spielmann 1983; Garlick 2001). The condition that affects individuals eating excess protein is termed "rabbit starvation" or "protein poisoning" and initially results in nausea and diarrhea after about a week of excess protein consumption, ultimately ending in abrupt death (Speth and Spielmann 1983). Clinical documentation of this syndrome is almost non-existent, with the exception of a single case study (Lieb 1929). Cordain and colleagues (2000) suggest the symptoms of rabbit starvation result from the limited capacity of the liver to up-regulate the enzymes required for urea synthesis, especially with increasing dietary protein intake. Cordain and colleagues (2000) calculations show that intake of dietary protein exceeding 40% of energy requires more enzymes than the average liver can up-regulate, which may result in hyperammonemia and hyperaminoacidemia that can cause some of the described symptoms seen in rabbit starvation. However, as little as 5% dietary protein is required to maintain bodily functions (Otten et al. 2006, 154). Therefore, the model was constrained such that dietary protein must be more than 5% and less than 40% of total nutrient concentration.

Table 3.5 Codes representing the relative dependence of various subsistence economies listed in the Ethnographic Atlas.

Murdock's Code	Percentage of Dependence
0	0–5%
1	6–15%
2	16–25%
3	26–35%
4	36–45%
5	46–55%
6	56–65%
7	66–75%
8	76–85%
9	86–100%

Adapted from Murdock (1967)

The subsistence ratios of modern hunter-gatherer groups listed in Murdock's (1967) Ethnographic Atlas and compiled by Cordain and colleagues (2000) provide ethnographic examples of worldwide hunter-gatherer subsistence for comparison to Lake Baikal. Murdock's (1967) Atlas has records of 1,267 of the world's societies and is useful in identifying cultural differences on a global scale. Of these, 229 were classified as hunter-gatherer economies, of which 14 reside in a northern taiga environment similar to Lake Baikal. Ethnographers have independently verified portions of the information contained within Murdock's Atlas (White and Brudner-White 1988), and later revisions by Grey (1999) included 105 specific ethnographic topics that were arranged into coded columns. Cordain's (2000) analysis included hunter-gatherer societies listed in the Atlas with an economy that relied solely on hunting, gathering, and fishing, as rated in columns 1–5 of the Atlas. Columns 1–5 have assigned values ranging from 0 to 9 denoting the societies relative dependence on 5 subsistence economies (Table 3.5), where column 1 is gathering, column 2 is hunting— including trapping and fowling— column 3 is fishing— including shell-fishing and whaling— column 4 refers to animal husbandry, and column 5 is agriculture (Murdock 1967). This filtered the number of societies from 1,267 to 229, to show those that had scores of 0 in columns 4 and 5. It should be noted that the ethnographic data collected and reported in the Ethnographic Atlas are approximations by Murdock of the ethnographer's or anthropologist's original observations. Likewise, Murdock never specified what values (i.e. by weight, or by energy) subsistence dependence was based on. Cordain and colleagues (2000) review more than 400 of the original references and found that most were reported as percentage by weight, though not all values could be verified. Therefore, the categories and subsistence ratios reported by Cordain and colleagues (2000) represent ordinal assessments of consumption based on cross-cultural data.

Table 3.6 Averages of dependence on subsistence economies in hunter-gatherer societies listed in the Ethnographic Atlas, by primary living environment (n=63).

Environment	**Plant Dependence**	**Hunting Dependence**	**Fishing Dependence**
Tundra (northern areas) (*n*=6)	6–15%	36–45%	46–55%
Taiga (northern coniferous forest) (*n*=14)	16–25%	26–35%	46–55%
Temperate forest (mostly mountainous) (n=*6*)	36–45%	16–25%	36–45%
Desert grasses and shrubs (*n*=11)	46–55%	36–45%	6–15%
Temperate grasslands (*n*=11)	26–35%	56–65%	6–15%
Subtropical bush (*n*=2)	36–45%	26–35%	26–35%
Subtropical rain forest (*n*=4)	36–45%	46–55%	6–15%
Tropical grassland (*n*=4)	46–55%	26–35%	16–25%
Monsoon forest (*n*=2)	36–45%	26–35%	26–35%
Tropical rain forest (*n*=3)	26–35%	26–35%	36–45%

Adapted from Table 2 in (Cordain et al. 2000)

Cordain and colleagues (2000) later calculated frequency distributions for each of the 10 categories of dependence in the three subsistence economies for the 229 hunter-gatherer societies listed in the Atlas. These were compiled by latitude across the 229 hunter-gatherer groups, the graphs of which showed an increasing dependence on hunted and fished resources and decreasing dependence on plant foods with increasing latitude (Cordain et al. 2000). Primary living environment information was available for 63 of the 229 listed hunter-gatherer groups. This information was included in a table listing the mean dependence on gathering, hunting, and fishing by their primary living environment (Table 3.6). Of these, 14 ethnographic accounts of hunter-gatherers are from taiga environments. However, Murdock indicated that the gathering subsistence economy is not limited to plant foods

but is considered to include also the collection of insects, small mammals, reptiles, amphibians, and invertebrates. Therefore, the inclusion of small land fauna in the gathering economy values may overestimate the relative contribution of plant foods given in Cordain and colleagues (2000) calculations of average hunter-gatherer diet.

In order to connect the ethnographic information to the archaeological data, the environment of Lake Baikal during the Middle Holocene must be considered. Environmental reconstructions of the area suggest that Lake Baikal had a taiga environment during the Holocene, with fully establish boreal coniferous and cold deciduous forests (Bezrukova et al. 2010). Inferred vegetative cover consisted of ~35% coniferous trees and shrubs between ~6,800 cal BP to present. Broadleaf trees represent around 10% of vegetation and the remaining 55% is determined to be open vegetation such as grasses and shrubs (Bezrukova et al. 2010). Given these values and the knowledge of past environmental conditions, a set of conservative priors was developed for the Lake Baikal region to restrict values of source food consumption to reflect known cross-cultural data (see taiga environment in Table 3.6).

Two dietary scenarios are explored in this analysis to test for statistical robusticity, (i.e. how much the results are affected by changes in input), where Scenario 1 incorporates restrictions on maximum dietary contributions, and Scenario 2 incorporates minimum values in addition to the previous priors. To account for uncertainty and small sample size, and in order to create conservative priors, designated values for each maximum and minimum contribution of each subsistence economy were increased beyond the spread indicated in Cordain and colleagues (2000) estimations (Table 3.7). Minimum values were determined by subtracting 5% from the minimum subsistence economy dependence in taiga environments (Table 3.5). Fishing and hunting took the tundra environment upper limit at its maxima, while the maximum for plant contribution is capped at the listed 25% in the taiga environment. The taiga environment is limited as such because Murdock includes small terrestrial fauna in the gathering subsistence economy, which may already overestimate plant contribution to overall diet.

Table 3.7 Priors of dietary scenarios 1 and 2.

Scenario 1	**Scenario 2**
Protein <.40	Protein <.40
Aquatic Sources <.55	Terrestrial Mammals >.26
Terrestrial Mammals <.45	Terrestrial Mammals <.45
Plant Sources <.25	Aquatic Sources >.46
-	Aquatic Sources <.55
-	Plant Sources >.10
-	Plant Sources <.25

3.9 Nutrient Composition of Food Groups

FRUITS is also able to account for variable macronutrient contributions to target data within the constructed model. For each of the dietary sources, a nutrient content (protein, carbohydrates, and lipids) expressed as a dry weight ratio was derived from macronutrient information of each food source retrieved (Table 3.8) from the USDA Food Composition Database (v.3.8.6.5 2018–02–04), operated by the Agricultural Research Service of the United States Department of Agriculture: https://ndb.nal.usda.gov/ndb/. Not all species could be directly retrieved from the database, as they are unique to the Lake Baikal area, such that some values are derived from slightly different relatives (e.g. ringed seal rather than *nerpa,* sitka deer rather than roe deer).

Table 3.8 Table listing macronutrient compositions of potential dietary Sources of EBA hunter-gatherers (or similar species).

Mammals	Carbohydrates%	Protein%	Fat%
Ringed Seal	0	51	49
Caribou	0	76	24
Elk	0	89	11
Sitka Deer	0	82	18
Plants	Carbohydrates%	Protein%	Fat%
Raspberry	89	4	7
Blackberry	75	19	6
Cloudberry	67	14	19
Cranberry	89	3	8
Pine Nuts	8	85	7
Mushrooms	50	13	37
Strawberry	85	8	7
Fish	Carbohydrates%	Protein%	Fat%
Carp	0	60	40
Whitefish	0	60	40
Pike	0	92	8
Perch	0	90	10

Data retrieved from USDA Food Composition Database (v.3.8.6.5 2018-02-04) https://ndb.nal.usda.gov/ndb/

These values were considered when aggregation of sources occurred, to ensure significantly different or variable macronutrient compositions were not aggregated into the same category. An average of the lipid, carbohydrate, and protein content of each aggregated food source was calculated, and the values incorporated into the model (Table 3.9). Because close relatives were used to best estimate the macronutrient content of some species and macronutrient composition of food sources can vary, a ±0.5 uncertainty was attached to each nutrient value to provide a sufficiently conservative guideline for proportions of carbohydrates, fat, and protein in dietary sources.

Table 3.9 Average macronutrient contents of aggregated food sources.

Food Source	Carb Avg.	Protein Avg.	Fat Avg.
Plants	66	20	14
Ungulates	0	84	16
Seal	0	51	49
Fish1	0	62	38
Fish2	0	76	24

3.10 Isotopic routing and Diet-Tissues Discrimination Factors

Diet-to-collagen and diet-to-bioapatite discrimination factors are based on the statistical model presented by Fernandes and colleagues (2012). This model can be considered equivalent to the graph-based model developed by Kellner and Schoeninger (2007), which was later updated by Froehle and colleagues (2010). The isotopic offsets used in Fernandes and colleagues (2012) model are derived from controlled feeding experiment data on small omnivorous mammals (Ambrose and Norr 1993; Howland et al. 2003; Jim et al. 2004; Tieszen and Fagre 1993; Warinner and Tuross 2009). The analysis of the derived data suggested a diet-to-collagen $\delta^{13}C$ offset of 4.8‰ ±0.2 and a diet-to-bioapatite $\delta^{13}C$ offset of 10.2‰ ±0.2. Since the stable isotope measurements from Khuzhir-Nuge XIV individuals are entirely derived from bone collagen and not bone carbonate, an offset of 4.8‰ ±0.5 was used throughout each scenario of the model. A higher uncertainty (±0.5) was incorporated into the model to account for any effects that body size may have on dietary offsets (Passey et al. 2005) since the original offset was calculated using data from small mammals. As there is a discrepancy regarding a standard diet-to-collagen $\delta^{15}N$ offset, the offset used in this analysis was calculated following Fernandes and colleagues (2015). A diet-to-collagen $\delta^{15}N$ offset of 5.5‰ ±0.5 represents a consensus from enrichment values of diet-to-hair δ^{15}N (Hedges et al. 2009; Huelsemann et al. 2009; Minagawa 1992; Minagawa et al. 1986; Schoeller et al. 1986; Yoshinaga et al. 1996), which was then summed with the documented ~1‰ isotopic offset between hair and bone collagen (Lehn et al. 2014; O'Connell and Hedges 1999; O'Connell et al. 2001). Though higher than the traditional offset of 3–4‰*,* this reference is isotopically similar to values reported for humans in a controlled feeding experiment (Hedges and Reynard 2007; O'Connell et al. 2012). While some scholars argue for a more conservative offset of 4.5‰, the Little Sea is dominated by aquatic food sources as evidenced in the high δ^{15}N values of individuals and the zooarchaeology of the region. As aquatic ecologies have extended food chains, and therefore a greater maximum of δ^{15}N, it stands to reason that a 5.5‰ ±0.5 is applicable in this case.

Fernandes and colleagues (2012) statistical analysis of published feeding experiments also showed that while bioapatite carbon does not reveal a bias towards any particular macronutrient, collagen carbon routes from 74 ±4% of carbon from dietary protein, where the remaining percentage is routed from a combination of lipids and carbohydrates. As such, macronutrient routing values of 74% and 26% for collagen carbon were incorporated into the model. For collagen nitrogen, dietary protein contributes essentially 100% of the nitrogen, and carbohydrates and lipids contribute 0%. These values were also given a conservative uncertainty of ±0.5.

3.11 Summary

After *a priori* aggregation, five sources were chosen to represent the variation in stable isotope signatures of available food items across Little Sea micro-region including seal, plants, ungulates, fish 1, and fish 2. Associated dietary offsets and macronutrient compositions were also considered for each source. Though only two dietary proxies are considered in this analysis (carbon and nitrogen of bone collagen), statistical robustness should be maintained with the addition of physiological and ethnographic priors. Isotopic routing values were also included in the analysis to account for the preference of nutrient routing in carbon and nitrogen of bone collagen. Once the parameters of the model and all necessary values were compiled, the model was run for each of the 30 individuals included in the analysis for Scenario 1 and Scenario 2. The results of the analysis are presented in Chapter 4 and discussed in Chapter 5.

Chapter 4: Results

4.1 Introduction

FRUITS produces a number of reports upon analysis for each individual. These outputs are integral for evaluating the performance of the model and determining whether the result is a good fit for the individual's stable isotope values. The results report is the primary textual document that records information such as the amount of time the simulation took, the user's input data, and the estimates generated. The output also includes a p-value for the model (explained in Section 4.2.1), indicating whether or not the estimations should be rejected or retained. The bulk of information contained within this document includes values of the estimated average, associated standard deviation, and values of the contribution from each source to individual diet with the 2.5, 50 and 97.5 percentile values. The results tabulate how much each source contributes to the proxy signals and how much the food source fractions (protein, fat, and carbohydrates) contribute to the consumer. A box plot window is one of two graphs generated to provide the user with information about the distribution's percentiles and are visualized in a second format in the posterior probability distribution window through bell curves representing the different food source groups against a function of estimation density. The last output produced by FRUITS is the convergence diagnostics window, which aids in determining the model performance and fit by tracking the convergence and autocorrelation of the Markov chains produced. This chapter provides a justification of the interpretation and assessment of the model output, followed by the presentation of results for each individual in the examined sample.

4.2 Interpreting Output

Within the constraints of the model, there are three possible outcomes. Individuals can be accepted, rejected, or there may have been a failure for the model to run. In the case of acceptance, it means that the model is a good fit for the stable isotope data and explains the variation. If the model is rejected, it means that the model cannot explain the data and alternative solutions should be explored. However, if the model has failed, it does not necessarily mean rejection. Instead, it means that the mixing problem was too complicated for the model to produce results. In this case, there may be a food source present in the isotope values that was not taken into account, or the model may simply require additional priors or proxies.

4.2.1 *Acceptance Criteria*

There are three main criteria for the acceptance or rejection of a model for an individual. First, the p-value of the model should be between 0.05 and 0.95. If the p-value is larger than 0.95, it means that there would be a greater than 95% chance of finding a result as close or closer than the result, and conversely, if the p-value is less than 0.05 there would be a less than 5% chance of finding a result as close or closer than the result. These extremes in p-values suggest that either the data is self-determining, or that it fits extremely poorly with the model. Bayesian p-values work slightly different frequentist approaches to statistics, as the properties of a classical p-value cannot hold when a composite null hypothesis is characterized by an unknown parameter theta (as in Bayesian analyses) (Gelman 2005). Instead, a Bayesian p-value compares a metric calculated from the observed data with the same metric calculated from the simulated data (that was generated with parameters drawn from the posterior distribution). The closer this value is to 0.5, the better the values calculated from the simulated data are distributed around the real observation. Summarized, it can be said that in a Bayesian context, “a posterior p-value is the probability, given the data, that a future observation is more extreme (as measured by some test variable) than the data" (Gelman 2005). The 0.05 and 0.95 cut-off values indicate that the results provided by the model are too far into the extremes of the distribution and should be rejected. Second, the convergence and autocorrelation graphs of the model should find a balance of oscillation with no significant changes in autocorrelation values. Third, the distribution should show small ranges of food source contributions in the boxplots, with no obvious errors or outliers. To be accepted the model has to meet all three of the above criteria (Figure 4.1 Example of K14GFS45 with acceptance criteria of model circled.). Figure 4.1a shows that the p-value for this individual is within the acceptable range (i.e. between 0.05 and 0.95). Additionally, the box plot and bell curve graph show precise estimations with no exaggerated values (Figure 4.1a and Figure 4.1b). The autocorrelation values on the right of Figure 4.1 show a consistent oscillation of around 0, which suggests that the observations are similar to each other over a function of time lag.

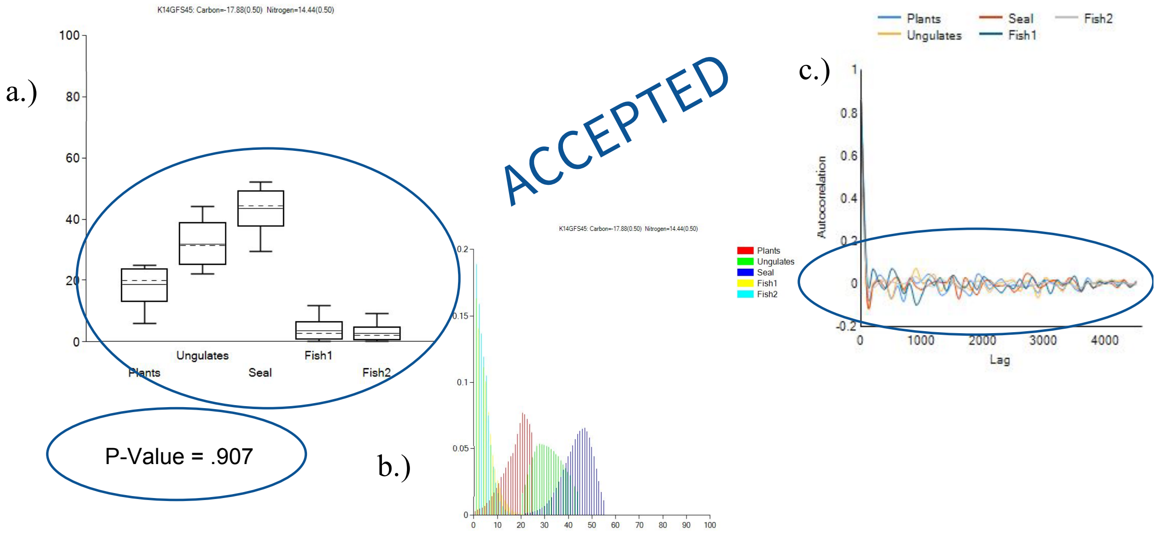

Figure 4.1 Example of K14GFS45 with acceptance criteria of model circled.

4.2.2 *Rejection Criteria*

The criteria for rejection of the model are the same as for acceptance, but the output has to fail only one of the three criteria to reject the model, though often all three will appear on a rejected individual. As shown in Figure 4.2 Example of K14GF34 with rejection criteria of model circled., poor autocorrelation and convergence, a p-value over 0.95, and obvious outliers in the distribution indicate that the proposed dietary scenario for this individual is not a good fit and therefore cannot explain their isotope values (Figure 4.2a). The example displays all three criteria indicating rejection. First, the p-value is greater than 0.95 (Figure 4.2a). Second, the box plot and bell curve graphs show large ranges in possible plant values and are not precise estimations (Figure 4.2.b). Thirdly, the autocorrelation graph on the right of the image shows that the ungulate, seal, and plant estimations are dissimilar over a function of time lag (Figure 4.2.c). While only one of these criteria needs to be violated for rejection, this individual is negative for all three.

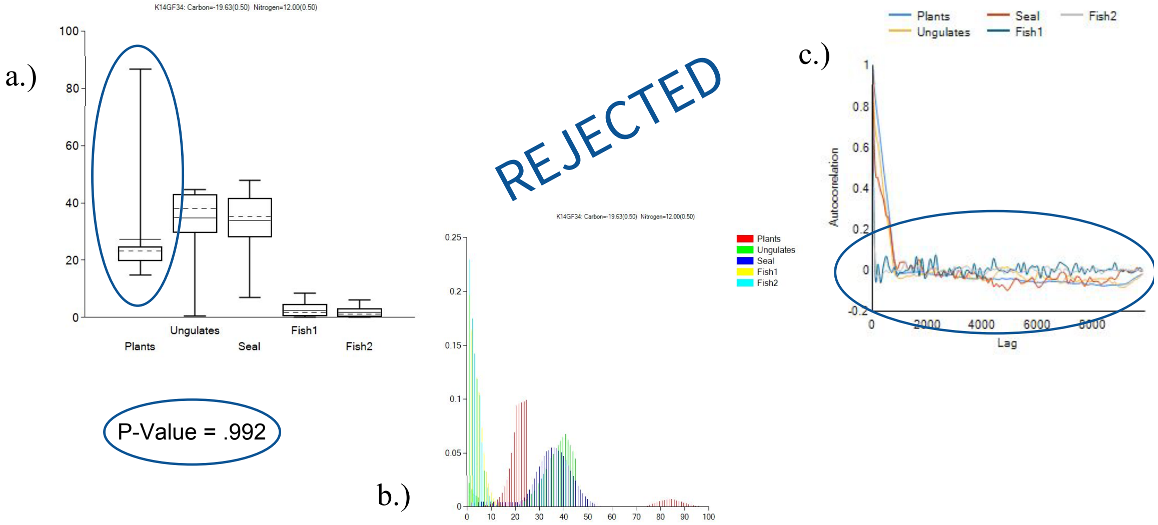

Figure 4.2 Example of K14GF34 with rejection criteria of model circled.

4.3 Estimation Likelihood

FRUITS produces contribution estimates modelled as a normal distribution for each dietary source. The software provides integrals for each source including the mean, median, standard deviation, and percentile (pc) values. Because each source is modelled as a normal distribution, the mean and the mode are equal. These values help to analyze and characterize the distribution such that it is possible to determine the likelihood of each estimate against a function of density. The mean value in this context is the value that is the densest (i.e. is the value that has been estimated most frequently). That is to say, though all values within the distribution are probable, the most likely based on the constructed model will be the mean since this is the value that has been estimated with the highest frequency. The standard deviation is a measure of variance or how far a set of numbers are from the mean. A small standard deviation (less than 1) suggests that the values are close to the mean, and this distribution has a narrow spread. Percentile values denote where the data are in relation to the overall population. For instance, the 2.5 percentile indicates that less than 2.5% of all estimations can be found below this point. Likewise, 97.5% of the sample can be found below the 97.5 percentile. In addition to the values above, FRUITS also produces a range for the 25th to 75th percentiles to indicate where 50% of the estimations are located relative to the population.

4.4 Assessing Model Performance

For the examined individuals, two dietary scenarios with differing priors were developed as discussed in Chapter 3 (Table 3.7). The overall performance of the model is determined by the number of accepted and rejected individuals compared to the number of failed analyses, combined with the relative precision of the dietary estimates. A statistically robust model should not dramatically change estimation values when some priors or other values are changed, but instead, produce similar results. When this occurs, it can be assured that the model is performing well and is not highly influenced by the user's parameters (Fernandes et al. 2015). Similarly, the p-values of individuals also give an indication of model performance. A value close to 0.5 indicates that the model is calculating values that are well distributed around the real observation. Initially, it was expected that the more constrained dietary Scenario 2 would produce more precise results due to the increased information provided to the model, whereas the less constrained model (Scenario 1) has more flexibility. Both models produced similar results, and can, therefore, be considered robust; however, Scenario 1 outperformed Scenario 2 in producing more consistent outputs for nearly every individual, with an exceptional rate of 27/30 individuals that produced accepted or rejected statuses rather than failing at the onset (Figure 4.4 Graph showing the accepted, rejected, and failed individuals' stable isotope values in Dietary Scenario 2.). This indicates that the model is meeting expectations with regards to this sample.

Compared to Scenario 1, Scenario 2 model performance is less satisfactory. There is a marked increase in the number of individuals that failed the model; only 15/30 individuals were able to produce results within this dietary scenario (Figure 4.4). However, there are some

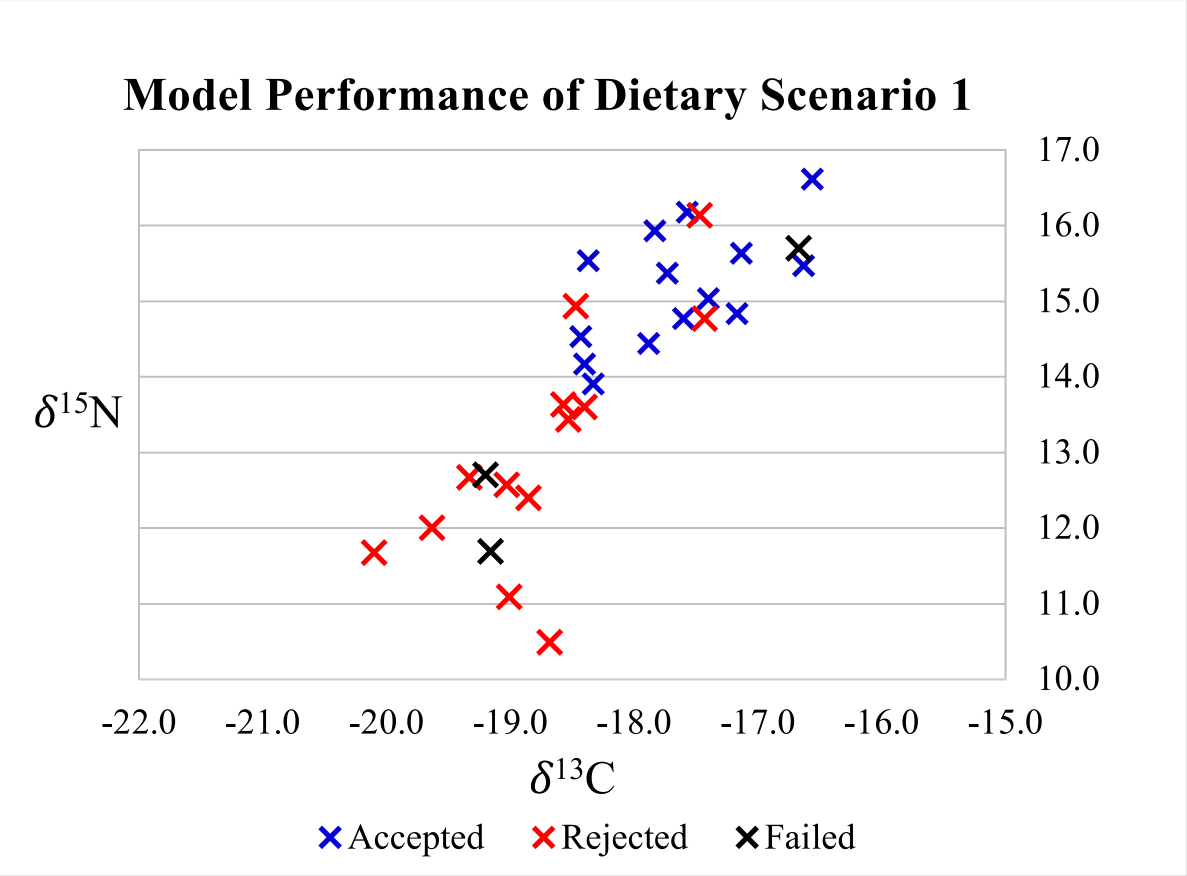

Figure 4.3 Graph showing the accepted, rejected, and failed individuals' stable isotope values in Dietary Scenario 1.

individuals that were rejected or failed in Scenario 1, that did produce results in Scenario 2, indicating that the more constrained model may be a better fit for some samples that experience issues with convergence, p-values, or autocorrelation. These exceptions will be discussed later within the individual results.

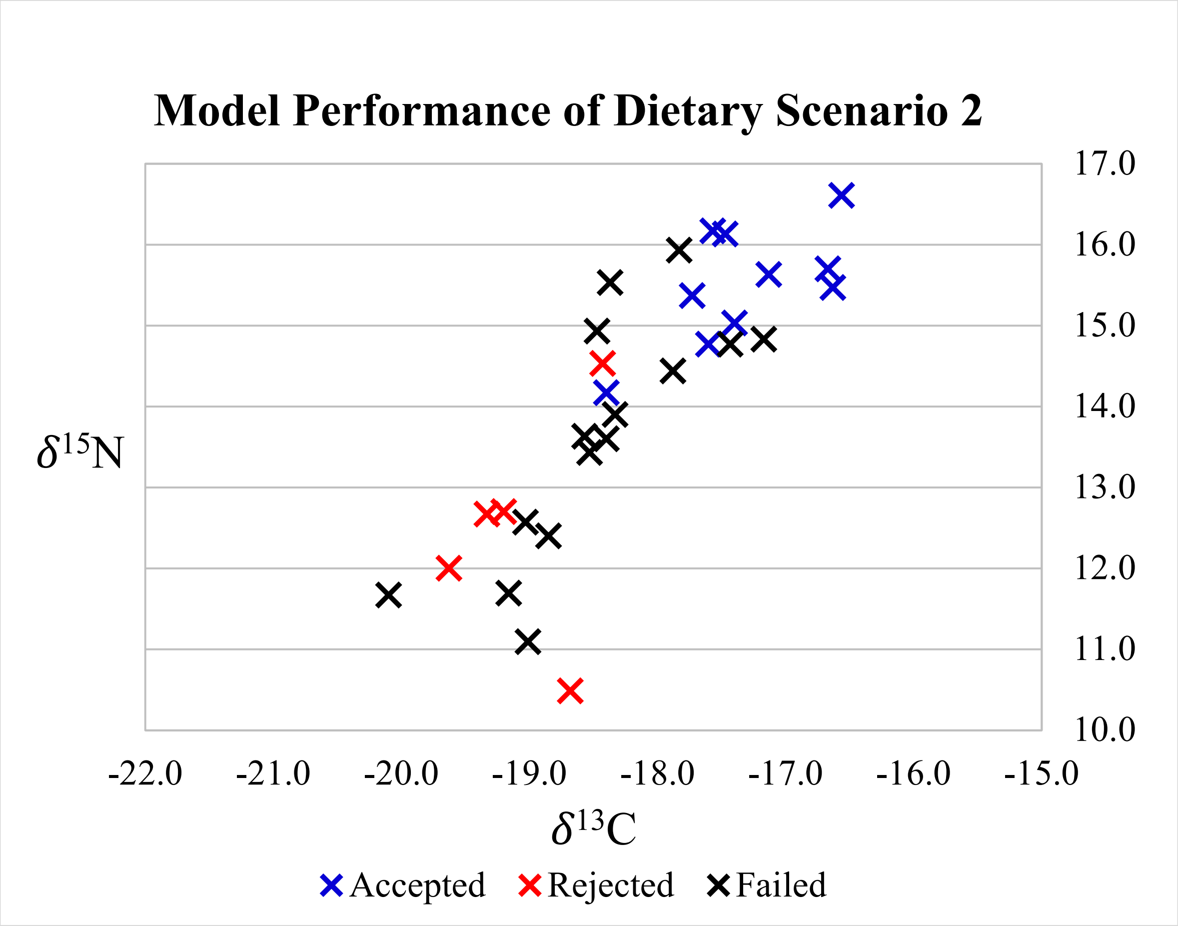

Figure 4.4 Graph showing the accepted, rejected, and failed individuals' stable isotope values in Dietary Scenario 2.

