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The beginning and spread of farming in Finland; and the subsistence in Iin Hamina, the Northern Ostrobothnian region

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A thesis submitted to the degree of Doctor of Philosophy (PhD)

Department of Archaeology

University of Durham

2015

Abstract

This work contributes to wider discussions of historical and prehistoric farming practices in marginal environments. In its origins, the process of adopting farming as a new mode of subsistence in Northern Europe was complicated, and its spread continued throughout Finland until the modern period. Farming can be an unreliable form of food production, and failures in cereal cultivation are still common. People's persistence in the face of such adversity allowed for cultivation practices to be adapted in a far northern climate

Discussions of early farming studies in Finland have been dominated by the question of whether single pollen evidence can be considered as reliable evidence of farming. This is based on the assumption that all cereal-type pollens indicate the presence of cereals. This assumption is considerably problematic: Cereal-type pollen includes several wild grasses that are also very common in Finland and thus cannot be considered as a reliable proof of cereal cultivation. It is not possible to study small scale farming using pollen analysis alone, but such analyses are useful for exploring when farming became well-established. This study combines the radiocarbon dates obtained from cereal-type pollen that was present in quantities larger than a single-grain. Using this approach it was observed that population size proxy and early farming studies correlate strongly. This suggests that cereal cultivation started to affect population size from approximately the last millennium BC onward, although the majority of this spread is seen during Iron Age and later periods.

In addition to improving the resolution of the earliest farming in Finland, this study also considers the impact these changes would have had upon diet. Protein intake can be studied using stable isotopes from human bone collagen if local background values are known. The Iin Hamina case study revealed that protein was mainly obtained from wild resources: According to the isotopic composition of human skeletal collagen, fish were a major dietary component. Moreover, reconstructions from incremental dentine analysis revealed that humans from Iin Hamina were well adapted to their environment.

Many aspects of early subsistence practices in Finland remain unknown. However, this study demonstrates that prehistoric cultivation was a multidimensional phenomenon in northern latitudes, and that this is an area that requires more attention in order to be more fully understood.

I, Maria Leena Lahtinen-Kaislaniemi, declare that this thesis, presented for the degree of Doctor of Philosophy at Durham University, is a result of my own original research and has not previously submitted to Durham University or any other institution.

Signed ______________________
Maria Lahtinen

Date ______________________

The candidate's contribution to the thesis:

The author has planned all the studies included in this thesis with the help of her supervisors. The author has carried out all laboratory work, except the running of the samples which was done mostly by Dr. Darren Gröcke and Andrew Gledhill. The author has written all of the work included in this thesis, apart from individual sentences provided by co-authors as suggestions of improving the writing, especially in the case of PAPER 1 where Professor Peter Rowley-Conwy participated on substantial editing of the text. This study was supervised by Dr. Janet Montgomery and Professor Peter Rowley-Conwy, but various co-authors also provided detailed feedback (i.e. Dr. Anna-Kaisa Salmi, Dr. Darren Gröcke, Dr. Markku Oinonen, Dr. James Walker, Mr. Miikka Tallavaara).

Durham
University

Department of Archaeology

Shaped by the past, creating the future

Maria Lahtinen-Kaislaniemi
Department of Archaeology
Durham University

21 December 2015

Dear Maria,

Yes of course you may use our joint paper on which you were lead author:

Lahtinen, M. and Rowley-Conwy, P. 2013. Early farming in Finland: was there cultivation before the Iron Age (500 BC?). *European Journal of Archaeology* 16(4), 660-684.

- in your PhD dissertation.

Best wishes

Peter Rowley-Conwy

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Archaeology has been my passion over the past years and continues to fascinate me. As a science oriented person, many application in archaeology interest me greatly.

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Table of content

INTRODUCTION

Decision making in everyday life is a vital part of all human cultures and societies. How we eat, dress, talk, and ultimately behave is a complex network of actions which varies across different cultural groups. This study focuses on one of the most fundamental aspects of human life: diet and farming. It is often said: "we are what we eat", and, more importantly, that food is not only the building blocks of life, it is also a part of identity and culture (Eriksson, 2003; van der Veen, 2003) in various ways. Food is constituted not only by what is available, but what we prefer to consume. Moreover, choices regarding food are not only reflective of individual enjoyment and broader cultural preferences, but also its production and how this process impacts upon population density, social structure, and the availability of other commodities. Finally it also impacts upon individuals in a society or in a group and their interaction with one another and their environment. Food affects all of us in every aspect of life, be it culturally, economically or socially; it is a vital concern for all humans. In marginal environment, such as North-East Europe, options are limited, but nevertheless as important and little understood. The subject of this thesis is to observe past farming in Finland with a special focus on subsistence of people at Iin Hamina, Northern Ostrobothnia, during the Medieval period (see map 1 for the location of the site).

The subsistence strategy is the means by which people obtain and consu6me food. The main subsistence strategy used by different peoples is also the main criterion to classify different types of societies. Most societies are regarded as either hunter-gatherer or farming based. However, this classification does have exceptions, though these are not necessarily taken into account, thus societies practising farming together with hunting or gathering have often been referred to simply as hunter-gatherers (Smith, 2001). The distinction between these two main classifications of subsistence is not politically neutral. Early farming has generally been regarded as one of the most important steps in human evolution. However, this view is informed by the traditional values of the Western Judeo-Christian World. It is a dichotomy where modernism (the learning of new technologies) and civilization is seen in opposition to barbarism, i.e. hunter-gatherers are seen as undeveloped compared with farming communities (Finlayson, 2010) and control over nature (which emphasis that humans are superior to nature). This view is also influenced by cultural evolutionary theory which implies that human culture develops like biological evolution, from simple to more complex forms (Childe, 1936; Steward, 1955). It sees farmers as innovative and advanced and hunter-gatherers as rural and simple. In reality, characterising the nature of these two modes of subsistence is a much more difficult proposition and Pluciennik (2014) has even suggested that the term 'Hunter-Gatherer' is outdated because of this historical burden. Moreover, both farmers and hunter-gatherers belong to the human species, with no fundamental difference in cognitive capacity. It is also possible to argue that the hunters and gatherers endeavour, at least in marginal areas, to cope with the natural variations in productivity each year, and thus require greater knowledge of a wider variety of species, whereas farmers rely upon a lower diversity of species, seeking to repeat the same processes with the same crops over several years. However, while it is increasingly recognised that there is little merit in comparing these modes of subsistence under this traditional and simplistic framework, there has also been a growing consideration for how we can effectively relate these societies to one another, explaining variations in food production, and how these subsistence strategies relate to the societies that they are used to describe.

As a mode of subsistence, food production carries different implications for everyday life compared to societies where economy is primarily based upon procuring resources from the wild. Stereotypically, the potential for farmers to produce surplus is seen as one of the most important of these differences. Surplus production makes it possible to sustain larger groups in smaller areas, thus increasing the sustainable population density of the area. However, not all differences associated with farming were positive: in various cases it is thought to have increased susceptibility to various illnesses, made people dependent on a low number of sources, and narrowed dietary breadth (Armelagos et al. 1991; Cohen and Armelagos 1984). In most of Europe farming can be discussed in relation to the “Neolithic package”: polished stone tools, ceramics, long-houses, sedentism and farming itself (the package is first mentioned by Childe 1929). However, this was not the case in many eastern European areas where pottery was in use before the adoption of farming (Jordan & Zvelebil, 2010) and sedentism was practised before farming was important (Costopoulus 2012). Moreover, it does not take into account the need to store in preparation for winter in cold climates, which is facilitated by a seasonal production of surplus. This capacity to store over difficult times can also lead to hierarchy, if limited resources are being kept possession of limited individuals (Woodburden 1982, Rowley-Conwy 2001). Furthermore, neither is food production limited on purely cultivation as also Hunter-Gatherers manipulate their environment in attempt to increase food production (Smith 2011, Rowley Conwy and Layton 2011).

All food production is highly dependent upon climate. Although it depends on the tolerance of the species in question ('environmental tolerance'), plants generally become more sensitive to climatic variation in areas that are closer to the boundaries of their 'habitat' (an area where particular plant is able to grow) (Lynch & Gabriel, 1987). Cereals have originated from a much warmer climate than that of northern Europe and the present day northern edge of their habitat is located in Finland. Therefore, as a marginal area for farming, Finland is a particularly interesting case for questions regarding the adoption of agriculture.

Farming in Finland

Finland is situated in northernmost Europe. When discussing diet and farming in this area, it is necessary to understand main characteristics of northerners and how it affects in farming practises. This is a short introduction how the geography and the climate shape the cultivation in this marginal land.

The border between temperate and mixed forest lies in southern Finland (see figure 1). This is important, as many species, such as hazelnuts and oak trees rarely grow north of this vegetation boundary. This boundary between Boreal forest and mixed forest is also the border of the area where cultivation is in most years successful and harvest failures are occasional, and thus where the difficulties related to climate start to increase towards north (Solantie, 1988, 2012). There is only one harvest season in Finland, and the growing season is short. Outside this period when plants grow (which even in south Finland lasts only for 100 days) not even grass is available. This makes farming a very risky form of livelihood, and during years of poor harvest, there will be a strain due to the lack of crop surplus for the winter. In order to understand cultivation in Finland, it's limitation in the north climate is first discussed.

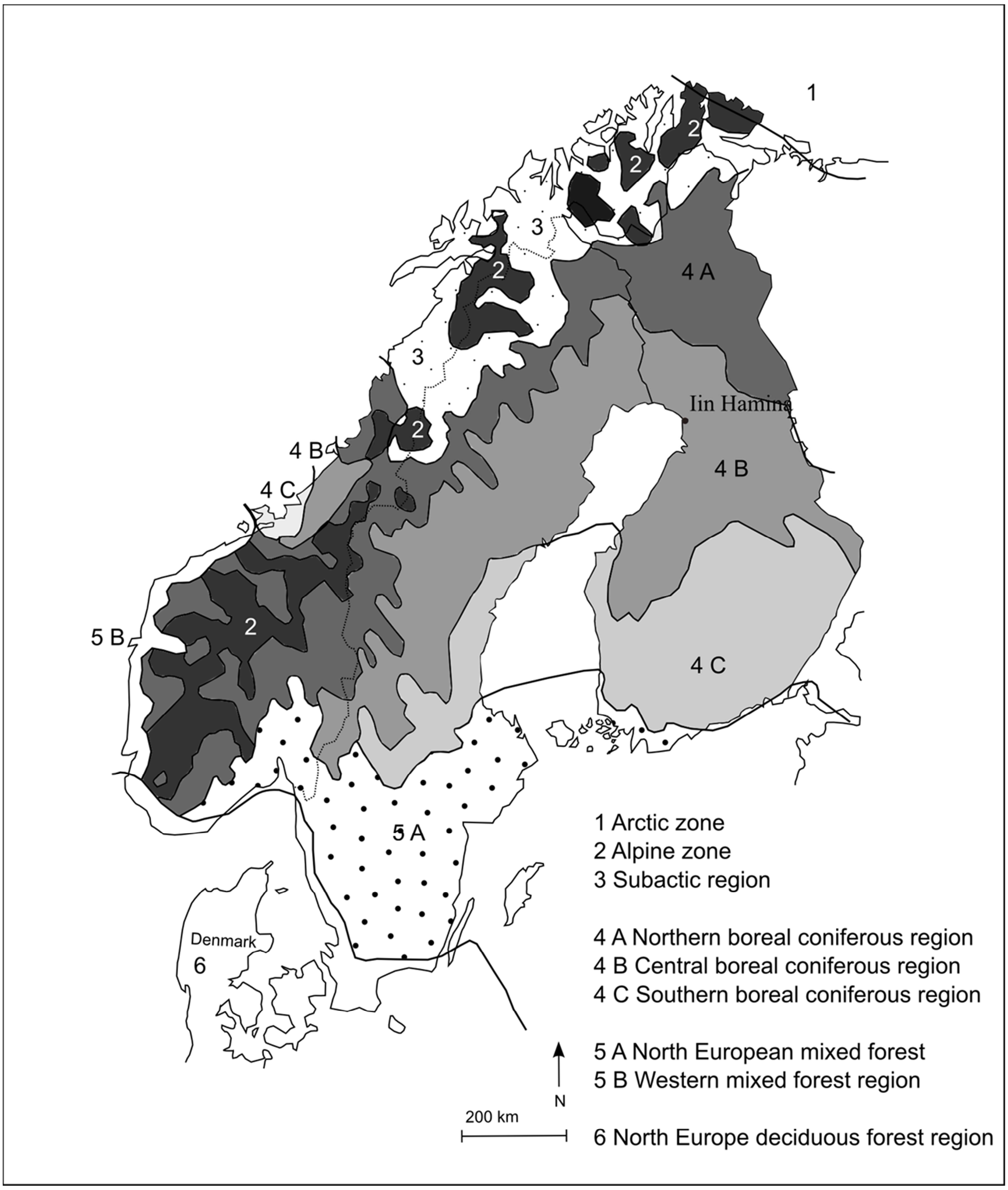

Figure 1. Map of the vegetation regions in the Fennoscandia (Redrawn after Sporrong, 2003)

Modern cultivation is practised only in areas where it is economically profitable in modern terms. Therefore the modern dispersal of cultivated land is not useful for revealing where for cultivation is possible and yields may be less certain or small, and therefore it is no longer practised. This marginal area is a trasitional zone in which farming is possible but increasingly less reliable; it is not the case that farming is simply possible or not. Parts of Finland, especially the northern areas, are in a region where such practices may be possible in good years with favourable climate, but where crop failures are also very common. In modern climate, the likelihood of reliable annual returns decreases as one progresses further north-eastwards (Solantie, 2012).

Figure 2 shows the northern borders of cultivation in the early 20th century. The map is based on Fullerton (1954) (Sweden); Leiviskä, (1934) and Soveri et al. (1956) (Finland). The northern border of barley cultivation in Norway is based on Sjögren (2009).

Because farming is no longer economically reasonable in many areas of Finland, we need to investigate historical evidence for cultivation in order to establish wherethe most northern border of cultivation is situated. This would help us to investigate the more distant past as it is unlikely that farming advanced much more north than this. Fortunately we have plenty of historical evidence of farming practises, and home based cultivation expanded until the mid-1900s into more marginal areas (Hanski & Tiainen, 1986). This was possible because of modifications in planning and innovations relating to farming practices. This border described was reached in the 1950's when these northern limits were identified, and farming in Finland was based on mixed practices where animal husbandry was combined with cereal cultivation (Simonen 1948). It is unlikely that cultivation was ever practised further north than this (see figure 2).

It is also possible to reflect the vulnerability of crop species in this northern climate from present to the past. In modern cultivation, the main reasons for low yields in Finland are early and late season frosts and the low number of growing degree days[1] (this is a measure of heat accumulation over a growing period). Furthermore, low precipitation early in the planting seasoncan result in lower yield (Peltonen-Sainio & Niemi, 2012; Peltonen-Sainio, 2012). Other risks include the possibility of drought in the early planting season, and/or heavy rain at the end of the season, which can limit the yields or cause failure in harvest (Kettunen et al., 1988). Winter harshness can affect the survival of the plants, and it is still used in the estimation of different zones for diversity of species (Gloning et al., 2012).

Due to the harsh climate, only spring planted barley can be successfully cultivated in Finland (Kettunen et al., 1988). In the 1970's different varieties of barley were recorded as requiring between 750 to 800 growing degree days (d°C, also called effective temperature sum) to ripen (see figure 3). It is highly unlikely that the barley varieties cultivated in the past would have had a significantly shorter growing season. A mean of the accumulated temperature (between 1961 and 1991) of this length has been documented in Lapland (Solantie, 2004). This corresponds with the northern limit of historically recorded barley cultivation (Soveri et al. 1952). Although there have been attempts to cultivate barley even further north, it did not ripen and was used as animal fodder (Edwards, 1972). The earliest varieties of spring wheat require minimum of 900 d°C for the fastest varieties and, 1100 d°C for the longest (Kettunen et al., 1988). Spring Oat requires 960 d°C to ripen and pea 930 - 980 d°C (Peltonen-Sainio and Rajala 2007). In comparison, before development of measure of growing degree days, growing season length was used in studying cultivation. Oat varieties known in 1920's Finland had growing requirements from 104 to only 93 days, and peas

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[1] Long days compensate short growing season in northern latitudes, and thus growing degree days is used instead of the length of the growing season in estimation of suitability of cultivates. It is calculated as following: $d^{\circ}C = \sum T_a - 5$, where T_a is daily average temperature on days when $T > 5\ ^{\circ}C$ (Konturi 1979, Klemola 1991).

from 103 to 97 days (Suninen, 1932).

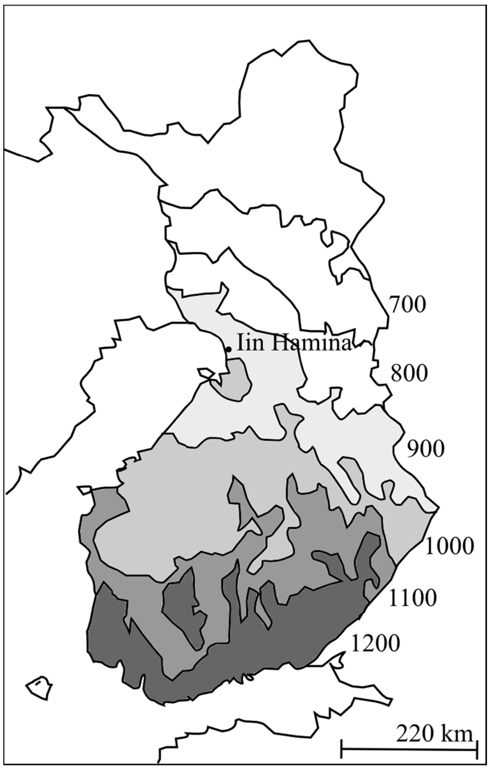

Figure 3. Map of mean growing degree days in Finland between 1971 and 2000 (redrawn after Ruosteenoja et al. 2011, p. 1482).

As explained, due to the harsh climate, the spread of crop cultivation in Finland is likely to differ from that recorded in central Europe. Even Estonia and southern Scandinavia are situated sufficiently further south to occupy a different vegetation zone (see figure 1). Discussion regarding the beginnings of cultivation in Finland has been rather simplistic. The earliest dates for evidence of cultivation being practised have been studied (Huurre, 2003a; Mökkönen, 2012; Vuorela, 1999a, b). Equally interesting, and less studied, are questions regarding the extent to which early crops contributed to people's diets and the kinds of impact that the adoption of agriculture had in broader society and the country, areas in which our knowledge is currently lacking. In this study, I consider not only when farming was first practised in Finland, but also how dependent people were on it, using the site of Iin Hamina as a case study (see location figure 1). The site of Iin Hamina was selected because of good preservation and availability of samples. Isotopic research on this scale has never previously been applied to Finnish skeletal material, and therefore it was necessary to select a site that provided sufficient materials for study.

Aims of the thesis:

This thesis has three main aims:

- To critically evaluate published pollen data pertaining to the earliest agriculture, and to reassess the spread of farming in Finland relative to this data.

- Estimate the advance of the cultivation by comparing radiocarbon dates obtained in the critically evaluated pollen analysis and population size proxy obtained from radiocarbon dates from archaeological material.

- To investigate the diet and its significance and evidence of environmental adaptation at Iin Hamina using analysis of stable isotopes.

Structure:

The thesis is structured as follows: the introduction (this section), two papers about the beginning and advance of farming in Finland, two background chapters detailing the site used for study and the methodology used, two papers of the subsistence practises on Iin Hamina, and the conclusions of the investigation. The format of the thesis enables the author to contribute directly to the world-wide audience, as the four papers form the core of this thesis. The first paper discusses the use of single pollen evidence as a proxy for early farming has been published (Lahtinen and Rowley-Conwy 2013, approval from co-author is included). The second paper summarises the published radiocarbon dates from pollen studies recording signatures suggestive of the beginning of farming in Finland. The third paper discusses the low importance of farming interpreted for the inhabitants of the Northern Ostrobothnian Medieval site Iin Hamina. The fourth paper considers environmental adaptation using dentine incremental isotope analysis in the Iin Hamina. References for these sections are provided at the end of each chapter.

PAPER 1

Early Farming in Finland: Was there Cultivation before the Iron Age (500 BC)?

Introduction

In this contribution, we consider the start of agriculture in Finland. Finland would have presented a major challenge to early farmers. It lies north of 60°N (Figure 1), and close to the northern limit for deciduous forest. However, it is still possible to practise cultivation, although modern farming is concentrated in the south-western corner and coastal areas. In most of Europe, the agricultural transition is equated with the start of the Neolithic. This is not, however, the case in Finland, where the start of the Neolithic is defined by the appearance of pottery (see Figure 2). The question ‘when did cultivation start?’ is under discussion in various parts of Europe, but while the question elsewhere is ‘was there pre-Neolithic cultivation?’ (e.g. Rowley-Conwy, 2004; Behre, 2007), in Finland it is ‘was there pre-Iron Age cultivation?’ In Finland, the Iron Age started c. 500 cal BC, and continued until AD 1200.

There is still no consensus as to when cereal cultivation started in Finland. Some have suggested that cultivation started as early as 3200–2300 cal BC, in the Neolithic Corded Ware (CW) culture (Vuorela & Hicks, 1996; Alenius et al., 2009; Mökkönen, 2010). Mökkönen (2010) suggests that the first cultivation might have begun even earlier. More recently, Alenius et al. (2013) and Nordqvist and Herva (2013) have argued that it could have been as early as the appearance of the first ceramics in 5000–4000 BC. These claims of early cultivation have sometimes been used uncritically (e.g. Costopoulus et al., 2012; Nordqvist & Herva, 2013). Finland, like other northern areas, generally has very poor organic preservation on archaeological sites, so finds of animal bones and macro botanical plant remains are very rare. Many of the claims for early agriculture are therefore based on palynological records (Huurre, 2003a), often single grains of cereal-type pollen.

We will argue that cultivation may have begun much later, as late as the start of the Iron Age (c. 500 cal BC). Finland is not alone in claiming early agriculture on the basis of pollen evidence (see the important paper by Behre, 2007). In Britain, Edwards (1989) identified numerous traces of ‘cereal-type’ pollen of Mesolithic age, but in a recent major study, Whittle et al. (2011: 808, 849) reject these claims and date the start of farming to the Neolithic. Claims for Mesolithic ‘cereal-type’ pollen have also recently been advanced in central and southern Europe (e.g. Tinner et al., 2007;

Jeunesse, 2008). Other areas of northern Europe have seen a similar debate. In northern Norway, Johansen and Vorren (1986) argued that ‘cereal-type’ pollen indicates that agriculture started in the mid-third millennium cal BC, although other lines of evidence suggest a date not much before 1000 cal BC (Valen, 2007). The Finnish debate should thus be seen as part of a wider European discussion.

Figure 1. Map of Finland showing various geographical features, and sites mentioned in the text, other than where pollen cores have been sampled. Distribution of Corded Ware from Nuñez (2004: Fig. 11).

Early agriculture in Finland: the debate

The Late Neolithic Corded Ware and Kiukainen cultures

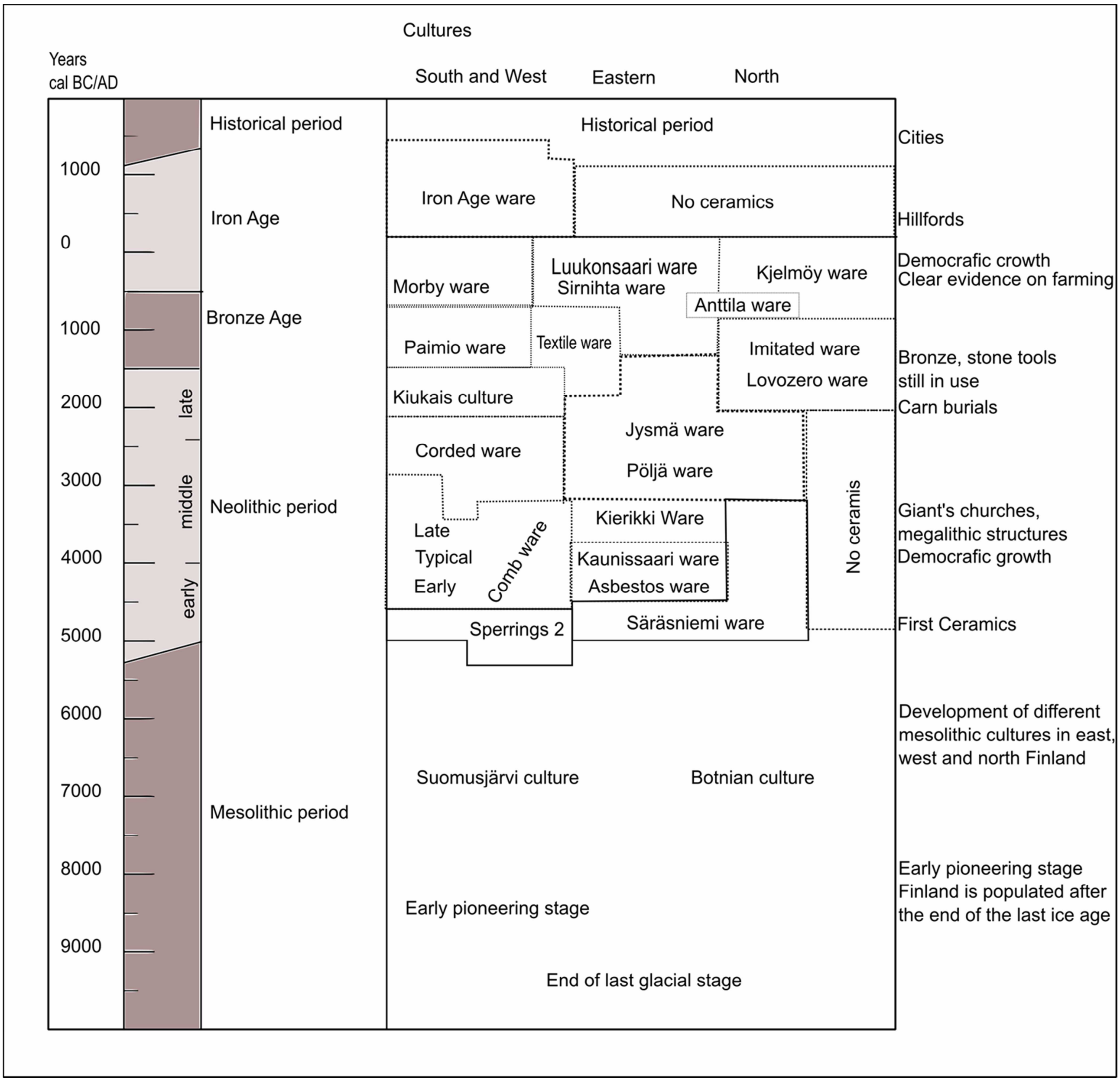

Figure 2. Chronological and cultural outline of prehistoric Finland. Redrawn with modifications from Carpelan (2002: Fig. 5).

The traditional view has been that farming was introduced into southern Finland by people of the CW archaeological culture (see Figure 1 for the CW distribution). This typologically Late Neolithic culture is associated with agriculture across a wide area of Europe. Various arguments have been advanced to support the claim for cultivation in Finland. Most of these involve pollen, and will be considered in detail below. The most recent claim that the Finnish CW was agricultural has been put forward by Mökkönen (2010). Mökkönen used new data concerning changes in settlement pattern, and a correlation between spruce and the CW culture, to claim that the CW people were cultivators. The change in settlement pattern was from more sheltered inland areas towards more coastal and open sites. This change could, however, be interpreted in the opposite way: there is no clear reason why such a settlement shift should be connected to cultivation, and it is questionable whether cultivation has anything to do with it. It might equally indicate more intensive fishing as part of an adaptation to the climate change.

Previous discussions have alluded to CW cultivation. Nuñez (2004) stresses the weaknesses in the evidence, but argues that the CW was indeed likely to have been partially agricultural, mainly based on the fact that CW people were agriculturalists elsewhere. He believes that farming was environmentally vulnerable this far north, and may have suffered a setback and disappeared almost totally soon after the CW period. Edgren (1999) argues that positive indicators of cultivation by the CW culture are lacking, and that the argument is based purely on the situation at CW sites in Sweden and the Baltic countries. Edgren believes that it is unlikely that cultivation occurred during the Late Neolithic period, although he does not say when it did start. He points out that the Pre-Roman Iron Age was the period of intensification of cultivation in southern Finland.

There have been various critiques of these early farming claims. Zvelebil and Rowley-Conwy (1984) wrote that ‘the palynological evidence for CW farming in Finland rests on a few uncertain identifications of cereal pollen—evidence which in view of the great similarities in size and shape of other Gramineae pollen..., could hardly justify the belief that CW economy was based on farming’ (Zvelebil & Rowley-Conwy, 1984: 115). Finds of single pollen grains have subsequently increased, but the same problems with reliability have remained (see Discussion below). Direct evidence for CW agriculture continues to elude archaeologists. A recent major radiocarbon programme using accelerator mass spectrometry was directed towards potential early domestic animal bones. None of the bones dated were of CW age; most were recent or modern in origin (Bläuer & Kantanen, 2013). Although the evidence from the subsequent Kiukainen period is broadly similar, one domestic animal bone, a sheep/goat carpal, has been directly dated to this period. The bone is from Pedersöre Kvarnabba, remarkably far north on Finland’s west coast (see Figure 1), and is dated to 3679 ± 33 BP (Ua-43043) (Bläuer & Kantanen, 2013: Table 1), or 2192–1960 cal BC[2]. It is also possible that animal herding and cereal cultivation were adopted at different

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[2] All calibrations in the article have been carried out using OxCal 4.1 and the IntCal 09 curve (Bronk Ramsay, 2009).

times.

The Bronze Age

There is some published evidence that could support Bronze Age cultivation. Zvelebil (1981) used productivity modelling to compare site locations and connections to land which is suitable for cultivation in south-western Finland. He showed that CW sites were not situated in close proximity to potential arable land. However, during the Bronze Age, the proximity of the archaeological sites to land suitable for cultivation increased. Thus, Zvelebil (1981) concluded that the Bronze Age economy was a combination of farming and hunting. However, since direct evidence is missing, this alone need not prove anything about cultivation. Such potentially cultivable areas can also be rich in natural flora, and might be optimal for wild animals such as elk (Alces alces). Another possibility is that these results simply reflect land uplift that made former sea floor sediments, like arable clays and silts, more available in the Bronze Age, as hunters also benefit from close proximity to watercourses. As Zvelebil and Rowley-Conwy (1984: 117) note, there is an 'auto- correlation between watercourses, sedimentary basins and soil fertility.' According to Zvelebil (1981), arable land does not become a major focus of the settlement pattern in south-western Finland during the mid-first millennium AD.

Table 1. Criteria used to classify wild grass and various categories of cereal-type pollen in the schemes of Andersen (1978) and Beug (1961).

Classification	Andersen (1978)	Beug (1961)
Wild grass	Mean pollen size <37 µm, Mean annulus diameter <8 µm, Surface pattern scabrate or verrucate	<37 µm, Pore <2,7 µm, Annulus diameter <2,7 µm, Annulus thickness <2,0 and >3,0 µm
Cerealea Group	No general cereal type	>37 µm, Pore >2,7 µm, Annulus diameter >2,7 µm, Annulus thickness between 2,0 and 3,0 µm
Hordeum type	Mean pollen size 32–45 µm, Mean annulus diameter, 8–10 µm, Surface pattern scabrate	Cerealea type which have surface structure punkt clumpen (punkt groups)
Triticum type	(together with Avena type) Mean pollen size >40 µm, Mean annulus diameter >10 µm, Surface pattern verrucate	Cerealea type which have surface structure punkt grupen

Sarmaja-Korjonen (1992: 146) argues that ‘there is no detailed Finnish pollen record that indicates continuous farming from the Bronze Age onward’. She points out that biostratigraphical correlation with the archaeological record might be poor because of wide error ranges in the radiocarbon dates, and also believes that cereal pollen might have been transported over long distances; thus, a decline in Picea (spruce) pollen together with single Cerealia-type pollen grains should be treated very cautiously as evidence of local cultivation. However, other palaeobotanists have suggested that cultivation began in the Bronze Age. Tolonen (1984) argues that the results from three pollen analyses in southern Finland are reliable. Two of those studies, from lakes Kantala and Kissalammi, suggest that cultivation started in the Late Bronze Age (Tolonen, 1978a, 1981). One of these is from Lake Ahvenainen, and has one pollen grain of Triticum-type and one of Hordeum-type in a level dated by varves to 1200–1300 BC (Tolonen, 1978c). Simola (1999) discusses cultivation in the Bronze Age as if it was an established fact, but does not give any references to support this idea. Having said this, he does admit that signs of early cultivation are scarce, and can only be seen in a small area of south-western Finland before the Iron Age (Simola, 1999).

Macrofossil evidence for agriculture remains very scarce. One directly dated domestic animal bone, a cow maxillary molar from Nakkila Viikkala, is dated to 3086 ± 30 BP (Hela-1271) (Bläuer & Kantanen, 2013: Table 1), or 1427–1271 cal BC. This is further south-west than the Kuikainen example mentioned above (Figure 1). These two bones remain the only directly dated evidence of domestic animals in Finland that necessarily predate the Iron Age.

Charred cereal grains are also very scarce. One directly dated grain of barley has been recovered from a multiperiod site from Kotirinne in Niuskala in the city of Turku (Figure 1). 30 years after its discovery, it remains ‘the oldest cereal grain find in Finland’, with a radiocarbon date of 3200 ± 170 BP (Ua-338), or 1891–1018 cal BC (Vuorela & Lampiäinen, 1988: 33). It is derived from a ‘grain from the lower part of the undisturbed layer’ (Vuorela & Lempiäinen, 1988: 36). This has been used as clear evidence of cultivation (Vuorela & Hicks, 1996; Lempiäinen, 1999; Huurre, 2003a; Mökkönen, 2010). This date is one of five from Niuskala, and when calibrated (Figure 3), they show a remarkably wide degree of spread. The date on the cereal grain has a very large standard deviation. A review of the dates both of the cereal grain and of the entire site is needed, and independent verification of the cereal date required. In the osteological study from Niuskala, no domestic animals were found. The bone fragments were identified as seal, fish and hare (Asplund et al., 1989). This suggests that this settlement was mainly fishing and hunting site.

Three other barley grains from two sites have been dated to nearer the end of the Bronze Age. Two from the site Jätinhaudanmaa in Laihia have been dated to 2785 ± 30 BP (Poz-23351) and 2590 ± 40 BP (Ua-33250) (Holmblad, 2010: 135), or 1008–844 cal BC and 831–552 cal BC, respectively. The one from Kitulansuo has been dated to 2990 ± 60 BP (Lavento, 1998), or 1400–1048 cal BC. However, the grain from Kitulansuo was published in a non-peer reviewed journal, with no contextual information or discussion of the date. The location of these sites is puzzling: Jätinhaudanmaa is remarkably far north and Kitulansuo remarkably far inland for such an early date; however, barley grains directly dated to about the same time have been recovered from Umeå (Viklund, 2011), opposite Jätinhaudanmaa on the Swedish side of the Gulf of Bothnia (see Figure 1). The presence of barley grains at these sites may indicate Late Bronze Age cultivation, but does not necessarily prove that it took place locally: we cannot rule out the possibility that they could have been traded into the area. More studies are urgently needed that focus on this issue.

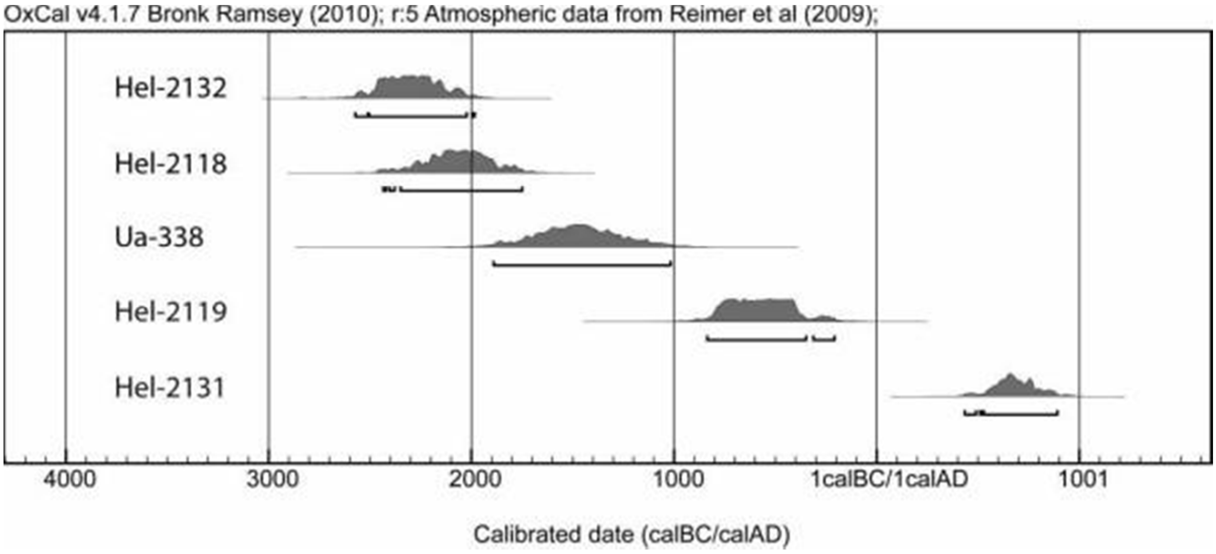

Figure 3. Calibration of the five radiocarbon dates from Niuskala. Us-338 is the cereal grain. Original dates from Asplund et al. (1989).

Apart from these isolated examples, macrofossil data suggest that cultivation began between AD 100 and 1000 in the south-western extremity of Finland (see Onnela et al., 1996). Most of the sites were excavated before Accelerator Mass Spectrometry dating was widely used, and so it is very likely that some dates are inaccurate. Plant macrofossil studies mainly cover southern Finland, and in many more northern areas, such studies are still lacking. Thus, more detailed analyses are needed. At the ancient field in Rapola, cereal macrofossils are dated to between AD 780 and 1217 (Vikkula et al., 1994). In Mikkeli, central Finland, they are dated to AD 596–1690 (Vanhanen, 2010a) (see Figure 1 for the location of these sites).

In Finland, the earliest evidence for agriculture thus comes from the pollen record. It is to this that we now turn our attention.

Are single pollen grains evidence of cereal cultivation?

Most sites at which early agriculture is claimed have only one grain of cereal pollen. The claim that single pollen grains are reliable evidence is based on the fact that self-pollinating (autogamous) Hordeum (barley) releases only small quantities of pollen into its immediate surroundings (Vuorela, 1973). The pollen is unlikely to be found, and thus it has been claimed that every single pollen grain provides reliable evidence of cultivation (Vuorela, 1986; Vuorela & Kankainen, 1991; Vuorela & Hicks, 1996; Alenius et al., 2009). Forests have an important filtering effect on pollen, which makes it even more difficult to find, especially in a mosaic-like forested area like those around slash-and-burn clearances. This has lead Vuorela (1999: 339) to state that ‘the first record of Cerealea pollen in pollen diagrams, in many cases, can be taken as an indication of the beginning of agriculture’. We do not argue against the unlikelihood of self-pollinating plants being seen in pollen analysis — barley pollen does not spread in large quantities. But does this mean that every pollen grain find is reliable evidence of cultivation?

There are various reasons to doubt it. We are not the first to raise these problems. In a major review article, Behre (2007) pointed out that there are several possible errors in the identification of single pollen grains of cereals, such as: reliability of identification; long-distance transportation of cereal pollen; long-distance transportation of large grass pollen; contamination; reliability of dating; reliability of anthropogenic indicators.

In summary, Behre (2007) highlights that it is impossible to prove whether single pollen grains are local or even from cultivated plants at all. He argues that a single pollen grain neither proves early cultivation nor the lack of it. Pollen analysis, used alone, might not be the right tool to research very small-scale changes.

Identification

Firstly, ‘cereal-type’ pollen does not always mean cereal pollen! It is only a classification type, which also includes several wild grasses. There are also several definitions as to how to distinguish cereal pollen from wild grass pollen and how to classify different cereal pollen types. Criteria used in early farming studies in Finland are from Rowley (1960), Beug (1961), Erdtman et al. (1961), Andersen and Bertelsen (1972), Andersen (1978), Faegri et al. (1989), Moore et al. (1991), and Reille (1992, 1995).

Andersen and Bertelsen (1972) and Rowley (1960) have tried to distinguish cereal pollen types on the basis of surface structure and exine. Rowley (1960) argues that most cereal pollens have an incised surface, but admits that this is not an exclusive criterion. Andersen and Bertelsen (1972) suggest that Hordeum vulgare (barley), Secale cereale (rye), Triticum monococcum (einkorn), and several wild species such as Agropyron repens, Ammophila arenaria, Elymus arenarius, and Glyceria fluitans all have similar sculptures (i.e. structures on the pollen surface), although Hordeum, Elymus, and Glyceria may have larger spinules. Both studies suggest that there are insufficient differences in surface or exine structure in wild and cultivated grass pollen to identify individual grains.

Other classifications are listed in Table 1, with a list of species falling into each class in Table 2. It is clear that in every classification there are several wild grasses that fall into the definition of cereal, Hordeum or Triticum type. The classification by Erdtman et al. (1961) does not fulfil modern scientific criteria because the measurements of the pollen grains (i.e. the data) on which the study is based were not published. Erdtman et al. (1961: 3) even state that ‘the descriptions are definitely provisional’ and ‘the size figures may sometimes even be misleading’. Therefore, this classification should not be used. Andersen (1978: 91) states that ‘the Hordeum-group includes cultivated species and some wild grasses’. Beug (1961) proposes that wild grasses, with few exceptions, belong to wild grass type, and those exceptions are included in the cereal-type group. Faegri et al. (1989: 284–85) summarize this as follows: ‘by statistical methods it is possible to differentiate between the pollen of various taxa if there is a sufficient number and no admixture, but since the various curves overlap, identification of individual grains remain impossible or doubtful.’ There is currently no method to distinguish every single wild grass from cultivated species. Every study is based on statistical differences and there is overlap between species of both classes.

Modern distributions of the Finnish wild species producing large pollen grains have been studied by the Natural Museum of Finland. The dispersion of wild large pollen grain species are reported in 1 × 1 km 2 (see Figure 4). The total number of squares examined in 2011 was 7993 (Lampinen & Lahti, 2012). Two species producing Hordeum-type pollen are found in Finland: Hordeum murinum is known from eleven squares, Glyceria fluitans from no fewer than 1385 squares, which accounts for over 17 per cent of all the squares (Lampinen & Lahti, 2012). Pollen grains of Leymus (previously Elymus) arenarius and Ammophila arenaria fall into Beug's (1961, 2004) Triticum-type, and several wild species fall into Beug's (2004) category of Cerealia-type pollen (Behre, 2007). In Finland, two such wild species are found, Setaria pumela in eleven squares and Avena fatua from 220 squares, accounting for nearly 3 per cent of the squares (Lampinen & Lahti, 2012). The modern distribution of Agrypyron species in Finland is twelve squares, and Bromus species 662 squares. Leymus species are common not only in the coastal area (see following discussion), but their modern distribution covers almost the whole of Finland (Lampinen & Lahti, 2012).

The Table 2. Species falling into the categories of cereal-type pollen listed in Table 1 Classification Andersen (1978) Beug (1961, 2004)

Classification	Andersen (1978)	Beug (1961, 2004)
Cerealea type	No Cerealia type	
Hordeum type	Ammophila arenaria, Agropyron repens, A. junceiforme, Glyceria fluitans, G. plicata, Bromus inermis, Elymus arenarius, Hordeum jubatum, H. murinum, H. vulgare, Triticum monococcum	Hordeum distichon, H. vulgare, H. murinum, H. nodosum, H. marinum, Otyza sativa, Elymus arenarius, Agropyron junceum, A. intermedium, A. caninum, A. littorale, Spartina maritima and partly Glyceria fluitans, G. plicata, Bromus mollis, B. erectus, B. inermis, Agropyron littorale, Secale Cereale, Triticum monoccium
Triticum type	Avena fatua, A. nuda, A. sativa, Triticum aestivum, T. compactum, T. dicoccocum, T. durum, T. polonicum, T. spelta	Triticum dicoccum, T. durum, T. dicoccioden, T. compactum, T. aestivum, T. spelta, T. monococcum, T. aegilopoides, Avena brevis, Avena nuda, Avena Strigoissa (?), Ammophila arenaria, Bromus div spe., Hordeum div, spec. Agropyron (?), Leymus arenarius

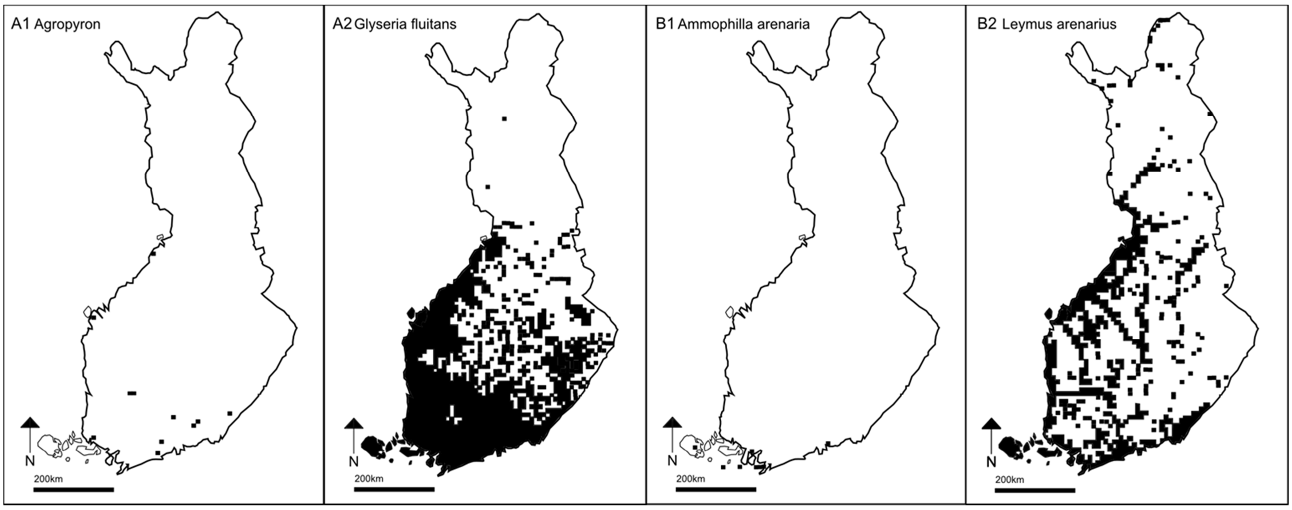

Figure 4. Modern distribution of wild grasses in Finland that fall into Beug's (1961, 2004) criteria as Hordeum (A1, A2) and Triticum (B1, B2). Maps redrawn and modified from Lampinen & Lahti (2012).

These problems have not, however, been much discussed in Finland. Tolonen (1984) did criticize the use of single pollen grains, stressing that size is the only separator between wild and cultivated grasses. However, several wild plants produce pollen so large that it will be considered as Cerealia-type. Other indicators of forest clearance (e.g. Plantago major and Chenopodiaceae) occur naturally in coastal areas of Finland, often together with the wild grasses that produce large pollen grains. Therefore, it is not possible to study the beginning of cultivation in such places and it would be also more secure to only use cereal pollen as evidence. Tolonen (1984) also mentioned the possibility of long-distance transport.

Donner (1984) also criticizes studies of early farming. He mentions the problems of distinguishing cereal from wild grass pollen, and argues that the solution is to use different limits. The first, the 'absolute limit', is the first occurrence of the taxon; the second, the 'empiric limit', is when the pollen curve becomes continuous; and the third, the 'rational limit', is when the frequency of pollen increases. He explains differences between the empiric and rational limits with reference to the introduction of rye, since it produces more pollen than other species, rather than an intensification of farming. However, he does not discuss whether the absolute limit, often only based on one pollen grain, can be considered as evidence for local farming. More recently Simola (2012) has criticized the paper by Mökkönen (2010) for citing little actual evidence for early agriculture, and emphasized that there are problems in the recognition of cereal-type pollen.

It is important to know the local history of the sampling site. In Finland, because of land uplift, the coast has moved throughout history. Single pollen grain evidence has been used as evidence for cultivation in the Tornio area before 3500 BP (Vuorela & Hicks, 1996—citing Tikkanen, 1978). However, Tikkanen (1978) showed that the period is clearly characterized by coastal vegetation. Wild grasses producing large pollen grains, such as Elymus and Agropyron, are common in coastal biotopes (Reynald & Hjelmroos, 1976). The large pollen grains are more likely to belong to these species than cultivated plants. At Merinjänjärvi, changes in lithology (Figure 5) suggest that when the first signals of cereal are seen, the site was coastal (Reynald & Hjelmroos, 1980). In such areas, pollen should not be used as the only indicator for cultivation.

Modern pollen dispersal has been used to evaluate whether pollen analysis can be used to study small-scale cultivation. Finland is a large country, and, in marginal northern areas where cultivation is small scale, indicators of cultivation are always sporadic. According to Hicks (1985: 82), '... one cannot expect to be able to distinguish close related activities at this level (e.g. cereal fields from hay fields)'. Thus, it is not possible to draw any conclusion about the beginning of cultivation based on pollen analyses (Hicks, 1985). This is supported by a study where modern pollen was used to test the representativeness of anthropological pollen (Hicks & Birks, 1996). These modern samples show that farms and fields cannot be distinguished, and furthermore both activities leave only a small amount of pollen evidence. This suggests that it is impossible to distinguish small-scale cultivation by pollen analysis.

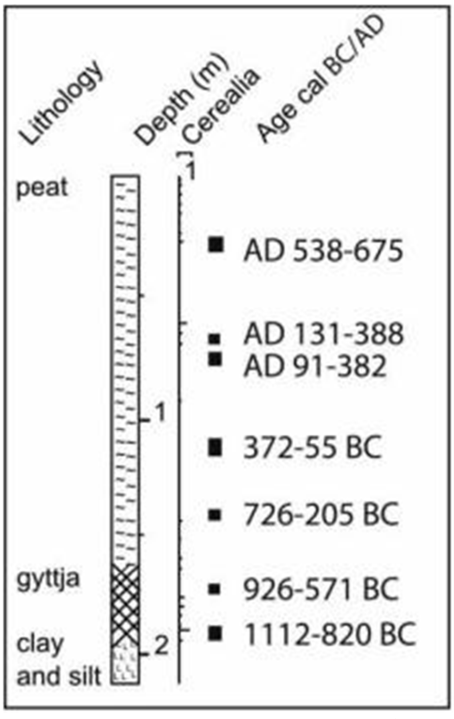

Figure 5. The lithology of Merinjänjärvi, showing the change from sea (i.e. clay and silt), through lake (i.e. gyttja), and finally the development of the bog. The coastal stage is marked by the presence of large size grass pollen falling into the definition of Cerealia-type. Redrawn with modifications from Reynald and Hjelmroos (1980: figs. on pp. 270 and 271)

Long-distance transportation

Long-distance transportation is always a problem in pollen studies. Evidence of modern long-distance transportation suggests that pollen can be transported by storms to Fennoscandia from as far away as North Africa or North America (Franzén & Hjelmroos, 1988). Studies of coloured snow from southern Sweden found that Hordeum-type pollen, together with that of other plants usually regarded as cultural indicators, including Plantago lanceolata and Urtica (nettle), is part of such particle movements. The source of such pollen is impossible to trace absolutely, but mineral grains and plants suggest that the origin was somewhere in Denmark, at least 200 km away from the sampling site (Franzén & Hjelmroos, 1988).

Pollen can travel not just hundreds of kilometres, but also thousands. Samples collected from the snow surface in close proximity to the Arctic Circle in central Sweden show this. Cerealia-type pollen was found, mainly Secale-type and Triticum-type. The closest area where cereals flowered before the time of sampling was Italy, and mineral particles even suggest North Africa. These data suggest that drawing conclusions from single pollen grains should be avoided (Hjelmroos & Franzén, 1994).

Dating and interpolating problems

Simola (1999) has pointed out that Vuorela and Hicks (1996) used pollen evidence uncritically and have used radiocarbon dates for early agricultural activity without any discussion of reliability of the results. Many of their radiocarbon dates come from bulk sediment samples. Simola states that the possibility of old carbon is not considered, and that the dating results are not even discussed. Bulk sediment was often used to date pollen cores in the 1970s and 1980s. It has been shown that such results can be in error by thousands of years (Barnekow et al., 1998; Grimm & Nelson, 2009; Stanton et al., 2010). This has long been known in Finland: Tolonen et al. (1976) showed that radiocarbon dates from several lakes in southern Finland are 500–800 years too old compared with known rates of land uplift or annual varves. Several other Finnish studies have produced similar results (Huttunen & Tolonen, 1977; Tolonen, 1980a, 1990). Tolonen et al. (1976) accepted that such dates are estimates and should not be considered as absolute dates. Therefore, estimating the beginning of farming should be based on several dates and results from several sites, and one must accept that some of the sites will give dates that may be too old. In another study, Pitkänen and Huttunen (1999) compared radiocarbon dates on leaves and sticks from Betula (birch) with annual varves from Lake Pönttölampi. The results showed that the radiocarbon dates were 500–1100 years older than the varve ages. Thus, any results should be considered with considerable caution.

In some studies, the layer with early farming evidence is not itself dated. Often, in pollen analysis, age-depth models based on sedimentation rates are used to place the results on a chronological scale, and ages for particular horizons are interpolated or extrapolated. One study compared such an age-depth model based on six radiocarbon dates to a lake's annual varves, and concluded that the age-depth model was in error by as much as 90–180 years (Telford et al., 2004). Most of the earlier studies in Finland used only two to four dates, and the samples spanned several years of sedimentation. Thus, it is very likely that in reality the errors are even greater. One major problem with extrapolating dates occurs when the latest radiocarbon date comes from below the level under consideration: the sediment at the surface is always recent and the sedimentation rate is fastest. To be able to interpolate, it is necessary to distinguish where the sediment ends (i.e. which is the topmost layer), which is always an estimation. In many cases, error limits are not even discussed and thus the uncertainty of the study is not known, which makes comparison of the studies more unreliable.

The spruce decline and forest fires

A decline in Picea (spruce) has often been used as evidence for cultivation, because the occurrence of single cereal-type pollen grains, other cultural indicator species, high levels of charcoal and the introduction of spruce often appear together in pollen diagrams. The explanation offered for this is that slash-and-burn cultivation worked well in spruce forests (Vuorela, 1986). However, in Finland, such cultivation has been practised until recently, and the most suitable forest type was in fact Betula-Alnus (birch and alder) forest aged about 15–30 years old (Heikinheimo, 1915).

Grönlund et al. (1992) used the spruce decline as evidence of a local forest clearance phase, and together with single pollen grains as an indication of early agriculture. Vuorela (1986) has even suggested that the decline of Picea pollen is the only indicator of early clearance for cultivation. However, it is not possible to distinguish between natural and anthropogenic fires, although fires are often visible in pollen diagrams before cereal pollen occurs. Natural fires do occur: Larjavaara et al. (2005) show that lightning can cause a fire in the Boreal forest.

A connection between spruce and cultivation is not accepted by all. Rowley-Conwy (1983) argued that a spruce decline can be explained without connection to human activity. His main point is that ‘fire is a natural component of spruce forest ecology’ (Rowley-Conwy, 1983: 206), and the so-called cultural indicators originate naturally in the area. A study from northern Sweden supports the idea that fire is an important element in spruce-dominated forest (Hörnberg et al., 2012). Similar results between spruce and fire connections are seen in boreal forests in Canada (Black & Bliss, 1980). Spruce did not spread in close proximity to swamps where fires were absent even if it was present in the area (Segerström et al., 2008).

In Finland, Mökkönen (2010) pointed out that the introduction of spruce does not correlate with the spread of the CW culture. If this culture did practice cultivation, as Mökkönen (2010) assumes, the appearance of spruce therefore cannot be explained by cultivation. Fire-interval studies have been made in the context of early cultivation studies. Huttunen (1980) reconstructed fire intervals in southern Finland. There were several changes in frequency. From AD 470 to 1100 mean frequency was 95 years; from then until AD 1600 the mean interval was 57 years; and between AD 1600 and 1900 it was 30 years. A continuous cereal pollen curve started around AD 1500. Similar results can be seen in eastern Finland, where the fire interval between the seventeenth and nineteenth centuries was around 30–40 years after the start of cultivation, and 100–200 years before that (Lehtonen, 1998; Pitkänen & Huttunen, 1999). In eastern Finland, a study of charcoal particles showed intervals of 320–520 years without a clear spruce connection. However, sampling did not reach to the modern surface, so this evidently reflects the natural fire frequency in boreal forest, not one caused by agriculture (Pitkänen et al., 2003a). Another study supports this: in eastern Finland, intervals are approximately 170–240 years until AD 1500, and, after that, approximately 50 years (Pitkänen et al., 2003b). More recent studies suggest longer intervals.

In northern Swedish Lappland, fire intervals fluctuated between shorter (approximately 200–300 years) and longer (approximately 500 years) periods. This in fact correlates better with climatic fluctuations than archaeological data (Caseldine et al., 2008). It is doubtful whether agriculture played any important role at all in such northern areas. In sum, it seems that fire intervals might have decreased after cereal cultivation started. Cultivation would also explain why there are differences between regions. In northern Finland, where cultivation was not possible, slash-and-burn cultivation was never practised and fire frequency stayed low. In southern and central Finland, the evidence suggests the opposite to what has previously been argued.

There is no evidence that slash-and-burn cultivation was practised in the early stages of cultivation. Furthermore, it was probably never important in the western part of the country. Thus, the spread of agriculture into eastern Finland might have been affected by the late innovation of fast-cycle slash-and-burn cultivation. However, more studies are needed from the western part of the country.

What do the pollen diagrams tell us?

On the basis of the arguments put forward in the previous section, it is questionable whether pollen provides any evidence concerning the beginning of cultivation in Finland. It might be a more recent innovation in Finland than has been previously suggested. Pollen studies that have been suggested to support the presence of early cultivation before the Iron Age are discussed here.

Stone Age cultivation before 1500 cal BC

The only evidence for this period is in the form of single pollen grains found at various sites around Finland. Seventeen examples are mentioned by Vuorela and Hicks (1996) and Mökkönen (2010). These are listed in Table 3, and plotted in Figure 6 (top).

As we have discussed, method of identification is important. The studies of the sites of Lamminjärvi, Lalaxkärret, and Humppila, Vasikkasuo and Karvalammi do not publish the criteria used for cereal pollen recognition (Tolonen, 1980a, 1980b; Aalto et al., 1985; Vuorela, 1990). At Könttärinlahti, a size criterion of 42 μm is mentioned and at Vasikkasuo, 41 μm is used, but at Könttärinlahti, the pollen is said to be Hordeum-type (Vuorela & Kankainen, 1991; Vuorela, 1994). In Northern Ostrobothnia, size (greater than 45 μm) and pore size (greater than 8 μm) were used to identify cereal-type pollen (Reynald & Hjelmroos, 1980). At Kankareenjärvi and Preittilänsuo, Beug's (1961) criteria were used. However, Kankaanjärvi was dated using bulk sediment dating, and it has already been mentioned that such dates are probably too old. Two cereal-type pollen grains (type is not mentioned) were found in different layers at Preittilänsuo (Tolonen, 1987); these could just as well be large wild grasses. At Katajajärvi, modern methods of morphology and size are used, and one Hordeum-type pollen grain was found in the Stone Age layers (Alenius et al., 2009). A similar situation is seen at Kemiö where one Hordeum-type pollen grain and one Secale-type pollen grain occur in Stone Age contexts (Alenius et al., 2008).

The most recent claim to find Hordeum-type pollen is by Alenius et al. (2013) from southern Finland. This paper published the criteria utilized. One grain of Fagopyrum esculentum (buckwheat) was dated to 6276 ± 55 BP (5369–5063 cal BC). It is possible for such large grains to travel long distances; also the possibility of modern contamination has to be considered with this single pollen grain. In a study like this, where the minimum number of pollen grains counted is 1100, it is much more likely that rare large size grass pollen grains will be recorded. Three single pollen grains of Hordeum-type connected to signs of erosion are not highly significant proof of cultivation, but may result from natural variation in wild grass pollen. This simply does not prove cultivation in the whole country.

Table 3. Sites producing claims of cereal cultivation during the Stone Age, earlier than 1500 cal BC.

Site	Classification used	Apart from single pollen, evidence of farming	Dating material and comments	Reference
1. Ahmasjärvi, Utajärvi	Grain size >45, annulus >8	Ignored	Bulk sediment, site unsuitable for such studies	Reynald & Hjelmroos (1980)
2. Jalasjärvi, Raahe	Grain size >45, annulus >8	Ignored	Bulk sediment, site unsuitable for such studies	Reynald & Hjelmroos (1980)
3. Sotkasuo, Utajärvi	Grain size >45, annulus >8	Ignored	Bulk sediment, site unsuitable for such studies	Reynald & Hjelmroos (1980)
4. Nimisjärvi, Vaala	Grain size >45, annulus >8	Ignored	Bulk sediment, site unsuitable for such studies	Reynald & Hjelmroos (1980)
5. Piplajärvi, Ylikiiminki	Grain size >45, annulus >8	Ignored	Bulk sediment, site unsuitable for such studies	Reynald & Hjelmroos (1980)
6. Iso-Mustajärvi, Tornio	Grain size >45, annulus >8	Ignored	Bulk sediment, site unsuitable for such studies	Reynald & Hjelmroos (1980)
7. Vasikkasuo, Puolanka	Not published	Modern period (100 ± 65)	Peat	Vuorela & Kankainen (1991)
8. Karvalampi, Pihtipudas	Not published	710 ± 50 BP, AD 1200–1400	Bulk sediment	Vuorela (1997)
9. Pieni-Summanen, Saarijärvi	Not published	1460 ± 100	Dating material is not mentioned	Vuorela (1995)
10. Lamminjärvi, Lammi	Not published	500 AD	Relative dating	Tolonen (1980a)
11. Katajajärvi Valkeala	Erdtman et al. (1961), Faegri & Iversen (1989), Moore et al. (1991), Reille (1992, 1995)	2780 (interpolated estimation) cal BP	Dating material is not published	Alenius et al. (2009)
12. Könttärinlahti, Keuruu	Not fully published, Grain size >42µm	1180 ± 110 BP	Dating material is not published	Vuorela (1994)
13. Järvensuo, Humppila	Not published	Only single pollen evidence, analysis did not reached surface	Dating material is not published	Aalto, Siiriäinen & Vuorela (1985)

14. Labbölenträsket, Kemiönsaari	Faegri & Iversen (1989), Moore et al. (1991), Reille (1992, 1995)	775 - 900 cal AD	Dating material is not published	Alenius (2008)
15. Laxkärret, Nauvo	Not published	No data	Dating material is not published, bulk sediment (?)	Vuorela (1990)
16. Kankareenjärvi, Salo	Beug (1961)	3530 ± 140 BP	Dating from bulk sediment, clearly too old	Tolonen (1987)
17. Preittilänsuo, Paimio	Beug (1961)	570 ± 100 BP	Dating from bulk sediment	Tolonen (1987)

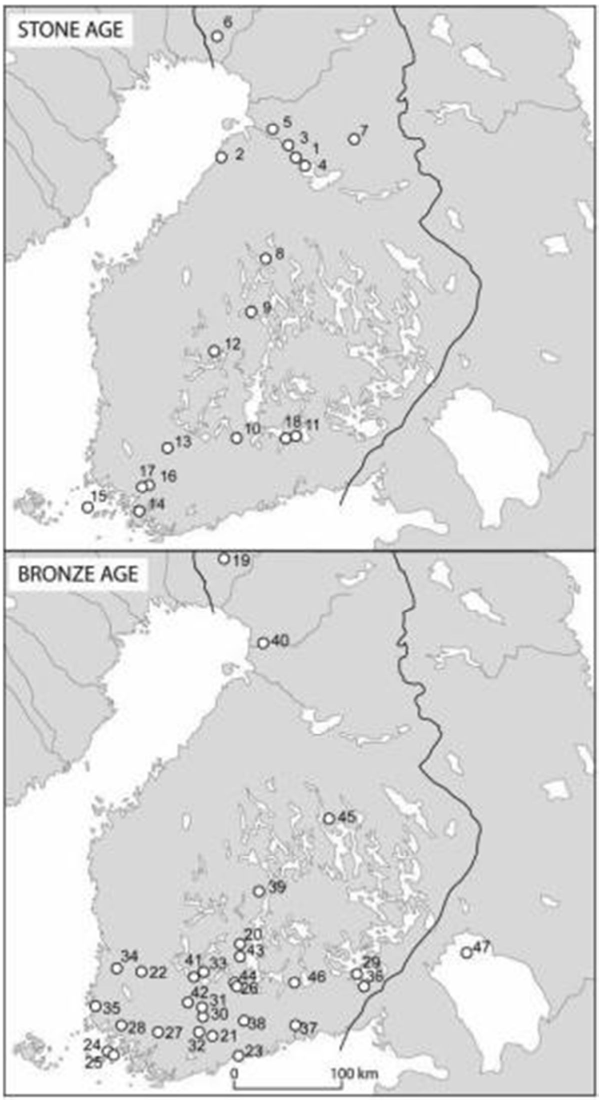

Figure 6. Maps showing distribution of pollen sites with cereal-type grains. Top: Stone Age, sites numbered as in Table 3; bottom: Bronze Age, sites numbered as in Table 4.

The only continuous pollen curve claimed from the Stone Age is from Lake Kankareenjärvi in south-western Finland, dated to 3530 BP. However, the author of the study has stated that compared to other studies in the region, the date is likely too old. Dating was done on bulk sediments, which are probably contaminated by old carbon. Furthermore, the site is coastal, and thus some large cereal-type pollen from wild grasses growing in these habitats should be expected.

Reynald and Hjelmroos (1980) studied six sites in the northern Ostrobothnia region. Every one of the sites shows evidence of cereal-type pollen. This has been used without any criticism as clear evidence of farming. However, most of the sites were coastal, and have scattered cereal-type evidence from the time the rising land caused the isolation of the lake. The large-grained wild species Elymus arenaria and Agropyron canina are common species in the area (Reynald & Hjelmroos, 1976), so any evidence should be treated very cautiously. Levels of cereal pollen were low and sporadic in every diagram, and no change from a natural to a farmed landscape can be seen. Radiocarbon dating in the area is problematic because of the recycling of old carbon. In the absence of any other source of evidence, it cannot be determined when cultivation first occurred. Historical sources suggest that it could be as recent as the medieval era (Luukko, 1954).

Bronze Age cultivation (1500–500 cal BC)

There are several sites that have claimed evidence of Bronze Age cultivation. They are listed in Table 4 and plotted in Figure 6[3].

There are only four sites with more than single pollen grains. They are Aholanlammi (Koivula et al., 1994), Loimaansuo (Vuorela, 1975), Antinlampi (Vuorela et al., 1993), and Kissalammi (Tolonen, 1981). At Loimaansuo and Antinlampi, the identification criteria were not published. One single Hordeum-type pollen grain from Antinlampi is stated to be as large as 60 µm. According to Faegri et al. (1989) this should apparently be classified as Elymus-type, although, since other criteria are not mentioned, this is not completely certain. Because of this, it is not possible to consider the pollen grains from these sites as reliable evidence.

At Aholammi, evidence is put forward for Bronze Age cultivation. A continuous cereal-type pollen curve starts after 3460 ± 90 BP (Koivula et al., 1994), or 2019–1531 cal BC. The radiocarbon dates have, however, been done on bulk organic material, which includes all organic material found in the

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[3] All dates are calibrated, and the original radiocarbon date is mentioned in parentheses. If the original paper published the calibration, only that is mentioned.

sediment; therefore, the date should be considered only very cautiously. The dating of the layer is the latest date in the core, so it is not known how accurate it is (see earlier discussion). The sample for radiocarbon dating was a 10-cm slice, which itself will cause great error limits (Koivula et al., 1994). At Kissalammi, Cerealia-type pollen appears as early as 3940 ± 110 BP (2864–2135 cal BC) but there are never more than one or two pollen grains (Figure 7). These pollen grains appear in the pollen diagram as Cerealia-type, but in the published text it is stated that ‘in the last part of QM-3060 ± 120 BP [1608–979 cal BC] Cerealia pollen grains, viz. Hordeum and Triticum types was connected with cultivation in the vicinity of the site’ (Tolonen, 1981: 217). It is not evident how many pollen grains from each genus were determined, or whether some grains were just of cereal type. The total amount of cereal-type pollen increases from 500 BC onward. The study was carried out by counting 1500 arboreal pollen grains per sample (Tolonen, 1981); this large total increases the likelihood that wild large-pollen species or long-distance transportation grains will be found. There is also one cereal-type pollen grain before the Bronze Age, so it is likely that some large-grain wild species grew near the site.

In northern Finland, only a limited number of studies have been done. Small amounts of cereal-type pollen are found at almost every site. Tikkanen (1978) states that coastal vegetation can clearly be seen in the diagrams and this will include wild grasses with large pollen grains. Thus, it is not possible to say whether the cereal-type pollen really comes from cultivated cereals. As already mentioned, cultural indicators are common in such an environment. As discussed in the Stone Age section, there is similar evidence in the study by Reynald and Hjelmroos (1976) from several sites in the northern Ostrobothnia region, so this evidence is not conclusive. However, it has been used to support the hypothesis that cultivation started in northern Finland soon after it began in the southern part of the country (Vuorela & Hicks, 1996; Mökkönen, 2010) However, the occurrences of cereal-type pollen are small and scattered. For example, cereal-type pollen is seen at Merijärvi from the basal section of the core, which dates to before the isolation of the lake. This can be viewed as evidence of the marine shore environment rather than cultivation. There is nothing other than pollen to suggest cultivation: the archaeological record suggests that cultivation started in the Medieval period (Huurre, 1983).