4.5 Individual Results

The results of the analysis will be presented for each of the 30 individuals analyzed. They are separated by diet group for ease of interpretation and discussion. The bulk of the discussion around dietary estimations will be on the results from Scenario 1, which produced the best and most robust results. Scenario 2 will be discussed only when the status (i.e. failed, rejected, or accepted) has changed from Scenario 1.

4.5.1 *K14_1997.011*

Table 4.1 Osteological Information of K14GFS11.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1997.011	35–50 y.	Adult	Male	3518±61	−18.4	15.5	GFS	Local

The p-value for this individual (Table 4.2) is 0.938 with satisfactory convergence. The graphs are also within the expected ranges and produce quite precise estimations for Scenario 1 (Figure 4.5). This indicates that the Little Sea dietary model provides a good match for this individuals stable isotope values (Table 4.2).

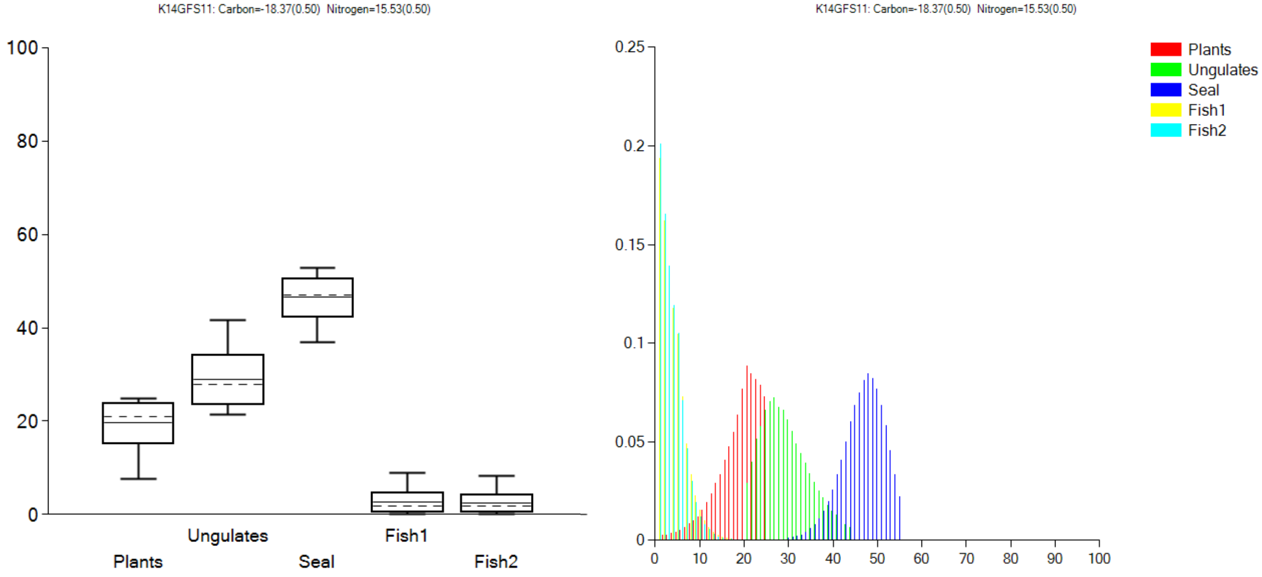

Figure 4.5 FRUITS results for K14GFS11, Scenario 1.

Table 4.2 FRUITS dietary source contribution estimations for K14GFS11, Scenario 1.

ESTIMATES *p-value=0.938*

Estimates of source/food contribution	

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.20	0.05	0.07	0.21	0.25	0.15–0.24
Ungulates	0.29	0.05	0.21	0.28	0.42	0.24–0.34
Seal	0.47	0.04	0.37	0.47	0.53	0.42–0.51
Fish1	0.03	0.02	0.00	0.02	0.09	0.00–0.05
Fish2	0.02	0.02	0.00	0.02	0.08	0.00–0.04

4.5.2 *K14_1997.012*

Table 4.3 Osteological Information of K14GFS12.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1997.012	25–35 y.	Adult	Unknown	3523±61	−18.3	13.9	GFS	Local

FRUITS produced quite precise estimations for Scenario 1 and the graphs contain no obvious errors (Figure 4.6). The p-value for this individual (Table 4.4) is 0.946 with moderate convergence which meets acceptance criteria. Therefore, this individual's stable isotope values correlate with a Little Sea diet (Table 4.4).

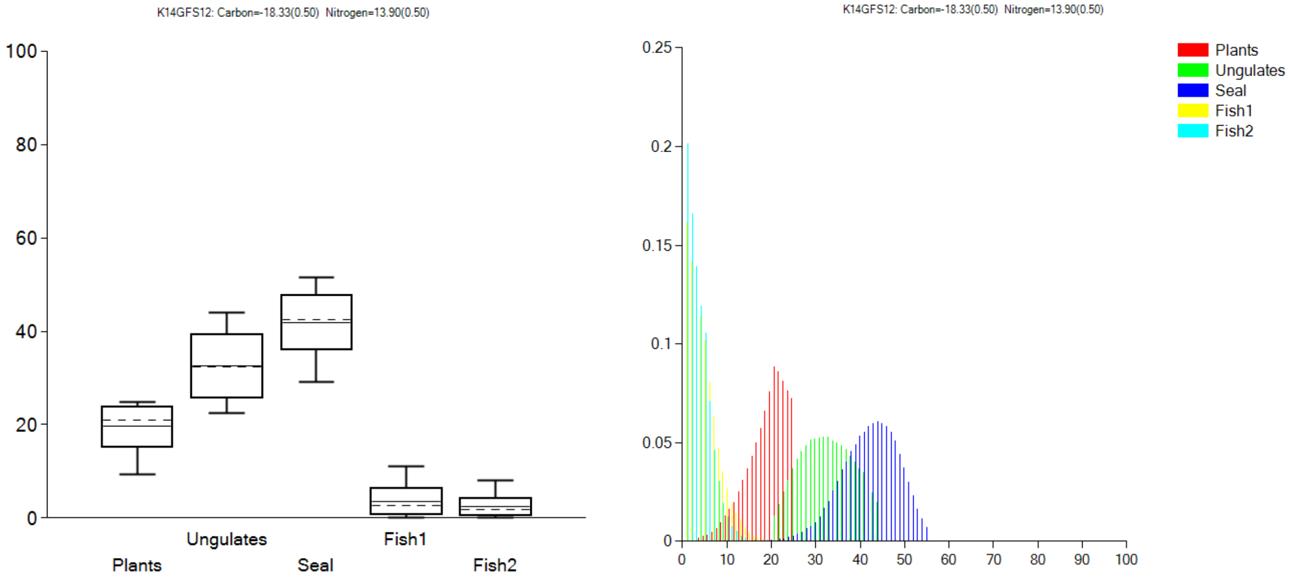

Figure 4.6 FRUITS results for K14GFS12, Scenario 1.

Table 4.4 FRUITS dietary source contribution estimations for K14GFS12, Scenario 1.

ESTIMATES	*p-value=0.946*
Estimates of source/food contribution	

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.20	0.04	0.09	0.21	0.25	0.15–0.24
Ungulates	0.33	0.06	0.22	0.32	0.44	0.26–0.40
Seal	0.42	0.06	0.29	0.42	0.51	0.36–0.48
Fish1	0.03	0.03	0.00	0.03	0.11	0.01–0.07
Fish2	0.02	0.02	0.00	0.02	0.08	0.00–0.04

4.5.3 *K14_1997.014*

Table 4.5 Osteological Information of K14GFS14.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1997.014	35–50 y.	Adult	Male?	3499±61	−18.4	14.5	GFS	Local

The p-value for this individual (Table 4.6) is 0.947 with moderate convergence, meeting the acceptance criteria. The values (Figure 4.**Error! Reference source not found.**7) are also within the expected ranges and produce quite precise estimations for Scenario 1. Therefore, the Little Sea dietary model provides a good match for the individuals stable isotope values (Table 4.6).

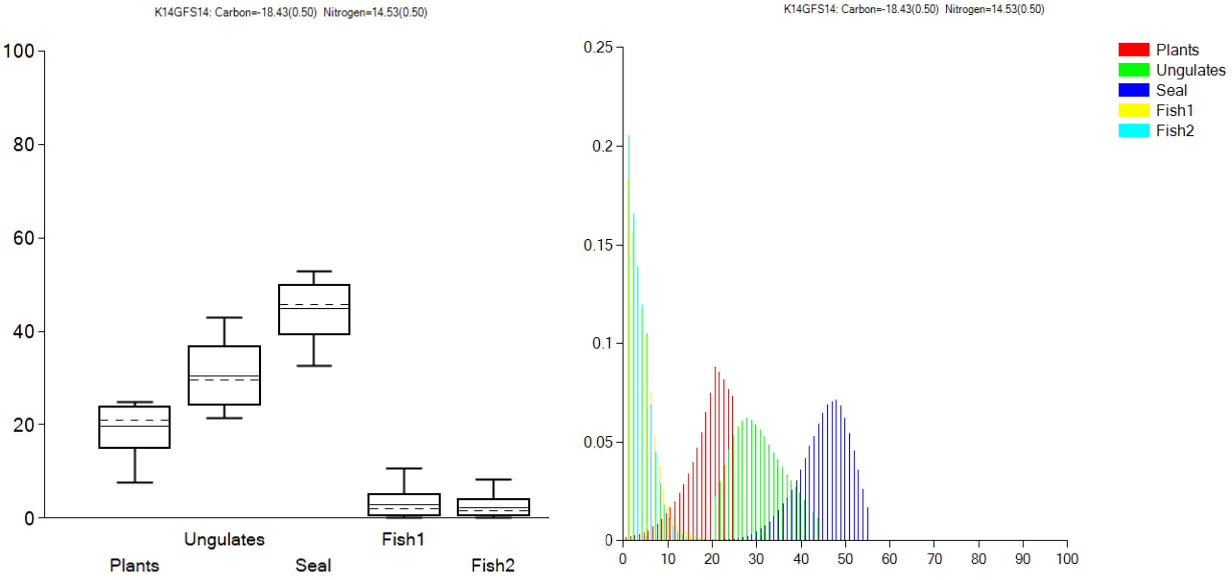

Figure 4.7 FRUITS results for K14GFS14, Scenario 1.

Table 4.6 FRUITS dietary source contribution estimations for K14GFS14, Scenario 1.

ESTIMATES *p-value=0.947*

Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.20	0.05	0.08	0.21	0.25	0.15–0.24
Ungulates	0.30	0.06	0.21	0.29	0.43	0.24–0.37
Seal	0.45	0.05	0.33	0.46	0.53	0.39–0.50
Fish1	0.03	0.03	0.00	0.02	0.11	0.01–0.05
Fish2	0.02	0.02	0.00	0.02	0.08	0.00–0.04

4.5.4 *K14_1997.015*

Table 4.7 Osteological Information of K14GFS15.

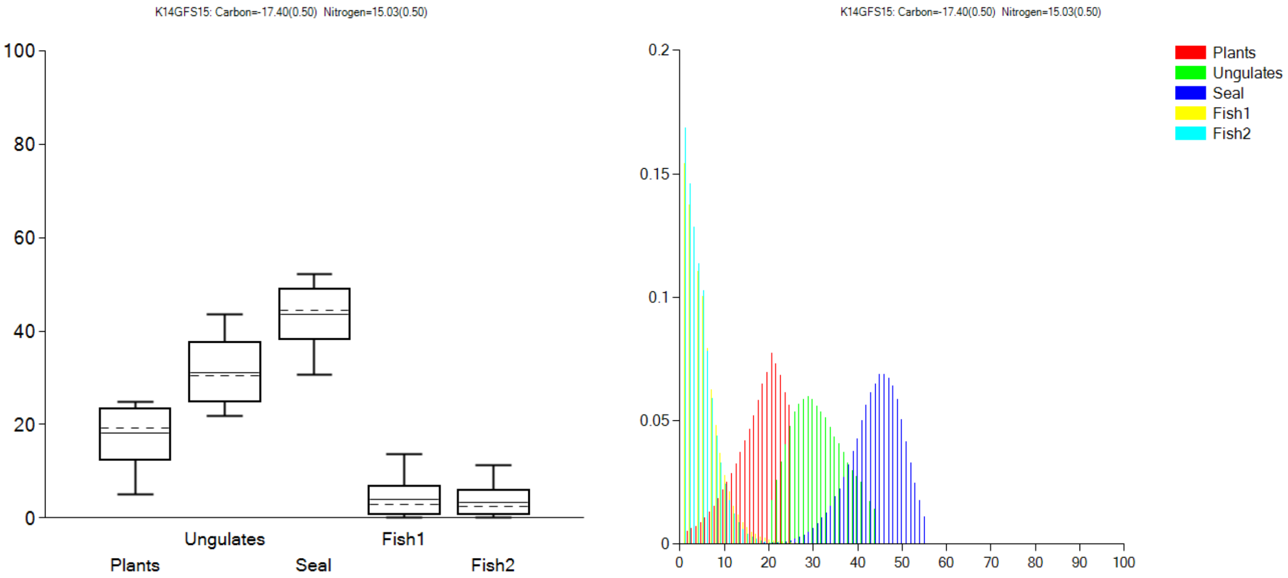

Figure 4.8 FRUITS results for K14GFS15, Scenario 1.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1997.015	25–35 y.	Adult	Male	3715±60	−17.4	15.0	GFS	Local

The Little Sea dietary model provides a good match for the individual's (Table 4.7) stable isotope values as indicated by the p-value (0.835) and the satisfactory convergence of the model. The graphs (Figure 4.8) are also within the expected ranges and produce quite precise estimations for Scenario 1 (Table 4.8).

Table 4.8 FRUITS dietary source contribution estimations for K14GFS15, Scenario 1.

ESTIMATES *p-value=0.835*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.18	0.05	0.05	0.19	0.25	0.12–0.23
Ungulates	0.31	0.06	0.22	0.30	0.43	0.25–0.38
Seal	0.44	0.06	0.31	0.44	0.52	0.38–0.49
Fish1	0.04	0.04	0.00	0.03	0.14	0.01–0.07
Fish2	0.03	0.03	0.00	0.02	0.11	0.01–0.06

4.5.5 *K14_1997.016*

Table 4.9 Osteological Information of K14GFS16.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1997.016	7–9 y.	Subadult	Unknown	3379±61	−17.6	16.2	GFS	Local

The graphs (Figure 4.9) are also within the expected ranges and produce precise estimations for Scenario 1. The p-value also passes with a value of 0.851. Though only moderate convergence was achieved for this individual (Table 4.9), it meets acceptance criteria. Therefore, this individual's stable isotope values correlate with a Little Sea diet (Table 4.10).

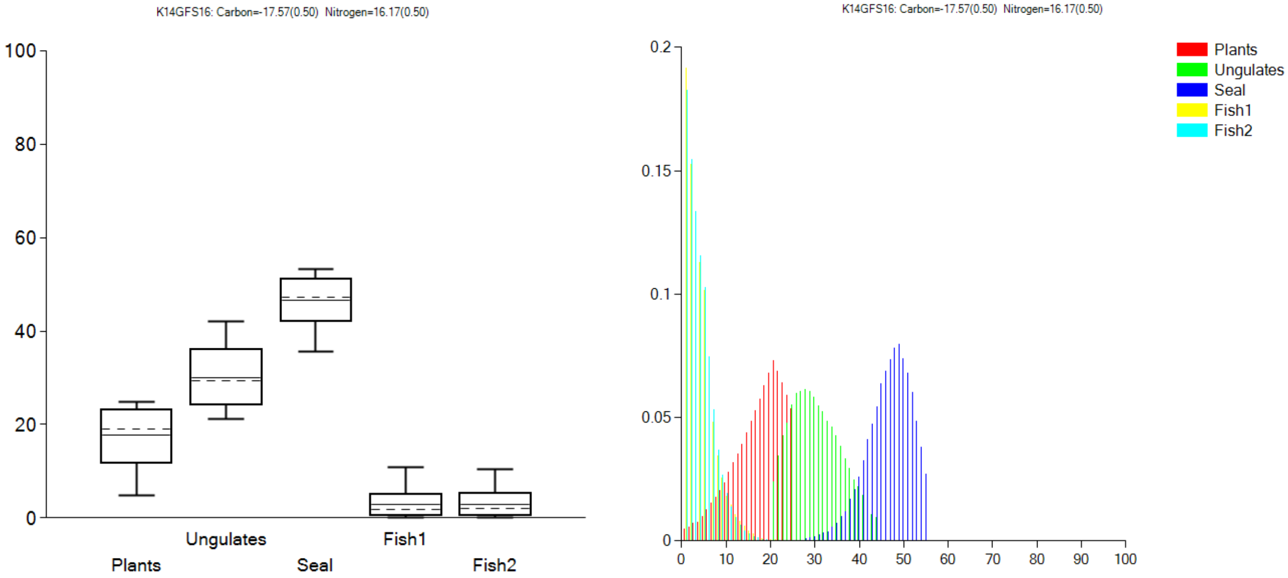

Figure 4.9 FRUITS results for K14GFS16, Scenario 1.

Table 4.10 FRUITS dietary source contribution estimations for K14GFS16, Scenario 1.

ESTIMATES *p-value=0.851*

Estimates of source/food contribution						
Source/Food	Mean	Sd	2.5pc	median	97.5pc	25–75pc
Plants	0.18	0.06	0.05	0.19	0.25	0.12–0.23
Ungulates	0.30	0.06	0.21	0.29	0.42	0.24–0.36
Seal	0.47	0.05	0.36	0.47	0.53	0.42–0.51
Fish1	0.03	0.03	0.00	0.02	0.11	0.00–0.05
Fish2	0.03	0.03	0.00	0.02	0.10	0.01–0.05

4.5.6 *K14_1998.039*

Table 4.11 Osteological Information of K14GFS39.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.039	9–11 y.	Subadult	Unknown	3509±61	−17.5	16.1	GFS	Local

Though the graphed values (Figure 4.10) are within the expected ranges and the p-value was acceptable (0.819), this individual (Table 4.11) was rejected for Scenario 1 because the model could not attain proper convergence. However, when run through Scenario 2, the model

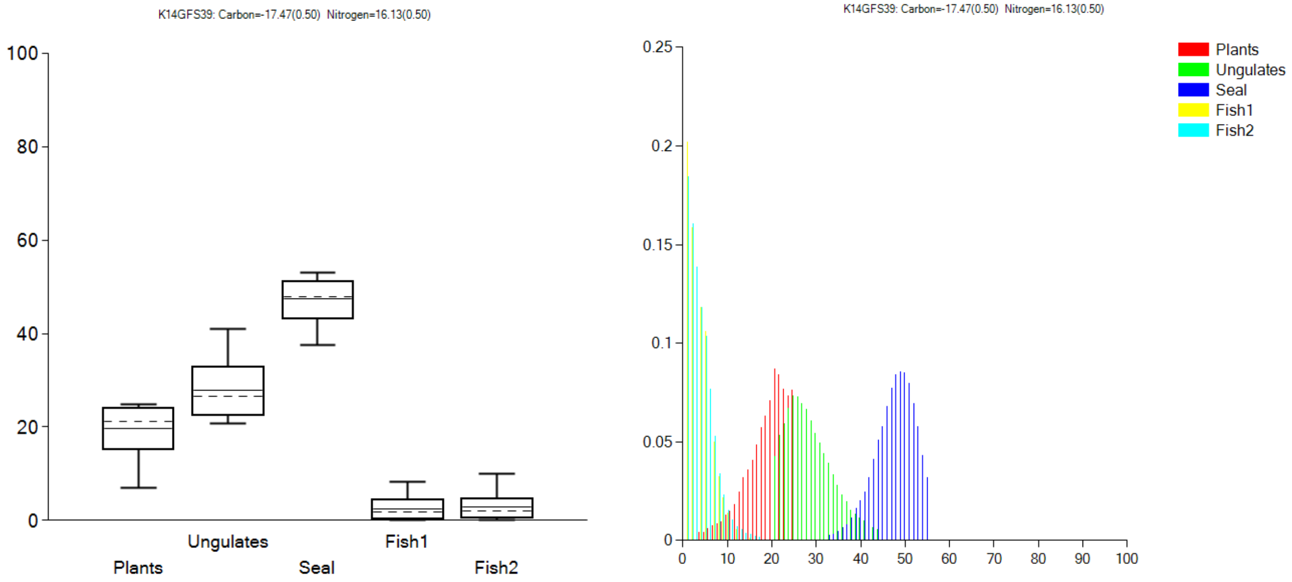

Figure 4.10 FRUITS results for K14GFS39, Scenario 1.

passed with satisfactory convergence and an acceptable p-value (0.831). The estimation values between Scenario 1 and Scenario 2 did not differ, such that it was determined that the stable isotope values of K14_1998.039 could, in fact, be explained by the Little Sea dietary model (Table 4.12).

Table 4.12 FRUITS dietary source contribution estimations for K14GFS39, Scenario 1.

ESTIMATES *p-value=0.819*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc	
Plants	0.20	0.05	0.07	0.21	0.25	0.15	0.24
Ungulates	0.28	0.05	0.21	0.27	0.41	0.23	0.33
Seal	0.47	0.04	0.37	0.48	0.53	0.43	0.51
Fish1	0.02	0.02	0.00	0.02	0.08	0.00	0.05
Fish2	0.03	0.03	0.00	0.02	0.10	0.01	0.05

Table 4.13 FRUITS dietary source contribution estimations for K14GFS39, Scenario 2.

ESTIMATES *p-value=0.831*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc	
Plants	0.19	0.04	0.11	0.20	0.25	0.15	0.24
Ungulates	0.28	0.05	0.21	0.28	0.39	0.23	0.33
Seal	0.46	0.04	0.36	0.47	0.53	0.42	0.51
Fish1	0.03	0.03	0.00	0.02	0.11	0.01	0.06
Fish2	0.03	0.03	0.00	0.02	0.10	0.01	0.05

4.5.7 *K14_1999.044*

Table 4.14 Osteological Information of K14GFS44.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1999.044	35–50 y.	Adult	Male	3392±61	−17.8	15.9	GFS	Local

The p-value for this individual (Table 4.14) is 0.889 with satisfactory convergence. The graphed values (Figure 4.11) are also within the expected ranges and produce precise estimations for Scenario 1. This indicates that the Little Sea dietary model is an excellent match for the individuals’ stable isotope values (Table 4.15).

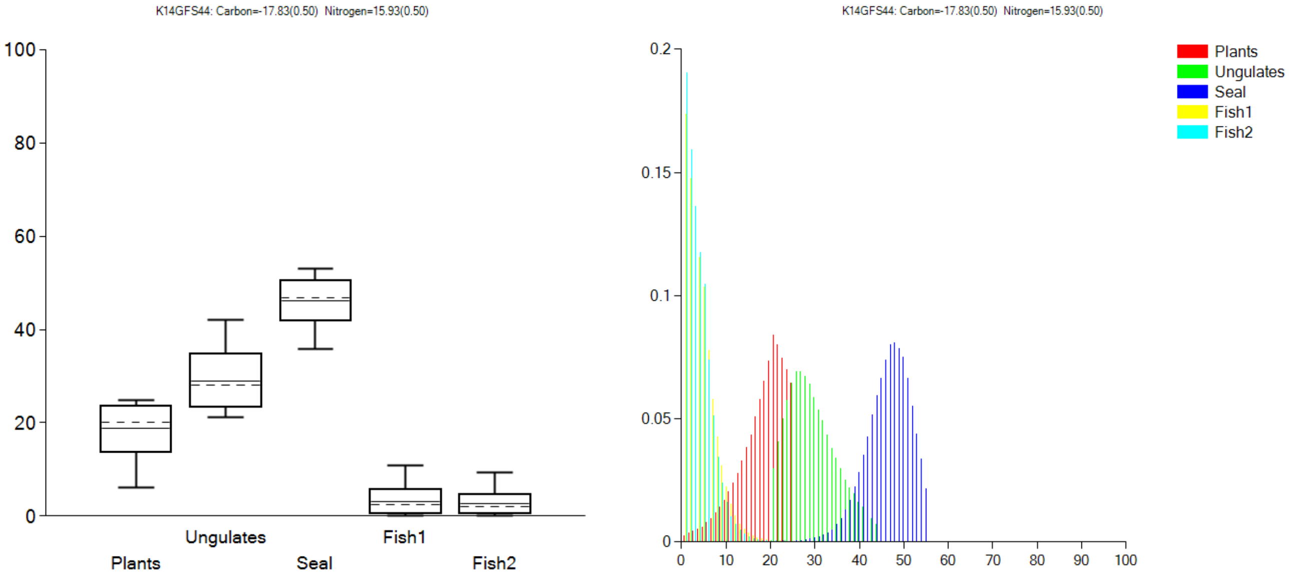

Figure 4.11 FRUITS results for K14GFS44, Scenario 1.

Table 4.15 FRUITS dietary source contribution estimations for K14GFS44, Scenario 1.

ESTIMATES *p-value=0.889*

Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.19	0.05	0.06	0.20	0.25	0.14–0.24
Ungulates	0.29	0.06	0.21	0.28	0.42	0.23–0.35
Seal	0.46	0.04	0.36	0.47	0.53	0.42–0.51
Fish1	0.03	0.03	0.00	0.02	0.11	0.01–0.06
Fish2	0.03	0.03	0.00	0.02	0.09	0.01–0.05

4.5.8 *K14_1999.045*

Table 4.16 Osteological Information of K14GFS45.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1999.045	8–10 y.	Subadult	Unknown	3540±59	−17.9	14.4	GFS	Local

The dietary estimates (Table 4.16) and FRUITS outputs (Figure 4.12) suggest that the Little Sea dietary model is a good fit for this individual (Table 4.17). Satisfactory convergence and a p-value of 0.907 support the acceptance of this model for the individual.

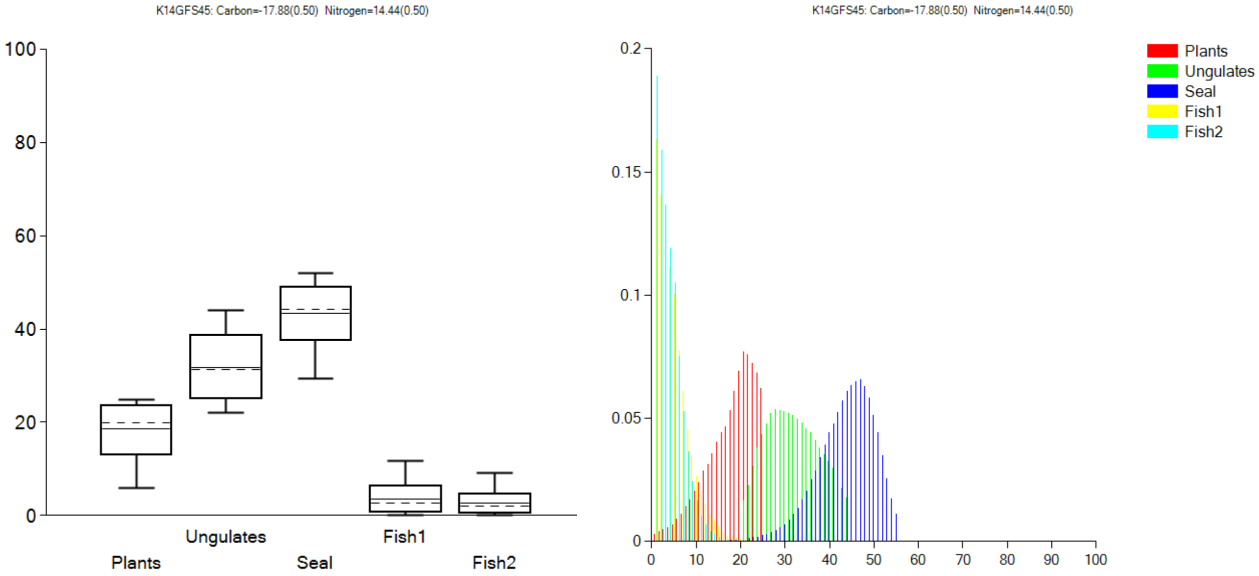

Figure 4.12 FRUITS results for K14GFS45, Scenario 1.

Table 4.17 FRUITS dietary source contribution estimations for K14GFS45, Scenario 1.

ESTIMATES *p-value=0.907*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.19	0.05	0.06	0.20	0.25	0.13–0.24
Ungulates	0.32	0.06	0.22	0.31	0.44	0.25–0.39
Seal	0.43	0.06	0.29	0.44	0.52	0.38–0.49
Fish1	0.04	0.03	0.00	0.03	0.12	0.01–0.07
Fish2	0.03	0.02	0.00	0.02	0.09	0.01–0.05

4.5.9 *K14_1999.055*

Table 4.18 Osteological Information of K14GFS55.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1999.055	35–50 y.	Adult	Male?	3505±61	−17.7	15.4	GFS	Local

The graphs (Figure 4.13) suggest that the Little Sea dietary model is a good fit for this individual (Table 4.18). The conclusion is complemented with a p-value of 0.883 and satisfactory convergence, indicating that this individual's stable isotope values can be explained with a Little Sea diet (Table 4.19).

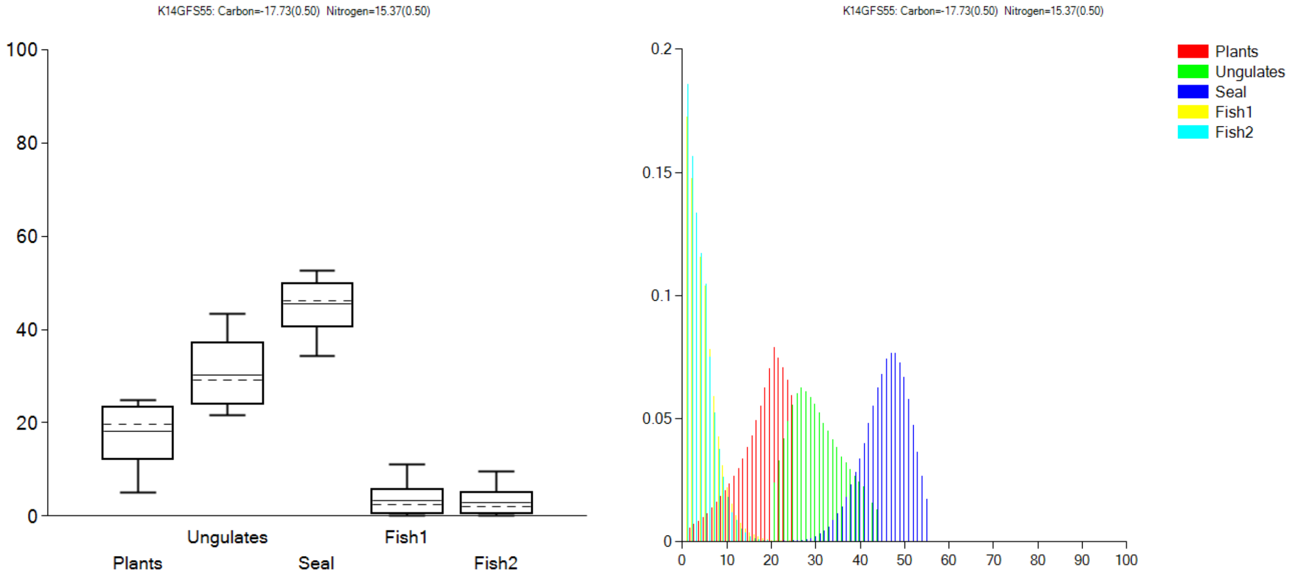

Figure 4.13 FRUITS results for K14GFS55, Scenario 1.

Table 4.19 FRUITS dietary source contribution estimations for K14GFS55, Scenario 1.

ESTIMATES *p-value=0.883*

Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.18	0.06	0.05	0.20	0.25	0.12–0.24
Ungulates	0.30	0.06	0.22	0.29	0.43	0.24–0.37
Seal	0.45	0.05	0.34	0.46	0.53	0.41–0.50
Fish1	0.03	0.03	0.00	0.02	0.11	0.01–0.06
Fish2	0.03	0.03	0.00	0.02	0.10	0.01–0.05

4.5.10 *K14_1999.059.02*

Table 4.20 Osteological Information of K14GFS5902.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1999.059.02	18–20 y.	Adult	Male	3439±57	−18.6	13.6	GFS	Local

Though the values (Table 4.21) are within the expected ranges, and the graphs appear as expected (Figure 4.14), this individual (Table 4.20) was rejected for Scenario 1. This is because the model could not attain proper convergence and the p-value was over 0.95 (0.964). When run through Scenario 2, the model failed to produce results. Therefore, it is highly unlikely this individual could not have subsisted on solely a Little Sea diet with their measured stable isotope values. Rather, it is more likely there are integral food sources missing from the analysis.

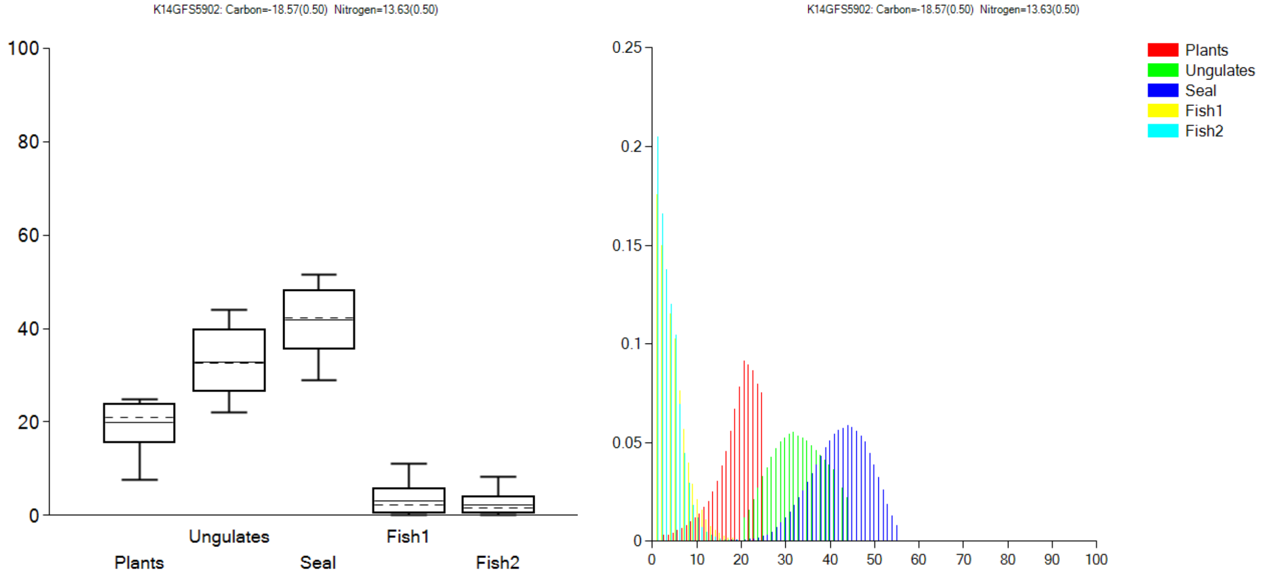

Figure 4.14 FRUITS results for K14GFS5902, Scenario 1.

Table 4.21 FRUITS dietary source contribution estimations for K14GFS5902, Scenario 1.

ESTIMATES *p-value=0.964*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.20	0.04	0.09	0.21	0.25	0.15–0.24
Ungulates	0.33	0.06	0.23	0.33	0.43	0.27–0.39
Seal	0.42	0.06	0.28	0.42	0.52	0.36–0.48
Fish1	0.03	0.03	0.00	0.03	0.11	0.01–0.06
Fish2	0.02	0.02	0.00	0.02	0.08	0.00–0.04

4.5.11 *K14_2000.063*

Table 4.22 Osteological Information of K14GFS63.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_2000.063	16–18 y.	Adult	Unknown	3528±62	−17.1	15.6	GFS	Local

The graphs (Figure 4.15) suggest that the Little Sea dietary model is a good fit for this individual (Table 4.22). The conclusion is complemented with a p-value of 0.778, though poor convergence resulted in the rejection of the model for Scenario 1. When run through Scenario 2, both the convergence and the p-value (0.78) were satisfactory with few changes to the dietary contribution estimations (Table 4.23 and Table 4.24), which indicates that the Little Sea diet is indeed a good fit for this individual's stable isotope values.

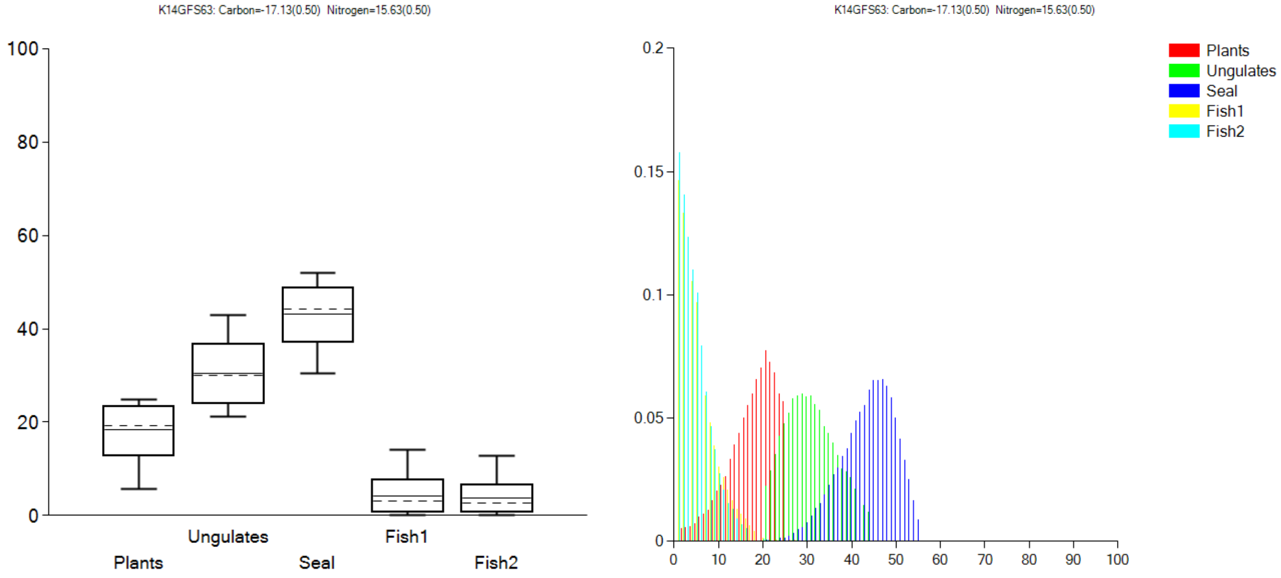

Figure 4.15 FRUITS results for K14GFS63, Scenario 1.

Table 4.23 FRUITS dietary source contribution estimations for K14GFS63, Scenario 1.

ESTIMATES *p-value=0.778*

Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.18	0.05	0.06	0.19	0.25	0.13–0.24
Ungulates	0.31	0.06	0.21	0.30	0.43	0.24–0.37
Seal	0.43	0.06	0.31	0.44	0.52	0.37–0.49
Fish1	0.04	0.04	0.00	0.03	0.14	0.01–0.08
Fish2	0.04	0.03	0.00	0.03	0.13	0.01–0.07

Table 4.24 FRUITS dietary source contribution estimations for K14GFS63, Scenario 2.

ESTIMATES *p-value=0.78*

Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.19	0.04	0.11	0.20	0.25	0.14–0.24
Ungulates	0.30	0.05	0.21	0.29	0.40	0.24–0.35
Seal	0.44	0.05	0.32	0.45	0.52	0.39–0.49
Fish1	0.04	0.04	0.00	0.03	0.14	0.01–0.08
Fish2	0.03	0.03	0.00	0.02	0.11	0.01–0.06

4.5.12 *K14_2000.064*

Table 4.25 Osteological Information of K14GFS64.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_2000.064	25–35 y.	Adult	Male	3636±61	−17.4	14.8	GFS	Local

Though the graphed values (Figure 4.16) are within the expected ranges and the p-value acceptable (0.851), this solution was rejected for Scenario 1 because the model could not attain proper convergence. When run through Scenario 2, the model failed to produce results. Therefore, it is highly unlikely this individual (Table 4.25) could have subsisted on solely a Little

Sea diet with their measured stable isotope values (Table 4.26). Rather, it is more likely that they represent a diet consisting of food sources from multiple ecological zones, or that there are integral food sources missing from the analysis for this particular person.

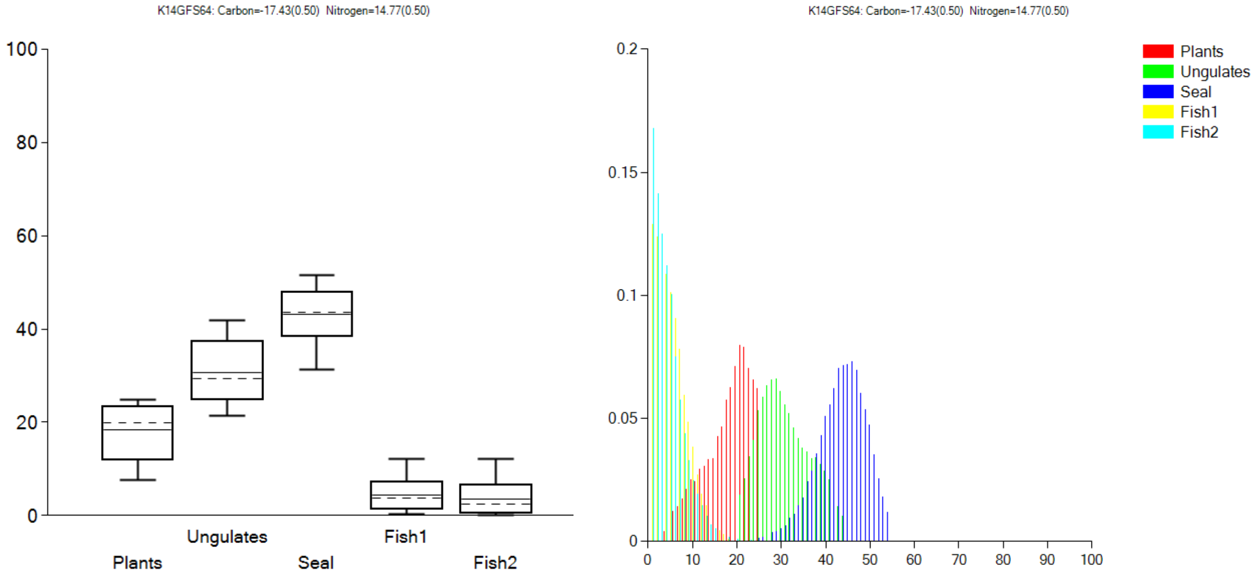

Figure 4.16 FRUITS results for K14GFS64, Scenario 1.

Table 4.26 FRUITS dietary source contribution estimations for K14GFS64, Scenario 1.

ESTIMATES *p-value=0.851*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.18	0.05	0.08	0.20	0.25	0.12–0.24
Ungulates	0.31	0.06	0.21	0.29	0.42	0.25–0.37
Seal	0.43	0.05	0.31	0.44	0.51	0.38–0.48
Fish1	0.04	0.03	0.00	0.04	0.12	0.01–0.07
Fish2	0.03	0.03	0.00	0.02	0.12	0.01–0.07

4.5.13 *K14_1993.002*

Table 4.27 Osteological Information of K14GFS02.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1993.002	20+ y.	Adult	Unknown	3682±62	−18.5	14.9	GFS	Non-local

Though the values (Table 4.28) and graphs (Figure 4.17) are within the expected ranges, this individual (Table 4.27) was rejected for Scenario 1 because the p-value (0.95) and convergence were unacceptable. When run through Scenario 2, the model failed to produce results. Therefore, it is highly unlikely this individual could not have subsisted on solely a Little Sea diet with their measured stable isotope values. Rather, it is more likely that they represent a diet derived from two ecological zones or there are food sources integral to the diet missing from the analysis.

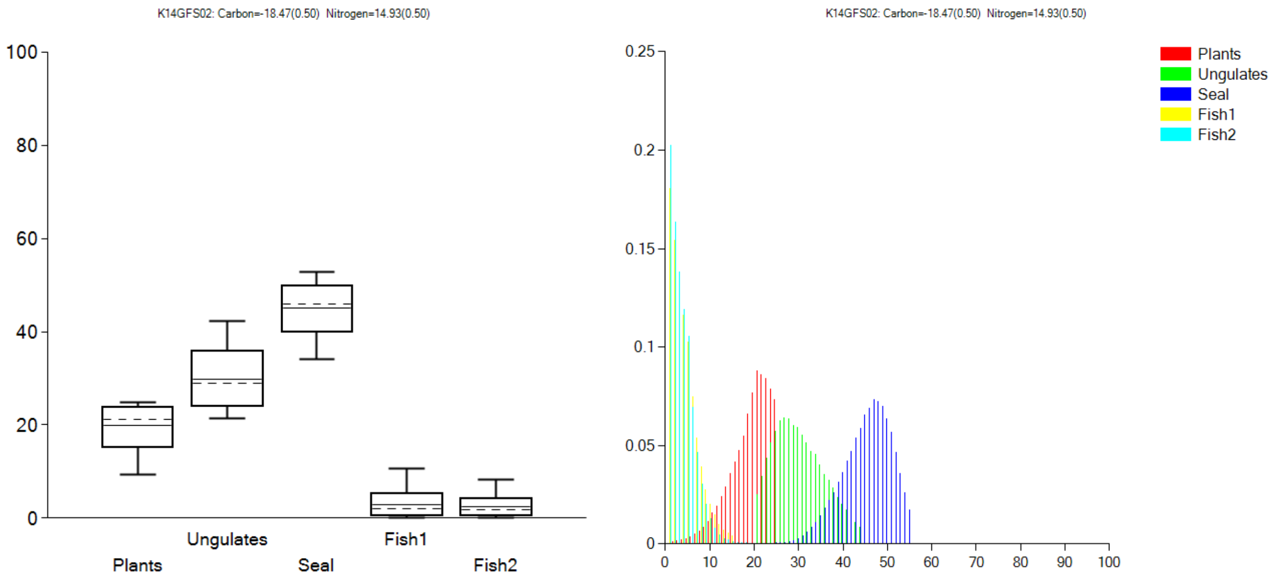

Figure 4.17 FRUITS results for K14GFS02, Scenario 1.

Table 4.28 FRUITS dietary source contribution estimations for K14GFS02, Scenario 1.

ESTIMATES *p-value=0.95*

Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.20	0.04	0.09	0.21	0.25	0.15–0.24
Ungulates	0.30	0.06	0.21	0.29	0.42	0.24–0.36
Seal	0.45	0.05	0.34	0.46	0.53	0.40–0.50
Fish1	0.03	0.03	0.00	0.02	0.11	0.01–0.05
Fish2	0.02	0.02	0.00	0.02	0.08	0.00–0.04

4.5.14 *K14_1993.005*

Table 4.29 Osteological Information of K14GFS05.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1993.005	20+ y.	Adult	Unknown	3864±61	−16.6	15.5	GFS	Non-local

The graph output (Figure 4.18) suggest that the Little Sea dietary model is a good fit for this individual (Table 4.29). The conclusion is complemented with a p-value of 0.704 and satisfactory convergence, indicating that this individual's stable isotope values can be explained with a Little Sea diet (Table 4.30).

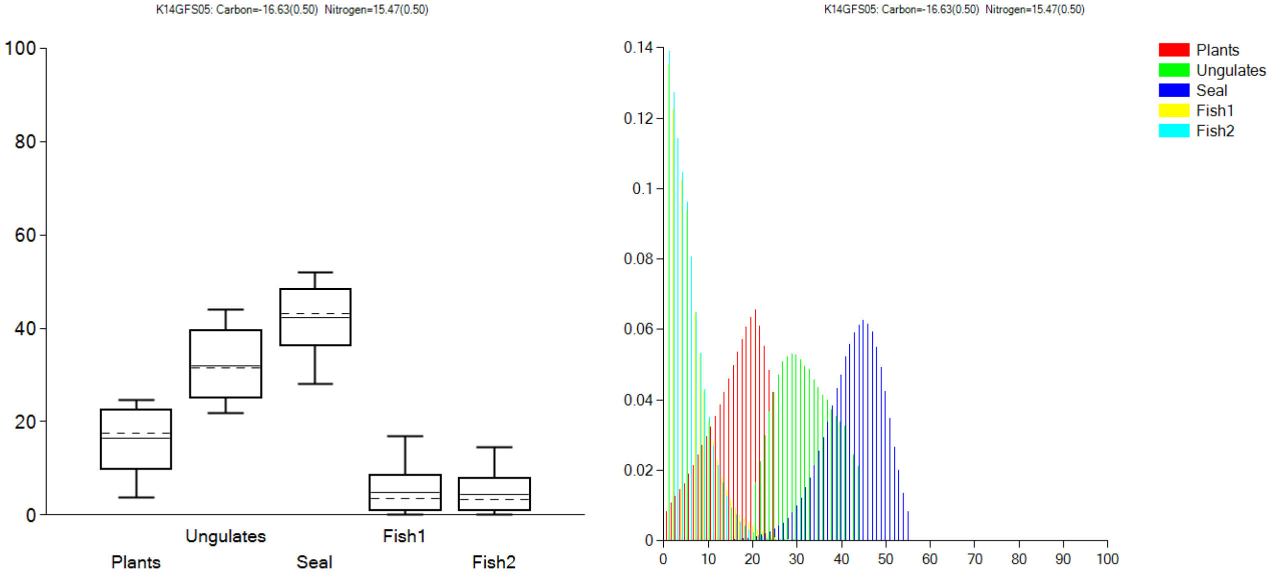

Figure 4.18 FRUITS results for K14GFS05, Scenario 1.

Table 4.30 FRUITS dietary source contribution estimations for K14GFS05, Scenario 1.

ESTIMATES *p-value=0.704*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.17	0.06	0.04	0.18	0.25	0.10–0.23
Ungulates	0.32	0.06	0.22	0.31	0.44	0.25–0.40
Seal	0.42	0.06	0.28	0.43	0.52	0.36–0.48
Fish1	0.05	0.04	0.00	0.03	0.17	0.01–0.09
Fish2	0.04	0.04	0.00	0.03	0.15	0.01–0.08

4.5.15 *K14_1997.010*

Table 4.31 Osteological Information of K14GFS10.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1997.010	20–25 y.	Adult	Unknown	3759±61	−18.5	13.4	GFS	Non-local

Due to the obvious impracticality of the graphs (Figure 4.19), this individual (Table 4.31) was rejected for Scenario 1 even though the p-value (0.586) and convergence were acceptable. When run through Scenario 2, the model failed to produce results. Therefore, it is highly unlikely this individual could not have subsisted on solely a Little Sea diet with their measured stable isotope values. Rather, it is more likely that there are important food sources missing from the analysis, or additional priors are required to provide more support to the model.

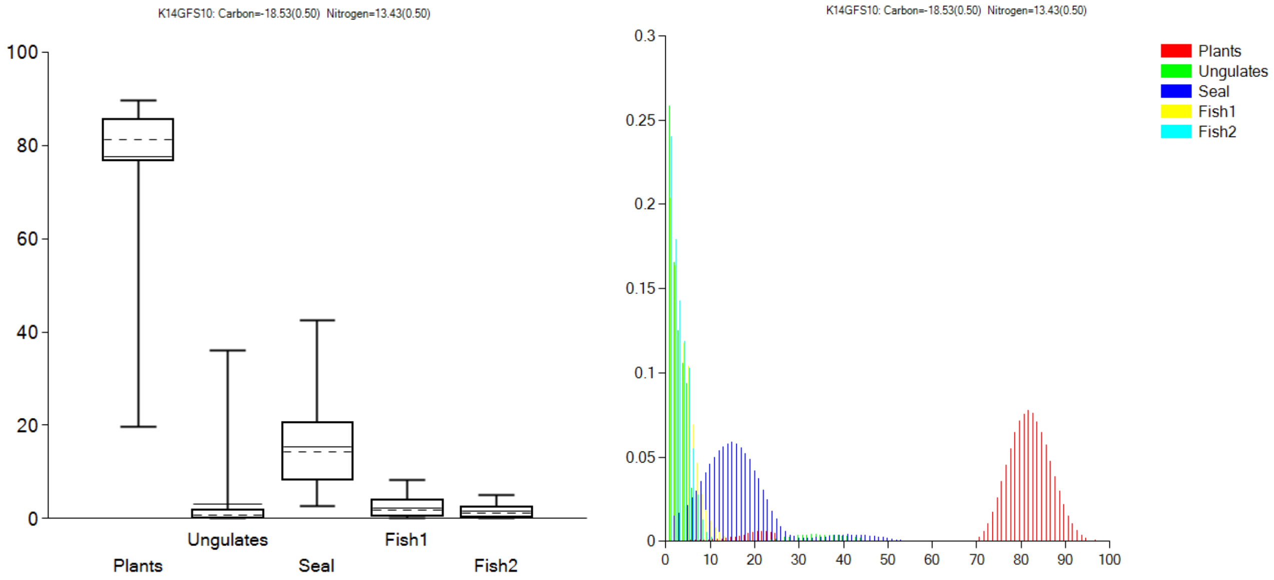

Figure 4.19 FRUITS results for K14GFS10, Scenario 1.

4.5.16 *K14_1997.019*

Table 4.32 Osteological Information of K14GFS19.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1997.019	35–50 y.	Adult	Female	3593±61	−16.7	15.7	GFS	Non-local

There was no output produced for this individual (Table 4.32) in Scenario 1, as the mixing problem was deemed too complex. However, when run through Scenario 2 the individual produced excellent results and with a p-value of 0.698 and satisfactory convergence. The graphs (Figure 4.20) and values (Table 4.32) also are well within the ideal dietary range. With these data considered, K14GFS19's measured stable isotope values do correlate with a Little Sea diet.

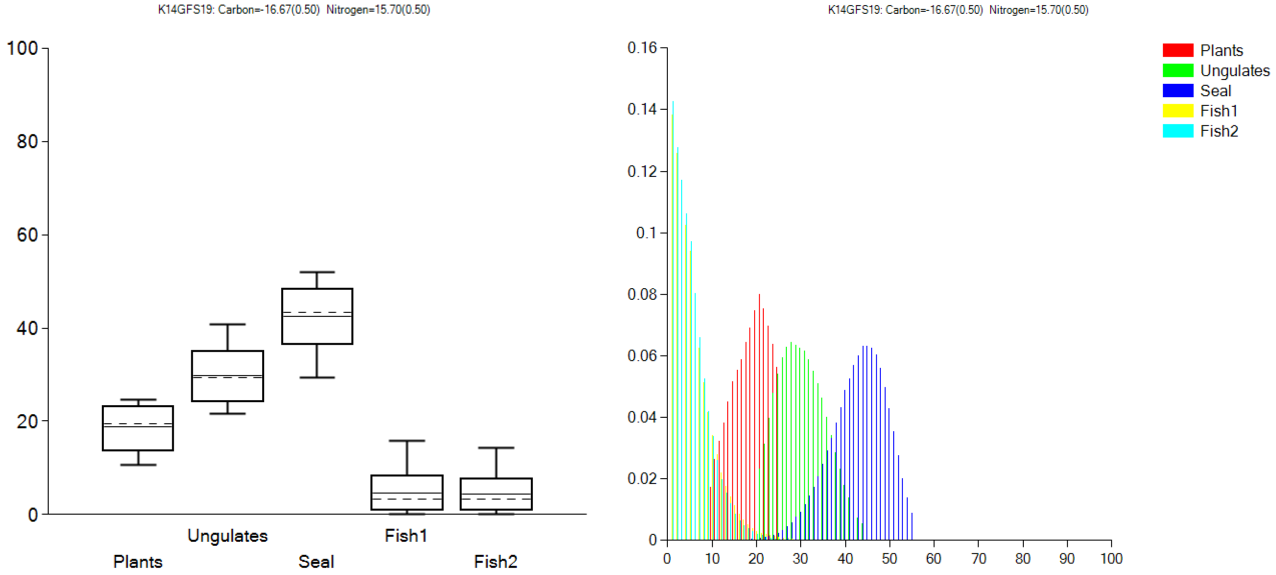

Figure 4.20 FRUITS results for K14GFS19, Scenario 2.

Table 4.33 FRUITS dietary source contribution estimations for K14GFS19, Scenario 2.

ESTIMATES *p-value=0.698*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.19	0.04	0.11	0.19	0.25	0.14–0.23
Ungulates	0.30	0.05	0.22	0.29	0.41	0.24–0.35
Seal	0.43	0.06	0.29	0.43	0.52	0.37–0.48
Fish1	0.05	0.04	0.00	0.03	0.16	0.01–0.09
Fish2	0.04	0.04	0.00	0.03	0.14	0.01–0.08

4.5.17 *K14_1998.038*

Table 4.34 Osteological Information of K14GFS38.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.038	35–50 y.	Adult	Male	3618±60	−18.4	13.6	GFS	Non-local

The graphs (Figure 4.21) show that Scenario 1 could be a possible diet as the values are well within the expected ranges (Table 4.35) and the p-value has a value of 0.948. However, the poor convergence rates mean that this individual (Table 4.34) was rejected. When run through Scenario 2, the model failed to produce results. Therefore, it is highly unlikely this individual could have subsisted on solely a Little Sea diet. Rather, it is more likely that there are vital food sources missing from the analysis.

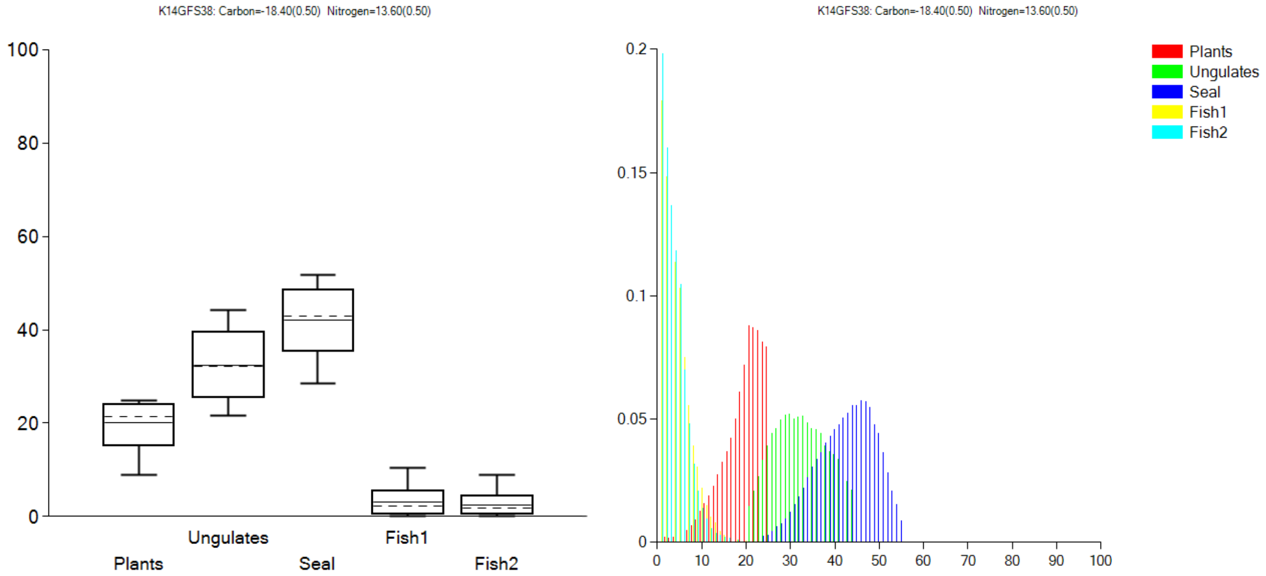

Figure 4.21 FRUITS results for K14GFS38, Scenario 1.