Table 4. Sites producing claims of cereal cultivation during the Bronze Age, 1500–500 cal BC

Site	Definition used for Cereal pollen	Apart from single pollen, evidence of farming	Dating material and comments	Reference
18. Lohijärvi, Ylitornio	Grain size > 40 µm	ignored	It is not possible to trace beginning from such site. See discussion.	Tikkanen (1978)
19. Aholammi, Jämsä	Grain size >37, annulus >8 µm, Anderssen 1978	3720 ± 220 cal BP (3460 ± 90BP)	Dating from bulk sediment. See below	Koivula, Raatikainen, Kananen & Vasari (1994)
20. Katinhännäsuo, Vihti	Not published	1580 ± 280 cal BP (1650 ± 140BP)	Dating from bulk sediment	Vuorela (1975a)
21. Loimaansuo, Huittinen	Not published	3670 ± 300 cal BP (3400 ± 130 BP)	Dating from bulk sediment	Vuorela (1975a)
22. Morträskt, Sipoo	Grain size >40µm , annulus >8 µm, Beug 1961, Andersen 1979	Between 2000 - 1000 BP (based on estimation)	Dating from bulk sediment was too old and thus estimation is done by comparing to other studies	Sarmaja-Korjonen (1992)
23. Isoskärret, Kemiö	Not published	2480 ± 190 cal BP	Dating from bulk sediment.	Aspelund & Vuorela (1989)
24. Mossdalen, Kemi	Not published	500 cal BP (based on estimation)	Dating from bulk sediment.	Aspelund & Vuorela (1989)
25. Ahvenainen, Koski	>42, Beaug 1961, Faegri & Ivarsen 1975, Rowley 1960, Andersen & Bertelsen 1972	(2400BP)	No dating	Tolonen (1978b)
26. Ketohaka, Salo	>42, Beaug 1961, Faegri & Ivarsen 1975, Rowley 1960, Andersen & Bertelsen 1972	2680 ± 360 cal BP (2320 ± 120 BP)	Dating from bulk sediment	Tolonen (1985)
27. Niuskala, Turku	Not published	No results before 30 cm	Sampling from modern field sediment	Vuorela & Lempiäinen (1988)
28. Syrjälänsuo, Taipalsaari	Not published	1500 ± 100 cal BP (1605 ± 40 BP)	Radiocarbon from moss	Vuorela & Kankainen (1993)
29. Hirvilammi, Loppi	Not published	Only sporadic traces (1-2) cereal pollens	Dating from bulk sediment. Results from 5cm (960 ± 100 BP) is clearly too old.	Rankama & Vuorela (1988), Vuorela (1993)
30. Kaartinlammensuo, Loppi	Not published	830 ± 150 cal BP (900 ± 90 BP)	Dating material is not mentioned.	Vuorela (1993)
31. Ryönänsuo, Vihti	Not published	120 ± 100 BP, modern	Dating material is not mentioned.	Vuorela (1993)
32. Kissalammi,	Beug 1961, Faegri &	2450 BP	Varve dating	Tolonen (1981)

Pälkäne	Ivarsen 1975, Rowley 1960, Andersen & Bertelsen 1972			
33. Siikasuo, Harjavalta	Not published	No dating from the beginning	Dating from peat	Vuorela (1991)
34. Kirkkojärvi, Vehmaa	Not published	1040 ± 260 cal BP (1140 ±140 BP)	Dating from bulk sediment	Vuorela (1975a)
35. Konnunsuo, Joutseno	Beug's (1964) criteria, only cerealia type was recognized	<620 ± 95, modern	Dating from bulk sediment	Tolonen & Ruuhijärvi (1976)
36. Haukkasuo, Valkeala	Beug's (1964) criteria, only cerealia type was recognized	1550 ± 240 cal BP (1670 ±140 BP)	Dating from bulk sediment	Tolonen & Ruuhijärvi (1976)
37. Työtjärvi, Hollola	Not published	2430 ± 280 cal BP (2350 ± 100 BP)	Dating from bulk sediment	Donner,Alhonen,Eronen,Jungner & Vuorela (1978)
38. Antinlampi, Laukaa	Not published	One separate stage 2890 ± 100 cal BP (2790 ± 40 BP), but more continuous 830 ± 90 cal BP (900 ± 40 BP) onward	Dating from bulk sediment	Vuorela,Uutela,Saarnisto,Ilmasti & Kankainen (1993)
39. Merijärvi, Ii	Grain size >45, annulua >8 µm	ignored	It is not possible to trace beginning from such site. See discussion.	Reynald & Hjelmroos (1976)
40. Kantala, Sääksmäki	Beug 1961, Faegri & Ivarsen 1975, Rowley 1960, Andersen & Bertelsen 1972	Estimation 1000BP	Dating is based on radiocarbon and sedimentation rate	Tolonen (1978a)
41. Kuivajärvi, Tammela	Not published	2690 ± 150 cal BP (2620±45 BP)	Dating from bulk sediment	Vuorela & Kankainen (1992)
42. Linnajärvi, Kuhmoinen	Beug 1961, Faegri & Ivarsen 1975, Rowley 1960, Andersen & Bertelsen 1972	<2650±120 BP (interpolation 2000 - 2200 BP)	Dating from bulk sediment and interpolation, Tolonen (1990) mentioned that it's likely to be 600 years too old	Tolonen (1990)
43. Lovojärvi, Lammi	Beug's (1964) criteria, only cerealia type was recognized	2710 ± 500 cal BP (2620±180 BP) and 2560 ± 438 cal BP (2500±180 BP)	Dating from bulk sediment, Huttunen & Tolonen (1977) believed that dating were 800 year too old	Huttunen & Tolonen (1977)
Dalkarbyträsk, Jomala	-	No dating	ignored	Fries (1963)
44. Heinälammi, Siilinjärvi	Not published	No dating	ignored	Simola,Grönlund,Taavitsainen & Huttunen (1991)
45. Katajajärvi	Erdtman et al. (1961), Faegri & Iversen (1989), Moore et al. (1991), Reille (1992,	c. 660 (cal BC)	Dating material is not published	Alenius et al. (2009)

	1995)			
46. Igumeeninlampi	Not published	c. 800 BP, in the neighbouring sites	Dating from plant macrofossils	Vuorela,Lampiainen & Saarnisto (2001)

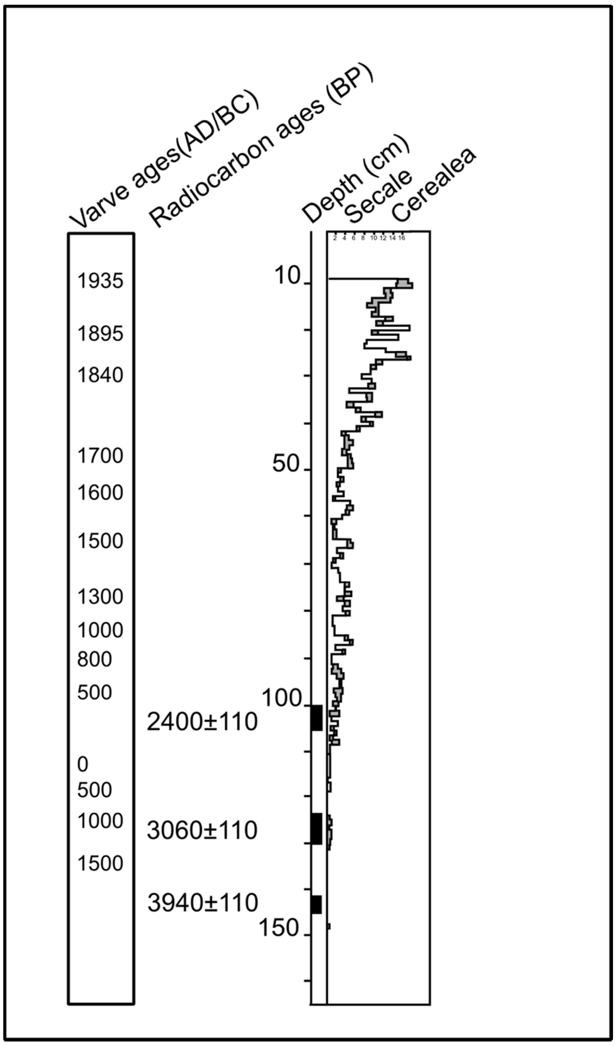

Figure 7. Pollen of cereal-type curve from Kissalammi. Redrawn with modifications from Tolonen (1981, Fig. 2)

Conclusions

Pollen analysis is a useful tool, but is not an absolute method for determining the presence of agriculture. Wild grasses can produce pollen of cereal-type, Hordeum- type, and Triticum-type. Consequently, any evidence derived from single pollen grains is always questionable. As there is not enough reliable evidence to support agriculture in Finland before the Iron Age, we conclude that more studies using different lines of evidence are required before Stone Age or Bronze Age cultivation can be proposed.

The evidence from Finland thus takes its place alongside that from most of the rest of Europe. The early pollen claims for cereal cultivation are anomalous, and increasingly out of line with all the other sources of evidence for agriculture. Finland acts as an important test-case for Europe as a whole: since prehistoric agriculture was a marginal economic activity so far north, the pollen claims focus attention on the issue across the continent. Future work by Finnish archaeologists on the date of the earliest agriculture in Finland will be of continental significance.

PAPER 2

The spread of cultivation in Finland was not a single event

This study summarises the dating results from published pollen studies that indicate the beginning of farming in Finland and the adjacent regions, and compares this to a population proxy obtained from archaeological materials and charcoal from archaeological contexts. The results indicate that the beginning of farming in Finland was a complex process with several intensification periods. Moreover, the most important expansion of cultivation occurred during the Iron Age and later periods.

Introduction

The beginning of cultivation is considered one of the most important developments in human history. Broadly speaking, it made sedentary society with hierarchical social structures possible, which allowed civilisations to grow and become more elaborate. On the other hand, it forced people to settle, have a less varied diet, work longer hours and suffer greater risks of sickness (Armelagos & Cohen, 2013; Spencer Larsen, 1995). These general rules have exceptions however: not every sedentary society was based around farming nor was every farming society (especially animal husbandry-based) sedentary. Nevertheless, it was a change that affected humans greatly in every place that it occurred.

Finland is situated at the northern agricultural periphery of Europe. Even when modern farming techniques are applied, ecological limitations prevent cultivation from being practised in many areas. In this harsh climate, cereal cultivation has never been an easy task, and catastrophic farming failures have occurred several times even throughout the 20th century (Peltonen-Sainio & Niemi, 2012). Moreover, the northern climate is not the only limiting factor for farmers, as approximately only 15 % of the land is suitable for field cultivation (Soini, 2010). Nonetheless, slash-and-burn type cultivation can be practised on unfavourable soils as it does not require work on the soils. This is one of the reasons it was the main method of cultivation in eastern Finland until the 20th century AD (Heikinheimo, 1915; Solantie, 1988).

The question of who first started farming in Finland is still under discussion. However, it is not only the question of when farming was firstly practised in Finland that is of interest, but also the particular processes involved when it spread throughout the country. This information could contribute to the more general discussion of the spread of farming in other marginal areas. In this paper, we will discuss previously suggested ideas about how farming spread throughout Finland and compare the pollen evidence with estimates of population size from the same area. This could help determine whether this was a single process or should be classified into several events. This means that while the focus of this paper is on the spread of farming it does not take into account agricultural intensification. By combining several published studies, we try to minimize the possibility of interpreting or over-emphasising any one case study, although this approach does not necessarily identify systematic errors, which will be discussed in the dating methods section.

The pollen evidence has been discussed previously in two review papers (Donner, 1984; I Vuorela & Hicks, 1996). Donner (1984) studied pollen results from southern Finland. His conclusions were: 1. that there is sporadic evidence of farming in the form of single grains of cereal pollen during the Bronze Age which could indicate cultivation, but that most signs of cultivation can be seen during the Iron Age and, 2. That the introduction of rye is visible in pollen cores pollen between AD 450 and 1000. Vuorela and Hicks (1996) estimate the spread of farming based solely upon pollen analysis. They include every single cereal-type pollen grain as evidence, and conclude that farming first started in the south-west of Finland approximately four thousand years ago and spread very quickly across the country. As already pointed out (Lahtinen & Rowley-Conwy, 2013; Simola, 1999), this synthesis is based on uncritical use of pollen studies and thus is very likely incorrect. Furthermore, this leaves out the important question of how farming spread throughout the country. This question is highly significant when discussing whether farming was introduced by immigrants, adopted by locals or through a combination of both these means (Galeta et al.,2011). It can be assumed that if there was significant immigration into the region of current day Finland, this could mean a fast introduction of farming into the most favourable areas (such as Varsinais-Suomi region) and a significant population increase.

The pollen studies are compared with an estimate of population size, which can be indicative of farming, because in most areas farming causes a significant increase in productivity which in turn causes population density to increase. In Europe and North America, this increase in population size has been studied using radiocarbon dates. In Britain, France and Denmark population size increased rapidly after the arrival of farming (Collard et al. 2010; Shennan et al., 2013). Collard et al. (2010)

also showed that the earliest cereal macrofossil dates correspond with an increase in the number of radiocarbon dates on other materials which are used as a proxy for population size in their study. This paper focuses on the pollen evidence from Finland as a proxy for early farming and compares this to estimates of population size based on radiocarbon dates covering most of Finland (Oinonen et al.,2010).

Spread of farming during the Prehistoric period

Recent discussions of the beginning of farming in Finland have argued for dates anywhere between 5000 BC to the final millennium BC (Alenius et al., 2013; Alenius, 2011; Bläuer et al., 2013; Lahtinen & Rowley-Conwy, 2013; Mökkönen, 2009). A long-lived debate in early farming studies in Finland has been about whether single cereal-type pollen grains are indicative of farming or not. Alenius et al. (2013) and Mökkönen (2009) based their arguments on Vuorela's (1970) finding, that barley does not produce a large quantity of pollen, so that in conjunction with cultural indicators, each grain of cereal type pollen can be used as a sign of human presence. Alenius et al. (2013) also report the discovery of a single pollen grain of buckwheat (*Fagopyrum esculentum*) dated to the 6th millennium BC, which they conclude to be evidence of the possibility that agriculture spread from east Asia, rather than the Fertile Crescent, to Finland. The emphasis of single pollen evidence was critiqued by Lahtinen & Rowley-Conwy (2013), by considering a common problem in pollen studies: “cereal-type” pollen comprises a group of various grains including those of both wild and cultivated grasses. This means that natural fires and marginal scale farming can produce similar pollen data and that the possibility of contamination requires consideration (Behre, 2006; Beug, 2004; Hornberg et al., 2014; Joly et al., 2007; Lahtinen & Rowley-Conwy, 2013). Consequently, each pollen study should be interpreted with caution. For example, *Hordeum* type pollen has been recorded from Lehmilampi (first in zones 3a, 3b and 3c, then not in hiatus zones 3d and 3e, and again in top most zone 4). This has been used to claim that cultivation was practiced (Augustsson et al., 2013). This claim is advanced regardless of the fact that in Augustsson et al.’s cluster analyse the last pollen zone with *Hordeum* type pollen (3c) and the overlying zone without it (3d), show closer similarities with each other than is found among zones beneath it where cultivation is considered to have been practised (i.e. zones 3a, b, c). Zone 3d was considered to reveal a period when cultivation was not practised or when there was 'little or no human disturbance', whereas zone 3c exhibited cultivation activities around the study site (Augustsson et al., 2013: 1254). This seems illogical and these similarities are not explained in their paper. This illustrates how difficult it is to interpret pollen data from a single core.

Apart from pollen analysis, the first indirect evidence for farming has been discovered through lipid residue analysis from Corded Ware (CW, 2800 – 2300 BC) pottery that identified traces of milk (Cramp et al., 2014). Analyses were done at several sites, but only one sample contained milk traces. It is not known whether these ceramics were locally manufactured. The analysis suggests that animal herding may have been practised along the south western coast of Finland during the CW period. Importantly, there are no traces of milk residue from the subsequent Kiukainen culture (2350 – 1500 BE), which suggests that this practise disappeared or that aquatic resource exploitation was re-established (Cramp et al., 2014). The CW culture occupied only the coastal areas, and the most fertile areas in the country, during the warmest period in the Holocene (Carpelan, 1999; Heikkilä & Seppä, 2003). It is possible that similar subsistence practices have since become impossible due to limitations imposed by climate.

Direct information of animal husbandry from the earliest stages of farming is scarce. Finnish osteological material is challenging as preserved bones are mostly burnt, fragmented or visible only as residual shadows in the soil. However, domestic animal bones can easily be distinguished from those of wild animals, because aurochs never lived in Finland and wild boar made only occasional visits. Cattle and pig bones can therefore be presumed to come from domestic animals. Only four individual bones of domesticates have been radiocarbon dated to before the Iron Age: one sheep/goat, two cows and a horse (Bläuer & Kantanen, 2013; Bläuer et al., 2013). If these dates are correct and these animals were herded locally, it remains possible that cereal cultivation and animal husbandry were adopted separately. Mannermaa and Deckwirth (2010) argue that even if small scale farming was practised, contemporary sites indicate farming and hunter-gathering taking place separately in the same areas during the early metal period (1500 BC - 500 AD). This is seen in both Varsinais-Suomi and Ostrobothnia, which are currently areas with the oldest published and dated cereal macrofossils (Holmblad, 2010). Mannermaa and Deckwirth (2010) summarise that from the available osteological evidence, not everyone practiced a farming-based subsistence economy even during the Iron Age in Finland.

Direct evidence of cereal cultivation in the form of macrofossils has not been collected systematically, and no evidence of cereals dated before the last millennium BC has been well published (see Lahtinen & Rowley-Conwy, 2013). This is not the only problematic area in studying Medieval and Iron Age farming, as there is a lack of evidence for farming related activities recorded from settlements from both periods (Mikkola, 2009). Most excavated sites are cemeteries, single objects or hoard finds (Mikkola, 2009). This makes it very difficult to estimate migrations or the establishment of new settlements or small scale variations. Unfortunately archaeological material is very limited and even recent historical periods (13th century AD onwards) are not represented in the archaeological record in many parts of the country.

Most recently, Josefsson et al. (2014) studied the spread of farming in northernmost Fennoscandia. Their conclusion was that farming started in the coastal region and then spread to the hinterland. Unfortunately their argument is undermined by the two studies they based their work on, one by Reynaud & Hjelmroos (1980) and the other by Augustsson et al. (2013). Problems in the first study have already been addressed in Lahtinen and Rowley-Conwy (2013), as they have used the criterion of a size of 45 μm to identify cereal-type pollen. However, this is in fact more likely to be from a wild grass than a cereal. It is possible that cultivation was practised in Nurmes (Lehmilampi), as Augustsson et al. (2013) stated, from 1800 BC onward, if the date is correct. Nonetheless, the site is in an area which has never been favourable for cultivation, and where people have had to supplement cereals with pine bark even into the 20th century (Koistinen, 1912). This leads to the question: why would someone start to cultivate in areas that are remote and marginal, rather than in the most suitable region (south Finland)? The other explanation is that early farming was present on a very small scale allover Finland, as Herva et al. (2014) recently suggested. In our opinion, this seems an even less likely scenario. Farming practices, like any other technological innovation, require continuity. Farmers need to harvest crops every year, and they would risk losing the knowledge involved in cultivation and cereal varieties adapted to their marginal environment. This information is vital for a successful harvest in rural areas of eastern and northern Finland where farming could be neither simplistic nor random. For example, slash-and-burn farming, which was the main type of cultivation until the 20th century in east Finland (Heikinheimo, 1915; Soininen, 1974), included several years of pre-planning, involving management of the forest, and in some forest types, several years of burning activities prior to the actual cultivation process (Soininen, 1974).

The spread of farming in the Medieval period and after

It has been suggested that farming did not spread into many areas of Finland until as late as the Medieval period (in Finland, the 13th to 16th century AD) or even the Early Modern period (Orrman, 2003; Orrman, 1991; Taavitsainen et al., 1998; Zvelebil, 2010). However, this assumption is based on very limited historical material. It is mainly based on letters from peasants complaining to the authorities that new settlers have occupied their land without approval (Soininen, 1957). This suggestion comes from sources that lack citations and would no longer meet academic standards.

It has been suggested that the interior and northern parts of Finland were populated by farmers much later than the southern part of the country. Part of this was the migration of Swedish farmers to the coastal areas of southern Finland in the 13th or 14th centuries AD, a similar migration of Swedish farmers to Ostrobothnia in the 14th century, and the population movement into inner and northern Finland in the 15th century. These migrations have been considered as having continued during the early modern period in the form of the migration of the Forest Finns into the northern Swedish interior and to the New World (Solantie 1988; Orman 1991; Wallerstöm 1995; Taavitsainen et al. 1998).

Korpela (2012) strongly objects to the theory of migration into Eastern Finland during the late Medieval period, claiming that the idea is based solely on historical documents that are very likely biased. Korpela (2012) argues that farmers become visible in remote areas only when the Swedish or Novgorod realm and church was established and began keeping records. Thus this assumed migration into new areas might reflect the establishment of centralized authority and record keeping, not actually a new occupation.

Immigration into new areas has been explained through the exploitation of uninhabited land for hunting and fishing, which eventually led to their occupation (Enbuske, 2006; Keränen, 1984; Luukko, 1959; Soininen, 1957). The utilization of these unsettled areas has been explained by the existence of the “erämaa” (English: wilderness) culture. Under this model, people travelled from their permanent settlements up to hundreds of kilometres for hunting, fishing and small-scale slash-and-burn cultivation. The wilderness was utilized during the summer, whereas winters were spent in permanent houses to which people returned with their harvest (Luukko, 1959; Taavitsainen et al., 2007; Taavitsainen, 1987; J. Taavitsainen, 2004; Taavitsainen et al., 1998). Korpela (2012) argues strongly against the existence of this tradition. He states that there is no motive for returning to more permanent sites during winter: “There were no legal, social, religious or other coercive structures that made them do so”, and there is no actual large-scale evidence (Korpela, 2012: 242). He suggests that it is very likely that the inner part of Finland was not empty, nor was wilderness used in the way that Taavitsainen (1987, et al. 1998, 2004, et al. 2007) have suggested Permanent occupation could have reached remote areas, but due to the lack of a central administrative system there are no records of this. He further suggests that pollen analysis has shown evidence of cultivation in these areas during the periods of the claimed migrations. Thus this model remains hypothetical.

Dating of pollen analysis

Establishing chronological timelines for events through high resolution dating methods is a major objective in all fields of archaeology and palaeobotany. It is particularly important when case studies are compared with one another. Only then is it possible to determine if different events are simultaneous and thus connected to each other. In pollen studies, the most common methods used are radiocarbon, varve or paleomagnetic dating. However, there is always a degree of uncertainty in the results, which cannot be precisely calculated. Therefore it is not always possible to estimate dates accurately. This means that dating results should always be critically examined, and discussed in light of potential variability due to differences in materials and methods.

Varve dating is based on the calculation of annual laminated sediment layers deposited in lakes. This can be studied only in very specific sedimentation environments where lamination is not disturbed during the formation of each varve. Typical environments are small lakes that are topographically closed or sheltered. Varve dating is the most precise dating method available for pollen cores, and since there is little disturbance in such an environment the pollen profiles are also often more reliable. However, this method can be problematic due to missing varves, issues with identification, and underestimation of sediment disturbance (Ojala et al., 2012).

Radiocarbon dating from bulk sediment has been long known to result in dates that are too old or too recent in sediment age-depth models. In Finland, the difference between varve and bulk sediment radiocarbon dates has been as much as 1500 years (Alenius, Saarnisto, Taavitsainen, & Lunkka, 2011; K. Tolonen, 1980; M. Tolonen, 1978c, 1981). Improvements in calibration have narrowed this difference in some studies (see table 1), which suggests that the offset might be smaller than was estimated. Finnish bedrock is not rich in carbonates, so this difference is not due to the effect of hard water, but is more likely due to the recycling of old organic carbon in the lake catchment area. Similar effects have been recorded in Sweden (Stanton et al. 2010; Zillén et al. 2003)

Table 1. Calibration of late 1970's radiocarbon samples was redone with Oxcal version 4.2 with calibration curve IntCal13 (Reimer et al., 2013; Stuiver et al., 2013). Table shows the difference between calibrated probability distribution and varve ages in Lake Ahvenainen (M. Tolonen, 1978a, b) and Lake Lampelonjärvi (K. Tolonen, 1980). Ages are in BC (-)/AD (+).

Site	Sample number	Radiocarbon age	Calibration lower range	Upper range	varve age	Difference
Ahvenainen	Su-690	800 (±100)	1023	1390	1473	83
	Su-691	970 (±100)	780	1267	1168	0
	Su-692	1450 (±100)	356	768	833	65
	Su-693	2010 (±100)	-354	230	546	316
	Su-722	2080 (±100)	-375	117	37	0
	Su-723	2300 (±100)	-757	-115	-304	0
	Su-724	2770 (±100)	-1213	-791	-915	0
	Su-695	3440 (±100)	-2017	-1508	-1464	-44
	Su-698	3290 (±100)	-1878	-1318	-1634	0
	Su-696	3550 (±100)	-2194	-1637	-2106	0
	Su-701	4040 (±100)	-2881	-2306	-2987	-106
	Su-702	4450 (±100)	-3484	-2896	-3630	-146
	Su-700	4820 (±100)	-3894	-3366	-4200	-306
Lampelonjärvi	Su-581	1450 (±50)	435	666	1557 to 1472	806
	Su-582	1840 (±130)	-165	530	1185 to 1153	623
	Su-583	2310 (±90)	-755	-170	1098 to 1043	1213
	Su-576	1830 (±130)	-158	534	604 to 556	22
	Su-577	2100 (±150)	-511	242	385 to 344	102
	Su-578	2330 (±70)	-750	-202	215 to 144	346
	Su-579	3580 (±150)	-2429	-1534	-1960 to -1800	0

Radiocarbon dating from peat samples has been shown to be more reliable because the organic material has grown in-situ and, unlike in lakes, there is less significant carbon recycling (Goslar et al., 2005). Studies show that pure sphagnum (peat moss) samples are very suitable for carbon dating and one study even suggests that there is no reservoir effect when only sphagnum leaves are used in dating samples (Blaauw et al., 2004). However, depending on which carbon fraction of the sample is used for dating, the results can vary significantly, by up to a thousand years (Brock et al. 2011; Shore et al., 1995).

Paleomagnetic dating is based on measuring the paleomagnetic secular variation (PSV) observed from several different proxies (Holcomb, 1986; Lund, 1996). This variation is seen in the sediment's magnetic orientation (natural remnant magnetisation), and when compared to known changes in Earth's magnetic field, it can be used for dating sediment layers (Creer, 1982; Mackereth, 1971). In other words, it is a relative tool that is calibrated with other dating methods, like varves or radiocarbon from other environments in close proximity. The advantage of this method is that it can be used to date lake sediments which would otherwise provide misleading radiocarbon dates due to carbon recycling, because it is not dependent on dating in a single sedimentation environment (Mackereth, 1971). Several studies suggest that it is highly accurate (error 50-100 years) in lakes in Finland (Haltia-Hovi et al. 2010; Kotilainen et al. 2000).

In summary, each dating method has particular issues and different levels of uncertainty that are not always possible to estimate. Because of these uncertainties, pollen events should be considered only as estimates, and it is important to understand that accuracy to within less than 100 years is simply impossible with the margin of error likely to be significantly greater.

Materials and methods

The data covers published and unpublished institutional reports of pollen studies conducted in Finland and surrounding areas. The total number of studies used in this study is 112. Unfortunately this does not cover the total area of Finland, but it is the best current approximation for the spread of farming. Data is presented in Appendix 1.

In each study, the beginning of a continuous cereal-type pollen curve was observed. The date of this layer was recorded in the database. In several pollen records cereal-type pollen shows a hiatus. In this instance, both radiocarbon dates were included. Dates were calibrated with Oxcal (version 4.2) using calibration curve Intercal 13 and summarized in a single graph (Ramsey, 2013). Calibration was performed even if a calibrated date was already published, in order to make the calibration distribution more comparable and accurate, especially in the case of older studies. Dates were then divided according to the dating method used and summarized. Summaries of the calibrated dates are presented in figure 1.

Detailed information regarding the summarised radiocarbon dates and interpolation parameters can be found in the online supplementary material. In summary, sites were excluded if: 1. the data needed extrapolation, 2. if the error margins could not be estimated, 3. the dating was considered considerably too old and erroneous. None of the sites were excluded on the basis that the event itself did not fit in with the wider picture of the beginning of the cultivation in Finland.

Results

The frequencies of the data are presented in figure 1. Summarised calibrated dates are presented in figure 1 together with breakdowns of different dating methods. Visual observation of the summary and the bulk sediment curves shows three different phases of intensification in the radiocarbon dates. The first increase is during the second millennium BC, during the Kiukainen culture, but notably it is absent in the peat dating results. The second can be seen in the first millennium BC, during the late Bronze Age, and the third in the middle of the first millennium AD during the Iron Age. In the varve and peat dating results, two different increases can be perceived during the Iron Age. Overall, in most studies the date of the beginning of farming is situated in between the first millennium AD and 16th century AD. Visually, the population size estimation correlates with the increase in the quantity of probability of radiocarbon of pollen studies that have recorded the beginning of continuous cereal-type pollen. The mean value of the calibrated dates is AD 450, and the standard deviation (1 σ) is 730 years.

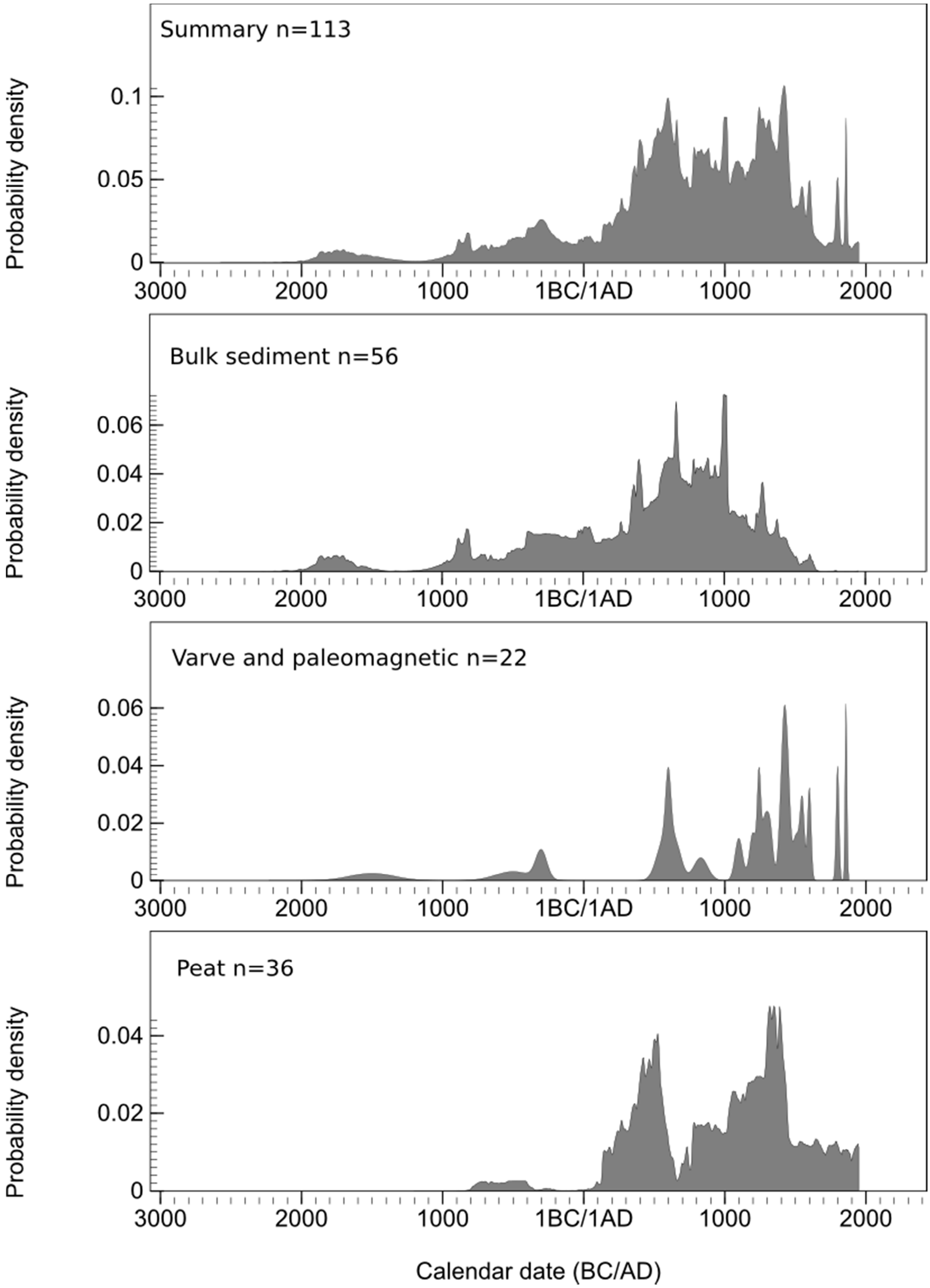

Figure 1. Summary of the calibrated radiocarbon probability distribution of all samples and breakdowns from radiocarbon dated of bulk sediment and peat, and paleomagnetic and varve dates.

As already mentioned, the accuracy of each dating method varies. The summary curves of the different dating methods were compared to summaries of the varve and paleomagnetic data. Bulk sediment radiocarbon results were shifted 0, 100, 200, 300, 350, 400, 500, 600 and 700 years younger. The best correlation between radiocarbon dates from bulk sediment and varves was reached when bulk sediment dates were shifted 600 years younger (R=0.64). The same test was carried out between peat radiocarbon dates and varve and paleomagnetic dates. In this case the best correlation was when peat dates were shifted 100 years younger (R=0.74). A new summary curve was made with peat radiocarbon results shifted 100 years and bulk sediment radiocarbon results shifted 600 years (see figure 3).

Discussion

Quantity of radiocarbon dates can be used a proxy for population size. The method might be robust, but it can allow estimated reconstruction of changes in population sizes (Timpson et al., 2014). The population increase was assessed by recording radiocarbon dates obtained from Finnish archaeological finds and charcoal (Oinonen et al., 2010). This method has been criticised, because of the underlying assumption that population size and productivity of consumables correlate (Contreras & Meadows, 2014). This assumption can be problematic when comparing mobile and sedentary groups or the transition from one into another. However, regardless of whether the change in cumulative quantity of radiocarbon dates is caused by population increase (i.e. increase in productivity) or because of a cultural change manifested with greater archaeological visibility, comparison of these events correlates with an increase in site recorded pollen. This most likely indicates a cultural change caused by the same factors. These population size estimates are based on radiocarbon dates from archaeological materials and are thus independent of the pollen analysis or radiocarbon dates obtained from the pollen cores.

As mentioned, farming is not the only possible explanation for an increase in population size. However, farming can be one of the causes, because it can increase the quantity of food extracted from an area. As seen in the graphs, there is a first large peak in the quantity of radiocarbon dates around 4000 BC, but none of the pollen studies support an increase in cultivation at this time. Therefore this peak cannot be explained by the introduction of farming practices. This population increase coincides with several proxies indicating rapid climatic warming: it has been suggested that this led to a natural increase in productivity leading to a higher carrying capacity of the landscape for hunter-gatherer populations (Tallavaara & Seppä, 2011).

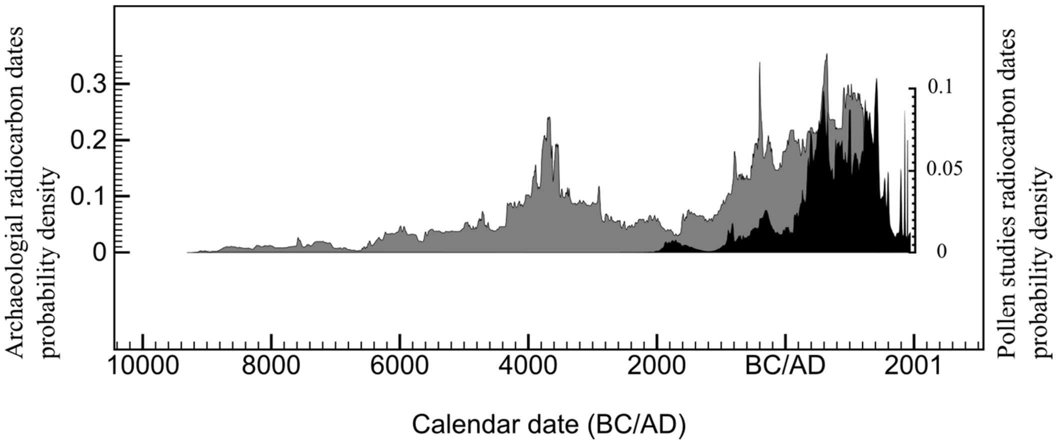

Figure 2. Temporal variation of relative population size (based on Tallavaara & Seppä, 2011) and the summary of the calibrated radiocarbon dates of this study.

During the last two peaks pollen studies correspond surprisingly well with estimates of the prehistoric population size (as seen in figure 2 and 3). These two proxies are completely independent from each other (although the reason for this evidence is most likely the same), which suggests that the pollen studies are likely to reflect actual events. It is not possible to identify the precise date or dates of these events, because of uncertainties in methodology, but it is likely that the first increase in the spread of cultivation took place during the last millennium BC and that the second expansion occurred during the first millennium AD. Acceptance of these results must be tempered by consideration of differences in the accuracy and reliability of the dating methods used. The accuracy of radiocarbon dating was greatly improved with the development of the AMS method, with reduced sample quantity requirements. It is not just the possibility of analytical errors that should be considered; if bulk sediment was used for dating, it is possible that old carbon was measured, causing results to be as much as 500 - 800 years too early (K. Tolonen & Ruuhijärvi, 1976).

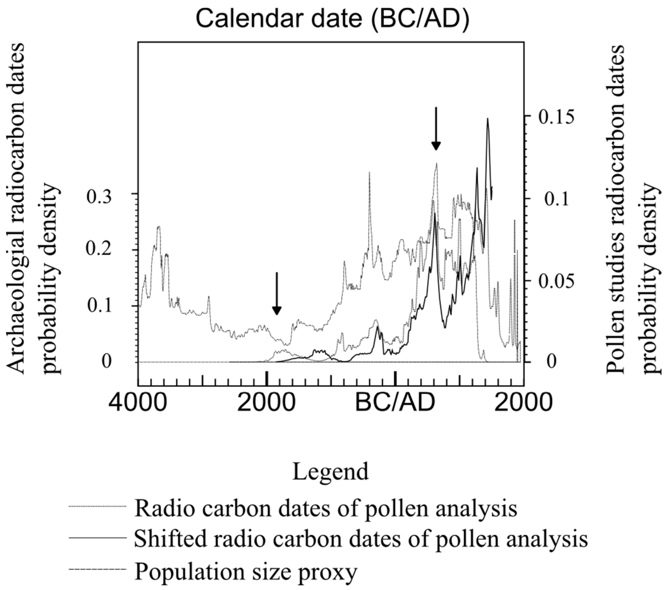

Figure 3. A graph showing temporal variation of radiocarbon probability density from pollen studies and population proxy (archaeological material and charcoal from archaeological contexts; Tallavaara & Seppä 2011) and pollen studies when the bulk sediment dates and peat dates are shifted 600 and 100 years respectively. Arrows indicate the location of estimated genetic bottle necks (based on Sundell et al. 2010).

Lipid residue analysis suggests that Corded Ware (CW) culture practised animal husbandry (Cramp et al. 2014), but this is absent from our pollen data and it is not visible in population size either. Moreover, there is a lack of any archaeological evidence for cultivation by CW people (Nordqvist & Häkälä 2014), although Siiriäinen (1980) argued that their lack of hunting related tools could indicate subsistence based on something other than hunting. The first studies indicating cultivation date to Kiukainen culture. Moreover, as already discussed by Lahtinen and Rowley-Conwy (2013), wild and cultivated species can be misidentified. It is possible that the three results indicating cultivation during the 'Kiukainen culture' or early Bronze Age between c. 2000 and 1500 BC in fact recorded wild species, or that the dating is incorrect. However, preliminary results suggest that starch grains of barley have been detected on an axe belonging to a Kiukainen culture context (Juhola et al. 2014), and a radiocarbon date obtained from a burned bone of sheep/goat dates to this period (2200-1950 BC; Bläuer & Kantainen, 2013). As Juhola et al. (2014) admit, future investigations on the reliability of the starch identification method are needed before these results can be accepted. It is also possible that burning caused the date of the bone to be too old. Furthermore, signs of cultivation from this period are seen in only three studies, two with bulk sediment dates - Aholammi (1957 – 1613 BC, Koivula et al. 1994) and Loimaansuo (2035 – 1716 BC, Vuorela 1975) - and one with a varve date - Kissalammi (c. 1500 BC, Tolonen, M., 1991). Because of the unreliability of bulk sediment dating, these results could date from the early Bronze

Age, when there is also a small increase in the population size proxy. The only other reliable evidence for farming from this period is a cow maxillary molar from Nakkila, southern Ostrobothnia (1427-1271 cal BC, Bläuer & Kantainen, 2013). Overall, the evidence for cultivation during the Kiukainen culture and early Bronze Age is very limited, and needs support from future studies.

The next increase in the pollen date probability and population size is from the late Bronze Age, c. 1000 BC. However, this is first visible on bulk sediment dates, which could suggest that this date is too old. Evidence of milk lipids has been discovered from Bronze Age vessels (undated) and direct dates have been obtained from two barley grains from Southern Ostrobothnia (1000-844 BC; 831-552 BC; Holmblad, 2010; Cramp et al., 2014). Evidence for early cultivation remains limited, but this could be indicative of minor Bronze Age farming practised on a very local scale. Corresponding weak signals of small scale cultivation are seen from similar latitudes in northern Sweden (Viklund 2011).

Radiocarbon analysis of pollen shows that the third increase during Iron Age started from c. 300 AD onward. This increase is mainly dominated by radiocarbon dates derived from peat samples. This coincides with an increase in the population size. However, a peak in the summary curve of the pollen analysis radiocarbon dates occurs at c. 600 AD. Because of uncertainty in the dating methods used in pollen analysis (as discussed above), it is more likely that the increase in the occupation of new areas in fact occurred between c. 600 and 700 AD. This increase may be connected to the introduction of rye cultivation. It was not possible to estimate in this study, which varieties or species of cereals produced these signals of cultivation. Nevertheless, it is interesting that during the Iron Age a change in macrofossil evidence in southern Sweden indicates an intensification of rye cultivation (Grabowski, 2011). Donner (1984) claims that rye spread to Finland between the 5th and 11th centuries which could be a possible explanation for the rise in the quantity of pollen studies indicating farming during the first millennium AD. This does not necessarily mean intensification of farming, as Donner (1984) has already argued: rye produces more pollen than barley and therefore has greater visibility in the pollen record. However, because of the simultaneous increase in population size, it is likely either that more suitable farming methods were developed, or that farming spread into new areas. The cultivation of rye could explain a population increase, as although rye is climatically more difficult to cultivate than barley, it provides larger harvests (Solantie, 1988). Another possibility is that this population size increase was connected to a growth in trade evidenced by an increase of imported objects from 700 AD onward (Huurre, 1979; Uino, 1999). Increased trade could have provided needed food supplements during a harvest failure therefore reducing pressure upon farmers.

The decrease in radiocarbon date probability at c. 700 AD is in agreement with the observation of a possible genetic bottleneck (Sundell et al. 2010). This would suggest a decline in the occupation of new areas by farming communities. This same decline in farms at c. 600 is recorded in Upland in southern Sweden (Lagerås, 2012) and in Estonia (Tvauri 2014). Furthermore, a tree ring summer temperature reconstruction from northern Sweden suggests that summers were cooler between 600 and 700 AD (Briffa et al. 1992). This could indicate a difficult time for a farming-based economy. Another possibility is that the northern border of farming was reached, and instead of occupying new areas, farming was intensified in these areas, which would not be visible in this study, but this seems a less likely scenario as the same phenomenon has been reported in the neighbouring countries.

The rate at which Neolithic farming spread across Europe has been estimated at only approximately one kilometre a year, although regional variations are significant (Bocquet-Appel et al., 2012; Galeta et al., 2011; Pinhasi et al., 2005). For example, the LBK culture spread over Central Europe at a rate of approximately 6 km per year (Dolukhanov et al., 2005). This would mean that even with a much slower rate, Finland (1200 km in length) could have been settled by farmers more quickly than has been previously estimated. It is not possible to draw conclusions based on migrations, at least not with such studies alone, but this study suggests a slow expansion process, which must have been different to the Central European Neolithic event.

Conclusions

The spread of farming was not a single event, but a long-lasting process, and therefore should be discussed as a process rather than an event. It is possible that there was a decrease in the spread of farming at c. 600 AD, coinciding with the possible genetic bottleneck suggested by Sundell et al. (2010). In light of pollen analyses, it seems likely that moving into new areas was a long-lived practise among farmers that continued at least until the 16th century AD in Finland. Moreover, these results suggest that there was no separate Medieval spread of farming but that the spread of farming continued during this period. After the most intensive stage of this expansion in the 16th century

AD, it is documented in several historical sources that Finns continued to spread, but to other parts of the Swedish realm, into Sweden's forested uplands, Lappland and to the new world in North America.

METHODS

Stable Isotope analysis in Archaeology

Stable isotope methods have been used in archaeology from the 1970s onward. Several reviews of the isotope method have been written during this time (Ambrose and Krigbaum, 2003; Kelly, 2000; Koch, 2007; Post, 2002; Schoeninger and Moore, 1992; Schoeninger, 1985; Schwarcz and Schoeninger, 1991; Van Der Merwe, 1982). This chapter summarises a brief discussion on the history of the development of the methodology and the current situation regarding information related to the dietary reconstruction of collagen and dentine.

Largely, the idea of collagen isotope reconstruction is based on the assumption that collagen isotope composition reflects diet (Schoeninger and DeNiro, 1984; Walker and DeNiro, 1986). This can be seen from the variation in the collagen carbon isotope composition of the studied animals and humans (see figure 1.). This variation is based on differences in carbon and nitrogen isotope ratios in marine and terrestrial food webs (Chisholm and Schwarcz, 1982; Schoeninger and DeNiro, 1984) and enrichment of heavier isotopes in each step of the food web (Schoeninger, 1985).

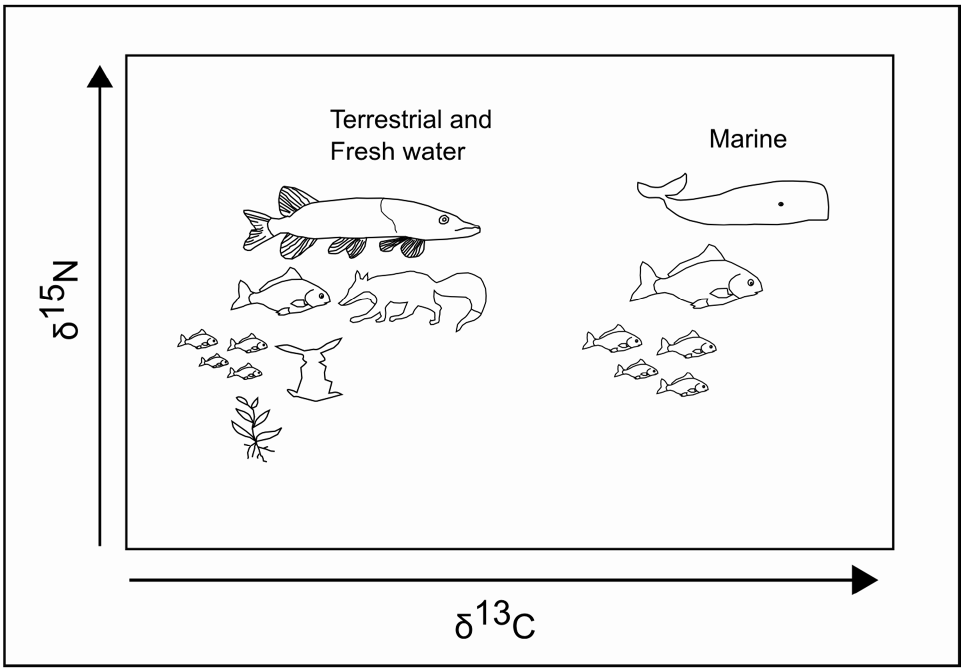

Figure 1. A scatter plot of carbon and nitrogen isotope composition variation in different species and environment. Terrestrial, freshwater and marine food webs can be distinguished with collagen nitrogen and carbon isotope composition (based Fuller et al., 2012 and Schoeninger and DeNiro, 1984: 636, 637).

Atoms, Elements and Isotopes

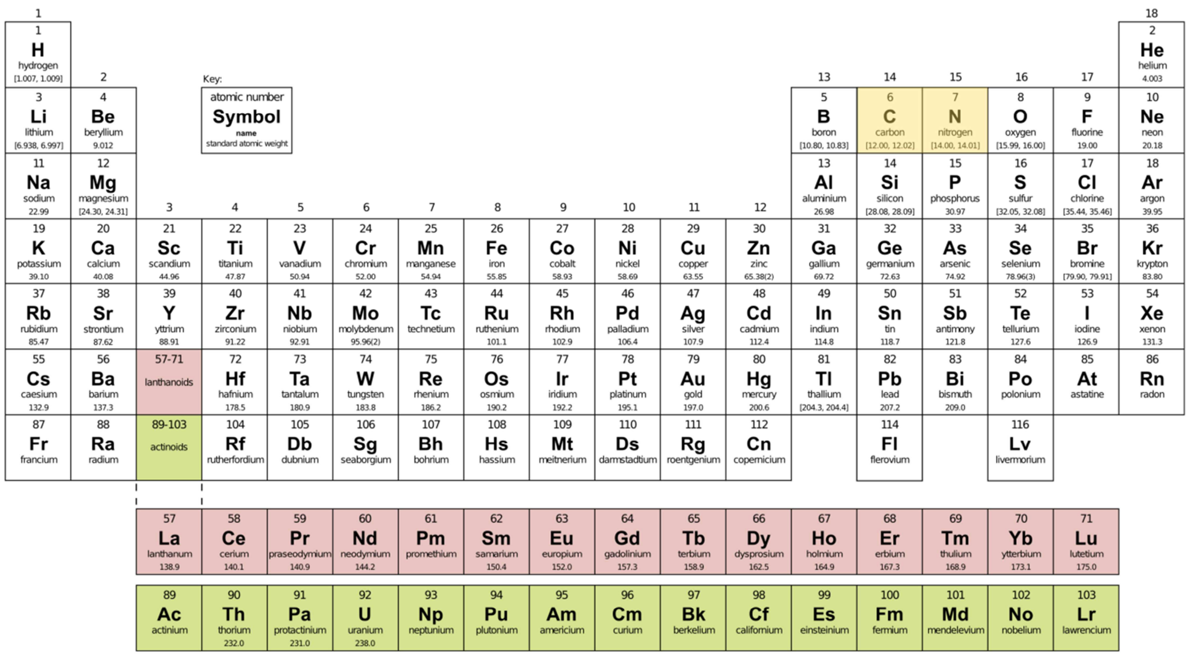

Figure 2. Periodic table of the elements and abundance of their isotopes, carbon and nitrogen highlighted with yellow (redrawn after Wieser et al., 2013, table 4).

Atoms are made of different particles. The three main particles are named protons, neutrons and electrons. Protons and neutrons form the nucleus of an atom and both have approximately similar masses. Compared to the nucleus the mass of the electrons is very small and therefore the mass of the atom is mostly characterised by the nucleus. This mass of the nucleus (i.e. neutrons and protons) has a given value of atomic mass unit (amu) that is one per particle. This mass unit is given as a superscript preceding the element symbol (for example notation for nitrogen that has seven protons and eight neutrons (15 amu) is ^{15}N, see figure 2). Isotopes are atoms of an element that have a same number of protons, but different number of neutrons, which means that the mass of an atom is different to its sister isotope. This small mass difference leads to a different kinetic energy and other thermodynamic properties, and is the reason for fractionation of the isotopes in different environmental processes (Kieffer, 1982; Urey, 1947). All elements have more than one isotope, but elements such as gold, bismuth, fluorine and sodium have only one naturally occurring isotope. The magnitude of fractionation depends on the relative mass difference of the isotopes of the element, e.g. a relative mass difference between isotopes of lighter elements is greater than the mass difference in heavier elements (Kieffer, 1982; Urey, 1947). For example hydrogen has two isotopes: ^{1}H and ^{2}H, of which have a difference in their mass ratio 1 to 1 (i.e. 100 %), whereas strontium has several isotopes, such as ^{82}Sr and ^{83}Sr and a mass difference ratio only 1 to 82 (i.e. 1 %) (Wieser et al., 2013). Isotopes of elements of with an atomic mass of less than 40 are observed to have a large enough difference in their masses to have a statistically significant fractionation which is detectable with most instruments (Schwarcz and Schoeninger, 1991).

Isotopes are categorized as stable and unstable (i.e. radioactive) isotopes. A half-life of an isotope is the period of time needed for half of the radioactive isotope to decay. There are 256 stable isotopes and two that have a very long half-life that they can be considered as stable. All together 19 elements have only one stable isotope accruing naturally (Be, F, Na, Al, P, Sc, Mn, Co, As, Y, Nb, Rh, I, Cs, Pr, Tb, Ho, Tm, and Au) (Wieser et al., 2013). Radiogenic isotopes are unstable and decay according to own characteristic half live. This study focuses on isotopes of two elements: carbon and nitrogen. Carbon has both stable and radioactive isotopes. This research analysed the stable isotopes ^{12}C and ^{13}C leaving out the radioactive ^{14}C (present in nature only in trace amounts) (Coplen et al., 2002) and synthetic ^{11}C. Nitrogen has only two naturally occurring isotopes ^{14}N and ^{15}N (Berglund and Wieser, 2011); other nitrogen isotopes are synthetic with half-lives from nine minutes to seconds (Audi et al., 2003).

Delta notations

Isotopes are not equally abundant in nature. For example, ^{12}C -isotope is the most common carbon isotope; its abundance is 98.93 % of all carbon (Berglund and Wieser, 2011; Coplen et al., 2002). To make it simpler for the reader, isotope ratios of light stable isotopes are often reported with delta notation (unit per mil).

δ Y (‰) = $((R_x/R_s)-1) \times 1\,000$[4]

where Y is the element, R is the isotope ratio (for example ^{15}N/^{14}N) of sample (x) or standard (s). This means that the isotope ratio in sample (R_x) is compared isotope ratio of a standard (R_s). For carbon the international standard used for comparison is the Vienna Peedee Belemnite (VPDB) marine fossil limestone formation from South Carolina (Craig, 1957) and for nitrogen isotope ratios

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[4] **(Coplen, 1994; Kendall and Caldwell, 1998)**

is the atmospheric nitrogen gas (AIR, i.e. Ambient Inhalable Reservoir).

The difference between the isotope ratios of two measured samples, such as different tissues, is given in $\Delta_x Y$ values. Where x is different substances (for example $\Delta_{collagen\text{-}muscle}$) and Y is the element that is compared. For example the notation of nitrogen isotope ratio ($\delta^{15}N$) between blood and collagen is $\Delta_{blood\text{-}collagen}{}^{15}N$. The unit for both delta values are per mil (‰).

The use of stable isotopes in dietary studies

Analysis of the nitrogen and carbon isotope composition of bone collagen is one of the most common methods used in archaeological reconstruction of diet. Both of the elements have different cycles and abundance in the biosphere. Understanding the carbon cycle started from empirical studies which showed that different environments have variations in their carbon isotope composition (Craig, 1957; Rankama, 1948). After this realisation, the carbon isotope composition of plants was studied in both the marine (Degens et al., 1968; Deuser et al., 1968; Sackett et al., 1965) and different terrestrial environments (Smith and Epstein, 1971, 1970). This lead to studies that showed that variation in carbon isotope composition can been seen also in marine and terrestrial animals' tissues (Haines, 1973; Smith and Epstein, 1970). Moreover this was seen in humans consuming either marine or terrestrial diets (Chisholm and Schwarcz, 1982). The differences in $\delta^{13}C$ and $\delta^{15}N$ values between sea and freshwater habitats of the same species have been observed in various studies. For example, this dissimilarity is clearly defined in the freshwater Lake Baikal and the Arctic Sea. Here, the Baikal seals (*Phoca s.*), the top carnivore species of the food chain, have collagen $\delta^{13}C$ values between -23.3 ‰ and -20.2 ‰ (Katzenberg et al., 2012; Weber et al., 2002) whereas ringed seals (*Phoca hispida*) from the Arctic Sea have collagen $\delta_{13}C$ values between -14.5 ‰ and -13.5 ‰ (Coltrain et al., 2004). This difference between freshwater and marine resources is also recorded in hair from Harbour seals (*Phoca vitulina*) in northern Quebec where, lake seals not only have lower $\delta^{13}C$, but also lower $\delta^{15}N$ values (Smith et al., 1996) (See figure 3). Similar differences were found in archaeological fish species, excavated from Belgium, that are known to migrate between fresh and salt water environments (Fuller et al., 2012).

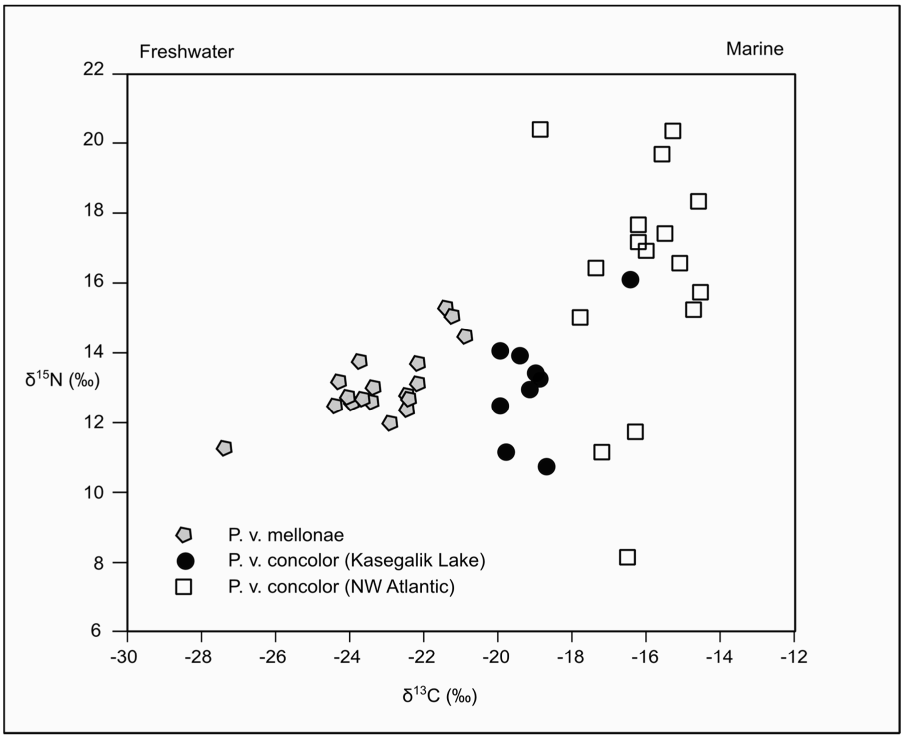

Figure 3. A scatter plot of seal hair isotope composition. Seal consuming resources from different environments have different collagen carbon and nitrogen isotope hair composition (redrawn after Smith et al., 1996: 276).

However, environment was not the only explanation of the carbon isotope composition of tissues of terrestrial plants and animals. It was also understood that plants have two main different photosynthetic pathways (Hatchs and Slack, 1970) that lead to two different carbon isotope compositions, which can be observed in the tissues of animals eating these plants (Minson et al., 1975). These two main photosynthetic pathways are named C_3 and C_4. The names derive from two different carbon cycles, where either three or four carbon atoms are synthesised. The C_3 pathway is used by most plants (Ehleringer and Monson, 1993). In that carbon cycle five carbon sugar phosphate, ribulose-bisphosphate and carbon dioxide is transferred into two molecules of 3-phosphoglycerate (which has the three carbon molecules). An enzyme called rubisco catalyses this event (Calvin and Bassham, 1962). The C_4 pathway is a more complex adaptation of the C_3 pathway. In it, phosphoenolpyruvate (PEP) catalyses phosphenolpyruve and atmospheric CO_2 into oxaloacetate (a four carbon atom acid, Hatch and Slack, 1966; Hatchs and Slack, 1970). The C_4 pathway was developed to resist more heat and dryness and therefore it is found mostly in tropical and warm climates (Edwards et al., 2010; Gowik and Westhoff, 2011). However, varieties of C_4 plants have been developed into more cold resistant and species such as millet can now be cultivated even in south Finland (Saarinen et al., 2012). However, these species are not commonly cultivated and are very unlikely to have been present before recent times.

Carbon and nitrogen isotope composition in bone collagen is a useful method for dietary reconstruction because of small variation of it in people consuming similar diet (i.e. individual differences on metabolism causing isotope fractionation are small). This small variation has been observed from a North American population that subsistence was based on bison hunting; they had only 0.3 ‰ (1σ) variations in their collagen carbon composition (Lovell and Nelson, 1986). However, as it was not a controlled experiment, and sample size was small in each age group, it would be necessary to ratify the results in the future.

Different tissues used in dietary reconstructions

The most commonly discovered archaeological human remains are bone, enamel and dentine. Bone and dentine are composed of different tissues which are intertwined mineral and organic components. The mineral component of the bone and dentine is mostly biohydroxyapatite, $Ca_{10}(PO4)_6(OH)_2$, whereas the organic component is mostly a protein complex called collagen. A small quantity of other organic substance, a ground substance, is present in bone and dentine. These non-collagenous proteins can also be preserved in bone but the collagenous proteins are more resistant to post-burial alteration, larger in quantity and therefore other protein types are present in only insignificant quantities (Schmidt-Schultz and Schultz, 2004). The mineral part of the bone is more likely to be altered than for example apatite in enamel, and is not often used in archaeometry because alteration is difficult to detect (Budd et al., 2000; Koch and Fogel, 1997; Nelson et al., 1986; Schoeninger and DeNiro, 1982). However, some studies have used bone apatite (Sullivan and Krueger, 1981) and even if methods for recognition of altered apatite and removal of the contamination have been developed (Lee-Thorp and Sponheimer, 2003; Pate and Hutton, 1988; Person et al., 1995; Price et al., 1992; Sillen and Sealy, 1995), currently the use of bone apatite in diet reconstructions remains doubtful.

Collagen is insoluble to water and can preserve in prehistoric bones, even if the bone minerals have been alter (Hedges and Wallaceb, 1978; Nelson et al., 1986). Collagen is a fibrous protein that can be found in bone but also in many other tissues. In most cases, only bone and tooth preserve in archaeological contexts, other type of tissues that have collagen, such as skin or muscle, are not discussed here as they are not studied in this research. Human bone collagen includes 20 different amino acids (Alanine, Glycine, Valine, Leucine, Isoleucine, Proline, Phenylalanine, Tyrosine, Serine, Threonine, Methionine, Arginine, Histidine, Lysine, Ornithine, Aspartic acid, Glutamic acid, Amide, Hydroxyproline, Hydroxyline) (Eastoe, 1955; Harding, 1963). There are different types of collagen - at least 16 have been discovered - but 80 to 90 percent of all collagen falls into the categories I, II and III. Differences between categories is the composition of the collagen, therefore not all tissues are not necessary comparative, even if isotope composition of collagen of the tissue is measured. Bone and dentine collagens are mainly type I collagen and that is formed from two different types of chains; one α1 and one chain of α2 structure. Moreover, it is a very large molecule, approximately 300 nm in length (Becker et al., 1986; Freeman, 2000). There are variations in bone collagen composition between different animals, these variations in no due difference in amino acids, but concentrations of the amino acids vary between different collagen groups. For example, fish bone collagen has more serine and glycine whereas mammalian collagen is has higher concentrations in hydroxyline and proline (Szpak, 2011). The building blocks of proteins, amino acids, can be classified as essentials and non-essentials. Essential amino acids cannot be synthesised in the body and thus are only derived directly from food. The essential amino acids for humans are valine, leucine, isoleucine, threonine, methionine, phenylalanine, lysine, tryptophan (Young, 1994).

Bone collagen is constantly being remodelled during the lifetime of the bone. Approximately 5 to 10 % of the bone collagen is renewed each year. The rate of remodelling is not completely understood and estimations vary. A medical study of modern living adults, suggest an estimate of 20 to 80 years for total remodelling of bone collagen (Hedges et al., 2007a). It is also known that turnover rate is not constant; it increases in perimenopausal and early post-menopausal women and slows with further ageing (Kini and Nandeesh, 2012). It also varies between individuals, and several factors effects on the remodelling rate have been observed: the genetic background; mechanical loading of the bones; vascular differences; nutritional factors; and hormonal factors (Kini and Nandeesh, 2012). However, it has been observed that collagen remodelling rate might not vary during the bone's growing period (Waters-Rist and Katzenberg, 2009). In contrast to bone collagen, dentine collagen does not remodel after it has developed (Smith et al., 2012). This difference makes it possible to study variation in past diet during an individual's lifetime until early adulthood. This technique of using dentine for dietary reconstructions has made it possible to study weaning from individuals who survived adulthood (Fuller et al., 2003; Richards et al., 2002; Wright and Schwarcz, 1999); recognising the victims of famines (Beaumont et al., 2013a) or dietary changes in marginal environment (Montgomery et al., 2013; White and Schwarcz, 1994).

The trophic level effect

To be able to reconstruct a diet, it is necessary to understand the process behind the development of analysed tissues and the rate tissue can be expected to enrich with ^{15}N or ^{13}C from the diet. This is often called a trophic level effect (also called discrimination value); the unit is per mil (‰). It means the difference between the isotope composition of the diet and the consumer's analysed tissue. In the early studies, where isotope methods were applied, it was known that isotope composition of plants vary according to different environments (marine or terrestrial); however, it was uncertain what kind of changes on isotope composition can be expected on animals consuming the plans. The trophic level effect of carbon isotope composition was first observed in controlled feeding experiments by DeNiro and Epstein (1978) to be on average +1 ‰. This study showed that the rate was “similar to different species rose using the same diet and for the same species raised on different diet” and that different tissues can have different trophic level effect (DeNiro and Epstein, 1978: p. 495). This was followed by a nitrogen isotope study of trophic level effects in a similar feeding experiment of mice (DeNiro and Epstein, 1981). They suggested that trophic level effect of mice varies between different tissues, but it is consistent in a species with a different diet. The rate of trophic level effect of $\delta^{15}N$ value varied between 1 and 9 ‰ according to the diet and the analysed tissue, but was on average 3 ‰. This 3 ‰ is often used in isotope reconstructions for the enrichment rate. However, in reality one value is likely inaccurate and a controlled feeding experiment of guppy, brine shrimp and mouse by Minagawa and Wada (1984) resulted a varied nitrogen isotope composition trophic level effect from 1.3 ‰ to 5.3 ‰. However, the study does not report what tissue was analysed, and therefore the results are problematic, but the study was used in the early stage of the diet isotope studies as important evidence for the existence of the trophic level effect.

Soon after these modern feeding experiments of different species, the trophic level effect was studied by comparing the collagen isotope composition of wild predators and their main prey. This study produced a large estimation: the difference in nitrogen isotope ratios between carnivores and their main pray herbivores from two valleys in Africa showed the trophic level effect to vary between 5 ‰ and 6 ‰, (Ambrose and DeNiro, 1986). In a review paper, Bocherens and Drucker (2003) concluded that there is variation in published feeding experiments and most studies suggest a range for the trophic level effect in collagen 0 to 2 ‰ for $\delta^{13}C$ values and 3 to 5 ‰ for $\delta^{15}N$ values. These results were based on the comparison of prey-predator mean collagen isotope composition. This study did not consider the possible variation in the trophic level effect in different levels of the trophic web and was limited to compare only collagen samples from carnivores and their main prey.

Krueger and Sullivan (1984) proposed a theoretical model to explain the variation that was observed in different feeding experiments. They suggested that differences in metabolic systems for herbivores, omnivores and carnivores could lead to different trophic level effects of carbon isotope composition of collagen. In their model, an herbivorous diet would be very likely to have an adequate amount of proteins, but a shortage of essential amino acids, which could mean that a substantial quantity of amino acids are being synthesised in the metabolic system of herbivores. This could lead to a large trophic level effect. On the other hand, a carnivorous diet, which is purely based on high protein, could consist of required amino acid content and therefore the carbon isotope signal of carnivores could be essentially more similar to the carbon isotope composition of their diet. In their model, an omnivorous diet can be a mixture of both, and trophic level shifts can vary according to the diet. Furthermore, they conclude that in the case of humans, if they consume sufficient amounts of meat in their diet, amino acid synthesis would not be needed and this could lead to a similar trophic level shift to that of observed in carnivores. They concluded that because of a difference in the rate of collagen synthesis, collagen does not necessarily reflect the total diet, but only the meat portion and therefore carnivore tissues would have more likely a different trophic level effect in isotope composition than herbivores. However, a small proportion of the proteins are transferred to energy if more optimal sources are not present, and this could affect the isotope composition of studied tissues. They also suggest that differences between apatite and collagen values could be due to differences in the carbon isotope composition of blood bicarbonate and atmospheric CO_2 molecules that are recycled in the body.

Even if there is agreement that protein consumption is the main control of the isotope composition of bone collagen, there are still many poorly understood processes behind this. Firstly, it is still unclear if species with similar diets would exhibit a similar trophic level shift between their diet and tissues or if this is characterised by species metabolism. In a controlled feeding experiment on mice, Tieszen and Fagre (1993) showed that trophic level shift can vary according to the diet even within one species. The difference between bulk diet and collagen values was observed to range from 1 ‰ to almost 8 ‰. This variation is large and may potentially lead to problems when applying dietary models, especially if other information on trophic level shift is unknown. Moreover, a controlled feeding experiment of captive red foxes found a larger difference in isotope ratios between the tissue types of these carnivores than was observed for herbivores (Roth and Hobson, 2000). A large data set of isotope composition of different animals of published feeding experiments (n=137) showed that there was no statistical difference between the trophic level effect of herbivorous, carnivorous and omnivorous animals (Vanderklift and Ponsard, 2003). However, even if they used large number of samples, their statistical analysis consisted insufficient number of samples in different of the categories. For example, in the comparison of mean value of trophic level effect, the number of vertebrate herbivores was only three individual animals, which is clearly inadequate number of such a large scale analysis. However, even if the sample was small in some categories, Vanderklift and Ponsard (2003) showed that trophic level effect of herbivores varied more than carnivores, this could suggest difference on metabolism between herbivores and carnivores. As already discussed, different tissues can have different trophic level effects and also they can reflect different part of the diet, and there is a difference between same tissue (such as muscle) of different animal categories such as birds, mammals, invertebrates and fish (Caut et al., 2009). Robbins et al., (2005) results suggests that one single value of the trophic level effect is not useful in estimation of past diet and more detailed information on individual tissue types on different animals is needed, as they showed a strong correlation between biologically valuable protein and the enrichment rate. This would suggest that herbivorous and carnivorous animals could have a difference in their trophic level effect and is in agreement with the model Krueger and Sullivan (1984) suggested. This model is also supported by Reitsema, (2013) who argues that when dietary protein is insufficient, bodies could “scramble” the collagen from other micro nutrients such as hydrocarbon. His evidence for the idea is from two case studies (Keenleyside et al., 2006; Prowse et al., 2004) that showed that non-essential amino acids can also derive from total diet and not only from proteins, and therefore the collagen and apatite isotope compositions can be similar.

Secondly, there is no agreement on the important question of the reason for the carbon and nitrogen isotope fractionation in animals and humans tissues (i.e. what explains the trophic level effect). Having a proven theoretical framework would be important in order to understand variation of the trophic level effect. Contradictory results are not explained, because the reason behind is unclear. For example, a high protein diet has been observed to increase the δ^{15}N value in omnivorous birds and llamas (Pearson et al., 2003; Sponheimer et al., 2003a), and in pigs and rodents (Froehle et al., 2010), but opposite results have been observed, as nitrogen content of the diet did not correlate with an δ^{15}N value increase in a study of several species (Robbins et al., 2005). The studies by Pearson et al. (2003) and compared the different diets of a single species, but Sponheimer et al. (2003b) studied different species with different diets. However, Robbins et al. (2005) suggest that the biological value of the protein (the rate that nitrogen is incorporated from absorbed protein to body) has a strong negative correlation (r^2= 0.72) with the trophic level effect. In other words, eating fish (high biological value) would lead to a smaller trophic level shift than eating carrots (low biological value). This would suggest that the enrichment for carnivorous animals could be different to marine animals and herbivores. This would be in agreement with the model already suggested by Krueger and Sullivan (1984) that it is not only the quantity, but also the type of protein that affects the trophic level effect. Moreover, this idea of importance of essential amino acid for trophic level effect is supported by Tieszen and Fagre (1993), who observed that in a low protein diet, the trophic level effect is smaller than protein rich diet.

Human hair has been studied in order to understand the trophic level effect in humans (see figure 4). Differences were observed in hair nitrogen and carbon composition of vegans, ovo-lacto-vegetarians and omnivores humans; δ^{15}N values in purely plant based diets was approximately 5 ‰ lower than omnivorous diet; and δ^{13}C values was 1.5 ‰ lower respectively (Petzke et al., 2005). Moreover, a controlled dietary study of human hair resulted approximately 5 ‰ enrichment in keratin, which suggest even as high as 6 ‰ for trophic level effect in nitrogen isotope ratio for collagen based reconstructions (O’Connell et al., 2012). This suggested that more information is needed and the interspecies approximations might be inaccurate.