Table 4.35 FRUITS dietary source contribution estimations for K14GFS38, Scenario 1.

ESTIMATES *p-value=0.948*

Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.20	0.05	0.09	0.21	0.25	0.15–0.24
Ungulates	0.32	0.06	0.22	0.32	0.44	0.25–0.40
Seal	0.42	0.06	0.28	0.43	0.52	0.35–0.49
Fish1	0.03	0.03	0.00	0.02	0.10	0.01–0.06
Fish2	0.03	0.02	0.00	0.02	0.09	0.00–0.05

4.5.18 *K14_1999.046*

Table 4.36 Osteological Information of K14GFS46.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1999.046	25–35 y.	Adult	Male	3527±61	−18.4	14.2	GFS	Non-local

The FRUITS outputs (Figure 4.22) show that Scenario 1 could have been a possible diet as the values are well within the expected ranges (Table 4.37 and 4.38). Though the convergence was satisfactory the individual (Table 4.36) was ultimately rejected in Scenario 1 with a p-value of 0.951. When run through Scenario 2, the values stayed nearly the same and the model passed all the criteria with a p-value of .948. With this in mind, it was decided that K14_1999.046's stable isotope values do broadly correlate with a Little Sea diet, though with less confidence than other targets due to the high p-value.

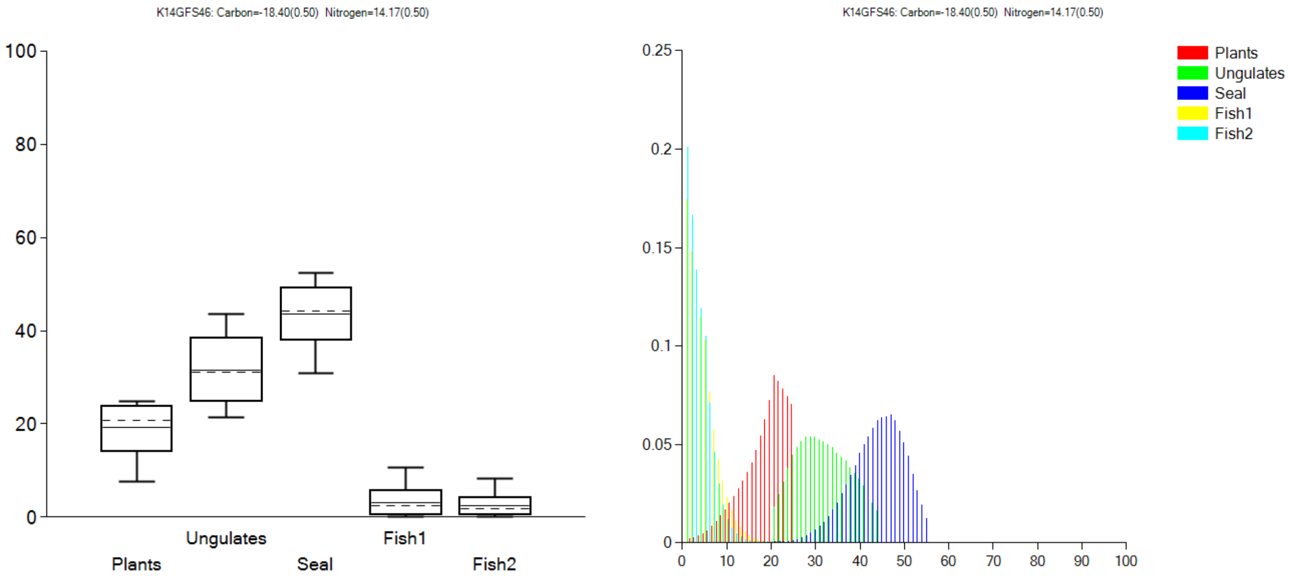

Figure 4.22 FRUITS results for K14GFS46, Scenario 1.

Table 4.37 FRUITS dietary source contribution estimations for K14GFS46, Scenario 1.

ESTIMATES *p-value =0.951*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.19	0.05	0.08	0.21	0.25	0.14–0.24
Ungulates	0.32	0.06	0.21	0.31	0.44	0.25–0.39
Seal	0.44	0.06	0.31	0.44	0.52	0.38–0.49
Fish1	0.03	0.03	0.00	0.02	0.11	0.01–0.06
Fish2	0.02	0.02	0.00	0.02	0.08	0.00–0.04

Table 4.38 FRUITS dietary source contribution estimations for K14GFS46, Scenario 2.

ESTIMATES *p-value =0.948*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.20	0.04	0.12	0.21	0.25	0.16–0.24
Ungulates	0.30	0.05	0.22	0.30	0.41	0.25–0.36
Seal	0.44	0.05	0.33	0.44	0.52	0.39–0.49
Fish1	0.03	0.03	0.00	0.03	0.11	0.01–0.06
Fish2	0.02	0.02	0.00	0.02	0.08	0.00–0.04

4.5.19 *K14_1999.051*

Table 4.39 Osteological Information of K14GFS51.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1999.051	18–20 y.	Adult	Male	3645±61	−17.6	14.8	GFS	Non-local

The graphed values (Figure 4.23) show that Scenario 1 could have been a possible diet as the values are well within the expected ranges (Table 4.40). The p-value passes with a value of 0.86. Though only moderate convergence was achieved for this individual (Table 4.39), it meets acceptance criteria. Therefore, this individual's values correlate with a Little Sea diet.

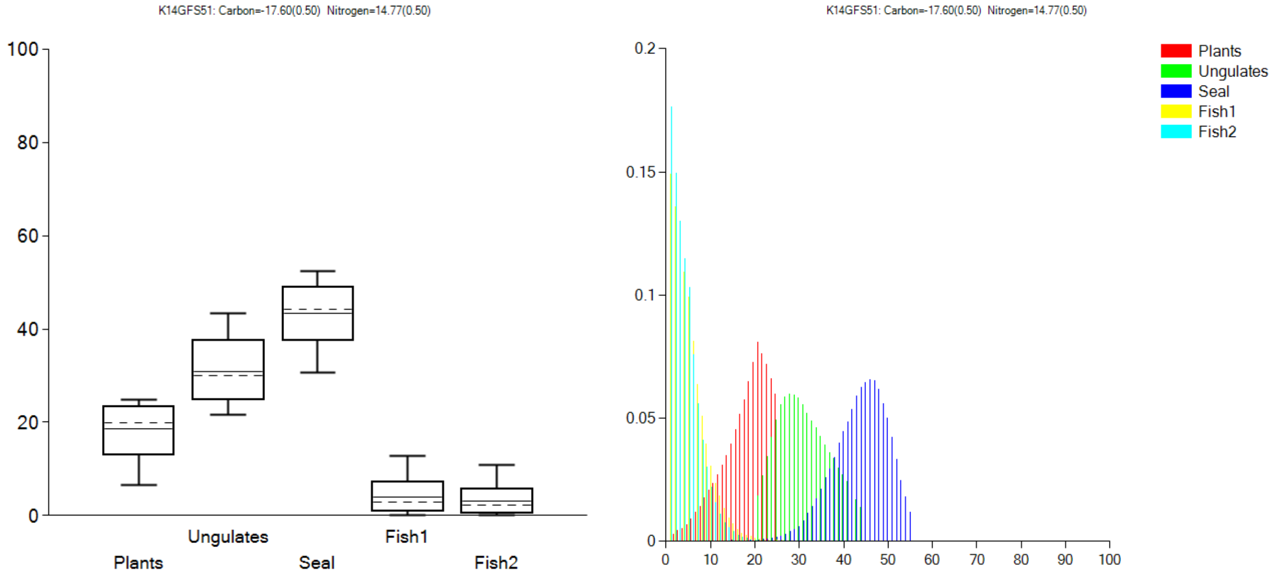

Figure 4.23 FRUITS results for K14GFS51, Scenario 1.

Table 4.40 FRUITS dietary source contribution estimations for K14GFS51, Scenario 1.

ESTIMATES *p-value=0.86*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.19	0.05	0.07	0.20	0.25	0.13–0.24
Ungulates	0.31	0.06	0.22	0.30	0.43	0.25–0.38
Seal	0.43	0.06	0.31	0.44	0.52	0.38–0.49
Fish1	0.04	0.03	0.00	0.03	0.13	0.01–0.07
Fish2	0.03	0.03	0.00	0.02	0.11	0.01–0.06

4.5.20 *K14_1999.057.02*

Table 4.41 Osteological Information of K14GFS5702

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1999.057.02	35–50 y.	Adult	Male	3639±57	−16.6	16.6	GFS	Non-local

The values presented (Figure 4.24) show that Scenario 1 could have been a possible diet as the values are well within the expected ranges. The p-value also passes with a good value of 0.655 and satisfactory convergence values. Therefore, this individual's (Table 4.41) stable isotope values correlate with a Little Sea diet (Table 4.42).

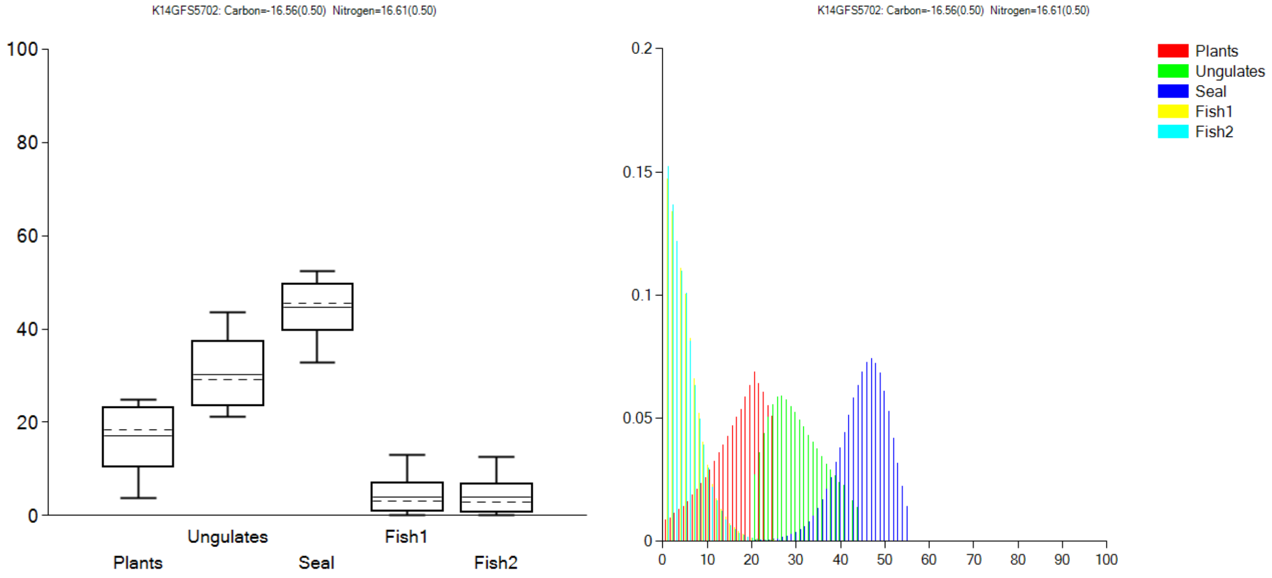

Figure 4.24 FRUITS results for K14GFS5702, Scenario 1.

Table 4.42 FRUITS dietary source contribution estimations for K14GFS5702, Scenario 1.

ESTIMATES *p-value=0.655*

Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.17	0.06	0.04	0.18	0.25	0.10–0.23
Ungulates	0.30	0.06	0.21	0.29	0.44	0.24–0.38
Seal	0.45	0.05	0.33	0.46	0.52	0.40–0.50
Fish1	0.04	0.03	0.00	0.03	0.13	0.01–0.07
Fish2	0.04	0.03	0.00	0.03	0.13	0.01–0.07

4.5.21 *K14_1999.058.01*

Table 4.43 Osteological Information of K14GFS5801

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1999.058.01	25–35 y.	Adult	Unknown	3709±61	−17.2	14.8	GFS	Non-local

The FRUITS output (Figure 4.25) shows that Scenario 1 could have been a possible diet as the values are well within the expected ranges. The p-value also passes with a value of 0.806. Though only moderate convergence was achieved for this individual (Table 4.43), it meets acceptance criteria. Therefore, this individual's stable isotope values correlate with a Little Sea diet (Table 4.44).

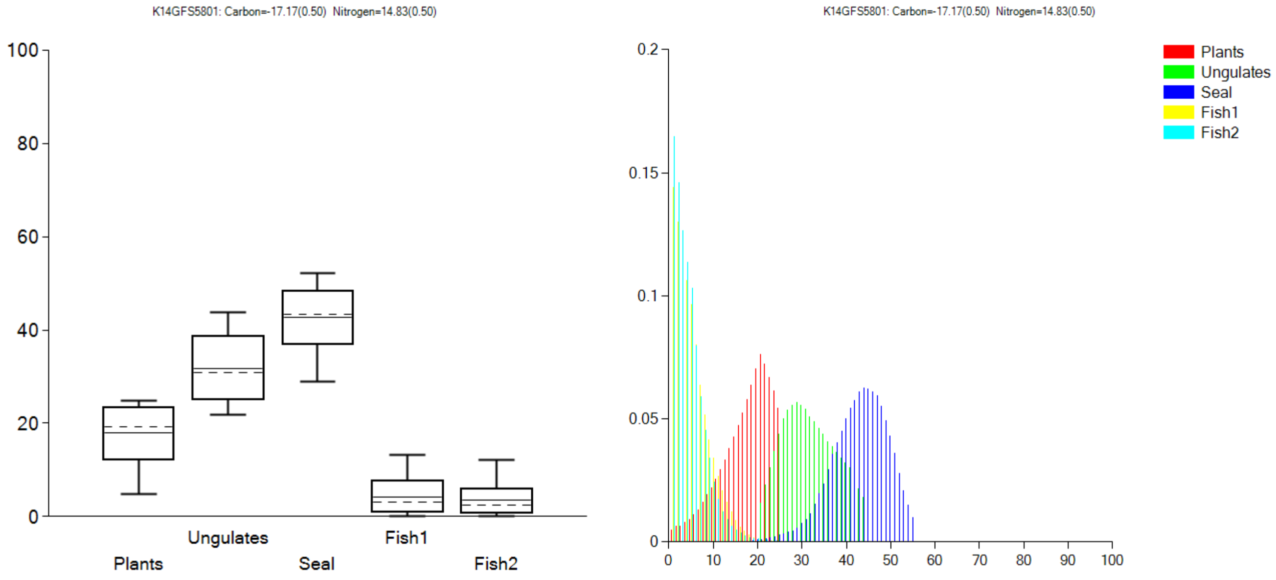

Figure 4.25 FRUITS results for K14GFS5801, Scenario 1.

Table 4.44 FRUITS dietary source contribution estimations for K14GFS5801, Scenario 1.

ESTIMATES *p-value=0.806*

Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Plants	0.18	0.05	0.05	0.19	0.25	0.12–0.23
Ungulates	0.32	0.06	0.22	0.31	0.44	0.25–0.39
Seal	0.43	0.06	0.29	0.43	0.52	0.37–0.49
Fish1	0.04	0.04	0.00	0.03	0.13	0.01–0.08
Fish2	0.03	0.03	0.00	0.03	0.12	0.01–0.06

4.5.22 *K14_1993.004*

Table 4.45 Osteological Information of K14GF04.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1993.04	20+ y.	Adult	Unknown	3532±61	−20.1	11.7	GF	Non-local

The graphs presented (Figure 4.26) provide no indication that Scenario 1 is an impractical diet, but the p-value of 0.996 and poor convergence values prove otherwise. This individual (Table 4.45) could not have subsisted on a Little Sea diet with their measured stable isotope values.

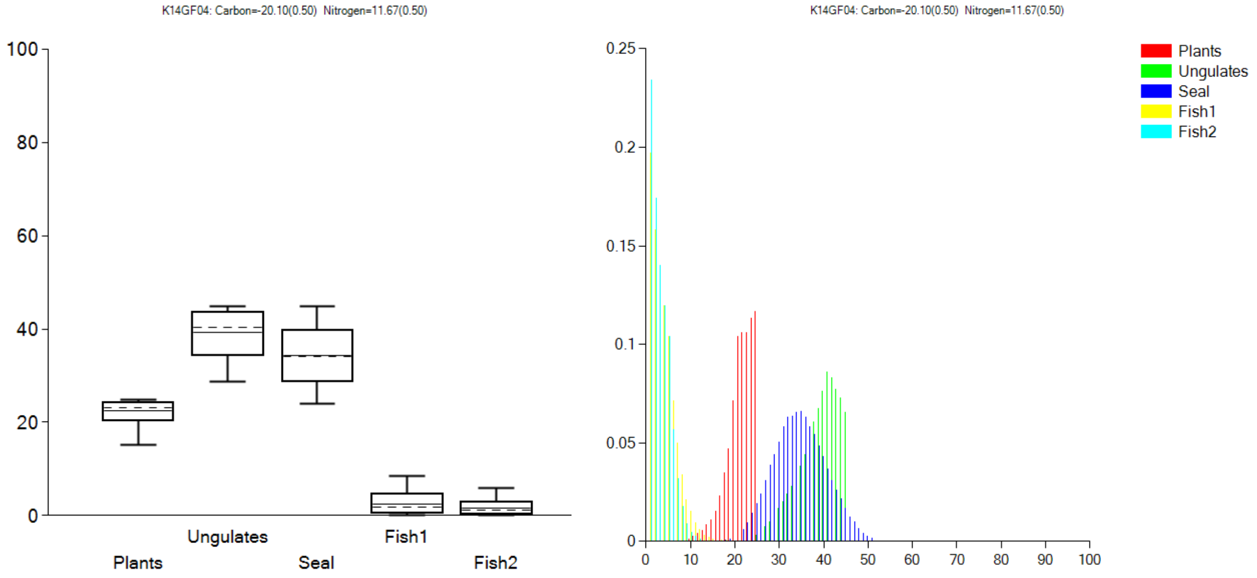

Figure 4.26 FRUITS results for K14GF04, Scenario 1.

4.5.23 *K14_1998.027.01*

Table 4.46 Osteological Information of K14GF2701.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1997.027.01	35–50 y.	Adult	Male	3390±61	−19.3	12.7	GF	Non-local

The FRUITS output (Figure 4.27) provides no indication that Scenario 1 is an impractical diet, but the p-value of 0.987 proves otherwise. This individual (Table 4.46) could not have subsisted on a Little Sea diet with their measured stable isotope values.

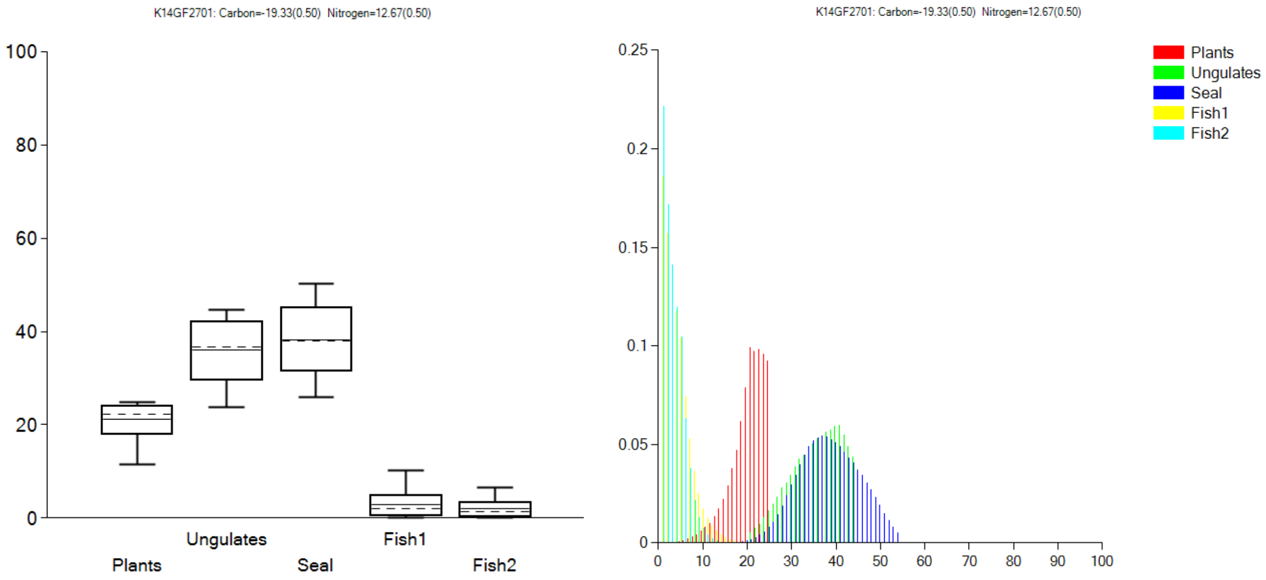

Figure 4.27 FRUITS results for K14GF2701, Scenario 1.

4.5.24 *K14_1998.034*

Table 4.47 Osteological Information of K14GF34.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.034	25–35 y.	Adult	Male	3587±65	−19.6	12.0	GF	Non-local

The graphs presented (Figure 4.28) show that Scenario 1 is not a possible diet, due to the extreme and nonsensical nature of the distribution. The p-value of 0.966 and poor convergence values support the rejection. This individual (Table 4.47) could not have subsisted on a Little Sea diet with their measured stable isotope values.

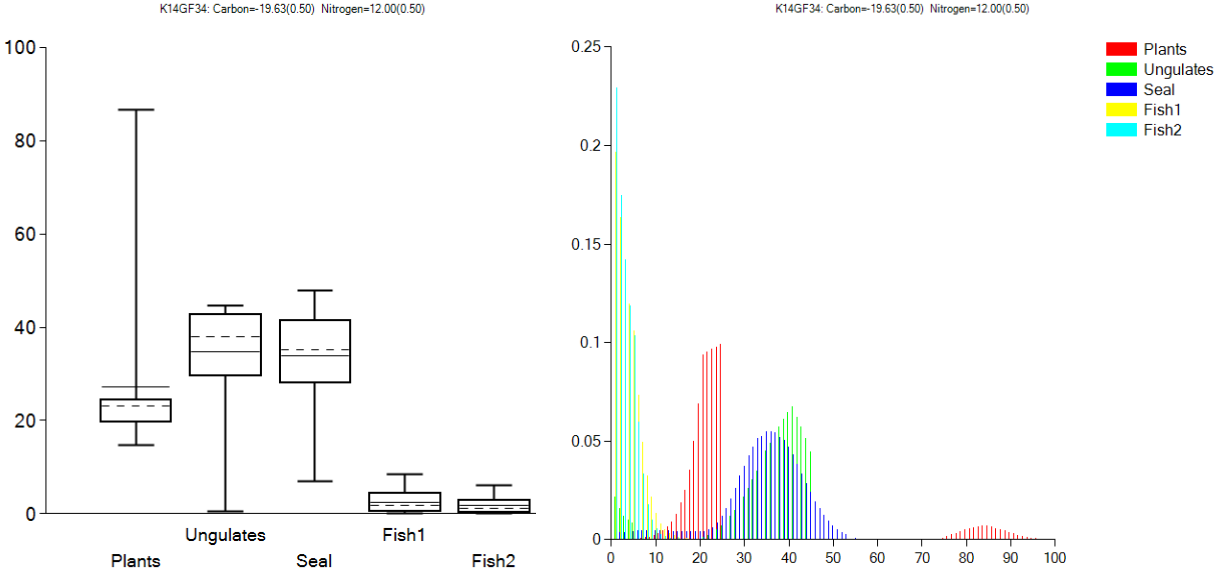

Figure 4.28 FRUITS results for K14GF34, Scenario 1.

4.5.25 *K14_1998.037.02*

Table 4.48 Osteological Information of K14GF3702.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.037.02	15–20 y.	Adult	Male?	3538±56	−19.2	11.7	GF	Non-local

No output was produced for this individual (Table 4.48) in either scenario, as the mixing problem was deemed too complex.

4.5.26 *K14_1998.035.01*

Table 4.49 Osteological Information of K14GF3501.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.035.01	18–20 y.	Adult	Male?	3514±61	−19.0	12.6	GF	Non-local

The FRUITS output (Figure 4.29) shows that Scenario 1 is an impossible diet, due to the extreme and nonsensical nature of the distribution. The p-value of 0.598 and satisfactory convergence values belies the data as passing some criteria. However, this individual (Table 4.49) could not have subsisted on a Little Sea diet with their measured stable isotope values.

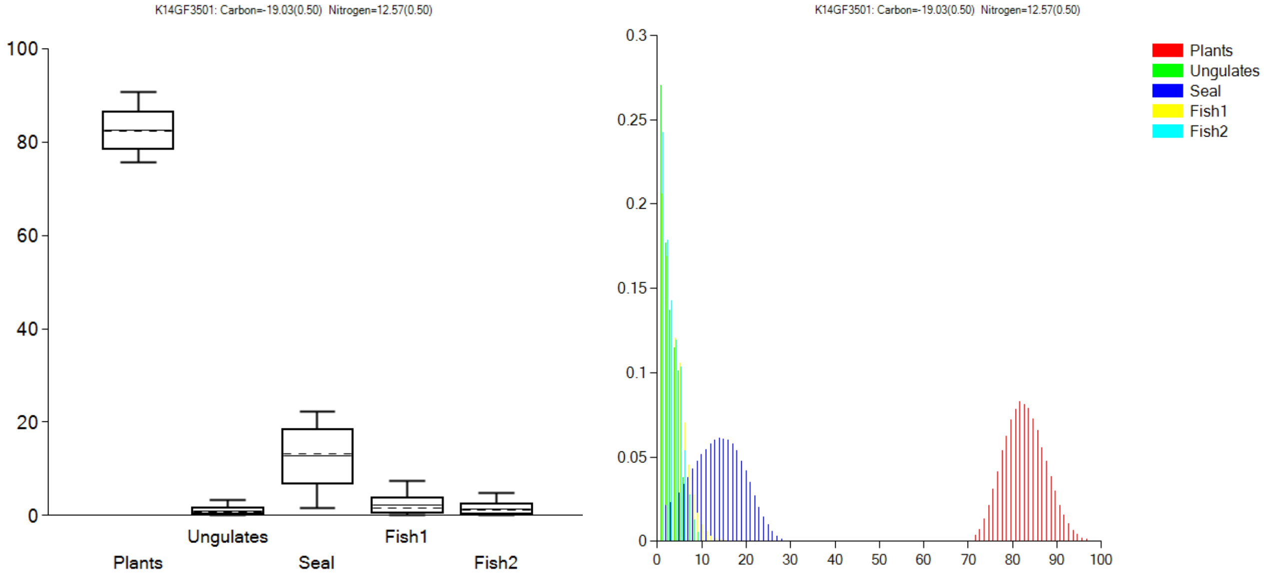

Figure 4.29 FRUITS results for K14GF3501, Scenario 1.

4.5.27 *K14_1998.036.01*

Table 4.50 Osteological Information of K14GF3601.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.036.01	35–50 y.	Adult	Unknown	3582±60	−18.9	12.4	GF	Non-local

The graphs presented (Figure 4.30) show that Scenario 1 could have been a possible diet as there are precise estimations within the expected ranges of source contribution. The convergence for this individual (Table 4.50) was also satisfactory but does not meet the p-value criteria, having a p-value of 0.975. Therefore, this individual could not have subsisted on a Little Sea diet with their measured stable isotope values.

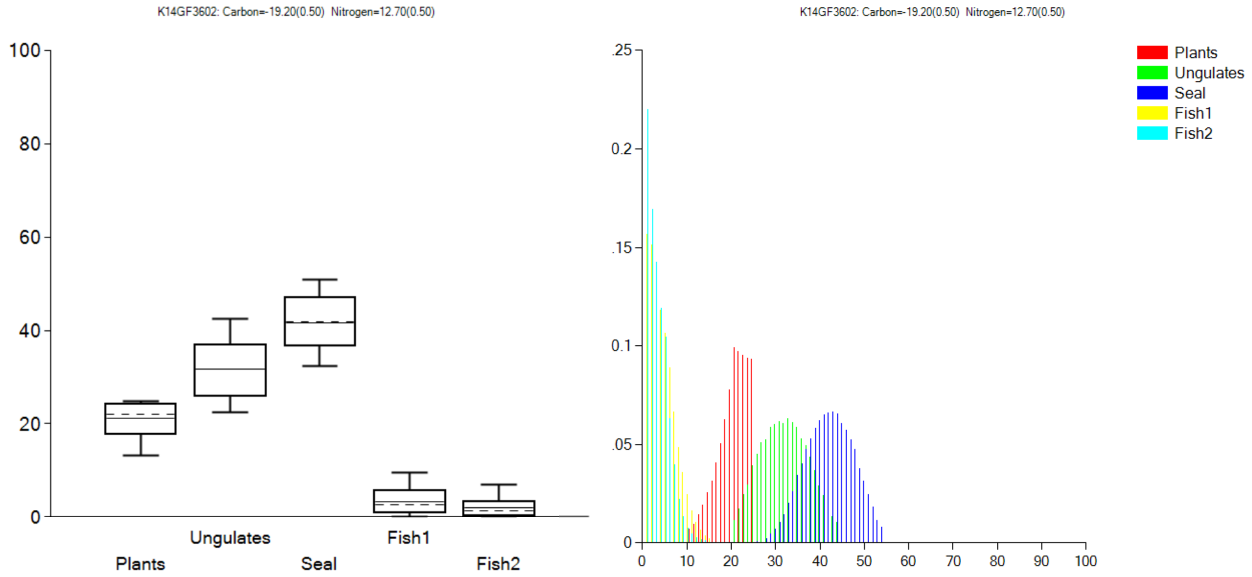

Figure 4.30 FRUITS results for K14GF3602, Scenario 2.