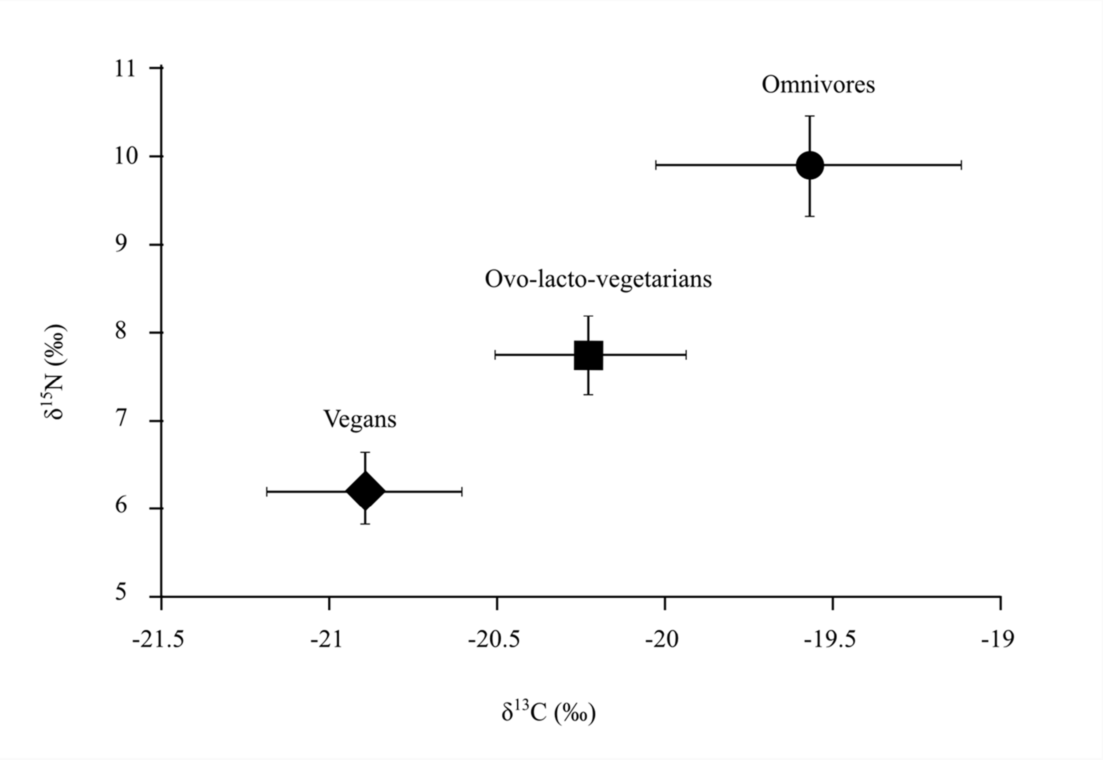

Figure 4. A scatter plot of nitrogen and carbon isotope composition of human hair of different dietary groups (Redrawn after Reitsema, 2013:446, data from Petzke et al. 2005).

Currently there are several studies with different species that evaluates diet-tissue isotope composition shift (some reviews collect evidence of primates (Crowley et al., 2010), overall review (Vanderklift and Ponsard, 2003), benthic food webs (Peterson, 1999). There are no longer easy answers for a single value of the trophic level effect and two controlled feeding experiments showed that the enrichment rate can vary substantially between different species (Ambrose and Norr, 1993) and omnivorous species eating different diet have different muscle collagen trophic level effect (Caut et al., 2008). The puzzle of isotopes is not as straight forward as firstly thought: it would bepossible to detect the protein source of the diet easily based on simple analysis. Trophic level effect can vary even within single species, for example according to the size of fish, because same species of fish of different size are situated in different trophic levels (Overman and Parrish, 2001). A significant difference in trophic level shift can be observed between marine, terrestrial and freshwater environments (Caut et al., 2009). It is not only what we eat, but also the proportions that affect the isotope compositions; Koch (2007) suggested that an increase the nitrogen isotope composition in a high protein diet is due to more non-essential amino acids are being synthesised from protein and this is agreed by Reitsema (2013). This is observed also in human hair samples from a controlled diet experiment, which suggest that carbon and nitrogen isotope ratios correlate positively with the quantity of animal protein in diet (Petzke et al., 2005).

It is not only diet, that affects the nitrogen isotope composition; breast feeding makes the child one trophic step higher than the mothers and increases their nitrogen isotope ratio (Fuller and Fuller, 2006; Richards et al., 2002). There are several factors having effect on the nitrogen isotope composition and increase of the $\delta^{15}N$ values has been observed such as starvation of humans (Hatch et al., 2006; Mekota et al., 2006); lack of water (Ambrose and DeNiro, 1986); seasonal low protein intake (Deschner et al., 2012; Vogel et al., 2012); morning sickness of mothers (Fuller et al., 2005); high protein intake (Sponheimer et al., 2003b); liver deceases (in rats) (Sick et al., 1997); Also lower $\delta^{13}C$ values have been observed from human hair of patients with liver cirrhosis (Petzke et al., 2006). These observed increases or decreases of isotope compositions should be taken into account when analysing carbon and nitrogen isotope composition of human samples as there are also other causes than diet affecting the isotope composition of human collagen.

The first archaeological applications

Isotope studies in archaeology started with a proposal: Hall (1967) suggested that carbon isotope composition could be used to study corn consumption. Soon after, isotope applications were used for the first time in archaeology to show consumption of maize in Native American population

(Vogel and Van der Merwe, 1977). This study was based on the fact that maize is a plant using the C_4 photosynthetic pathway. Eating this C_4 plant leads to a different carbon isotope signal than the other vegetation, mainly C_3 plants, consumed in the studied area. When consumption of maize increased, this led to a significant shift in carbon isotope composition of bone collagen (Vogel and Van der Merwe 1997). This study showed that isotopes can be used in archaeology to study diet and several similar studies appeared shortly after. Vogel and Van der Merwe (1997) also suggest that the trophic level shift from diet to humans could be as high as 6 ‰. This large shift is supported by observation in collagen composition of European humans that differ approximately 6 ‰ from the mean of C_3 plants (which could be expected to be the main type of plants in Europe, Vogel and Van der Merwe, 1977). First studies suggesting that isotope signals can reveal the use of marine resources in bone collagen and analyses showed a significant difference to those populations to that use terrestrial food sources such as milk or cereals (Chisholm et al., 1983; Schoeninger et al., 1983).

In Europe, the reconstruction of diet has been mainly based on investigation of terrestrial and marine consumption. One of the early studies showed a sharp shift in diet at the beginning of the cultivation in Denmark (Tauber, 1981). Tauber (1981) demonstrated how Mesolithic population subsistence was based on marine resources and there was a sharp shift at the beginning of the Neolithic, when people started using mainly terrestrial sources. Similar results have been observed in several European countries, such as Portugal (Lubell et al., 1994); in Öland island Sweden (Eriksson et al., 2008) and in Britain (Richards et al., 2003). Later on these studies were criticised, because archaeological and biomolecular evidence showed consumption of marine foodstuff and collagen might not have recorded small scale consumption (Craig et al., 2007; Milner et al., 2004). This, in fact, was the case in Shetland islands where sporadic marine resources were used in the early Neolithic (Montgomery et al., 2013).

Alteration and diagenesis

In the first studies, it was not known if the prehistoric bones they sampled were sufficiently well-preserved to provide reliable biogenic values. Hedges and Wallaceb, (1978) extracted proteins similar to collagen, but reported that the molecules had a different amino acid composition to their modern comparisons. Even if post-depositional processes were poorly understood, results of the bone collagen isotope studies were reasonable, which convinced some researchers about the use of isotopes to study the past diet, and several different populations were studied (Bender et al., 1981). Because the question of preservation was unknown, it was necessary to prove that the method works in every situation and on differently preserved samples: Bones buried in archaeological contexts are surrounded by natural contamination processes such as microbes that were likely to alter the material (Ambrose, 1990). After the first attempts, a study showed that collagen has preserved and could be used to study the biogenic dietary signal which was a very significant discovery; it is possible to test whether samples are preserved well enough by comparing the molecular ratio of carbon and nitrogen (often called C/N ratio) (DeNiro, 1985). DeNiro (1985) suggested that the prehistoric samples had similar collagen isotope composition to modern species if the C/N ratio was between 2.9 and 3.6 (DeNiro, 1985). This is supported by the discovery from a large data set from Oxford radiocarbon laboratory that have carbon and nitrogen atomic ration mean 3.29 (±0.27), which suggested that the range 3.1 and 3.5 is well suited for recognition of well-preserved collagen (Van Klinken, 1999).

The C/N ratio is now an important part of the evaluation of the quality of the samples. A second quality criterion was the collagen yield. Ambrose (1990) observed that the transition from well-preserved bone to contaminated in collagen yield between 3 and 4 % for herbivorous animals and 1.2 % and 1.8 % for humans. Even smaller yields (1 %) have been observed to result in reasonable isotope composition and amino acid profiles similar to collagen (Van Klinken, 1999) which is in agreement with the detailed results obtained from various archaeological sites (Dobberstein et al., 2009).

In addition to collagen yield, Ambrose (1990) suggested that carbon (above 4.5%) and nitrogen (above 0.5%) concentrations in collagen could be added into the quality criteria of samples considered well preserved. Ambrose (1990) also found that modern animals contain up to 47 % of carbon. This is in agreement with Van Klinken (1999) who reports that modern Western Europe mean carbon percentages in bone vary between 26 and 43.8 % and this could be used with other quality criteria when assessing alteration. Furthermore, Van Klinken (1999) suggested, based on the bone composition of modern animals, which the acceptable range for total nitrogen should be between 11 and 16 %.

Quality control assessment is an important part of the isotope studies and the only way to guarantee that the isotope results represent unchanged original values. This needs to be done for every sample using the methods described above, as it has been found that bone collagen preservation can vary even within a single site and preservation of collagen cannot be visually observed (Jans et al., 2002).

Different laboratory methods

To be able to analyse collagen, it is necessary to isolate it from the mineral and other proteins in bone. This can be done with various methods and these laboratory methods can effect on analysis of the isotope ratios in bone collagen and dentine. The most common methods used in isotope studies have been:

1. Modified Longin method (Brown et al., 1988):
Mineral matrix is dissolved in weak (0.5 M) HCl solution; the collagen is solubilised in pH 3 HCl solution and filtered with ultra filter and freeze dried.

2. NaOH pre-treatment (DeNiro and Epstein, 1981):
NaOH treatment is used before the solubilisation to remove humic acids followed by method 1.

3. Longin method (Longin, 1971):
Mineral matrix is dissolved in weak (0.5 M) HCl solution; the collagen is solubilised in pH 3 HCl solution.

4. EDTA (ethylenediaminetetraacid) method (Tuross et al., 1988):
Bone samples are demineralized in weak EDTA and washed multiple times to remove the EDTA.

These methods have been compared in various studies. (Jørkov et al., 2007) showed that in comparison of the methods 1, 2 and 3, the collagen yields and carbon isotope ratios are dependent on the method for collagen extraction but nitrogen isotope ratios were constant. Nevertheless, they suggest that differences in these methods are small scale and would most likely not influence interpretation on the isotope results in archaeological analysis. Tuross et al., (1988) compared methods 1, 2 and 4 showed that if the bones are well preserved, isotope composition is similar, but poorly preserved bones shows variation between each method. According to Tuross et al. (1988) study, EDTA method seems to produce higher yields of collagen compared to the two other methods.

Cleland et al., (2012) showed that the use of hydrochloric acid as the reagent produces cleaner samples than use of EDTA, because the remove of the HCl from samples is easier. Moreover, EDTA method required more working hours (Cleland et al., 2012). However, HCl can hydrolyse collagen and split the molecule into smaller particles (Fountoulakis and Lahm, 1998), which can lower yields if samples are being filtered (Cleland et al., 2012; Tuross et al., 1988). Furthermore, very small differences were reported between different methods: Results of a study also suggest that hydrolysing demineralised bone powder could be an unreliable method to use for collagen extraction (Cleland et al., 2012; Pestle et al., 2014). It was also detected that even if the bone is altered, extraction with HCl resulted a similar amino acid composition to collagen, which suggests that it can be extracted successfully and preserve even if other tissues of the bone has been altered (Schoeninger et al., 1989).

A recent study suggest that use of filters is not required if the yield is high and the samples fulfill the discussed quality criteria (Sealy et al., 2014). This is particularly useful in large data sets as funding is often limiting the sample size and the filters are one of the most expensive parts of the analysis. In summary, these studies suggest that all of these methods can be used in well-preserved bone material. Method one is the most commonly used one for collagen and applied in this study for bulk collagen; because it was unclear if bone collagen is well-preserved, filters were used in this study for bulk collagen samples. Method three was used to study dentine collagen; Collagen preservation is dentine is likely to be higher and therefore filtering of the sample is not necessary.

Origin of the isotope signal in bone collagen

Even if several empirical observations of trophic level effects have been done, the mechanisms that cause fractionation from diet to bone collagen isotope composition are not completely understood. Already in the first studies, different tissues of modern animals showed different isotope compositions (DeNiro and Epstein, 1978; Jacobson et al., 1972). This was assumed to be caused by a different remodelling period between each tissue type. Moreover, early studies assumed that collagen would represent the average of the total diet (Van Der Merwe, 1982). Sullivan and Krueger (1981) showed that herbivorous collagen and apatite correlates linearly and very strongly with the type of plants they digest and mixing models can be used to calculate the percentage of C_4 or C_3 in their diet. According to Sullivan and Krueger (1981) this suggested that the process behind the collagen and apatite formation and fractionation should be possible to resolve.

After a decade of dietary research of collagen and bioapatite carbonate, it was shown in controlled feeding experiments that it is mainly dietary protein that affects the isotope composition of collagen (Ambrose and Norr, 1993; Tieszen and Fagre, 1993). Similar conclusions have been observed elsewhere (Jim et al., 2004). It has been very clear that after these studies, that investigations based on collagen evaluate mainly the protein source and that estimations of the whole diet needs to be based on several methods, for example a comparison between apatite and collagen isotope composition. This is possible because it was shown that collagen and bioapatite isotope composition represent different parts of the diet (Crowley et al., 2010; Lee-Thorp et al., 1989). Crowley et al., 2010) showed that there is a difference between the apatite and collagen carbon isotope ratio in primates regardless of body size, sex, or habitat. This supports the idea that apatite and bone collagen isotope $\delta^{13}C$ and $\delta^{15}N$ values represent different sources of carbon.

Environmental differences

Because of large differences in the relative mass of carbon and nitrogen isotopes they fractionate in environmental processes. This means that nitrogen and carbon isotope composition differs geographically. For example, the parts of the trees growing closer to the ground have higher $\delta^{13}C$ value than the canopy (Vogel 1978). Vogel (1978) studied this 'canopy effect' first in Germany and it was soon observed also in Amazonian rainforest (Medina and Minchin, 1980). This was also seen in the diet of animals living on different levels of the canopy (Ambrose and DeNiro, 1986). Ambrose and Deniro (1986) also discovered that animals eating on the forest floor have significantly lower carbon isotope ratio than browsers.

Other factors affect isotope composition, such as nitrogen recycling. It has been observed that manuring increases the nitrogen isotope ratios of plants because nitrogen is re-used and fractionated (Bogaard et al., 2007; Fraser et al., 2011; Kanstrup et al., 2012). This would also increase the nitrogen isotope ratio in the higher trophic levels and would significantly affect the isotope composition of animal and plant based food. This could increase the nitrogen isotope composition of humans without a change in diet.

As previously mentioned, the first isotope reconstructions in Europe were based on differences between marine and terrestrial food sources. Reconstructions based on the idea that consumption of fish could be seen from isotope are no-longer valid because freshwater environments has similar isotope signature than terrestrial environments (Dufour et al., 1999). This is an important consideration when undertaking studies in countries, such as Finland and Sweden, which have large lakes which have the potential to provide a significant source of food.

Summary

Collagen preserves well in archaeological bones and can be successfully isolated from the mineral component of bone. The study of collagen is useful in dietary reconstructions, but it does not reconstruct the total diet: the collagenreflects mostly the protein intake and thus gives us only a one sided story. There is still much we do not understand in the collagen enrichment of the heavier carbon and nitrogen isotopes. One of the most important questions is the trophic level effect of humans and other omnivorous species. It seems that animals inhabiting different stages in the trophic levels have the different trophic level effects because of the availability of essential amino acids. This would lead to a conclusion that omnivores' trophic level shift could vary according to the diet. Recent studies suggest that human collagen trophic level effect for nitrogen isotope composition range from 5 to 6 ‰. Moreover, each sample needs to fulfil quality criteria when accepting the measurements: the sample has C% between 26 and 43.8 %, N% between 11 and 16 %, collagen yield more than 1%, and C/N ratio between 2.9 and 3.6.

BACKGROUND FOR THE THE IIN HAMINA – THE MEDIEVAL BURIAL SITE IN THE NORTHERN OSTROBOTHNIA

The introduction of farming practises has been previously discussed in Finland (see former chapters). However, the proportion of farmed food in diet has not recieved much attention. This study introduces isotope analysis on the Finnish dietary studies. This chapter introduces the Iin Hamina site in the Northern Ostrobothnian context. It will briefly summarise previous studies regarding the Northern Ostrobothnian area, and the difficulties and challenges that archaeologists have to face when studying this complex area with very little evidence. Further on, the paper 3 and paper 4 are provide a step forward in understanding the diet in this region during the 16th and 17th centuries.

Geography of Northern Ostrobothnia

Finland is situated between 60 and 70 °N latitude. The climate in Finland is mainly characterised by northern polar fronts, continental influences from the East (cold winds during winter, warm during summer) and marine effects from the Gulf stream (warming effects) (Kersalo and Pirinen, 2009). This means that even though Finland is situated in northern Europe, at the same latitude as Greenland, the climate is warmer, and climatically Finland belongs to the subarctic zone. The Northern Ostrobothnian region is located in northern Finland (see map 1). It is situated in the subarctic zone, middle Boreal vegetation zone, and the main vegetation type is pine forest. Soil types are mainly sand, moraine and silt, but more than 50 % of the land area is covered by sphagnum peat wetland (Rikkinen, 1980).

Map 1. The Map of Finland, the location of Northern Ostrobothnia, and the town Ii.

Post-glacial rebound still causes land uplift in the Northern Ostrobothnian region. Fertile land has been rising from the sea since the end of the last Ice Age (Saarnisto, 2005). This is optimal for archaeologists, as people prefer to occupy areas in close proximity to water, and the land uplift has been used in dating estimations of sites. It also means that sites have an absolute minimum age, the date when the site rose above sea level and thus became available for human occupation. As we can see from the land uplift rate curve (figure 1), the uplift has not been constant, but has slowed down towards modern times.

Archaeological Background

The chronology of Northern Ostrobothnia has been divided into the Stone Age (approximately 7500 to 1600/1250 BCE), the Early Metal Age (approximately 1600/1250 BCE until 300 CE), the Iron Age 300 CE until 1300 CE) and the Historical period (from circa 1300 CE onward) (Carpelan, 1999; Huurre, 1983). The river Ii valley is especially famous for its Stone Age large-scale centres (Costopoulus et al., 2012) and megalith structures, the 'Giant churches' (Okkonen, 2003). Simultaneous to the Neolithic population decline in Finland approximately 4000 BCE (Tallavaara and Seppä, 2011), population and sedentism also declined in Northern Ostrobothnia. It has even been suggested that population in Northern Ostrobothnia stopped producing and using ceramics at the end of the Early Metal Period (Huurre, 1983). However, this is not necessarily an indication of abandonment of the area (Hakamäki et al., 2013a).

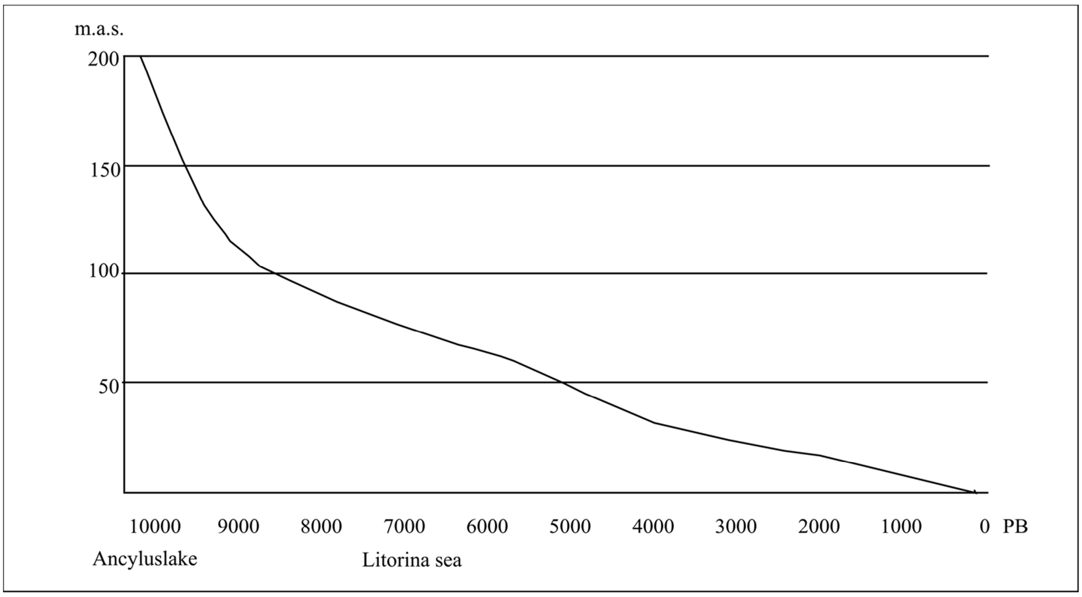

Figure 1. A graph showing the sea level from different periods. This describes the general rate of land uplift in Finland (redrawn after Saarnisto, 2005: 166).

The classical debate in northern Finland has centred around whether there was population continuity, or a migration from the south in the Medieval period (Luukko, 1954; Vahtola, 1992). Due to the lack of research, little is known of the Iron Age (500 BC – AD 1200), in the Northern Ostrobothnia region (Mäkivuoti, 2013). Limited evidence for a human presence is found again only from AD 1000 onward in the form of a small number of occupation sites devoid of human graves (Koivunen, 1992; Kuusela and Tolonen, 2013). Even though there is limited archaeological evidence and unreliable, although continuous, cereal type pollen evidence, Kuusela et al. (2011) assumes the area was uninterruptedly and permanently occupied during the Iron Age. However, this hypothesis exaggerates the power of pollen analysis. There is simply no evidence for farming during the Iron Age because there is not enough data to support this (see Lahtinen and Rowley-Conwy 2013). Consequently, it is possible that there was no permanent, farming-based, occupation in Northern Ostrobothnia before the Medieval period. This is evident in the inner part of Northern Ostrobothnia, where single artefacts are only found in areas that have been used during previous periods, which suggests similar patterns of livelihood, most likely hunting, fishing and gathering (Kuusela et al., 2011). It is surprising that the situation is very different in the Tornio river area, approximately 80 km north from Ii, where evidence for permanent occupation has been discovered from the late Iron Age onward (Wallerstöm, 1995).

The Iron Age (the period proceeding the Medieval period) is challenging for researchers in the area of Northern Ostrobothnia. Studies of the Iron Age in the region of Northern Ostrobotnia are characterised by the abundance of archaeological materials, and minimal resources to conduct excavations. Surveys have revealed several cairns and settlement impressions in the area, but sites are excavated only rarely, and thus the dating of many archaeological discoveries is uncertain. Several cemeteries and iron casting sites in the area suggest that Northern Ostrobothnia was likely inhabited during the late Iron Age and early medieval period (Hakamäki et al., 2013b; Kuusela and Tolonen, 2011; Kuusela et al., 2013) but details about the way of living or occupational processes are still missing. The latest discoveries in Iin Illinsaari, the Suutarinniemi site, included human burials, which suggests that the surroundings in Ii were used during the Late Iron Age (Kuusela et al., 2013), but details on the behaviour or permanency of these people are still unclear. Moreover, poor preservation, scarce finds and unclear structure imprints make the interpretation of the sites very difficult (Kuusela, 2012). Also, nothing in the archaeological record implies that these people were cultivators (Korteniemi 1992, Mäkivuoti 1992), but the opposite can also be argued as there are simply no reliable pollen reconstructions from the area, nor macrofossil studies. Thus, more research on any area of archaeology is vitally needed in the Northern Ostrobothnian area.

Individual discoveries, such as a Karelian type metal fibula, have been made in the village of Ii. This could represent a trade connection to Karelia (Hakamäki et al., 2013b). Other single artefacts have been discovered around northern Finland and Sweden, but not in association with settlements (Koivunen, 1985). A recent discovery of a cemetery site in the village Ii has been typologically dated from the 12th to 13th century AD. This suggests that the lack of extant evidence for human burials at the other sites might be simply due to a lack of visible traces on the ground. These buried features are often left undiscovered, due to very limited resources on surveys in northern Finnish archaeology (Kuusela et al., 2013). Nonetheless, no radiocarbon dates have been published from the site, and thus it is possible that people in Ii continued to use typologically earlier styles of jewellery and the dates are therefore deceptive.

The economy of the Iron Age and Medieval period in Ostrobothnia is still mainly unknown. Nothing in the archaeological record supports the conclusions that these people were settled farmers (Mäkivuoti, 2013). Macrofossil analysis has started in the Northern Ostrobothnian area, but currently the site studies are only from historical period sites, and it is thus not yet possible to make conclusions based on microfossils. The people in Northern Ostrobothnian area started to pay taxes on cereals from year 1540 onward. This has been interpreted as the beginning of cultivation in the region (Luukko, 1954), but it does not provide evidence enough as large-scale taxation did not took place before this (Seppälä 2009). Nor does is explain whether all people cultivated or not, and to which extent they consumed their farmed food themselves (Seppälä 2009). Also in the 17th century the tax was lower than in other regions in Finland (Seppälä 2009 and Luukko 1954), which could be explained by the smaller yields in harvest. In the years 1571 and 1600 Northern Ostrobothnia together with Ahvenanmaa were noted as the most important cow herding area of the country (Seppälä 2009). However, there is no record before 1540 of cows being kept in the area (Seppälä 2009).

Fish is widely available in the region and river Ii has been famous for its salmon. Fishing is very likely to have been important in the area. According to the Acerbi (1802) travel story, in the year 1799 AD salmon was an important exported item from the Oulu region. This was a luxury product, and the salmon from this area was one of the most expensive salmon types in Stockholm at the time. Other important export items from the area were tar, perch, butter, tallow, pikes and planks. The town Oulu was also importing rare items such as wine, oil and lemons. Acerbi (1902) travelled to Northern Ostrobothnia and stayed over the winter in Oulu where he studied the local culture. He described how several types of food were eaten (fish, pig, cow, birds, milk, and barley) and how they served wine and used wild game such as western capercaillie (*Tetrao urogallus*). He wrote that in the region of Oulu, an annual cycle of hunting and fishing was practised; Birds were hunted only during the summer season (May-Middle June), while the hunting of other animals and fishing was done solely during the winter months. The season for seal hunting was in the springtime, when ice cover of the sea started to break, and mainly seal pups were targeted. He wondered why only few people adapted fire guns, and that hunting was mainly done in traps. Tornio, a town further north from Oulu, exported mainly: butter, salmon, herring, planks, timber, tar, furs (reindeer, fox, wolfs and other) and birds. They also imported supplies of corn, flour, falt, flax, woollen clothes, linen, tobacco, spices and hemp. In Tornio, they not only exchanged items with towns further south, but they also trated with nomadic Sami (Acerbi 1802). This travel story is interesting, although not necessarily accurate, as the intention of Acerbi was not to write a scientific article but rather an entertaining travel story. He was most likely unable to speak the local language to the extent that he could have interviewed people himself, assuming that the population of the area was Finnish/Sami speaking at the time he visited. It is not mentioned whether all people in Oulu took part in every type of hunting activity, or that everyone had similar meals. Since this story is mainly based on his companion Mr. Julian's stories and interviews, it is possible that some parts are fictional or misunderstood.

Climate between the 14th to 16th centuries AD

The impact of climate on cultivation and the productivity of nature is larger in marginal areas than anywhere else. The radiocarbon dates from Iin Hamina suggests that the burials were made from early 15th to very early 17th century (Kallio-Seppä, 2011). During the period Iin Hamina was used, the annual temperature was cooler and it was characterised by the Little Ice Age, which affected Finland from 15th century AD onward. After this period, another more drastic, cooler period affected the country 17th and 18th century AD, resulting in a large-scale famine (Luoto et al., 2009, 2008; Muroma, 1991). Unfortunately we have no records of the effect the little Ice Age had on the population in Northern Ostrobothnia or wheather there was famine in the area from the period of the Iin Hamina.

The climate is still affecting farming dramatically in the Northern Ostrobothnian region, which still suffers regularly from harvest failures. During the period 1953 – 1983, which was a climatically warm period, significant failure occurred six times and smaller failures another five times (see figure 2). During the same period, the south-western part of the country (Varsinais-Suomi) suffered only one major failure in rye harvest, and one failure in spring wheat harvest (Kettunen et al., 1988).

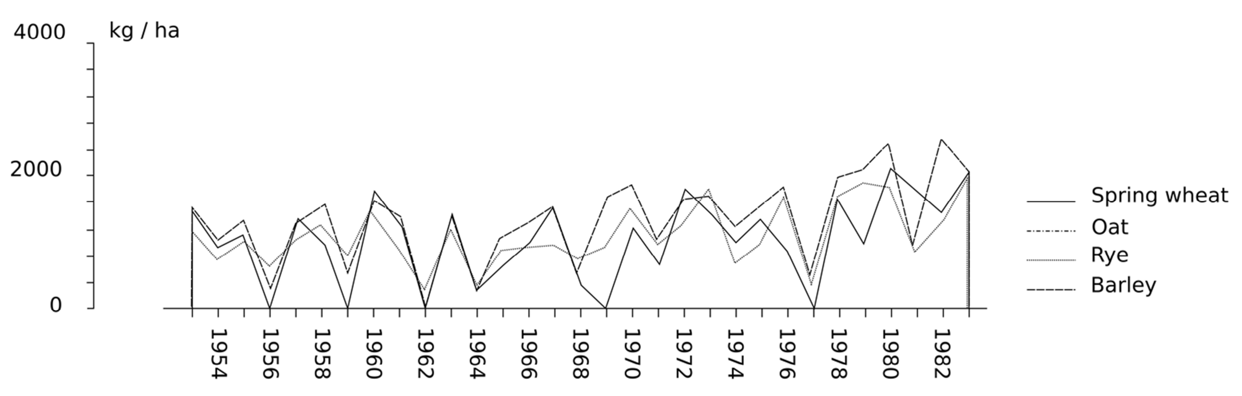

Figure 2, total amount of cereal produced per hectare in North Ostrobothnia (redrawn after Kettunen et al., 1988).

In this northern climate, summer temperature is one of the most important elements contributing to a good harvest: During the Early Modern period, the mean summer temperature and harvest yield strongly correlated in south Finland (Holopainen and Helama, 2009). The correlation between the temperature and the yield is likely to be even stronger in northern Finland, where the growing season is shorter. Furthermore, Holopainen et al. (2012) suggest that the dependence of climatic events during the Little Ice Age were likely stronger than seen today as the farming methods have since developed.

Variation in summer temperature can be observed from different climate proxies. Warmer summer temperatures in Lapland have been observed during period AD 931-1180 and 17th century AD, until the beginning of middle 19th century AD, when a short cooler period took place (Helama et al., 2009). In Eastern Finland, varved lake sediments recorded a Middle Age anomaly, which was possibly caused by milder winters between AD 1060-1280 and several cooler phases (between AD 1300–1390, 1440–1560, 1640–1710 and 1770–1860) (Haltia-Hovi et al., 2010).

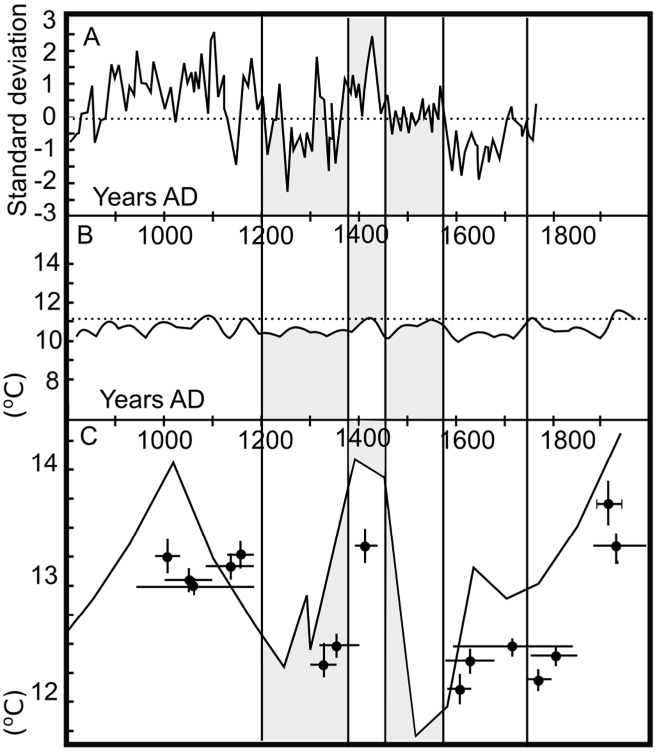

Figure 3. A summary of three different summer temperature reconstructions. A tree ring reconstruction of north Fennoscandian summer temperatures (Briffa et al., 1992) B. Multiproxy

reconstruction on summer temperature in northern Fennoscandia (McCarroll et al., 2013) C. Tree ring reconstruction of the summer temperature in Lapland (Helama et al., 2009).

In northern Sweden, tree rings indicate cooler summers from periods that took place between AD 1110-1150, AD 1190-1360 and AD 1570-1750 and increasingly warmer periods around AD 1140's, between AD 1580-1620 and around AD 1640's (Briffa et al., 1992). This study shows that cooler summers might have been more common between 1400 AD and the end of 1500 AD. Moreover, another tree ring study estimates a cooler period particularly between AD 1451 and1480, when the temperature was approximately 1.2 °C cooler than the mean temperature during previous 2000 years (Esper et al., 2012). Similar results to support the argument that there were in fact cooler summers were seen in tree ring data from Finnish and Swedish Lapland (McCarroll et al., 2013).

In summary, most of the climatic studies suggest that summers could have been warm when the first burials in Iin Hamina were made in early 15th century. Therefore, the burials in Iin Hamina were made at the point when summers became cooler.

The site Iin Hamina

The site Iin Hamina (Lat: 65° 19' 30" Lon: 25° 22' 14") is situated in the Northern Ostrobothnian region, approximately 35 km north from the city Oulu. The site is situated in the mouth of the river Ii in a small peninsula close to the Baltic Sea coast. The site was found in year 1898 during a field survey and was later partially damaged in the 1960’s due to pipe construction work (Kallio-Seppä 2010).

Vahtola (1988) argues that the name of the place 'Ii' originates from Sami language words iddja or ijje, meaning night. The prefix ii- also appears in central Finland, however, according to Vahtola (1988) it still should be considered as deriving from the Sami language. A clearer etymology for the ii-prefix has been recorded in place names in the Sami dominated areas of Lapland during the historical period (Vahtola, 1988). This may indeed be true; however, Vahtola (1988) does not explain why a significant coastal place would be named as night. It could, for example, suggest a long term or traditional night camp area. Nor is there discussion about the possibility of the use of this same prefix in Finnish, as the word in both languages is similar (fin. ilta). Whatever the etymology, the continuation of the use of the Sami and Finnish names indicates long-standing connections between these two language groups.

The earliest written information describing the place Ii is in a letter from the 1370's, which mentions a chapel in the mouth of the river Ii (Elo et al., 1998). The location of this chapel has not been discovered and it is unclear whether it was situated in the Iin Hamina. However, the location of the Iin Hamina cemetery could suggest that at least one church could have been located in the current town Ii before the foundation of the current church in early 17th century AD. It is not known whether there was a village or harbour, during the period when the Iin Hamina cemetery was used, but historical records show that between 1600 and 1700 AD Ii was intensively used as a marketplace.

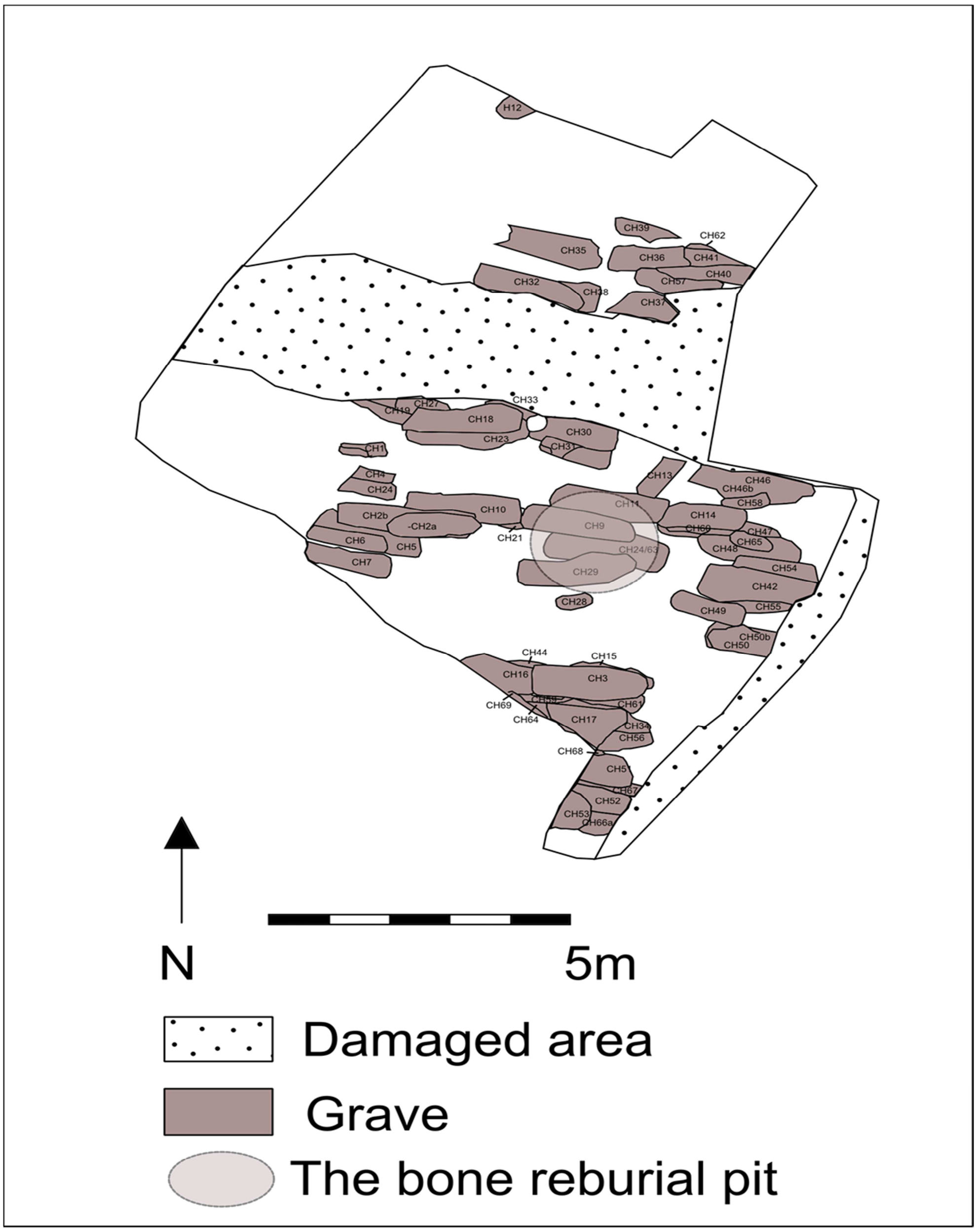

Figure 4. Map of the excavation area of the Iin Hamina site (Kallio-Seppä, 2011a). Most human skeletal material was discovered from the reburied bone pit.

Discoveries in the Iin Hamina excavation

The site Iin Hamina is the largest excavated cemetery in north Finland. Its importance in the studies of Medieval north Finland is unique, and therefore any information of this little known area and period is considered important. Only a small number of artefacts were discovered from the site, but many well-preserved human remains were found. Most of studies made from Iin Hamina have been published in the book 'Iin Haminan Kirkko ja Hautausmaa – Arkeologisia tutkimuksia' (2011, ed. Kallio-Seppä, Ikäheimo, Paavola), which is addressed to a public audience, and therefore does not include all the details which would be essential for scientific studies. However, this important evidence cannot be dismissed, as it is a significant part of the scarce information available from the site and skeletal collections. This chapter attempts to summarise the information available.

The site is situated in the modern village of Ii and is no longer visible above ground level (site visited by the author in 27.5.2014). An excavator was used in the removal of the topsoil, and the topmost layer consisted of recent materials from the 19th and 20th centuries. Beneath the modern layer, only a few artefacts and 13 coins were discovered. All material from those below modern layers dated from the 15th to 16th centuries CE (Kallio-Seppä, 2011b). In the excavated area, several different wooden structures were interpreted as the foundations of buildings. One of those structures had an east-west orientation, which according to Kallio-Seppä (2011a), could indicate that it was a church or a chapel. The burials underneath of this wooden structure differed in density, while all coins (dated 14th and 15th century) were only discovered inside the structure (Kallio-Seppä, 2011a). Kallio-Seppä (2011a) interpreted that the area, situated underneath the structure, had remained untouched and unused for burials, which could suggest that the structure was abandoned when the burials were made. The wooden structure has not been dated.

Green window glass fragments were discovered from the layers of the Iin Hamina cemetery. They were was typologically dated to the 16th century and were found in the soil contents of four graves. The glass was extremely rare at the time in Northern Finland and must have been highly valuable and shows the high status of the site. According to Kallio-Seppä (2011a), these glass fragments were possibly older than the graves in which they were discovered. Rather than being deliberately placed, it is quite possible that the glass had been damaged in a fire and left in the soil, which was later used for filling the graves. In the light of radiocarbon dates obtained from the site (see chapter 4) this theory seems plausible. There is no clear evidence that a church was situated in the site, but glass fragments suggest a high status building (Kallio-Seppä, 2011a). The main soil type in the area is sand, with occasional horizontal layers of clay between sand layers. All of the burials were made above one of the clay laminates. All the burials are rectangular, just slightly larger than coffins, but with rounded corners. Neither the history of land use in Ii nor the land use after burials is clear due to the modern activities that have lowered the current ground floor (thus making it impossible to estimate burial depth). The depth of the graves was 0.4 - 1.0 meters from the modern top soil (Korpi and Kallio-Seppä, 2011).

The burials were made close to each other or inter-cutting, and according to Kallio-Seppä (2010) the burial ground seemed non-organised. A total of 50 in-situ burials were discovered, including human remains from 70 individuals who were situated outside of the "church" structure while the rest of the skeletal remains of 20 individuals were found inside. Most in-situ burials were fragmented and thus sex (in 32 cases) or age (in 19 cases) could not be estimated. In the churchyard, both male (9 individuals) and female (9 individuals) were buried, and there is no difference between those found outside and inside the church. Fourteen of the skeletons found were children (>15 years old), one of which was less than one year old. Only one skeleton could be categorised as aged more than 50 years old (Korpi and Kallio-Seppä, 2011).

Table 1. Number of individuals; sex and age according to Korpi and Kallio-Seppä (2011).

Age/sex	Male	Female	Unspecified sex	SUM
0-15		1	13	14
16-25	7	2		9
>26	1	10		11
Unspecified age			19	19
SUM	8	13	32	53

Korpi and Kallio-Seppä (2011) also argue that number of children was high compared to the other Finnish cemeteries. It is clear that age estimation of children is easier than adults where as sex estimation is mostly impossible and leaving 19 possible male or female skeletons, which is almost as many as among the group of recognised sex. However, due to the small number of samples and the fact that not many Medieval cemeteries have been excavated in Finland, it is not possible to draw any clear conclusions.

Most of the skeletons were situated in individual burials, but on two occasions a child was buried together with an adult (graves 46 and 50) and in one case two children were buried together. Inside the church there were at least 18 individual graves. Burials were made close to each other, and were sometimes cutting each other or on top of each other. The site continued underneath modern buildings and thus it was not possible to excavate all human remains in the area, nor to determine the size of the cemetery. It was not possible to excavate some of the burials completely, and in these cases only the lower part of the skeleton was excavated, and thus sex or age estimation was impossible to conduct (Korpi and Kallio-Seppä, 2011).

All the in-situ burials were made in wooden coffins. The wood was mostly degenerated, so only fragments were discovered under skeletons, or shadows of the remnants were seen in the excavation profile. Exceptionally, a complete wooden area was found in the bottom of one grave: four individual barns were laid under the burial in grave 9. In 35 graves, iron nails were found, which is seen as evidence of wooden coffins. The wood from 12 coffins was analysed, and determined to be pine (Pinus) in 9 cases; spruce (Picea) in one case; and both spruce and pine in two cases (Korpi and Kallio-Seppä, 2011). Both are common trees in the area, and thus it is likely that local materials were used.

All graves were dug in an east-west orientation, heads were situated eastward. Only two bodies were buried in an NE-SW orientation inside the “church” structure. According to Korpi and Kallio-Seppä (2011) this might indicate continuation of non-Christian burial culture, or it might have simply been a mistake. All burials were made faces up, which is a very common practise in the Christian tradition. In 20 graves it was possible to estimate arm position but there were no general patterns. Different sized small circular stones were found from burials, but their connection to the burials was unclear. However, the soil in the area is well sorted sand, which does not include such stones. This would suggest that they were deliberately laid in the grave (Korpi and Kallio-Seppä 2011). In one grave there were remains of a shroud, though it is possible that others were already decomposed. One female in grave number 36 had fabric fragments and a copper cross jewel around her neck (Korpi and Kallio-Seppä, 2011). In grave number 44, under the burial, an individual human skull was found, and inside it an amulet made of seal tooth (Salmi, 2011a). Moreover, in grave 27 an iron bullet was found. Even though it was degenerated and thus made interpretation difficult, according to Nurmi (2011) it was clearly unused. It dates typologically from the 16th to 17th century AD (Nurmi, 2011).

A charnel burial pit was discovered. Most human skeletal remains were discovered from a bone pit. It was approximately 1.9 meters in length and 0.5 meters deep. It contained unburned human bones and some burned bones. Skeletal remains were mainly skulls and long bones. Bones were situated in random positions. Only one coin was found (dated 15th to 16th century), but it was discovered from filling soil and very likely reburied with soil. Lower and upper jaws were not attached, indicading that the reburial was made after the decomposition of soft tissue. It is possible that bones were reburied during the 1960's pipe work, but no clear evidence for this has been found (Korpi and Kallio-Seppä, 2011).

Skeletal remains have been studied for sex and age estimation, which were mainly determined from skulls. Based on facial measurements, sex was specified for 129 individuals, of which 62 were determined to be male and 67 female. Age was also estimated from teeth, which were possible to obtain from 149 body parts (Kallio-Seppä et al., 2009). Kallio-Seppä (2011 or 2009) does not mention whether age or sex estimation was done only from the upper jaws or if both jaws were studied. Therefore, it is possible that one person is recognised as two if both of his/her jaws were used, making it impossible to draw definite conclusions. Also, these are not reported at individual levels, which limits the use of biological sex and age in this study.

Table 2. Age variations in Iin Hamina graveyard based on Kallio-Seppä et al., (2009) investigation.

Age (years)	Quantity
0-10	7
10-20	24
20-50	87
50-	31
SUM	149

Coins

From the Iin Hamina excavations, altogether 13 coins were found (Kallio-Seppä, 2010). They were minted from the 14th to the 16th century (Jylkkä-Karppinen, 2010), which corresponds to the beginning of money usage in the area. The majority of coins (11 of them) were made in Sweden (Stockholm and Västerå), one in Turku (Finland, during Iin Hamina cemetery under the Swedish reign) and one in Oslo (Norway) (Jyrkkä-Karppinen, 2011). Most of the coins were found inside the structure, althought not from clear contexts, but from mixed soils. Only two of them could be connected to burials, whereas others were found in sediment layers above burials (Jylkkä-Karppinen, 2010).

Macrofossils

Five macrofossil samples were taken from five different graves from the possible location of the occupants' stomachs. Approximately 2 kg of soil samples was analysed from each sample. Only a few macrofossils were found, while several were recognisably burned. Results are shown in table 3 (Tranberg, 2011). Organic material preservation in Finland is poor, so these results were as expected. According to Tranberg (2011), the finds a indicate nutritious and moist soil. Tranberg (2011) argues that the typical soil found around the graveyard is coarse sand, so it is likely that these plants were either brought, or the land was farmed. Though most of the recognisable seeds were burnt, it is unlikely that those originated from food. It is also possible that the seeds had been accidentally dropped into the graves. The number of individual macrofossils was small, and thus any conclusions are uncertain.

3. Table: All of the samples were taken from the possible place of the stomach. (number = quantity, x = existence, underlined = sample was burned) Table is based on Tranberg (2011).

Grave number	CH2B	CH46	CH47	CH55	CH56
Sex/age of the human remains	M/young adult	Adult and child	Child (~15)	F/~30	M/adult
SEEDS:					
Brassica rapa spp.					1
Carex spp.					1
Chenopodium album	1			1	
Rudus ideaeus	1				
INSECTS:					
Otiorthyncus ovatus	1	2			
Formicidae		1			
OTHER:					
Cenococcum	x	x	x	x	x
Bone fragment		x		x	
Picea albies needle	2				
Betula bark	x				
Unidentified plant material	x	x			
Charcoal	x	x	x	x	x

Osteological analyses

Human skeletal remains

Height and weight estimation were carried out using the methods published in Maijanen and Niskanen, (2009), which resulted in a mean height of 156 cm and weight of 64 kg (Kortelainen et al., 2011). Women were approximately 154 cm and men 162 cm tall, which is a remarkable 11 cm and 15 cm shorter, respectively, than the current population (Kortelainen et al., 2011). It is possible that the majority of people buried in the Iin Hamana whose sex was not possible to determine were women, as the average estimation of the Iin Hamina height is shorter than during the 17th and 18th century in Oulu (even if the bones are approximately similar in length and the average height of women is the same in Oulu and Ii) (Kortelainen et al., 2011). Therefore, skeletons and individual bones for which sex could not be determined would affect the mean height of the Iin Hamina site (Kortelainen et al., 2011).

Fragmented animal bones

Fragmented animal bones were found in sedimentary layers either in graves or in the soil above. Altogether there were 3,122 pieces of bone (of which 3,111 were burned bone), a total of 1397 g. Most of the bones were badly fragmented and burned, thus knowledge which actual animal those are from remains a mystery. Animal and human bone (un-burnt and burnt) remains were found in the same context, which implies that bone fragments were likely in the soil and mixed during the burial processes (Salmi, 2011b). Few bone remains were recognisable, and therefore it is not possible to make any clear conclusions based on the data. However, the existence of animals such as cow and sheep/goat (which are not native in Finland) clearly implies that animal husbandry took place somewhere near the Iin Hamina site at the time when burials were made. As Iin Hamina was used for several decades as a graveyard, and there was no individual dating, it is unfortunately not possible to say clearly when those animals lived.

Table 4: Animal bones found in Iin Hamina. Table is based on Salmi (2011b).

Number	Context	Cattle (Bos taurus)	Sheep /Goat	Cinine (Canidea)	Cat (Felis catus)	Human (Homo sapies)
Grave 16	Grave 16					1
Grave 48	Grave 48	1				1
Sample from area CSY23	Graves 2 and 4-7	1				
Sample from area CSY33	Grave/mixed soil	1	1			
Sample from area CSY50	Grave/mixed soil					
Sample from area CSY65	Mixed soil			1		
Sample from area CSY77	Graveyards soil	1				
SUM		4	1	1	1	2

Paleopathological research of the human bones

Skeletal bones

Only adults were included in the study of the pathological changes in human skeletal remains. At the Iin Hamina site, human skeletal remains were better preserved in the bone pit than those found in the in-situ burials. This could be due to post-burial differences, or it is possible that only well-preserved bones were reburied when the pit was made. Paleopathological analysis was carried out with challenged bone preservation, and without any knowledge about bone pit's history. The results are shown in table 5 (Heikkilä, 2011). Since individual bones were studied, including pathological characteristics of the effect on bone preservation, it is possible that some of the individuals are researched several times. According to Heikkilä (2011), broken bones could have been counted as two. The book was written for general public audience, and it does not provide any information about procedures that were used in the research, or any information regarding how many bones were studied. Results are only shown as percentages without any indication of the counting method used (if these were the number of bones found, the percentage in type of bones, or from the whole population). Therefore it is not possible to make any certain conclusions. However, the lack of rickets (vitamin D deficiency) is surprising, although this could be due to the limited preservation of the diagnostic bones.

Table 5. Results of paleopathological investigation of non-scull bones (in percentage). Table is based on Heikkilä (2011).

	Percentage of bones that are effected
DISH	
New bone formation under periostis	43,14
Osteoarthrosis	82,35
Osteochondritis dissecans	4,9
Schmorl's nodule	21,57
Ancylosis or ancylosis articulationis coxae	0
Eburnation	0,98
Spina bifida	2,94
Spondylolysis/spondylolisthesis	0
Rickets (vitamin D deficiency)	0
Trauma	2,94

Skulls

44 randomly selected skulls were examined by Heikkilä (2011). Twelve of the selected skulls were children, and were discarded from the study. Results are shown in table 6 in percentages. Some possible reasons for death were seen. According to (Heikkilä, 2011), cribra orbitilia and porotic hypertostosis originate from anaemia, which can be caused by disease (such as thalassemia) or a deficient diet. However, a more detailed study by Väre et al. (2013) shows that cribra orbitalia was common in Iin Hamina (effected approximately 20 % of skulls), and because it was found to be common in both sexes, it is more likely to be caused by pathogens (including anaemia, and possibly malaria).

Table 6: The table shows percentage of different illnesses observed from 33 investigated adult skulls (Heikkilä 2011).

	Percentage of bones that are effected
Cribra orbitalia	12,5
Erosive changes	0
Ossa suturalia	31,25
Endocranial woven bone formation	15,63
Scurvy	3,13
Sinuitis	15,63
Osteoarthrosis	0
Osteoma	0
Porotic hyperostosis	6,25
Trauma	3,13

Teeth

Table 7. Dental pathologies according to age (based on Vilkama 2011).

	Young (10-20)	Adults(20-50)	Senior(50-)
Caries	9%	9%	9%
Calculus	2%	9%	31%
Enemal hypoplasia	13%	8%	4%
Ante mortem tooth loss	-	93	205
Periapical abscess	-	14	14
Periodontitis upper jaw	-	17%	83%
Periodontitis lower jaw	-	17%	63%

Dental pathologies can be indicative of diet and general health. Most pathologies seen in the Iin Hamina, like in other archaeological populations, are connected to dental plaque, which is one of the key elements in dental pathogens (Vilkama, 2011). From the Iin Hamina site, the collection of 1,197 teeth in 303 jaws (both lower and upper) was studied. Several pathologies were determined, including caries, calculus, enemal hypoplasia, ante mortem tooth loss, periondintis and periapical abcesses (see table 7. and 8., Vilkama and Niinimäki, 2011).

Table 8. Dental pathologies according to sex.

Sex	Male	Female
Caries	13%	5%
Calculus	12%	14%
Enemal hypoplasia	10%	7%
Ante mortem tooth loss	127	116
Periapical abscess	4	13
Periodontitis upper jaw	23%	35%
Periodontitis lower jaw	28%	32%

Dental hypoplasia is indicative of dietary stress such as starvation, but can also form during other physical stress, such as illness (Spencer Larsen, 1997). Of the Iin Hamina teeth, only eight percent of investigated teeth had dental hypoplasia, of which none were reported as strong. This could mean that dietary stress (if there was any) was brief (Vilkama and Niinimäki, 2011). This was mainly identified from the incisors and canine teeth and in young individuals (Vilkama and Niinimäki, 2011). Enamel in these at the latest teeth develops before the age of five (AlQahtani et al., 2010). Moreover their results suggest a strong age correlation with dental periodontitis, which suggest that young people had a more coarse diet, possible also higher levels of carbohydrates in their diet, which increased with age (Vilkama, 2011). Low levels of dental calculus and caries, wearing pattern, and dental pathologies suggest that the diet in Iin Hamina was low in carbohydrate, and most likely high in protein (Lahtinen et al., 2013; Vilkama and Niinimäki, 2011).

Summary

Iin Hamina cemetery is the largest burial site excavated in North Finland. The coin finds date typologically from the 15th and 16th century AD (Jylkkä-Karppinen, 2010). Three other artefacts were discovered from the Iin Hamina (a cross feckless, a seal tooth pendant and a bullet) (Kallio-Seppä et al., 2010; Nurmi, 2011; Salmi, 2011a). Dental investigation suggests high protein consumption among population in the Iin Hamina and increased soft foodstuff with age (Vilkama and Niinimäki, 2011).

PAPER 3

Mixed livelihood society in Iin Hamina – a case study of medieval diet in the Northern Ostrobothnia, Finland

This study investigates the diet of a large Medieval population buried in Iin Hamina, northern Finland. Iin Hamina is situated in close proximity to the Bothnian Bay coast and the river Ii. The cemetery dates from the 15th to 17th centuries AD. Carbon and nitrogen isotope compositions of human bone at Iin Hamina, and animal bones excavated in Northern Ostrobothnia from pre-industrial contexts, were analysed in order to study the main protein source of human diets. The results indicate that freshwater and marine fish were the dominant protein source for the people buried at the Iin Hamina.

Introduction

Finland is situated on the northern periphery of Europe's cultivation zone. The northern border of cultivation and, thus, the most northern limit of cereal ripening in Europe lie within the country (Soveri et al. 1956). Even if it were possible to have a successful harvest in favourable years in the Nordic climate, it is a very risky way of living and becomes more difficult with increasing latitude. Despite modern improvements of crop species genetics and farming technology, significant failures occur regularly; for example in 1987, 45 % of crops failed in Finland (Peltonen-Sainio and Niemi, 2012). Although still uncertain, it is assumed that farming reached the Northern Ostrobothnia either during the Iron Age (500 BC - 1200 AD) or the Medieval period (1300 - 1500 AD) (see figure 1. Koivunen, 1992; Vahtola, 1992). However, it is unclear how important domesticated animals and plants were to the farming communities in Finland and what proportion they represented of human diet. In this study we investigated the protein of the diet in northern Finland by undertaking stable isotope analysis of the population buried in the large cemetery at Iin Hamina, in Northern Ostrobothnia (figure 1). As subsistence based solely on terrestrial wild animals is unknown in northern Fennoscandia, the aim of the study is to investigate if terrestrial farmed foods are identifiable in human diets and if the population constitutes an isotopically homogeneous group. In case the farming contributes an insignificant proportion to the diet, it is likely that marine or freshwater fish may have been consumed in large quantities. Such evidence will contribute to a better picture of early social structure in the little-known region of Northern Ostrobothnia and a European population living near the Arctic Circle.

Figure 1. A map of Finland showing the site locations in Northern Ostrobothnia discussed in the text: Rovaniemi, Kuusamo, Tornio, Ii (Ii Hamina) and Oulu.

The area of Northern Ostrobothnia

A longstanding debate in northern Finland has focused on whether there was population continuity and if a migration occurred from the south in the Medieval period. Due the lack of research and materials, little is known of the Iron Age (500 BC – AD 1200) which proceeds the Medieval period, in Northern Ostrobothnia. It is still not known when farming started in Northern Ostrobothnia. Palynological studies to investigate the beginning of cultivation in the region and subjected to modern statistical methods have not been done. Such methods are vital: interpreting pollen analysis from the area is difficult because the coastal regions of Finland are natural environments for cultural indicator species and wild cereal-type pollen producers (see more Lahtinen and Rowley-Conwy 2013). One study shows sporadic cereal-type pollen from the bottom of the sedimentation of the sampling site upward (Reynaud and Hjelmroos, 1980). Contrary to Raynaud and Hjelmroos interpretation, Lahtinen and Rowley-Conwy (2013) suggest that this is more likely to represent evidence for local wild species than cultivation. Moreover, the quantities of cultivation indicators were low in quantity even near the surface, which suggests that cultivation was never large scale. This conclusion is supported by the fact that in the Early Modern Period cereals were imported into the region and by the 17th century AD only rye, turnips and barley were cultivated (Virrankoski 1973).

As discussed above, little is known of the occupation of the region during the Medieval period, but it is likely that either living conditions were not favourable for a farming-based society or that the population was not numerous. Julku (1985) suggests that even in the 16th century AD, it was not possible to survive purely as a traditional farming-based society in Northern Ostrobothnia and that the economy was mainly based on hunting and fishing; small fields and cattle herding provided only a minor input into diet. However, this is based on very limited historical evidence: Julku (1985) argues that the economy of the area is visible through the geographical location of the houses, the majority of which were situated either at river mouths or in coastal areas. Water would not only provide fish resources but also a fast transportation route. Moreover, Julku (1985) suggests that hunting was significant as furs remain important items for export during the Early Modern Period. In their opinion the importance of the utilization of wild resources can be seen in the spatial distribution of houses which are not found in village-like clusters during the Middle Ages and the Early Modern Period, but any direct evidence for this is still missing from the Middle Age period and Julku does not mention his source material for the interpretation of Middle Age subsistence. However hunting is documented in records from the 18th century AD where hunting is considered as an essential part of farming and not as a different profession (Soininen, 1974). Moreover, wild animal bones have been discovered in large quantities from Northern Ostrobothnian towns and settlements in contexts dating from the 17th to 19th centuries AD, and from rural settlement sites dating from the 16th to the 18th centuries AD (Puputti, 2008; Salmi, 2011a). Moreover, in archaeological animal bone assemblages from Northern Finland and Sweden, up to 30 % of the number of identified specimens (NISP) and up to 70 % of the minimum number of individuals (MNI) are wild animal species. These include wild birds, arctic hares, reindeer, and at coastal locations, seal (Salmi, 2011a, 2011b). Fur-bearing species are typically not common, and all the skeletal elements of the wild species are generally present in the dwelling-site assemblages, indicating that wild animals were utilized primarily for food (Puputti, 2010). In contrast, contemporaneous animal bone assemblages from Southern Finland typically contain only a few percent of wild animal bones (Tourunen, 2008).

The village of Ii and the Iin Hamina cemetery

The village of Ii (65° 19' 30", 25° 22' 14") is in Northern Ostrobothnian ~35 km north of the city of Oulu (see Figure 1). It is not known where the earliest Medieval occupation around Ii was or when it started. Neither is it known when the parish of Ii was established, but the presence of an existing chapel in Ii was mentioned for the first time in documents dating from AD 1374 (Elo et al., 1998; Vahtola, 1992). However, there is no historical or archaeological evidence of any settlements in Ii from that period (Tanska, 2011). On the assumption that a church or a chapel would not be built without a congregation and hence, a town (Tanska, 2011), it is accepted that there were permanent settlements in the town of Ii. However, this might not be the case: for example, in 17th century Finnish Lapland, churches were established in places people gathered for other reasons, such as markets or where reindeer migration routes would pass annually (Kylli, 2005, 2012).

The cemetery at Iin Hamina is situated at the mouth of the river Ii on a small peninsula in the town of Ii. The site was initially discovered in AD 1898 during a field survey by members of an historical society, and in the 1960s it was partly damaged during pipe construction work (Kallio-Seppä 2010). In the summer of 2009, a rescue excavation was undertaken by the Finnish National Board of Antiquities directed by Tiitta-Kallio Seppä (Kallio-Seppä, 2010). In total, 70 in-situ burials were discovered, but 65 individuals were excavated, the majority of skeletal material coming from a comingled charnel pit (Kallio-Seppä, 2010). Based on cranial remains, the minimum number of individuals (MNI) in the charnel pit was assessed 160 (Heikkilä, 2011). The remains in the charnel pit were possibly the result of reburied skeletal remains excavated during earlier construction work, when no archaeologist was present. In-situ burials were excavated separately and the pit as one unit. Next to the excavation area, excavator continued to dig, but in this case burials were only recorded from profiles, not excavated. This resulted additional the discovery of 40 burials and 20 skulls (Kallio-Seppä, 2010). The minimum number of individuals was calculated at 290 from excavation and following documentation of the profile. Kallio-Seppä (2011a) argues that, because the graves were closely packed and often inter-cutting, the cemetery was likely used over several decades or centuries.

The burials were made mainly without artefacts: the only grave goods recorded from the cemetery are 13 coins, one metal cross and one seal tooth pendant. The cross's closest parallel have been discovered at Kuusamo (North Western Finland) and several examples from Russian Karelia (Kallio-Seppä et al., 2010). The coins dated from the 14th to 16th century AD and 11 of them have been stamped in Sweden, one in Norway and one in Turku (Finland) (Jylkkä-Karppinen, 2010). In most in-situ graves a wooden platform was discovered under the body (Korpi and Kallio-Seppä, 2011). Graves were cut into yellowish sand but in some graves the filling was clearly different, being darker, and possibly organic-rich, sediment (Kallio-Seppä, 2010). Infilling included highly fragmented bone material. Fragments were small, mostly charred and the majority non-identifiable (Salmi, 2011b). Identified bones consisted of four cow fragments, one goat/sheep fragment, one dog and one cat fragment (Salmi, 2011b). Dental pathologies, such as a low caries rates and good dental health, amongst the Iin Hamina skeletal material suggests that the population’s diet contained a high level of protein whereas carbohydrate consumption was low (Lahtinen et al., 2013; Vilkama, 2010).

Unfortunately no palynological data is currently available from Northern Ostrobothnia, but several tree ring studies obtained from Finnish and Swedish Lapland suggest that the climate during the period the Iin Hamina cemetery was characterized by the Little Ice Age anomaly (Briffa et al., 1992; Helama et al., 2009; McCarroll et al., 2013). It affected north Finland during the 15th and 16th centuries AD. Compared to previous and relatively warmer periods, the cool anomaly most likely influenced cultivation success because early and late frost would have been more common and the growing season shorter.

Stable isotopes of collagen for dietary reconstruction

Carbon and nitrogen stable isotope analysis has been used successfully for many decades in archaeology (Bocherens and Drucker, 2003; Koch, 2007; Post, 2002; Schoeninger, 2014) (Bocherens and Drucker, 2003; Koch, 2007; Post, 2002; Schoeninger, 2014). Reconstructions made from collagen are based on the fact that it is produced primarily from ingested protein (Ambrose and Norr, 1993; Fuller et al., 2005; Jim et al., 2004; Tieszen and Fagre, 1993) and that there is a trophic level increase of $\delta^{15}N$ and $\delta^{13}C$ values in each step of a food web (Schoeninger and DeNiro, 1984). The processes leading to this trophic level effect are not completely understood (Hedges and Reynard, 2007; Schoeller, 1999), however it has been reliably observed in several controlled feeding experiments (Ambrose, 1991; DeNiro et al., 1985; Hobson and Schell, 1996; Schoeninger and DeNiro, 1984; Sponheimer and Robinson, 2006). Studies on modern animals suggest that the trophic level enrichment of $\delta^{15}N$ and $\delta^{13}C$ values varies between 3 - 6 ‰ and 0 - 2 ‰ respectively (Bocherens and Drucker, 2003; Hedges et al., 2007b; O'Connell et al., 2012). A recent controlled diet study on modern living humans undertaken on hair suggests that the trophic level effect on the nitrogen isotope ratio in humans is closer to the upper end of the scale (i.e. ~6 ‰) (O'Connell et al., 2012).

At the base of the food web, plants have two main photosynthetic processes (C_3 and C_4) that lead to distinctly different carbon isotope compositions (van der Merwe, 1982). This difference is transferred in each step of the food web. However, in Finland, the C_4 carbon cycle is uncommon, as it is mainly used by tropical plants such as, millet, sorghum, sugar cane and maize, which are not indigenous to northern Europe and were unlikely to have been farmed in Finland during the period under investigation and millet cultivation was unknown in later historical periods (Soininen, 1974). Attempts at growing modern varieties of millet have been successful in Northern Ostrobothnia, but resulted in low yields, and the varieties tested were very sensitive to frost and were harvested before ripening (Saarinen et al., 2012). Therefore, it is unlikely that people in Iin Hamina would have consumed C_4 plants or that they would have fed them to domestic animals.

It has become clear that short term non-food originating causes can significant change the carbon and nitrogen isotope ratios in humans: for example body stress such as morning sickness during pregnancy or starvation can increase $\delta^{15}N$ values in rapidly growing tissues (Ambrose, 1991; Fuller et al., 2005; Mekota et al., 2006; Sealy et al., 1987) but the long term effects on bone collagen are not known.

There is also a small climatic factor that may affect $\delta^{13}C$ values (Ambrose, 1991; Hedges et al., 2004; Klinken et al., 1994). This is seen in the first step of the food web: $\delta^{13}C$ values in C_3 plants vary by as much as 1 – 2 ‰ depending on climatic conditions (Heaton, 1999). Therefore, it is important to have comparative appropriate faunal samples from the same environment when reconstructing human diet.

Typically the marine animals' bone collagen carbon isotope composition can be clearly distinguished from freshwater habitat sources such as lakes (DeNiro and Epstein, 1978; McConnaughey and McRoy, 1979). The Baltic Sea is a brackish area that has five major basins; the Bothnian Bay; the Bothnian Sea; the Baltic Proper; the Gulf of Riga; and the Gulf of Finland. It has been observed that the isotope composition of organic sediments in the Baltic Sea varies between basins and that their carbon isotope composition strongly correlates with salinity (Emeis et al., 2003; Rolff and Elmgren, 2000). Furthermore, the Bothnian Bay is situated in the northernmost part of the Baltic Sea, where the salinity of surface water is currently approximately 3 - 4 psu (practical salinity unit) or 1 to 3 ‰. Salinity in the Baltic Sea varies considerably and surface water in the Baltic proper can reach approximately 30 psu (Samuelsson, 1996). This is still significantly less than in the oceans: the salinity of the Atlantic Ocean varies between 34 and 37 psu (Antonov et al., 2010).

This strong link between salinity and carbon isotope composition can be explained as a mixture of two carbon sources from terrestrial and marine origin (Kiljunen et al., 2008; Ukkonen et al., 2014). This leads to a significant difference in isotope composition between the Baltic Sea and the Atlantic Ocean, which can be observed in marine animals such as cod (Orton et al., 2011). Although cod cannot breed in low salinity basins like the Bothnian Bay, variation in the isotopic composition of the species can be seen even within the Baltic proper and the Kattegat area (Barrett et al., 2011).

The Baltic Sea hosts faunal species originating from both freshwater and marine habitats. It has relatively low species diversity and therefore dramatic changes or environmental catastrophes can easily be seen in all the steps of the sensitive food web. The Isotope composition of the food web has varied during the history of the sea. This is visible in the bone collagen of seals, a top predator in the area (Ukkonen et al 2014). During the history of the Baltic Sea, seal bone collagen carbon isotope composition has been observed to vary in the brackish basins between -21.7 ‰ and -15.9 ‰ (Ukkonen et al. 2014). This large variation is due to changes in ecology and the carbon cycle during history of the Baltic Sea (Ukkonen et al., 2014). During a higher salinity stage of the Baltic Sea, between 6000 BP and 3000 BP, carbon isotope composition of seal bone collagen varied between -17.7 ‰ and -15.6 ‰ (Eriksson, 2004; Eriksson et al., 2008; Fornander et al., 2008; Ukkonen et al., 2014) However, thereafter, the Baltic sea has freshened and seal values have increased, especially in the Bothnian Bay where salinity has dropped dramatically from 10 to 11 ‰ down to 1 to 3 ‰ (Widerlund and Andersson, 2011, 2006). This is in agreement with modern observations of substantial organic freshwater carbon in the Bothnian Bay plankton (Rolff and Elmgren, 2000).

However, seasonal variation in freshwater-dissolved organic carbon (DOC) is high (Zwaifel et al., 1995) and seals are migratory animals. Nevertheless, because of the strong link between salinity and carbon isotope composition, we can expect higher seal collagen δ^{13}C values than has been observed in the earlier periods of the sea, during investigated period, especially in the Bothnian Bay area where salinity is at lowest. Variation in isotope composition between seals studied from various periods of the sea is large (Ukkonen et al. 2014), and therefore samples from different areas or periods from the Baltic sea are not comparable and samples which are used as reference values for reconstructions should be, not only from similar salinity stage of the sea, but also from a similar basin of the sea.