4.5.28 *K14_1998.036.02*

Table 4.51 Osteological Information of K14GF3602.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.036.02	4–6 y.	Subadult	Unknown	3660±38	−19.2	12.7	GF	Non-local

There was no output produced for this individual in Scenario 1, as the mixing problem was deemed too complex. This could have been due to the individuals' age (Table 4.51), which is still near the weaning age. This suggests there may have been a nursing signal still in effect within the bone collagen that could not be addressed by the current dietary model. When run through Scenario 2, results were produced (Figure 4.31). With a p-value of 0.981 and poor convergence indicate that the Little Sea dietary model cannot explain the variation seen in the stable isotopes of this individual.

4.5.29 *K14_1998.037.01*

Table 4.52 Osteological Information of K14GF3701.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.037.01	15–20 y.	Adult	Male?	3689±60	−19.0	11.1	GF	Non-local

The graphs (Figure 4.32) show that Scenario 1 could have been a possible diet as the values are somewhat within expected ranges. The convergence for this individual (Table 4.52) was also satisfactory but does not meet the p-value criteria, having a p-value of 0.982. Therefore, this individual could not have subsisted on a Little Sea diet with their measured stable isotope values.

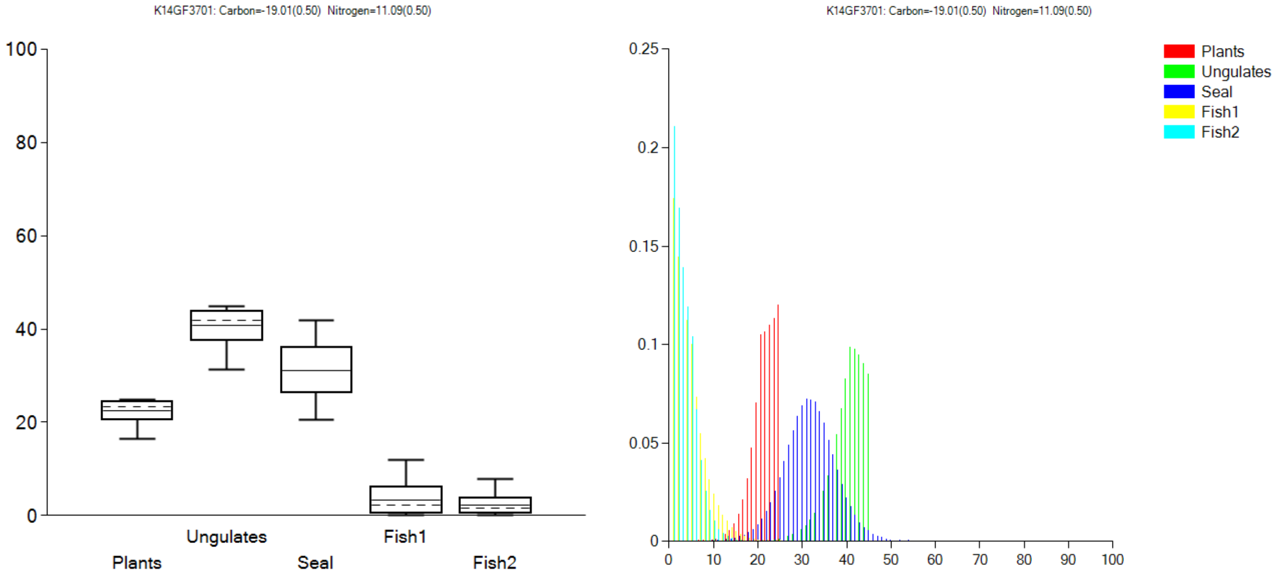

Figure 4.32 FRUITS results for K14GF3701, Scenario 1.

4.5.30 *K14_2000.077*

Table 4.53 Osteological Information of K14GF77.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_2000.077	12–15 y.	Subadult	Unknown	3775±56	−18.7	10.5	GF	Non-local

The graphs presented (Figure 4.33) show that Scenario 1 could have been a possible diet as the values are somewhat within expected ranges. The convergence for this individual (Table 4.53) was also satisfactory but does not meet the p-value criteria, instead having a p-value of 0.973. Therefore, this individual could not have subsisted on a Little Sea diet with their measured stable isotope values.

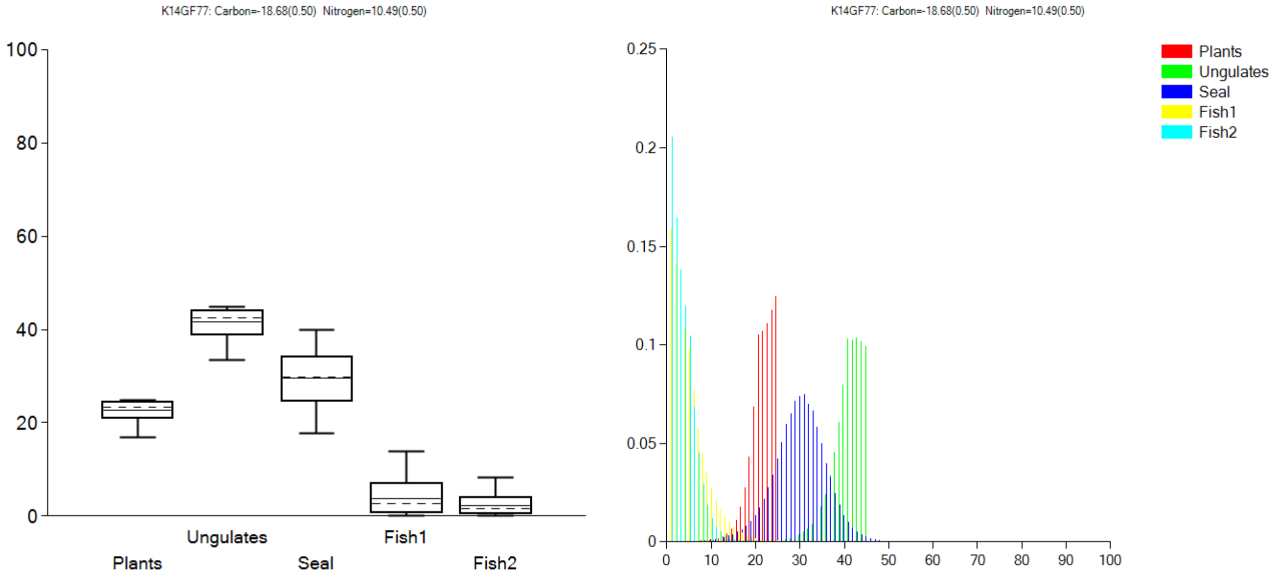

Figure 4.33 FRUITS results for K14GF77, Scenario 1.

4.6 Summary

4.6.1 *GFS Locals*

If the hypothesis that the GFS Local group represents people that lived and procured their resources in the Little Sea area is true, the GFS-Locals group should provide the best acceptance rates for the Little Sea model; as the model was constructed to identify a diet consisting of animal and plant resources found in the Little Sea (Table 4.54). Out of 12 individuals, 9 were accepted while 3 were rejected by the model for Scenario 1 (Figure 4.34). The acceptance rate of the model with the target group suggests that this model is meeting expectations with regard to identifying and quantifying the GFS diet of the Little Sea micro-region.

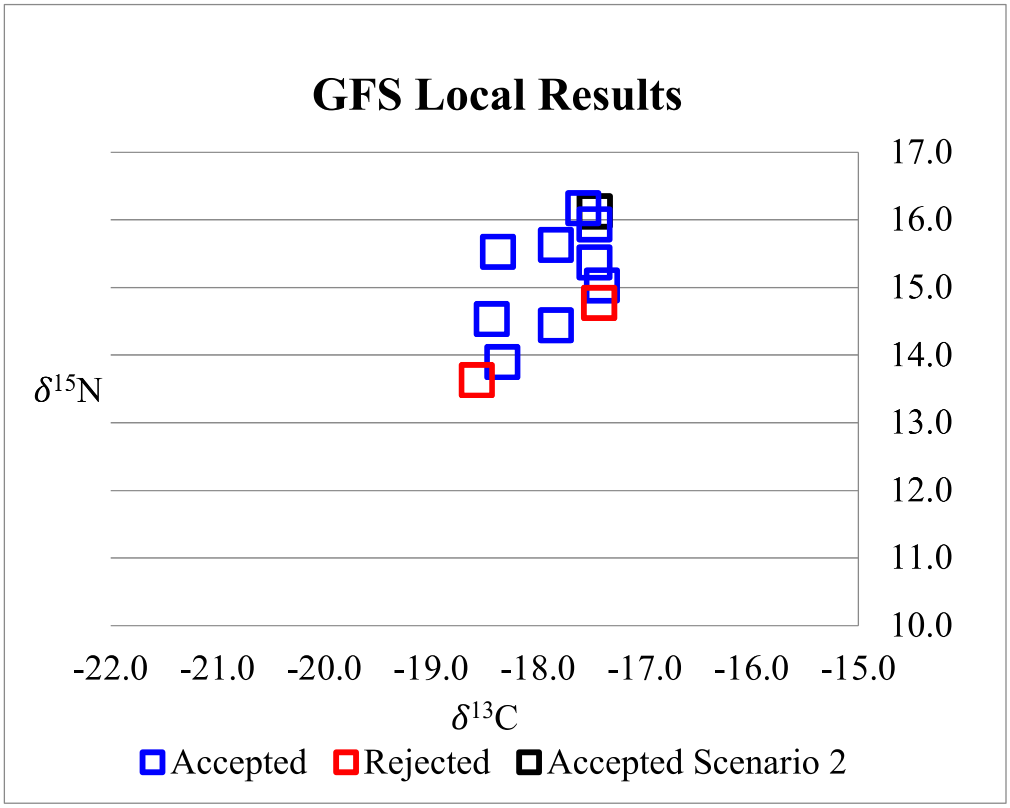

Figure 4.34 Results of FRUITS Analysis for GFS Locals from Khuzhir-Nuge XIV.

Table 4.54 Results of Little Sea Analysis for GFS Locals from Khuzhir-Nuge XIV.

Group	*Study ID*	$\delta^{13}C$	$\delta^{15}N$	*Scenario 1 Status*	*Scenario 2 Status*	*p-Value*	*Convergence*
GFS Local	K14GFS11	−18.4	15.5	Accepted	—	0.938	Moderate
GFS Local	K14GFS12	−18.3	13.9	Accepted	—	0.946	Great
GFS Local	K14GFS14	−18.4	14.5	Accepted	Rejected	0.947	Moderate
GFS Local	K14GFS15	−17.4	15.0	Accepted	Accepted	0.835	Great
GFS Local	K14GFS16	−17.6	16.2	Accepted	Accepted	0.851	Moderate
GFS Local	K14GFS39	−17.5	16.1	Rejected	Accepted	0.819	Poor
GFS Local	K14GFS44	−17.8	15.9	Accepted	—	0.889	Great
GFS Local	K14GFS45	−17.9	14.4	Accepted	—	0.907	Great
GFS Local	K14GFS55	−17.7	15.4	Accepted	Accepted	0.883	Great
GFS Local	K14GFS5902	−18.6	13.6	Rejected	—	0.964	Poor
GFS Local	K14GFS63	−17.1	15.6	Rejected	Accepted	0.778	Poor
GFS Local	K14GFS64	−17.4	14.8	Rejected	—	0.851	Poor

4.6.2 *GFS Non-Locals*

It is hypothesized that because the GFS Non-Local group should represent a group of people that migrated to the Little Sea at one point in their life, there should be both accepted and rejected individuals, depending on how much they relied on Little Sea resources (Table 4.55). Figure 4.35 shows that there is more variability regarding acceptance, rejection, and failure for the model to run compared to the GFS Local group. Out of 9 cases, there was only 1 failure, 5 targets were accepted, and 3 were rejected. The acceptance rate of the model with the target group suggests that this model is meeting expectations with regard to identifying and quantifying the GFS diet of the Little Sea micro-region, even when there is a possibility of mixed dietary signals with Non-Local origins or recent migrants to the Little Sea.

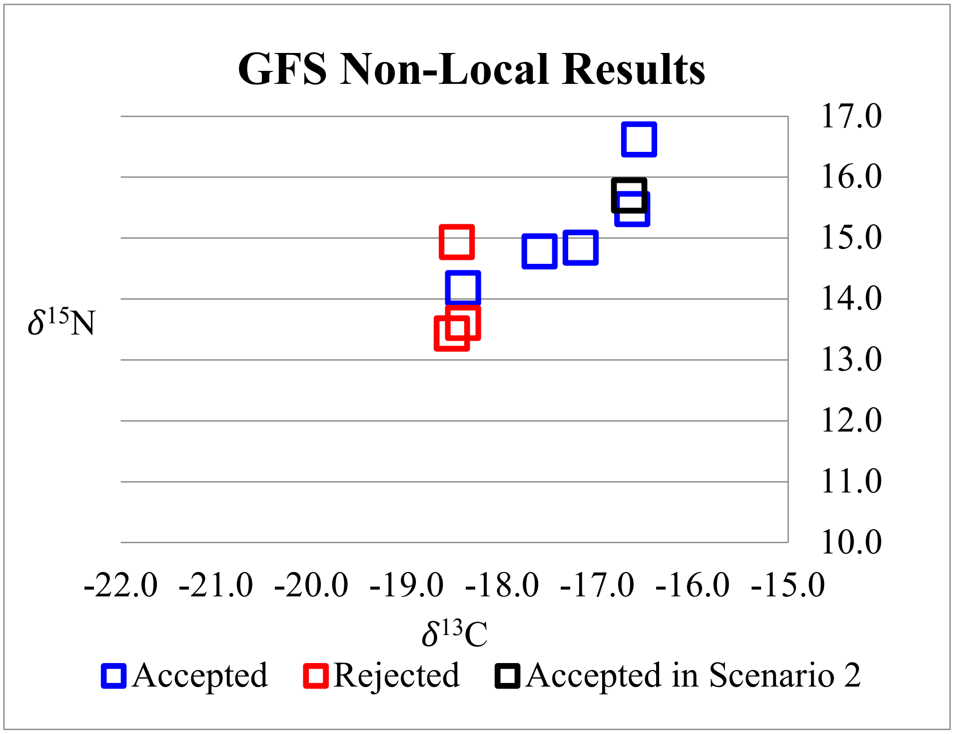

Figure 4.35 Results of FRUITS Analysis for GFS Non-Locals from Khuzhir-Nuge XIV.

Table 4.55 Results of Little Sea Analysis for GFS Non-Locals from Khuzhir-Nuge XIV.

Group	*Study ID*	*$\delta^{13}C$*	*$\delta^{15}N$*	*Scenario 1 Status*	*Scenario 2 Status*	*p-Value*	*Convergence*
GFS Non-Local	K14GFS02	−18.5	14.9	Rejected	—	0.95	Poor
GFS Non-Local	K14GFS05	−16.6	15.5	Accepted	Accepted	0.704	Great
GFS Non-Local	K14GFS10	−18.5	13.4	Rejected	—	0.586	Moderate
GFS Non-Local	K14GFS19	−16.7	15.7	—	Accepted	—	—
GFS Non-Local	K14GFS38	−18.4	13.6	Rejected	—	0.948	Poor
GFS Non-Local	K14GFS46	−18.4	14.2	Accepted	Accepted	0.951	Great
GFS Non-Local	K14GFS51	−17.6	14.8	Accepted	Accepted	0.86	Great
GFS Non-Local	K14GFS5702	−16.6	16.6	Accepted	Accepted	0.655	Great
GFS Non-Local	K14GFS5801	−17.2	14.8	Accepted	—	0.806	Moderate

4.6.3 *GF Non-Locals*

As expected, the GF Non-Local group experienced high rates of rejection for the model created for the Little Sea diet (Figure 4.36). Of the 9 individuals, 7 were rejected and 2 failed to produce results. The p-values were the primary reason for rejection, but there also were cases of irrational graphs and poor convergence (Table 4.56). These results suggest that these individuals did not live, or at least procure their food, from the Little Sea micro-region where Khuzhir-Nuge XIV is situated. It also supports the archaeological evidence and hypothesis that these individuals migrated from elsewhere, with the Upper Lena being a strong candidate for a location from which GF individuals would have sourced their aquatic foods (Weber and Goriunova 2013).

Table 4.56. Results of Little Sea Analysis for GF Non-Locals from Khuzhir-Nuge XIV.

Group	*Study ID*	*$\delta^{13}C$*	*$\delta^{15}N$*	*Scenario 1 Status*	*Scenario 2 Status*	*p-Value*	*Convergence*
GF Non-Local	K14GF04	−20.1	11.7	Rejected	—	0.996	Poor
GF Non-Local	K14GF2701	−19.3	12.7	Rejected	Rejected	0.987	Great
GF Non-Local	K14GF34	−19.6	12.0	Rejected	Rejected	0.966	Poor
GF Non-Local	K14GF3501	−19.0	12.6	Rejected	—	0.598	Great
GF Non-Local	K14GF3601	−18.9	12.4	Rejected	—	0.975	Great
GF Non-Local	K14GF3602	−19.2	12.7	—	—	—	—
GF Non-Local	K14GF3701	−19.0	11.1	Rejected	—	0.982	Great
GF Non-Local	K14GF3702	−19.2	11.7	—	—	—	—
GF Non-Local	K14GF77	−18.7	10.5	Rejected	Rejected	0.973	Great

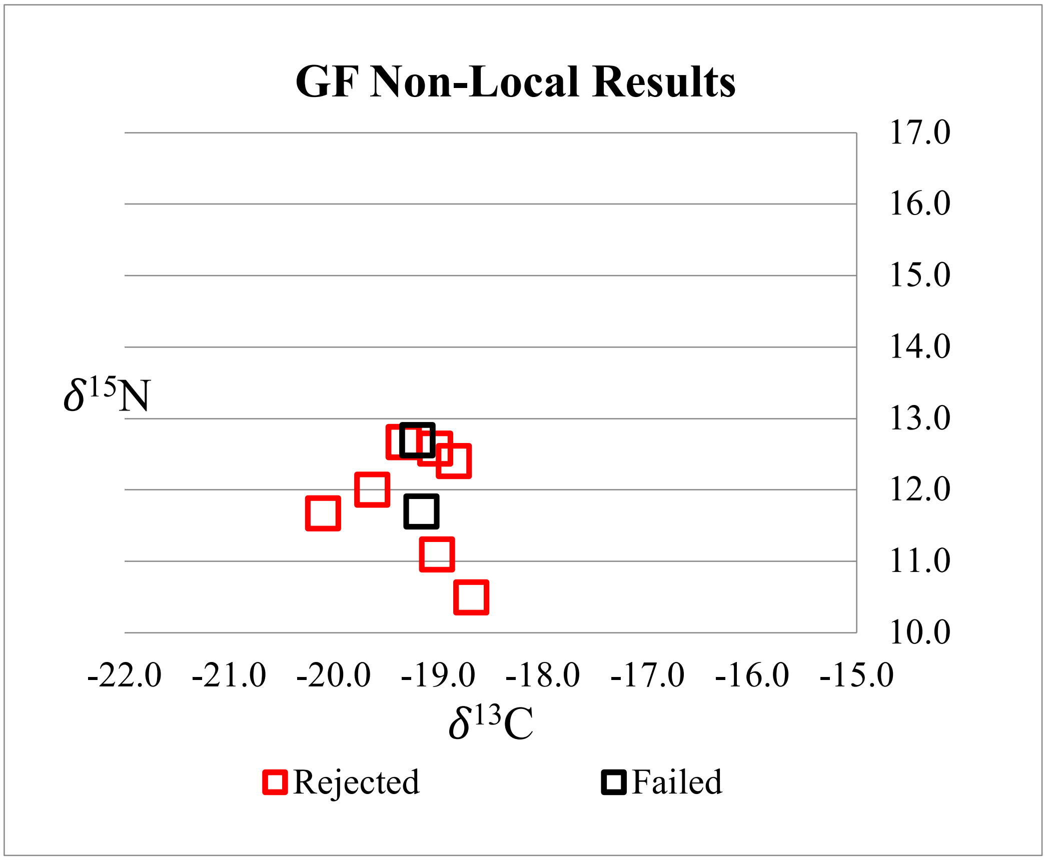

Figure 4.36 Results of FRUITS Analysis for GF Non-Locals from Khuzhir-Nuge XIV.

Chapter 5: Discussion

5.1 Introduction

The purpose of Chapter 5 is to discuss the patterns seen within the three groups; GFS Local, GFS Non-Local, and GF Non-Local. Also, this chapter further investigates diet structure of the GF Non-Local group through the development of a secondary FRUITS model. An evaluation of the methods and FRUITS models follows. The hypotheses that drive this research are listed below:

Hypothesis 1: If the GFS Locals are largely accepted by the model and produce precise estimates, it can be posited that the Little Sea FRUITS model adequately represents the dietary landscape of the Little Sea.

Hypothesis 2: If Hypothesis 1 is accepted, the GFS Non-Local group will show a mix of accepted and rejected individuals, where the accepted individuals represent long-term migrants, whose dietary signatures reflect a local diet, and the rejected individuals represent either:

a. recent migrants whose dietary signatures have not yet transitioned to a completely local values, or
b. migrants who continue to obtain dietary resources from two distinct isotopic food webs.

Hypothesis 3: If Hypothesis 1 is accepted, and the model predicts a high contribution from the Fish 1 and Fish 2 groups and a low or near zero contribution from the Baikal seal for GF individuals, it can be posited that they are obtaining the aquatic portion of their diet from Lake Baikal.

Hypothesis 4: If Hypothesis 1 is accepted, and all individuals belonging to the GF dietary group are rejected by the Little Sea FRUITS model, it can be posited that the aquatic portion of their diet is a source other than Lake Baikal.

a. If Hypothesis 4 is accepted, it is possible that these individuals reflect migrants from the Upper Lena, or other isotopically similar ecosystems.

5.2 Diet Groups

The results presented in Chapter 4 are the subject of the following discussion, which aims to contextualize the individual results within their respective diet groups and the broader Baikal research area.

5.2.1 *GFS Locals*

An averaged GFS diet can be characterized by contributions of 0–22% Lake Baikal fish (Fish 1 and Fish 2 combined), 7–25% plant-derived foods, 22–43% meat, marrow, fat, or offal of ungulate species, and 32–52% seal meat, marrow, fat, or offal. The means of each dietary source contribution are 3%, 3%, 19%, 31%, and 44%, respectively (Table 5.1). While the contributions of ungulates are within the approximations of previous research, the remaining values are rather unexpected (Weber and Goriunova 2013; Katzenberg et al. 2009; Katzenberg et al. 2012). The low fish values indicate that fishing for the GFS group was not as important as game and seal hunting, as fish contribute less than 22% (Fish1 and Fish2 summed) of the overall diet. Faunal remains recovered within the Little Sea micro-region support a decline in the use of fish as a primary dietary resource during the EBA, specifically at Ityrkhei (Losey, Nomokonova, and Goriunova 2008). Developed Neolithic layers (II, III) at the site provided 1,907 NISP fish remains from 1976 excavations (290m^3 excavated), which were conducted without the use of sieves. The Early Bronze Age layer (I) produced 252 NISP fish, indicating a steep decline in the procurement of fish at this site. Subsequent 2005 excavations (7m^3 excavated) that used 3mm sieves recovered no fish remains from the EBA (I), but 2,896 NISP from the Developed Neolithic (layer IV). These values are interesting, especially as Ityrkhei is a site located within a small basin of a shallow cove, that provides easy access to fish habitats. Zooarchaeological analyses have also indicated that fishing and fish processing was the primary subsistence activity at this site (Khamzina 1991, 78; Nomokonova, Losey, and Goriunova 2009, 40). Excavations at another habitation site (Sagan Zaba II) also indicate a continuing trend of decline in fishing, but in this instance from the Bronze Age to the Iron Age as pastoralism became prominent (Nomokonova et al. 2010). Sagan-Zaba II is located along the open western coast of Lake Baikal, where fishing would not be as productive as in Ityrkhei, but the site provides access to seal colonies in the early spring. While the predominant subsistence activity at Sagan-Zaba II during the Bronze Age was seal hunting and processing, a continuing pattern of decline in fish remains is also seen. Recovered faunal remains from layers III–B, with radiocarbon dates 2600 ±145 BP and 3370 ±55 BP, show that only 548 out of 7,976 NISP were fish. The presence of fish continues to decline in subsequent layers, with only 57 fish specimens out of 2,791 NISP recovered in Layer I. While Ityrkhei and Sagan-Zaba II represent sites with different primary activities, both indicate a continuing pattern of decline in the procurement of fish.

Table 5.1 Averages of Little Sea estimations from GFS individuals.

Dietary Sources	Average of Means	Average of 2.5 percentiles	Average of 97.5 percentiles
Fish1	3%	0%	12%
Fish2	3%	0%	10%
Plants	19%	7%	25%
Seal	44%	32%	52%
Ungulates	31%	22%	43%

Another noteworthy result is the high seal contribution to the GFS diet. While it has been previously suggested that seal played an important role for GFS individuals, this study suggests that seal constituted nearly 32–52% of the total diet. Due to the seasonal availability of seal, it would be difficult to attain the amount necessary to compose nearly 44% of the food intake for the GFS diet group, especially as part of a long-term dietary strategy. Though these values are unexpected, the occupations at Bugul'deika II show a pattern of extensive seal procurement during the Bronze Age that corroborates the findings. Out of 1,184 identified remains, 65% are *Phoca siberica* in Layer II–3, while 37% of 1,159 NISP are *Phoca siberica* in Layer II–2 (Losey, Nomonokova, and Savel'ev 2016).

However, the high seal contribution may be an artificial inflation seen in the FRUITS estimations resulting from the isotope values. It has been documented that there is variation in nitrogen routing in human physiological pathways and that elevated nitrogen levels occur during multiple and frequent starvation episodes (Mekota et al. 2006; Hughes, Whiteman, and Newsome 2018; Reitsema 2013). Starvation episodes and stress can be documented in the skeleton through pathological lesions that occur during tissue formation, allowing researchers to identify whether or not there have been periods of significant stress in an individual's life history. However, the EBA population at Khuzhir-Nuge XIV does not exhibit high frequencies of linear enamel hypoplasia and are not expected to have been under substantial nutritional stress at any point during the life course (Lieverse 2010).

An alternative explanation for these high seal values would be the consumption of young seals in preference to older individuals. Young seals would exhibit nitrogen values one trophic level above their mothers during weaning while maintaining similar carbon values. If EBA hunter-gatherers did frequently consume breastfeeding seal pups, the model could only explain this through an elevated proportion of seal in the diet to achieve the same nitrogen levels as a smaller quantity of infant seal would. It has been noted that seal behaviour is tied to the formation of ice each year, which creates a differential spatial distribution of seal across Lake Baikal (Weber et al. 1998). Pregnant females (and therefore yearling seals) tend to congregate more along the eastern half of the Lake where ice forms first in late autumn, though some can be found along the western shores. Females beyond reproductive age and males tend to occupy the western portion, as they can maximize their time feeding in open water and make their dens when ice forms later in the season. Baikal seals birth their young in dens dug into the ice covering the lake near the end of February. These young seals are unable to swim and continue to nurse off of their mothers for a period of 1–2 months, which is nearly double the amount of nursing time of other seal species (Kozhov 1963, 145–146). During this period, they would be vulnerable to hunters on the sea ice, who have the opportunity to collect a nutritious food source with simple tools, such as clubs.

Excavations at Bugul'deika II indicate that yearling and juvenile seals were preferentially procured compared to adult seals during the BA (layers II-2 and II-3) (Losey et al. 2016). The largest age category in the BA sample was the yearling seals (MNI = 21), followed by juvenile seals (MNI= 12). Young adult (MNI= 12) and older adult seals (MNI= 4) were present in small numbers. When compared to the healthy modern Baikal seal population, the emphasis on yearling and juvenile seals becomes clearer. The population structure of seals in Lake Baikal generally follows a pattern of 16% yearlings (<1 years), 41% juveniles (1–5 years), 26% young adults (6–10 years), 10% older adults (11–15 years), and 7% over the age of 16 (Pastukhov 1993, 14). The relative proportion of seal remains in the Bugul'deika BA sample is 43% yearlings, 24% juveniles, 24% young adults, and 8% older adults. Additionally, seasonality of death clearly reflects the exploitation of seal behaviours that are tied to the ice regime. Examination of seasonality of death for yearling seal remains indicates they were hunted most extensively in early spring, indicating that individuals took advantage of the melting ice that made the yearlings vulnerable to hunters. Juvenile and adult seals were hunted from late spring to early summer, exhibiting a higher frequency of seasonality of death in summer. This corresponds to the season of molting, which often leaves the seals lethargic and weak. While molting, seals bask on the ice or rookeries, allowing access to seals that do not have the energy to defend themselves or escape (Kozhov 1963, 145–146; Nomokonova et al. 2015). While there exists documented archaeological evidence that EBA hunter-gatherers in Lake Baikal did consume yearling seals, the amount of yearling seal required to raise the FRUITS estimation values is of central concern to the improvement of any subsequent models. In addition, it is likely that the stable isotope averages of seals in the faunal sample reflect those of only adult remains. As the original intent was to use these samples for radiocarbon dating, the primary concern was the perceived quality and preservation of the bone. As such, a sampling bias most certainly took place with a preference for adult long bones, since these are less porous than juvenile bone and preserve with greater integrity. Therefore, further analysis of infant archaeological seals is required to determine the level of influence elevated nitrogen values would have on human nitrogen values as compared to adult seals.

The last conceivable reason for the high seal contributions is the existence of an important high nitrogen food resource that was not considered in this analysis. A likely contender for this would be the waterfowl around Lake Baikal, which feed off of fish in the lake which are expected to have nitrogen isotopic signatures around 10‰, similar to other avian species previously documented (Katzenberg et al. 2012). Lake Baikal is host to spring and autumn migrations of waterfowl with a minimum of 10–12 million birds stopping in the Baikal region every year (Mel'nikov 2006). Though most of these migratory birds settle in the Selenga River Delta and Torei Lakes, a number of important staging areas are littered across the Baikal region, including the Barguzin River valley, Arangatui Lakes, as well as the Verkhniaia, Angara, and Kichera River mouths (Mel'nikov 2006). During these migrations, waterfowl are earthbound and vulnerable to predation for 2–4 months beginning in June as they mate and molt their flight feathers, making both them and their eggs a feasible resource. To date, the project has not obtained a sufficient number of stable isotope values from prehistoric avian specimens to investigate this possibility, and modern specimens are problematic due to environmental impacts and behavioural changes including the consumption of discarded food refuse. While waterfowl continue to be a possible dietary resource for EBA hunter-gatherers, this is no reliable way of testing this hypothesis with current data.

The FRUITS results indicate fairly substantial reliance on plant foods, despite the short growing season. Plants and their role in the diets of the Lake Baikal hunter-gatherers have not historically been the focus of dietary research, with most previous studies expecting their contribution to overall diet to be negligible (i.e. <5%) (Katzenberg and Weber 1999; Katzenberg, Goriunova, and Weber 2009; Katzenberg et al. 2012; Weber and Bettinger 2010). However, this study suggests that plants did, in fact, play an important role in the diets of Lake Baikal hunter-gatherers. While the environmental conditions in the Baikal region may not be conducive to identifying preserved plant remains in archaeological deposits, the implications of plant foraging and processing should be noted. The plants that are likely to have been exploited by EBA hunter-gatherers include pine nuts, inner tree bark, young shoots and buds, roots, bulbs (such as onion, garlic, Siberian lily, and martagon lily) berries, mushrooms, moss, and lichen (Okladnikov 1950). With the exception of pine nuts, most of these foods do not require heavy processing to be fit for human consumption. They are easily foraged for and grow in predictable areas. In addition, while not extremely tasty, edible moss and lichens would be readily available throughout the year and may have served as a resource in times of food scarcity.

There were two GFS Local individuals (K14_1999.059.02 and K14_2000.064) who were rejected by the model assessments due to poor convergence. While not differing in their stable isotope values by a large degree from others in the GFS Local group, these individuals nonetheless could not attain sufficient convergence for Scenario 1 of the Little Sea model, and both failed to produce any results for Scenario 2. As there is a higher rejection frequency than expected for the GFS Local group, it cannot be said that the model is a perfect fit. Rather, this indicates that the model could use improvement in its estimation parameters, or there exists a dietary source that is not currently considered in the analysis that constitutes an important part of the diets of GFS individuals. Unfortunately, there is no way to estimate how much a dietary resource could contribute to the overall diet if it were not included in the model unless an entirely new model is constructed. Likewise, some of the p-values for the individuals in the GFS group are very close to the 0.95 cut-off, suggesting that the model is not the best fit to describe the Little Sea diet. Any model adjustments should aim to obtain p-values closer to 0.50, as this indicates better model performance. In summary, the results are consistent with the acceptance of Hypothesis 1, and it can be considered that the FRUITS Little Sea model is at least moderately representative of the dietary landscape of micro-region. Suggestions for improvements for parameters and model construction and analysis are discussed in a later section.

5.2.2 *GFS Non-Locals*

Given that Hypothesis 1 has been accepted, and the Little Sea FRUITS model can be further considered in regard to the GFS Non-Local group. As predicted in Hypothesis 2, the GFS Non-Local group presented a mix of both accepted and rejected individuals. Values for dietary estimation can be characterized by the averaged GFS diet discussed above for those that were accepted. Three GFS Non-Local individuals were rejected in Scenario 1 and failed to produce results in Scenario 2. As such, the diet of rejected targets cannot be explained by the Little Sea FRUITS model, though an improved model may alter these results. As there are no major differences in dietary contribution values between the accepted GFS Locals and GFS Non-Locals, this may suggest some GFS Non-Locals within this study are long-term migrants or at least ate a GFS diet within the last 7–10 years prior to death. Since all individuals within the GFS Non-Local group were over the age of 20, it would appear that they spent their younger years elsewhere prior to living within the Little Sea area; but, died long enough after migration that their stable isotope values reflected those of a lifetime resident of the Little Sea. Within the current analysis, it is not possible to differentiate between recent migrants whose dietary stable isotope signatures have not yet transitioned to a fully local diet and migrants who continue to obtain dietary resources from two distinct isotopic food webs. However, there are at least three GFS Non-Local individuals that represent either of these possibilities within the current sample.

5.2.3 *GF Non-Locals*

As expected, the Little Sea model rejected all GF Non-Locals, indicating that the Little Sea diet is not one that can explain the variation and stable isotope values seen in this group. Therefore, Hypothesis 3 should be rejected. If a GF diet could be explained through the absence of seal, the model would still produce results estimating the seal contribution to be a negligible amount. Rather, the results are in support of Hypothesis 4, according to which these individuals were not receiving the aquatic portion of their diet from the Little Sea.

5.3 Upper Lena Mixing Model

As the Little Sea mixing model was not a possible explanation for the diets of the GF Non-Locals, it was decided to test another model that could perhaps explain better the variation seen in their diet. The previously stated hypothesis has been that these GF Non-Locals may represent migrants from the Upper Lena micro-region of Cis-Baikal, due to their low nitrogen and more negative carbon stable isotope values (Weber and Bettinger 2010; Weber et al. 2016). However, prior to running a secondary model, it is important to ensure that the human stable isotope values from the Little Sea are not significantly different from those from individuals buried in the Upper Lena micro-region. While the average Upper Lena diet is even more negative in carbon and lower in nitrogen compared to the GF Non-Locals when examined together, the differences are not statistically significant (Figure 5.1). In an attempt to explore whether a diet comprised of Upper Lena riverine fish could explain the dietary patterns seen within the GF Non-Locals group, an additional model was constructed employing the stable isotope values expected for the Upper Lena. The results of this model are presented below.

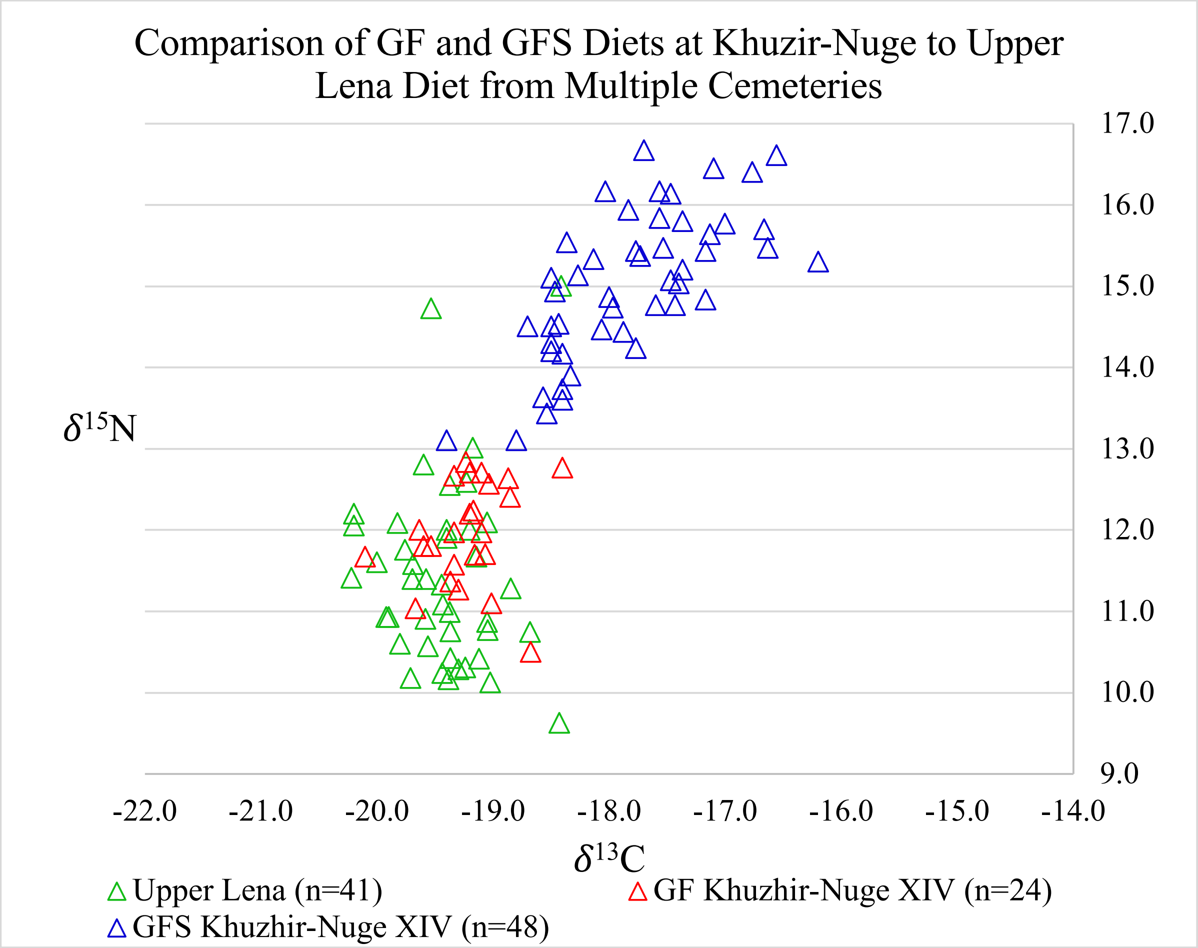

Figure 5.1 Stable isotope values for EBA adults from Khuzhir-Nuge XIV and the Upper Lena microregion (Borki, Makarovo, Makrushina, Manzurka, Obkhoi, Ulus Khalskii, Ust'Iamnaia, Ust'-Ilga, and Verkholensk cemeteries). Data obtained from published stable isotope values in (Weber et al. 2011).

5.3.1 *Priors and Model Information*

The Upper Lena model was set up with the same priors and dietary information as Scenario 1 of the Little Sea, outlined in Chapter 3, with only one exception. The Fish 1 and Fish 2 values of the Little Sea model were replaced with a single fish group of aggregated stable isotope values obtained from modern lenok, ide, and pike specimens collected from the Upper Lena River. A complete list of the updated stable isotope values associated with the four dietary groups in the Upper Lena model (Table 5.2).

Table 5.2 Stable Isotope Values of Dietary Groups in the Upper Lena FRUITS Model.

Plants	**δ^{13}C**	**δ^{15}N**	
Plants	−23 ±1.5	2 ±1	
Plant Total	−23 ±1.5	2 ±1	
Seal	**Avg. of δ^{13}C**	**Avg. of δ^{15}N**	**No. of Samples**
Seal	−21.5	14.0	36
Seal Total	−21.5	14.0	36
Lena Fish	**Avg. of δ^{13}C**	**Avg. of δ^{15}N**	**No. of Samples**
Lenok	−27.2	11.6	3
Pike	−24.6	10.8	2
Ide	−26.1	10.6	1
Lena Fish Total	−26.2	11.2	6
Ungulates	**Avg. of δ^{13}C**	**Avg. of δ^{15}N**	**No. of Samples**
Moose	−19.2	3.7	1
Red Deer	−19.4	5.8	33
Roe deer	−19.7	5.2	3
Ungulate	−19.6	5.5	82
Ungulate Total	−19.6	5.5	119

Because riverine systems mix their carbon contents due to the constant movement of water, riverine fish exhibit small carbon differences, in contrast to the stratified carbon values of Lake Baikal (Dodds and Whiles 2010, 156). Nitrogen values, however, will still reflect variation related to the fishes place in the food web. In the case of the Upper Lena all fish stable isotope values are within 2.5‰ for δ^{13}C, and 1‰ for δ^{15}N, indicating that they are very similar isotopically and can be considered one analytical grouping. There has been insignificant environmental impact regarding infrastructure or industrial development within the Upper Lena area, such that the stable isotope values can be considered approximate to archaeological values once the δ^{13}C values are corrected for the Suess Effect.

5.3.2 *Model Results*

The results of the Upper Lena model are shown first for each individual, and then discussed as a group for the GF Non-Locals below. The acceptance and rejection criteria for the Upper Lena model remained the same as the Little Sea model, as discussed in Chapter 4.

5.3.2.1 K14_1993.004

Table 5.3 Osteological Information of K14GF04.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1993.004	20+ y.	Adult	Unknown	3532±61	−20.1	11.7	GF	Non-local

The p-value for this individual is 0.846 with satisfactory convergence (Table 5.4). The graphs produced by FRUITS (Figure 5.2) are also within the expected ranges and produce quite precise estimations for the Upper Lena model. This indicates that the Upper Lena dietary model is a good match for this individual's stable isotope values (Table 5.3).

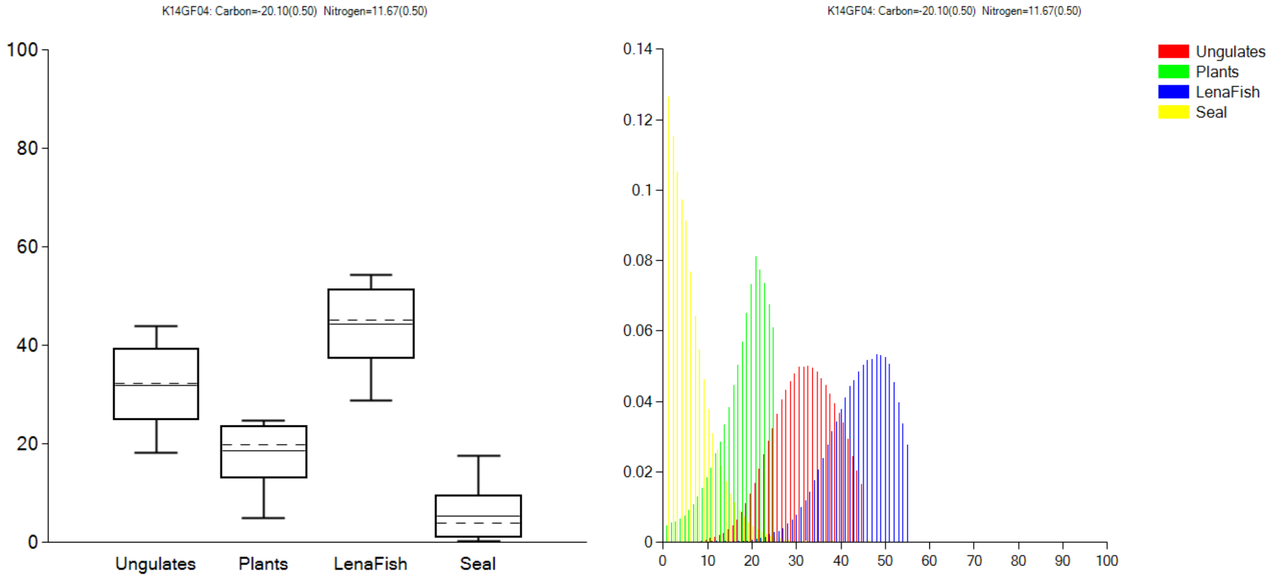

Figure 5.2 FRUITS Results for K14GF04, Upper Lena.

Table 5.4 FRUITS dietary source contribution estimations for K14GF04, Upper Lena.

ESTIMATES	*p-value=0.846*					
Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Ungulates	0.32	0.07	0.18	0.32	0.44	0.25–0.39
Plants	0.19	0.05	0.05	0.2	0.25	0.13–0.24
Lena Fish	0.44	0.07	0.29	0.45	0.54	0.37–0.52
Seal	0.05	0.05	0	0.04	0.18	0.01–0.10

5.3.2.2 K14_1998.027.01

Table 5.5 Osteological Information of K14GF2701.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.027.01	35–50 y.	Adult	Male	3390±61	−19.3	12.7	GF	Non-local

The convergence of K14_1998.027.01 was satisfactory and consistent with acceptance criteria (Figure 5.3). The results also produced a p-value of 0.692 (Table 5.6). This indicates that the Upper Lena model predicts the diet of this individual within a significant amount of precision (Table 5.5).

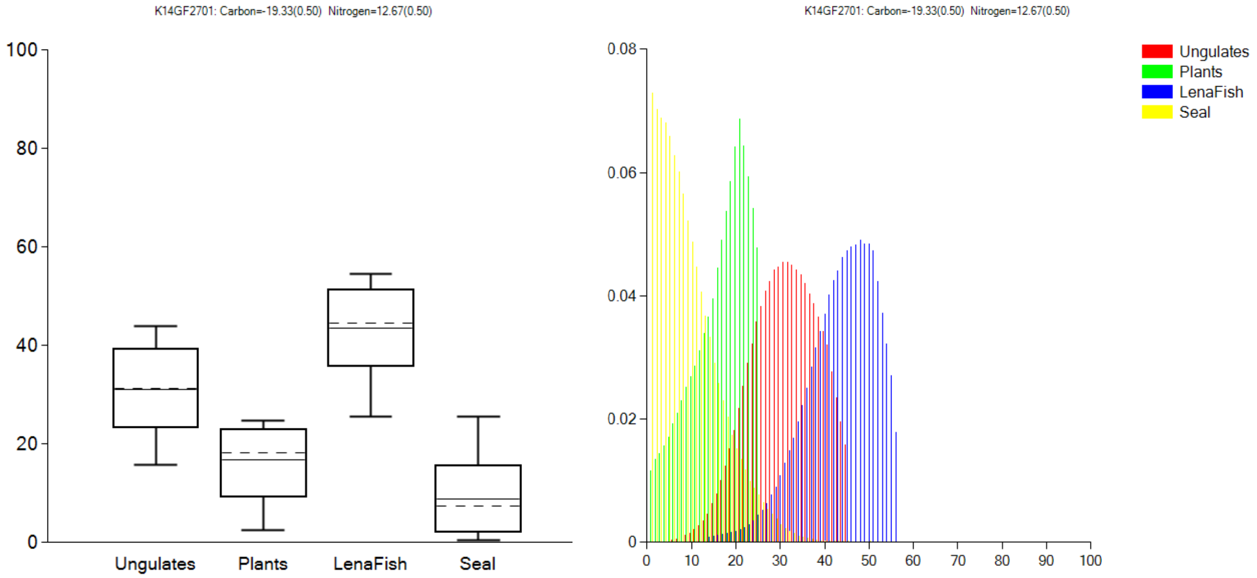

Figure 5.3 FRUITS Results for K14GF2701, Upper Lena.

Table 5.6 FRUITS dietary source contribution estimations for 14, Upper Lena.

ESTIMATES *p-value=0.692*

Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Ungulates	0.31	0.08	0.16	0.31	0.44	0.23–0.39
Plants	0.17	0.06	0.02	0.18	0.25	0.09–0.23
Lena Fish	0.43	0.08	0.25	0.45	0.54	0.36–0.51
Seal	0.09	0.07	0.00	0.07	0.26	0.02–0.16

5.3.2.3 K14_1998.034

Table 5.7 Osteological Information of K14GF34.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.034	25–35 y.	Adult	Male	3587±65	−19.6	12.0	GF	Non-local

The FRUITS Upper Lena model produced satisfactory results in dietary contributions with K14_1998.034's isotopic data (Table 5.7). The p-value was 0.768 (Table 5.8), with good convergence, indicating that the diet could be explained by these values with a significant degree of precision (Figure 5.4).

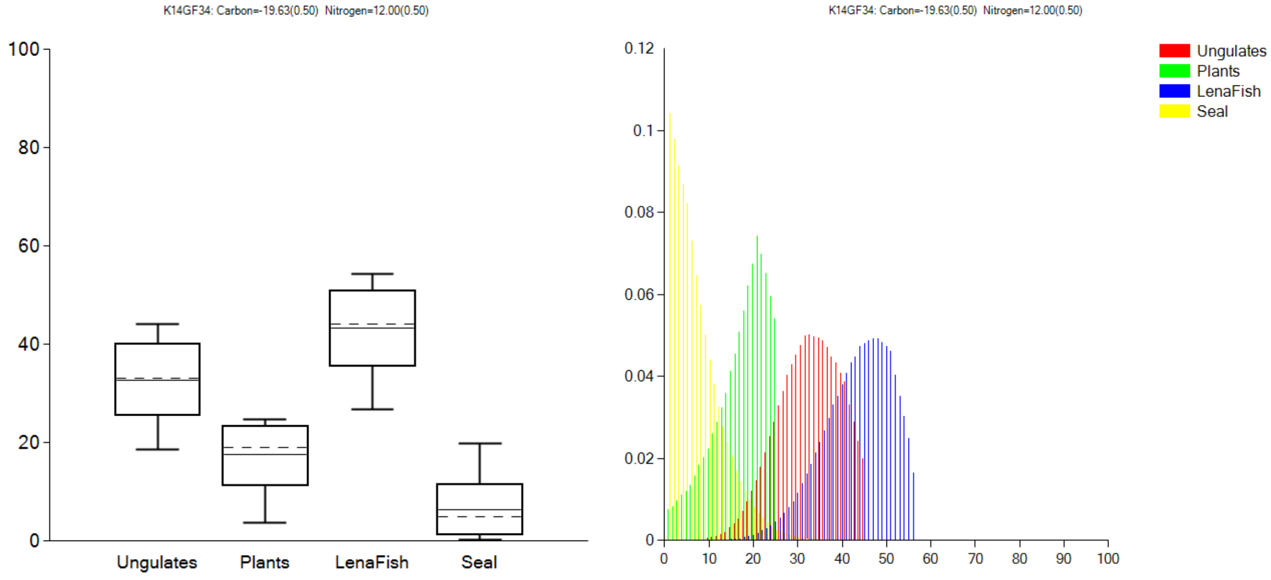

Figure 5.4 FRUITS Results for K14GF34, Upper Lena.

Table 5.8 FRUITS dietary source contribution estimations for K14GF34, Upper Lena.

ESTIMATES *p-value=0.768*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Ungulates	0.33	0.07	0.19	0.33	0.44	0.26–0.40
Plants	0.18	0.06	0.04	0.19	0.25	0.11–0.23
Lena Fish	0.43	0.07	0.27	0.44	0.54	0.36–0.51
Seal	0.06	0.05	0.00	0.05	0.20	0.01–0.12

5.3.2.4 K14_1998.035.01

Table 5.9 Osteological Information of K14GF3501.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.035.01	18–20 y.	Adult	Male?	3513±61	−19.0	12.6	GF	Non-local

The results for individual K14_1998.35.01 (Table 5.9) obtained a p-value of 0.648 with satisfactory convergence (Table 5.10), along with the majority of the GF Non-Locals. This indicates the Upper Lena model explains the diet of this individual well (Figure 5.5).

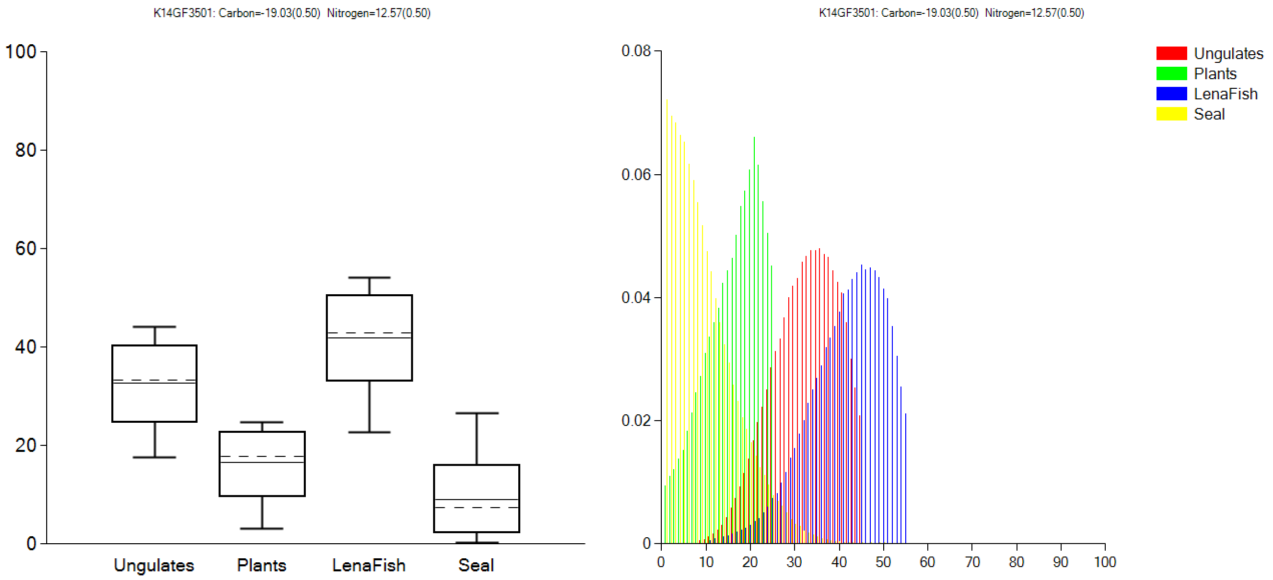

Figure 5.5 FRUITS Results for K14GF3501, Upper Lena.

Table 5.10 FRUITS estimates of dietary sources for K14GF3501, Upper Lena.

ESTIMATES	*p-value=0.648*					
Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Ungulates	0.33	0.07	0.18	0.33	0.44	0.25–0.40
Plants	0.17	0.06	0.03	0.18	0.25	0.10–0.23
Lena Fish	0.42	0.08	0.23	0.43	0.54	0.33–0.51
Seal	0.09	0.07	0.00	0.07	0.27	0.02–0.16

5.3.2.5 K14_1998.036.01

Table 5.11 Osteological Information of K14GF3601.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.036.01	35–50 y.	Adult	Unknown	3582±60	−18.9	12.4	GF	Non-local

This individual (Table 5.11) was the only one rejected for the Upper Lena model in the GF dietary group due to illogical plant distribution shown (Figure 5.6), even though the convergence and p-value were within the acceptable range (Table 5.12). The reason for the rejection is not outwardly obvious, as the stable isotope values of this individual are not much different from others within the same group. In fact, this individual clusters with three others near the upper limits of δ^{15}N values in the GF group. However, this individual has the least negative carbon values in addition to one of the highest nitrogen values. This combination may suggest that this individual consumed some fish or other dietary sources that are isotopically lighter in carbon, while still maintaining a high trophic level. It may also be possible that this individual represents an intermediary value between a GF and GFS value that cannot be explained by either model alone.

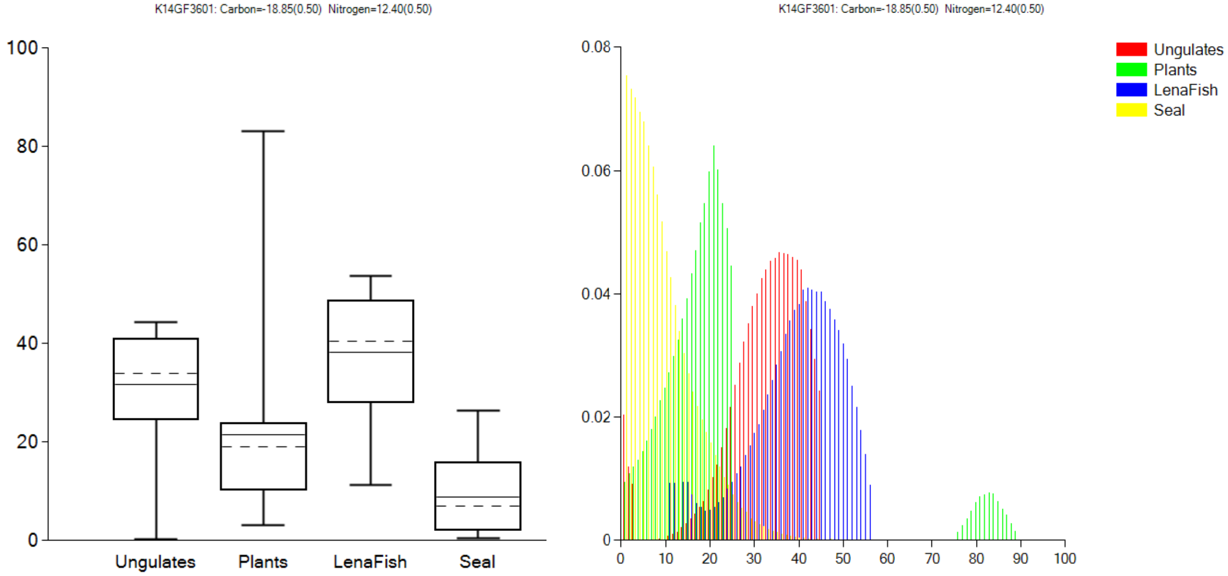

Figure 5.6 FRUITS Results for K14GF3601, Upper Lena.

Table 5.12 FRUITS dietary source contribution estimations for K14GF3601, Upper Lena.

ESTIMATES *p-value=0.608*

Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Ungulates	0.32	0.11	0.00	0.34	0.44	0.24–0.41
Plants	0.21	0.18	0.03	0.19	0.83	0.10–0.24
Lena Fish	0.38	0.11	0.11	0.40	0.54	0.28–0.49
Seal	0.09	0.07	0.00	0.07	0.26	0.02–0.16

5.3.2.6 K14_1998.036.02

Table 5.13 Osteological Information of K14GF3602.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.036.02	4–6 y.	Subadult	Unknown	3660±38	−19.2	12.7	GF	Non-local

While it was somewhat expected that the model may encounter some difficulties with this individual (Table 5.13) due to its age and the possibility for a nursing or weaning signal to create issues in estimating diet, this does not seem to be the case. Rather, the Upper Lena model is able to account for the stable isotope values with a substantial amount of precision with a satisfactory convergence value and a p-value of 0.669 (Table 5.14). It is thought that this individual must not have a strong nursing signal within their bone collagen at time of death, or that the mixed isotopic result of nursing and/or weaning can still be accounted for through the Upper Lena model ranges (Figure 5.7).