Material and Methods

Ninety-nine human individuals were sampled from the cemetery at Iin Hamina. Unfortunately, no uncarbonized animal bones were discovered during the excavation in Iin Hamina, thus the faunal data was supplemented with15 animal bone samples from Oulu (approximately 35 km to the south), Rovaniemi (120km to the north) and Tornio (approximately 80 km to the north-west),. The sites in Oulu are Franzeeninpuisto, Kajaaninkatu and Pikisaari. Pikisaari was excavated in 2011 by the National Board of Antiquities. Franzeeninpuisto was typologically dated to the 18th and 19th centuries AD and the dating was confirmed from historical maps (Hyttinen, 2012). Kajaaninkatu and Franzeeninpuisto were excavated in 2003 and typologically dated to the 17th to 19th centuries AD (Maijanen, 2003). The site in Rovaniemi, Ylikylä, was excavated between 1978 and 1979 and has been radiocarbon dated to the 11th to 17th centuries AD (Paavola, 1996). In Tornio, the site of Keskikatu was excavated during the summer of 2002 and typologically dated from 17th to 18th centuries AD (Herva, 2003).

To avoid the possibility of double sampling from the commingled burial pit, human bone samples were taken only from the mandible. From in-situ burials mandible was preferred but in 26 cases other types of bone were sampled (see Appendix 2). Two samples from individuals CH15 and 143A mandibles were sent to the Scottish Universities Environmental Research Centre AMS facility for radiocarbon dating.

Collagen samples were prepared in the Department of Archaeology at Durham University. The surfaces of the bones were cleaned using air-abrasion with aluminium oxide powder, photographed and weighed. The extraction method followed that of Brown et al. (1988). The samples were demineralized in 0.5 M HCL and heated for 24 - 48 hours at 75 ºC until denatured. All samples were filtered with ultra filters (30 kD) and the resulting solutions were freeze dried. Samples were analysed using a Costech Elemental Analyser (ECS 4010) coupled to a ThermoFinnigan Delta V Advantage in the Department of Earth Sciences at Durham University and ten samples in the University of Bradford with a Thermo Flash EA 1112. Carbon-isotope ratios are Craig-corrected for ^{17}O contribution (Craig, 1957) and reported in standard delta (δ) notation in per mil (‰) relative to the VPDB and Air scale. Samples were measured in duplicates and mean values are reported. Analytical error for δ^{13}C and δ^{15}N using international standards (Durham IAEA 600, USGS 24, USGS 40, IAEA N1, IAEA N2) were less than 0.1 ‰ and internal standards was 0.2‰. These were obtained as part of the isotopic analysis using internal standards (i.e., Glutamic Acid, 40.82% C and 9.52% N).

To ensure good quality collagen and to minimize the use of diagenetically alterated samples, several indicators were used to assess the quality of the sample: collagen yield (between 1 - 22%), and carbon mass percentage (26.0 - 43.6 %), nitrogen mass percentage (11 - 16%), carbon and nitrogen atomic ratio (2.9 - 3.6) (Ambrose, 1990; Schoeninger et al., 1989; Van Klinken, 1999).

Results

Radiocarbon dates

Two radiocarbon dates were obtained from individuals CH15 and 143A (Table 1). Dates ware calibrated with Calib 6.0 using the INTERCAL09 calibration curve. Results suggest calibrated probability distribution from 1430 to 1633 AD.

Table 1. Results from radiocarbon dates from Iin Hamina.

Individual	Material	Lab code	Date (BP)	Calibration (2σ, AD)	Reference
CH36	Bone	Hela-2303	472±30	1409-1455	(Kallio-Seppä, 2011)
CH64	Bone	Hela-2543	324±30	1481-1644	(Kallio-Seppä, 2011)
CH69	Bone	Hela-2542	411±30	1430-1521 (0.883) 1579-1580 (0.001) 1591-1620 (0.116)	(Kallio-Seppä, 2011)
143A	Bone (mandible)	SUERC-48355	382 ± 34	1442-1527 (0.631) 1554- 1633 (0.369)	This study
CH15	Bone (mandible)	SUERC-48356	339 ± 34	1468- 1641	This study

Stable isotopes

Collagen was successfully extracted from 78 human and 22 animal; 22 human samples produced no or insufficient collagen. Samples were measured in duplicate and the mean values are provided in Appendix 2 and presented in table 2, and figures 2 and 3. The human samples carbon isotope ratios range from -22.2 ‰ to -18.8 ‰ (mean -20.4 ‰, SD (1σ) 0.7) and the nitrogen isotope range from 9.5 ‰ to 13.9 ‰ (mean 12.4 ‰, SD (1σ) 0.8 ‰).

Table 2. Summary of the results presented in Appendix 2.

	n	Mean δ^{15}N (‰)	SD δ^{15}N	Mean δ^{13}C (‰)	SD δ^{13}C	Range δ^{13}C (‰)	Range δ^{15}N (‰)
Humans	78	**12.4**	0.8	**-20.4**	0.7	3.6	**4.4**
Terrestrial animals	15	**4.4**	2.2	**-21.6**	1.2	4.1	**8.3**
Marine animals	5	**12.4**	0.8	**-18.4**	2.6	6	**2.3**
Aquatic animals	2	**10.4**	3.0	**-22.5**	1.3	1.9	**4.3**

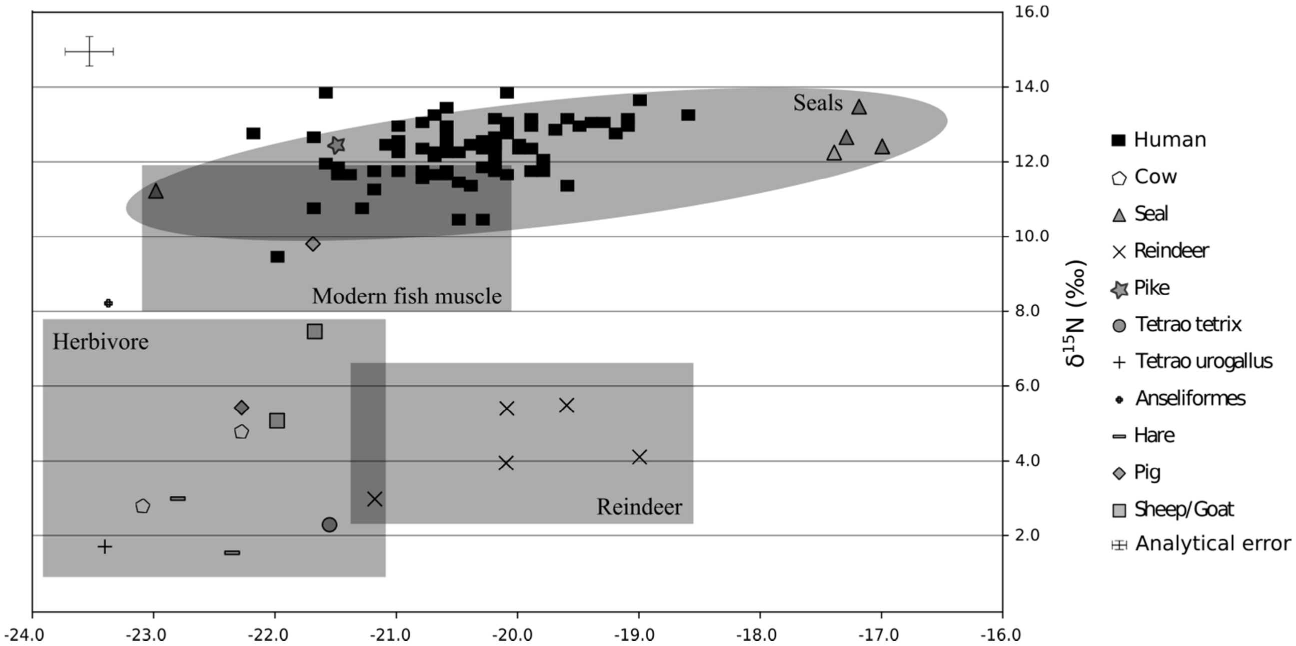

Figure 2. A plot of carbon and nitrogen isotope data for humans from the site of Iin Hamina and faunal samples from Rovaniemi Ylikylä, Oulu Pikisaari, Oulu Franzeeninpuisto, Oulu Kajaaninkatu and Tornio Keskikatu. Data for modern fish muscle is from (Sinisalo et al., 2006).

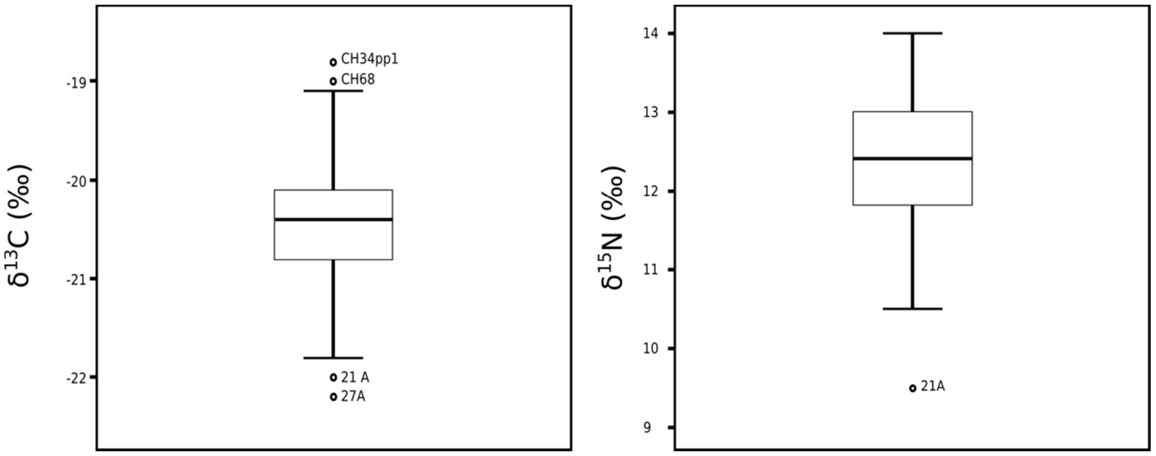

Figure 3. Box and whiskers plot of nitrogen and carbon isotope composition of humans of the Iin Hamina. Note the very different nitrogen composition of the individual 21A.

Sample characteristics were analyzed with SPSS 21 software. A Shapiro-Wilks test ($p > 0.05$), visual estimation of boxplot (figure 3), histogram and normal Q-Q plots showed that the human carbon isotope ratios at the Iin Hamina are normally distributed (Razali and Wah, 2011; Shapiro and Wilk, 1965) with skewness -0.114 (SE = 0.274) and a kurtosis 0.148 (SE = 0.541). For nitrogen isotope ratios, the Shapiro-Wilks test ($p = 0.007$) suggests that the nitrogen isotope ratios are not normally distributed. However visual observation of the box-plot, the histogram, and Q-Q plot, supports that the data is approximately normally distributed. It is very likely that Shapiro-Wilks test failed to estimate the normality because the sample size is small, the variation on the data is small, and there is one significantly different data point (lower than Q1-(2.2 (Q2-Q1)) sample (21A) that affects the skewness and kurtosis of the data significantly (Razali and Wah, 2011). As a result of this observation, the sample 21A is assumed to be an outlier in the data set.

The carbon isotope ratios of the herbivorous animals range from -23.4 to -19.6 ‰ (mean -21.6 ‰, n=15, see table 2) and nitrogen isotope range from 1.6 to 7.4 ‰ (mean 4.4 ‰, SD (1σ) 2.2, n=15, see table 2). The reindeer samples have higher carbon isotope ratios than other herbivores except one (TOKE-4023). Furthermore, four seal samples have the highest δ^{13}C values of the samples, but one seal has a very low carbon isotope ratio of -23.0 ‰. The only fish sample of this study, a pike, produced a δ^{13}C value of -21.5 ‰ and a δ^{15}N value of 12.5 ‰.

Discussion

Radiocarbon dates

Five radiocarbon dates, have been obtained from bone material from Iin Hamina (Table 1). Three dates are from published literature and two were analysed in this study. Individuals CH15 and 143A were discovered in the reburial bone pit and these results are contemporary to the dates obtained from individuals from in-situ burials. This supports the assumption that secondary burials were made from bone material discovered during earlier construction works and both burials are likely to be from the same population (Korpi and Kallio-Seppä, 2011). The result for the sample CH69 should be viewed with caution, as the collagen yield obtained from the bone in this current study was very low, and the collagen yield of the dated bone was not published originally. The results are consistent with the dating evidence for the coins discovered from the cemetery (Jylkkä-Karppinen, 2010). These results strongly suggests that the cemetery was in use during the 15th to 16th century AD, until a new church was built in AD 1620 and a new cemetery was established at a different location in the town at which time the cemetery of Iin Hamina was probably abandoned (Kallio-Seppä, 2011a)

The bone collagen stable isotopes in Iin Hamina

Terrestrial isotope signature

The reindeer samples have similar carbon and nitrogen isotope ratios to modern caribou in Canada (δ^{13}C values from -20.2 ‰ to -18.8 ‰ and δ^{15}N values from 4.2 ‰ to 6.3 ‰) (Drucker et al., 2001). Furthermore, these values are typical for open-environment herbivores (Drucker et al., 2008). The two cow samples (2.8 ‰ and 4.8 ‰) have lower δ^{15}N values than those obtained previously from archaeological sites in Sweden: mean values δ^{13}C = -21.6 ‰, SD (1σ) 1.3 and δ^{15}N = 5.41 ‰, SD (1σ) 1.39, n=21 (Eriksson, 2004; Eriksson et al., 2008; Linderholm et al., 2008a; Linderholm and Kjellström, 2011; Linderholm et al., 2008b; Lindkvist, 2007). A similarcomparative range to the cows and hares can be discovered from archaeological contexts in Sweden: δ^{13}C values from -24.5 ‰ to -21.0 ‰, and δ^{15}N values from 1.8 ‰ to 3.5 ‰, n= 7 (Fornander et al., 2008; Kosiba et al., 2007; Linderholm et al., 2008a; Linderholm et al., 2008b). These suggest these animals had a similar diet, at a similar trophic level, in a similar environment: the common link could be that they all inhabited a forested, Boreal environment where the δ^{15}N values of plants have been shown to be low (Drucker and Bocherens, 2009). Furthermore, the low δ^{15}N values in cows may also indicate that manuring of fodder or intensive use of pasture land (i.e. nitrogen reuse) was not practised, as such practices have been shown to increase δ^{15}N values of plants (Bogaard et al., 2007; Fraser et al., 2011). This possible non-use- of pasture is also supported by the traditions of keeping cows in varied forested areas which has been documented in 17th century Finland and continued until the 20th century (Soininen, 1974; Virrankoski, 1973). Moreover, in Medieval and 16th century Northern Ostrobothnia, cattle were mainly fed with hay collected from natural meadows in the river valleys and coastal areas (Luukko 1954: 186–192, 462–479).

Two pig samples, from the city of Oulu, have the highest terrestrial animal nitrogen isotope ratios. This could be explained by the fact that the pigs were discovered from an urban centre (in the town of Oulu) and they are omnivorous and can digest human disposal, which would possible increase δ^{15}N values compared to animals digesting only plants. However, with only two samples, it is not possible to draw any conclusive statement about pig husbandry in general. Two goat or sheep (it was not possible to determine exact species) samples from Oulu have collagen isotope composition that are very similar to most herbivores in Scandinavia. This might suggests that these animals are kept differently to cows discovered from the same area, or that they have eaten human food waste with higher nitrogen isotope composition. In summary, the δ^{15}N values of herbivores range from 1.8 ‰ to 7.4 ‰, which is very low compared to published studies of archaeological remains from Scandinavia.

Marine and freshwater isotope signature

Fish are very rarely discovered from archaeological excavations in Northern Ostrobothnia. This might be due to preservation problems or that the archaeological methods used in past excavations failed to recover small fragmented fish bones. For this reason, only one fish bone from an archaeological context was measured. The δ^{13}C and δ^{15}N values of the pike in this study were -21.5 ‰ and 12.5 ‰ respectively, which are similar to isotope values measured from pike bone samples elsewhere: one sample in Sweden from Sigtuna (δ^{13}C -20.4 ‰ and δ^{15}N 13.1 ‰); one in Holmegard (δ^{13}C -22.8 ‰ and δ^{15}N 10 ‰); and seven from Denmark in Storelyin (δ^{13}C from -25.9 ‰ to -21.6 ‰ and δ^{15}N from 6.6 ‰ to 8.9 ‰, n=7) (Fischer et al., 2007; Kjellström et al., 2009). Pike lives both in freshwater and brackish marine environments. Both, the fresh water and the Bothnian sea (a brackish marine environment) carbon range of the food web in Ostrobothnia is currently unknown, thus the isotope ratio of the pike measured in this study cannot determine which environment this fish inhabited. A bird identified as belonging to the Anseliformes order (it was not possible to determine the species more precisely) had isotope ratios that were untypical for herbivores: some species of this order consume fish and a diet of freshwater fish may explain the low carbon and high nitrogen isotope ratio observed. The three seal collagen analysed in this study cluster together, but one seal carbon isotope ratio (-23.0 ‰) is lower. This could suggest a different origin than the Bothnian Bay area or that the carbon isotope composition range is much larger in the Bothnian Bay than the other three samples suggest

The human population

Collagen isotope composition of the Iin Hamina humans is normally distributed, apart from one outlier (21A). The individual 21A has a statistically significantly lower nitrogen isotope ratio than the rest of the population. This could indicate a diet containing relatively more terrestrial meat, or a significant amount of vegetables or cereals. These would be more difficult to get access to and were likely highly valuable at Iin Hamina, thus this difference in isotope ratios could indicate a higher consumption of these souces, i.e. difference in social status. A further possibility is that this individual emigrated from an area where a different diet prevailed but this would need corroborating with additional evidence such as strontium and oxygen isotope analysis.

Isotope methods have been used to study different past populations around the Baltic Sea. Research on early farmers in southern Scandinavia has shown that their diet was mainly terrestrial (Eriksson et al., 2008; Fischer et al., 2007; Fornander, 2006; Fornander et al., 2014; Lidén et al., 2003, figure 4) with debatable quantity of additional fish (Craig et al., 2007; Milner et al., 2004); For example isotope studies of early farmers sites indicate extensive terrestrial diet in Torsberg (mean $\delta^{13}C$ value -20.1‰, SD (1σ) 0.4 and $\delta^{15}N$ value 9.4 ‰, SD 0.9 (1σ) in the late Neolithic and Bronze Age) (Eriksson et al., 2008), the Resmo 3th phase (mean $\delta^{13}C$ value -20. 0‰, SD (1σ) 0.4 and $\delta^{15}N$ value 9.9 ‰, SD (1σ) 0.8) (Eriksson et al., 2008), or in Algutsrum (mean $\delta^{13}C$ value -20.0 ‰, SD (1σ) 0.4 and $\delta^{15}N$ value 9.9 ‰, SD (1σ) 0.8) (Eriksson et al., 2008). In these studies, the mean $\delta^{15}N$ values are typically less than 10 ‰, and $\delta^{13}C$ value approximately -20 ‰. Similar collagen $\delta^{13}C$ values in the Iin Hamina site and early farmers in south Scandinavia would suggest that the diet could have been terrestrial. However $\delta^{15}N$ values are higher, which suggests that the main source of protein in Iin Hamina is different.

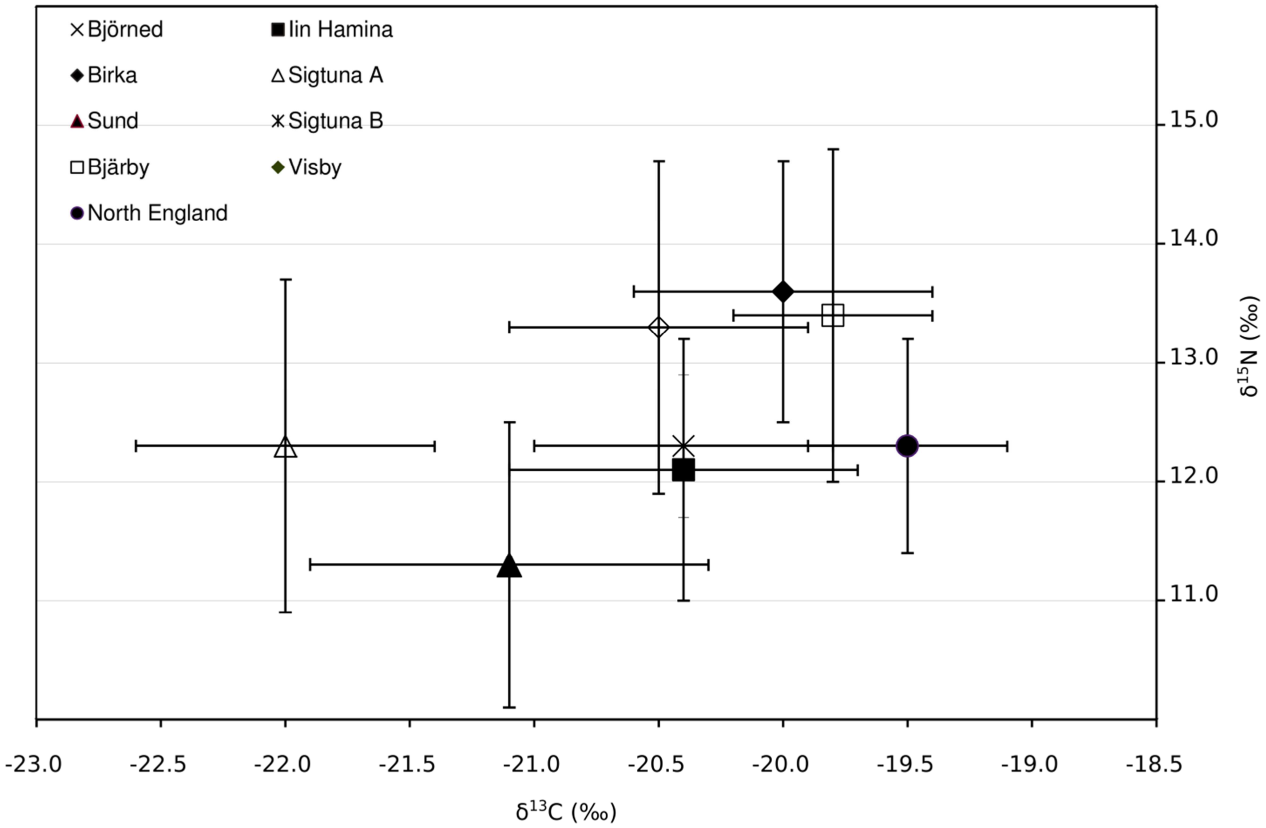

Figure 4. Scatter plot of Sigma 1 distribution of isotope composition from sites which have similar carbon or nitrogen isotope ration with the Iin Hamina site. Data according to; Björned (Linderholm et al., 2008a); Birka (Linderholm et al., 2008b); Visby (Lindkvist, 2007); Bjärby (Howcroft et al., 2012); Sigtuna (Kjellstrom et al., 2009; Linderholm and Kjellström, 2011), North England (Muldner & Richards, 2005). and Sund (Lidén, 2012) in Åland island.

A mixed diet has been observed with isotope and osteological analysis from human skeletal material in Viking Age Haithabu (mean δ^{13}C value -20.0 ‰, SD (1σ) 0.5 and δ^{15}N value 11.5 ‰, SD (1σ) 1.4) and its succeeder Medieval city of Schleswig (Schleswig Rathausmarkt late stage mean δ^{13}C value -19.7 ‰, SD (1σ) 0.8 and δ^{15}N value 11.9 ‰, SD (1σ) 1.1) (Becker and Grupe, 2012; Grupe et al., 2013). The sites are situated in the south coast of the Baltic Sea and close to freshwater, brackish and marine resources, and had a shift from more fish based to more terrestrial diet (Grupe et al., 2013). These results are very similar to the Iin Hamina isotope composition. However, the site is situated considerable more south (1500 km) in area where growing season is significantly longer and winters are shorter which makes it more suitable for economy based on farming.

Several sites in southern and central Sweden population's collagen isotope composition is overlapping with Iin Hamina (see figure 3): Sigtuna (Kjellstrom et al., 2009; Linderholm and

Kjellström, 2011); Björned (Linderholm et al., 2008a); Birka (Linderholm et al., 2008b); Visby (Lindkvist, 2007); Bjärby (Howcroft et al., 2012). Although some of the individuals from these sites have higher nitrogen isotope ratios than found at Iin Hamina, the diet was considered to be mainly terrestrial. Notwithstanding this evidence, fresh water fish consumption was considered by the authors as a possibility at least one of the sites (Sigtuna), but not as a main proportion of diet.

Although the range of human isotope ratios could indicate a terrestrial diet, there are strong arguments proposing fish as the main source of protein in the diet of humans at the Iin Hamina. Firstly herbivore nitrogen isotope ratios from the Northern Ostrobothnian area are lower than those obtained for archaeological herbivores from Scandinavia or in Haithabu and Schleswig (cow δ^{15}N values vary between 4.1 to 6.8 ‰) (Becker and Grupe, 2012). Cattle keeping has been considered as the most profound farming activity in the medieval and early modern Northern Ostrobothnia (Virrankoski, 1973). If dairy products or cow meet were the main source of protein at Iin Hamina, humans should have lower δ^{15}N values than those observed at Iin Hamina. However, with limited baseline faunal data, it is not possible to exclude all contribution of terrestrial animals, but it seems less likely scenario.

Secondly, because of a short growing season, it is very questionable if it would have been possible to provide enough winter fodder for domestic animals to be able to produce meat or milk products year around. Currently, around the Iin Hamina area the growing season is c. 180 days which means that at least half of each year farmers are completely dependent on winter storage. During the Iin Hamina burials, the Little Ice Age anomaly suggests that growing season was likely shorter (Luoto, 2012; Luoto et al., 2008). A short growing season would require intensive collecting and storing of animal food, for which there is currently no evidence during the Medieval period, although small scale collecting of fodder from natural meadows could have been practised (Luukko 1954). However, Soininen (1974) even suggests that collecting of winter fodder did not start before the 18th century in Finland. Moreover, in early modern Northern Ostrobothnia cows were mainly used for dairying, not for meat production, and butter was an important tax item (Salmi, 2011a).

Thirdly, the pike measured in this study has similar carbon isotope ratios to the humans at the “terrestrial” end of the carbon isotope ratio range. As pike is the top carnivore in the freshwater food chain, it is very likely that humans consumed same fish species . This could explain similar isotope ratios for humans and pike. Moreover, although modern samples are not necessarily comparable to pre-industrial samples, a variety of modern fish muscle carbon isotope composition range between -

23.0 ‰ and -20.0 ‰ with nitrogen isotope composition 8 ‰ to 12 ‰ in the Bothnian Bay area (Sinisalo et al., 2006). This would lead to very similar isotope composition that was observed from humans buried in Iin Hamina if 3 ‰ trophic level shifts would be used in estimation.

Fourthly, human at Iin Hamina have similar collagen nitrogen isotope ratio level as seals, which could suggest a similar trophic level. Although this conclusion assumes that humans and seals consuming the same diet would display a similar trophic level shift, it also implies that seals were not in themselves a significant part of the human diet. Moreover, whilst the nitrogen isotope ratio of the pike indicates it occupies a similar trophic level to the seals and humans, the carbon isotope ratios are consistent with a freshwater diet. As the human carbon isotopes range largely between the pike and the seals with no obvious correlated increase in nitrogen isotope ratios, it is possible to conclude that the dietary protein of the population in Iin Hamina was predominantly sourced from a mixture of freshwater and marine fish with a negligible input from terrestrial meat or crops.

Similar dependence on fish has been observed in other parts of the subarctic region. For example in the early historic population in Ontorio, Canada (Katzenberg, 1989). Hunter-gatherer-fishers in various northern climates have been dependent on marine mammals or fish (Coltrain, 2010). Marine dominant diet was also common in Mesolithic Scandinavia (Bonsall et al., 2009; Eriksson et al., 2008; Fischer et al., 2007; Jørkov et al., 2007; Lidén et al., 2003).

Conclusions

This study demonstrated that terrestrial and marine diets for humans in the Bothnian Bay area are not as clearly demarcated as previously suggested. These results suggest that at Iin Hamina both brackish and freshwater fish were consumed in significant quantities whereas domestic animals had a negligible input into the diet of humans. These results are consistent with a population following a robust a sustainable subsistence strategy that was suited to the high-latitude, coastal location of Iin Hamina, where it would have been very difficult to survive on domesticated crops, and animals alone.

In contrast, and somewhat surprisingly, one human individual had a lower $\delta^{15}N$ value than the general population, which could indicate the consumption of terrestrial meat or plants. In agreement with Dufour et al. (1999), Becker and Grupe (2012) and Grupe et al. (2009) this study shows that freshwater fish and terrestrial diets can have overlapping carbon isotope ratios, but it also shows that their nitrogen isotope ratios can be similar. Thus future work should focus on confirming fish consumption in studies where this is the case. Finally, it is recommended that further work to determine the stable isotope ratios of archaeological fish bones from the Baltic Sea region should be undertaken wherever possible as they are currently under-represented in the archaeological record.

PAPER 4

Biomolecular evidence for environmental adaptation in Medieval Iin Hamina, Northern Finland

Introduction

Dark, cold and distant, Finland is one of the most marginal areas in Europe where cultivation is practiced. Livelihoods dependent upon farming have always been risky and challenging, especially during cool climate anomalies like the Little Ice Age. In this paper we consider the adaptation and survival of a population at Iin Hamina in northern Finland during the last stage of this particular cool anomaly (Luoto et al., 2008) with stable isotopes from ten individuals' dentine incremental samples. Iin Hamina, the site at which the individuals were buried, is dated to between the 15th and 16th centuries AD (Kallio-Seppä 2011a, paper 3). This will increase our knowledge of subsistence during the Little Ice Age, as there is currently no information on the difficulties faced by populations surviving through this climatic fluctuation for most of the country. This study will examine the evidence specific to northern Finland, where our understanding about the period is generally quite limited. This land is not fertile, even in modern times, and the limited resources available during the winter months would have been key factors for survival in this area. How humans adapted to this environment is one of the most interesting questions of the human past in the north. The dentine incremental samples from the ten individuals buried in Iin Hamina are used to reconstruct dietary histories through their isotopic composition. This information will contribute to our understanding of dietary change and stress in the Northern Ostrobothnia during the Little Ice Age anomaly.

The Iin Hamina site

Iin Hamina is a large cemetery site in the modern village Ii in the Northern Ostrobothnian region. The site is situated on the riverbank of the river Ii, one the largest rivers in Finland, and close to the Baltic Sea coast. The burials at Iin Hamina were made during the 15th and 16th centuries AD (Kallio-Seppä, 2011a; Kallio-Seppä et al., 2009, paper 3). There are at least 290 individuals buried at the site (Kallio-Seppä, 2011a). Both in-situ burials and a large reburial of selected human remains were discovered during rescue excavations conducted in 2009 (Kallio-Seppä, 2010). The reburials were likely made during pipeline construction work in the 20th century in the village, though there is no direct evidence to support this theory (Kallio-Seppä, 2010). Two radiocarbon dates obtained from reburied human remains show that they are contemporary with those obtained from the in-situ burials (Korpi and Kallio-Seppä, 2011 and paper 3) and thus are likely to be from the same population. This site is the only largely excavated cemetery from this period in this area, and a large burial ground compared to contemporary sites which been excavated in Finland.

This site was selected because of its unique characteristics: the period it dates from, high quality of preservation, availability of samples, and its northerly location. The study area, Northern Ostrobothnia, is in close proximity to the Arctic Circle, but is in fact located in the subarctic climate zone; the main vegetation is Boreal forest (i.e. Taiga). Currently, the growing season in Ii is approximately 180 days. This means that for the period outside this growing season, approximately half of the year, very little plant-based food is available. Sources of protein are widely available because hunting and fishing may be practised year-round. Human diet cannot, however, be based solely on protein: medical studies suggest that protein intake cannot exceed approximately 35 per cent of total energy in the diet, as a higher intake would cause serious health problems (Bilsborough and Mann, 2006 and citations therein). Over-consumption of protein can cause poisoning and starvation symptoms in weeks, and for most human groups, protein intake does not exceed more than 25 per cent of their daily calorie intake (Noli and Averyb, 1988; Speth, 1987 and their citations). There are some exceptions: according to anthropological studies, indigenous northern Canadian people can consume up to 40 per cent of their daily energy as protein together with other animal based food-groups such as fat (Draper, 1977). In the case of Iin Hamina, it is not known whether protein intake was close to this maximum capacity, but a diet based solely on protein remains untenable in Northern Finland.

Methods

Dentine isotope analysis

Skeletal material in the Iin Hamina cemeteries has been previously studied carbon and nitrogen stable isotopes (paper 3). In that paper, these isotopes was analysed using the bone collagen of 78 individuals from the Iin Hamina cemetery and 15 animals from pre-industrial contexts excavated at the northern Finnish sites in Rovaniemi, Tornio and Oulu. Bone collagen is an optimal sample for reconstructing averages of long-term diet as it reforms throughout the entire human lifetime and has a slow rate of turnover and thus can represent diet over several decades (Hedges et al., 2007a; Sponheimer and Robinson, 2006). In contrast to this, most teeth develop during childhood and early adulthood, thus isotope analysis from dentine analysis can be used for temporal studies (Wright 1999; Howcroft et al. 2012; Eriksson & Lidén 2012). In particular, the isotope composition of incremental dentine samples provide a good record of breastfeeding and weaning (Eerkens et al. 2011; Beaumont et al. 2013; Burt & Garvie-Lok, 2013; Beaumont et al. 2015). In this study, however, we focus on the diet of the population and thus use samples from teeth (second and third molars are prioritised) that are likely to have passed weaning age.

Dentine has inorganic and organic components that form the structure of a tooth. The former is mostly apatite $[Ca_{10}(PO_4)_6(OH,F,Cl)_2]$ that can be found from different parts of the tooth, such as enamel and cementum as well as dentine (Linde and Goldberg, 1993). The organic fraction is mostly collagen and a small quantity of 'ground substance', e.g. non-collagenous proteins (Linde and Goldberg, 1993). The collagen proteins in dentine can be used in temporal reconstructions of diet (Drucker et al., 2001), as teeth do not reform after the completion of their growth (Balasse et al., 2001). Moreover, unlike bone collagen, which reflects diet over a long period (Hedges et al., 2007a), dentine collagen reflects isotope composition of diet during its development. Furthermore, even though dentine tissue does not reform, ion exchange is possible: this has been observed between fillings used in dentistry and the dentine (Knight et al., 2007). This suggests that ion exchange in the carbon composition of dentine might be possible. It should be noted, however, that the observed ion exchange of inorganic compounds was of a very small scale (ion exchange layers were microns) and thus do not noticeably impact upon interpretations made from the incremental dentine analysis.

Temporal reconstructions of diet with the isotope composition of dentine collagen can give information about sources of nutrition from infancy until the full development of the third molar. Even pre-birth conditions can be studied, as dentine starts to develop early in humans, and the first teeth develop in-utero (AlQahtani et al., 2010). The development of dentine starts during the initiation stage, and continues throughout the bud, cap and bell stages of tooth growth. The crown develops first, followed by root, continuing until the formation of the whole tooth is complete (Linde and Goldberg 1993). The incremental growth of the dentine collagen is apparent in conical layers of dentine formed concentrically within one another, growing like a series of overlapping sleeves (Hillson, 2005). It is likely that each sample in this study represents several of these conical layers because the sampling process was done using horizontal sections (see Beaumont et al. 2013); the method used in this paper averages the isotope composition of each sample. Consequently, the results are likely to present an underestimate of short term changes in diet. Any variation in isotope composition is more likely to represent annual or longer term changes, rather than those of a monthly scale, and can indicate if there were any problems resulting from the short-term dietary habits (Montgomery et al., 2013). This methodology allows the study of not only the victims of starvations and illness, but also individuals who survived through difficult times of hardship (manifested in dietary stress) into adulthood, and thus avoiding the 'osteological paradox', a term used to refer to problems relating to when the dead are erroneously portrayed as a truly representative sample of a past living population (Beaumont et al. 2013, Wood et al. 1992). Moreover, isotope analyses from incremental dentine collagen samples offer a better resolution than isotope studies made from bulk bone collagen (Beaumont et al. 2013; Montgomery et al. 2013; Sandberg et al. 2014).

Although the time scale of the dietary reconstruction is limited to the period of development for the dentine collagen, this method allows the study of temporal variations of diet in areas and from periods where historical records are not available, such as for Iin Hamina in Northern Ostrobothnia. Furthermore, in marginal climates, temporal reconstructions allows investigation into whether people had constant subsistence practises, or if some types were prioritised over others (as shown in studies of early farming as practiced on the Shetland Islands [Montgomery et al. 2014]). It is also possible that dietary stress is evident in the isotope composition of the dentine from the people of Iin Hamina. This should be apparent in such cases as that at Iin Hamina - similarly with regards to preindustrial Finnish crop yields, where most people did indeed survive harvest failures, many of them into adulthood (Hayward et al. 2012).

The reconstruction of temporal variation in diet can provide unique insight into strategies of adaptation and survival in marginal areas. It was previously mentioned in paper 3 that fish was probably the main source of protein, but, as noted above, humans require other nutrients than protein to survive and live healthily. There is no information yet available, however, regarding what the non-protein edibles consumed by people of Iin Hamina were. It cannot be determined through bulk collagen isotopic data, as bone collagen is mostly formed from consumed protein (Ambrose and Norr, 1993; Jim et al., 2004), although contribution from other macronutrients, such as fat and sugar, has been suggested as contributing as much as 20 per cent into the isotope composition of bone collagen (Fernandez 2012, Craig et al. 2013). However, a shortage of food can be observed: a controlled feeding experiment using mice revealed that a calorie restricted diet increased $\delta^{15}N$ values in bone collagen, although $\delta^{13}C$ values were not affected (Robertson et al. 2014). Likewise, in another study, this time on birds, an increase of $\delta^{15}N$ values was observed in avian liver and muscle tissue when a calorie restricted diet was introduced (Hobson et al. 1993) and has also been observed in assessments of excreta from fasting reptiles (McCue & Pollock 2008). An opposite result (i.e. a decrease of δ^{15}N values) has been observed in the blood of song sparrows when a restricted calorie diet was applied (Melospiza melodia, Kempster et al. 2007) as well as in puffins (Williams et al. 2007). Avian test subjects can, however, have substantially different metabolisms to mammals. Most importantly, the Robertson et al. (2014) study is in agreement with observations made on human hair from clinical studies conducted with patients suffering a restricted calorie diet as a result of anorexia nervosa (Mekota et al., 2006) and in the urine of bonobos (*Pan paniscus*), in cases where restricted calorie diets have also been monitored (Dechner et al. 2011). Therefore it is considered most likely that restriction on calorie intake will increase bone collagen δ^{15}N values, which will be observable in dentine collagen increments. Such an increase in nitrogen isotope composition when living on restricted calories has been observed in other cases using this method: for example, signals of starvation were observed in the human dentine incremental samples taken from individuals who died during the Irish Potato Famine (Beaumont et al., 2013b). In this particular study, we use analysis of incremental dentine isotope composition to observe temporal patterns in dietary variation and stress.

Materials

Eighteen human teeth were selected on the basis of the bulk collagen study (detailed in paper 3) isotope compositions. Samples were selected from individuals of varying bone bulk collagen isotope composition (see figure 1). This data set also includes the only significant outlier of the study, the individual 21A (paper 3). The second and third molars from each individual were sampled. Due to restrictions on sample availability, the permanent third molar of individual 21A and the second molar of individual CH15 were not assessed. Furthermore, the second molars of the individuals 144A and Se10 were not sampled as they had been damaged during the post excavation process. Altogether, nineteen teeth were used in this study. All sectioned teeth were fully grown with completed roots. Tooth crowns were not worn down to the dentine, apart from in samples of individual CH-34pp1; whose teeth were damaged leaving dentine exposed.

The age estimation of the dentine of each tooth is derived from the median age from the study by AlQahtani et al. (2010). For age estimation of an increment sample, the length of dentine development was divided equally by the number of increment samples (Appendix 2). The age of the development for each tooth varies between individuals (AlQahtani et al. 2010) and is likely to be approximation. The dentine of the first molars start to develop in utero (approximately in week 30) and is completed between the age of 8.5 and 12.5 years (median 10.5), but the growth of the tooth itself is completed between the ages of 7.5 and 9.5 years (median age: 8.5 years) (AlQahtani et al., 2010). The dentine of the second molars starts to develop between the age of 2.5 and 4.5 years (median 2.5), while the root is completed between the age of 12.5 and 14.5 years (median 14.5 years) (Al AlQahtani et al., 2010). The dentine of the third molars has a more varied initial development age, ranging between 7.5 and 14.5 years (median 8.5) and the root is completed between the ages of 17.5 and 23.5 years (median 19.5) (AlQahtani et al., 2010). AlQahtani's sample population included only 12 males and 12 females, which is a very small sample, and it is possible that variation in the growing age of the third molar could be even greater.

Laboratory methods

Each tooth was photographed and bisected vertically in half. From the selected half of the tooth, enamel was removed and all surfaces were cleaned with a hand drill before the samples were weighed. The sampling method used is described in detail in Beaumont et al. (2013) with the process of collagen extraction following that set out by Longin (1971). The treated half was then demineralized in a 0.5 M HCl solution until the sample was flexible and did not release carbon dioxide. Each half tooth was sliced into 1 mm layers and the layers were then placed in individual tubes. The tubes were filled with a pH 3 HCl solution and heated for 48 hours at 75^{o}C in order to reflux the collagen. Dissolutions were centrifuged for 4 minutes with 30k runs per minute and then freeze-dried. The result product is considered as dentine collagen.

Samples were measured at Durham University and the University of Bradford (see appendix 2). Carbon and nitrogen isotope compositions were measured in duplicate at the Durham University Department of Earth Sciences using a Costech Elemental Analyser (ECS 4010) coupled to a Thermo Finnigan Delta V Advantage. Carbon-isotope ratios were corrected for ^{17}O contribution (Craig, 1957) and reported in standard delta (δ) notation in per mil (‰) relative to the VPDB and AIR scale. Data accuracy was monitored through analyses of in-house standards, which are stringently calibrated against international standards (e.g., USGS 40, USGS 24, IAEA 600, IAEA N1, IAEA N2). Analytical uncertainty for $\delta^{13}C_{org}$ and $\delta^{15}N_{tot}$ measurements was ±0.1 ‰ for replicate analyses of the international standards and <0.2‰ on the replicated sample analysis. Total organic carbon and total nitrogen data was obtained as part of the isotopic analysis using an internal standard (i.e. Glutamic Acid, 40.82 per cent C and 9.52 per cent N). The University of Bradford duplicated samples were analysed with a Thermo Flash EA 1112 and coupled to a Delta plus XL via a Conflo III interface and reported in standard delta notation (δ) per mil (‰) relative to the VPDB and AIR scale. Based on analysis of the internal and international standard (IAEA N1, IAEA N2, IAEA600, ANU Sucrose, PEF1) accuracy of 0.2 ‰ or greater was obtained.

Diagenetic alteration of collagen discovered from archaeological contexts may have changed the original isotope composition. It has been suggested, however, that by using the following criteria, altered bone collagen samples can be recognized from the data:

1. The total carbon percentage was between 28.8 and 44.8 per cent (Ambrose, 1990).
2. The total nitrogen percentage was between 10.2 and 16.5 per cent (Ambrose, 1990; Van Klinken, 1999).
3. The collagen yield of the tooth was not lower than 3 per cent (Ambrose, 1990).
4. The nitrogen and carbon molecular ratio is between 2.9 and 3.5 (DeNiro, 1985).

The yield was measured from the whole tooth, but other criteria were obtained from each sample independently.

Results

The mean of the duplicate delta value, calculated and reported in the results, is presented in appendix 2, together with C/N ratios, C and N per cent. The quality criterions introduced above were met with most samples. 39 of the samples did exceed 44.8 per cent carbon limit. This could be due the carbon composition having been observed in bone collagen, and not in dentine. Even if this criterion was exceeded, carbon and nitrogen ratios fell within the limit and this suggests that the preservation of dentine was good and the isotope compositions were not altered. Moreover, analyses from dentine with even higher carbon composition have been shown to result in reliable isotope composition (Beaumont et al. 2014).

In a scatter plot of the isotope composition of the samples (figure 1), incremental samples cluster in close proximity (no more than one ‰ difference) to the bulk collagen isotope composition. Furthermore, no significant sudden increase or decrease of nitrogen isotope composition (tables 1, appendix 2, figures 1, 2, 3) apart from individual 21A and CH15 is apparent. A summary of the isotope composition of the teeth is shown in table 1. Visual observation of the isotope composition profiles in figure 3 shows that no similarities in variation were apparent.

Contrary to overall minor (less than one ‰) changes, the first molar of individual 21A shows an increase in the nitrogen isotope ratio of the crown (figure 3). Apart from that first sample of the first molar, the samples from the individual 21A cluster together with higher nitrogen and carbon isotope composition than the bulk collagen sample (figure 1). Based on a visual observation of the isotope composition temporal changes of individual 21A, there are two increases in the nitrogen isotope ratio; the isotope composition increases around ages of 4 and 9. The increase at approximately 4 years of age is visible in both first and second molars. Large scale change (more than 2 ‰) in δ^{13}C and δ^{15}N value of the CH15 third molar is clearly visible in figure 1.

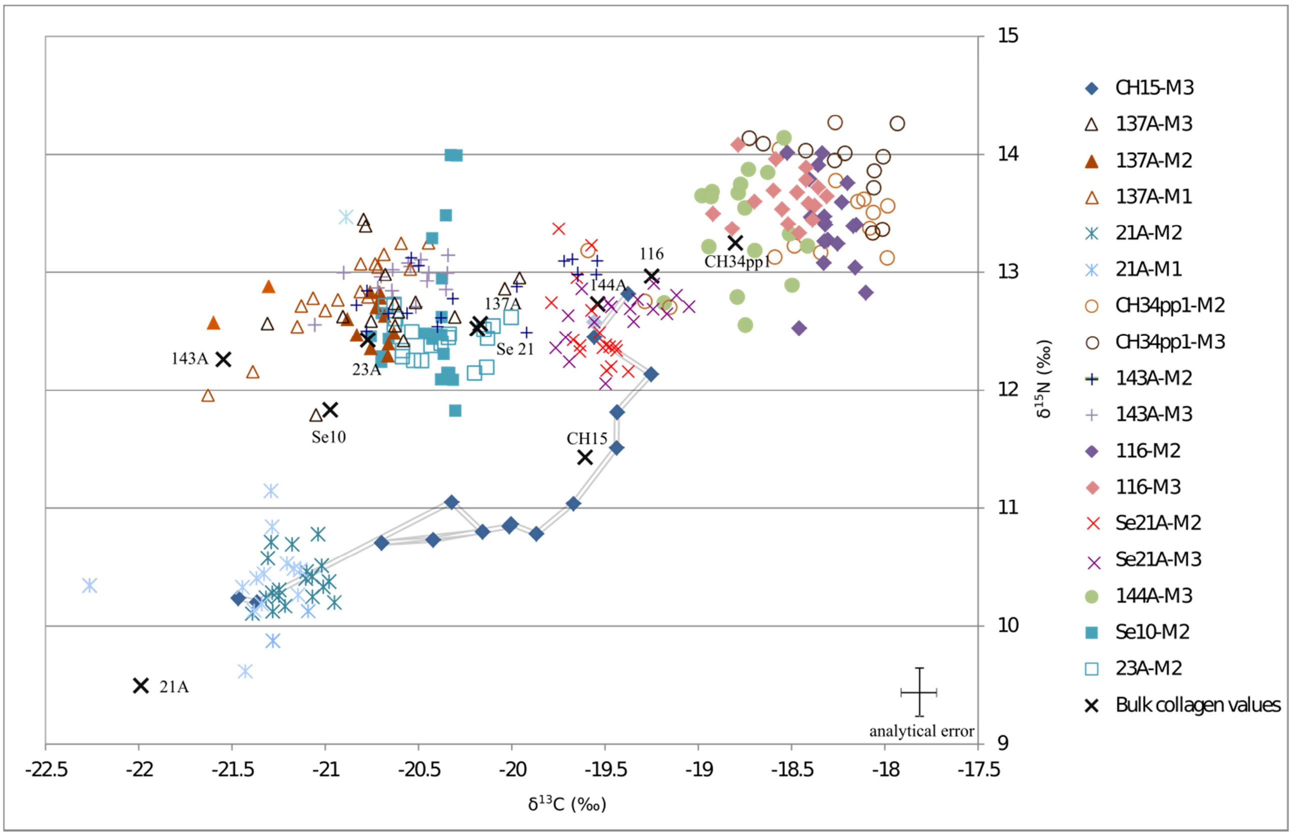

Figure 1. Scatter plot of the incremental dentine and bulk collagen sample's nitrogen and carbon isotope compositions, connecting line are on temporal order from grown to root (bulk collagen isotope compositions from paper 3). Note the individual CH15 radical changes (with connecting line) in both carbon and nitrogen values.

A first and second molar was studied from two individuals (21A and 137A, see figure 2). This was an important part for evaluating the reliability of methods for determining the age or the isotope composition of incremental. This was particularly important when comparing second and third molars, because age estimation of the third molar varies more than in other teeth (Al AlQahtani et al., 2010) and thus has the highest likelihood of being inaccurate. Visual observation of the isotope composition of incremental samples from the first and second molars of individuals 21A and 137A show that samples of the same age provided similar isotope compositions, with simultaneous changes, which suggests that the ageing is probably accurate and that the changes analysed from incremental dentine samples are indeed real changes. This is in agreement with Beaumont et al. (2013) and Fuller et al. (2003), which suggests that the method is reliable and that dietary changes can be studied from dentine incremental samples.

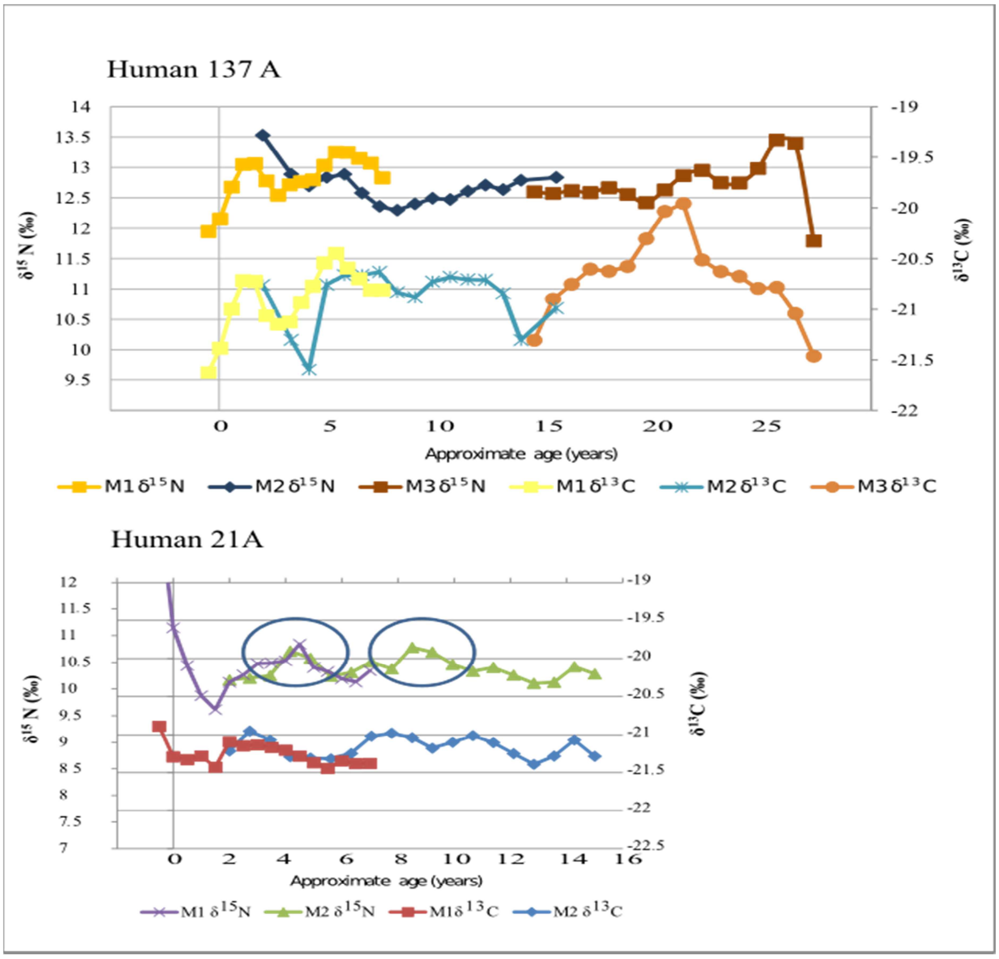

Figure 2. Isotope ratio profiles of Human 137A three molars and Human 21A first and second molar. The increase in nitrogen isotope composition when carbon isotope composition remains unchanged is circled.

Result characteristics

Table 1. Minimum, Maximum, Mean and range of $\delta^{13}C$ and $\delta^{15}N$ values and Spearman's rank correlation coefficient (r_s) of $\delta^{13}C$ and $\delta^{15}N$ values of each tooth. Means of each column is calculated into the last row of the table.

Tooth	**Min $\delta^{13}C$ (‰)**	**Max $\delta^{13}C$ (‰)**	**Mean $\delta^{13}C$ (‰)**	**Range (‰)**	**Min $\delta^{15}N$ (‰)**	**Max $\delta^{15}N$ (‰)**	**Mean $\delta^{15}N$ (‰)**	**Range (‰)**	**r_s**
IIHA-CH15-M3	-21.5	-19.3	-20.1	2.2	10.2	12.8	11.2	2.6	0.811
IIHA-137A-M3	-21.5	-20.0	-20.8	1.5	12.4	13.4	12.7	1.0	0.192
IIHA-137A-M2	-21.6	-20.6	-20.9	1.0	12.3	13.4	12.7	1.2	-0.157
IIHA-137A-M1	-21.6	-20.4	-20.9	1.2	11.9	13.2	12.8	1.3	0.954
IIHA-21A-M2	-21.4	-21.0	-21.2	0.4	10.1	10.8	10.4	0.7	0.207
IIHA-21A-M1	-21.4	-20.9	-21.3	0.6	9.6	13.5	10.5	3.9	0.679
IIHA-CH34pp1-M2	-19.6	-18.0	-18.4	1.6	12.7	14.7	13.4	2.0	0.432
IIHA-143A-M2	-20.8	-19.5	-20.2	1.3	12.5	13.1	12.8	0.6	0.516
IIHA-143A-M3	-21.1	-20.3	-20.6	0.7	12.6	13.1	12.9	0.6	0.509
IIHA-116-M2	-18.5	-18.1	-18.3	0.4	12.5	14.0	13.4	1.5	-0.273
IIHA-Se21A-M2	-19.8	-19.1	-19.4	0.7	12.2	13.4	12.5	1.2	-0.647
IIHA-se21-M3	-19.8	-19.1	-19.4	0.7	12.1	12.9	12.6	0.8	0.513
IIHA-144A-M3	-19.2	-18.4	-18.8	0.8	12.6	14.1	13.4	1.6	0.120
IIHA-CH34pp1-M3	-18.7	-18.0	-18.3	0.8	13.3	14.3	13.9	0.9	-0.428
IIHA-Se10-M2	-20.8	-20.3	-20.4	0.5	11.8	14.0	12.5	2.2	0.122
IIHA-116-M3	-18.9	-18.3	-18.5	0.6	13.4	14.1	13.7	0.8	-0.005
IIHA-23A-M2	-20.7	-20.0	-20.4	0.7	12.1	12.7	12.4	0.6	-0.191
IIHA-23A-M3	-21.4	-20.4	-20.9	1.0	12.0	13.1	12.5	1.1	0.810
Means	-20.46	-19.53	-19.93	0.9	12.02	13.38	12.58	1.4	0.19724821

Result characteristics were studied in order to compare incremental dentine isotope composition profiles (figures 3 and 4). Following a visual assessment of the results histograms for each tooth independently (appendix 3), it is clear that neither $\delta^{13}C$ nor $\delta^{15}N$ are normally distributed in any of the sampled teeth. Minimum, maximum, mean and range of the $\delta^{13}C$ and $\delta^{15}N$ values are listed in table 1. Rarnge (difference between minimum and maximum value) of $\delta^{15}N$ values is at highest 3.85 ‰ and at lowest 0.59 ‰ (mean 1.38), and for $\delta^{13}C$ values, is at highest 2.21 ‰ and lowest 0.42 ‰ (mean 0.92).

In order to test similarities in the behaviour of the $\delta^{13}C$ and $\delta^{15}N$ value curves (see Appendix 3), Spearman's rank order correlation was tested between $\delta^{13}C$ and $\delta^{15}N$ value curves (see table 1). This describes similarities in the behaviour of the curve; if the two curves are simultaneously increasing or decreasing (correlation) or moving in opposite directions (negative correlation). This could indicate whether or not changes in the profiles are related to dietary range (assumingly to correlate) or if nitrogen and carbon vary independently (as discussed before, calorie restricted diet increases $\delta^{15}N$ values, but not necessarily $\delta^{13}C$, thus limited correlation could indicate dietary stress). Variance in correlation is substantial, from almost perfect correlation (0.95) to almost zero correlation (-0.005), and both negative and positive correlations appear. Correlation coefficients are not normally distributed, nor are any of the parameters reported in table 1 (see also Appendix 5). Therefore statistical analyses which assume normality cannot be used. The different parameters of table 1 were compared though: Spearman's and Kendall's rank order correlation was run using SPSS 21. A negative correlation between the mean carbon isotope composition and correlation of the two curves (r_s) is statistically significant [Kendall's tau **(τ)** correlation coefficient and Spearman's rho (ρ)]. Surprisingly, range of $\delta^{13}C$ and $\delta^{15}N$ values did not correlate with any other variable or with each other (at 0.05 nor 0.01 confidence levels). Kendall's tau b test showed a negative correlation between min $\delta^{13}C$ and r_s (at level 0.05, correlation coefficient -0.428, significance 0.01) and the same correlation was also observed with Spearman's rho (-0.551, significance 0.018). There is less correlation of the simultaneous behaviour of $\delta^{13}C$ and $\delta^{15}N$ values curves (figure 3). Correlation is not a proof of causality, but, especially in case of dietary reconstruction where two variables are not independent, causality can affect correlation. In this observation, higher carbon isotope compositions exhibit a more simultaneous behaviour of the $\delta^{13}C$ and $\delta^{15}N$ values curves (i.e. higher r_s). This could suggest that when more marine resources were consumed, either diet is more monotonous (curves are flat), or that these individuals are less affected by other influencing factors in the isotope composition of human dentine, such as starvation, which could be expected to cause a different behaviour of the curves. As there is no correlation between range of $\delta^{13}C$, $\delta^{15}N$ values (i.e. flatness of the curve) and r_s, the later seems the more likely scenario. This interpretation is, however, provisional, as the sample size is small and therefore may be significantly affected by a single individual's lifestyle.

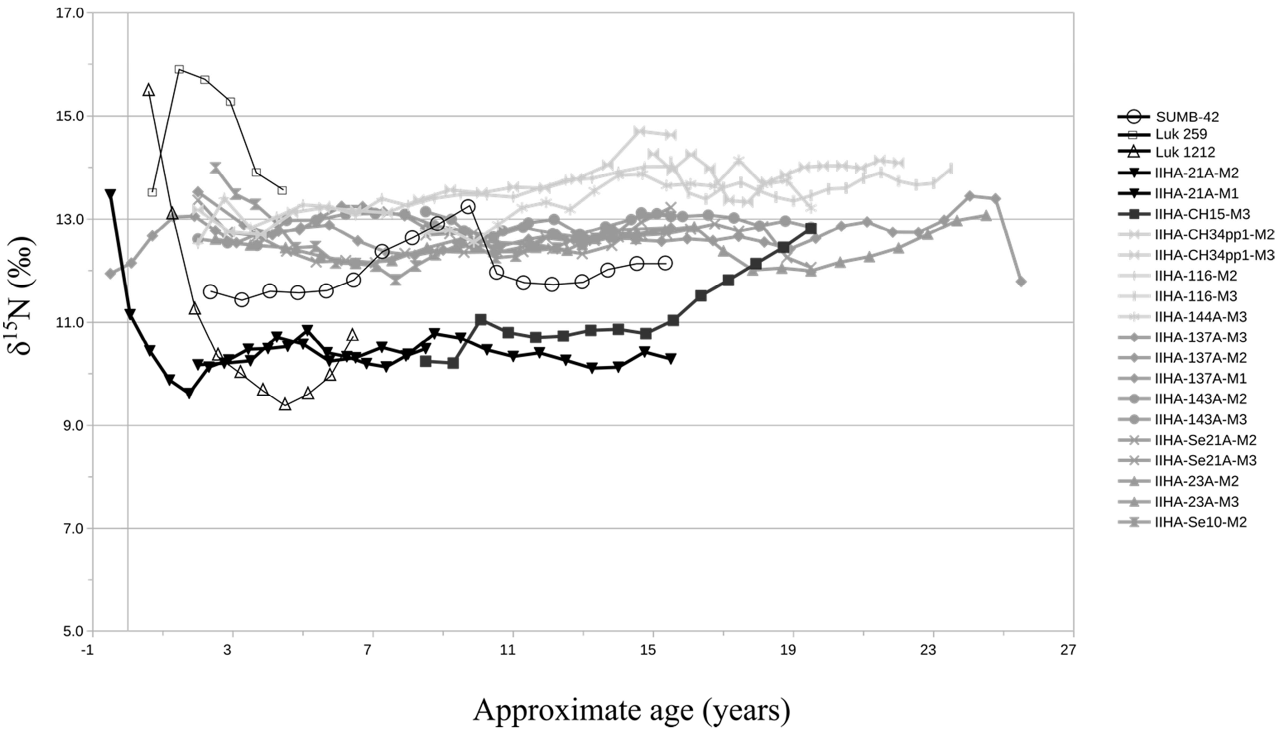

Figure 3. Summarised data (from Appendix 2 and 3) of incremental nitrogen isotope profiles. Samples SUM2 redrawn according to Montgomery et al (2013) and LuK 259 and Luk 121 redrawn after Beaumont et al. (2013a). Note the scale of the changes in the isotope composition.

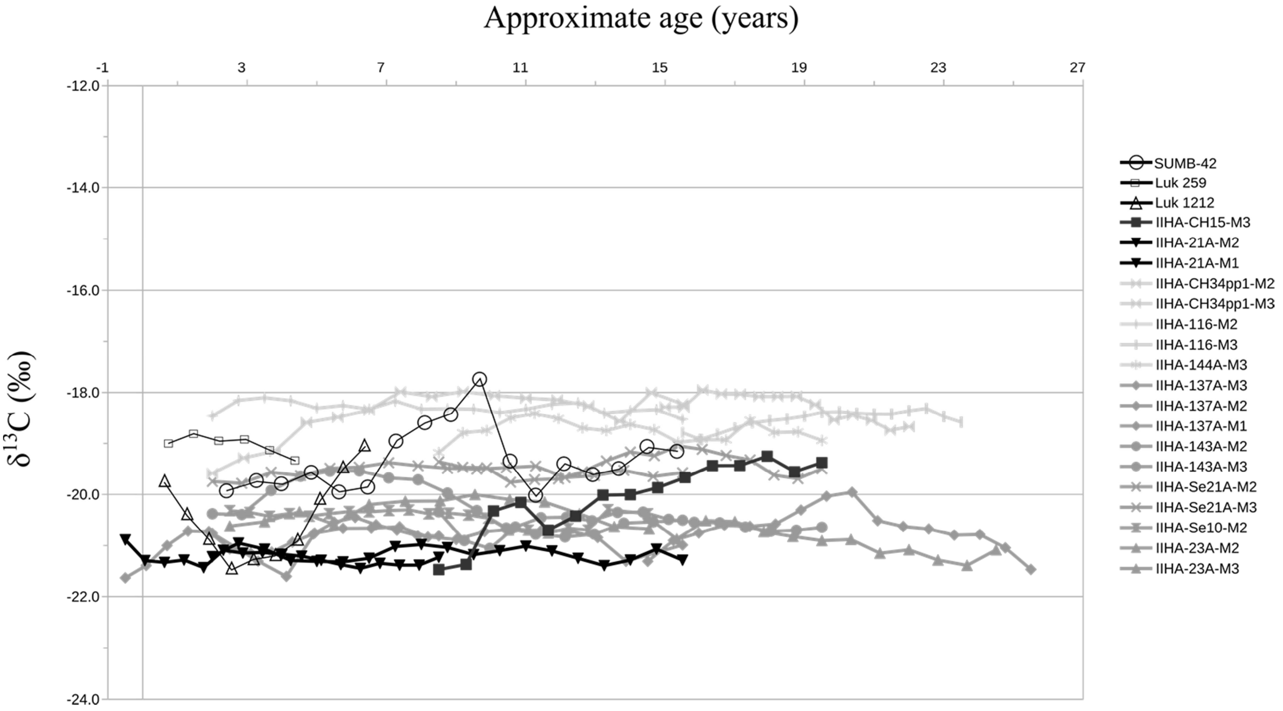

Figure 4. Summarised data (from Appendix 3 and 4) of incremental carbon isotope profiles. Samples SUMB-42 redrawn according to Montgomery et al (2013) and LuK 259 and Luk 121 redrawn after Beaumont et al. (2013a). Note the scale of the changes of profiles SUMB-42, Luk-1212 and IIHA-CH15.

Discussion

Visual assessment of the isotope compositions of the incremental dentine samples shows that the majority of the incremental dentine profiles can be described as flat (Figures 3 and 4, Appendix 3) and the range in $\delta^{13}C$ and $\delta^{15}N$ values is approximately 1 ‰ or less in most of the teeth and there is a strong correlation between temporal changes of $\delta^{13}C$ and $\delta^{15}N$ values ($r_s > 0.4$ or $r_s < -0.4$) in nine of them. This range of 1 ‰ or less is observed in living humans with monotonous diet, too (Lovell et al. 1986). There are few exceptions to this general, small-scale range in isotope composition: A larger than approximately 1 ‰ range in $\delta^{13}C$ and $\delta^{15}N$ values (table 1, figure 2) is observed in the third molar (M3) from the individual CH15. This indicates a change in the diet, from the range of the individual 21A bulk collagen composition to the other end of the range of the bulk collagen carbon and nitrogen isotope ratios. Changes in CH15 third molar incremental samples correlate very strongly ($r_s = 0.8$) and thus likely indicate a significant change of diet towards more marine based subsistence rather than as a result of dietary stress. According to Kallio-Seppä (2010) the individual in question is female. As the wisdom teeth develop in early adulthood (Al AlQahtani, 2010), it is possible that this change could be due to mobility through marriage or some other social arrangement, or that the person had immigrated to the area and adopted the local diet. Isotope composition of the mandible provides an average of several years diet prior to death (Tricker et al. 2002). In this case, mandible collagen had not yet reached equilibrium with the new diet. Mandible collagen isotope composition does not reflect individual’s diet over longer period, and bone collagen isotope composition had started to turnover towards the isotope composition of the new diet (Figure 1). This would also suggest that the isotope composition derived from the diet of an individual can be restored, unaltered in dentine, that reconstructions from dentine incremental samples do reflect past diet, and that bulk collagen samples do not necessarily accurately describe the diet of the individual.

Another exception of the overall low variability is apparent in the profile of the first molar of individual 21A. The first incremental sample from the tooth shows a higher nitrogen isotope ratio than can be observed from the other samples from both molars (table 1, figure 3). It is likely that the first sample is anomalous and does not reflect the person's diet, but, this sample's isotope composition has developed in close proximity to the time of birth of the person or in-utero (Al AlQahtani, 2010). Therefore the high nitrogen isotope composition of the sample could be an indication of breastfeeding, child development in-utero, or that the mother had a different diet during the pregnancy. In clinical studies, babies’ nail keratin indicates that infants have a 2 to 3 ‰

higher keratin nitrogen isotope ratio than their mothers (Fuller and Fuller, 2006). Similarly this has been observed from a British medieval site, where the difference between rib and second molar crown indicates increased values by 1.2±0.4‰ for $\delta^{13}C$ and 3.2 ±0.8‰ for $\delta^{15}N$ (Fuller et al., 2003), and at an ancient Californian site with a 3 to 5 ‰ drop in $\delta^{15}N$ values after breastfeeding was recorded (Eerkens et al., 2011). There is, however, no indication of such behaviour in the $\delta^{15}N$ values, apart from for the individual 21A, as can be observed in both molars at the age of 4 and 9 years (see figure 2 circulated areas). This could indicate dietary stress, as only the $\delta^{15}N$ values are changing, whereas the $\delta^{13}C$ values do not (in agreement with Robertson et al. 2014 and Mekota et al. 2006).

Individuals CH34pp1, 143A, 116, Se21, and 23A show a rise in the nitrogen isotope composition of dentine close to the age 15 (Appendix 3 and 4)). As it is observed at around the same age, it could suggest that it relates to a growing spurt during puberty. The effects of growth spurts on isotope composition are unknown though, and consequently this interpretation remains provisional. Moreover, culturally driven short-term changes in diet cannot be excluded and these aspects require further consideration.

In general, only individual 21A showed signals of possible stress, and the nitrogen isotope composition increases twice. Although both increases are only approximately 0.5 ‰, first of the increases is recorded in both studied teeth and occurs without a change in $\delta^{13}C$ value. This could indicate that the individual experienced dietary stress at two different points during her growth. This individual is an outlier in the bulk collagen samples though and probably cannot be considered representative of the broader local population (paper 3). The possibility that this person originated non-locally should be investigated with strontium and oxygen isotope analysis. Only then it would be possible to determine if dietary stress can be verified during the Little Ice Age period from Northern Ostrobothnia using this sample.

There are several possible explanations for the observed results. Firstly, due to a lack of indication of starvation, it is possible that cultivation did not play any significant role in the diet of people of Iin Hamina and thus harvest failures during the Little Ice Ace did not cause famine. Even though the history of cultivation in Northern Ostrobothnia is unknown, pollen studies indicate that it was likely very small scale (Reynaud and Hjelmroos 1980, Lahtinen and Rowley-Conwy, 2013) and it is therefore possible, that the climate did not have a significant impact on resource availability. In such a scenario, the little Ice Age may not have had a discernible effect on the subsistence of the people in Iin Hamina meaning that there would be no sign of dietary difficulties to be found. Secondly, the sample size is small, consisting of only ten individuals, it may quite easily not demonstrate the average diet of the general area. For most individuals included in the study, two teeth were studied, which means that the period of reconstruction is approximately twenty years per person. Consequently, this may be a more likely interpretation that there was no significant dietary stress or shifts in subsistence during this period.

Subsistence in marginal areas: Iin Hamina in Northern Ostrobothnia

Failures in farming are a common phenomenon in Finland and rural agrarian communities must have had survival mechanisms against regular poor yields. Recently, it has been argued that subsistence returned from farming to hunting, gathering and fishing after the Corded Ware period, even in the most prominent region in the south-western part of the country (Cramp et al., 2014). This creates the impression that it is impossible to have a sedentary, farming based society in throughout the majority of Finland without vital supplementary resources. Harvest failures and even dramatic drops in farming yields are still very common in Finland. Consequently, a purely farming-based society seems impossible without imports or supplementary wild resources.