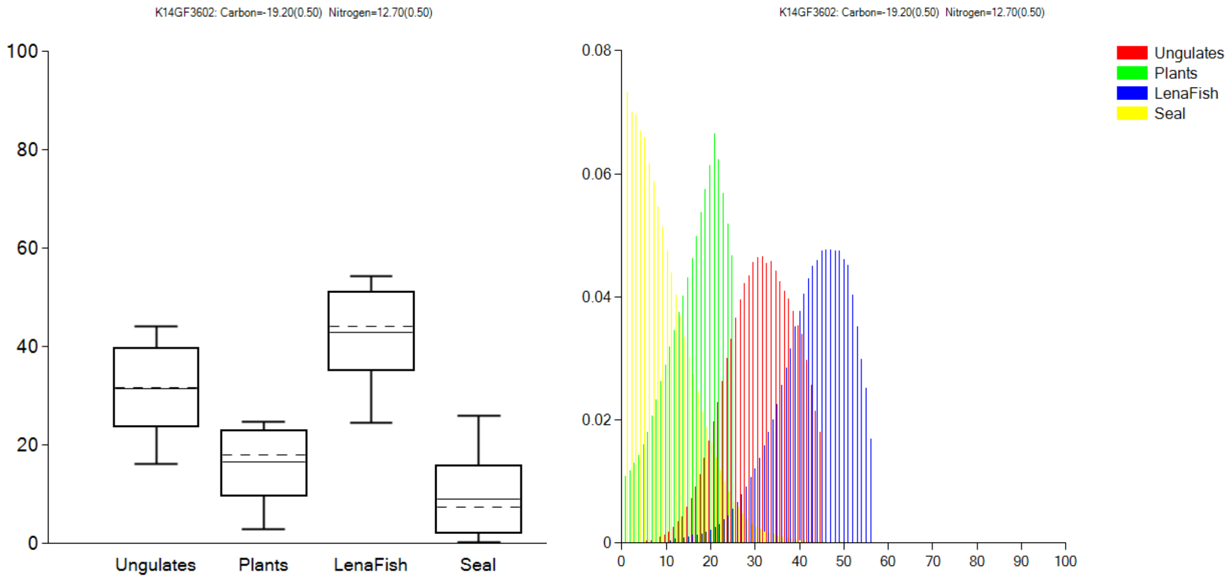

Figure 5.7 FRUITS Results for K14GF3602, Upper Lena.

Table 5.14 FRUITS dietary source contribution estimations for K14GF3602, Upper Lena.

ESTIMATES *p-value=0.669*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Ungulates	0.32	0.08	0.16	0.32	0.44	0.24–0.40
Plants	0.17	0.06	0.03	0.18	0.25	0.10–0.23
Lena Fish	0.43	0.08	0.24	0.44	0.54	0.35–0.51
Seal	0.09	0.07	0.00	0.07	0.26	0.02–0.16

5.3.2.7 K14_1998.037.01

Table 5.15 Osteological Information for K14GF3701.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.037.01	15–20 y.	Adult	Male?	3690±60	−19.0	11.1	GF	Non-local

The Upper Lena model appears to explain this individual's (Table 5.15) diet well (Figure 5.8). These results can be considered precise due to the acceptance of the model with satisfactory convergence and a p-value of 0.708 (Table 5.16), coupled with small distribution spreads of each dietary source.

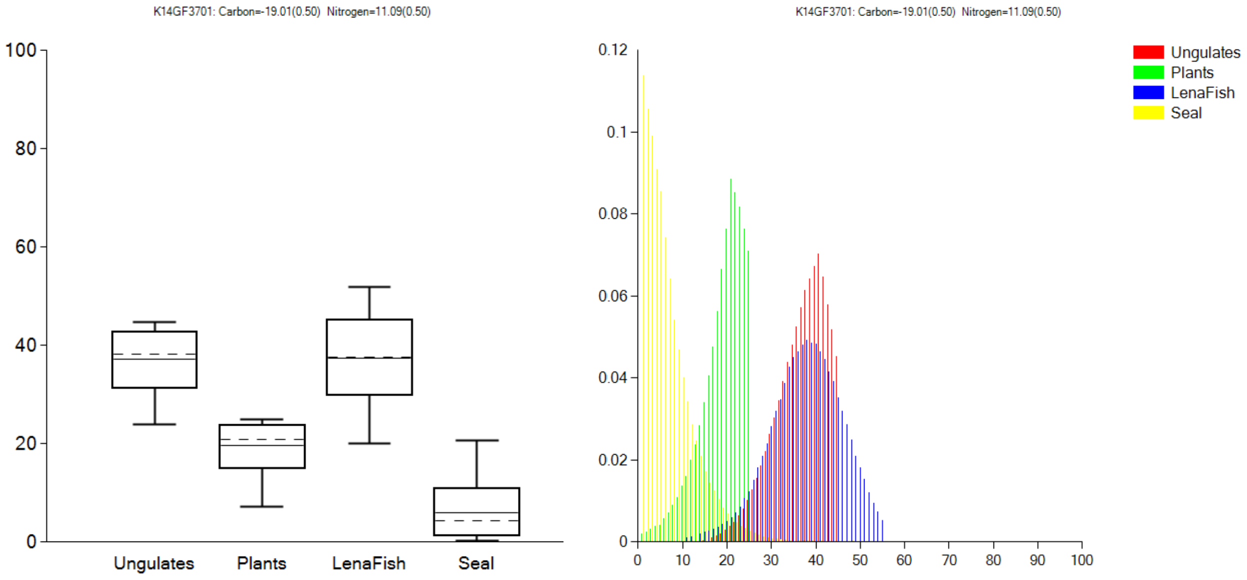

Figure 5.8 FRUITS Results for K14GF3701, Upper Lena.

Table 5.16 FRUITS dietary source contribution estimations for K14GF3702, Upper Lena.

ESTIMATES *p-value=0.708*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Ungulates	0.37	0.06	0.24	0.38	0.45	0.31–0.43
Plants	0.20	0.05	0.07	0.21	0.25	0.15–0.24
Lena Fish	0.37	0.08	0.20	0.38	0.52	0.30–0.45
Seal	0.06	0.05	0.00	0.04	0.21	0.01–0.11

5.3.2.8 K14_1998.037.02

Table 5.17 Osteological Information of K14GF3702.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_1998.037.02	15–20 y.	Adult	Male?	3538±56	−19.2	11.7	GF	Non-local

As with the majority of the other GF Non-Local individuals included in this analysis, this individual (Table 5.17) was accepted by the Upper Lena model. The estimates of dietary source contributions for this individual (Table 5.18) and are supported by satisfactory convergence rates and a p-value of 0.705 (Figure 5.9).

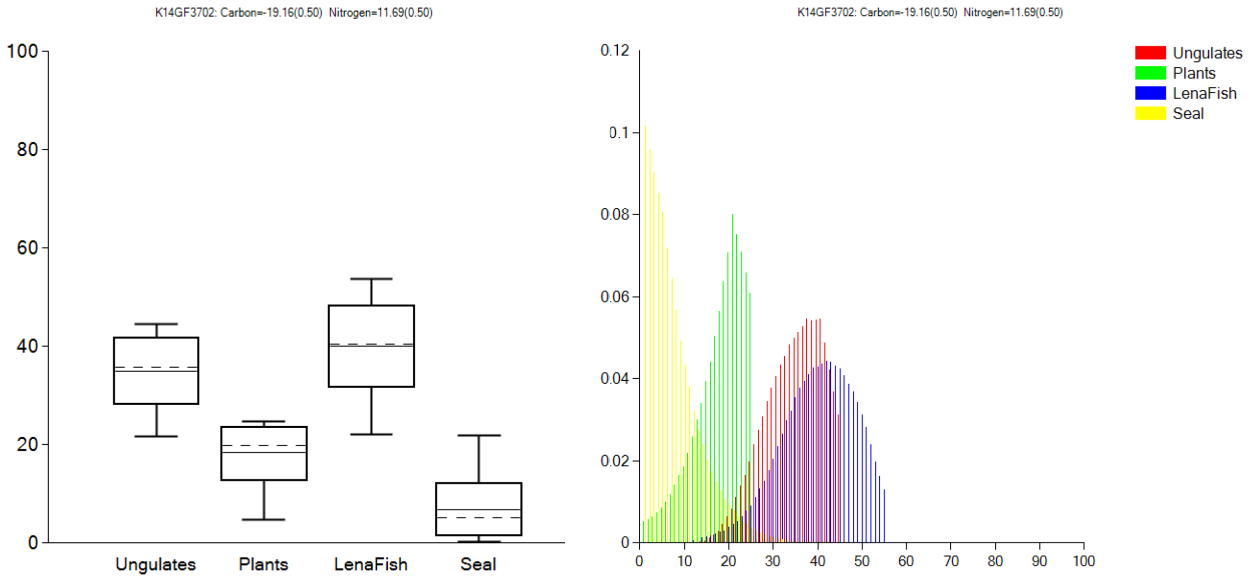

Figure 5.9 FRUITS Results for K14GF3702, Upper Lena.

Table 5.18 FRUITS dietary source contribution estimations for K14GF3702, Upper Lena.

ESTIMATES *p-value=0.705*

Estimates of source/food contribution						
Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Ungulates	0.35	0.06	0.22	0.36	0.44	0.28–0.42
Plants	0.18	0.05	0.05	0.20	0.25	0.13–0.24
Lena Fish	0.40	0.08	0.22	0.40	0.54	0.32–0.48
Seal	0.07	0.06	0.00	0.05	0.22	0.01–0.12

5.3.2.9 K14_2000.077

Table 5.19 Osteological Information of K14GF77.

Master ID	Age	General Age	Sex	^{14}C Date	δ^{13}C	δ^{15}N	Diet	Birth
K14_2000.077	12–15 y.	Subadult	Unknown	3775±56	−18.7	10.5	GF	Non-local

The results produced by the Upper Lena model for K14_2000.077 (Table 5.19) follow the pattern of acceptance established in the previously discussed individuals. With a p-value of 0.672 and satisfactory convergence (Table 5.20), the model provides precise estimations of dietary source contributions for this individual (Figure 5.10).

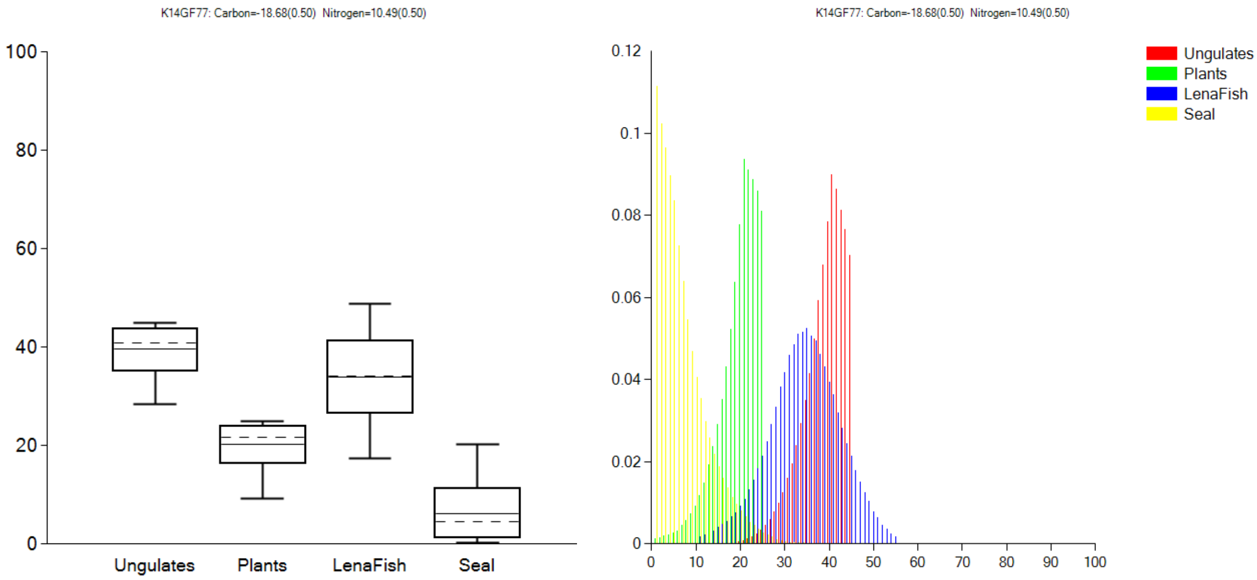

Figure 5.10 FRUITS Results for K14GF77, Upper Lena.

Table 5.20 FRUITS dietary source contribution estimations for 18, Upper Lena.

ESTIMATES *p-value=0.672*

Estimates of source/food contribution

Source/Food	Mean	sd	2.5pc	median	97.5pc	25–75pc
Ungulates	0.40	0.04	0.28	0.41	0.45	0.35–0.44
Plants	0.20	0.04	0.09	0.22	0.25	0.16–0.24
Lena Fish	0.34	0.08	0.17	0.34	0.49	0.27–0.42
Seal	0.06	0.05	0.00	0.05	0.20	0.01–0.11

5.3.3 *Summary of Model Results*

The Upper Lena model produced excellent results for the GF Non-Local group (Table 5.21). Only one individual was rejected for the model (Figure 5.11), whereas the rest were accepted with p-values and convergence within the acceptable ranges outlined in Chapter 4. This can be partially attributed to the reduction of dietary sources from five groups to four, which allows the model to perform with greater statistical stability.

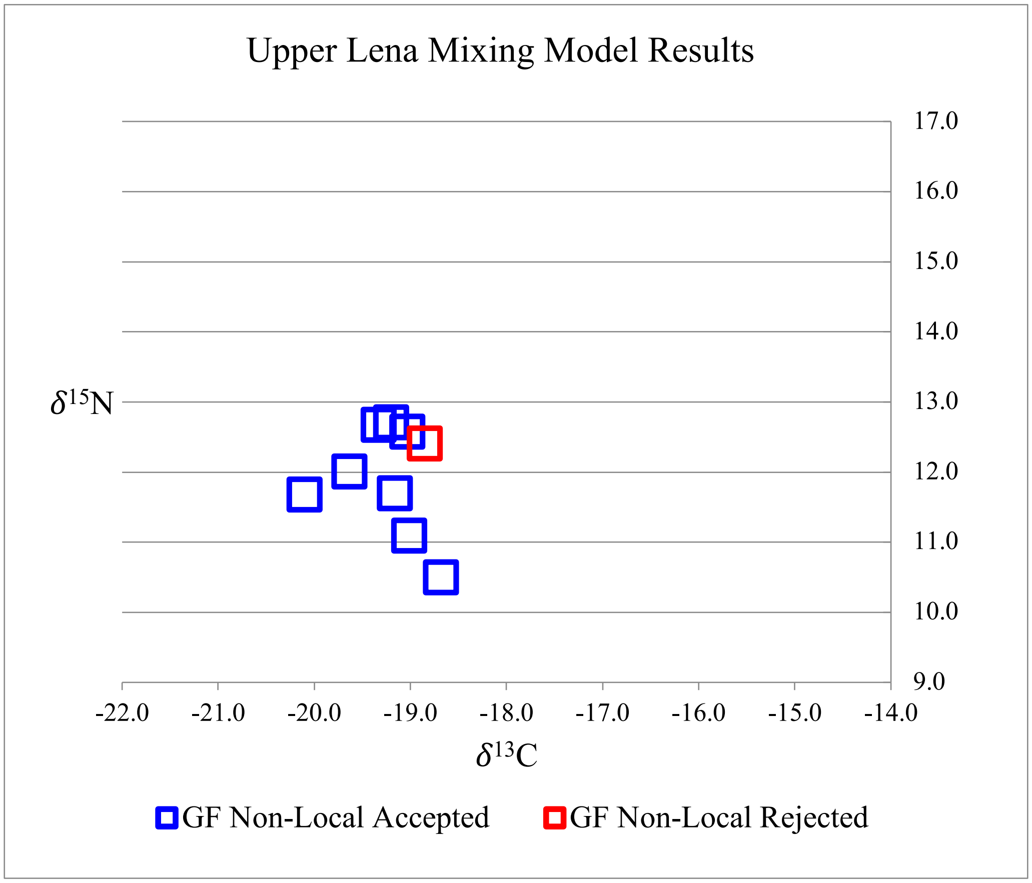

Figure 5.11 Results of the Upper Lena FRUITS mixing model.

Table 5.21 Results of Upper Lena Analysis for GF Non-Locals from Khuzhir-Nuge XIV.

Group	*Study ID*	*$\delta^{13}C$*	*$\delta^{15}N$*	*Upper Lena Scenario*	*P-Value*	*Convergence*
GF Non-Local	K14GF04	−20.1	11.7	Accepted	0.846	Great
GF Non-Local	K14GF2701	−19.3	12.7	Accepted	0.692	Great
GF Non-Local	K14GF34	−19.6	12.0	Accepted	0.768	Great
GF Non-Local	K14GF3501	−19.0	12.6	Accepted	0.648	Great
GF Non-Local	K14GF3601	−18.9	12.4	Rejected	0.608	Modeate
GF Non-Local	K14GF3602	−19.2	12.7	Accepted	0.669	Great
GF Non-Local	K14GF3701	−19.0	11.1	Accepted	0.708	Great
GF Non-Local	K14GF3702	−19.2	11.7	Accepted	0.705	Great
GF Non-Local	K14GF77	−18.7	10.5	Accepted	0.672	Great

Concerning patterns seen within the consumption estimations, the low values of seal contribution are within the expectations of the GF diet (Table 5.22). These individuals are distinguished from the GFS individuals by their lower nitrogen and more negative carbon values. While previous research suggested the separation of diet groups based on the consumption of seal, the Little Sea model indicates that the GF diet cannot be explained by the absence of seal alone, as this would have resulted in the acceptance of the Little Sea model (Weber and Bettinger 2010; Weber et al. 2011; Weber and Goriunova 2013). Rather, the GF diet can be explained through the consumption of Upper Lena fish in addition to a reduced consumption of seal. The Upper Lena model confirms this hypothesis, as the results indicate that the aquatic element of the GF individuals diet, with the exception of seal, is sourced from the Upper Lena or other isotopically similar waterways. Of particular interest are the high rates of fish intake in these individuals. GF individuals within the sample are estimated to have consumed between 22–53% fish from the Upper Lena river system, approximately equal to the consumption of ungulate species, which also ranges from 18 to 44% of total diet. This is a marked increase compared to the fish contribution estimations for the Little Sea model. Plant values are similar to the GFS results, hovering around a mean of 19% of the total dietary contribution, with a range between 5 and 31%. These values are of particular interest, as it would appear that dietary groups between Lake Baikal and the Upper Lena were consuming similar proportions of terrestrial and aquatic resources but each with a different focus on aquatic species. The Little Sea model indicates an emphasis on the consumption of seal (32—52%), with a smaller focus on cove-and-lagoon fishes (0–22%). Intriguingly, the Upper Lena model shows an opposite pattern— where Upper Lena fish are the primary aquatic resource (22–53%), with seal contributing a small amount to the overall diet (0–23%). While seal may have contributed up to 23% of the GF diet in some individuals, it is more likely that the actual consumption is closer to the mean of 7% total dietary intake.

Table 5.22 Averages of Upper Lena estimations for GF individuals.

Dietary Sources	Average of Means	Average of 2.5 percentiles	Average of 97.5 percentiles
Lena Fish	40%	22%	53%
Plants	19%	5%	31%
Seal	7%	0%	23%
Ungulates	34%	18%	44%

The high acceptance rate and p-values closer to 0.50 indicate that the model constructed for the Upper Lena is an excellent fit for estimating the GF diet, more so than the Little Sea model for estimating GFS diet. In addition, only one individual was rejected by the model. As this individual (K14_1998.036.01) has the least negative carbon and one of the highest nitrogen values in the GF dietary group, the rejection may suggest that this individual consumed a dietary resource not considered in the analysis. An alternative explanation may be that this individual's values represent contributions from both Upper Lena and Little Sea fish, which would result in the rejection of the individual from both models. In summary, the results of the Upper Lena model are in support of accepting Hypothesis 4, that the GF Non-Local group are obtaining the aquatic portion of their diet from an area other than Lake Baikal; most likely from the Upper Lena, or another isotopically similar riverine system.

5.4 Possible Limitations

As with all research, it is recommended to evaluate the success of the methods applied and subsequent results. Importantly, the results of this analysis have been produced with reconstructed plant and aggregated animal stable isotope values from the Cis-Baikal region. The quantity of stable isotope values from faunal samples used in calculating dietary averages can be considered adequate for this analysis as discussed in Chapter 3; however, fish and plant isotope averages will most likely exhibit change with the addition of more samples. Though any change is expected to be minimal, there may be some outliers or unexpected results when additional sources are considered. This is primarily due to the low sample size for fish from the Little Sea micro-region (n=16), and the paucity of measurements for plants (n=1). While berries, bulbs, young sprouts, and inner tree bark are not expected to deviate significantly from the measured isotopic values of pine nuts, this is not the case for mushrooms and lichens. As mushrooms and lichens are not technically plants, they are not expected to behave in the same way as C_3 plants in terms of their nitrogen and carbon values. Rather they are fungi, or the result of a symbiotic relationship between fungi and algae. Fungi are detritivores which derive their nutrient enrichment values from decomposing material that, in life, may have occupied variable tropic levels. This would suggest they uptake variable amounts of nitrogen and should see some variability in their nitrogen stable isotope values. The conservative uncertainty values used— as mentioned in Chapter 3— provide sufficient leeway to consider the results representative, though the inclusion of a broader sample of source stable isotopes values, for fish and fungi, in particular, would increase the overall confidence in the model parameters.

Another way of increasing confidence in the model would be to address how the dietary resources were aggregated. Source aggregation is a necessary part of building a Bayesian model unless the diet is restricted to only a few sources. Where possible, it is best to aggregate similar sources together, taking care to consider any significant differences in stable isotope values. In this research, two fish groups were created to account for the diversity in isotopic signatures between and within species in Lake Baikal for the Little Sea model; though, the data are better interpreted when separated into three groups. After analyzing the posterior distribution for a preliminary analysis with three fish groups, if one group contributes a negligible amount to the overall diet (i.e. less than 5%) it could be excluded from any subsequent modelling, thereby increasing confidence in the estimation values and selected dietary source groups. However, if three fish groups were to be included, the model would require the inclusion of three dietary proxies rather than the two that were available for this research. The proxy could take the form of any other isotopes (e.g. strontium or oxygen), alternative target material (e.g. carbonate), or even amino acids. Regardless, additional proxies must be available for isotopic values of all sources and consumers prior to inclusion in the model. This requirement can make a large-scale dietary estimation analyses a challenge when zooarchaeological and human stable isotopes are often studied and reported for different purposes. For instance, stable isotope studies on faunal remains are often done with a specific purpose in mind, whether it be to define dietary source ranges or aid in radiocarbon dating. Collagen is the most often used material for these analyses, and the addition of carbonate or other stable isotope values would not add much value for these specific purposes, especially considering the cost of analysis. In the case of the data collected by BAP, there are few values of alternative isotope proxies available for fauna in the Little Sea. Therefore, with the current available data the inclusion of an additional dietary group would cause the model to be statistically underdefined, the results of which would be invalid.

The current stable isotope database provides four proxies for the human samples from Khuzhir-Nuge XIV, though proxies for faunal samples are restricted to carbon and nitrogen stable isotopes. Isotopic work on strontium does provide the opportunity to include available values in the Little Sea model for both human and faunal data from previous publications (Haverkort et al. 2008; Weber and Goriunova 2013). However, the Little Sea has a rather small sample of faunal strontium values, and what values there are for animals do not reflect all of the dietary sources available (Weber and Goriunova 2013). For strontium data to be included in the Little Sea model as a third proxy, it would require a larger sample for dietary sources. Carbon and nitrogen values of collagen samples are the only proxies that are available in sufficient quantities for both the faunal and human targets in this context. If additional proxies were incorporated into the model it would not only increase the model's ability to handle additional sources— thereby allowing the separation of fish species into three or more isotopically distinct groupings— it would also increase the precision and validity of the estimates produced by the model. Future work in the Upper Lena or Southwest Baikal micro-regions may be able to consider the inclusion of strontium isotopes as an additional proxy, as these micro-regions have a greater quantity of isotopic values than the Little Sea to consider for analysis.

There is still the question of why some individuals failed to produce any results at all. While it is easy to explain away the unknown through technical difficulties, FRUITS does provide some indicators as to why the model fails, one of which is software error. FRUITS was built from a base BUGS code and is in its third iteration of updates. Though it was originally created for use on a Windows system, FRUITS can be used on an Apple device with the help of a recommended mirroring software called Wine. If there are inconsistencies with the translation of the original code written for a Windows computer to an Apple computer, there may be issues in the ability of the model. If there is a poorly written or mistranslated section of source code, critical software errors could occur when processing complex models. While it is not possible to discard or evaluate this possibility, the author of the program is committed to improving the FRUITS program and resolving such conflicts through further research and development.

The most likely reason that some individuals failed to produce any results is the use of a two–proxy, five–source model supported through complicated priors. While traditional mixing models would consider this equation to be statistically underdefined, FRUITS is able to calculate the output with statistical confidence due to the addition of prior information. Since the mixing model uses the rules and information the user provides to constrain the results, if the priors and stable isotope information provided are not able to create a sufficient number of possible dietary scenarios, or the parameters produced by these results fall outside the defined acceptable ranges, FRUITS may simply fail to produce any results. In this case, it is recommended to use additional proxies or priors— if available— to provide a better framework. This was the primary reason for the creation of Scenario 2, in which the priors have additional information to help with model constraint. In fact, Scenario 2 does produce results for three of the eight GFS individuals that failed under Scenario 1.

While the Little Sea and Upper Lena models were constructed with attention to the model parameters and technical capabilities of both software and hardware, there is room for improvement in both method and parameters. Further improvements regarding parameters and isotope values of dietary sources— such as infant seal— may improve the model and subsequent results. However, no method is infallible, and all results obtained must be subject to evaluation and critique.

5.5 Research Implications

These results have both confirmed hypotheses and encouraged the reconsideration of certain conjectures concerning the dietary intake of EBA hunter-gatherers of Lake Baikal. The unexpectedly high values of both plants and seal in the GFS diet provide a foundation for an analysis of strategies and techniques involved in resource procurement. The work conducted has implications for the interpretation of isotopic and zooarchaeological analyses, as well as the understanding of certain mortuary characteristics. In addition, this study has also demonstrated the flexibility and applicability of the new generation of mixing models in dietary reconstruction. A short review of the contributions of this study is provided below.

5.5.1 *Stable Isotope Analysis*

Previous studies have attributed variation in stable isotope signatures between the GF and GFS diet groups to differential use of available dietary sources (Katzenberg et al. 2009; Katzenberg et al. 2012). Specifically, Katzenberg and colleagues (2009; 2012) work suggested that while all individuals relied on shallow water fish from Lake Baikal, individuals buried in the East Sector (the majority of which belong to the GF dietary group) placed a greater emphasis on terrestrial mammals, while those in the West Sector (all of which are GFS) relied more heavily on seals and shallow water fish. However, the values produced in this work suggests that both GF and GFS individuals consumed terrestrial resources in similar quantities. Both groups consumed, on average, 50% aquatic (fish and seal summed) resources, 30% terrestrial mammals, and 20% plant material. Rather, it appears that the variation in stable isotope values can be attributed to a differential use of the various available foods. In terms of aquatic resources, the GF diet group focused on Upper Lena (or other isotopically similar) riverine fish (40%) with a smaller proportion of seal (7%), whereas the GFS group subsisted on cove-and-lagoon Baikal fish (6%) with a substantial focus on seal consumption (44%). Weber and colleagues (2011) were the first to note that the removal of seal from the GFS diet was insufficient to account for the isotopic distribution of the GF diet group, which displays a narrow range of carbon values. The results of the Little Sea model support these observations and reinforce the idea that the GF diet is not only characterized by reduced intake of seal, but also by the presence of fish from the Upper Lena; if the GF diet could be characterized only by a lack of seal as compared to the GFS diet group, the GF individuals would have still been accepted by the Little Sea model. Further, the development of the Upper Lena model has shown that while seal may have contributed up to 23% towards a GF diet, their values can only be explained through the consumption of carbon-light fishes, such as those found in the Upper Lena.

Some general conjectures about the diet of individuals at Khuzhir-Nuge XIV have been validated by this model as well. For instance, the emphasis on aquatic foods is shown to be a valid expectation, given that on average 50% of an individual's diet (regardless of GF or GFS) came from an aquatic source. More specifically, the spread of the data indicates that aquatic consumption of GF individuals could be anywhere between 22–76% and 32–74% for the GFS diet group. Likewise, terrestrial mammals— specifically ungulate species— are shown to have been consumed less than aquatic sources (22–43% for GFS, 18–44% for GF), but in greater quantities than plants. Most initial studies assume that plants contributed a negligible (i.e. <5%) amount towards the diet for EBA hunter-gatherers (Katzenberg et al. 2009; Katzenberg et al. 2012; Weber and Goriunova 2013; Weber et al. 2011; Weber et al. 2016). However, this research contradicts this, indicating that the average diet contained anywhere between 7–25% plant material for GFS and 5–31% for GF, with mean values of 19% for both diet groups. Overall, the FRUITS dietary estimations produced in this study both refute and corroborate previous conjectures about the nature of the EBA hunter-gatherer diet at Khuzhir-Nuge XIV and provide quantifiable estimations of dietary consumption that can be compared to other dietary information, such as faunal remains.

5.5.2 *Zooarchaeology*

One of the more pressing concerns of this research was to determine the proportion of seal that contributed to the GFS diet. While it was known that GFS individuals relied on seal, the degree to which this was a dietary staple was debated, as seal is the most seasonally restricted resource in the Baikal region. The values generated by the Little Sea model suggest that there was a substantial emphasis on seal as a primary dietary resource for GFS individuals, with between 32–52% of the average diet composed entirely of seal. If further investigation regarding the effect of young seal isotope values does not result in changes to the estimations of seal contribution in the GFS group, further analysis on the faunal remains in the Little Sea during the EBA may provide some additional clues on this matter.

Interestingly, the faunal record does not show such a clear emphasis on seal during the EBA. Instead, excavations at Sagan-Zaba II indicate a decrease in the number of seal remains between the Neolithic (Layer IVB-A) and Bronze Age (Layer III-B), as the quantities reported were nearly halved (NISP= 854 for Layer IVB-A compared to NISP= 416 for Layer III-B). This pattern is coupled with an increase in the overall number of fish remains (NISP= 83 for Layer IVB-A and NISP= 548 for Layer III-B), which suggests a change in food procurement at this site (Nomokonova et al. 2015). However, this is not a universal pattern in the Little Sea.

In contrast to Sagan-Zaba II, Bugul'deika II does see a substantial increase in the number of seal remains during the EBA (NISP= 1,264 in Layers II-2 and II-3) compared to the LN (NISP= 26 in Layers III and IV-1), with small sample of fish (NISP= 16 for Layers II-2 and II-3, NISP= 0 in Layers III and IV-1) in the same strata (Losey et al. 2016). Age estimations of seal remains in the EBA layers indicate that sealing was focused on yearling and juvenile specimens, similar to the LN layers at Sagan-Zaba II (Losey et al. 2016). The inverse relationship between these two sites in comparison to the values produced by this model is quite interesting and could lead to important insights regarding regional changes in procurement strategies. It may not be that the subsistence strategies changed, but rather the location of subsistence activities did, producing contradictory patterns in the faunal record. However, little can be concluded from patterns seen in only two archaeological sites.