Fish played a significant role in the life of humans in Iin Hamina (paper 3). The site is situated in close proximity to the Baltic Sea and the river Ii, where they could have accessed a constant year-round source of protein through this resource. Moreover, it is unlikely that the inhabitants of Iin Hamina experienced a lack of proteins, but rather a shortage of other vital elements of nutrition. As already mentioned, typically, human diet cannot exceed 30 per cent protein, and therefore more than 70 per cent of daily energy needs to be obtained from other sources. This non-protein component of the diet may comprise fat, such as seal fat used by native Americans (Draper, 1977), or carbohydrates, such as pine phloem as used by the Sami people in northern Fennoscandia and during the historical period, when they were often referred to as a starvation food by Finns (Zackrisson et al 2000). Salmon, one of the fattiest of fish, has a maximum of 13 per cent fat, which is 61 per cent of the calories derived from the fish, and 12 per cent protein which is the other 39 per cent of the energy (Finnish National Institute for Health and Welfare, FNIHW). The availability of salmon is seasonal though, and most fish in Baltic Sea have a relatively low fat content. For example, the energy from perch derives from 18 per cent fat, 82 per cent protein (FNIHW), which is too low to make it a viable candidate as a main or exclusive source of nutrition. In cases of failure in other resources, we would expect that fish consumption might have become a larger part of their diet. High protein consumption is known to increase the nitrogen isotope ratio (Sponheimer et al., 2003b). In order to supplement carbohydrates lost through poor harvest yields, the total amount of proteins in daily energy could have been increased, something which should be visible in the nitrogen isotope ratio. This was not, however, what was observed in the incremental analysis.

If farming was not an important part of people's livelihood in Iin Hamina, they must have had sources of food other than fish in their diet. In paper 3, we demonstrated that the consumption of fish was very likely an important part of the human diet for the people buried at Iin Hamina. Subsisting on only fish would not be enough for the human diet though, and other sources of nutrition (such as a constant supply of vitamin C) would be necessary. Presence of other nutrition sources, this is very likely as pathological changes of the sort that are caused by scurvy were detected in only one individual (out of 44 studied skulls) from the skeletal material from Iin Hamina (Heikkilä, 2011). This strongly suggests that they must have had a regular alternative source of vitamin C. As farming is not a reliable means of resource management and failures occur systematically, supplementary foods have been a vital part of survival in northern latitudes. The use of pine phloem as a food supplement is ethnographically and archaeologically known from the Northern Fennoscandian area (Zackrisson et al 2000). It provided an important source for carbohydrate and vitamin C during the winter months, a period when other sources are not available (Östlund et al., 2004). Moreover pine needle tea is high in vitamin C and was known by the Swedish army to cure scurvy during the 18th century (Schick, 1943). There is no record that pine needle tea or pine bark was used in Iin Hamina, but pine needles are available widely year-round in the area. The carbon isotope composition of the pine phloem and needles should be investigated as it is possible that these contributed to the isotope composition of the individuals.

There are several possibilities that made life sustainable in Northern Ostrobothnia without dependence upon exclusively farming. One option would have been extensive gathering and supplementary hunting. Currently, we have no direct evidence for gathering in the area during the period in question. Julku (1985) argues that farms utilized the wilderness extensively, something that is seen from the distribution of houses in the late 16th century: farms were situated far from each other, not in village like clusters, suggesting that the surroundings were an important source of wild food resources (e.g. berries). Survival was most likely more difficult during the Little Ice Age anomaly because the net primary productivity of the Boreal Forest correlates strongly with temperature (Zheng et al., 2004). The level of decreased productivity during this period (for example in wild berries) is not known. Furthermore, cereals and other cultivators that originated in much warmer climates might be much more sensitive to climatic factors than local wild species.

Consequently, a failed harvest might not necessarily have correlated with a low yield in wild resources.

The second option is that trade was used to supplement poor harvest yields, and that significant amounts of food were imported into the area. The cross pendant (originating possibly from Karelia) buried in the Iin Hamina suggests that trade was indeed practised (Kallio-Seppä et al., 2010), but the extent to which the community of Iin Hamina engaged in it remains unknown. Trade was certainly a common practice elsewhere in Northern Ostrobothnia during later periods, and even luxurious items, such as silk have been discovered (a silk glove has been recovered from Liminka layers dating approximately to the 17th century [Salmi et al., 2012]). Imported items and foods may have been an important factor in survival. This is seen to be the case in a study of 18th century Finland, which shows that during years of low rye yield, the poorest social class suffered much worse than people who could afford supplementary cereals (Hayward et al., 2012). As farming failures are common in the area, food supplement was not only used during exceptional years, but also more commonly as a source of food for normal diet. Surprisingly, Hayward et al. (2012) did not find a correlation with climate, cereal yield and death rate in pre-industrial south Finland. This seems to suggest that maybe people in Finland had different survival mechanisms that remain poorly understood. As the supplementary foods must have been an important component of subsistence practises, it is possible that some years in which farming failures occurred were not visible using the sampling method employed in this study, and that finer scale sampling should be used in order to detect such seasonal variation.

The third option is a combination of the above: trade, fishing, hunting and gathering providing the needed supplement for harvest failures. Unfortunately, it is not possible to say which of these options people in Iin Hamina predominantly relied upon. In the light of the preliminary evidence described here, however, it is likely that the people of Iin Hamina were well adapted to their local environments and thus, even during the Little Age, did not endure significant dietary stress. This, in turn, could suggest that the population was not heavily dependent upon farming, as our analyses show no indication of a calorie restricted diet, nor do they support arguments of dramatic change in food procurement. Moreover, because herbivores in Northern Ostrobothnia have a lower nitrogen isotope composition than has been obtained from those in South Scandinavia (paper 3), if these animals formed a substantial dietary component, it should be reflected in our incremental isotope analysis. We did not, however, observe significant changes in isotope composition of the dentine, which suggests that subsistence practises did not vary substantially on a yearly basis. This signature instead could be interpreted as evidence of that food production and gathering was constantly practised and that subsistence strategies remained similar throughout the lifetime of the individuals analysed from Iin Hamina.

Summary

It is possible to study environmental adaptation and periods of famine using isotope methods from incremental dentine samples as an indicator of long-term dietary stress. The results obtained from the individuals buried at Iin Hamina do not, generally, show signs of dietary stress. On the basis of this lack of stress, it is suggested that the local population were well adapted to their northern climate. One female individual, 21A, showed a small increase in the nitrogen isotope ratios of her incremental dentine samples, but not an increase in carbon composition, which can be indicative of a restricted calorie diet. The individual 21A also had a different diet when compared to the broader population buried at Iin Hamina, which could suggest that the person had different diet compared to others. The sample size used for this study is small and therefore these results may only be considered preliminary and cannot be used for the attempts at larger-scale interpretation. The reconstructions show diet for more than 20 years for most of the studied individuals, which would suggest that it was very unlikely that people at Iin Hamina at least experienced little in the way of dietary stress.

CONCLUSIONS

This dissertation is divided into eight chapters, but the core of the thesis comprises the four papers that make chapters 2, 4, 6 and 7 referred to as paper 1, paper 2, paper 3, and paper 4. These papers each cover different aspects of the research topic and deal with various different methods and techniques used over the course of the project. The papers are first summarized below and then discussed in greater detail.

Paper 1 discusses the difficulties in interpreting pollen data. The aim is to show that with single pollen data, in the absent of other proxies such as material culture or botanical macrofossils, it is not possible to determine if particular types of pollen derive from wild or cultivated species. This demonstrates that current evidence indicating small-scale farming before the Iron Age is not enough to support early farming.

Paper 2 summarises the radiocarbon dates pertaining to the first signals of farming (excluding single pollen grain evidence) from published studies and compares this to the population proxy obtained from archaeological radiocarbon samples. The main results from these observations were that an increase in population correlates very strongly with an increase in the evidence for farming from the last millennium BC onward. Moreover, the spread of cultivation was a complex processes and involved several periods of intensification of the spread and the Medieval expansions of farming was one of the final steps on the long lasting phenomenon.

Paper 3 is a case study focusing on the site of Iin Hamina, Northern Ostrobothnia. The site covers burials from 15th to 16th century (Kallio-Seppä, 2010). This period was primarily characterised climatically by the Little Ice, with shorter summers and consequently a shorter growing period. The Medieval period in Northern Ostrobothnia had previously been thought to be when the first farming and sedentary settlers from the south Finland spread into this area (Vahtola, 1992). However, this study showed that the main protein consumed at Iin Hamina was likely to be fresh water and marine fish, and not terrestrial animals as might be expected from a farming community. Moreover, this study showed that isotope reconstructions in the Bothnian Bay area are difficult to interpret as the main sources (marine fish, seals and terrestrial animals) may have very similar isotope composition. This may be problematic if the isotopic composition of local fauna and flora is unknown and comparison is based solely on studies from the southern part of the Baltic sea.

Paper 4 analysed ten individuals buried in the Iin Hamina cemetery using dentine incremental isotope analysis. This study concluded that the people of Iin Hamina most likely did not suffer from long periods of food shortage or other large scale dietary stress. Taking into account the climatic anomaly of the Little Ice Age during this period, these results further suggest that farming was likely not an integral component of subsistence practices in the Iin Hamina.

The beginning of farming in Finland and neighbouring areas

All of the cultivated plants and domestic animals characterising farming in Finland were originally alien to the area, with the exception of occasional wild boar invasions (Ukkonen et al., 2014), and thus cannot have been domesticated in Finland. It is likely, instead, that farming practises spread from neighbouring areas. Discussion of early farming in the Baltic countries is ongoing and it has been mainly based on pollen analysis (and therefore is affected by the same issues discussed in paper 1). Statistical analysis of pollen proxies from multiple sites in Estonia shows the beginning of cultivation to have taken place between 4000 to 2000 BP (i.e. 2000 BC to 0 BC/AD; Reitalu et al., 2013). However, domesticated animal bones have been discovered from the same context as Corded Ware pottery, but the bones have not been radiocarbon dated and thus the association remains speculative (Kriiska, 2003; Lõugas et al., 2007). One pig has been radiocarbon dated to 2700-2500 cal BC (Lõugas et al., 2007) but as the author state, it is difficult to distinguish wild and farmed individuals, especially in the case of a single find. A single burnt barley seed has been discovered intact from a Corded Were potsherd, but it has neither been published in the scientific literature nor radiocarbon dated (Jaanits, 1992). At this point, it is not possible to draw definite conclusions from this very limited evidence and it has been suggested that cultivation was not well established before the mid-Bronze Age (Lõugas et al., 2007). This research would be vital for understanding the spread of farming into Finland as the Gulf of Finland is narrow (approximately 50 km at the most narrow point) and can be easily crossed either during the summer by boat or during the winter on ice.

Although the southern part of Sweden is situated in a different climate zone than even the southwest part of Finland, this area is relevant as another possible route for the spread of farming into north-eastern Europe. It is also an area which has been studied intensively and thus is well known. Based on radiocarbon dates from an extensive collection of cereal macrofossils and domesticated animal bone, cultivation in South Scandinavia is estimated to have started between 4000 – 3700 BC (Rowley-Conwy, 2004; Sørensen and Karg, 2012; Sørensen 2014; Eriksson et al., 2008). Even though there has been discussion of whether Neolithic farmers consumed fish or not (Milner et al., 2004; Richards and Schulting, 2006; Craig et al. 2011), there remains no evidence of the intensive exploitation of seals, a significant contrast with northern Baltic areas (Ukkonen, 2002). Farming continued to spread during the Late Neolithic and Bronze Age towards Norway and North Sweden (Pedersen and Widgren, 2000; Prescott, 1996; Viklund, 2011). If farming spread from the Scandinavian Peninsula into Finland, it is likely that the timing of the spread would not have been earlier than this. Previously the evidence for farming in northern Sweden had been based solely on pollen, but recently several macrofossils have been directly dated to Bronze Age (1200 – 800 BC, Viklund, 2011). Although the evidence is still scarce from northern Sweden, it seems that there was an expansion of farming into the same latitudes and climatic zone within which southern Finland is also situated during this period.

The Åland Islands are situated between Finland and Sweden and operate as an autonomous area of Finland. The islands are visible from the Swedish mainland, and, once reached, Finland would have been visible within their eastward viewshed. They were likely an important navigational aid for water based transportation across the area. The first domesticated animals in the Åland Islands have been discovered from contexts associated with the Pitted Ware culture (Storå, 2000). The two oldest cattle bones date to 3400±60 BP (1881- 1585 BC[5]) and 3725±65 BP (2338-2310 BC[5]) and a sheep bone has been dated to 3710±80 BP (2397-2346 BC[5]) (Storå, 2000). Although it has not been confirmed whether these domesticates were of local origin, Storå (2000) claims that the bones are from complete skeletons which suggests that whole animals were butchered on the islands. A cereal macrofossil has been discovered from a Pitted Ware site, but neither the site nor the cereal has been radiocarbon dated rendering the reliability of the association doubtful (Lindqvist, 1988). Further doubt is cast upon this particular find as the Pitted Ware culture is not known to have practised farming elsewhere within its cultural sphere in Sweden (Eriksson et al., 2008). Although this argument clearly did not preclude the same culture from practising animal husbandry on the Åland Islands, it would be important to test this hypothesis with strontium isotope analysis. It is also likely that they interacted with farming communities and exchanged farming products with the Pitted Ware people, and thus a small quantity of cultivated products could be found from PW settlement sites. Nevertheless, sealing and fishing remained highly important activities for much later periods, even into the Bronze Age (Lindqvist, 1988; Siiriäinen, 1980). Thus the timing of the first farming in the Åland Islands remains speculative and more research is needed.

In mainland Finland, detection of milk lipid residues from a pottery sherd of the Corded Ware (CW) culture provides the earliest indirect evidence of animal husbandry (Cramp et al., 2014). As mentioned in paper 1, pollen studies do not indicate cereal cultivation during this period, which suggests that if there was cultivation, then it was of a very small scale and likely restricted to barley, which does not produce large quantities of pollen, and is therefore often not visible in pollen studies. Moreover, extensive macrofossil analysis of two CW sites did not recover any cereals

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[5] Calibration was done with Oxcal 4.2 using IntCal 13 calibration curve, the dates are reported in 95.4 % probability.

(Zvelebil, 1981). Äyräpää (1950: 29) states that the CW culture only occupied the region in Finland that is climatically and geographically most favourable to farming, which might support animal husbandry or farming. Moreover, Siiriäinen (1980) pointed out that assemblage from this culture lack hunting tools, which may also support arguments of a farming based subsistence. However, Nordqvist and Häkälä (2014) dismiss the discovery of the milk residue mentioned earlier, suggesting that the CW culture did not practise farming in Finland as, indeed, it did not in other parts of east Europe, but rather continued hunting, fishing and gathering. Their belief is based upon the location of the site and the lack of evidence for farming. No archaeological data suggest subsistence based on anything other than hunting, fishing and gathering. No farming related tools have been discovered from CW contexts; no grinding stones or sickles have been found (Asplund, 2008). Keeping significant quantities of animals even in south Finland requires a substantial supplement of winter fodder, and an appropriate toolkit for the collection of it. Nevertheless, during this period, which was characterized by the Holocene climatic optimum, population size correlated strongly only with the climatic factors, which suggests that if cultivation was practised it did not visibly affect in population size (Tallavaara and Seppä, 2011). Currently the evidence is insufficient to prove that farming was practised.

In the subsequent Kiukainen culture period, intensive seal hunting and extensive exploitation of marine resources was practised (Cramp et al., 2014; Meinander, 1954). According to Siiriäinen (1980), unlike the preceding CW period, hunting equipment has been found from the Kiukainen period. However, their toolkits also included quern-stones and sickles (Meinander 1954, Salo 1972, Siiriäinen 1980). As these tools were mostly discovered before the widespread use of radiocarbon dating in Finland, they deserve reinvestigation, particularly as many of these tools may also have been used by hunter-gatherers in the same way that pottery was adopted in Finland before the adoption of farming (Jordan and Zvelebil, 2010). Moreover, Asplund (2008) points out that these finds are undated and the security of their context is debated; the sites where these grinding stones have been discovered were used during multiple periods and these artefacts could date considerably younger. In contrast to the previous CW period, direct evidence suggestive of small scale farming has been obtained; one burnt sheep/goat bone has been dated to this period (3679±33, 2200 - 1950 BC; Bläuer and Kantanen, 2013). Although carbonate fraction of bone has been used successfully for radiocarbon dating (Laning et al. 2001), Burning can alter the radiocarbon age making the date appear younger or older depending on the firing wood, temperature and post depositional alteration. (Olsen et al. 2013, Zazzo & Saliége 2011, Van Strydonck 2009) Nevertheless, this could have been exploitation of domestic animals similar to what the Pitted Were culture practised on the Åland Islands: importing a wild animal for consumption.

The Kiukainen culture period was a time, in which genetic modelling has suggested a bottleneck in population (Sundell et al., 2010). This is visible also as a decrease in the population size proxy (Oinonen et al., 2010) and the density of settlement sites (Siiriäinen, 1980). Cereal starch grains associated with a Kiukainen vessel has been found, However, the pot sherd dates to the Bronze Age (1131-973 BC, Juhola et al., 2014). As discussed in paper 2, this date is either erroneous or alternatively the use of Kiukainen pottery was continued longer than has previously been suggested. Moreover, the authors admitted that the method itself is not completely understood, conceding that starch grains can vary considerably geographically, and that these results should be tested with further studies. With the limited history of investigation into the evidence for early farming, there remains much about the process that is unknown or more complex than we can currently comprehend. As Siiriäinen (1980) has already suggested, that using only archaeological data (the lack of hunting tools associated with the Corded Ware culture), it is possible that animal husbandry with cattle was practised in the coastal region of Finland, but that it declined during the Kiukainen phase (Cramp et al., 2014). If the Kiukainen culture did practise cereal cultivation and animal husbandry, the importance of farmed food remains unknownm, and it is possible that it was relatively insignificant as no large population growth is observed (paper 2). Moreover, their main source of protein was most likely derived from sealing, fishing and wild game hunting (Carpelan, 1999; Cramp et al., 2014; Siiriäinen, 1980).

Evidence of farming in the coastal areas does not necessarily mean that the rest of the country was occupied by farmers. Both the Corded Ware, and Kiukainen cultures exclusively occupied coastal areas of Finland (Carpelan, 1999; Nordqvist and Häkälä, 2014) leaving most of the country undoubtedly occupied by hunter-fisher-gatherers. Contemporary with the CW and Kiukainen cultures, the inner, eastern and northern parts of Finland were occupied by groups using asbestos ware, such as the Kierikki, Pöljä and Jysmä wares (Carpelan, 1999). The reservoir effect of radiocarbon dates obtained from food crusts on asbestos ceramics, and carbon isotope composition of the food crust suggests that fishing was an important dietary component in these cultures (Zhulnikov et al., 2012). Moreover, it is likely that these groups interacted and exchanged goods with one another, and according to Carpelan (1999), the Kiukainen culture emerged from these interactions between CW and inland Finland cultures and exhibits similarities to both traditions.

During the beginning of the Nordic Bronze Age, flint sickles first appear in the archaeological record, although a discovery is also mentioned from a Kiukainen site is (Salo, 1972). However, most of these studies were conducted before the widespread use of radiocarbon dating, and sickles are individual discoveries from unclear contexts, and thus the date of the sickles seems problematic. According to Asplund (2008) deposition of these sickles in wetlands might suggest that these objects were used as votive offerings, which might be reflective of the growing importance of cultivation. However, the Nordic Bronze Age in Finland was, according to Siiriäinen (1980), predominantly characterised by grey seal hunting. As mentioned in paper 1, according to Zvelebil, (1981) arable land only became important during the early Iron Age, and the proximity of fertile land and settlements began during the Bronze Age. This close proximity to former sea sediments (such as clay) can reflect the uplift of new fertile land or other available resources. Salo (1970) argues that Bronze Age settlements indicate year-around occupation, which could imply that farming started to take place in Satakunta area. According to Lavento (2014) the Bronze Age in Finland was characterised by small scale occupational centres and even the coastal areas considered to be part of the Nordic Bronze Age differed considerably from those of the South Scandinavian culture, and could have been characterised by different subsistence strategies, although these are not elaborated upon. There are a few indicators of farming from the Bronze Age: A single cow tooth has been discovered from a Bronze Age cairn (Bläuer et a. 2013); three macrofossils from the south Ostrobothnian area have been dated to the last millennium BC (Holmblad, 2010): the pollen evidence and population proxy would support the idea that farming did not spread to Finland before than the very late Bronze Age (during the last millennium BC), although this method fails to record very small scale cultivation. As already mentioned, the starch grains from a Kiukainen potsherd date to the Bronze Age (Juhola et al. 2014), which could have been part of this first establishment of farming. However, the importance of farmed food at this time remains unknown. It is still likely that the whole country was not dependent upon farming and that most of the intensification of farming took place during the Iron Age.

As discussed in paper 2, farming began to be practised on a larger scale and to have a more significant impact upon society from the last millennium BC, when an increase in both farming and population density begins. This apparent increase in significance does not preclude the practise of cultivation before this period, as pollen studies do not necessarily record small scale farming, but there remains insufficient evidence to support this theory. Therefore, a more informed understanding of marginal farming cannot be gained without intensive investigations using other methods such as macrofossil or lipid analyses. However, the most profound increase in the spread of farming and in its impact on the society is apparent during the Iron Age. There was a substantial decrease in the spread of farming c. 700 AD, and this date corresponds with the timing of a genetic bottleneck (Sundell et al., 2014). This event was likely connected to a climatic event during (paper 2) this period although such an association requires further investigation. Moreover, the scale and importance of any such event remains unknown.

The question of when the first farming in Finland began remains unclear. Tracing the earliest indicators is something of a slow and random process, as the majority of excavations in Finland are rescue excavations, where areas are threatened with destruction by construction work. In past excavations, macrofossils were not systematically collected, and their collection remains a non-standard practise. Moreover, macrofossils are not well preserved in the acidic soils, unless they are charred, which makes their identification more difficult. Therefore the discovery of cereal macrofossils is very rare and results are likely biased due the taphonomic aspects of the charring activity. Consequently, alternative methods of investigation, such as the collection and analysis of phytoliths, represent important complementary approaches for expanding our knowledge.

In archaeology we investigate material culture remains, but innovations involve also informational knowledge which the material culture resembles. The beginning of farming involves learning new types of activities. Farming is a continuous process from year to year, and consequently requires strategies for sustainable harvests and livestock to provide for future returns. It also requires different expertise than gathering, as most cultivated plants require unique knowledge of suitable growing conditions, fertilization processes, and general care and maintenance. Such information is highly important in marginal zones, such as Finland, where the timing of planting and harvesting is crucial for success. This would also mean that farming could not have been practised as an occasional pursuit, as it would have been imperative that this knowledge was passed on to future generations. Nunes (1999) has suggested that because of difficulties in establishing agricultural systems, cultivation was introduced on several occasions and that it played a major role in food production from an early stage. However, on the basis of the current evidence, it is difficult to interpret whether farming was first practised by a few individuals whereas others remained economically dependent upon alternative modes of subsistence: estimating the scale of farming during these early periods is highly problematic.

Contrary to what has previously been suggested, nothing supports the idea that the first farming in Finland was of a slash-and-burn nature (excluding use of fire for clearance). As mentioned in paper 1, there is no palynological evidence that indicates short cycles of fire ecology. This is especially the case in western Finland (Morris et al., 2015), where the earliest evidence of farming has been found. In addition to the lack of palynological evidence for this practice, there is also a scarcity of archaeological evidence. As slash-and-burn agriculture does not necessarily require unique toolkits, this may have decreased its archaeological visibility. In the face of this lack of evidence, we can reject the idea that farming developed from more simple (assumed to be slash-and-burn type) processes to more complex methods (permanent field cultivation). Instead, it is more likely that innovations were adopted from the neighbouring areas. This is seen in at least one site, during the Early Iron Age, where field cultivation was practised together with fertilization (Vanhanen and Koivisto, 2015). This relationship between these practises suggests that plant cultivation was linked to animal husbandry. Although compost may also be used, traditional methods where animals were kept in forests and manure was brought to the fields could have been practised (Soininen, 1974).

The importance of cultivation in Iin Hamina and Finland

As already discussed in the introduction, farming cannot be simplified as existing or non-existing, in marginal areas. Moreover, this study demonstrated that if we want to understand the effects of cultivation on population size and whole society, it is also important to understand the proportion of cultivated food in the diet. Therefore this question on beginning on the prehistoric farming practises is needed to connect to dietary reconstructions with isotope analysis.

Ideally, this investigation should have included several sites from different periods in Finland. However, this was not possible, due both to financial restrictions and to limitations in sites and materials available for study. However, this study has contributed towards the discussion of farming practises in northern Ostrobothnia during the climatic anomaly of 'the Little Ice Age' between the 15th and 16th centuries AD (Helama et al., 2009).

Communities contemporary to the society at Iin Hamina in the South of Finland practised farming, even in remote areas such as the Gubbacka settlement (close to modern Helsinki) where cereals were cultivated and animals were kept (Kivikero, 2010; Vanhanen, 2010b). Papers 3 and 4 indicate that the same was not true at Iin Hamina. It is likely that cultivation was a very limited source of food as subsistence was based predominantly on fishing. The population of Iin Hamina did not largely suffer from a lack of vitamin D (Heikkilä, 2011). Vitamin D deficiency is typical in modern societies that inhabit northern latitudes, one of the factors affecting it, is lack of exposure to sunlight (Webb and Pilbeam, 1990). This could suggests that either they spent more time outdoors or had food which was high in vitamin D. Dental pathologies support the suggestion that the diet at Iin Hamina was likely low in carbohydrates and high in protein (Vilkama, 2011). Consequently this suggests that fish were consumed in large quantities.

As discussed in paper 4, human diets cannot be solely protein based. However, many current hunter-gatherers occupying Subarctic or Arctic regions rely upon a seasonally high protein intake (Speth and Spielmann, 1983). This period is very stressful for the body, and inadequate nutrition can cause serious health problems (Noli and Averyb, 1988). For example Steffansson (1944) describes how protein poisoning can develop and kill a human in two weeks, if no food other than lean meat is consumed. This is also why modern hunter-gatherer avoids low-fat game during shortages of non-protein based foodstuffs (Speth and Spielmann, 1983). This period, when protein is available but the other components of the diet are absent, typically occurs during the winter and spring months. Humans can avoid protein poisoning by supplementing their diets with either fat or carbohydrates. As an example of a predominantly meat based diet, modern Arctic hunter-gatherers often use animal fat, which allows them to subsist almost exclusively on animal derived food (Sharma, 2010). The fact that humans cannot survive solely on a high protein diet also makes cereals highly important in the north, as they provide not only energy, but also a vital non-protein dietary component. This lack of nutrition rather than energy, makes non-protein dietary components vital for survival, and possibly acts as a limiting factor in population size. Incremental dentine analysis from the population of Iin Hamina does not suggest a shortage of food during their lifetimes (paper 4), and this can be interpreted as evidence that the population was well adapted to their local environment, even during the climatic fluctuation of the Little Ice Age.

It is possible that farming was never a dominant mode of subsistence in most parts of Finland. The climate in Finland remains generally unfavourable to cereal cultivation. Total failures still regularly occur and therefore it is vital to have a surplus production to supplement periods of shortage. For example in northern Ostrobothnia, failure occurs almost every third year in cereal cultivation (Kettunen et al., 1988). It is unlikely that the cultivation of cereals was easier in the past, and as it was not possible to rely on cultivation, it is very likely that farmers were required to exploit alternative resources (hunting-fishing and gathering) or engage in trade with other groups. Similarly, in other marginal areas, such as in Neolithic Shetland Islands (Montgomery et al. 2013) sporadic marine resources were used, in Indonesia (Wad et al., 1997) and the Amazonian rain forests (Gould 1985) hunting is practised alongside farming. Moreover, hunting and fishing are observed to have been an important part of the diet in prehistoric populations in the south-central Arizona desert (Szuter, 1991) and Jomon societies in Japan (Crawford 1992). This would suggest that in marginal areas, there is a phenomenon where subsistence strategies comprised various approaches, and not exclusively practises of cultivation or hunting, gathering or fishing.

As mentioned in paper 2, cultivation and population density increase simultaneously during the last millennium BC. This suggests that cultivation increased productivity in Finland and therefore allowed the population size to increase. Bearing in mind that most parts of Finland did not have any native nuts or acorns during these periods, there would have been a shortage of easily storable carbohydrates and fats. Berries may have been collected, but preservation is difficult with the exception of the lingonberry (*Vaccinium vitis*), cloudberry (*Rubus chamaemorus),* cranberry (*Vaccinium microcarpum* and *Vaccinium oxycoccos)* and black crowberry *(Empetrum nigrum),* in which their acidity serves as a natural preservative. However, berries decompose more easily than cereals and cloudberries and cranberries (which grow in peat bogs mainly in the North of Finland) are energy-consuming to gather and yield considerably less calorific return than nuts or acorns. Therefore, it is possible that cereals provided an increase in carbohydrate consumption during the critical winter/spring months when a scarcity of non-protein foods may have been experienced. This is a situation in which the total quantity of available food is not the only reason increasing the food supply and yet it can very be critical for survival. In a similar case, Speth & Spielmann (1983) have asserted that carbohydrates would have been much more effective than fats during such periods. If incremental dentine analysis could provide a better resolution, questions regarding seasonality, or whether animal fat or plant foods were used, could be addressed and this theory could be further investigated.

Terminology - Hunting farmers and farming hunter-gatherers

Modes of subsistence have commonly been used in the classification of human groups. The definitions have commonly been either as hunter-gatherers (in some cases also fishers) or farmers.

The main difference between farmers and hunter-gatherers is that farmers are more dependent on the farmed food than not, but they may also hunt, fish and collect edible wild foods. Zvelebil (1986, 12) even argues that hunter-gathering and cultivation are incompatible types of subsistence. This is simply not the case in marginal areas where failures in farming occur commonly; this cannot be universally true. At least in Finland, hunting and gathering coexist with farming even in modern society. In the case of past societies, a seasonal reliance upon wild resources (fish for example) is likely to have been vital. This could only have been replaced either by major imports of foods in difficult years, or by extensive storage.

Smith (2001) argues that the definition of hunter-gatherers is difficult, as the distinction between domesticated and non-domesticated is an artificial construct in many regions. Moreover, Smith (1998) showed how difficult it is to describe people who are not purely hunter-gatherers or farmers. In Finland, the domestication of wild animals is only problematic with regards to reindeer, as this is the only species that was semi-domesticated in northern Fennoscandia. Most of the animals and plants farmed in Finland must have been imported. Sørensen (2014) supports the idea that hunter-gatherer communities in northern Europe were able to practise small-scale and seasonal animal husbandry. This may have been possible as farming groups did occur in the South Baltic region much earlier than in the north. There would likely have been contacts with these groups that could have introduced domesticated livestock. However, this would not have been a possibility in areas where hunter-gatherers were not in contact with farmers; as such practises cannot be conducted merely on occasion but must be maintained and transmitted generationally.

As reindeer were likely the only native species to be domesticated within Finland, models assuming a "taming stage" are simply insufficient to describe the economic process by which farming began in Finland. This also renders the terms used to describe transitional periods between farming and hunting-gathering during this process inadequate (such as Harris' (1996, 1989) or Ford's (1985) stage models of farming or animal husbandry). Smith (2001) suggests that the term 'low level food production' could be used to describe societies between these two categories. Zvelebil (1996) introduced a three stage model by which cultivation slowly replaced hunting and gathering. This model does not take into account fishing, which is a wild source of food, but can be procured close to occupation sites and thus allows permanent settlements. Moreover this model fails to describe the situation in an area where cultivation is problematic and farming regularly fails. The dilemma is that if fish is the main source of protein for farmers, should we perhaps talk about hunter-fisher-farmer-gatherers? Fish and other marine resources may be obtained year around, even from sedentary camps, and are widely available in Finland.

In the complex picture of subsistence in Finland, we need to use more accurate terminology than simply the dichotomy between hunter-gatherers and farmers. Moreover, even during the 18th and 19th centuries, farmers did not only practise cultivation, but also hunting, gathering, marketing, handicraft, tar manufacturing etc. (Soininen, 1974). All this would suggest that a purely farm-based subsistence is simply not possible in most parts of Finland. Therefore it would be more appropriate to term this a poly-subsistence-based economy, and the people practising it could be described as multi-practioners rather than just farmers. Furthermore, it is likely that subsistence varied greatly between different parts of Finland.

Final conclusions

Early farming in Finland was not a simple phenomenon and much more research is needed in order to understand the full complexity of the beginnings of cultivation.

1. The overview of pollen studies suggests that the spread of farming in Finland was a complex phenomenon, and that the spread of farming in various provinces increased at several different times. Farming started to have a significant impact on the country during the Iron Age when it developed synchronously with an increase in population size and became more visible in records produced through pollen analysis.

2. Isotopic studies from the Iin Hamina site support the interpretation that fresh water and Baltic sea fish were the main source of protein for the people buried there, and that farming had a very limited impact on the overall diet and was of limited importance in the survival of the people in northern Finland even as late as the Medieval period.

Suggestions for future research:

Initially it was planned that this thesis would include several sites for study, but unfortunately it was not possible to obtain more skeletal material in the time frame dictated by the thesis. Therefore this should be considered as a preliminary study, and it is hoped that further isotope work from other areas and periods will be possible in the future.

Pollen analysis is not the best method to investigate small-scale cultivation and other independent proxies are needed ratify pollen results. There is a need for wider application of alternative scientific techniques in Finnish archaeology. This would generate more and alternative datasets for investigation into subsistence strategies and prehistoric and early historic economies in Finland. Methods such as sampling for macrofossils, soil DNA, starch grain analysis, phytoliths and the chemical composition of hearths and lipid residue analysis of pottery should become more standard archaeological procedures in future excavations. Such improvements would be very important for resolving the issue of small scale cultivation at a resolution that might be invisible in pollen studies. From pollen analyses, more statistically-based investigations should be developed.

A main area for future work in Finnish archaeology should be the re-evaluation of material culture. Archaeological materials should be re-investigated with modern methods to allow for more insightful interpretations. Currently, there is no concise text book covering the prehistory or the medieval archaeology of Finland. This makes it very difficult for researchers to engage with topics related to Finnish prehistory or early history. There remain large and profound aspects of Finnish archaeology that urgently require more attention.

This thesis is the first PhD level research on isotopes of archaeological material from Finland. Currently, archaeological bones from this area are clearly understudied. Isotope analysis of carbon, nitrogen, sulphur, oxygen, strontium and lead of skeletal material, both human and faunal, should be carried out. This method would help us determine the proportion of the diet constituted by different components, the different practises used in animal husbandry, and the migration of populations. Skeletal material is scarce and does not preserve well in acidic Finnish soils. Therefore the value of such research cannot be stressed enough.

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APPENDIX 1

Number	**Name**	**Beginning**	**End**	**Median**	**Dating method (if not radiocarbon)/source (B= bulk sediment, p=peat, M= modelled**	**Y (N)**	**X (E)**	**Reference**
1	Aholampi	-1957	-1613	-1782	B	61.895	25.217	Koivula et al., 1994
2	Ahvenainen	-354	230	-28	B	61.031	25.119	Tolonen M., 1978a
3	Ahvenistonjärvi	-382	-222	-302	Varves	60.995	24.417	Grönlund and Simola, 2009
4	Alasenjärvi	1275	1632	1403	B	61.012	25.740	Vuorela, 1978
5	Antinlampi	1034	1215	1125	B	62.316	25.982	Vuorela et al., 1993
6	Arminjärvi	428	880	653	B	61.024	24.345	Vuorela, 1975
7	Asilammi	-482	60	-229	B	61.563	25.148	Tolonen M., 1990
8	Bonästräsk	667	890	772	B	60.073	23.356	Tolonen M., et al., 1976
9	Gördorna	1297	1406	1348	P	60.176	22.683	Alenius, 2008
10	Hampträsk	654	968	788	B	60.291	25.256	Sarmaja-Korjonen, 1992
11	Hannusjärvi	775	969	881	B	60.090	24.411	Alenius, 2011
12	Hattulanselkä	127	326	205	terrestrial macrofossil (P)	61.045	24.410	Grönlund and Simola, 2009
13	Haukkasuo	73	642	363	P	60.844	26.936	Tolonen K., and Ruuhijärvi, 1976
14	Heinälampi	1456	1556	1506	Varves	63.124	27.654	Grönlund et al., 1992
15	Iidesjärvi	-749	53	-274	B	61.484	23.812	Alhonen, 1981

16	Isorahka	679	952	813	P	60.900	21.633	Tolonen K., et al., 1976
17	Isoskärret	-804	-232	-556	P	60.155	22.750	Aspelund and Vuorela, 1989
18	Jaatilanjärvi	237	562	399	B	61.879	25.186	Vuorela, 1994
19	Joutjärvi	777	1207	1010	B	60.977	25.700	Vuorela, 1978
20	Kaakotinlampi	536	1024	769	B	61.414	25.868	Vuorela, 1981
21	Kaartinlammensuo	987	1276	1128	P	60.741	24.195	Vuorela, 1993
22	Kangerjoki	1471	0	1673	P	66.119	28.99	Hicks, 1976
23	Kantala	172	428	330	P	61.164	24.042	Tolonen M., 1978b
24	Karvalampi	1219	1393	1286	B	63.338	25.625	Taavitsainen et al., 2007
25	Katajajarvi	-1148	-751	-924	B	61.168	26.846	Alenius et al., 2009
26	Katajärvi 2	1047	1268	1195	B	61.168	26.846	Alenius et al., 2009
27	Katamossen	711	1025	898	P	63.183	22.300	Wallin and Segeström, 1994
28	Katinhännänsuo	85	646	385	B	60.390	24.467	Vuorela, 1975, Vuorela 1972
29	Kattilanlahti	1238	1322	1280	Varves	61.400	27.17	Simola et al., 1988
30	Ketohaka	-171	527	167	B	60.420	23.140	Tolonen M., 1985
31	Kirjavanlampi	393	836	613	M, B	61.695	30.76	Alenius et al., 2004
32	Kirkkojärvi	641	1181	883	B	60.683	21.646	Vuorela, 1975
33	Kirkkolampi	901	1116	1005	B	61.785	30.001	Alenius and Laakso, 2006
34	Kirkkosaari	1446	1798	1567	P	60.857	24.491	Vuorela, 1993
35	Kirvesjärvi	1850	1870	1860	Varves	62.200	26.57	Simola et al., 1988
36	KissalammiA	-752	-252	-502	Varves	61.256	24.355	Tolonen M., 1981
37	KissalammiB	-1812	-1192	-1502	Varves	61.256	24.355	Tolonen M., 1981
38	Kitulansuo	687	992	853	P	61.506	27.365	Saastamoinen, 1999
39	Konnunsuo	1219	1450	1346	P	61.039	28.460	Tolonen, K. and Ruuhijärvi, 1976
40	Könttärinlahti	644	1039	844	B	62.284	24.709	Vuorela, 1994

41	Kuittijärvi	100	300	200	Varves	65.192	30.321	Alenius et al., 2011
42	Kuivajärvi	-915	-795	-842	B	60.782	23.858	Vuorela and Kankainen, 1992
43	Kunnonniemensuo	780	1279	1088	P	62.100	30.21	Tolonen K., 1984
44	Kynnarträsken	901	1036	1002	B	60.095	24.166	Alenius, 2011
45	Labböleträsk	428	990	723	B	60.090	22.735	Alenius, 2008
46	Lappträsket	892	1152	1004	B	60.048	23.656	Tolonen et al., 1976
47	Lehijärvi	81	681	434	B	61.052	24.3003	Vuorela, 1975
48	Lemusuo	1029	1394	1223	P	60.198	23.223	Vuorela, 1985
49	Levisträsk	260	529	388	B	59.987	23.266	Alenius, 2011
50	Likolampi	1220	1480	1350	Varves	60.894	27.597	Tomminen, 2005
51	Linnajärvi	-381	73	-136	B	61.632	25.189	Tolonen, M. 1990
52	Linnasuo	427	603	521	P	61.633	25.196	Tolonen, M. 1990
53	Lintunemossen	994	1275	1135	B	63.124	22.184	Tolonen, K. et al., 1976
54	Loimaansuo	-2035	-1416	-1714	B	61.136	22.673	Vuorela, 1975
55	Lojärvi	637	1148	845	B	60.209	24.510	Tolonen, K. et al., 1976
56	Lovojävi	-1049	-176	-618	B	61.077	25.033	Huttunen and Tolonen, K. 1977
57	Löytysenlampi	-91	127	19	B	60.975	28.155	Tomminen, 2006
58	Majenemossen	1045	1415	1267	P	63.133	22.3	Miettinen ja Vuorela, 1988
59	Mäyrälampi, Keuruu	379	795	589	B	62.353	24.618	Koivula et al., 1994
60	Mäyrälampi, Hankasalmi	-378	-2	-184	B	62.342	26.234	Koivula et al., 1994
61	Mossen	1216	1625	1363	P	60.165	22.695	Vuorela, 1990
62	Mustikkalampi	1046	1153	1100	Varves	61.430	28.2	Simola et al., 1988
63	Myllypuro	-748	-198	-396	P	61.556	21.979	Aalto et al., 1980
64	Nälköönsuo	720	1297	1073	P	60.297	24.196	Tolonen, K. and Ruuhijärvi, 1976
65	Nautajärvi	1394	1454	1424	Varves	61.805	24.679	Ojala and Alenius, 2005

66	Nerderskogen	1280	1432	1352		63.267	22.283	Wallin and Segeström, 1994
67	Niemispääbog	716	1260	1008		61.900	22.633	Tolonen, K. et al., 1976
68	Niikkalanlampi	1185	1290	1250	B	61.371	30.907	Vuorela et al., 2001
69	Orijärvi	730	930	830	Paleomagnetic	61.400	27.14	Alenius et al., 2008
70	Pakarinlampi	1363	1437	1400	Varves	62.428	28.644	Huttunen ja Simola, 1986
71	Pärkönsuo	664	1119	881	Varves	60.850	21.662	Tolonen, K. et al., 1976
72	Parusuo	214	682	480	P	61.042	21.617	Vuorela, 1991
73	Pegrema	1326	1649	1500	B	62.367	34.678	Vuorela et al., 2001
74	Petarträsk	256	530	381	B	59.967	23.900	Alenius, 2011
75	Pieni summanen	385	770	575	B	62.674	25.327	Taavitsainen et al., 2007
76	Pienikuuppalampi	5	400	201	B	61.170	29.55	Miettinen et al., 2002
77	Piilosuo	143	605	402	P	60.783	24.650	Tolonen, K. and Ruuhijärvi, 1976
78	Pitkälampi	1420	1480	1450	Varves	62.256	30.462	Grönlund and Asikainen, 1992
79	Pohjanlampi	55	401	224	B	62.221	25.780	Taavitsainen et al., 2007
80	Pytärälampi	1278	1362	1320	Varves	62.299	28.591	Huttunen and Simola, 1986
81	Puutienlampi	563	637	600	Varves	62.071	28.899	Simola et al., 1985
82	Rukatunturi	1026	1392	1214	P	66.166	29.1507	Hicks, 1976
83	Ryönänsuo	1528	0	1798	P	60.438	24.177	Vuorela, 1993
84	Säkinlampi	430	659	588	B	62.475	26.497	Taavitsainen et al., 2007
85	Santamäensuo	125	680	447	B	60.420	23.150	Tolonen M., 1985
86	Siikasuo	1216	1634	1372	P	61.300	22.065	Vuorela, 1991
87	Sistuslampi	782	1225	993	Modelling	62.704	25.222	Koivula et al., 1994
88	Skiitanlahti	425	665	577	B	61.391	30.918	Vuorela et al., 2001
89	Söderbyträsket	1022	1155	1096	B	60.055	22.432	Alenius, 2008
90	Sotkulampi	1520	1580	1550	Varves	61.470	27.51	Simola et al., 1988

91	Storträsk	625	764	663	B	60.093	23.236	Alenius, 2011
92	Suurijärvi, Kerimäki	1151	1248	1200	Varves	61.828	29.060	Simola, et al., 1986
93	Suurjärvi	580	740	660	Varves	61.834	29.057	Grönlund, 1991
94	Syrjälä Mire	356	552	466	P	61.213	28.103	Vuorela, 1995
95	Syrjälänsuo	346	559	465	P	61.172	28.052	Vuorela and Kankainen, 1993
96	Taruslampi	422	950	677	B	61.486	25.625	Vuorela, 1982
97	Tervalampi	520	680	600	Varves	61.683	29.389	Simola et al., 1985
98	Tjärnen	900	1030	997	B	60.047	23.225	Alenius, 2011
99	Träskmyre	416	655	551	P	63.15	21.583	Wallin and Segeström, 1994
100	Tullerinsuo	233	623	433	P	61.339	21.948	Vuorela, 1991
101	Työtjärvi	-769	-204	-469	B	60.996	25.464	Donner et al., 1978
102	Työtjärvi	-769	-204	-469	B	60.996	25.464	Donner et al., 1978
103	Vähä-Pitkusta	1301	1631	1434	terrestrial macrofossil (P)	60.488	23.649	Hakala et al., 2004
104	Väiskänsuo	-767	-97	-383	Modelling	60.917	21.700	Tolonen et al., 1976
105	Vasikkasuo	1668	1947	1820	P	64.678	27.857	Vuorela and Kankainen, 1991
106	Vikperä	975	1245	1099		63.233	22.217	Wallin and Segeström, 1994
107	Vitsjön	1020	1445	1265	B	59.963	23.315	Tolonen, M. and Tolonen, K. 1988
108	Vitsjön bog	1267	1617	1379	P	59.965	23.310	Tolonen, M. and Tolonen, K. 1988
109	Vohtenkellarinsuo	94	649	399	P	60.409	22.678	Vuorela, 1983
110	Vuojärvi	670	1119	892	B	62.414	25.935	Vuorela et al.,1993
111	Vuorijärvi	1576	1624	1600	Varves	62.170	27.400	Simola et al., 1988
112	Ylimysneva	1485	0	1725	P	62.142	22.87	Huttunen, 1990

APPENDIX 2

A table of δ^{13}C values; δ^{15}N values and quality criteria of humans and animals which were successfully analysed in this study. Human burial context are classified into bone charnel (pit) or in-situ burials. Individual bones ware discovered in-situ contexts in excavated areas where burial was not excavated completely or only partial bones were preserved.

Sample nro	Context	**Mean δ^{13}C**	**Mean δ^{15}N**	C%	N%	C/N	Bone	Collagen Yield (%)	Species	Site
7A	pit	**-21.7**	**10.8**	44.49	15.77	3.3	Mandible	11.3	Homo sapiens sapiens	Iin Hamina
9A	pit	**-20.2**	**12.5**	44.42	15.34	3.4	Mandible	13.3	Homo sapiens sapiens	Iin Hamina
CH10	in-situ	**-20.1**	**11.7**	42.78	15.36	3.2	zygomatic	17.9	Homo sapiens sapiens	Iin Hamina
Se10	in-situ	**-21.0**	**11.8**	43.34	15.60	3.2	Mandible	18.3	Homo sapiens sapiens	Iin Hamina
14A	pit	**-20.3**	**12.4**	42.90	15.09	3.3	Mandible	18.9	Homo sapiens sapiens	Iin Hamina
CH15	in-situ	**-19.6**	**11.4**	40.77	13.69	3.5	Mandible	3.8	Homo sapiens sapiens	Iin Hamina
21A	pit	**-22.0**	**9.5**	42.81	15.08	3.3	Mandible	15.6	Homo sapiens sapiens	Iin Hamina
Se21	in-situ	**-20.2**	**12.5**	43.87	15.32	3.3	Parietal	16.9	Homo sapiens sapiens	Iin Hamina
22A	pit	**-20.4**	**12.5**	42.37	15.10	3.3	Mandible	19.6	Homo sapiens sapiens	Iin Hamina
23A	pit	**-21.1**	**12.5**	41.96	15.39	3.2	Mandible	5.1	Homo sapiens sapiens	Iin Hamina
24A	pit	**-20.3**	**11.9**	41.93	15.39	3.2	Mandible	19.4	Homo sapiens sapiens	Iin Hamina
26A	pit	**-20.6**	**11.8**	43.22	15.71	3.2	Mandible	16.5	Homo sapiens	Iin

									sapiens	Hamina
27A	pit	**-22.2**	**12.8**	43.20	14.86	3.4	Mandible	19.3	Homo sapiens	sapiens Iin Hamina
28A	pit	**-20.0**	**12.4**	43.57	15.36	3.3	Mandible	14.9	Homo sapiens	sapiens Iin Hamina
29A	pit	**-19.1**	**13.2**	41.39	15.12	3.2	Mandible	16.7	Homo sapiens	sapiens Iin Hamina
CH29	in-situ	**-19.1**	**13.0**	43.79	15.55	3.3	Mandible	17.4	Homo sapiens	sapiens Iin Hamina
CH34pp1	individual bone	**-18.6**	**13.3**	40.22	13.87	3.4	Mandible	9.2	Homo sapiens	sapiens Iin Hamina
67A	pit	**-20.2**	**12.7**	42.71	14.90	3.3	Mandible	3.8	Homo sapiens	sapiens Iin Hamina
76A	pit	**-21.5**	**11.7**	44.35	15.56	3.3	Mandible	16.4	Homo sapiens	sapiens Iin Hamina
91A	pit	**-19.9**	**13.2**	42.22	15.27	3.2	Mandible	8.1	Homo sapiens	sapiens Iin Hamina
116	pit	**-19.9**	**13.0**	42.18	14.87	3.3	Mandible	28.5	Homo sapiens	sapiens Iin Hamina
137A	pit	**-20.2**	**12.6**	42.47	15.34	3.2	Mandible	17.4	Homo sapiens	sapiens Iin Hamina
138A	pit	**-20.5**	**10.5**	42.87	15.17	3.3	Mandible	17.6	Homo sapiens	sapiens Iin Hamina
141A	pit	**-20.7**	**12.2**	43.86	15.38	3.3	Mandible	19.8	Homo sapiens	sapiens Iin Hamina
142A	pit	**-20.7**	**12.3**	44.33	15.18	3.4	Mandible	16.9	Homo sapiens	sapiens Iin Hamina
143A	pit	**-21.0**	**12.3**	42.93	15.05	3.3	Mandible	19.2	Homo sapiens	sapiens Iin Hamina
144A	pit	**-19.2**	**12.8**	42.33	15.60	3.2	Mandible	14.3	Homo sapiens	sapiens Iin Hamina
145A	pit	**-19.9**	**12.4**	43.51	14.88	3.4	Mandible	21.0	Homo sapiens	sapiens Iin Hamina

146A	pit	**-19.4**	**13.1**	43.46	15.54	3.3	Mandible	20.4	Homo sapiens	sapiens Iin Hamina
148A	pit	**-20.6**	**13.5**	40.76	12.70	3.7	Mandible	3.9	Homo sapiens	sapiens Iin Hamina
266	pit	**-20.8**	**11.8**	43.99	14.85	3.5	Zygomatic	20.8	Homo sapiens	sapiens Iin Hamina
CH2b	in-situ	**-20.6**	**12.3**	41.94	14.95	3.3	femur sinister	7.7	Homo sapiens	sapiens Iin Hamina
CH3	individual bone	**-19.3**	**13.1**	41.52	14.88	3.3	mandible	7.7	Homo sapiens	sapiens Iin Hamina
CH4	in-situ	**-20.8**	**11.6**	42.12	15.18	3.2	femur dexter	9.3	Homo sapiens	sapiens Iin Hamina
CH8	individual bone	**-19.9**	**11.8**	41.90	14.97	3.3	unknown	23.6	Homo sapiens	sapiens Iin Hamina
CH9	in-situ	**-20.4**	**11.4**	42.12	15.15	3.2	mandible	19.8	Homo sapiens	sapiens Iin Hamina
CH11	in-situ	**-20.1**	**12.8**	42.21	15.32	3.2	Maxilla sin.	15.0	Homo sapiens	sapiens Iin Hamina
CH11b	in-situ	**-19.8**	**12.1**	41.99	14.94	3.3	Maxilla sin.	13.2	Homo sapiens	sapiens Iin Hamina
CH16	in-situ	**-20.6**	**12.7**	41.40	14.79	3.3	tibia sin.	9.9	Homo sapiens	sapiens Iin Hamina
CH21	in-situ	**-20.3**	**12.6**	41.68	15.29	3.2	Cranium	20.1	Homo sapiens	sapiens Iin Hamina
CH23	in-situ	**-20.6**	**13.0**	41.92	15.06	3.2	Maxilla	16.8	Homo sapiens	sapiens Iin Hamina
CH24	in-situ	**-20.1**	**13.0**	42.09	14.92	3.3	costa dex.	24.2	Homo sapiens	sapiens Iin Hamina
CH28	in-situ	**-20.1**	**13.9**	41.96	14.71	3.3	Cranium	18.4	Homo sapiens	sapiens Iin Hamina
CH32	in-situ	**-20.7**	**12.2**	42.03	14.91	3.3	femur sin.	15.9	Homo sapiens	sapiens Iin Hamina
CH34	in-situ	**-21.5**	**11.9**	42.09	14.44	3.4	costa	13.8	Homo	sapiens Iin

									sapiens	Hamina
CH44	in-situ	**-21.0**	**13.0**	42.16	12.98	3.8	tibia dex.	10.9	Homo sapiens sapiens	Iin Hamina
CH45	in-situ	**-20.5**	**11.5**	42.25	14.85	3.3	femur or tibia	14.1	Homo sapiens sapiens	Iin Hamina
CH50b	in-situ	**-20.8**	**13.1**	41.52	14.24	3.4	Cranium	7.3	Homo sapiens sapiens	Iin Hamina
CH55	in-situ	**-19.7**	**12.9**	42.11	14.47	3.4	pelvis dex.	10.9	Homo sapiens sapiens	Iin Hamina
CH56	in-situ	**-20.0**	**12.5**	42.64	15.31	3.2	femur dexter	12.0	Homo sapiens sapiens	Iin Hamina
CH59	in-situ	**-20.7**	**13.3**	40.37	12.74	3.7	femur sin.	3.2	Homo sapiens sapiens	Iin Hamina
CH64	in-situ	**-20.3**	**10.5**	42.15	15.38	3.2	radius sin.	14.4	Homo sapiens sapiens	Iin Hamina
CH66a	in-situ	**-21.0**	**12.5**	42.49	14.39	3.4	tibia sin.	6.1	Homo sapiens sapiens	Iin Hamina
CH67	in-situ	**-19.1**	**13.1**	42.80	15.44	3.2	ulna sin.	12.5	Homo sapiens sapiens	Iin Hamina
CH68	in-situ	**-19.0**	**13.7**	42.61	15.08	3.3	tibia dex.	12.9	Homo sapiens sapiens	Iin Hamina
1A	pit	**-20.2**	**12.1**	47.30	16.97	3.3	mandible	11.6	Homo sapiens sapiens	Iin Hamina
4A	pit	**-20.5**	**12.3**	46.78	16.75	3.3	mandible	15.3	Homo sapiens sapiens	Iin Hamina
10A	pit	**-19.6**	**13.2**	47.47	17.04	3.2	mandible	9.1	Homo sapiens sapiens	Iin Hamina
11A	pit	**-20.7**	**11.7**	47.67	16.71	3.3	mandible	7.6	Homo sapiens sapiens	Iin Hamina
13A	pit	**-20.6**	**13.0**	47.39	16.71	3.3	mandible	16.3	Homo sapiens sapiens	Iin Hamina
16A	pit	**-20.2**	**12.4**	46.97	16.67	3.3	mandible	8.4	Homo sapiens sapiens	Iin Hamina

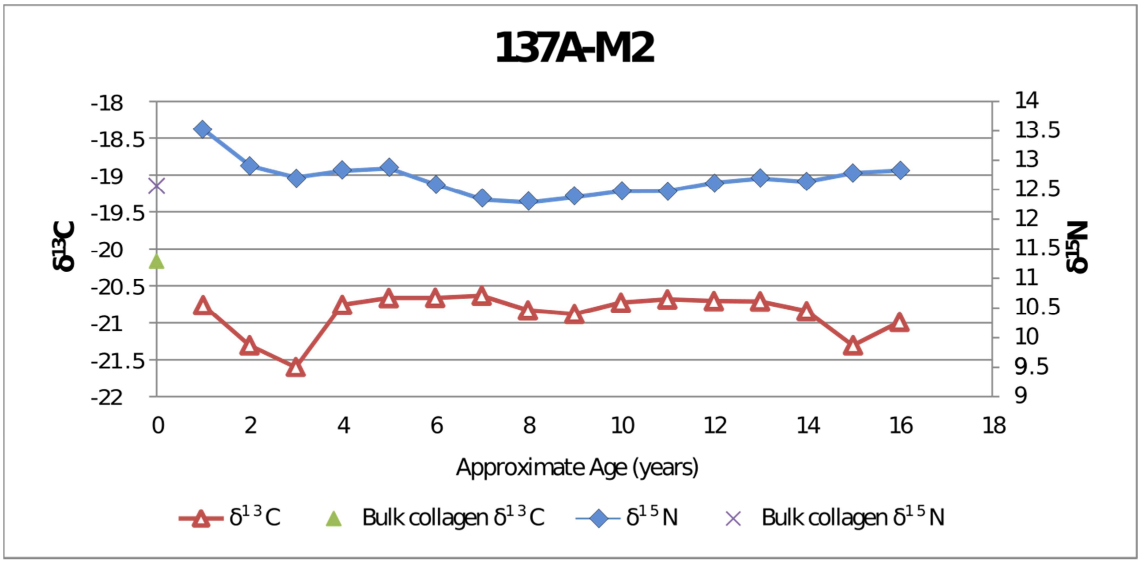
19A	pit	**-20.6**	**11.7**	47.62	17.13	3.2	mandible	11.7	Homo sapiens	sapiens Iin Hamina
20	pit	**-21.6**	**12.0**	47.69	15.70	3.5	mandible	13.9	Homo sapiens	sapiens Iin Hamina
20A	pit	**-20.2**	**13.2**	47.63	16.95	3.3	mandible	9.4	Homo sapiens	sapiens Iin Hamina
25A	pit	**-20.1**	**13.1**	48.02	15.83	3.5	mandible	12.1	Homo sapiens	sapiens Iin Hamina
30A	pit	**-21.6**	**13.9**	43.75	14.72	3.5	mandible	11.7	Homo sapiens	sapiens Iin Hamina
58A	pit	**-19.5**	**13.0**	47.53	16.29	3.4	mandible	9.2	Homo sapiens	sapiens Iin Hamina
70A	pit	**-19.8**	**11.8**	47.54	16.19	3.4	mandible	14.0	Homo sapiens	sapiens Iin Hamina
77A	pit	**-20.6**	**12.4**	47.78	16.73	3.3	mandible	12.2	Homo sapiens	sapiens Iin Hamina
78A	pit	**-20.2**	**11.8**	47.67	16.90	3.3	mandible	12.5	Homo sapiens	sapiens Iin Hamina
80A	pit	**-21.2**	**11.3**	47.27	16.73	3.3	mandible	15.9	Homo sapiens	sapiens Iin Hamina
85A	pit	**-21.0**	**12.6**	47.69	16.09	3.5	mandible	8.3	Homo sapiens	sapiens Iin Hamina
89A	pit	**-20.2**	**13.2**	47.94	16.04	3.5	mandible	14.4	Homo sapiens	sapiens Iin Hamina
122A	pit	**-20.8**	**12.4**	47.73	15.60	3.6	mandible	13.1	Homo sapiens	sapiens Iin Hamina
123A	pit	**-21.4**	**11.7**	47.73	16.62	3.4	mandible	6.5	Homo sapiens	sapiens Iin Hamina
139A	pit	**-21.7**	**12.7**	47.80	15.86	3.5	mandible	12.3	Homo sapiens	sapiens Iin Hamina
140A	pit	**-21.2**	**11.8**	47.83	16.45	3.4	mandible	13.3	Homo sapiens	sapiens Iin Hamina
CH36	in-situ	**-21.3**	**10.8**	44.57	15.34	3.4	mandible	13.0	Homo	sapiens Iin

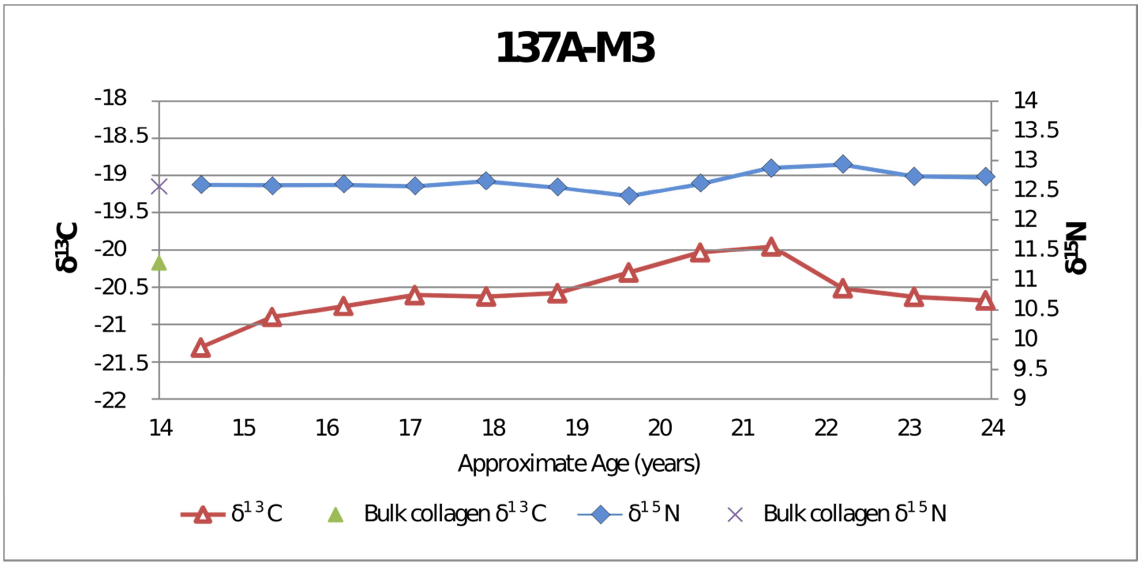
								sapiens	Hamina
OKAJA-1-C	**-23.1**	**2.8**	40.60	14.11	3.4	phalanx media	16.7	Bos taurus	Oulu Kajaaninkatu
OPIK-1-C	**-22.3**	**4.8**	43.11	14.90	3.4	phalanx distlis	14.7	Bos taurus	Oulu Pikisaari
OKAJA-2-S	**-22.0**	**5.0**	44.01	15.55	3.3	tibia distalis	18.7	Ovis aries/Capra hircus	Oulu Kajaaninkatu
OPIK-2-S	**-21.7**	**7.4**	42.89	14.83	3.4	atlas	15.3	Ovis aries/Capra hircus	Oulu Pikisaari
OKAJA-3-P	**-22.3**	**5.5**	43.54	14.98	3.4	pelvis	27.1	Sus scrofa domesticus	Oulu Kajaaninkatu
OPIK-3-P	**-21.7**	**9.9**	43.52	14.58	3.5	maxila	16.2	Sus scrofa domesticus	Oulu Pikisaari
OKAJA-4-H	**-22.4**	**1.6**	44.58	14.86	3.5	scapula	3.9	Lepus timidus	Oulu Kajaaninkatu
OPIK-4-H	**-22.8**	**3.0**	42.19	15.25	3.2	tibia prox.	18.8	Lepus timidus	Oulu Pikisaari
OFRA-2-G	**-21.6**	**2.3**	43.95	14.54	3.5	humerus	13.9	Tetrao tetrix	Oulu Franzeninkatu
OPIK-7-M	**-22.4**	**1.7**	42.11	14.37	3.4	carpometacarbus	9.9	Tetrao urogallus	Oulu Pikisaari
OPIK-8-A	**-23.4**	**8.2**	41.89	14.86	3.3	coracoideum	10.3	Anas sp.	Oulu Pikisaari
OKAJA-5-F	**-21.5**	**12.5**	43.36	15.65	3.2	dentale	13.7	Pisces	Oulu Kajaaninkatu
OFRA-1-D	**-19.6**	**5.5**	42.95	14.93	3.4	tibia distalis	10.8	Rangifer tarandus	Oulu Franzeninkatu

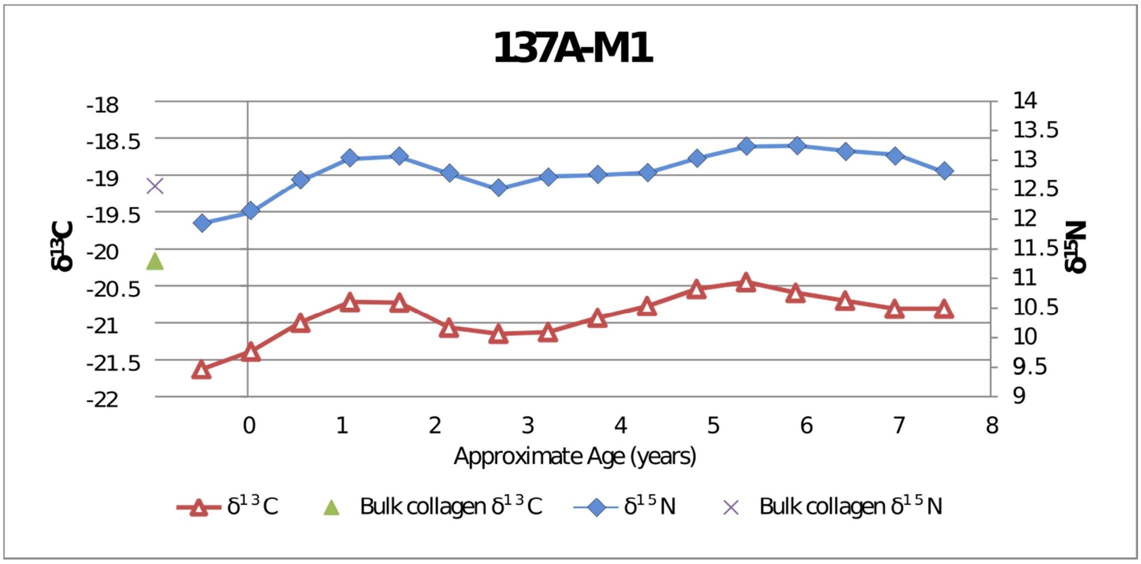
									nkatu
OPIK-5-D	**-20.1**	**5.4**	44.13	13.98	3.7	radius prox.	7.5	Rangifer tarandus	Oulu Kajaaninkatu
ROTI-1458	**-20.1**	**3.9**	44.91	14.76	3.5	humerus	8.1	Rangifer tarandus	Rovaniemi Ylikylä
TOKE-SY22P	**-19.0**	**4.1**	44.60	15.55	3.3	humerus	15.4	Rangifer tarandus	Tornio Keskikatu
TOKE-4023	**-21.2**	**3.0**	43.31	12.55	4.0	humerus	6.7	Rangifer tarandus	Tornio Keskikatu
TOKE-4042	**-17.2**	**13.5**	44.12	14.85	3.5	metatarsal V	16.3	Phocidae	Tornio Keskikatu
TOKE-SY7H	**-17.3**	**12.6**	44.57	15.25	3.4	scapula	25.4	Phocidae	Tornio Keskikatu
TOKE-SY39	**-23.0**	**11.2**	44.06	14.42	3.6	ulna	9.6	Phocidae	Tornio Keskikatu
TOKE-SY22S	**-17.0**	**12.4**	44.87	14.96	3.5	scapula	3.3	Phocidae	Tornio Keskikatu
OPIK-6-S	**-17.4**	**12.2**	42.91	14.42	3.5	scapula	16.2	Phocidae	Oulu Kajaaninkatu

APPENDIX 3

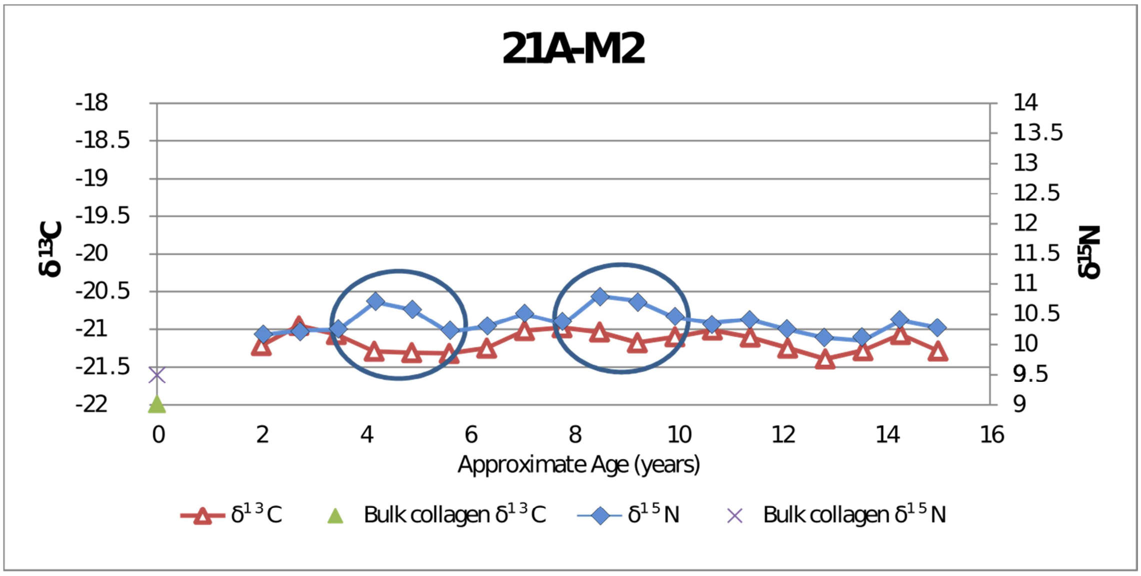
Profiles of the incremental samples isotope composition. Each tooth is presented individually and increase in δ^{15}N values while δ^{13}C remains unchanged is circulated.



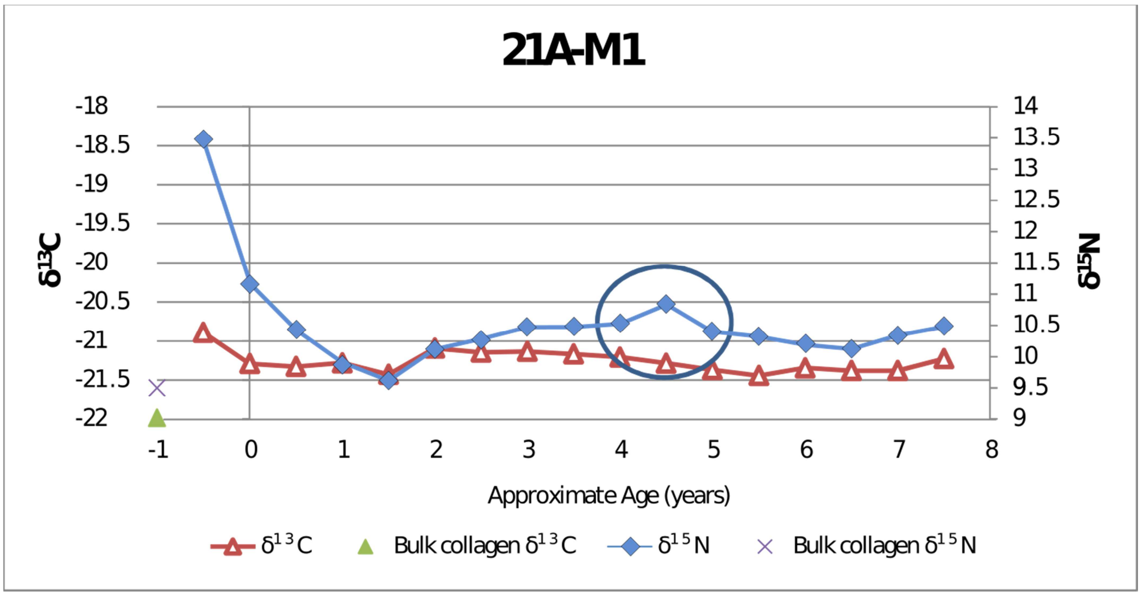


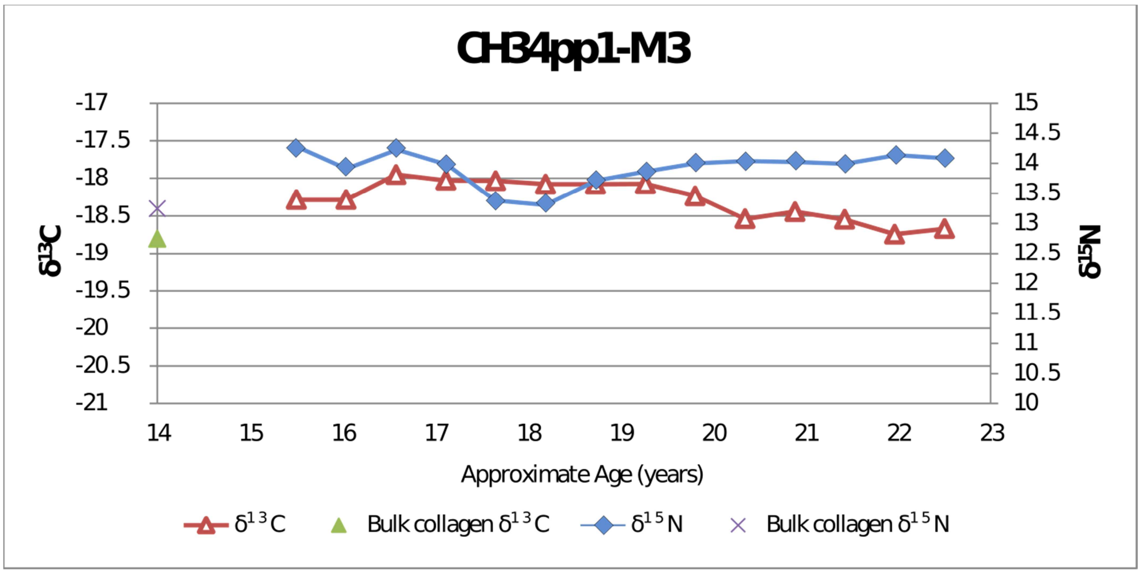


137A-M1
δ13C
-18
-18.5
-19
-19.5
-20
-20.5
-21
-21.5
-22
δ15N
14
13.5
13
12.5
12
11.5
11
10.5
10
9.5
9
0 1 2 3 4 5 6 7 8
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N



21A-M2
δ13C
-18
-18.5
-19
-19.5
-20
-20.5
-21
-21.5
-22
δ15N
14
13.5
13
12.5
12
11.5
11
10.5
10
9.5
9
0 2 4 6 8 10 12 14 16
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N


21A-M1
δ13C
-18
-18.5
-19
-19.5
-20
-20.5
-21
-21.5
-22
δ15N
14
13.5
13
12.5
12
11.5
11
10.5
10
9.5
9
-1
0
1
2
3
4
5
6
7
8
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N


CH34pp1-M3
δ13C
-17
-17.5
-18
-18.5
-19
-19.5
-20
-20.5
-21
δ15N
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
14
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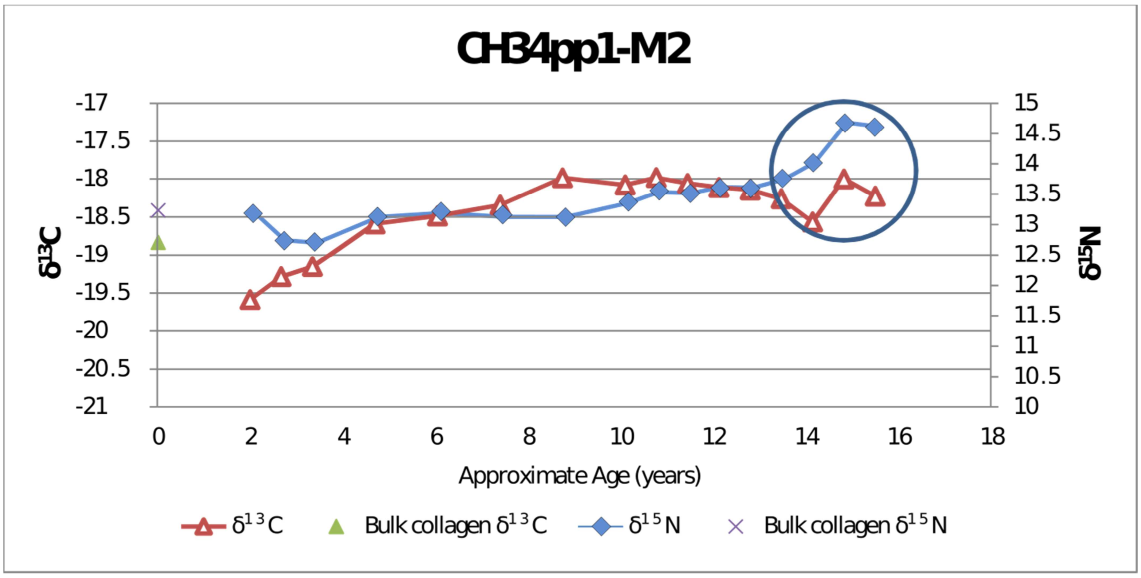
23
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N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14
13.5
13
12.5
12
11.5
11
10.5
10
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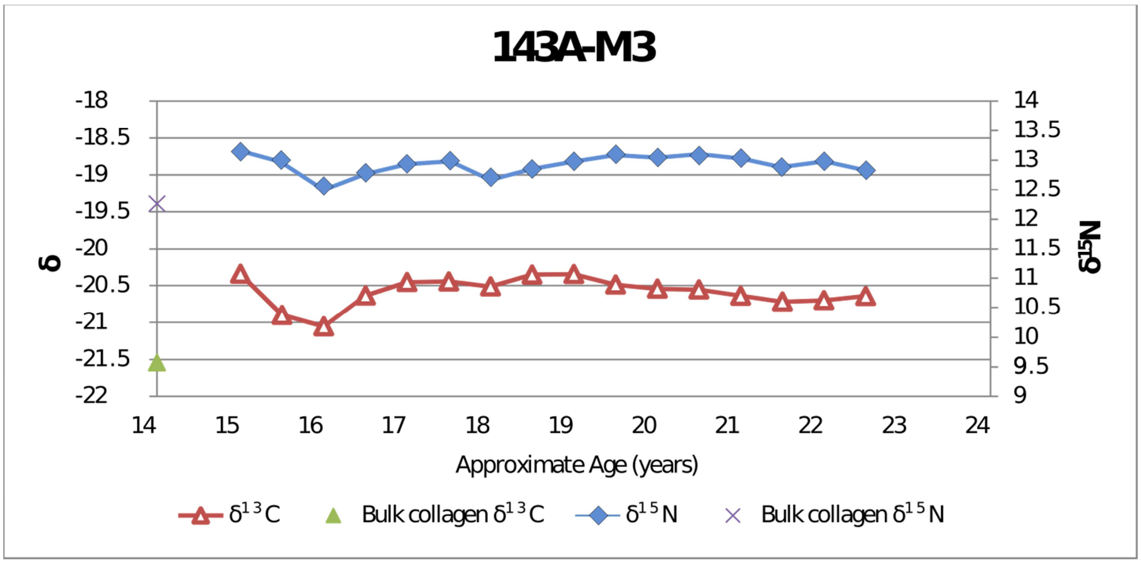
18
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N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δ15N
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10.5
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9.5
9
14
15
16
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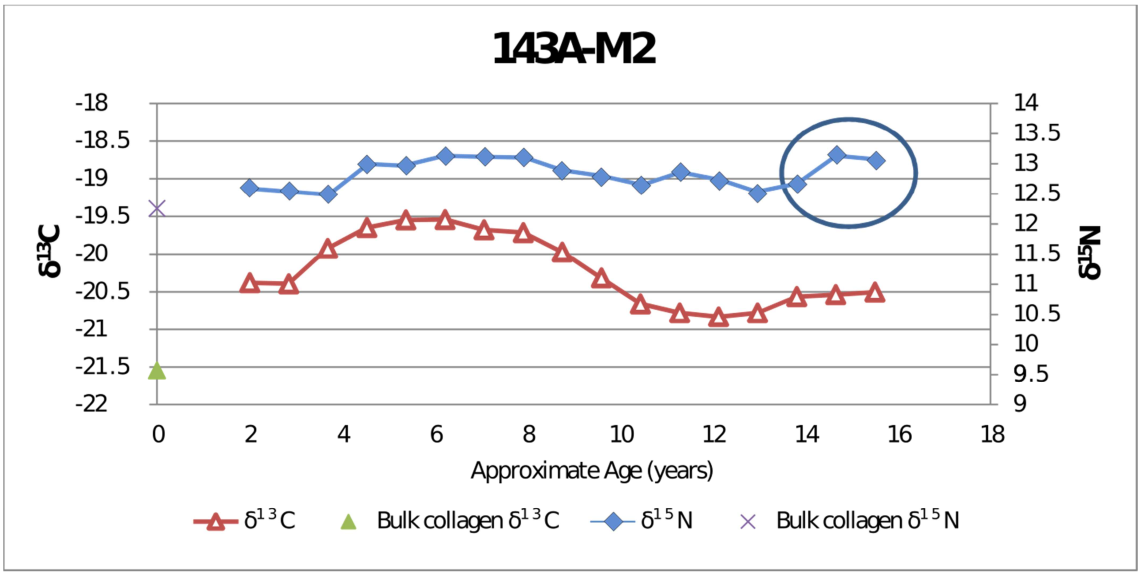
22
23
24
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N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-20.5
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13.5
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12.5
12
11.5
11
10.5
10
9.5
9
0
2
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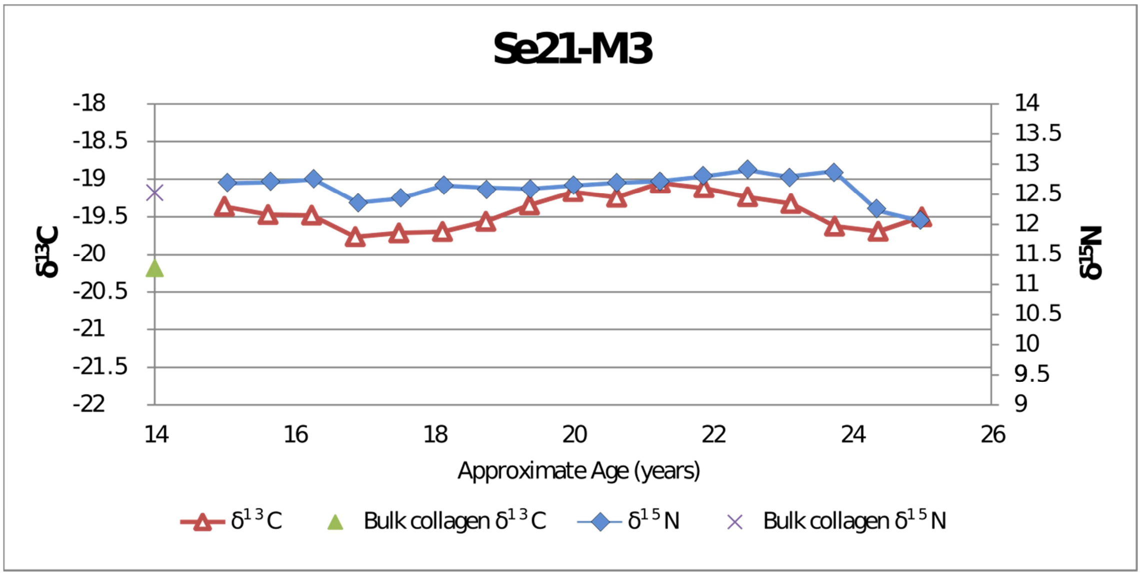
10
12
14
16
18
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N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-20.5
-21
-21.5
-22
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13.5
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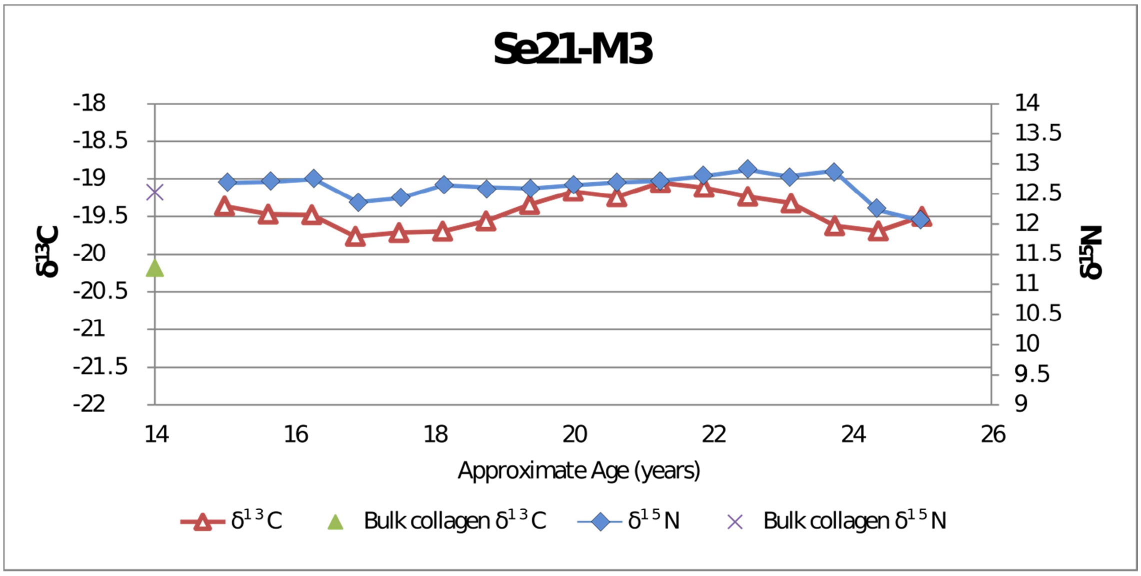
12.5
12
11.5
11
10.5
10
9.5
9
14
16
18
20
22
24
26
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N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13.5
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12
11.5
11
10.5
10
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20
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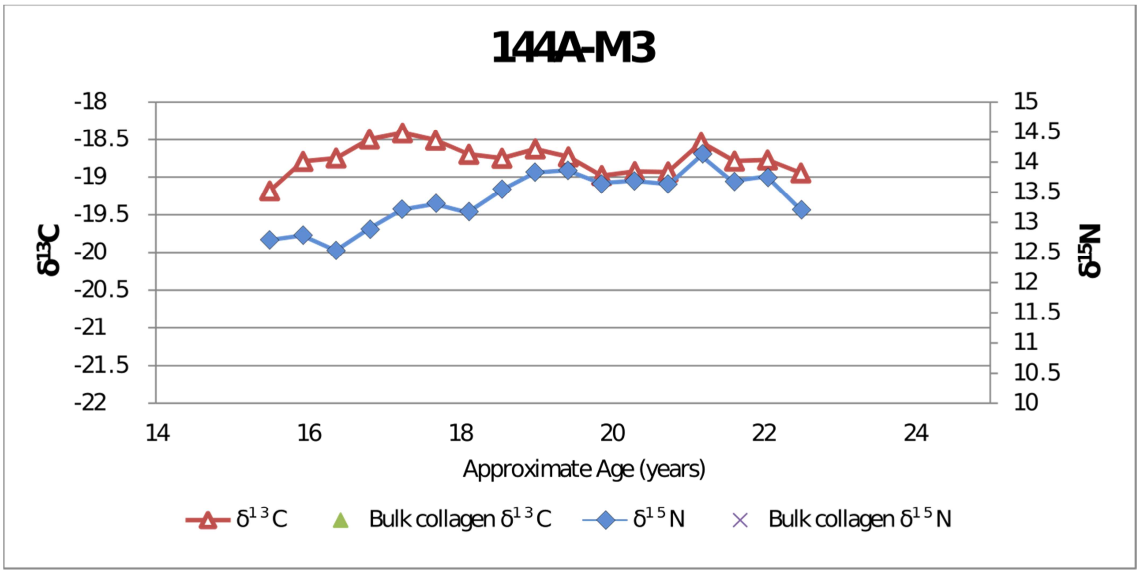
24
26
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N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12.5
12
11.5
11
10.5
10
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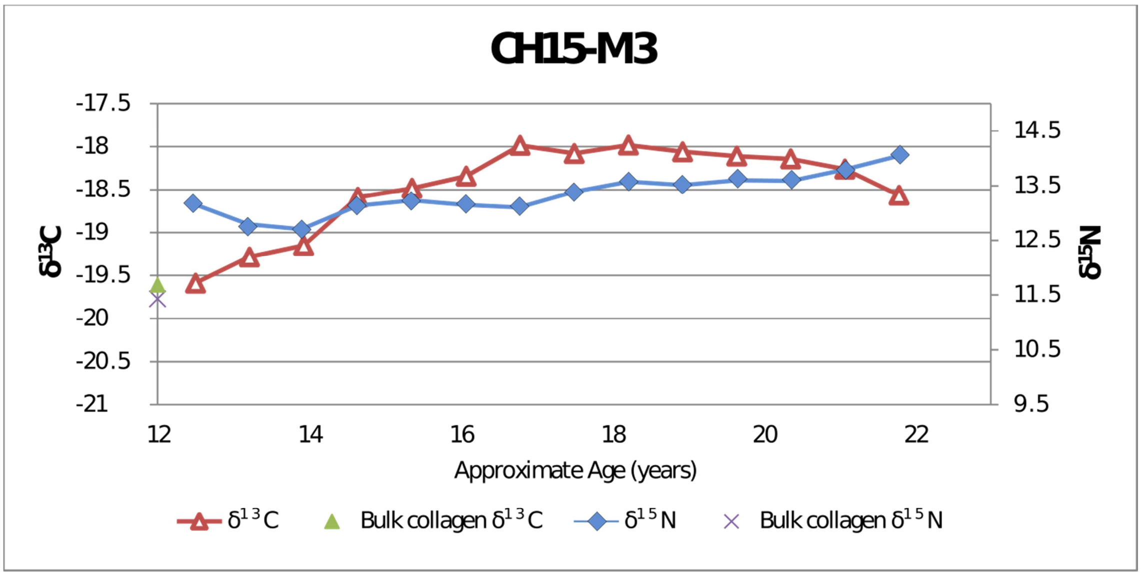
16
18
20
22
24
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N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-19
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-20
-20.5
-21
δ15N
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12.5
11.5
10.5
9.5
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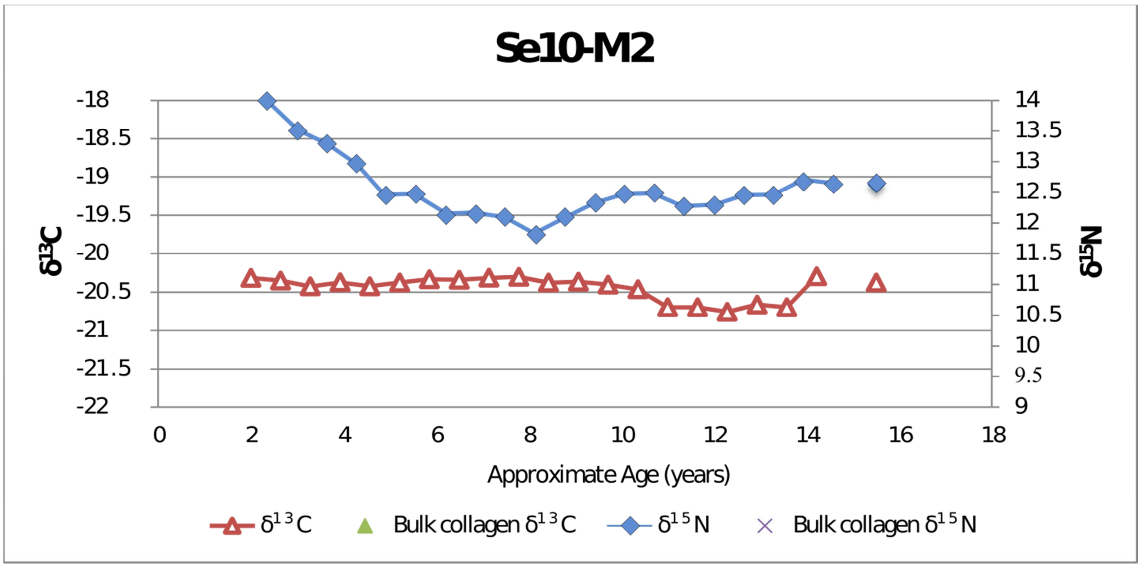
14
16
18
20
22
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N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-19.5
-20
-20.5
-21
-21.5
-22
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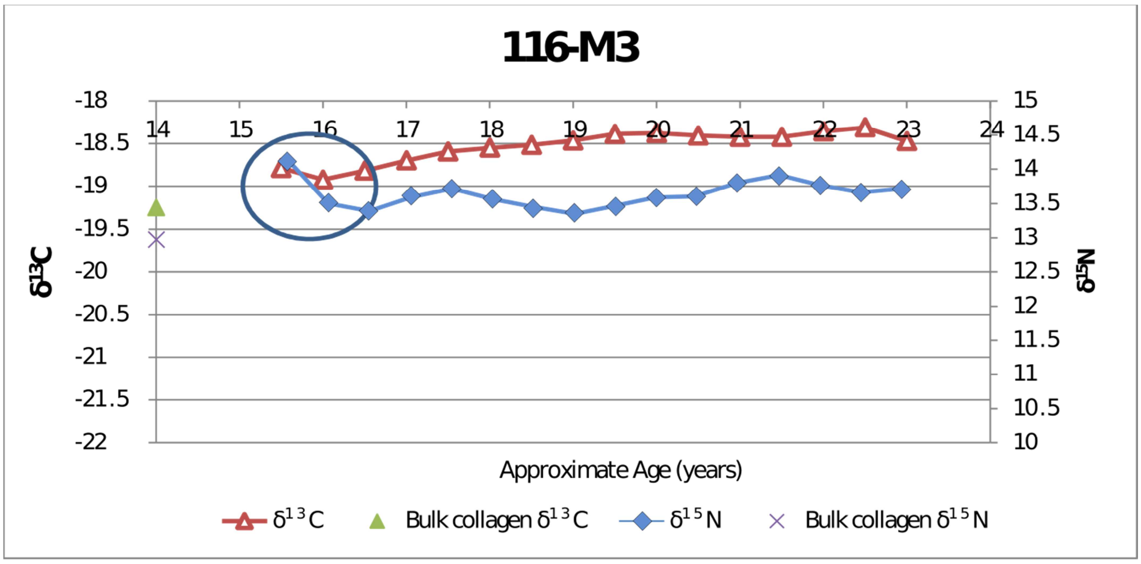
13.5
13
12.5
12
11.5
11
10.5
10
9.5
9
0
2
4
6
8
10
12
14
16
18
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N


116-M3
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-18
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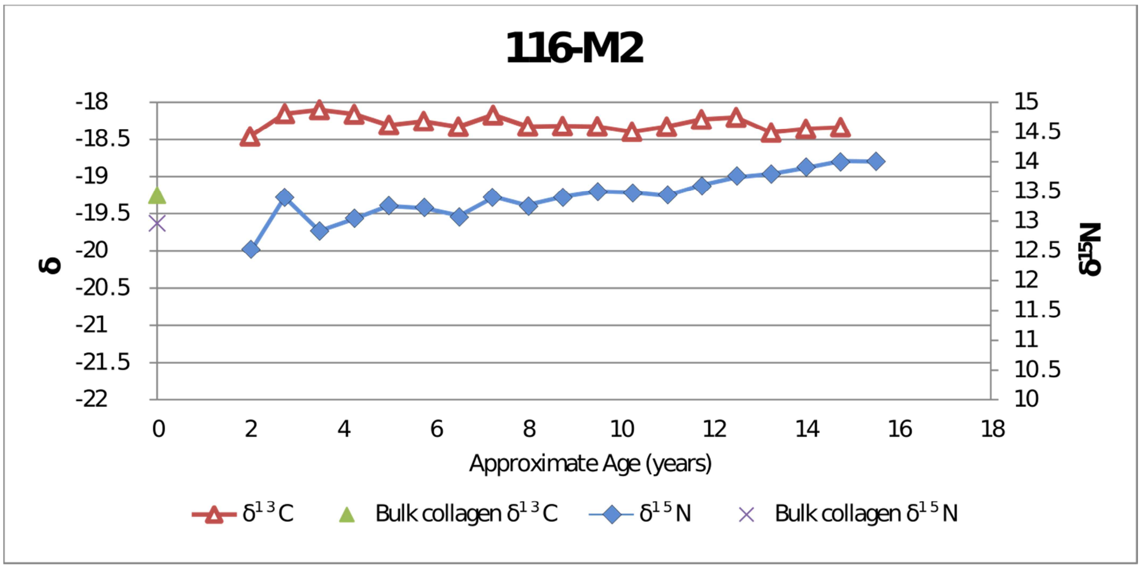
-19
-19.5
-20
-20.5
-21
-21.5
-22
14
15
16
17
18
19
20
21
22
23
24
δ15N
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N


116-M2
δ
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-19
-19.5
-20
-20.5
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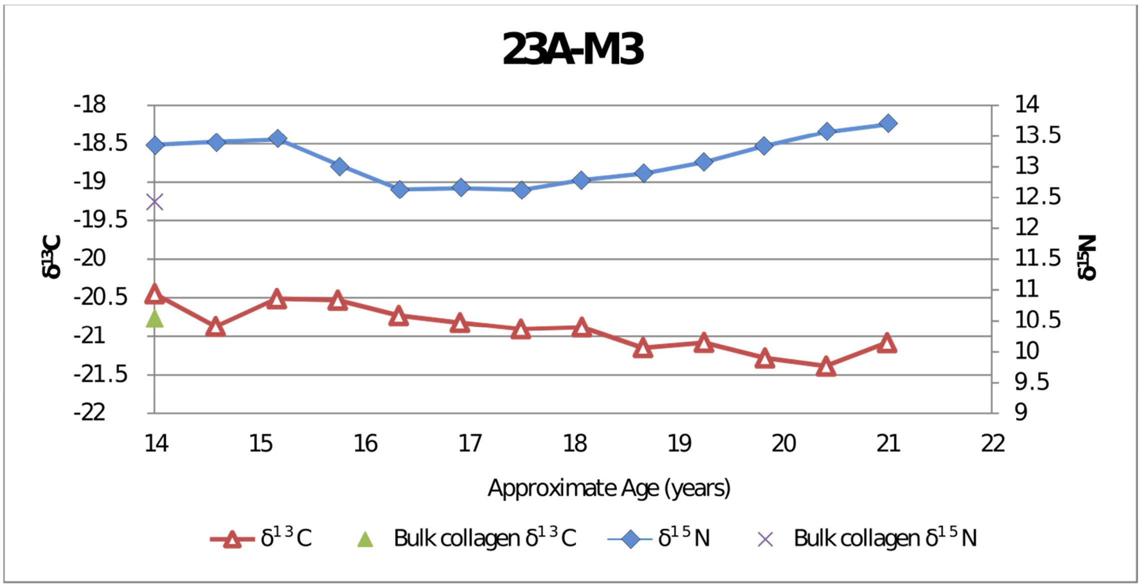
10
12
14
16
18
δ15N
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N


23A-M3
δ13C
δ15N
-18
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-19
-19.5
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-21
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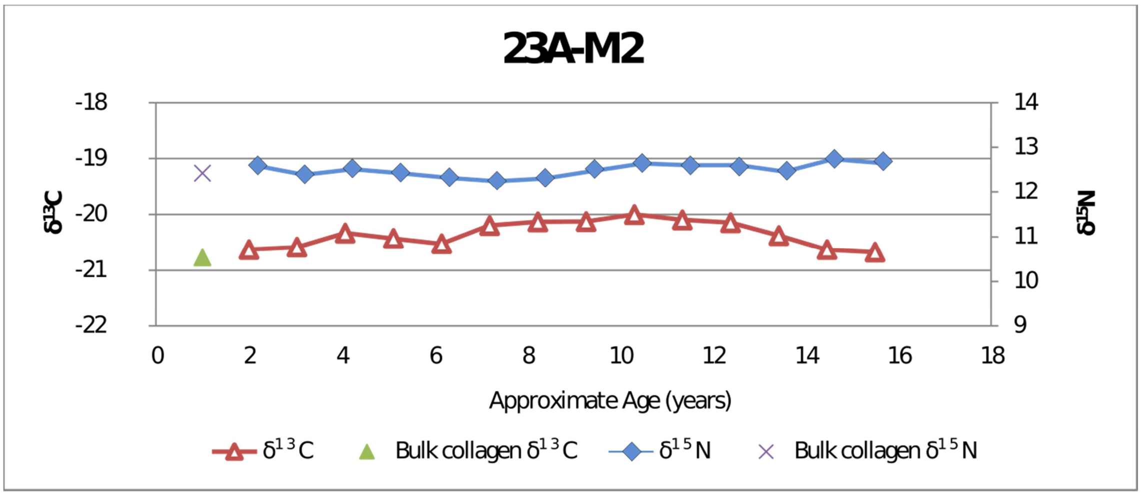
13.5
13
12.5
12
11.5
11
10.5
10
9.5
9
14
15
16
17
18
19
20
21
22
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N


23A-M2
δ13C
δ15N
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-19
-20
-21
-22
14
13
12
11
10
9
0
2
4
6
8
10
12
14
16
18
Approximate Age (years)
δ13C
Bulk collagen δ13C
δ15N
Bulk collagen δ15N

APPENDIX 4

Sample numbers	Lab	Age (years)	$\delta^{13}C$ (‰)	$\Delta^{15}N$ (‰)	C/N	C (%)	N (%)
IIHA-137A-M3-1	B	14.5	-21.3	12.6	4.0	40.5	11.9
IIHA-137A-M3-2	B	15.4	-20.9	12.6	3.8	40.5	12.3
IIHA-137A-M3-3	B	16.2	-20.8	12.6	3.6	40.7	13.0
IIHA-137A-M3-4	B	17.1	-20.6	12.6	3.6	40.5	13.1
IIHA-137A-M3-5	B	17.9	-20.6	12.7	3.6	40.5	13.1
IIHA-137A-M3-6	B	18.8	-20.6	12.6	3.3	41.0	14.5
IIHA-137A-M3-7	B	19.6	-20.3	12.4	3.3	41.0	14.5
IIHA-137A-M3-8	B	20.5	-20.0	12.6	3.3	41.0	14.5
IIHA-137A-M3-9	B	21.4	-20.0	12.9	3.3	40.9	14.5
IIHA-137A-M3-10	B	22.2	-20.5	12.9	3.3	40.8	14.3
IIHA-137A-M3-11	B	23.1	-20.6	12.7	3.3	42.7	15.1
IIHA-137A-M3-12	B	23.9	-20.7	12.7	3.3	44.4	15.5
IIHA-137A-M3-13	B	24.8	-20.8	13.0	3.4	41.1	14.2
IIHA-137A-M3-14	B	25.6	-20.8	13.4	3.4	42.6	14.5
IIHA-137A-M3-15	B	26.5	-21.0	13.4	3.5	42.2	13.9
IIHA-137A-M3-16	B	27.4	-21.5	11.8	3.3	41.3	14.5
IIHA-137A-M2-1	B	2.0	-20.8	13.5	3.4	41.3	14.0
IIHA-137A-M2-2	B	3.3	-21.3	12.9	3.4	42.0	14.6
IIHA-137A-M2-3	B	4.1	-21.6	12.7	3.3	41.8	14.6
IIHA-137A-M2-4	B	4.9	-20.8	12.8	3.3	40.9	14.5
IIHA-137A-M2-5	B	5.8	-20.7	12.9	3.3	41.4	14.6
IIHA-137A-M2-6	B	6.6	-20.7	12.6	3.3	41.0	14.6
IIHA-137A-M2-7	B	7.4	-20.6	12.4	3.3	40.8	14.4
IIHA-137A-M2-8	B	8.2	-20.8	12.3	3.3	41.1	14.4
IIHA-137A-M2-9	B	9.0	-20.9	12.4	3.3	41.1	14.5
IIHA-137A-M2-10	B	9.8	-20.7	12.5	3.3	40.5	14.4
IIHA-137A-M2-11	B	10.6	-20.7	12.5	3.8	43.3	13.1
IIHA-137A-M2-12	B	11.4	-20.7	12.6	3.3	40.8	14.2
IIHA-137A-M2-13	B	12.3	-20.7	12.7	3.4	40.6	14.1
IIHA-137A-M2-14	B	13.1	-20.8	12.6	3.4	40.2	13.6
IIHA-137A-M2-15	B	13.9	-21.3	12.8	3.6	41.6	13.5
IIHA-137A-M2-16	B	15.5	-21.0	12.8	3.4	40.8	13.9

Sample numbers	Lab	Age (years)	$\delta^{13}C$ (‰)	$\Delta^{15}N$ (‰)	C/N	C (%)	N (%)
IIHA-137A-M1-1	B	-0.5	-21.6	11.9	3.3	40.5	14.2
IIHA-137A-M1-2	B	0.1	-21.4	12.1	3.3	40.5	14.2
IIHA-137A-M1-3	B	0.7	-21.0	12.7	3.3	40.7	14.4
IIHA-137A-M1-4	B	1.3	-20.7	13.0	3.2	40.5	14.6
IIHA-137A-M1-5	B	1.9	-20.7	13.1	3.3	40.5	14.4
IIHA-137A-M1-6	B	2.5	-21.1	12.8	3.3	40.4	14.3
IIHA-137A-M1-7	B	3.1	-21.1	12.5	3.3	40.4	14.3
IIHA-137A-M1-8	B	3.7	-21.1	12.7	3.3	40.5	14.3
IIHA-137A-M1-9	B	4.3	-20.9	12.8	3.3	40.6	14.4
IIHA-137A-M1-10	B	4.9	-20.8	12.8	3.3	40.6	14.2
IIHA-137A-M1-11	B	5.5	-20.5	13.0	3.3	40.4	14.4
IIHA-137A-M1-12	B	6.1	-20.4	13.2	3.3	40.6	14.2
IIHA-137A-M1-13	B	6.7	-20.6	13.2	3.3	40.5	14.2
IIHA-137A-M1-14	B	7.3	-20.7	13.1	3.4	40.6	14.1
IIHA-137A-M1-15	B	7.9	-20.8	13.1	3.4	40.7	14.0
IIHA-137A-M1-16	B	8.5	-20.8	12.8	3.5	41.1	13.7

Sample numbers	Lab	Age (years)	$\delta^{13}C$ (‰)	$\Delta^{15}N$ (‰)	C/N	C (%)	N (%)
IIHA-21A-M2-1	D	2.0	-21.2	10.2	3.3	46.0	16.3
IIHA-21A-M2-2	D	2.7	-21.0	10.2	3.2	42.6	15.4
IIHA-21A-M2-3	D	3.4	-21.1	10.2	3.3	47.4	16.9
IIHA-21A-M2-4	D	4.2	-21.3	10.7	3.3	46.2	16.5
IIHA-21A-M2-5	D	4.9	-21.3	10.6	3.3	46.6	16.6
IIHA-21A-M2-6	D	5.6	-21.3	10.2	3.3	46.6	16.6
IIHA-21A-M2-7	D	6.3	-21.2	10.3	3.2	42.9	15.5
IIHA-21A-M2-8	D	7.1	-21.0	10.5	3.3	46.6	16.5
IIHA-21A-M2-9	D	7.8	-21.0	10.4	3.3	46.3	16.4
IIHA-21A-M2-10	D	8.5	-21.0	10.8	3.3	46.7	16.6
IIHA-21A-M2-11	D	9.2	-21.2	10.7	3.3	46.3	16.4
IIHA-21A-M2-12	D	9.9	-21.1	10.5	3.3	46.8	16.3
IIHA-21A-M2-13	D	10.7	-21.0	10.3	3.3	45.5	16.0
IIHA-21A-M2-14	D	11.4	-21.1	10.4	3.3	45.5	16.1
IIHA-21A-M2-15	D	12.1	-21.2	10.3	3.3	45.5	16.1
IIHA-21A-M2-16	D	12.8	-21.4	10.1	3.3	45.7	16.0
IIHA-21A-M2-17	D	13.6	-21.3	10.1	3.3	45.2	15.9
IIHA-21A-M2-18	D	14.3	-21.1	10.4	3.3	45.0	16.0
IIHA-21A-M2-19	D	15.0	-21.3	10.3	3.3	45.0	15.9
IIHA-21A-M1_1	D	-0.5	-20.9	13.5	3.3	46.3	16.3
IIHA-21A-M1_2	D	0.0	-21.3	11.1	3.2	43.7	16.2
IIHA-21A-M1_3	D	0.5	-21.3	10.4	3.2	43.6	16.1
IIHA-21A-M1_4	D	1.0	-21.3	9.9	3.1	43.7	16.2
IIHA-21A-M1_5	D	1.5	-21.4	9.6	3.2	43.6	16.0
IIHA-21A-M1_6	D	2.0	-21.1	10.1	3.2	43.5	16.1
IIHA-21A-M1_7	D	2.5	-21.1	10.3	3.2	42.4	15.6
IIHA-21A-M1_8	D	3.0	-21.1	10.5	3.2	43.5	16.0
IIHA-21A-M1_9	D	3.5	-21.2	10.5	3.2	43.6	16.0
IIHA-21A-M1_10	D	4.0	-21.2	10.5	3.2	43.8	16.1
IIHA-21A-M1_11	D	4.5	-21.3	10.8	3.2	43.8	16.1
IIHA-21A-M1_12	D	5.0	-21.4	10.4	3.2	43.7	16.1
IIHA-21A-M1_13	D	5.5	-21.4	10.3	3.2	43.7	16.0
IIHA-21A-M1_14	D	6.0	-21.3	10.2	3.2	43.7	16.0
IIHA-21A-M1_15	D	6.5	-21.4	10.1	3.2	43.7	16.0
IIHA-21A-M1_16	D	7.0	-21.4	10.3	3.2	43.8	15.9
IIHA-21A-M1_17	D	7.5	-21.2	10.5	3.2	43.2	15.9

Sample numbers	Lab	Age (years)	$\delta^{13}C$ (‰)	$\Delta^{15}N$ (‰)	C/N	C (%)	N (%)
IIHA-CH34pp1-M2-1	D	2.0	-19.6	13.2	3.3	47.2	16.7
IIHA-CH34pp1-M2-2	D	2.9	-19.3	12.8	3.3	46.8	16.6
IIHA-CH34pp1-M2-3	D	3.8	-19.2	12.7	3.3	47.1	16.7
IIHA-CH34pp1-M2-4	D	4.7	-18.6	13.1	3.3	46.7	16.6
IIHA-CH34pp1-M2-5	D	5.6	-18.5	13.2	3.3	47.2	16.8
IIHA-CH34pp1-M2-6	D	6.5	-18.3	13.2	3.3	47.3	16.7
IIHA-CH34pp1-M2-7	D	7.4	-18.0	13.1	3.3	46.5	16.5
IIHA-CH34pp1-M2-8	D	8.3	-18.1	13.4	3.3	46.8	16.5
IIHA-CH34pp1-M2-9	D	9.2	-18.0	13.6	3.3	46.7	16.5
IIHA-CH34pp1-M2-10	D	10.1	-18.1	13.5	3.3	46.1	16.2
IIHA-CH34pp1-M2-11	D	11.0	-18.1	13.6	3.3	46.0	16.2
IIHA-CH34pp1-M2-12	D	11.9	-18.1	13.6	3.3	46.1	16.2
IIHA-CH34pp1-M2-13	D	12.8	-18.3	13.8	3.3	46.3	16.3
IIHA-CH34pp1-M2-14	D	13.7	-18.6	14.0	3.5	48.0	16.2
IIHA-CH34pp1-M2-15	D	14.6	-18.0	14.7	3.3	46.4	16.4
IIHA-CH34pp1-M2-16	D	15.5	-18.2	14.6	3.3	46.2	16.2
IIHA-CH34pp1-M3-1	D	15.0	-18.3	14.3	3.2	44.1	16.0
IIHA-CH34pp1-M3-2	D	15.5	-18.3	13.9	3.2	44.1	16.1
IIHA-CH34pp1-M3-3	D	16.1	-18.0	14.3	3.1	43.6	16.2
IIHA-CH34pp1-M3-4	D	16.6	-18.0	14.0	3.2	44.0	16.2
IIHA-CH34pp1-M3-5	D	17.2	-18.0	13.4	3.2	44.0	16.1
IIHA-CH34pp1-M3-6	D	17.7	-18.1	13.3	3.2	43.7	15.9
IIHA-CH34pp1-M3-7	D	18.2	-18.1	13.7	3.2	43.7	15.9
IIHA-CH34pp1-M3-8	D	18.8	-18.1	13.9	3.2	44.2	16.1
IIHA-CH34pp1-M3-9	D	19.3	-18.2	14.0	3.2	44.0	16.0
IIHA-CH34pp1-M3-10	D	19.8	-18.5	14.0	3.2	44.1	16.0
IIHA-CH34pp1-M3-11	D	20.4	-18.4	14.0	3.2	44.1	16.0
IIHA-CH34pp1-M3-12	D	20.9	-18.5	14.0	3.2	44.2	16.0
IIHA-CH34pp1-M3-13	D	21.5	-18.7	14.1	3.2	43.8	15.8
IIHA-CH34pp1-M3-14	D	22.0	-18.7	14.1	3.2	44.1	16.0

Sample numbers	Lab	Age (years)	δ^{13}C (‰)	Δ^{15}N (‰)	C/N	C (%)	N (%)
IIHA-143A-M3-1	D	15.0	-20.3	13.1	3.2	43.4	16.0
IIHA-143A-M3-2	D	15.5	-20.9	13.0	3.1	43.5	16.1
IIHA-143A-M3-3	D	16.0	-21.1	12.6	3.2	43.7	16.1
IIHA-143A-M3-4	D	16.5	-20.6	12.8	3.2	43.5	16.0
IIHA-143A-M3-5	D	17.0	-20.5	12.9	3.2	43.0	15.8
IIHA-143A-M3-6	D	17.5	-20.4	13.0	3.2	43.5	15.9
IIHA-143A-M3-7	D	18.0	-20.5	12.7	3.2	43.9	16.0
IIHA-143A-M3-8	D	18.5	-20.4	12.9	3.2	43.9	16.1
IIHA-143A-M3-9	D	19.0	-20.3	13.0	3.2	43.7	16.0
IIHA-143A-M3-10	D	19.5	-20.5	13.1	3.2	43.6	16.0
IIHA-143A-M3-11	D	20.0	-20.5	13.1	3.2	43.9	16.2
IIHA-143A-M3-12	D	20.5	-20.6	13.1	3.2	43.8	16.1
IIHA-143A-M3-13	D	21.0	-20.6	13.0	3.2	44.0	16.1
IIHA-143A-M3-14	D	21.5	-20.7	12.9	3.2	43.2	15.8
IIHA-143A-M3-15	D	22.0	-20.7	13.0	3.2	43.3	15.8
IIHA-143A-M3-16	D	22.5	-20.6	12.8	3.2	43.7	16.0
IIHA-143A-M2-1	D	2.0	-20.4	12.6	3.3	46.0	16.2
IIHA-143A-M2-2	D	2.8	-20.4	12.5	3.3	45.9	16.2
IIHA-143A-M2-3	D	3.7	-19.9	12.5	3.3	46.5	16.4
IIHA-143A-M2-4	D	4.5	-19.6	13.0	3.3	45.9	16.3
IIHA-143A-M2-5	D	5.4	-19.5	13.0	3.1	43.7	16.2
IIHA-143A-M2-6	D	6.2	-19.5	13.1	3.1	43.9	16.3
IIHA-143A-M2-7	D	7.1	-19.7	13.1	3.1	43.6	16.1
IIHA-143A-M2-8	D	7.9	-19.7	13.1	3.1	43.6	16.1
IIHA-143A-M2-9	D	8.8	-20.0	12.9	3.2	43.5	16.1
IIHA-143A-M2-10	D	9.6	-20.3	12.8	3.1	43.4	16.1
IIHA-143A-M2-11	D	10.4	-20.7	12.7	3.2	43.7	16.1
IIHA-143A-M2-12	D	11.3	-20.8	12.8	3.3	46.1	16.2
IIHA-143A-M2-13	D	12.1	-20.8	12.7	3.2	43.9	16.2
IIHA-143A-M2-14	D	13.0	-20.8	12.5	3.2	43.9	16.2
IIHA-143A-M2-15	D	13.8	-20.6	12.7	3.2	43.8	16.2
IIHA-143A-M2-16	D	14.7	-20.5	13.1	3.2	43.7	16.1
IIHA-143A-M2-17	D	15.5	-20.5	13.1	3.2	43.8	16.2

Sample numbers	Lab	Age (years)	$\delta^{13}C$ (‰)	$\Delta^{15}N$ (‰)	C/N	C (%)	N (%)
IIHA-Se21A-M2-1	D	2.0	-19.7	13.4	3.2	42.9	15.7
IIHA-Se21A-M2-2	D	2.8	-19.8	12.7	3.2	43.5	15.9
IIHA-Se21A-M2-3	D	3.7	-19.6	12.7	3.2	43.6	16.0
IIHA-Se21A-M2-4	D	4.5	-19.6	12.4	3.2	43.6	16.0
IIHA-Se21A-M2-5	D	5.4	-19.5	12.2	3.2	43.6	16.0
IIHA-Se21A-M2-6	D	6.2	-19.5	12.2	3.2	42.0	15.4
IIHA-Se21A-M2-7	D	7.1	-19.4	12.2	3.2	43.5	15.9
IIHA-Se21A-M2-8	D	7.9	-19.4	12.3	3.2	43.6	15.9
IIHA-Se21A-M2-9	D	8.8	-19.5	12.4	3.2	43.4	15.9
IIHA-Se21A-M2-10	D	9.6	-19.5	12.4	3.2	43.6	15.9
IIHA-Se21A-M2-11	D	10.4	-19.5	12.4	3.2	43.6	15.9
IIHA-Se21A-M2-12	D	11.3	-19.4	12.4	3.1	41.9	15.6
IIHA-Se21A-M2-13	D	12.1	-19.7	12.4	3.2	42.5	15.6
IIHA-Se21A-M2-14	D	13.0	-19.6	12.3	3.2	42.3	15.6
IIHA-Se21A-M2-15	D	13.8	-19.5	12.5	3.2	42.6	15.6
IIHA-Se21A-M2-16	D	14.7	-19.6	12.9	3.2	42.8	15.6
IIHA-Se21A-M2-17	D	15.5	-19.6	13.2	3.2	42.8	15.6
IIHA-Se21A-M3-1	D	8.5	-19.4	12.7	3.2	42.7	15.8
IIHA-Se21A-M3-2	D	9.2	-19.5	12.7	3.2	42.9	15.8
IIHA-Se21A-M3-3	D	9.9	-19.5	12.7	3.2	43.3	15.9
IIHA-Se21A-M3-4	D	10.6	-19.8	12.4	3.2	43.3	15.9
IIHA-Se21A-M3-5	D	11.3	-19.7	12.5	3.2	43.4	16.0
IIHA-Se21A-M3-6	D	11.9	-19.7	12.6	3.2	43.4	15.9
IIHA-Se21A-M3-7	D	12.6	-19.6	12.6	3.2	43.3	15.9
IIHA-Se21A-M3-8	D	13.3	-19.3	12.6	3.2	43.4	15.9
IIHA-Se21A-M3-9	D	14.0	-19.2	12.7	3.2	43.5	15.9
IIHA-Se21A-M3-10	D	14.7	-19.2	12.7	3.2	43.9	16.1
IIHA-Se21A-M3-11	D	15.4	-19.1	12.7	3.2	43.7	16.0
IIHA-Se21A-M3-12	D	16.1	-19.1	12.8	3.2	43.4	15.8
IIHA-Se21A-M3-13	D	16.8	-19.2	12.9	3.2	42.5	15.6
IIHA-Se21A-M3-14	D	17.4	-19.3	12.8	3.2	43.7	16.0
IIHA-Se21A-M3-15	D	18.1	-19.6	12.9	3.2	44.0	16.0
IIHA-Se21A-M3-16	D	18.8	-19.7	12.3	3.2	43.5	15.8
IIHA-Se21A-M3-17	D	19.5	-19.5	12.1	3.2	43.4	15.8

Sample numbers	Lab	Age (years)	δ^{13}C (‰)	Δ^{15}N (‰)	C/N	C (%)	N (%)
IIHA-144A-M3-1	D	15.5	-19.2	12.7	3.2	42.5	15.5
IIHA-144A-M3-2	D	15.9	-18.8	12.8	3.2	42.8	15.6
IIHA-144A-M3-3	D	16.4	-18.7	12.6	3.2	43.1	15.7
IIHA-144A-M3-4	D	16.8	-18.5	12.9	3.2	42.9	15.6
IIHA-144A-M3-5	D	17.3	-18.4	13.2	3.2	42.5	15.4
IIHA-144A-M3-6	D	17.7	-18.5	13.3	3.2	42.9	15.6
IIHA-144A-M3-7	D	18.1	-18.7	13.2	3.2	43.1	15.6
IIHA-144A-M3-8	D	18.6	-18.7	13.5	3.2	43.1	15.6
IIHA-144A-M3-9	D	19.0	-18.6	13.8	3.2	43.1	15.6
IIHA-144A-M3-10	D	19.4	-18.7	13.9	3.3	43.0	15.4
IIHA-144A-M3-11	D	19.9	-19.0	13.7	3.3	42.9	15.4
IIHA-144A-M3-12	D	20.3	-18.9	13.7	3.2	43.0	15.5
IIHA-144A-M3-13	D	20.8	-18.9	13.6	3.2	43.2	15.6
IIHA-144A-M3-14	D	21.2	-18.5	14.1	3.2	43.0	15.5
IIHA-144A-M3-15	D	21.6	-18.8	13.7	3.2	42.7	15.3
IIHA-144A-M3-16	D	22.1	-18.8	13.7	3.2	43.1	15.5
IIHA-144A-M3-17	D	22.5	-18.9	13.2	3.3	43.3	15.4
IIHA-CH15-M3-1	B	12.5	-21.5	10.2	3.3	40.8	14.3
IIHA-CH15-M3-2	B	13.2	-21.4	10.2	3.3	40.8	14.4
IIHA-CH15-M3-3	B	13.9	-20.3	11.1	3.3	40.6	14.4
IIHA-CH15-M3-4	B	14.6	-20.2	10.8	3.3	40.6	14.4
IIHA-CH15-M3-5	B	15.4	-20.7	10.7	3.3	40.7	14.2
IIHA-CH15-M3-6	B	16.1	-20.4	10.7	3.3	40.9	14.3
IIHA-CH15-M3-7	B	16.8	-20.0	10.8	3.3	40.7	14.4
IIHA-CH15-M3-8	B	17.5	-20.0	10.9	3.3	40.8	14.4
IIHA-CH15-M3-9	B	18.2	-19.9	10.8	3.3	40.5	14.4
IIHA-CH15-M3-10	B	18.9	-19.7	11.0	3.3	40.5	14.3
IIHA-CH15-M3-11	B	19.6	-19.4	11.5	3.3	40.8	14.3
IIHA-CH15-M3-12	B	20.4	-19.4	11.8	3.4	40.7	14.2
IIHA-CH15-M3-13	B	21.1	-19.3	12.1	3.4	40.9	14.2
IIHA-CH15-M3-14	B	21.8	-19.6	12.5	3.5	41.1	13.9
IIHA-CH15-M3-15	B	22.5	-19.4	12.8	3.4	41.0	14.0

Sample numbers	Lab	Age (years)	$\delta^{13}C$ (‰)	$\Delta^{15}N$ (‰)	C/N	C (%)	N (%)
IIHA-Se10-M2-1	D	2.0	-20.3	14.0	3.2	43.6	15.8
IIHA-Se10-M2-2	D	2.6	-20.4	13.5	3.2	43.6	15.8
IIHA-Se10-M2-3	D	3.3	-20.4	13.3	3.2	43.7	15.8
IIHA-Se10-M2-4	D	3.9	-20.4	12.9	3.2	44.1	15.9
IIHA-Se10-M2-5	D	4.6	-20.4	12.4	3.2	44.2	16.0
IIHA-Se10-M2-6	D	5.2	-20.4	12.5	3.2	44.2	16.0
IIHA-Se10-M2-7	D	5.9	-20.3	12.1	3.2	43.8	15.8
IIHA-Se10-M2-8	D	6.5	-20.3	12.1	3.2	44.0	15.8
IIHA-Se10-M2-9	D	7.1	-20.3	12.1	3.2	44.0	15.9
IIHA-Se10-M2-10	D	7.8	-20.3	11.8	3.2	43.8	15.8
IIHA-Se10-M2-11	D	8.4	-20.4	12.1	3.2	44.0	15.9
IIHA-Se10-M2-12	D	9.1	-20.4	12.3	3.2	44.1	15.9
IIHA-Se10-M2-13	D	9.7	-20.4	12.5	3.2	43.0	15.9
IIHA-Se10-M2-14	D	10.4	-20.5	12.5	3.2	42.9	15.8
IIHA-Se10-M2-15	D	11.0	-20.7	12.2	3.2	43.1	15.8
IIHA-Se10-M2-16	D	11.6	-20.7	12.3	3.2	43.5	15.9
IIHA-Se10-M2-17	D	12.3	-20.8	12.5	3.2	42.8	15.6
IIHA-Se10-M2-18	D	12.9	-20.7	12.4	3.2	43.5	15.8
IIHA-Se10-M2-19	D	13.6	-20.7	12.7	3.2	42.9	15.5
IIHA-Se10-M2-20	D	14.2	-20.3	12.6	3.2	43.1	15.6
sample was lost		14.9					
IIHA-Se10-M2-22	D	15.5	-20.4	12.6	3.2	43.3	15.6

Sample numbers	Lab	Age (years)	$\delta^{13}C$ (‰)	$\Delta^{15}N$ (‰)	C/N	C (%)	N (%)
IIHA-116-M3-1	D	15.5	-18.8	14.1	3.2	43.1	15.5
IIHA-116-M3-2	D	16.0	-18.9	13.5	3.2	43.0	15.5
IIHA-116-M3-3	D	16.5	-18.8	13.4	3.2	43.4	15.8
IIHA-116-M3-4	D	17.0	-18.7	13.6	3.2	43.4	15.7
IIHA-116-M3-5	D	17.5	-18.6	13.7	3.2	43.3	15.6
IIHA-116-M3-6	D	18.0	-18.6	13.6	3.2	43.3	15.6
IIHA-116-M3-7	D	18.5	-18.5	13.4	3.3	43.3	15.5
IIHA-116-M3-8	D	19.0	-18.5	13.4	3.2	43.3	15.6
IIHA-116-M3-9	D	19.5	-18.4	13.5	3.2	43.3	15.6
IIHA-116-M3-10	D	20.0	-18.4	13.6	3.2	43.7	16.0
IIHA-116-M3-11	D	20.5	-18.4	13.6	3.2	43.7	15.9
IIHA-116-M3-12	D	21.0	-18.4	13.8	3.2	43.9	16.0
IIHA-116-M3-13	D	21.5	-18.4	13.9	3.2	43.5	15.9
IIHA-116-M3-14	D	22.0	-18.4	13.7	3.2	44.0	16.1
IIHA-116-M3-15	D	22.5	-18.3	13.7	3.2	43.6	16.0
IIHA-116-M3-16	D	23.0	-18.5	13.7	3.2	43.8	16.0
IIHA-116-M3-17	D	23.5	-18.6	14.0	3.2	43.7	15.9
IIHA-116-M2-1	D	2.0	-18.5	12.5	3.2	43.7	16.0
IIHA-116-M2-2	D	2.8	-18.2	13.4	3.2	43.8	16.1
IIHA-116-M2-3	D	3.5	-18.1	12.8	3.2	43.8	16.1
IIHA-116-M2-4	D	4.3	-18.2	13.0	3.2	43.7	16.1
IIHA-116-M2-5	D	5.0	-18.3	13.3	3.2	43.7	16.0
IIHA-116-M2-6	D	5.8	-18.3	13.2	3.2	43.9	16.1
IIHA-116-M2-7	D	6.5	-18.3	13.1	3.2	44.1	16.1
IIHA-116-M2-8	D	7.3	-18.2	13.4	3.1	42.8	16.0
IIHA-116-M2-9	D	8.0	-18.3	13.3	3.2	42.8	15.5
IIHA-116-M2-10	D	8.8	-18.3	13.4	3.2	42.9	15.9
IIHA-116-M2-11	D	9.5	-18.3	13.5	3.2	43.1	15.9
IIHA-116-M2-12	D	10.3	-18.4	13.5	3.2	43.1	15.9
IIHA-116-M2-13	D	11.0	-18.3	13.4	3.2	43.1	15.8
IIHA-116-M2-14	D	11.8	-18.2	13.6	3.2	43.2	15.8
IIHA-116-M2-15	D	12.5	-18.2	13.8	3.2	43.3	15.9
IIHA-116-M2-16	D	13.3	-18.4	13.8	3.2	43.1	15.8
IIHA-116-M2-17	D	14.0	-18.4	13.9	3.2	43.0	15.7
IIHA-116-M2-18	D	14.8	-18.3	14.0	3.2	43.2	15.7
IIHA-116-M2-19	D	15.5	-18.5	14.0	3.2	43.2	15.6

Sample numbers	Lab	Age (years)	δ^{13}C (‰)	Δ^{15}N (‰)	C/N	C (%)	N (%)
IIHA-23A-M2-1	D	2.5	-20.6	12.6	3.2	43.3	15.9
IIHA-23A-M2-2	D	3.5	-20.5	12.5	3.2	43.6	16.1
IIHA-23A-M2-3	D	4.5	-20.3	12.4	3.2	44.0	16.2
IIHA-23A-M2-4	D	5.5	-20.6	12.3	3.2	44.6	16.3
IIHA-23A-M2-5	D	6.5	-20.2	12.1	3.2	44.1	16.2
IIHA-23A-M2-6	D	7.5	-20.1	12.2	3.2	44.0	16.2
IIHA-23A-M2-7	D	8.5	-20.1	12.4	3.2	44.1	16.2
IIHA-23A-M2-8	D	9.5	-20.0	12.6	3.2	44.4	16.3
IIHA-23A-M2-9	D	10.5	-20.1	12.5	3.2	43.1	15.6
IIHA-23A-M2-10	D	11.5	-20.1	12.5	3.2	43.8	16.1
IIHA-23A-M2-11	D	12.5	-20.4	12.4	3.2	44.3	16.3
IIHA-23A-M2-12	D	13.5	-20.6	12.7	3.2	43.9	16.1
IIHA-23A-M2-13	D	14.5	-20.7	12.7	3.2	44.0	16.0
IIHA-23A-M3-1	B	14.5	-20.4	12.7	3.2	42.3	15.5
IIHA-23A-M3-2	B	15.3	-20.9	12.8	3.2	42.6	15.7
IIHA-23A-M3-3	B	16.2	-20.5	12.9	3.2	43.1	15.9
IIHA-23A-M3-4	B	17.0	-20.5	12.4	3.2	43.2	16.0
IIHA-23A-M3-5	B	17.8	-20.7	12.0	3.2	42.3	15.5
IIHA-23A-M3-6	B	18.7	-20.8	12.0	3.2	42.7	15.8
IIHA-23A-M3-7	B	19.5	-20.9	12.0	3.2	42.6	15.6
IIHA-23A-M3-8	B	20.3	-20.9	12.2	3.2	42.7	15.7
IIHA-23A-M3-9	B	21.2	-21.1	12.3	3.2	42.6	15.6
IIHA-23A-M3-10	B	22.0	-21.1	12.4	3.2	42.7	15.7
IIHA-23A-M3-11	B	22.8	-21.3	12.7	3.2	42.5	15.6
IIHA-23A-M3-12	B	23.7	-21.4	13.0	3.2	41.9	15.4
IIHA-23A-M3-13	B	24.5	-21.1	13.1	3.2	42.0	15.4

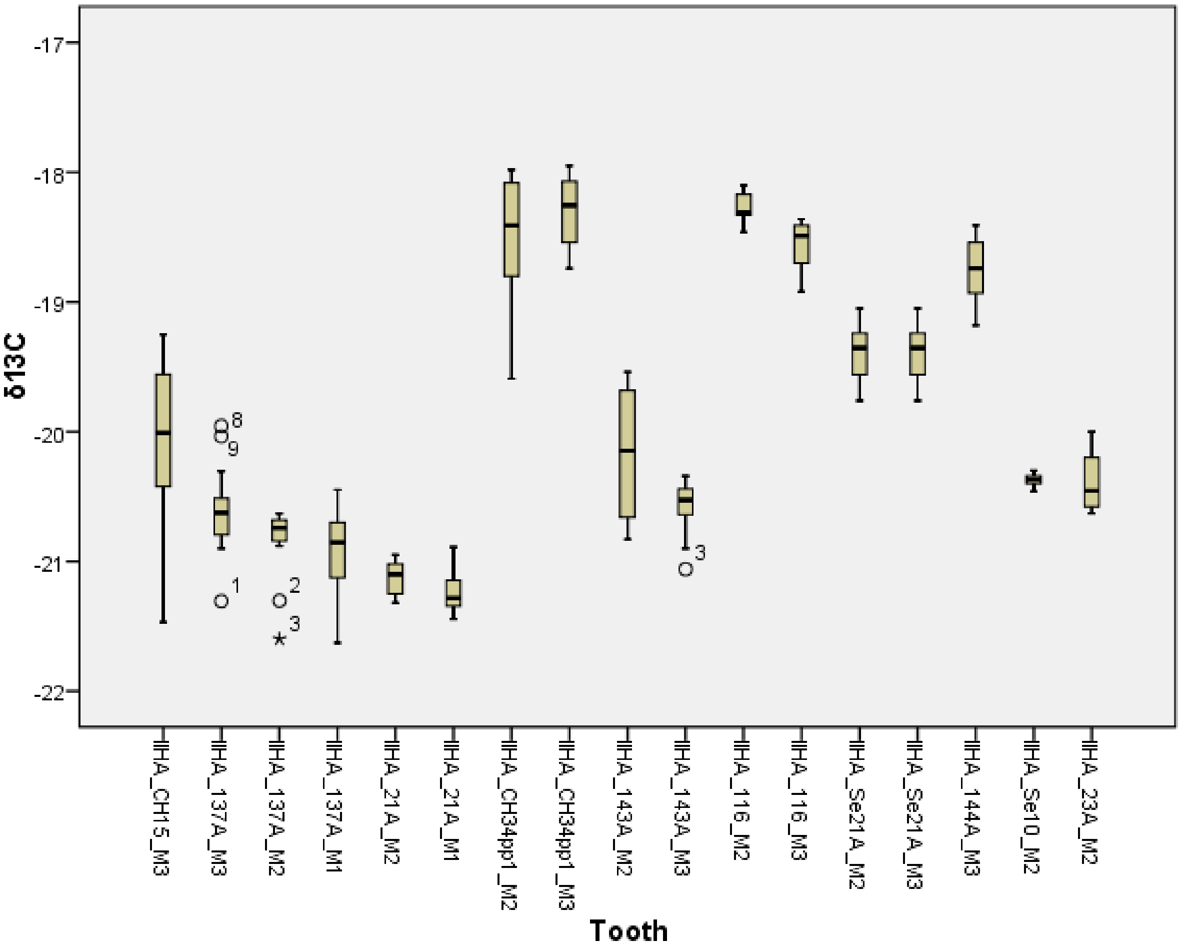
APPENDIX 5

Dentine statistics pictures

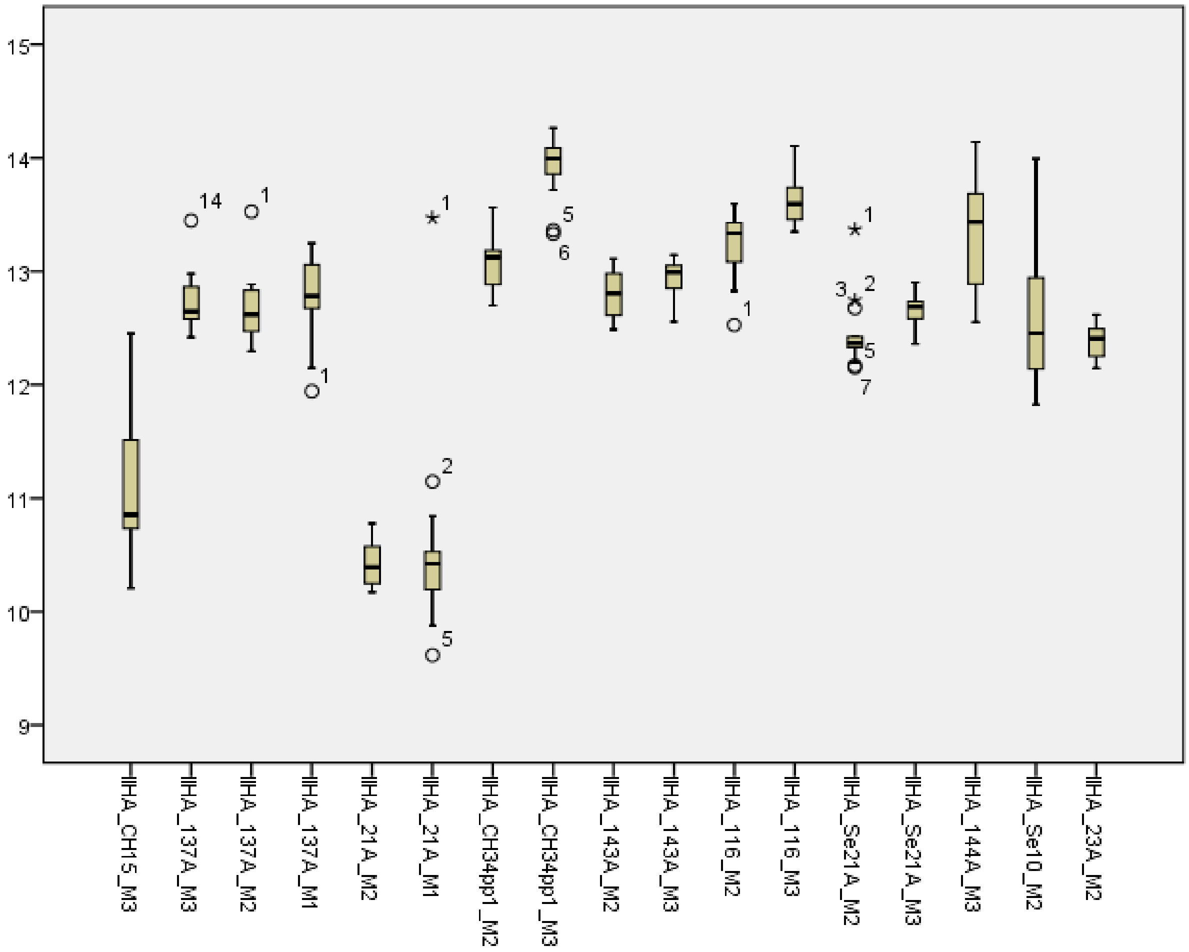
In this appendix histogram of δ15N δ13C values of each tooth has been analysed with SPSS statistical software for histogram and descriptive statistics (Q-Q plot).

δ^{13}C

Box plot of all carbon isotope composition of dentine incremental samples of each tooth.