Fish dominates the faunal record at Ityrkhei and is considered to be the primary subsistence activity at this site (Khamzina 1991, 78; Nomokonova, Losey, and Goriunova 2009, 40). However, both the 1976 and 2005 excavations indicate a steep decline in the presence of fish remains from the LN to the EBA. The results of this analysis suggest that Lake Baikal fish such as perch, roach, dace, burbot, and whitefish constituted only 6% of the GFS diet during the EBA. While the faunal record at Ityrkhei seems to support a decline in the importance of Baikal fish as a dietary resource, conclusions should not be drawn from a single site.

The contradictory patterns of species representation seen in the faunal records at Sagan-Zaba II, Itrykhei and Bugul'deika II suggest that the faunal record is not as useful for quantitative estimates of dietary consumption, though the information garnered from these samples is important for qualitative analyses. In fact, a systematic analysis of the distribution of faunal remains across the micro-region and how they changed from the Neolithic to the Bronze

Age would help investigate distributional changes in subsistence activities, which would affect the relative proportions of faunal remains at each site. This would help clarify whether the results of this study are valid, specifically the high estimations of seal consumption. If seal was consumed with an average GFS diet containing 44% seal, this should be represented by a significant amount of seal remains in archaeological camp sites throughout the Little Sea region during the EBA. Unfortunately, a comprehensive analysis of faunal remains across the Little Sea is beyond the scope of this study.

5.5.3 *Mortuary Archaeology*

The results of this research have provided insight into the dietary composition of hunter-gatherers in the Little Sea micro-region which has led to a number of questions. One concern revealed by this analysis is the implication that the GF individuals do not have a diet that reflects an intake of Little Sea fish resources, but rather of the Upper Lena or other ecologically similar area.

Weber and Goriunova (2013) suggest that it is likely that people interred at Khuzhir-Nuge XIV were all members of the same micro-regional EBA community. This implies that some of them may have interacted on a daily basis or belonged to the same kinship or social unit (Weber and Goriunova 2013). However, in terms of isotopic values, the EBA GF diet group is similar to the EBA of the Upper Lena region (Weber et al. 2002; Weber and Goriunova 2013). This research supports this, but further suggests that the primary characteristics of the GF diet are the inclusion of Upper Lena fish in addition to the much reduced consumption of seal. It is not only the nitrogen values that distinguish the GF from the GFS diet group, but the carbon values as well. To explain the differences in the diet groups given the results of this research, three hypotheses are considered; first, the cemetery population of Khuzhir-Nuge XIV represents a single cohesive social group, second, the diet groups of Khuzhir-Nuge XIV represent entirely independent groups with no social interaction, thirdly, that the diet groups represent two populations that interacted, but have an unknown level of relatedness.

If the first hypothesis is to be accepted, the GF individuals would have to belong to the same community as the GFS diet group. Since the GF individuals have a diet indicative of Upper Lena fish resources, this would then suggest that they may be recent migrants to the Little Sea. As bulk bone collagen values represent the last 7–10 years of life, this hypothesis would indicate that GF individuals died and were interred soon enough after migration that a new dietary shift was not registered. While this scenario would explain why they are buried in the Little Sea instead of the Upper Lena despite maintaining Upper Lena stable isotope signatures, it does not take into consideration the continued presence of a small proportion of Baikal seal in the GF diet. If these individuals do represent recent migrants whose dietary signatures have not yet transitioned to a local diet, neither seal nor Baikal fish should be represented in their estimated contribution values. Instead, we find that while GF individuals did not consume Baikal fish, there is a small but important contribution of seal towards the GF diet.

This brings us to the second hypothesis, where the diet groups represent two distinct populations with no interaction. Given that the cemetery was in use between 3270 ± 60 and 3864 ± 60 cal. B.P. during the Early Bronze Age, this is a relatively short period of time for two separate populations to use the cemetery (Weber et al. 2016b). In addition, there is no temporal separation between the internments of GF and GFS individuals, indicating they were using the cemetery concurrently. This indicates at least some level of interaction between these two groups, thereby disqualifying hypothesis two.

This brings us to hypothesis three, that the diet groups represent two populations that interacted, but have an unknown level of relatedness. A review of the established mortuary data of Khuzhir-Nuge XIV indicate that there is evidence to support the hypothesis that the GF and GFS diet groups are two distinct populations that shared some level of social relatedness (McKenzie, 2006; McKenzie, Weber, and Goriunova 2008).

For example, in EBA graves at Khuzhir-Nuge XIV 128 red deer canines were found in direct association with 19 EBA burials in 17 graves (Weber and Goriunova 2013). Burials of 8 GF individuals contained 90 teeth, while 8 GFS burials contained the remaining 33. The pattern of association with the GF diet group is further emphasized when considering the fact that there are only 25 GF burials compared to 49 GFS burials. Of the red deer canines associated with individuals that also have strontium data for tooth enamel (n=8), 80 canines are associated with non-locals (both GF and GFS), while only 6 are placed with Little Sea locals (GFS only) (Weber and Goriunova 2013). Given the correlation with diet and place of birth, this may indicate that these red deer canines are representative of a social identity associated with the Upper Lena. Though, the presence of red deer canines associated with a few GFS local burials indicates that whatever social identity is communicated by these artifacts is not isolated to non-locals, suggesting some level of cultural diffusion.

When considered alongside the spatial distribution of individuals with the GF and GFS diet across the Khuzhir-Nuge XIV cemetery, the pattern becomes even more apparent (Figure 5.11). Previous work on spatial patterning of graves at Khuzhir-Nuge XIV suggest that the placement of graves relative to each other reflects deliberate decisions conditioned by the social structure of these groups, facilitating the separation of the cemetery to the West, Centre, and East Sectors (McKenzie, 2006; McKenzie, Weber, and Goriunova 2008). The West Sector of the cemetery is composed entirely of GFS individuals, while the Centre and East Sector have a mix of both diet groups where individuals with the GF diet form distinct clusters (Figure 5.12). Of particular interest, the GFS burials associated with red deer canines, only 2 are located in the West Sector, accounting for a total of 3 canines (Weber and Goriunova 2013). The remaining 125 canines are found in the Centre and East Sector, distributed among GFS and GF individuals.

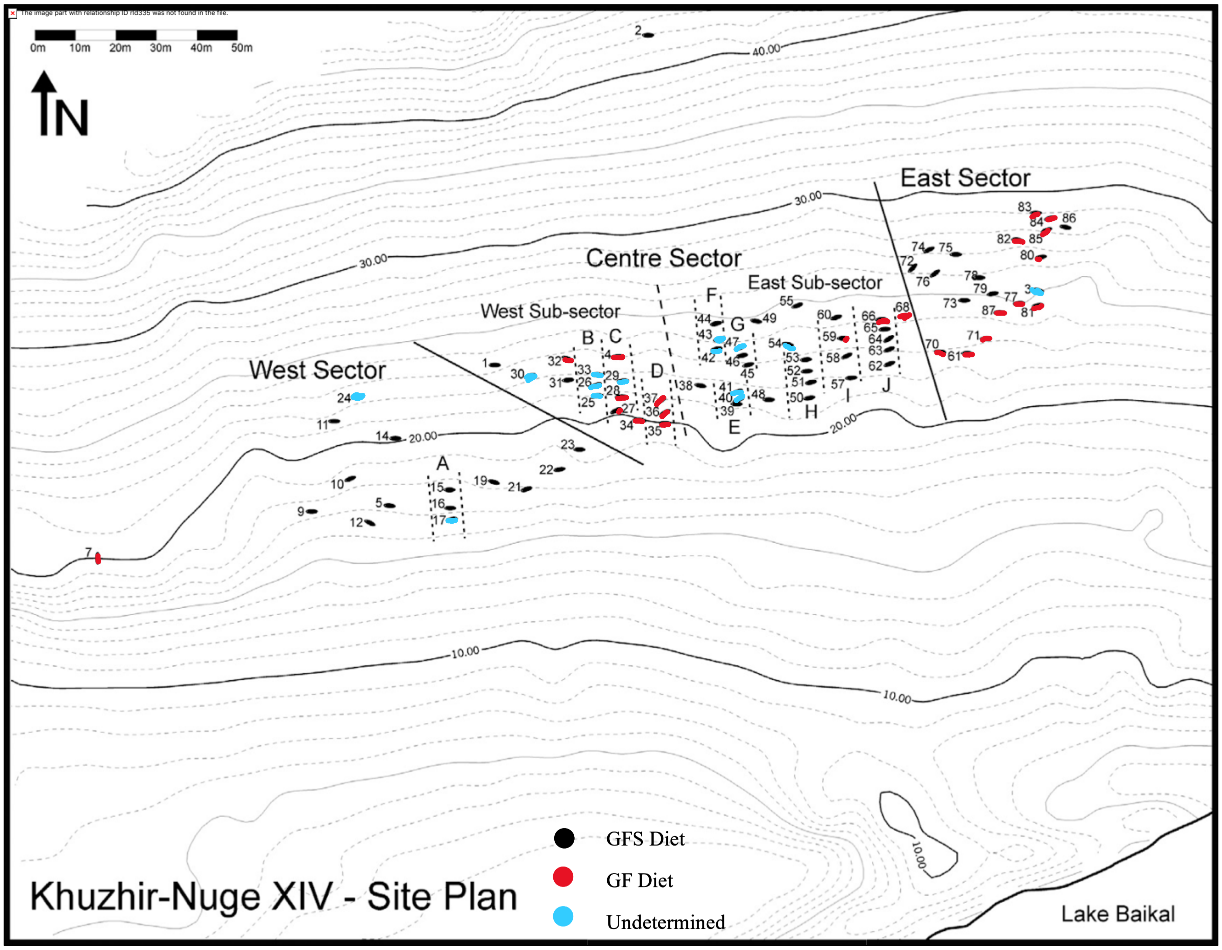

Figure 5.12 Khuzhir-Nuge XIV site plan with GFS and GF burials indicated by black and red ovals, respectively. Undetermined diet values are represented by blue ovals. Adapted from Figure 10 in (Weber and Goriunova 2013).

This research indicates that the GF and GFS diet groups exploited two different ecological niches. While the Upper Lena model suggests GF individuals consumed Upper Lena riverine fish in addition to a small proportion of Baikal seal (mean of 7%), the diet of GFS individuals can be entirely explained through local Little Sea resources. To eaccount for this dietary variability despite being interred at the same location, an alternative explanation would be that GF individuals were highly mobile between the Upper Lena and Little Sea micro-regions on a seasonal round, a hypothesis that has been previously posited (Weber and Goriunova 2013). Weber and Goriunova (2013) suggest that non-locals (GF and GFS) may have entered the Little Sea area from the Upper Lena following two different rounds of seasonal migration. If seasonal migration of these two groups were the case, the dietary signatures of both the GF and GFS non-locals should see input from different ecological niches.

While the results of GF diet group within this research are consistent with Weber and Goriunova's (2013) hypothesis, the GFS individuals are not. Given that the GFS non-local diets can be entirely explained through the Little Sea model, it is more likely that the GFS non-locals represent long-term migrants into the Little Sea micro-region. In contrast, the GF diet group is more likely to represent a group conducting seasonal migrations to the area primarily for the procurement of seal in early spring, as their values can be explained through the Upper Lena model, with some contribution of Baikal seal.

Faunal data in the Little Sea region also suggest a seasonal migratory round, as habitation sites where terrestrial mammals dominate the faunal record are undocumented in the Little Sea (Losey et al. 2016). This would suggest at least some individuals moved away from the lake shore to locations better suited for procuring terrestrial resources. These could have included partially forested areas that provide better shelter for deer than open areas of the Little Sea coastline and rivers with productive runs of spawning fish, the Upper Lena being one such area (Losey, Nomokonova, and White 2012).

If it is accepted that the GF diet group represents a social community based in the Upper Lena that practiced migration to the Little Sea following the ice regime and seal hunting season, it leads to the question of why these individuals are buried at Khuzir-Nuge XIV rather than other contemporary operational cemeteries located in the Upper Lena micro-region. While any direct conclusions at this point would be premature, a preliminary hypothesis can be posited. Based on the principle of Occam's Razor, the simplest explanation given the statement above is that if an individual expired during their seasonal round to the Little Sea region, it would be more practical to bury their dead in that location, rather than transport them back to the Upper Lena. Since the ground begins to thaw in early May, (coinciding with the seal hunting season) it would place the GF non-locals in the Little Sea at a point where they would have access to seal and the ability to dig graves to dispose of their dead. Additionally, if it is assumed that both groups had a similar population structure and mortality profile, the cemetery should display a similar quantity of internments for both diet groups. However, the relative proportion of GF (n=25) compared to GFS (n=49) graves, supports a reduced use of the cemetery by GF individuals, indicating a non-exclusive use of Khuzhir-Nuge XIV; which would then suggest that GF individuals used multiple cemetery locations to dispose of their dead.

The presence of indicators of social identity that correspond to locality of birth and diet group support the hypothesis that GF non-locals represent an EBA community based in the Upper Lena micro-region; which suggests this group practiced migration to the Little Sea, perhaps on a seasonal cycle, following the ice regime and seal hunting season. In addition, the GFS non-locals that were accepted by the Little Sea model, who may have retained aspects of Upper Lena social identity (inferred from the presence of red deer canines in GFS non-local burials), represent long-term migrants; most likely, they were raised in other micro-regions, and permanently relocated to the Little Sea micro-region at least 7–10 years prior to death. It becomes apparent then, that while the two diets may, in fact, represent different territorial groupings, this was not a factor in cemetery membership. Rather, it can be inferred that their social relationships and ties resulted in their co-internment at Khuzhir-Nuge XIV despite differences in primary social membership, as evidenced by the interplay of locality of birth, diet, and social identity represented through red deer canines and spatial distribution patterns within this cemetery population.

5.6 Summary

The results obtained from the Little Sea model fit within the expectations and criteria used to evaluate the model, thereby supporting the conclusion that the GFS diet is comprised of seal, Lake Baikal fish, ungulates, and plants. Hypotheses concerning the locality from which the GF dietary group obtained their aquatic resources were verified by the complete rejection of GF individuals by the Little Sea model. By providing quantitative estimates of dietary contributions the model called into question some previous inferences concerning the relative importance of dietary sources in the diet of hunter-gatherers of Lake Baikal. The results have subsequently encouraged further revision of previous interpretations of EBA at Khuzhir-Nuge XIV and have demonstrated the applicability of dietary modelling for future work.

Chapter 6: Conclusions

6.1 Revisiting the Hypotheses

The purpose of this section is to review and assess the work conducted to determine the success and impact of the results. Outcomes of the hypotheses are presented and discussed. As a reminder, the hypotheses that have driven this work are presented below:

Hypothesis 1: If the GFS Locals are largely accepted by the model and produce precise estimates, it can be posited that the Little Sea FRUITS model adequately represents the dietary landscape of the Little Sea.

Hypothesis 2: If Hypothesis 1 is accepted, the GFS Non-Local group will show a mix of accepted and rejected individuals, where the accepted individuals represent long-term migrants, whose dietary signatures reflect a local diet, and the rejected individuals represent either:

  a. recent migrants whose dietary signatures have not yet transitioned to a completely local values, or
  b. migrants who continue to obtain dietary resources from two distinct isotopic food webs.

Hypothesis 3: If Hypothesis 1 is accepted, and the model predicts a high contribution from the Fish 1 and Fish 2 groups and a low or near zero contribution from the Baikal seal for GF individuals, it can be posited that they are obtaining the aquatic portion of their diet from Lake Baikal.

Hypothesis 4: If Hypothesis 1 is accepted, and all individuals belonging to the GF dietary group are rejected by the Little Sea FRUITS model, it can be posited that the aquatic portion of their diet is a source other than Lake Baikal.

  a. If Hypothesis 4 is accepted, it is possible that these individuals reflect migrants from the Upper Lena, or other isotopically similar ecosystems.

Hypothesis 1 was tested by the construction and application of the Little Sea model. The results support the supposition that the Little Sea model is at least moderately representative of the Little Sea diet. In this case, Hypothesis 1 was accepted. However, further improvements to the parameters and methodology of the mixing problem may increase the validity and applicability of the model to the Little Sea diet, the GFS local diet in particular.

In light of the acceptance of Hypothesis 1, the other hypotheses can now be considered. The results documented for the Little Sea model are in support of Hypothesis 2. As predicted, the GFS non-local group did compose of both accepted and rejected individuals. It is highly likely that GFS non-locals that were accepted by the model have a diet that can be explained solely through Little Sea resources. However, the model was unable to address the secondary hypothesis for the GFS non-locals that were rejected by the model. With current models and parameters, it is not possible to distinguish between recent migrants whose stable isotope values had not yet transitioned to a completely local diet, and those who continued to obtain food from two distinct isotopic food webs.

Hypothesis 3 was rejected by the results of the Little Sea model. No valid results were produced. GF values could not be explained through a Little Sea diet where the sources included ungulates, Baikal fish, seal, and plants. However, this led to the testing of Hypothesis 4 to indicate whether the values were indeed of a non–Baikal nature. The Upper Lena ecosystem was chosen as the most likely to explain the GF diet group values, as the GF stable isotope values are similar to the EBA diet of the Upper Lena. The model accepted all but one GF individual. The results of this model indicate that the GF diet can be explained through the presence of Upper Lena fish, ungulates, plants, and a small proportion of seal. As a result, Hypothesis 4 was accepted.

6.2 Overview of Research

Previous work by the Baikal Archaeological Project has provided a substantial knowledge for more specific and targeted analyses such as this one, which was primarily concerned with characterizing the diets of EBA hunter-gatherers within the Little Sea micro-region. This analysis was guided by a set of dietary hypotheses derived from the current state of literature on the topic. Priors to constrain the model were created through assessment of physiological processes, ethnographic information, and zooarchaeological findings relevant to the subject matter.

While stable isotope analysis is able to reconstruct an individuals diet, the non-specific nature of these results limits interpretive assessments of resource importance to relative contributions. This led to the examination of mixing models as a potential avenue to provide quantifiable measurements of dietary source contribution to overall diet. FRUITS is currently a leading model for the examination of such questions in an archaeological context. The ability of FRUITS to consider non-isotopic priors that further constrain the data is paramount to precise estimations in the field of archaeology, which often only focuses on obtaining data from one or two stable isotopes.

It was found that the Little Sea model provides precise estimations of the dietary contributions of the GFS diet with moderate performance. As more GFS local individuals were rejected by the model than anticipated, further improvements to the parameters of the Little Sea model are evidently required. Regarding dietary estimation values, there were some unexpected results; these include the high plant contribution and the low fish contribution to the GFS diet. It remains undetermined whether the GFS Non-Locals represent recent or longstanding migrants to the Little Sea area, as the model was unable to determine any major differences in diet between local and non-local individuals with the GFS diet. GF individuals responded as expected to the

Little Sea model, as each individual was rejected or failed to produce results, indicating that they were not consuming Little Sea aquatic resources. Instead, the results suggest that the GF individuals were obtaining the aquatic element of their diet from elsewhere, possibly from the Upper Lena micro-region as suggested by the results of the Upper Lena model. This implies that the GFS and GF dietary groups exploited foods originating from different ecological settings and employed variable subsistence strategies.

Not only does the research presented here confirm and contradict current conjectures concerning the nature of hunter-gatherer diet in the Lake Baikal area, it also offers support to examining social identity within and between these groups, who were exploiting different environmental locales. It appears that these individuals could be considered as two social groups as defined by their dietary intake, though there exists an unknown level of relatedness as represented by their mutual use of the cemetery.

6.3 Research Evaluation

6.3.1 *Methods*

The decisions regarding parameter construction and source aggregation as outlined in Chapter 3 reflect the knowledge and decisions of the investigator and have ultimately affected research outcomes. While these choices resulted in the development of a model that performed well, it is highly likely that other choices would generate somewhat different, perhaps better, results. The results achieved through these methods were subsequently able to address the previously stated Hypotheses, indicating that the methods used are justified. Given that new information has potentially been published on both mixing models and the Baikal region since the completion of this research, it is likely that small changes to the methods would be made if analysis were to begin anew, though the overall process would remain the same. In reflection of this, some adjustments for future research are suggested below.

The first suggestion would be a more extensive review of ethnographic literature. A further ethnographic review may have resulted in the adjustment of the maxima and minima assigned to the relative proportions of subsistence economies that were used to constrain the models. While the current study employed a global assessment of hunter-gatherer subsistence, a focused review of hunter-gatherers living in a taiga environment may provide more accurate ranges on which to base the maxima and minima. This may also contribute to the consideration of other potential dietary sources.

Further research regarding the isotopic offsets between bone, fat, and muscle would also increase confidence in estimation values; specifically, how these values could be affected by different cooking or processing practices. While it is assumed that the uncertainty values attributed to each of the isotopic offsets are conservative enough to account for this variation, additional literature or analysis to substantiate these claims would improve overall confidence. Macronutrient estimations face similar uncertainties. While macronutrient estimations were found for some species included in the analysis, some were restricted to values obtained from close taxonomic relatives. In addition, food processing practices, such as roasting or fermenting, may significantly affect the macronutrients available for consumption. The current model does consider this variation through conservative uncertainty values, though further analysis would determine whether the values used are sufficient.

Further to the above suggestions, testing of additional or different priors for the Little Sea model may help to produce more precise results. An optimal p-value of between 0.50 and 0.80 for each individual would indicate excellent model performance. While some individuals in this study attained such values, while there were those whose values were above 0.90, which, while acceptable, indicates that the model constructed for the Little Sea may not be the best fit. A number of changes could be made to the priors and aggregation parameters of the model. While the limitation on dietary protein and plant intake should remain, the other priors could be revisited. For instance, it would be helpful to calculate the maximum possible yearly seal yield from Lake Baikal given modern seal population values. While this may not accurately reflect ancient hunting practices or rates of procurement, it would provide an upper limit which may inform a subsequent model on the practicalities of a diet composed of over 40% seal.

While the above suggestions require small adjustments to the approach, given a considerable commitment of resources and time, more substantial work would be considered. Primarily, more stable isotope values for wild plants in the Baikal region would be instrumental in determining whether the reconstructed plant values used in this analysis are viable. While it cannot be assumed that the modern values would reflect the values present in the EBA, additional plant values would indicate whether or not there is significant variation in carbon or nitrogen values of flora in the region, which would have implications for how plants are accounted for in the model.

Likewise, the addition of a third proxy would considerably increase the analytical capabilities of the model. While strontium ($^{87}Sr/^{86}Sr$) is a likely choice to provide an addition baseline value for the sample, $\delta^{13}C_{carbonate}$ values would also do the same, and may be able to provide some additional dietary information for discussion. However, while these values are available for humans in the sample, they are not for the faunal materials. The addition of either of these proxies would require a significant commitment of time and resources. Though, if three proxies were used, the number of groups considered in the model could be expanded. The parameters could then be manipulated such that the fish would be split into three groupings, which is a superior way to aggregate these species with regards to the documented spread and variation in their stable isotope values. In addition to more sources, the results produced would be more precise with a third proxy guiding the estimations. The third proxy may also allow other sources such as birds, young seal, or other riverine fish to be incorporated into similar models.

6.3.2 *FRUITS*

As with all stable isotope mixing models, there are both advantages and disadvantages to FRUITS. While it has been established that FRUITS improves upon some issues that previous generations of mixing models could not address, the software is not without deficiencies. FRUITS can be installed on multiple computer platforms and comes free of charge. The user-friendly interface and help sections provide an environment that is conducive for the self-directed. The outputs of the model are easily integrated with Excel to create tables, and graphs are produced as a by-product of the analysis. Additionally, once a model is constructed, it can be saved and returned to at any point. This means that while it is costly with regards to time in order to create a model that performs well, once this is established, further research and results can be readily produced. However, these are just technicalities of the software.

The disadvantages of this program that were directly experienced in this research indicate that while the model is a step in the right direction, improvements are still required for full functionality. Of primary concern is the lack of certainty to address how and why some individuals simply failed to produce results. This is especially the case when individuals with similar isotopic values produce differential results; where one is accepted and the other fails. While FRUITS provides a list of possible reasons for failure, the lack of specificity simply indicates that the reason could stem from a number of issues, such that there is no real resolution to why these individuals failed.

An additional technical problem is the fact that while FRUITS is able to conduct a series of analyses at once (i.e. run a number of models concurrently) if one individual in the group fails, results are not produced for the entire batch. In the case of this study, this means that each individual had to be run separately for each scenario, otherwise the model would simply not work. This resulted in the unnecessary duplication of work and an increase in time cost to complete analyses.

Further to the above issues, there are a number of inherent aspects of mixing models that limit the analysis. The general principle of scientific experimentation is that all variables are controlled but one. This allows the researcher to determine whether or not the outcome is dependent on the uncontrolled variable. However, mixing model research requires decision-making based on current available information, which may or may not accurately reflect the real conditions of the target population. As such, it is not possible to determine whether all confounding or extraneous variables have been accounted for. A poorly constructed model will not have a high degree of legitimacy, and though a model may be constructed with attention to potential confounding variables, this does not ensure validity.

The nature of FRUITS results mean that the model is only able to indicate whether the individual is a match for the constructed dietary model. A negative outcome provides no further information on what other scenarios could possibly explain the values. Therefore, only targeted questions that produce either positive or negative results can be reliably applied to FRUITS research. A consequence of this are ambiguous answers to questions when a model only has a moderate performance rate. For example, while the Upper Lena model performed extremely well and was able to provide positive results for the GF non-local individuals, the Little Sea model performed with variable success which suggests the model is not the best fit to explain the dietary variability in the GFS diet. Alternatively, it is possible that individuals could be accepted by a number of models (or scenarios) that may or may not provide similar estimations. However, results will only provide information on the model they were produced with, and no others.

6.4 Future Directions

The research presented here opens the opportunity to further analyze dietary structure among hunter-gatherer groups in the Baikal region. These future studies can address questions of dietary contribution in other areas of Cis-Baikal, dietary trends over time, or individual life histories.

These results also have implications for research currently in progress. A forthcoming micro-sampling study involving individuals from Khuzhir-Nuge XIV aims to obtain short term averages (9–12 months) of dietary variability to determine patterns of consumption over the life course (Van der Haas, forthcoming). Future collaborative work would integrate the Little Sea model with the microsampling results such that the analysis may provide insight into dietary changes throughout the life course, and whether there were differences in the foods used for weaning or later childhood. In particular, a focus on the GFS Non-locals may indicate whether they ate a GFS diet throughout life, or whether they ate a GF diet in childhood, prior to migrating to the Little Sea.

Further to the work discussed above, additional micro-regional models are presently being developed in order to characterize the diets of individuals living along the Angara River and Southwest Baikal, and how they may differ from those living in the Little Sea or Upper Lena (Scharlotta, Weber, and Chaput, forthcoming). This analysis will help characterize and differentiate inter-regional dietary patterns across the Cis-Baikal region. Further, the results will contribute to the further analysis of Little Sea individuals by providing baseline dietary estimations for another micro-region.

Continuing from the analysis presented here, future work will examine patterns and dietary trends throughout the Early Bronze Age in the Little Sea. Khadarta IV, a cemetery located within the Little Sea displays the best chronological sequence in the Little Sea for the Early Bronze Age. Individuals interred here display the GF and GFS diet, similar to Khuzhir-Nuge XIV. The analysis would use the Little Sea model produced in this study and select a sample of individuals spaced evenly throughout the duration of the EBA. The results may be able to determine whether dietary contributions of EBA hunter-gatherers changed over time, and by how much. In addition, a comprehensive micro-regional faunal analysis of the Little Sea could be concurrently developed, aiming to provide an overview of species found at multiple sites across the area and identify changes in species representation through time. This study would be combined with values produced from the FRUITS examination of dietary trends at Khadarta IV, to determine whether dietary patterns seen in the stable isotope values are reflected in the faunal record.

Prior to the above studies, further improvements to the Little Sea model will be developed in light of the critiques outlined in Chapter 5. An extended range of prior information will be explored to better constrain the Little Sea model and increase model performance. Additionally, there will be an attempt to address whether or not yearling seal values impact the proportion of estimated seal contribution. If the model performance increases or estimation values of seal decrease, it can be posited that yearling seal values have a significant impact on the model and should be incorporated in subsequent iterations. However, if model performance does not improve and estimation values remain similar to those presented in Chapter 4, it would stand to reason that yearling seal values do not significantly impact the estimation of dietary proportions in FRUITS.

In order to achieve these goals of dietary investigation, relevant stable isotope values will be required, with a focus on filling analytical gaps regarding the Little Sea faunal record. The expansion of the faunal isotope database will aid in the creation of future models and increase their statistical capabilities. If such stable isotope work is conducted, a focus on archaeological bird specimens, young seals, fish, and strontium values of terrestrial animals should guide the research. Planned excavations in the Upper Lena micro-region provide an excellent opportunity to obtain additional faunal remains. The project may also consider investigating how subsistence strategies responded to and changed with environmental pressures. All future analyses would provide additional information and may better contextualize the modelling results produced here.

6.5 Concluding Remarks

Mixing models have historically been known to have many faults and intrinsic pitfalls that complicate the process of estimating dietary contributions. It has taken 20 years of continuous development to identify areas of improvement and create a mixing model that considers multiple aspects of stable isotope analysis, allows prior knowledge to be applied to the scenario, and is user-friendly. While there remains room for improvement and further development, research in stable isotope mixing models is developing at a fast and dynamic pace. The work presented here shows that incorporating non-isotopic parameters into mixing models is a step forward to increasing their applicability to scientific research. Further, this research has shown that in cases where plant materials or other dietary sources may not preserve in the archaeological record, mixing models allow an approximation of the contribution of these potential sources to the diet of individuals and regional groups.

In the case of Lake Baikal, this research has shown that FRUITS can build a mixing model capable of obtaining quantitative measures of food source contributions within an archaeological context with limited ecological information**.** These measures have subsequently prompted the re-examination of previous expectations of the dietary content of EBA hunter-gatherers in the Little Sea. Future work will revisit the parameters and data of the model, with the aim to improve model performance and methodology. To conclude, this research has contributed to the overall scientific discourse and supports the utility of mixing models in stable isotope research within the context of archaeology.

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