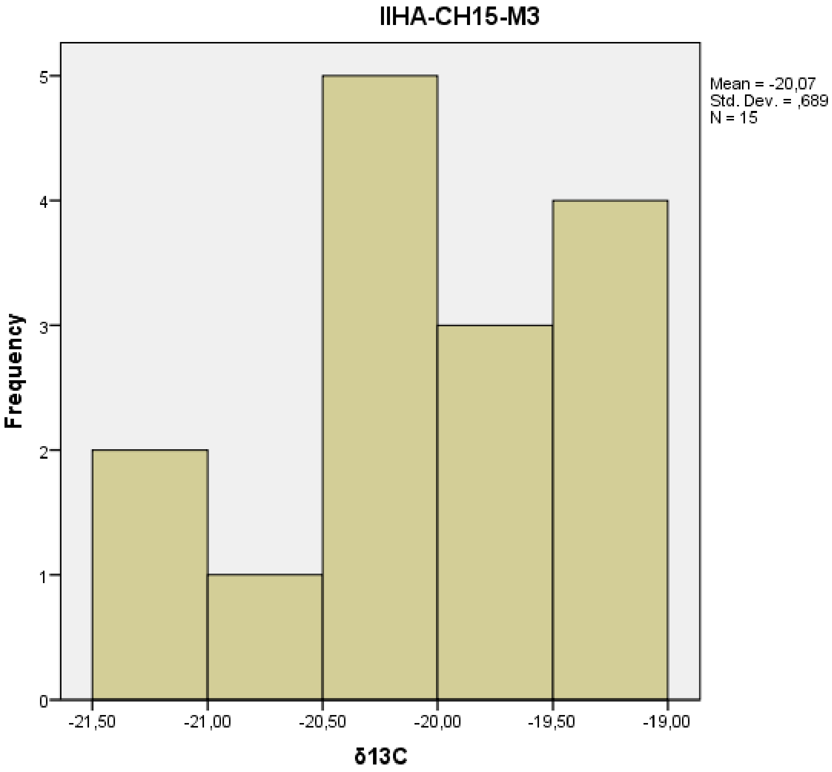


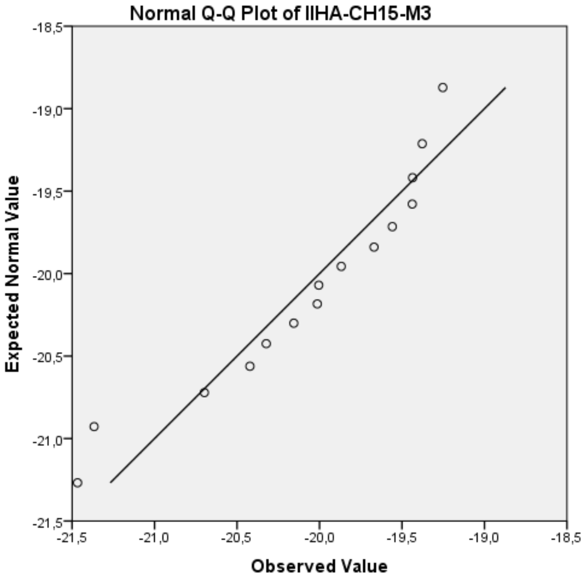
Box plot of Nitrogen isotope composition of tooth

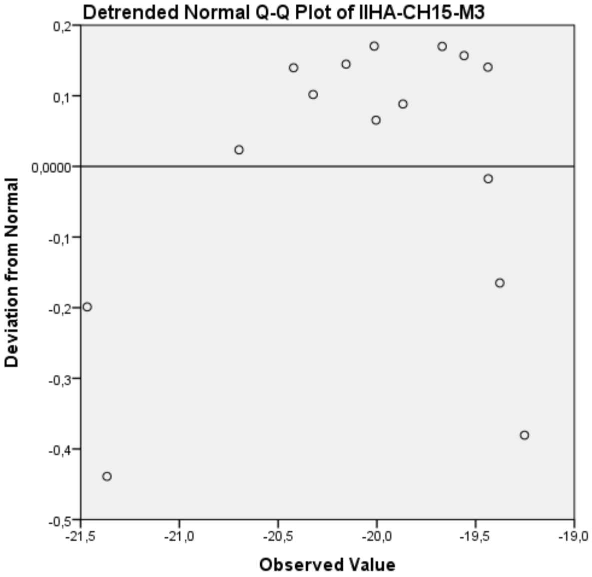


IIHA-CH15-M3

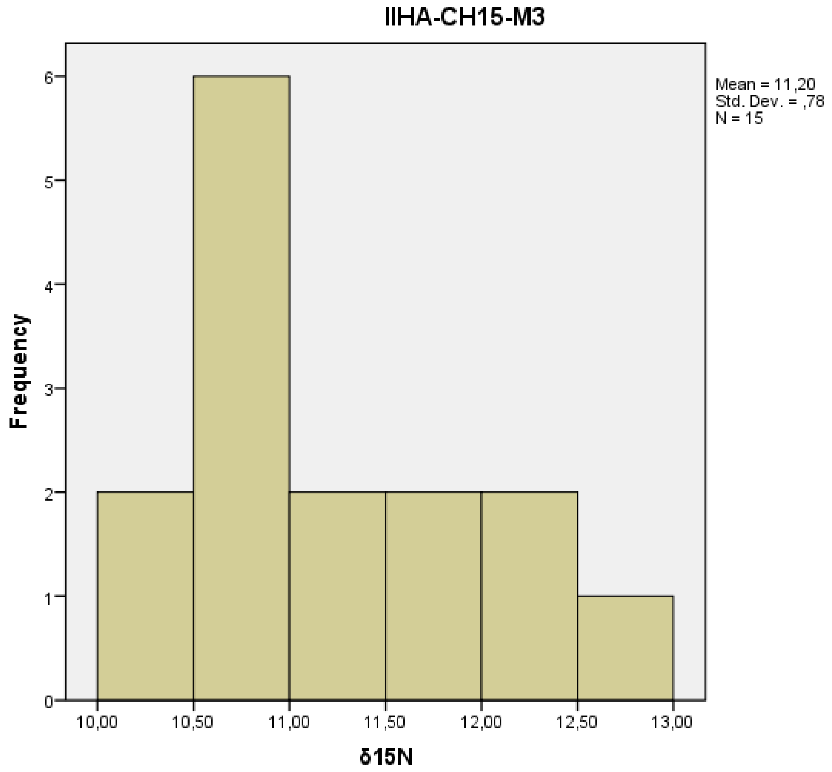
$\delta^{13}C$

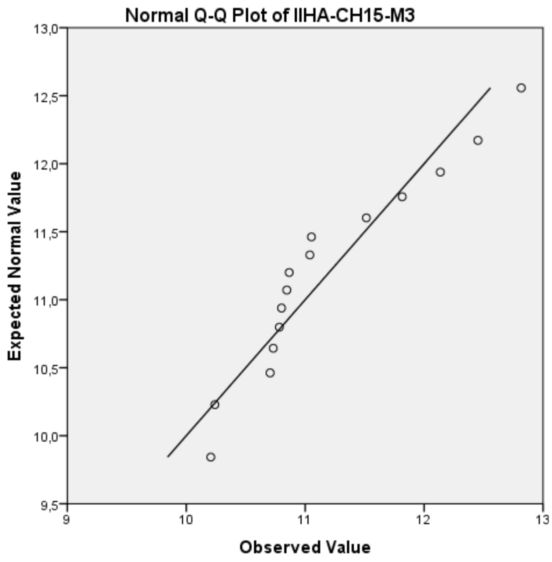


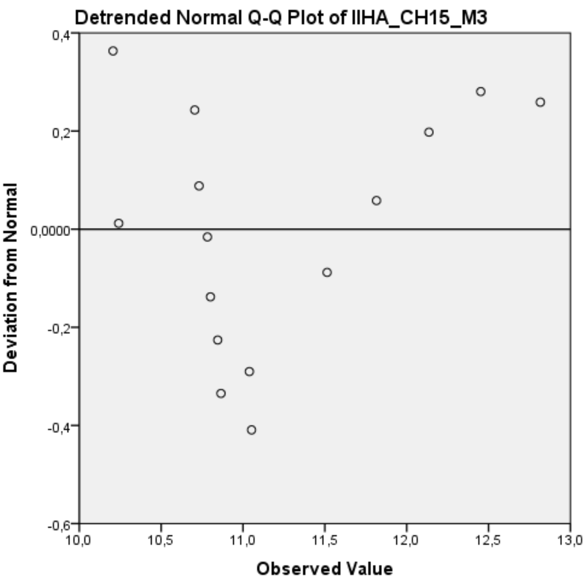




δ^{15}N

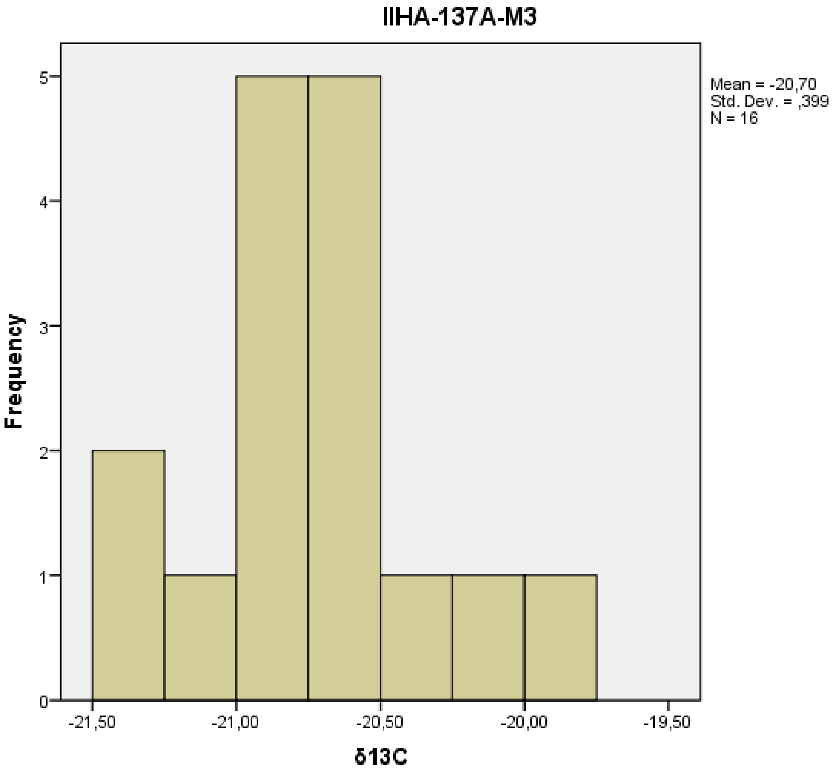

IIHA-CH15-M3
Mean = 11,20
Std. Dev. = ,78
N = 15
Frequency
0
1
2
3
4
5
6
10,00
10,50
11,00
11,50
12,00
12,50
13,00
δ15N

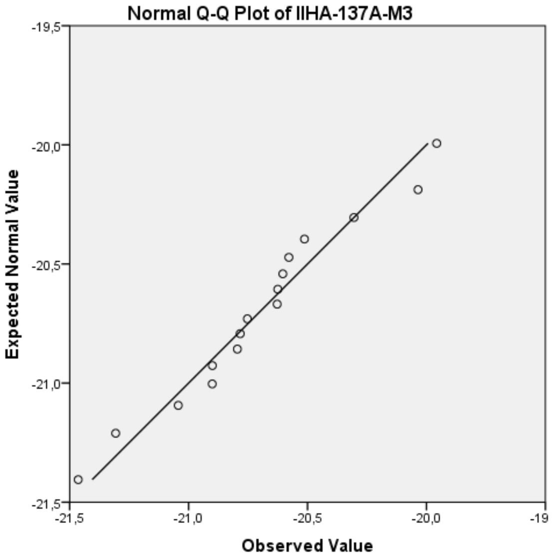

Normal Q-Q Plot of IIHA-CH15-M3
Expected Normal Value
9,5
10,0
10,5
11,0
11,5
12,0
12,5
13,0
9
10
11
12
13
Observed Value

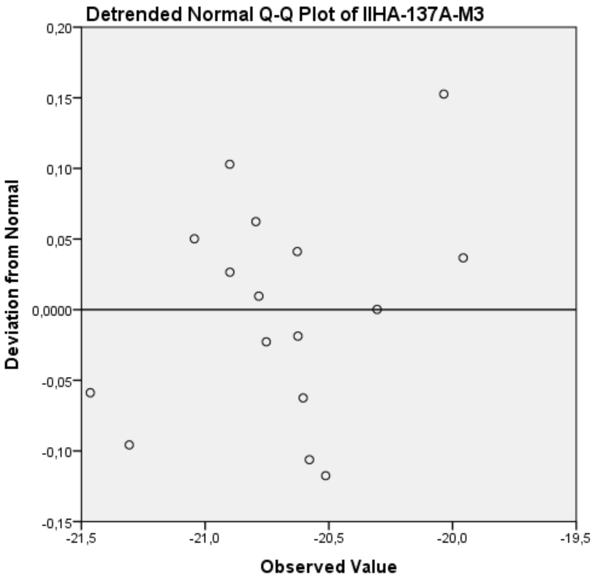

Detrended Normal Q-Q Plot of IIHA_CH15_M3
Deviation from Normal
-0,6
-0,4
-0,2
0,0000
0,2
0,4
10,0
10,5
11,0
11,5
12,0
12,5
13,0
Observed Value

IIHA-137A-M3

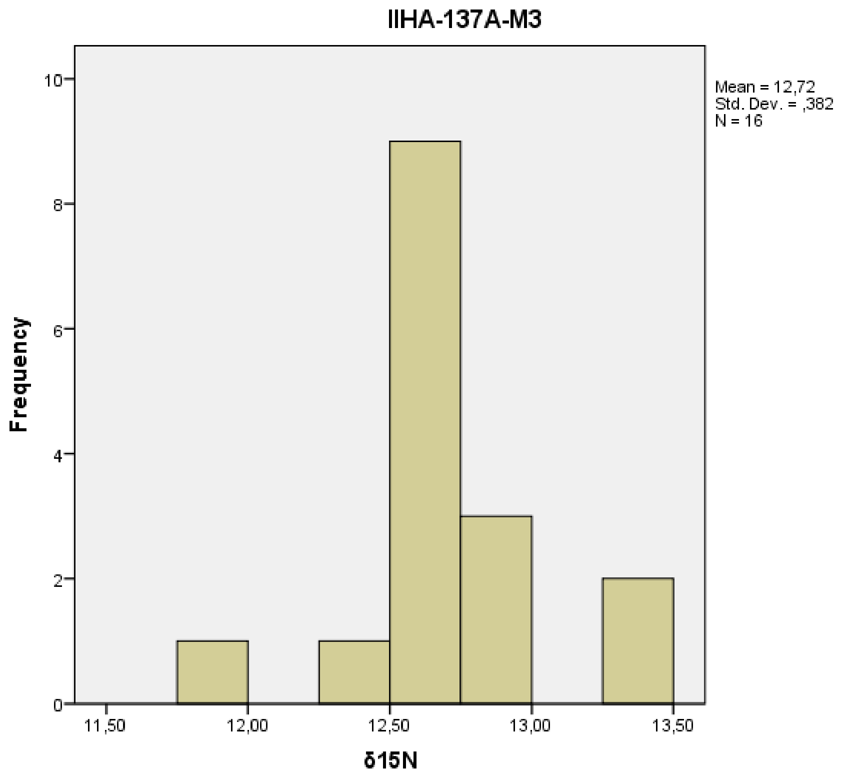
$\delta^{13}C$

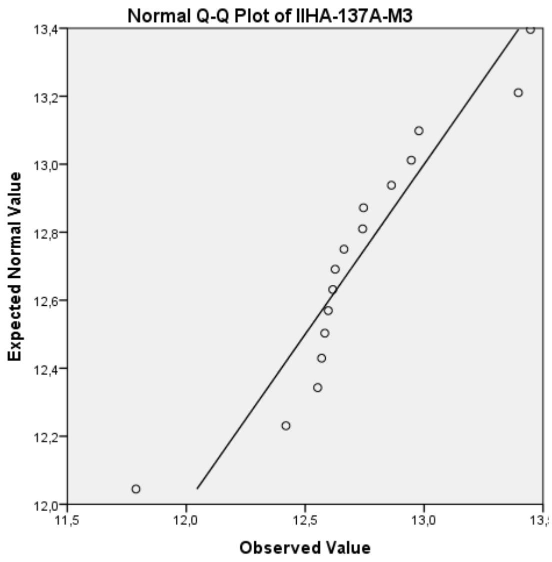


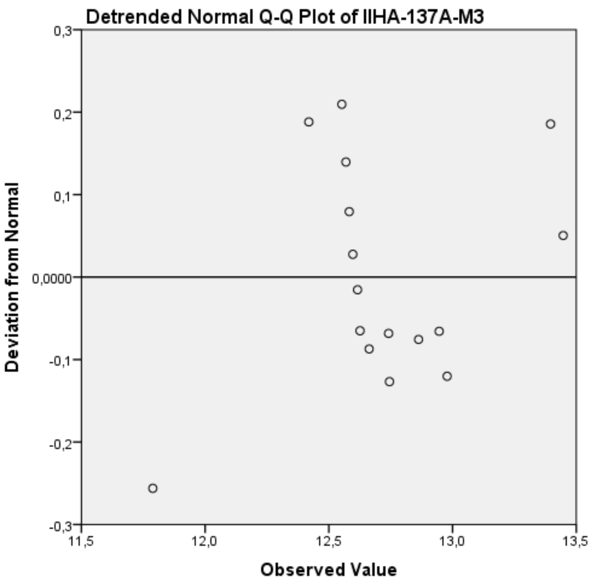




δ^{15}N

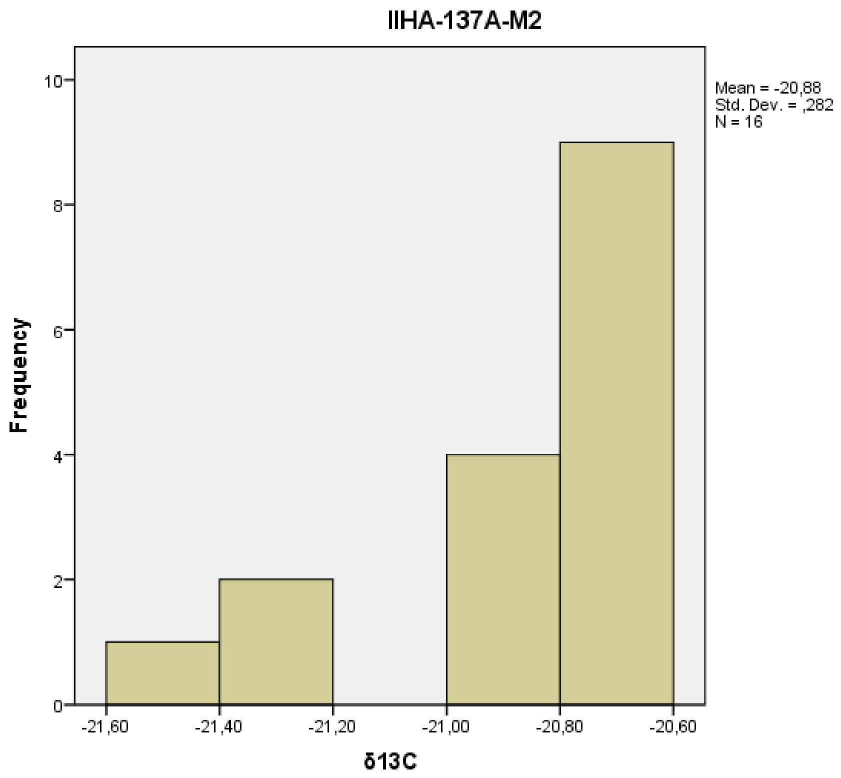

IIHA-137A-M3
Mean = 12,72
Std. Dev. = ,382
N = 16
Frequency
10
8
6
4
2
0
11,50
12,00
12,50
13,00
13,50
δ15N

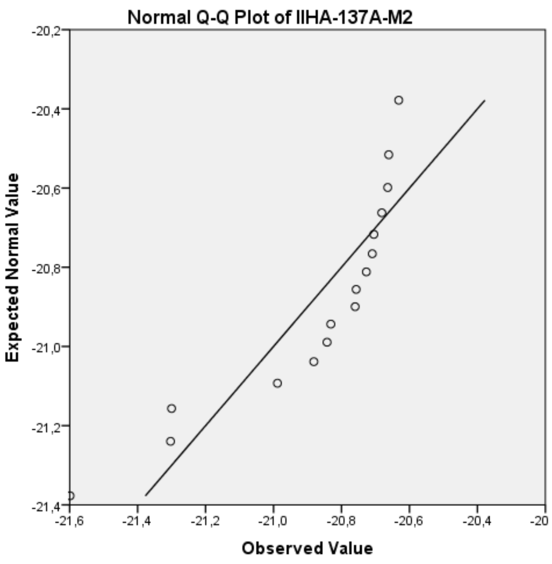

Normal Q-Q Plot of IIHA-137A-M3
Expected Normal Value
13,4
13,2
13,0
12,8
12,6
12,4
12,2
12,0
11,5
12,0
12,5
13,0
13,
Observed Value

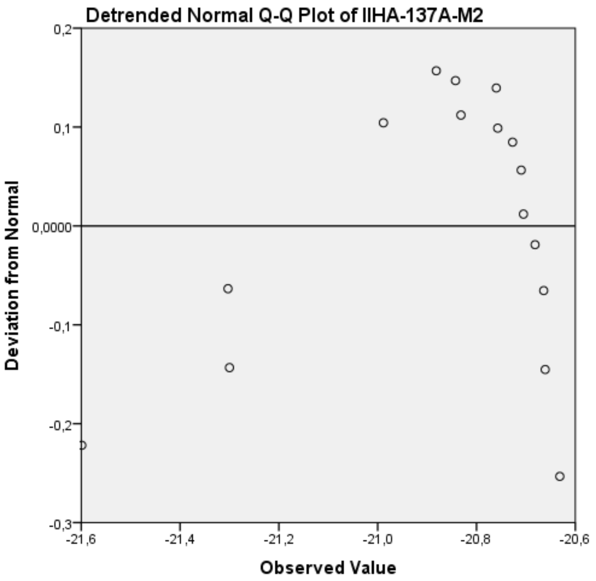

Detrended Normal Q-Q Plot of IIHA-137A-M3
Deviation from Normal
0,3
0,2
0,1
0,0000
-0,1
-0,2
-0,3
11,5
12,0
12,5
13,0
13,5
Observed Value

IIHA-137A-M2

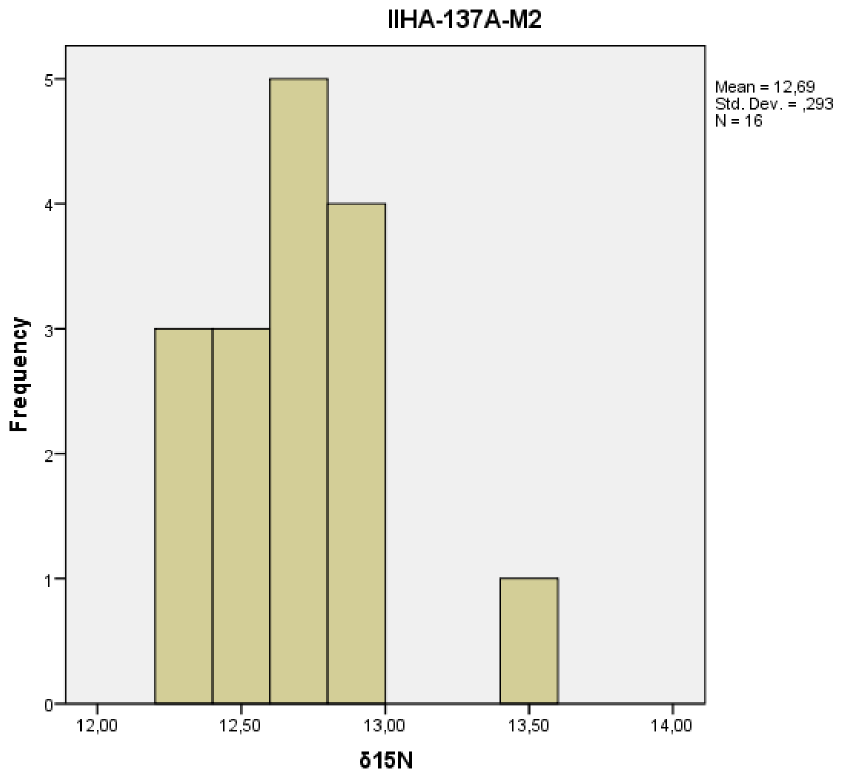
δ^{13}C

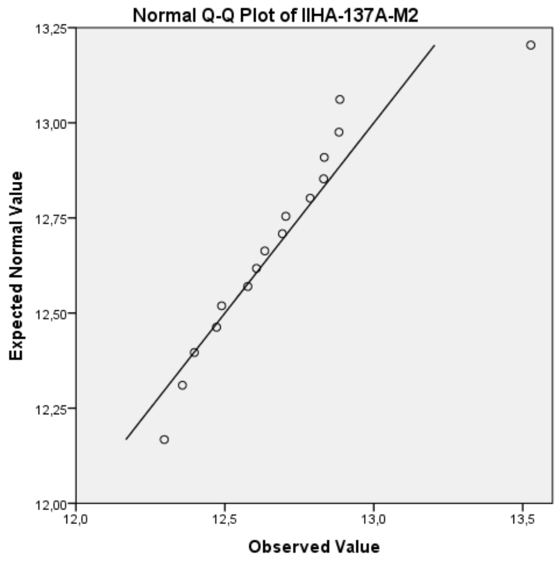


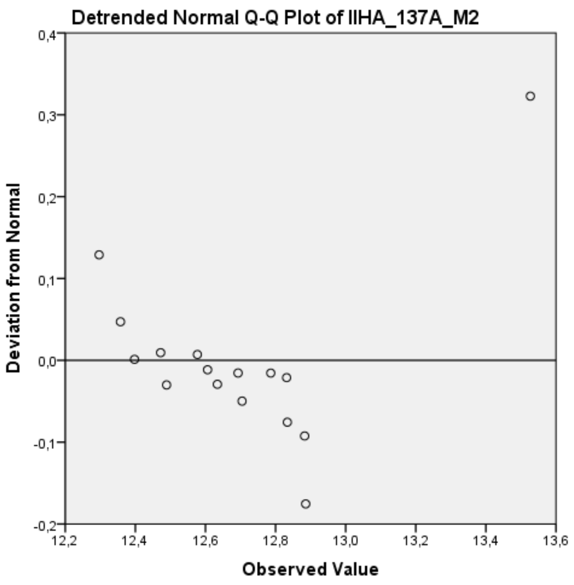




δ^{15}N

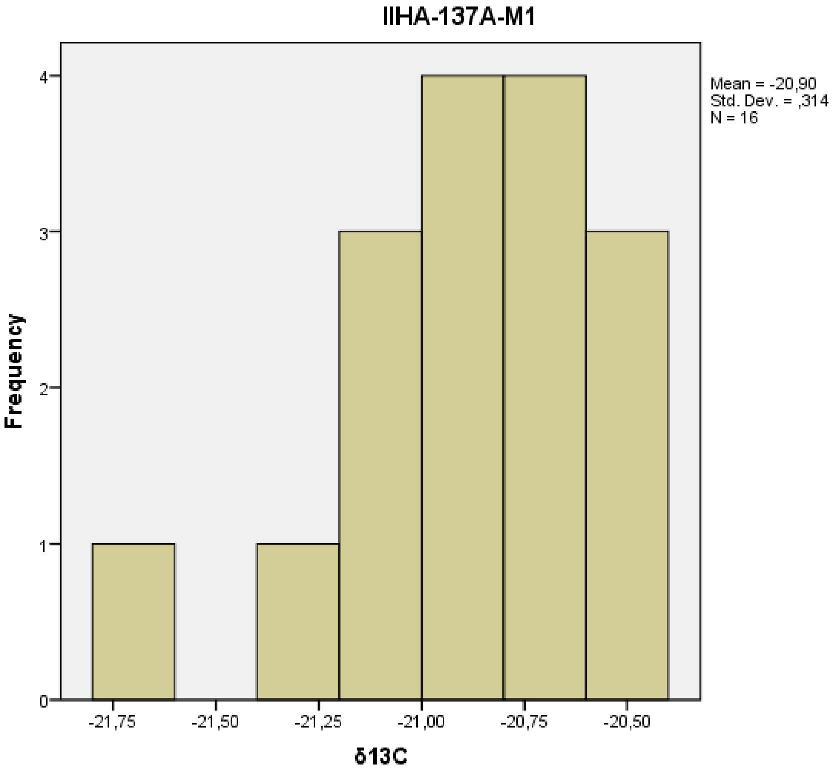

IIHA-137A-M2
Frequency
5
4
3
2
1
0
12,00
12,50
13,00
13,50
14,00
δ15N
Mean = 12,69
Std. Dev. = ,293
N = 16

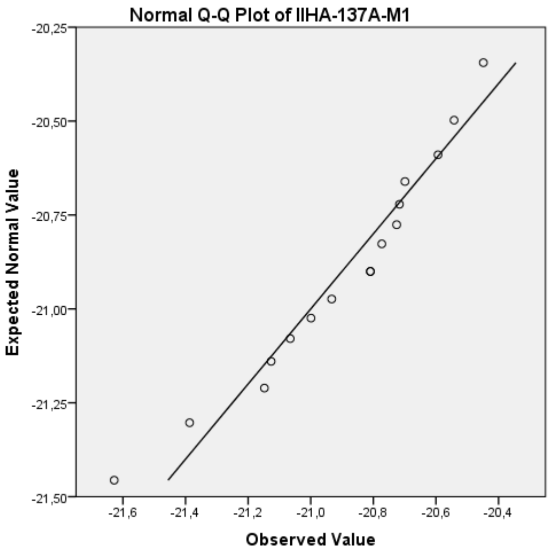

Normal Q-Q Plot of IIHA-137A-M2
Expected Normal Value
13,25
13,00
12,75
12,50
12,25
12,00
12,0
12,5
13,0
13,5
Observed Value

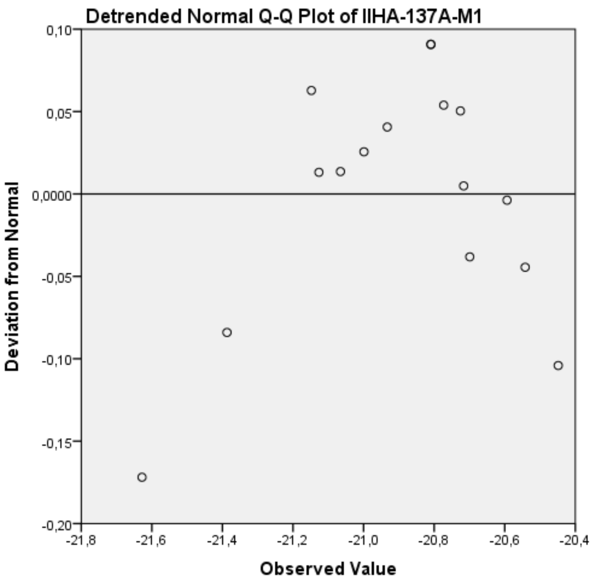

Detrended Normal Q-Q Plot of IIHA_137A_M2
Deviation from Normal
0,4
0,3
0,2
0,1
0,0
-0,1
-0,2
12,2
12,4
12,6
12,8
13,0
13,2
13,4
13,6
Observed Value

IIHA-137A-M1

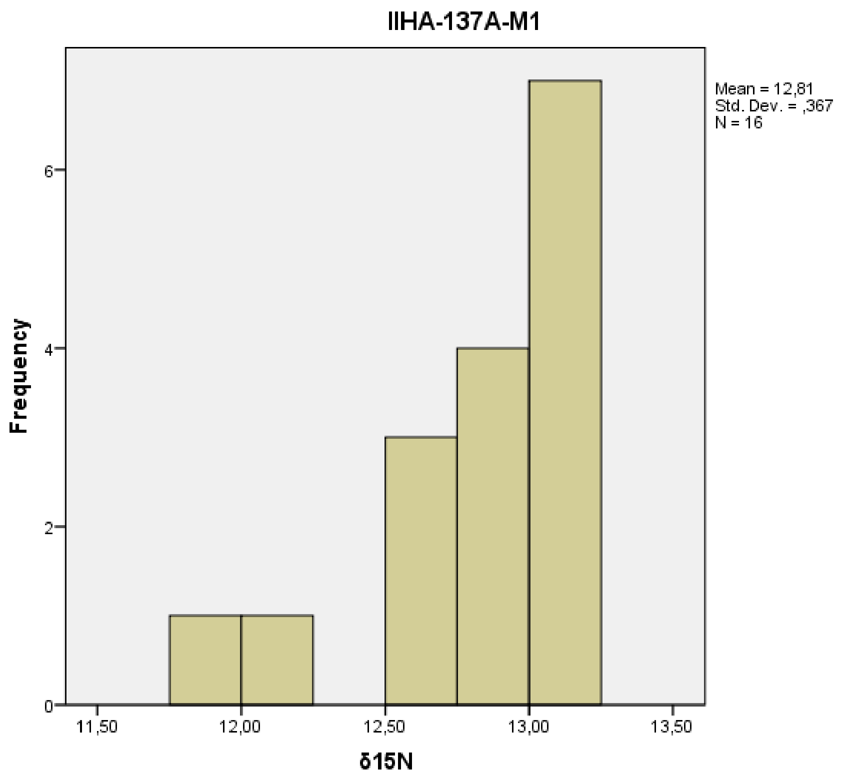
$\delta^{13}C$

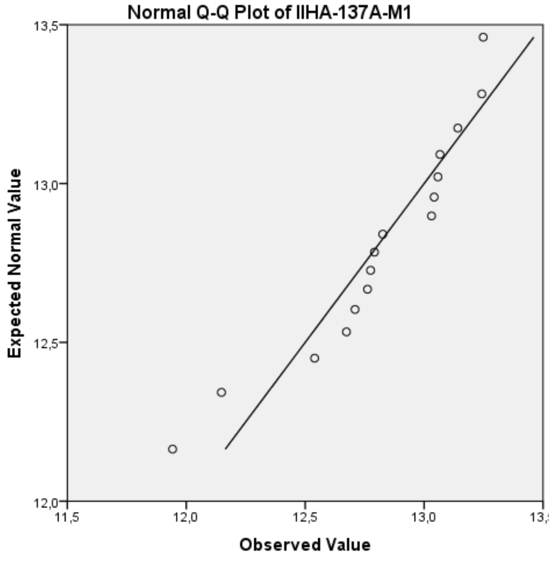


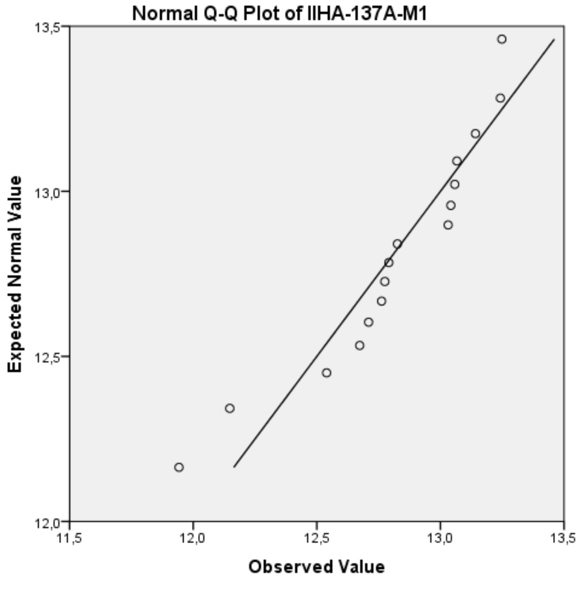




δ^{15}N

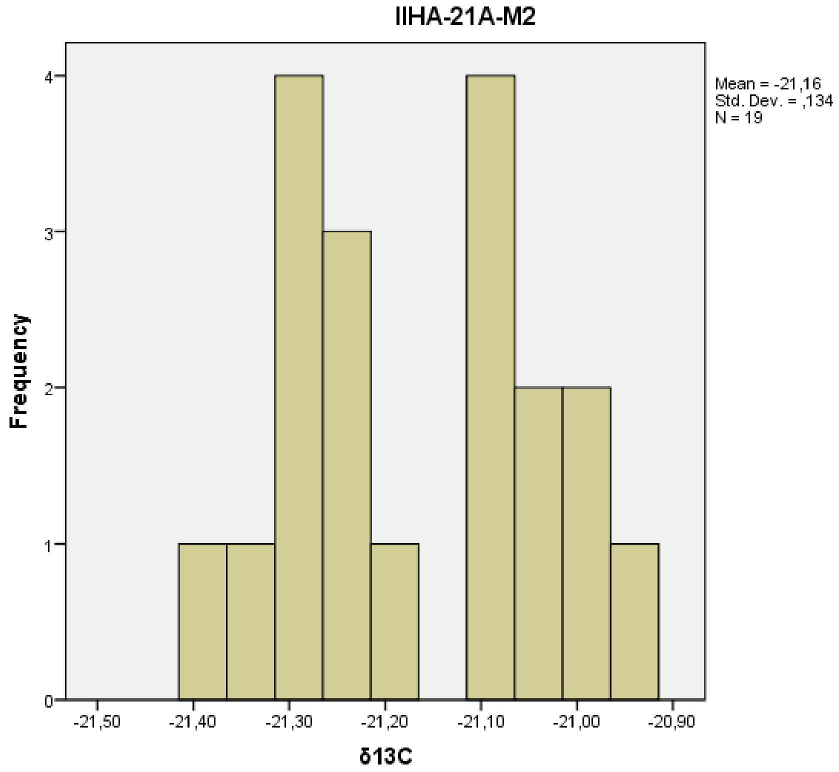

IIHA-137A-M1
Mean = 12,81
Std. Dev. = ,367
N = 16
Frequency
0
2
4
6
11,50
12,00
12,50
13,00
13,50
δ15N

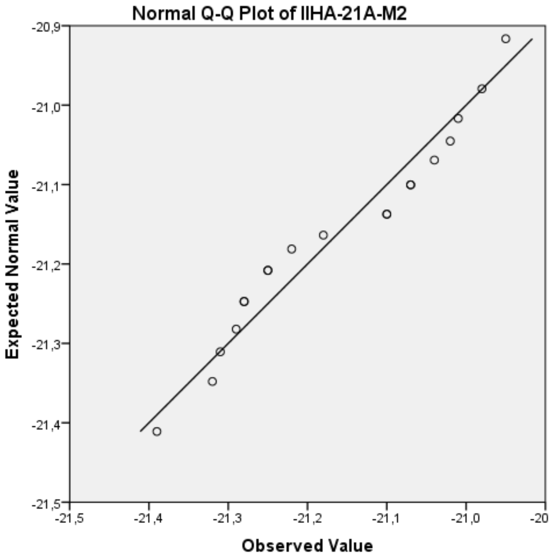

Normal Q-Q Plot of IIHA-137A-M1
Expected Normal Value
12,0
12,5
13,0
13,5
11,5
12,0
12,5
13,0
13,
Observed Value

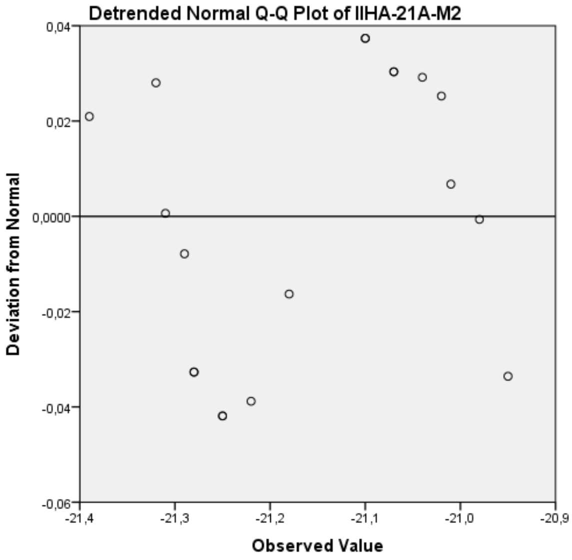

Normal Q-Q Plot of IIHA-137A-M1
Expected Normal Value
12,0
12,5
13,0
13,5
11,5
12,0
12,5
13,0
13,5
Observed Value

IIHA-21A-M2

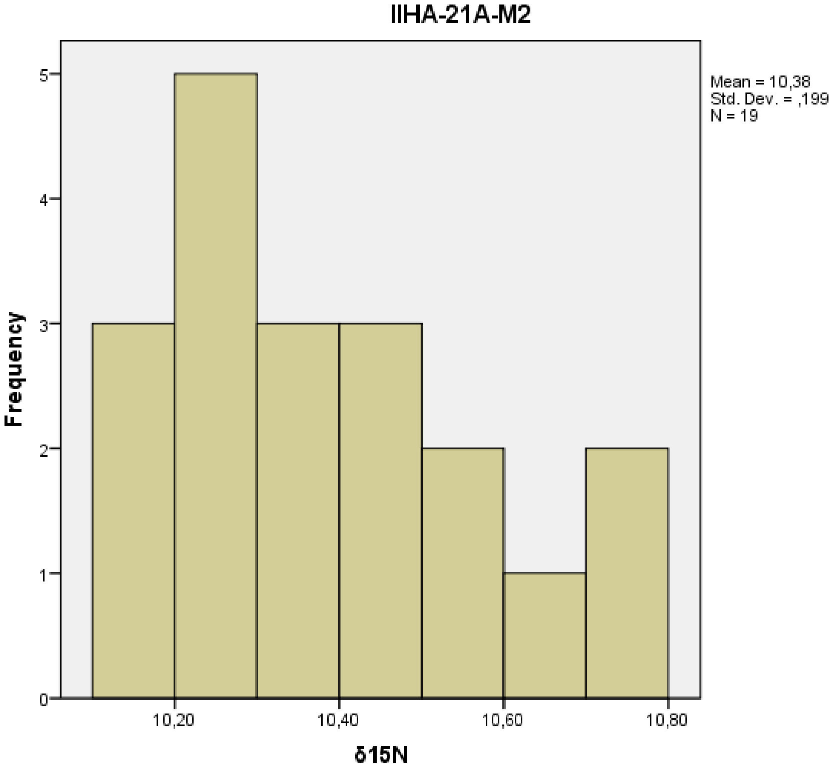
$\delta^{13}C$

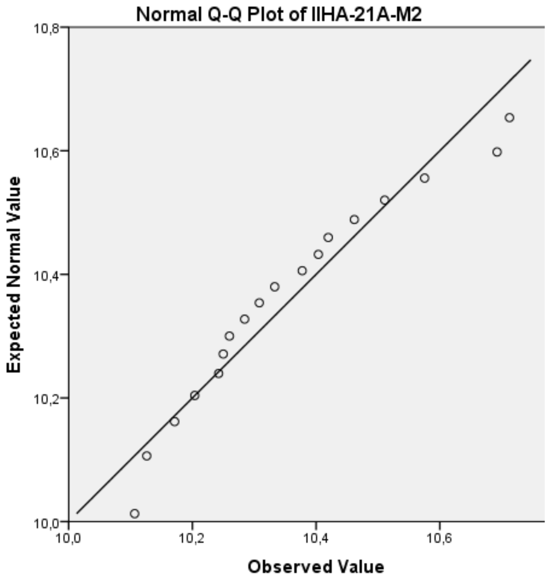


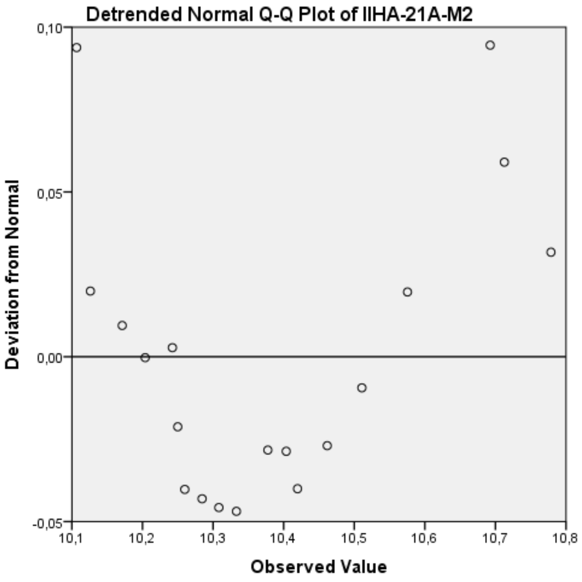




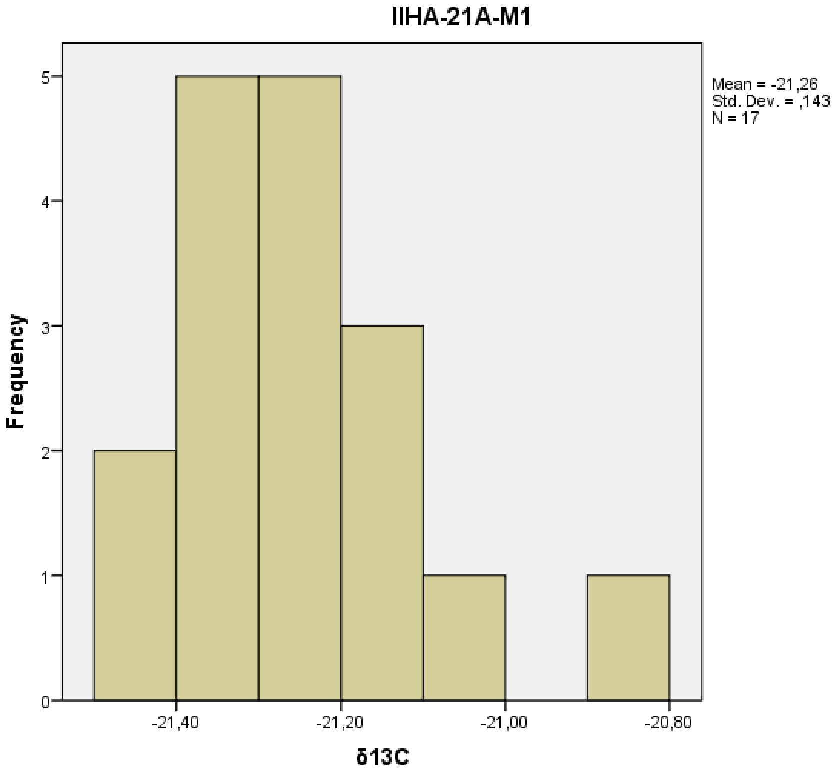
$\delta^{15}N$


IIHA-21A-M2
Mean = 10,38
Std. Dev. = ,199
N = 19
Frequency
0
1
2
3
4
5
10,20
10,40
10,60
10,80
δ15N

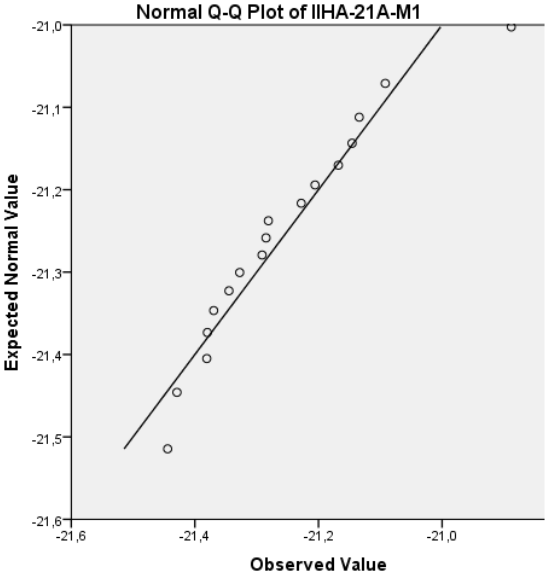

Normal Q-Q Plot of IIHA-21A-M2
Expected Normal Value
10,0
10,2
10,4
10,6
10,8
10,0
10,2
10,4
10,6
Observed Value

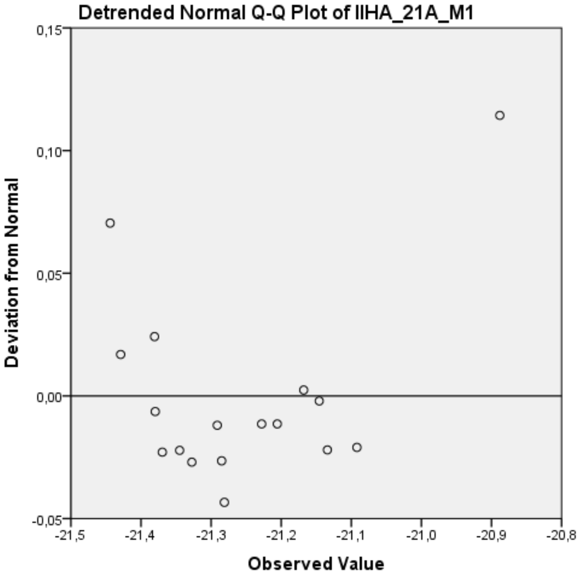

Detrended Normal Q-Q Plot of IIHA-21A-M2
Deviation from Normal
-0,05
0,00
0,05
0,10
10,1
10,2
10,3
10,4
10,5
10,6
10,7
10,8
Observed Value

IIHA-21A-M1

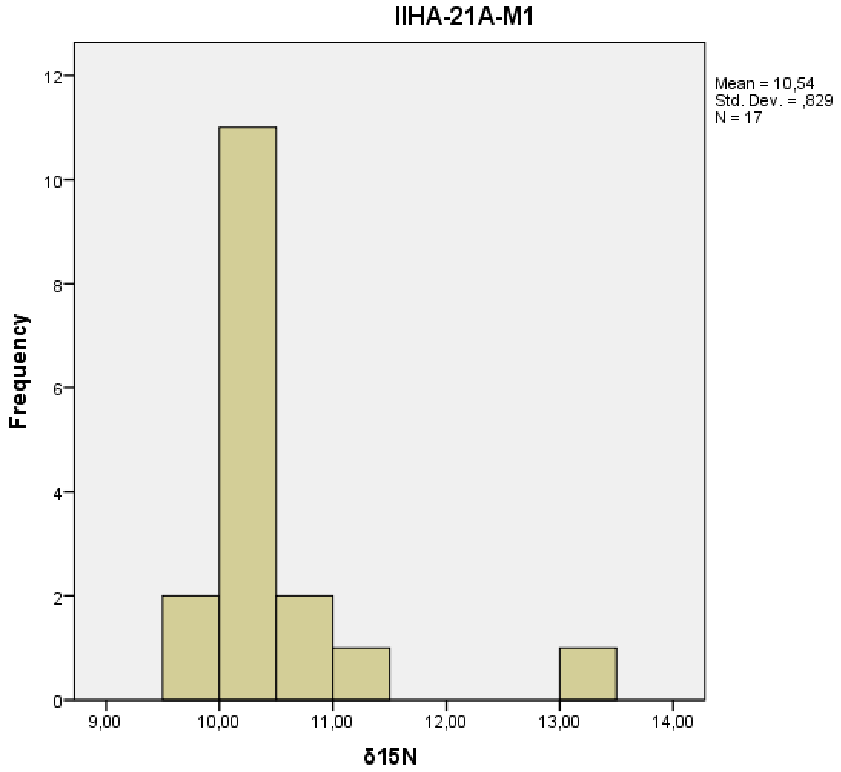


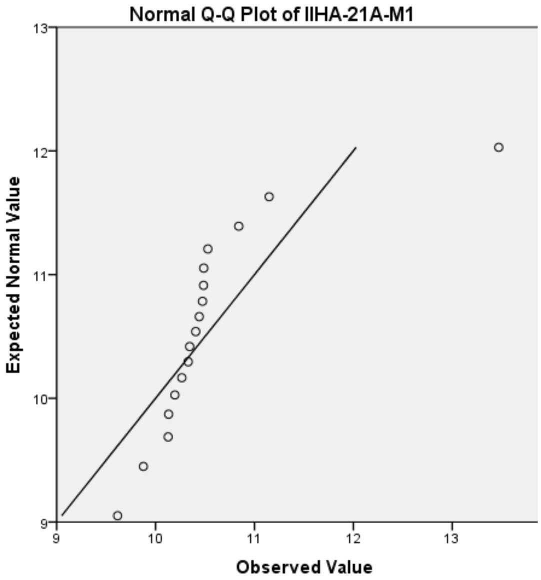
$\delta^{13}C$

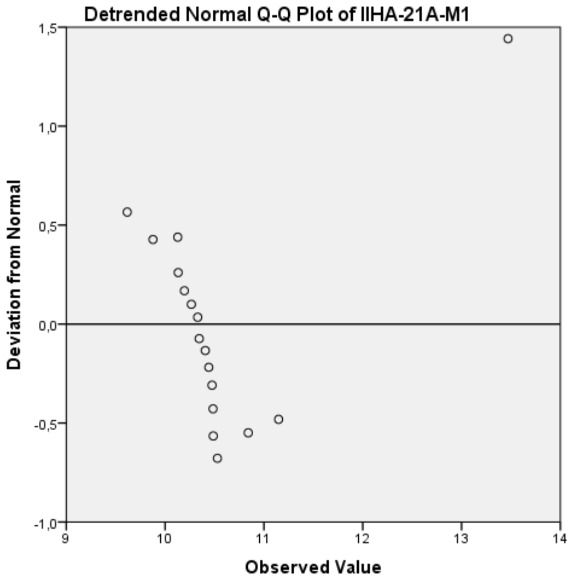




δ^{15}N

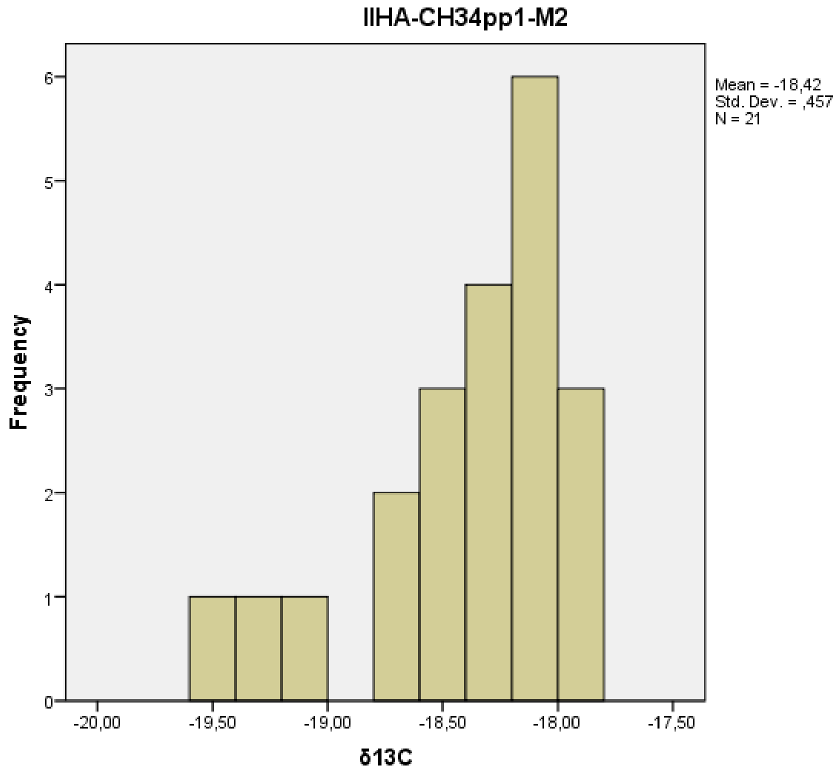

IIHA-21A-M1
Mean = 10,54
Std. Dev. = ,829
N = 17
Frequency
0
2
4
6
8
10
12
9,00
10,00
11,00
12,00
13,00
14,00
δ15N

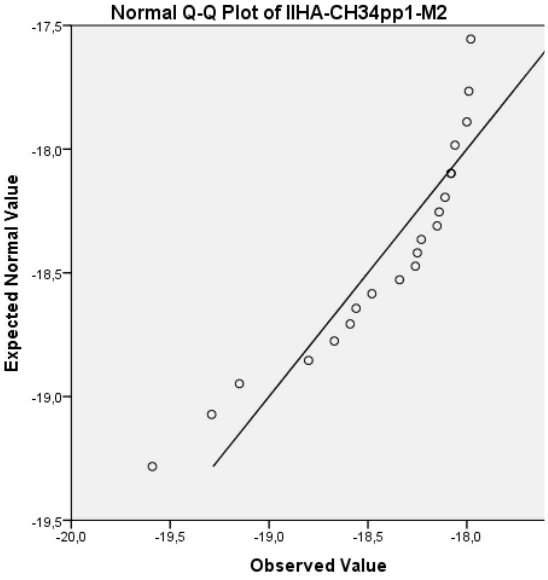

Normal Q-Q Plot of IIHA-21A-M1
Expected Normal Value
9
10
11
12
13
9
10
11
12
13
Observed Value

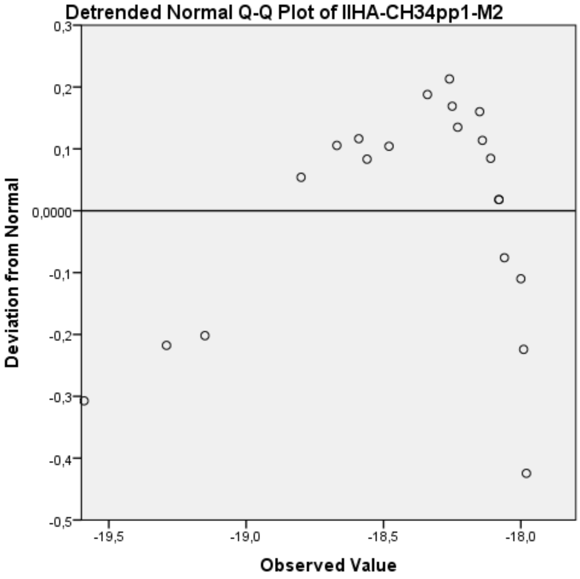

Detrended Normal Q-Q Plot of IIHA-21A-M1
Deviation from Normal
1,5
1,0
0,5
0,0
-0,5
-1,0
9
10
11
12
13
14
Observed Value

IIHA-CH34pp1-M2

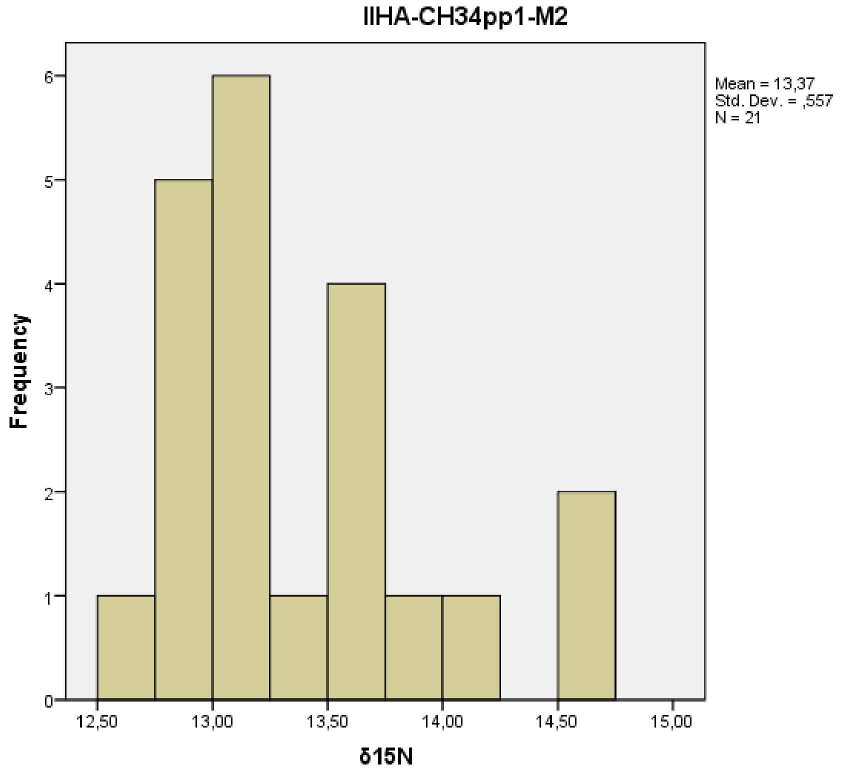
$\delta^{13}C$

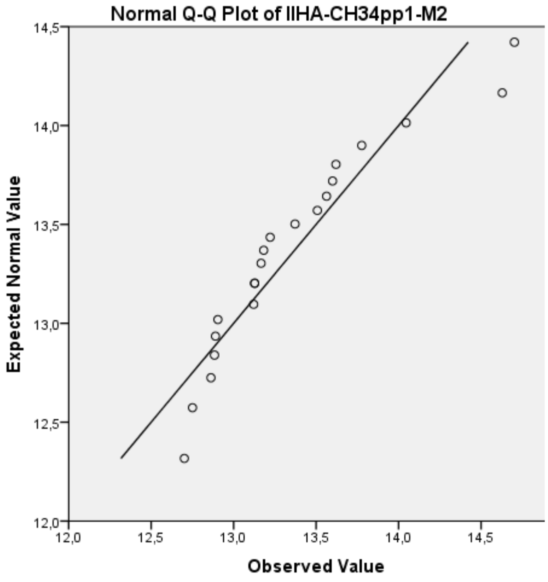


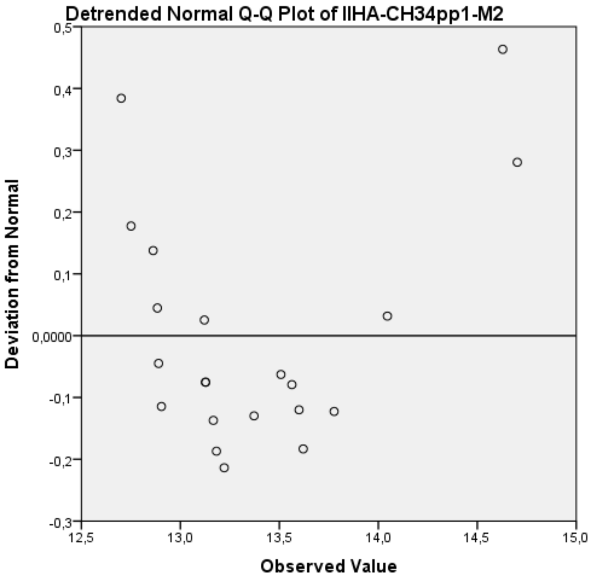




$\delta^{15}N$

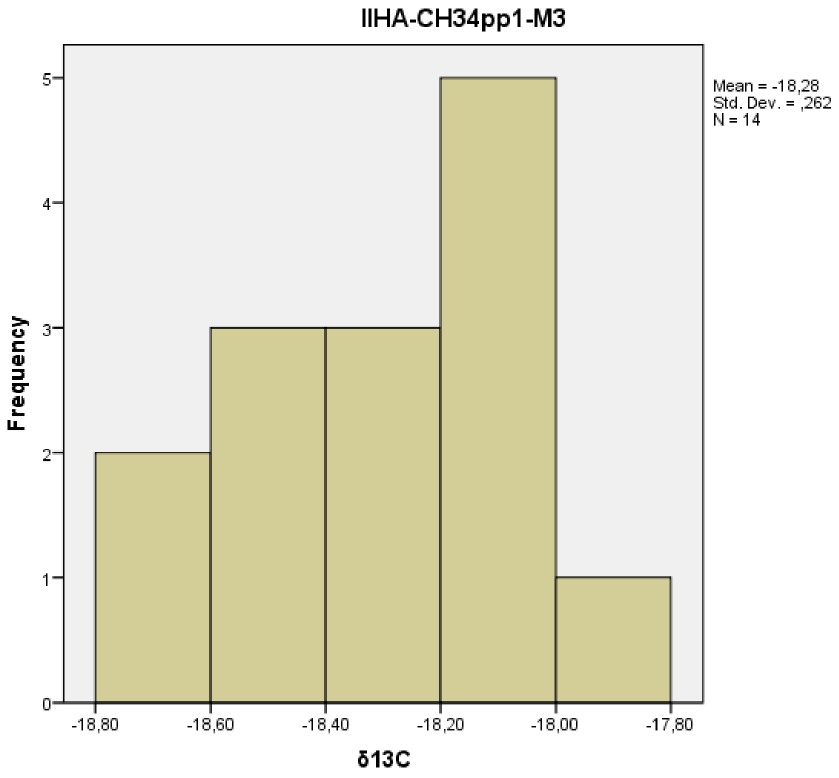

IIHA-CH34pp1-M2
Mean = 13,37
Std. Dev. = ,557
N = 21
Frequency
0
1
2
3
4
5
6
12,50
13,00
13,50
14,00
14,50
15,00
δ15N

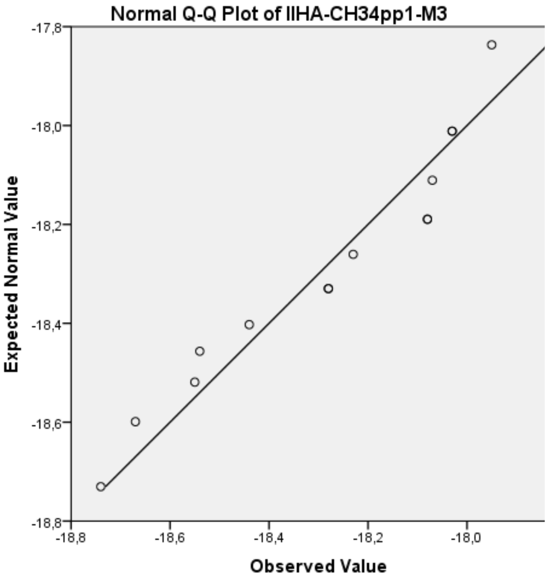

Normal Q-Q Plot of IIHA-CH34pp1-M2
Expected Normal Value
12,0
12,5
13,0
13,5
14,0
14,5
Observed Value

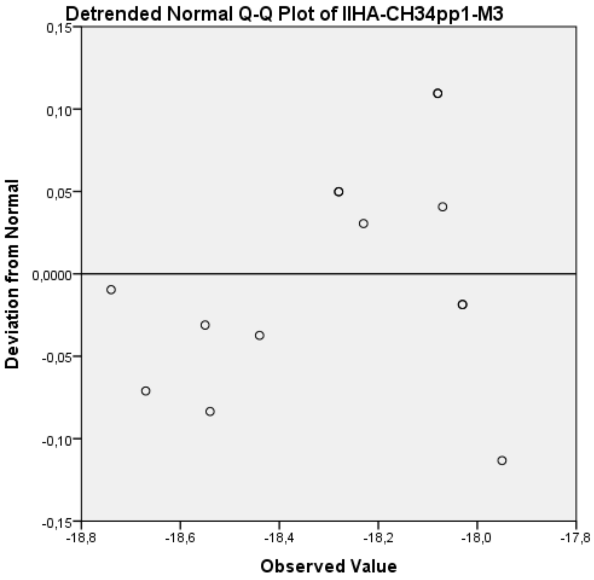

Detrended Normal Q-Q Plot of IIHA-CH34pp1-M2
Deviation from Normal
0,5
0,4
0,3
0,2
0,1
0,0000
-0,1
-0,2
-0,3
12,5
13,0
13,5
14,0
14,5
15,0
Observed Value

IIHA-CH34pp1-M3

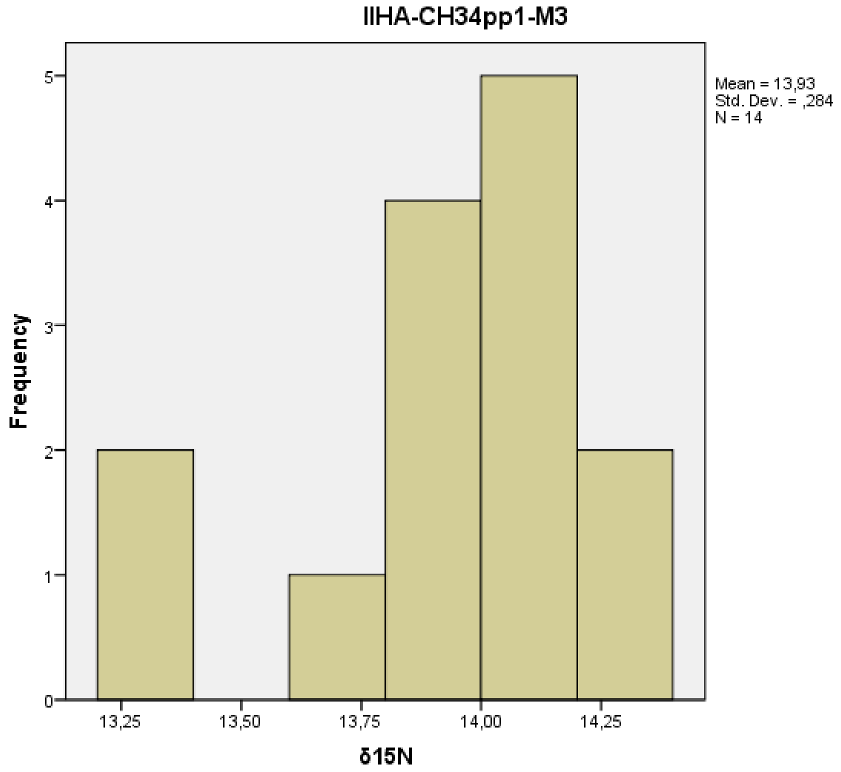
δ¹³C

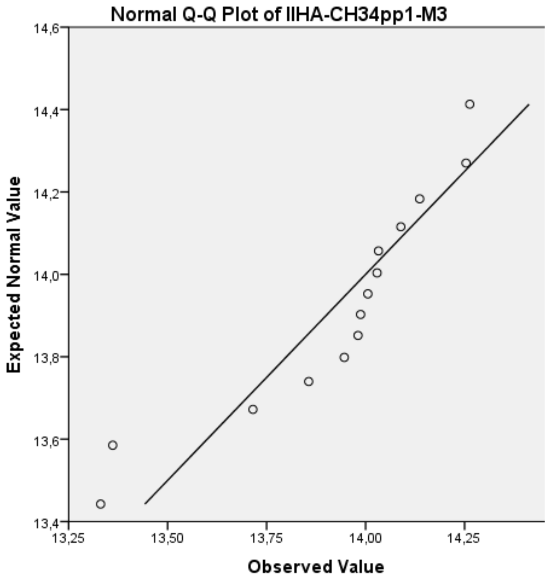


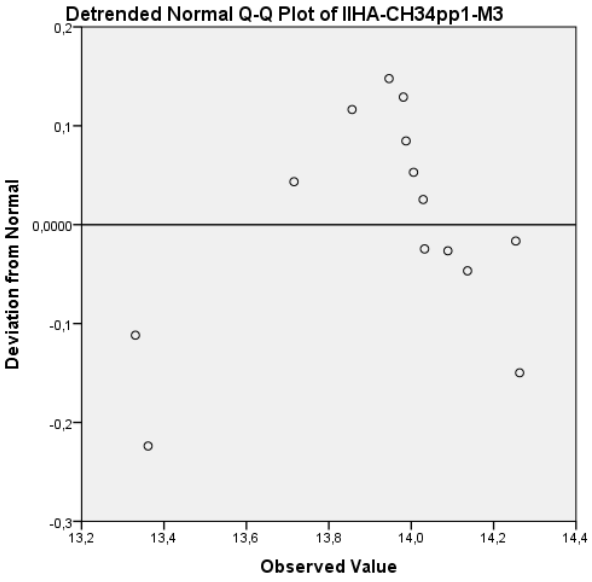




δ^{15}N

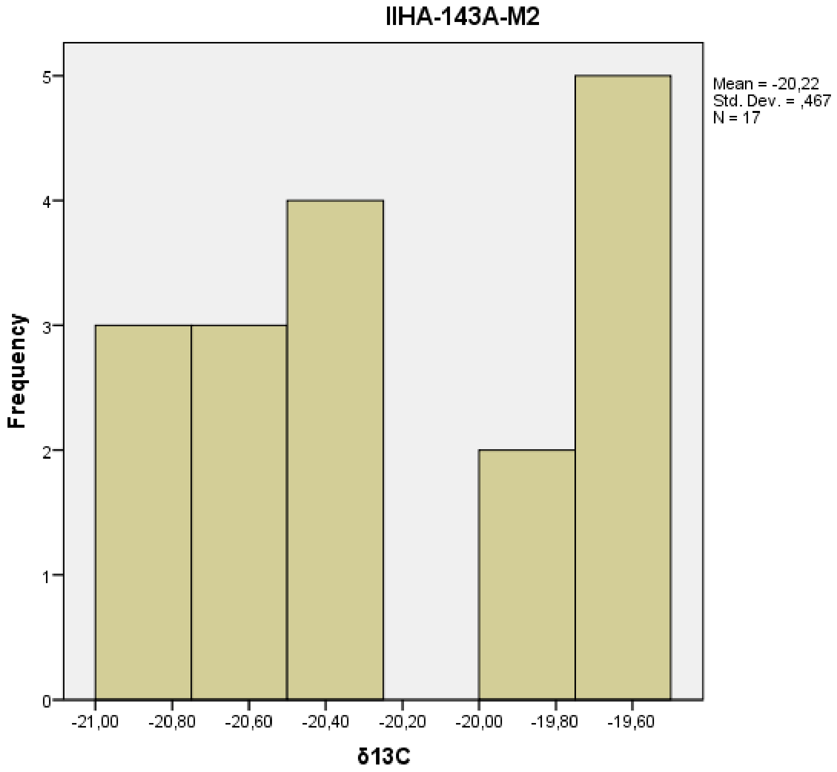

IIHA-CH34pp1-M3
Frequency
δ15N
0
1
2
3
4
5
13,25
13,50
13,75
14,00
14,25
Mean = 13,93
Std. Dev. = ,284
N = 14

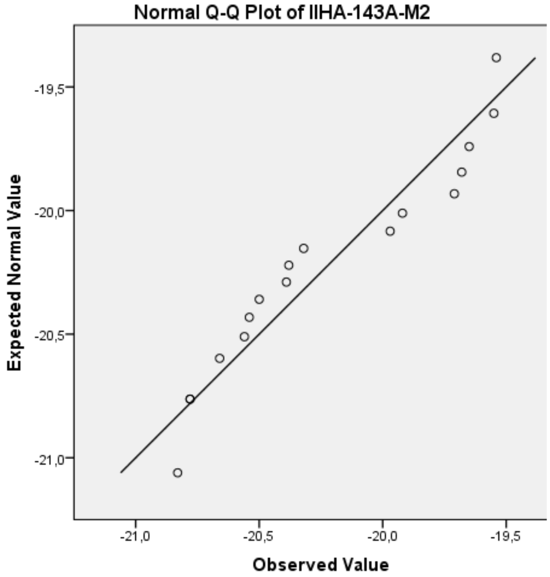

Normal Q-Q Plot of IIHA-CH34pp1-M3
Expected Normal Value
Observed Value
13,4
13,6
13,8
14,0
14,2
14,4
14,6
13,25
13,50
13,75
14,00
14,25

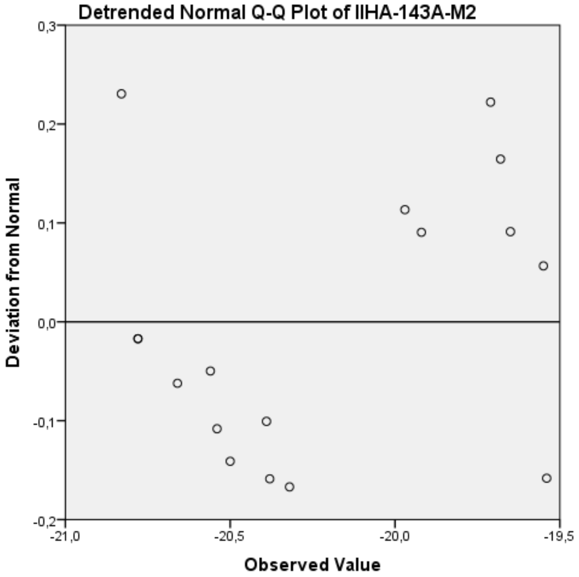

Detrended Normal Q-Q Plot of IIHA-CH34pp1-M3
Deviation from Normal
Observed Value
0,2
0,1
0,0000
-0,1
-0,2
-0,3
13,2
13,4
13,6
13,8
14,0
14,2
14,4

IIHA-143A-M2

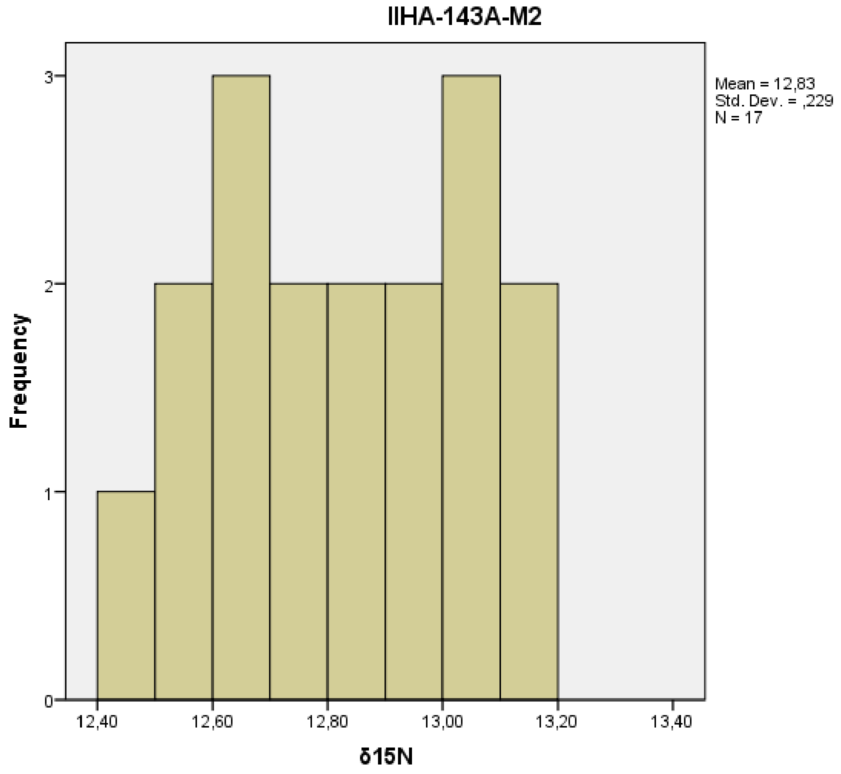
δ^{13}C

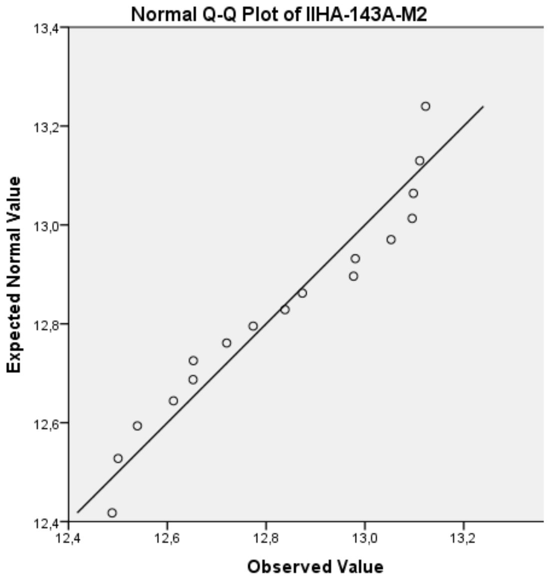


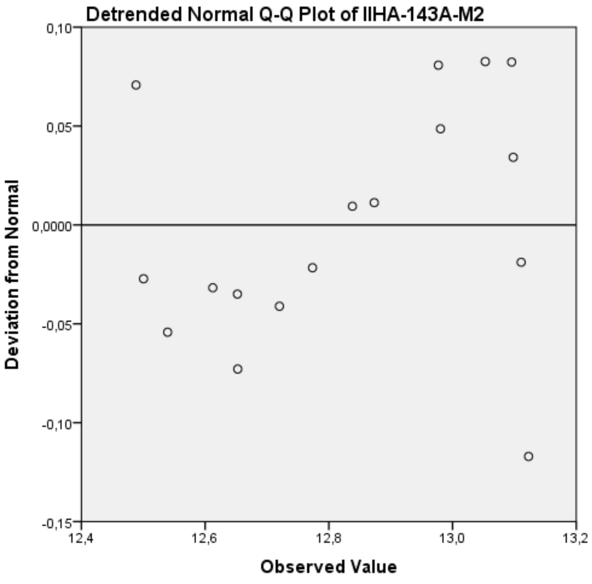




δ^{15}N

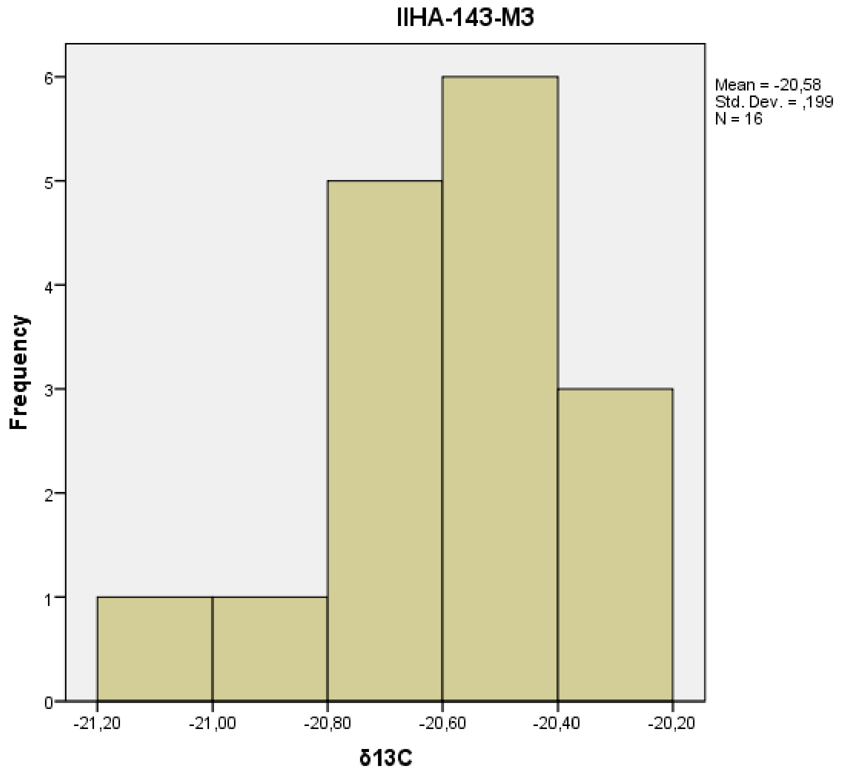

IIHA-143A-M2
Mean = 12,83
Std. Dev. = ,229
N = 17
Frequency
0
1
2
3
12,40
12,60
12,80
13,00
13,20
13,40
δ15N

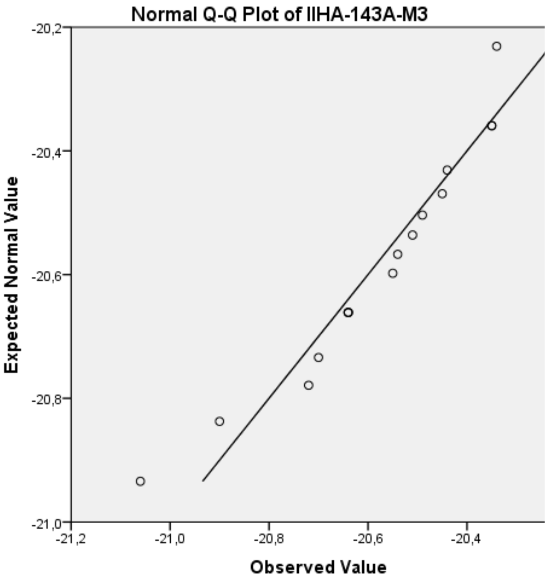

Normal Q-Q Plot of IIHA-143A-M2
Expected Normal Value
13,4
13,2
13,0
12,8
12,6
12,4
12,4
12,6
12,8
13,0
13,2
Observed Value

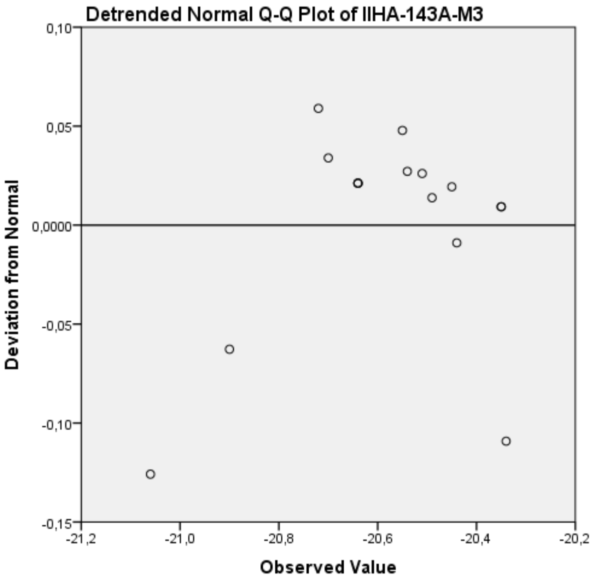

Detrended Normal Q-Q Plot of IIHA-143A-M2
Deviation from Normal
0,10
0,05
0,0000
-0,05
-0,10
-0,15
12,4
12,6
12,8
13,0
13,2
Observed Value

IIHA-143A-M3

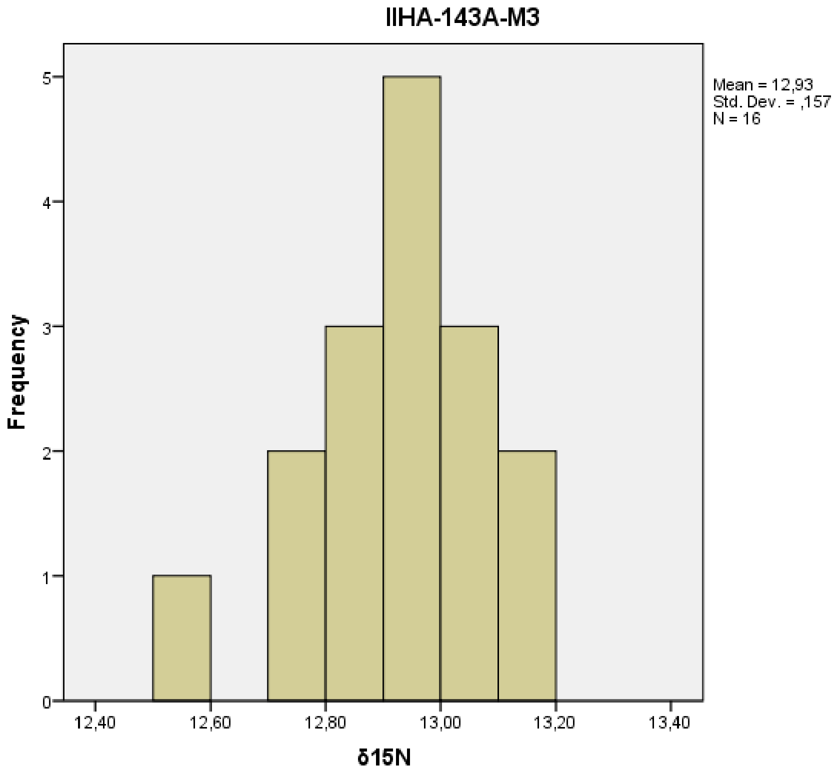
$\delta^{13}C$

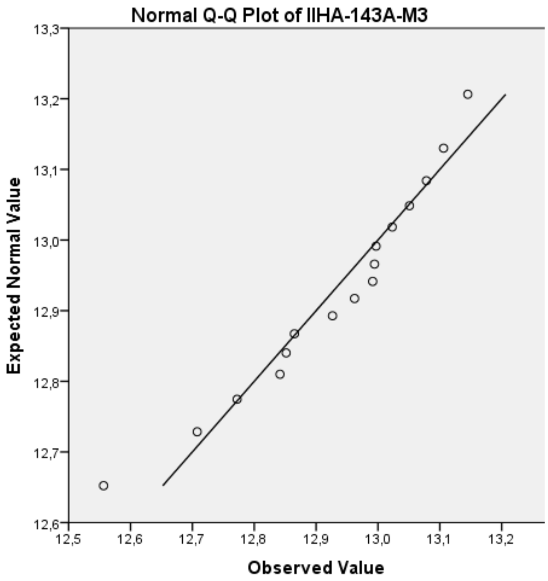


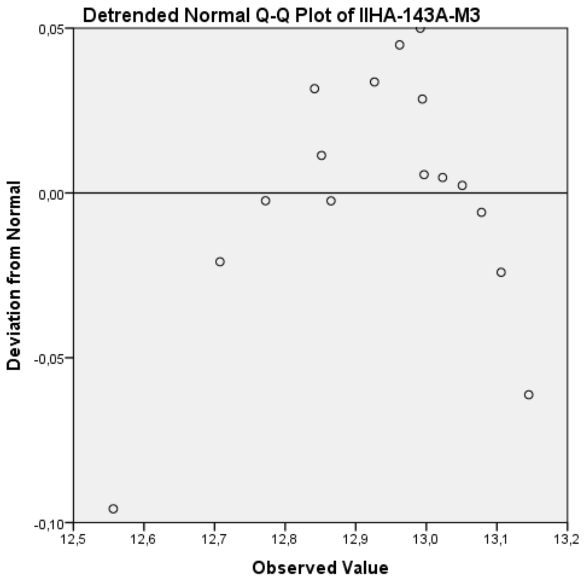




δ^{15}N

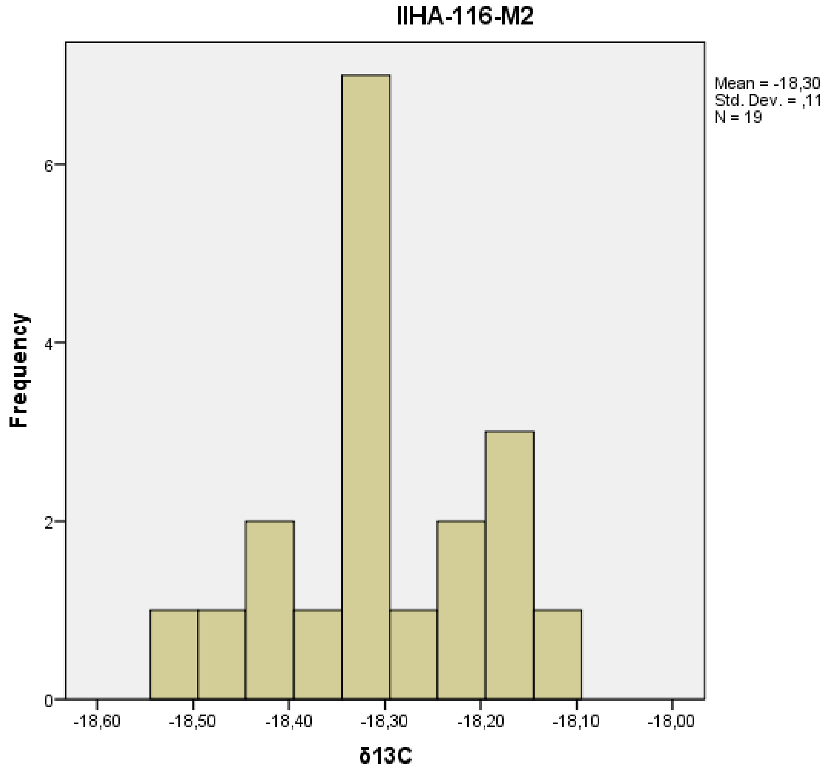

IIHA-143A-M3
Mean = 12,93
Std. Dev. = ,157
N = 16
Frequency
0
1
2
3
4
5
12,40
12,60
12,80
13,00
13,20
13,40
δ15N

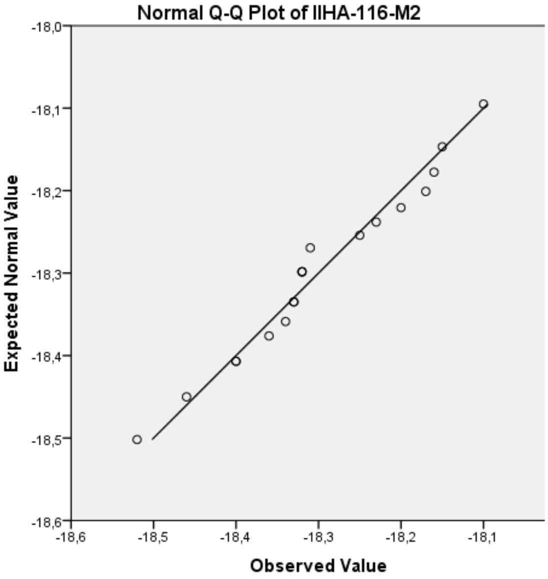

Normal Q-Q Plot of IIHA-143A-M3
Expected Normal Value
13,3
13,2
13,1
13,0
12,9
12,8
12,7
12,6
12,5
12,6
12,7
12,8
12,9
13,0
13,1
13,2
Observed Value

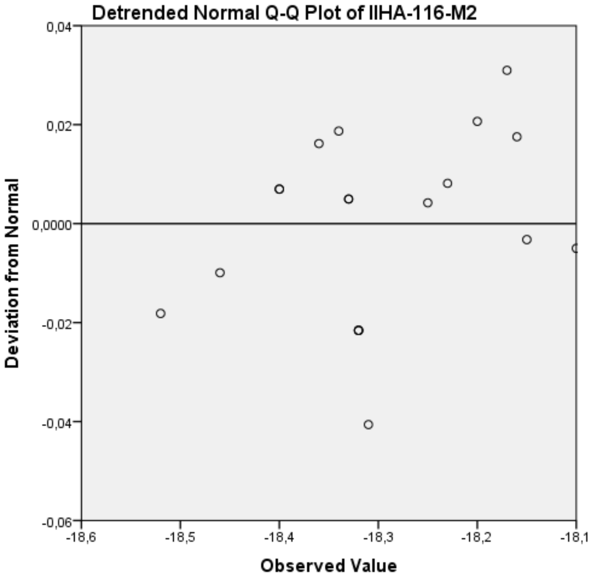

Detrended Normal Q-Q Plot of IIHA-143A-M3
Deviation from Normal
0,05
0,00
-0,05
-0,10
12,5
12,6
12,7
12,8
12,9
13,0
13,1
13,2
Observed Value

IIHA-116-M2

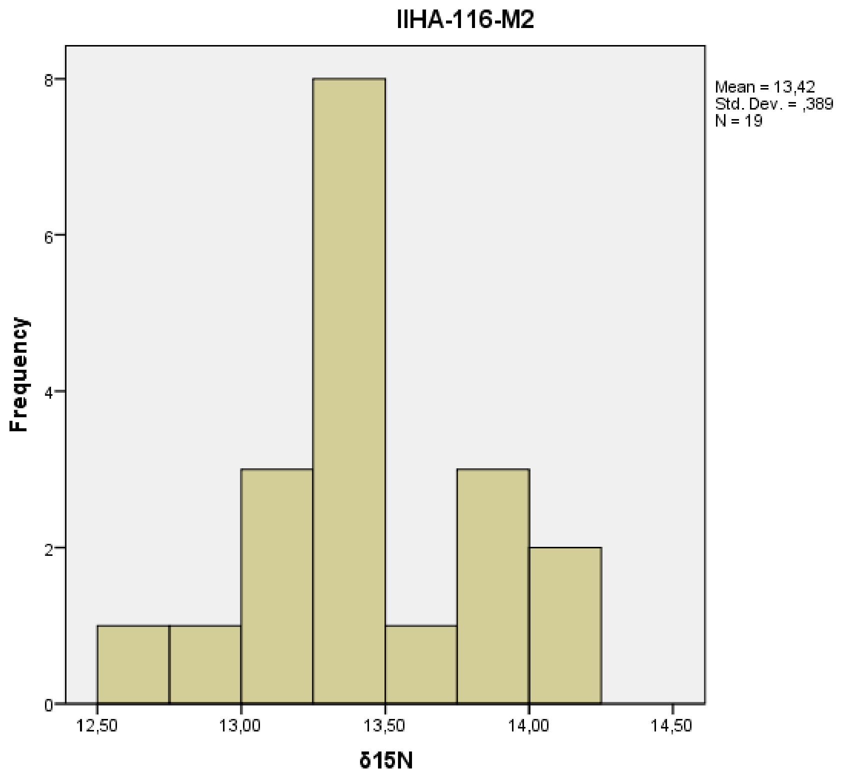
$\delta^{13}C$

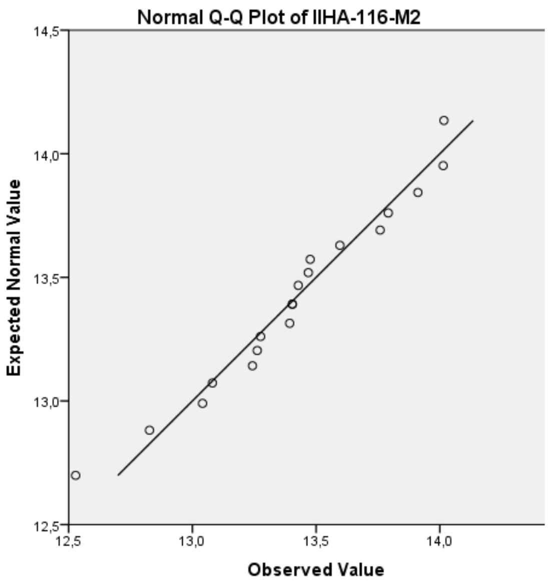


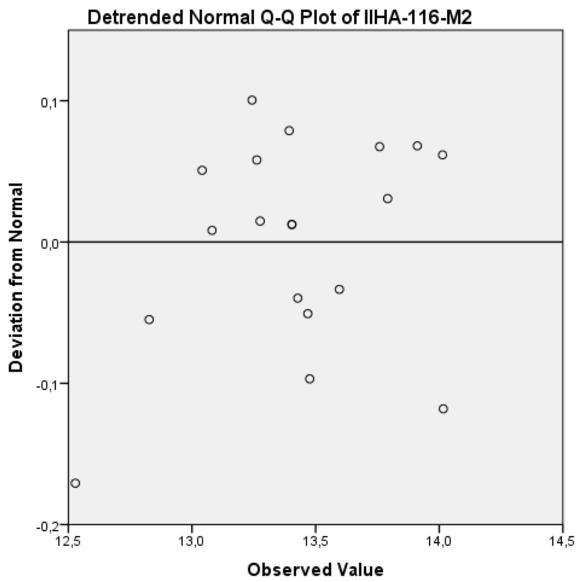




δ^{15}N

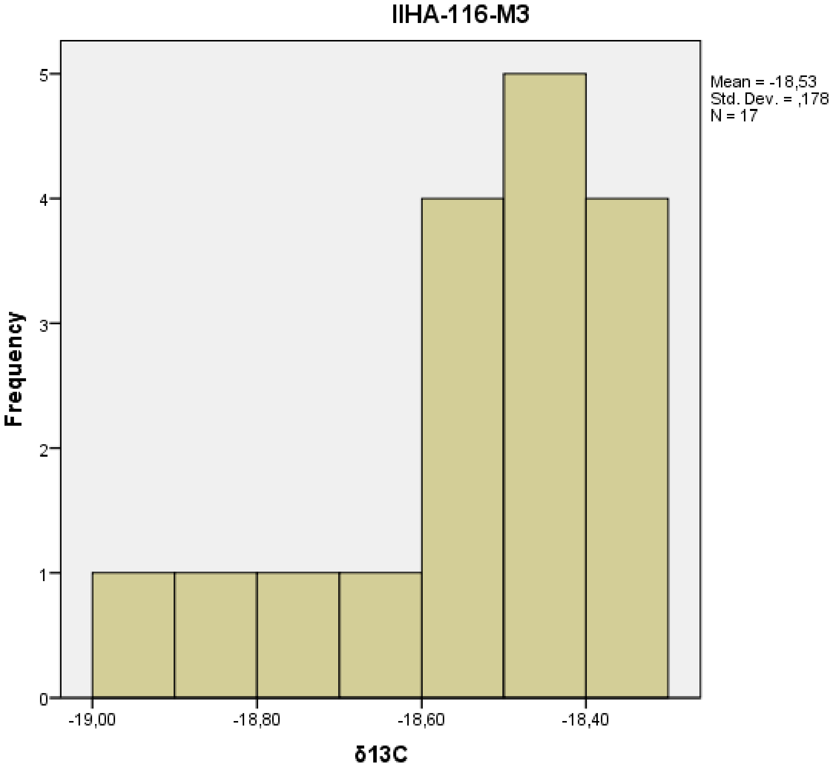

IIHA-116-M2
Mean = 13,42
Std. Dev. = ,389
N = 19
Frequency
0
2
4
6
8
12,50
13,00
13,50
14,00
14,50
δ15N

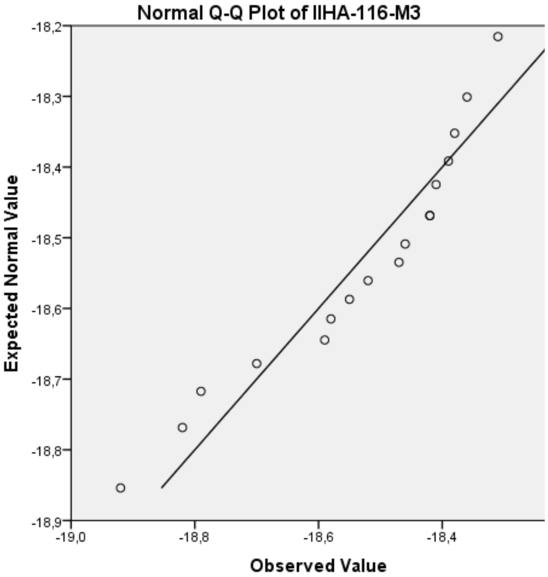

Normal Q-Q Plot of IIHA-116-M2
Expected Normal Value
12,5
13,0
13,5
14,0
14,5
12,5
13,0
13,5
14,0
Observed Value

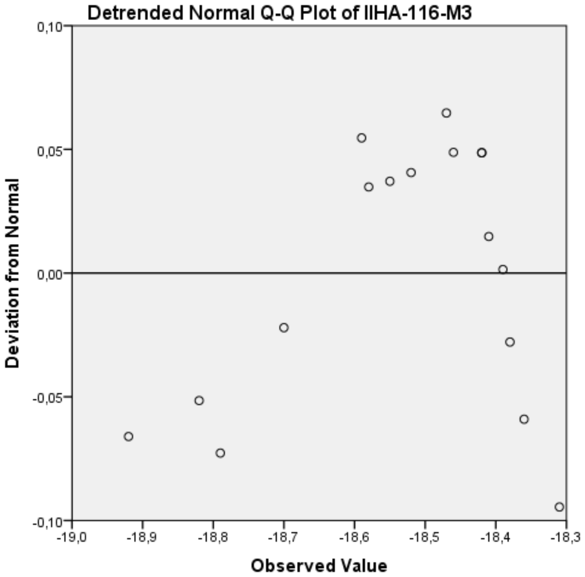

Detrended Normal Q-Q Plot of IIHA-116-M2
Deviation from Normal
-0,2
-0,1
0,0
0,1
12,5
13,0
13,5
14,0
14,5
Observed Value

IIHA-116-M3

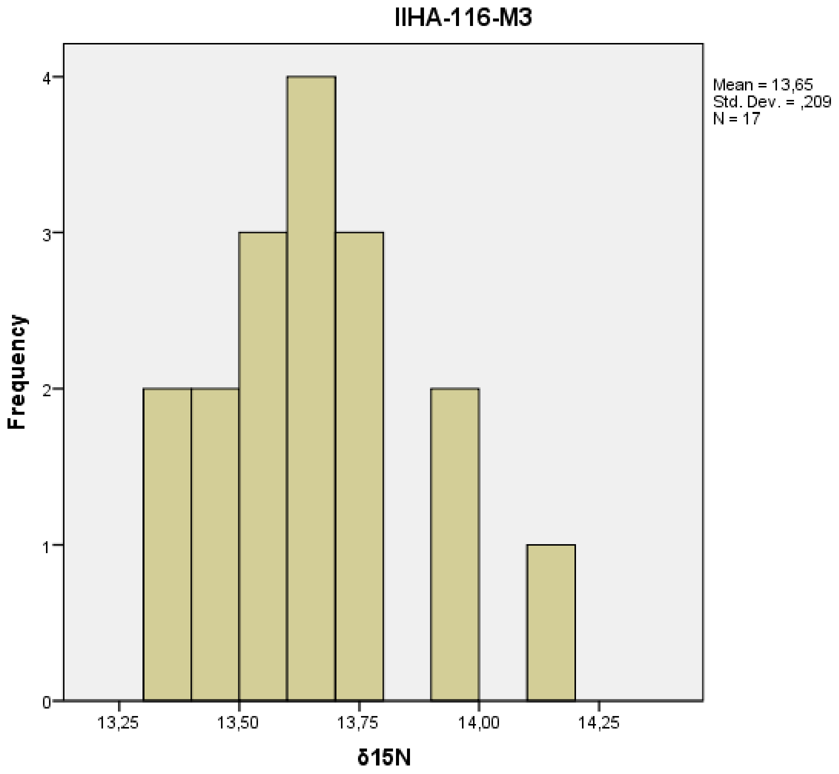
$\delta^{13}C$

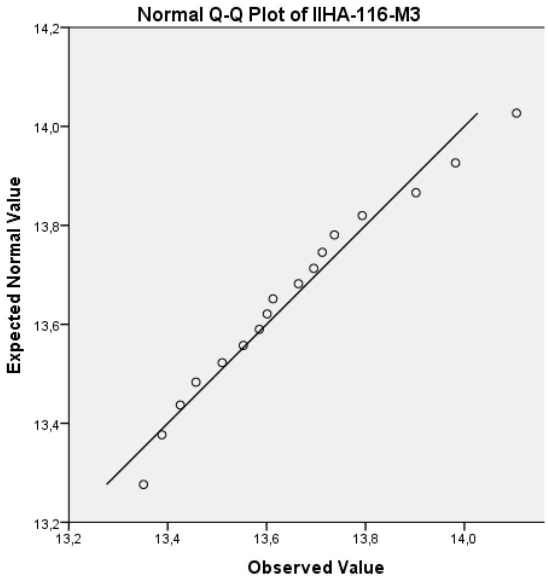


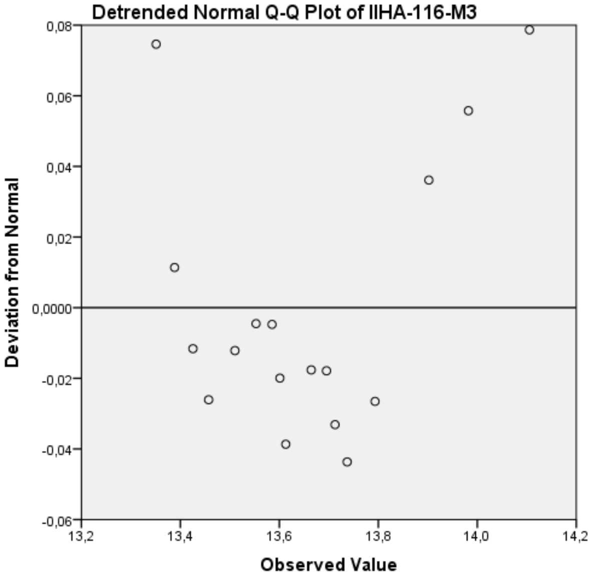




δ^{15}N

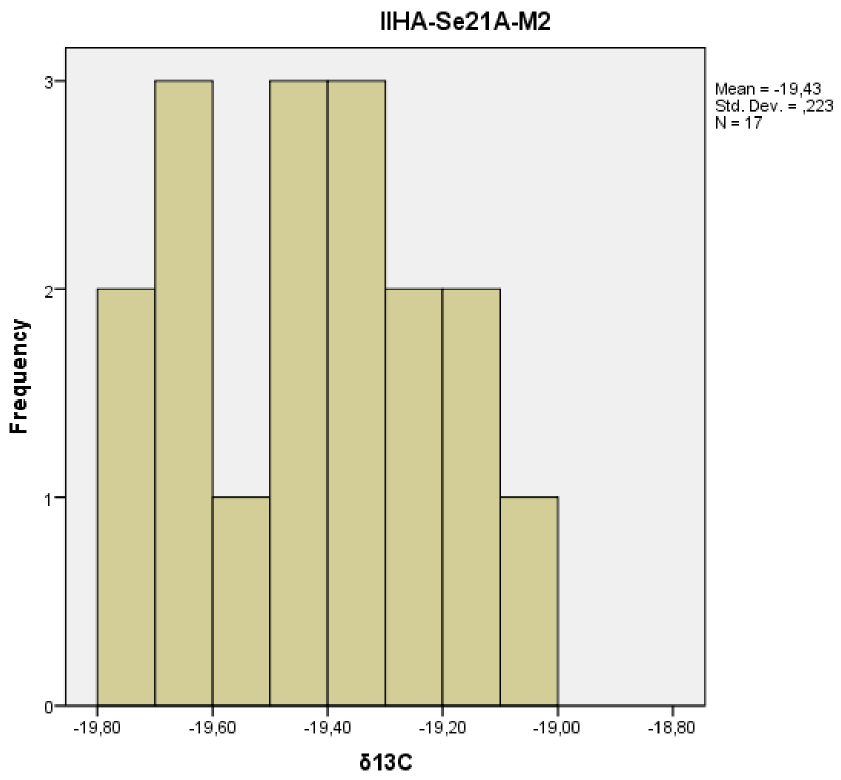

IIHA-116-M3
Mean = 13,65
Std. Dev. = ,209
N = 17
Frequency
0
1
2
3
4
13,25
13,50
13,75
14,00
14,25
δ15N

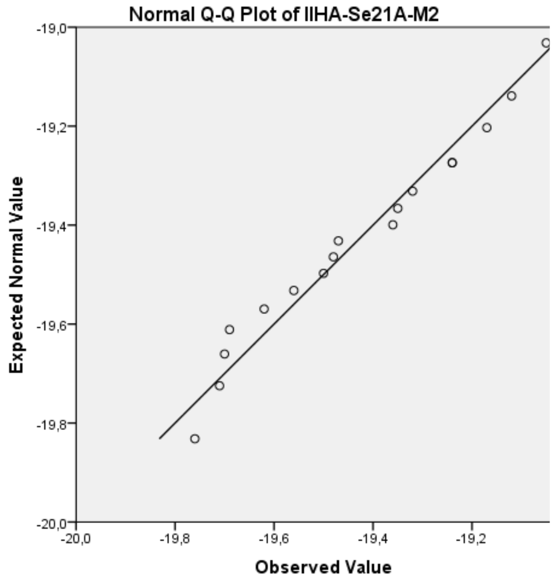

Normal Q-Q Plot of IIHA-116-M3
Expected Normal Value
13,2
13,4
13,6
13,8
14,0
14,2
13,2
13,4
13,6
13,8
14,0
Observed Value

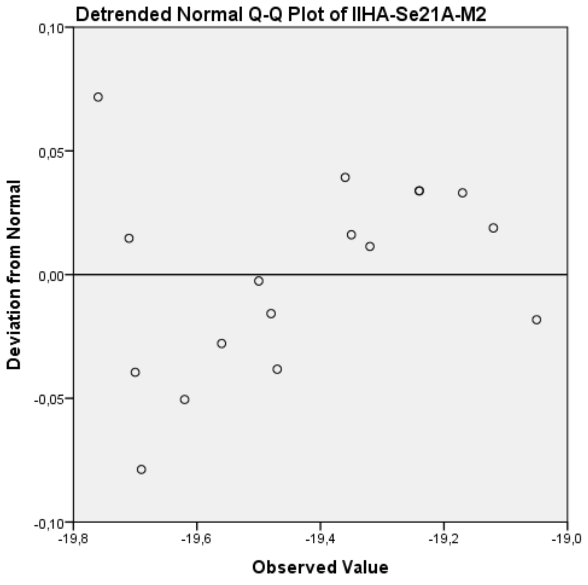

Detrended Normal Q-Q Plot of IIHA-116-M3
Deviation from Normal
0,08
0,06
0,04
0,02
0,0000
-0,02
-0,04
-0,06
13,2
13,4
13,6
13,8
14,0
14,2
Observed Value

IIHA-Se21A-M2

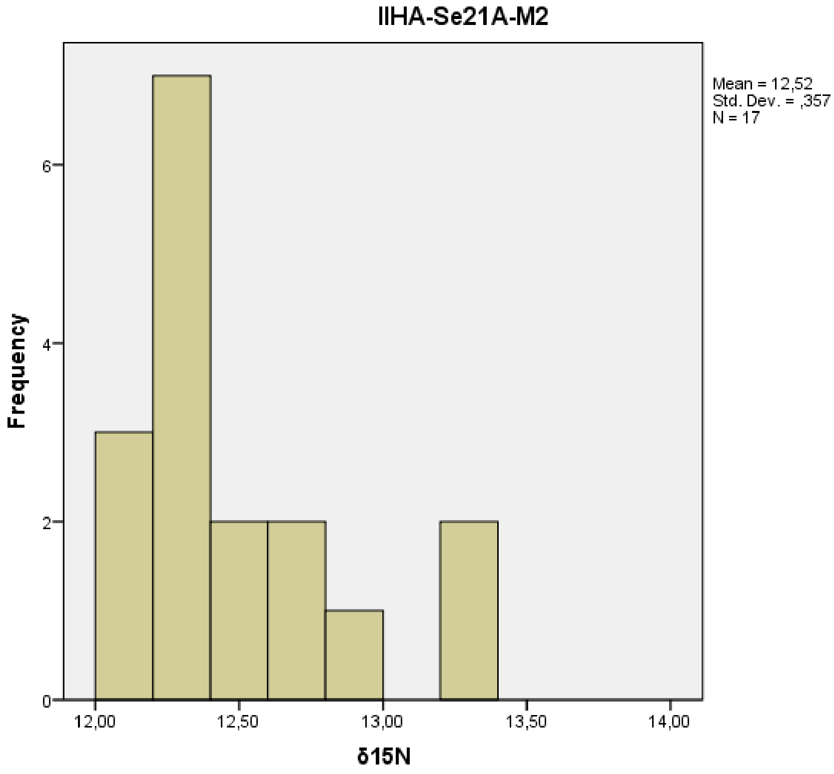
$\delta^{13}C$

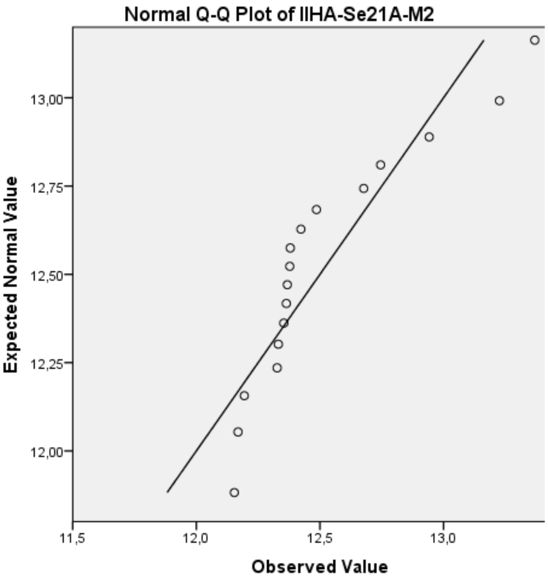


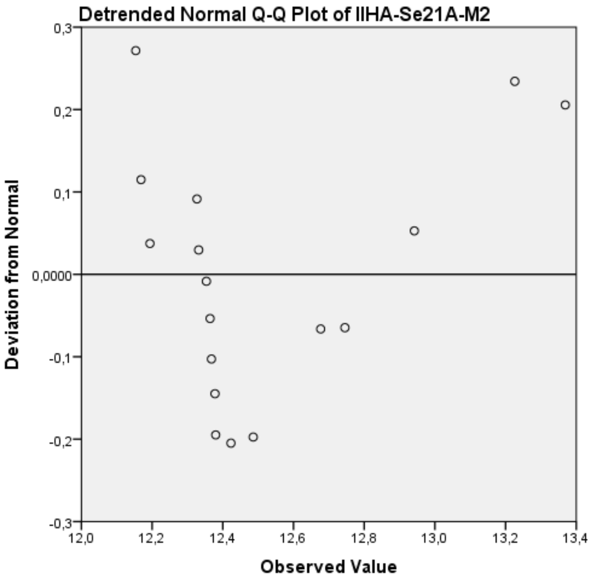




δ^{15}N

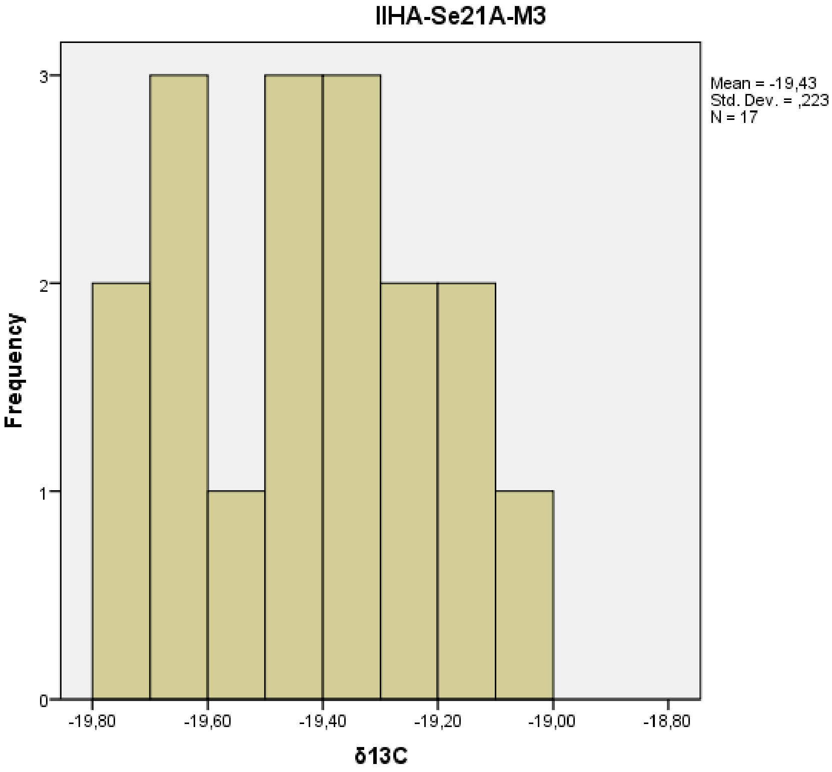

IIHA-Se21A-M2
Mean = 12,52
Std. Dev. = ,357
N = 17
Frequency
0
2
4
6
12,00
12,50
13,00
13,50
14,00
δ15N

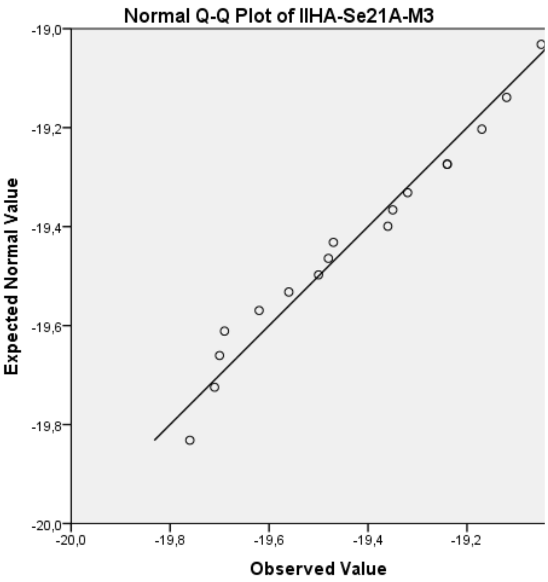

Normal Q-Q Plot of IIHA-Se21A-M2
Expected Normal Value
12,00
12,25
12,50
12,75
13,00
11,5
12,0
12,5
13,0
Observed Value

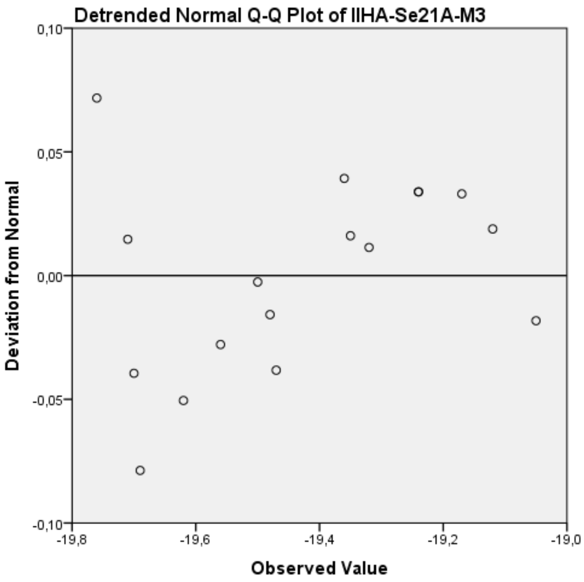

Detrended Normal Q-Q Plot of IIHA-Se21A-M2
Deviation from Normal
0,3
0,2
0,1
0,0000
-0,1
-0,2
-0,3
12,0
12,2
12,4
12,6
12,8
13,0
13,2
13,4
Observed Value

IIHA-Se21A-M3

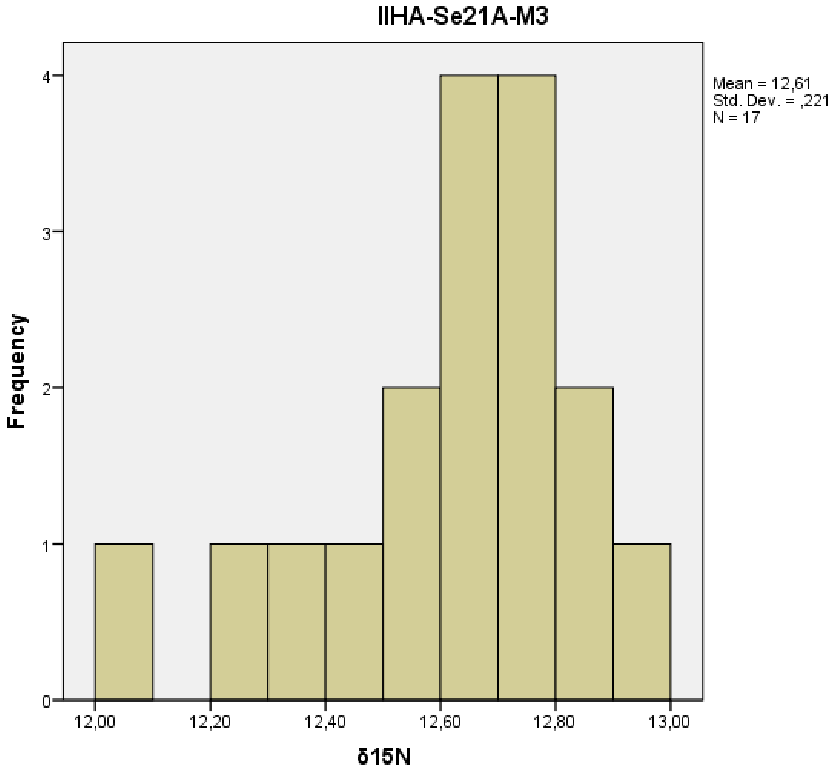
$\delta^{13}C$

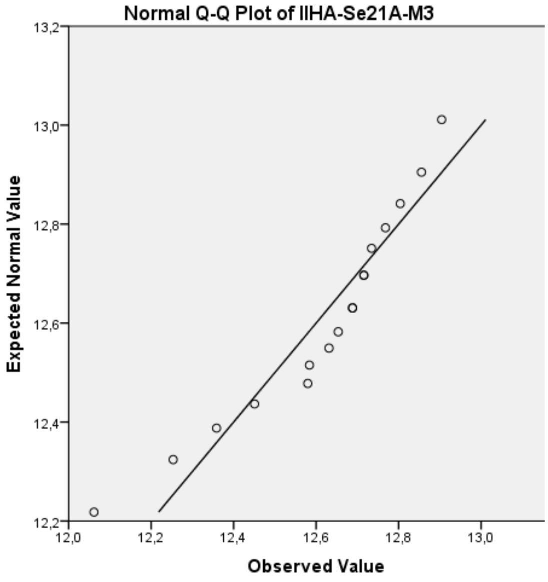


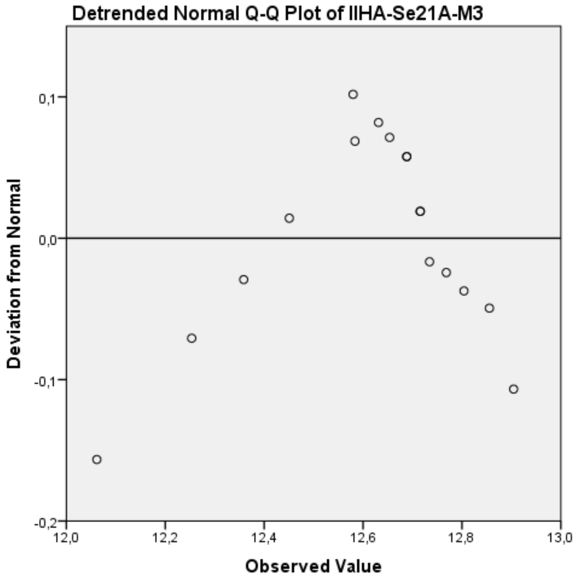




δ^{15}N

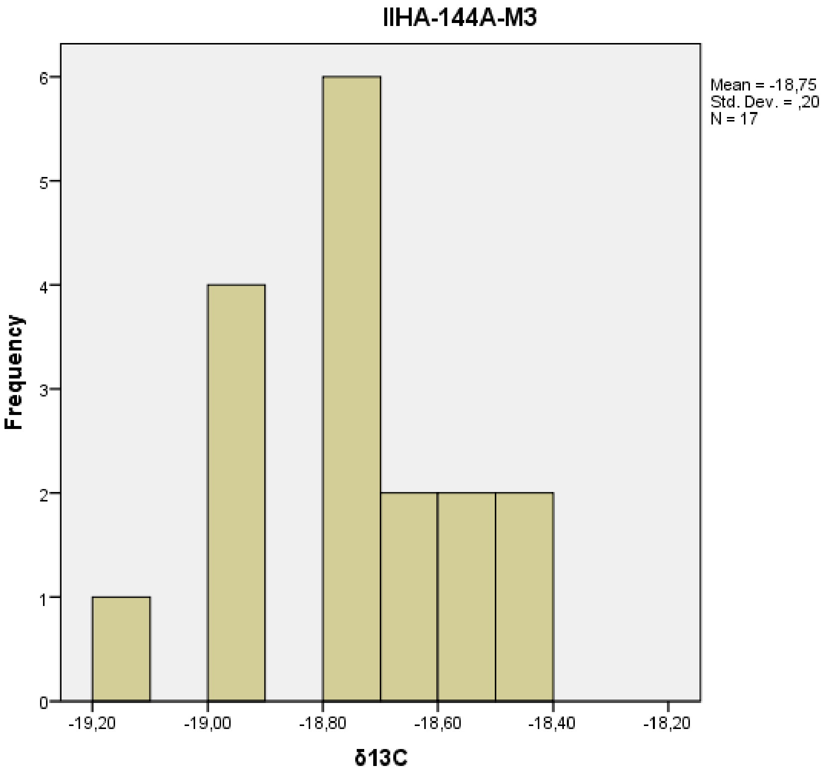

IIHA-Se21A-M3
Mean = 12,61
Std. Dev. = ,221
N = 17
Frequency
0
1
2
3
4
12,00
12,20
12,40
12,60
12,80
13,00
δ15N

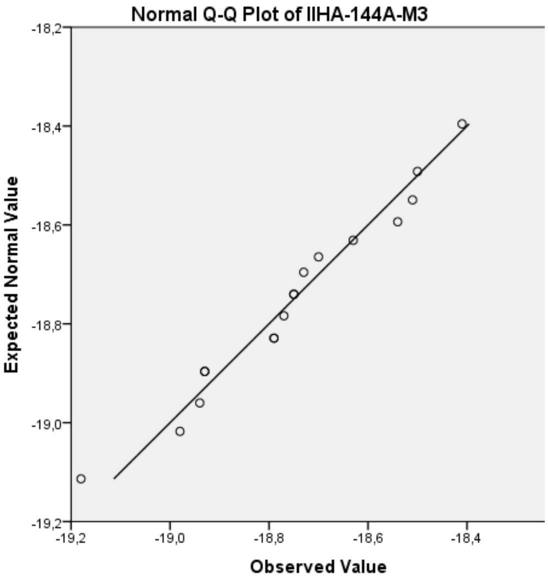

Normal Q-Q Plot of IIHA-Se21A-M3
Expected Normal Value
13,2
13,0
12,8
12,6
12,4
12,2
12,0
12,2
12,4
12,6
12,8
13,0
Observed Value

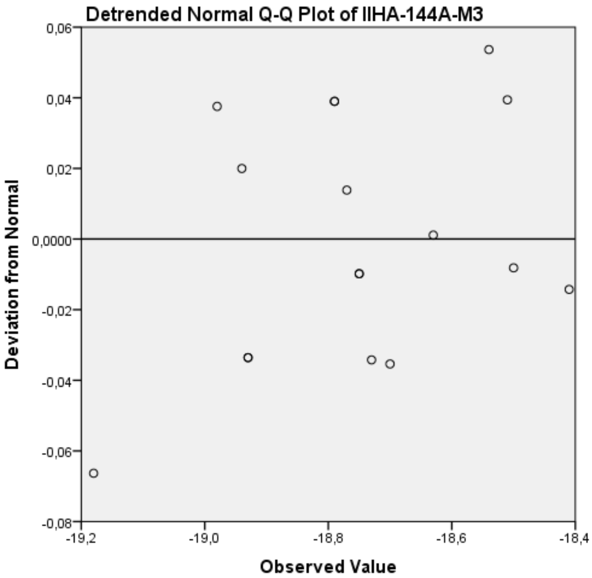

Detrended Normal Q-Q Plot of IIHA-Se21A-M3
Deviation from Normal
0,1
0,0
-0,1
-0,2
12,0
12,2
12,4
12,6
12,8
13,0
Observed Value

IIHA-144A-M3

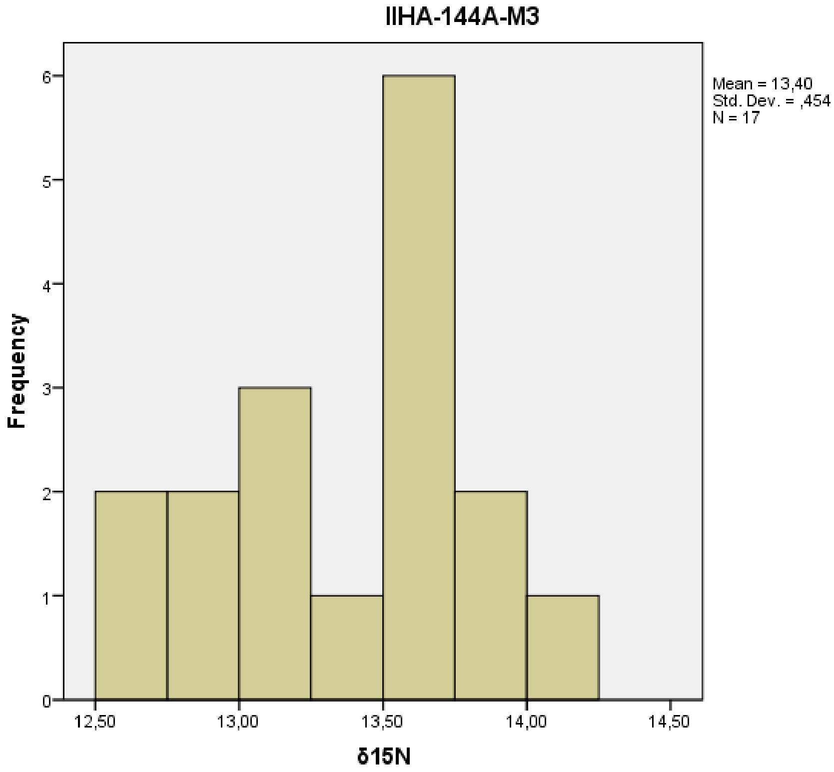
$\delta^{13}C$

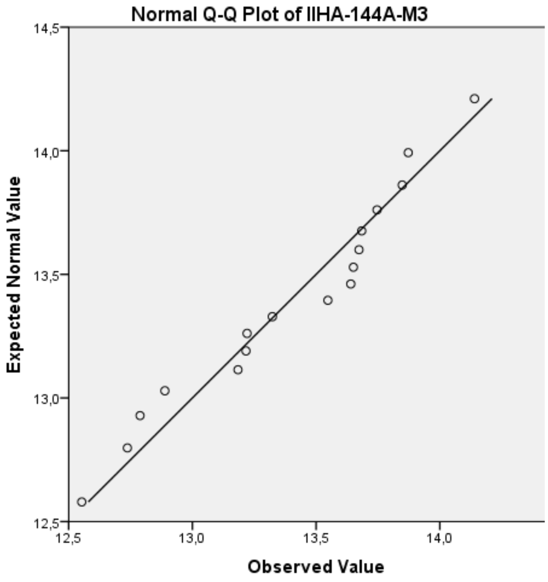


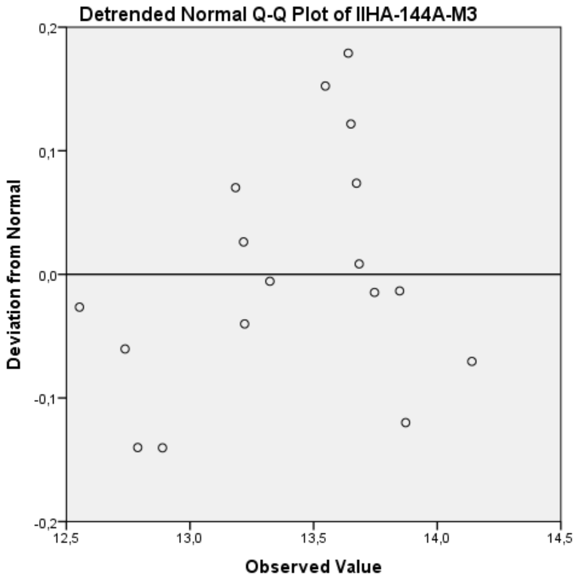




δ^{15}N

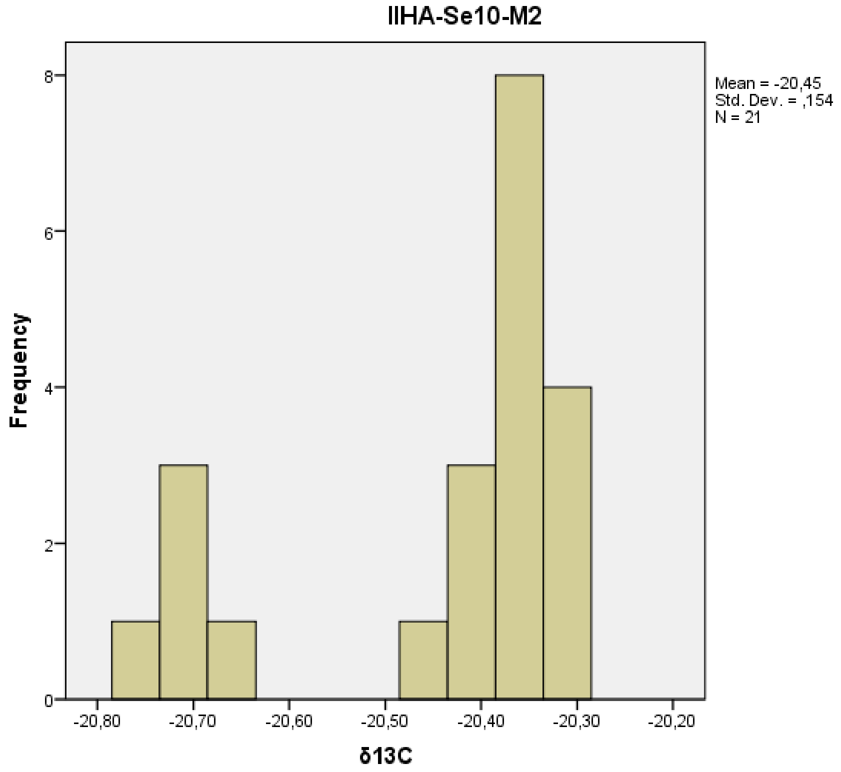

IIHA-144A-M3
Frequency
0
1
2
3
4
5
6
12,50
13,00
13,50
14,00
14,50
δ15N
Mean = 13,40
Std. Dev. = ,454
N = 17

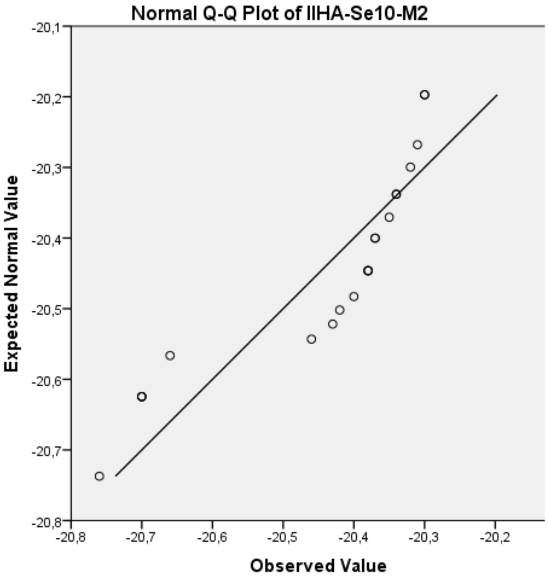

Normal Q-Q Plot of IIHA-144A-M3
Expected Normal Value
12,5
13,0
13,5
14,0
14,5
Observed Value

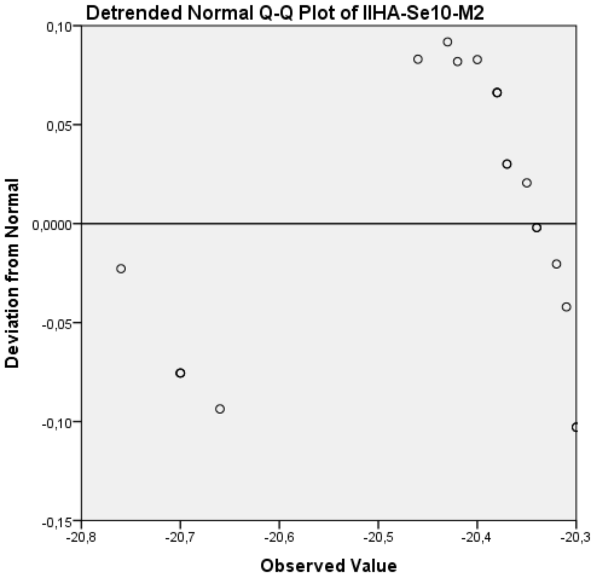

Detrended Normal Q-Q Plot of IIHA-144A-M3
Deviation from Normal
-0,2
-0,1
0,0
0,1
0,2
12,5
13,0
13,5
14,0
14,5
Observed Value

IIHA-Se10-M2

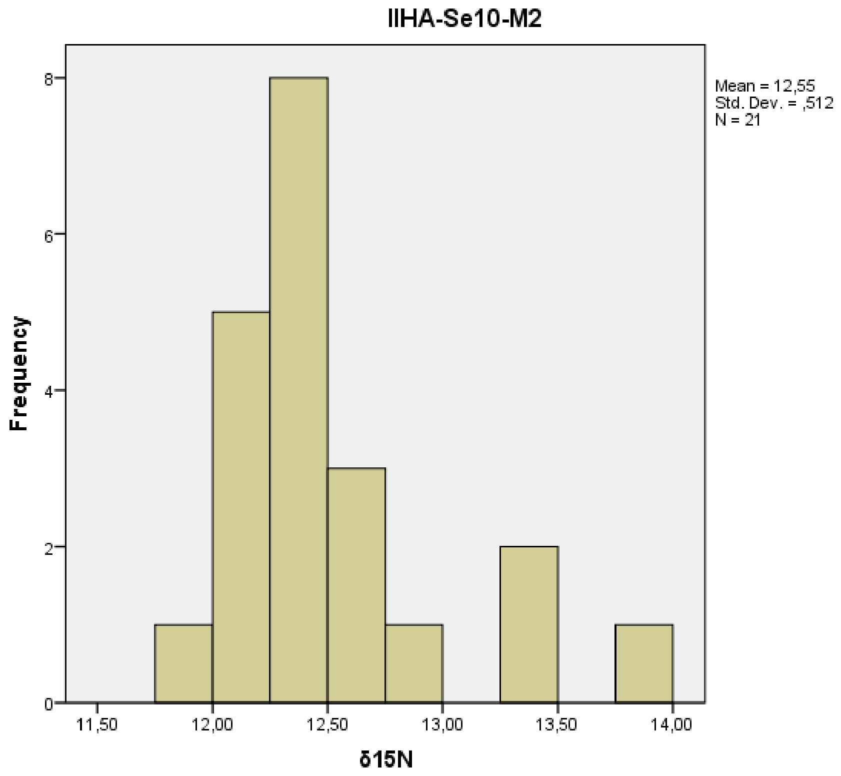
$\delta^{13}C$

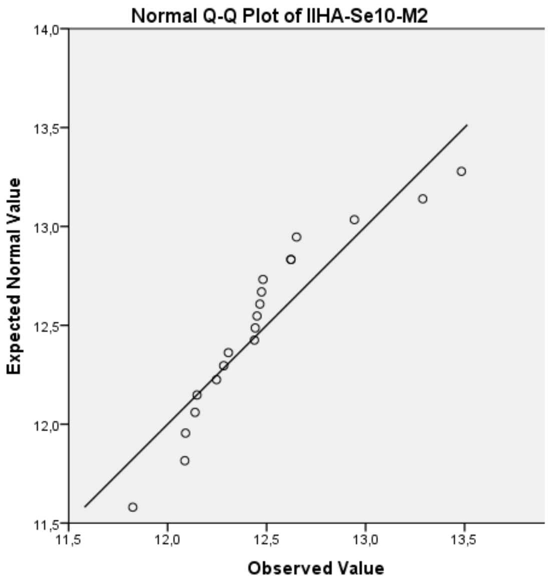


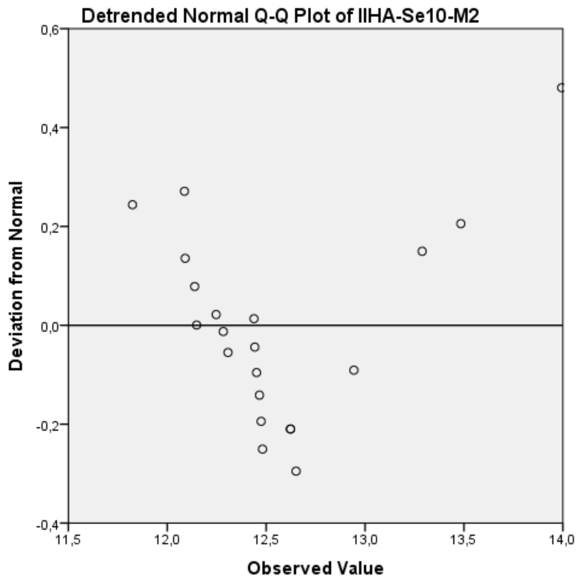




$\delta^{15}N$

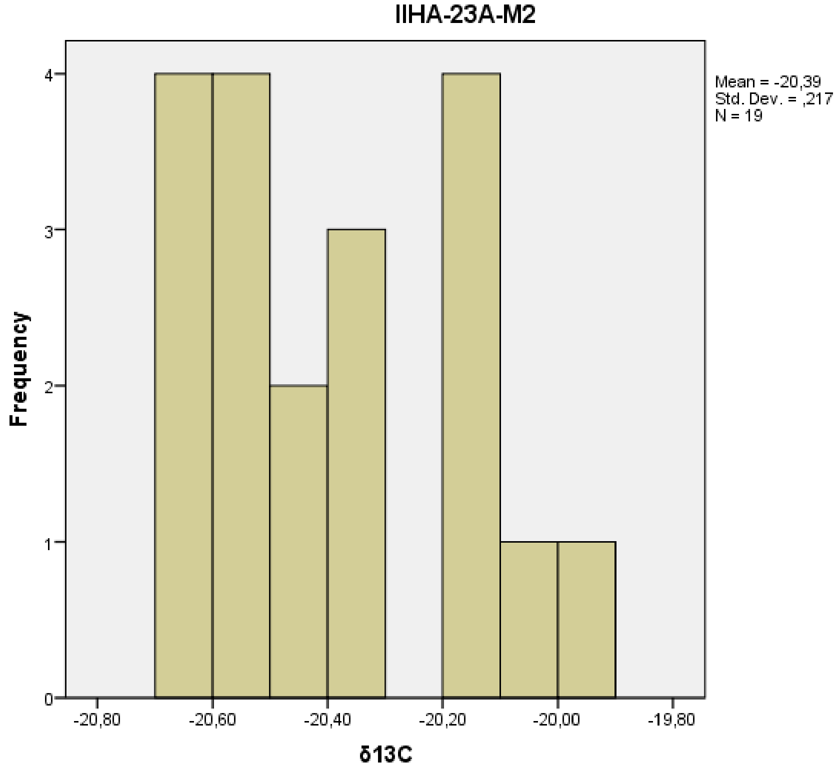

IIHA-Se10-M2
Mean = 12,55
Std. Dev. = ,512
N = 21
Frequency
0
2
4
6
8
11,50
12,00
12,50
13,00
13,50
14,00
δ15N

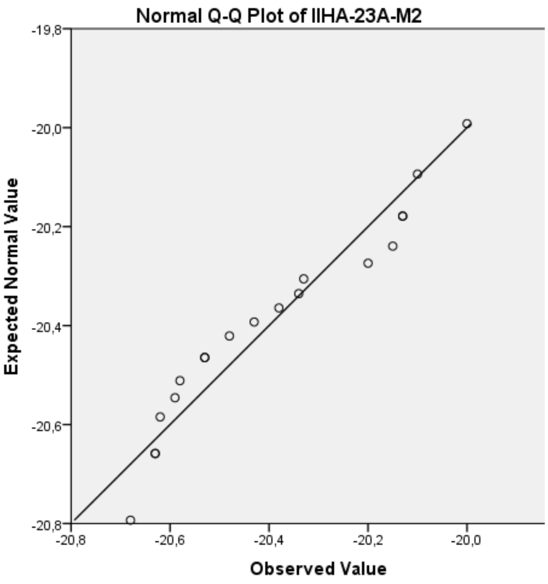

Normal Q-Q Plot of IIHA-Se10-M2
Expected Normal Value
11,5
12,0
12,5
13,0
13,5
14,0
11,5
12,0
12,5
13,0
13,5
Observed Value

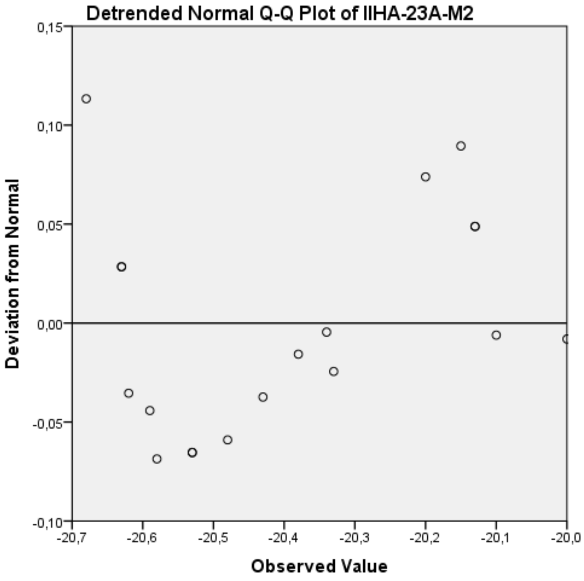

Detrended Normal Q-Q Plot of IIHA-Se10-M2
Deviation from Normal
-0,4
-0,2
0,0
0,2
0,4
0,6
11,5
12,0
12,5
13,0
13,5
14,0
Observed Value

IIHA-23A-M2

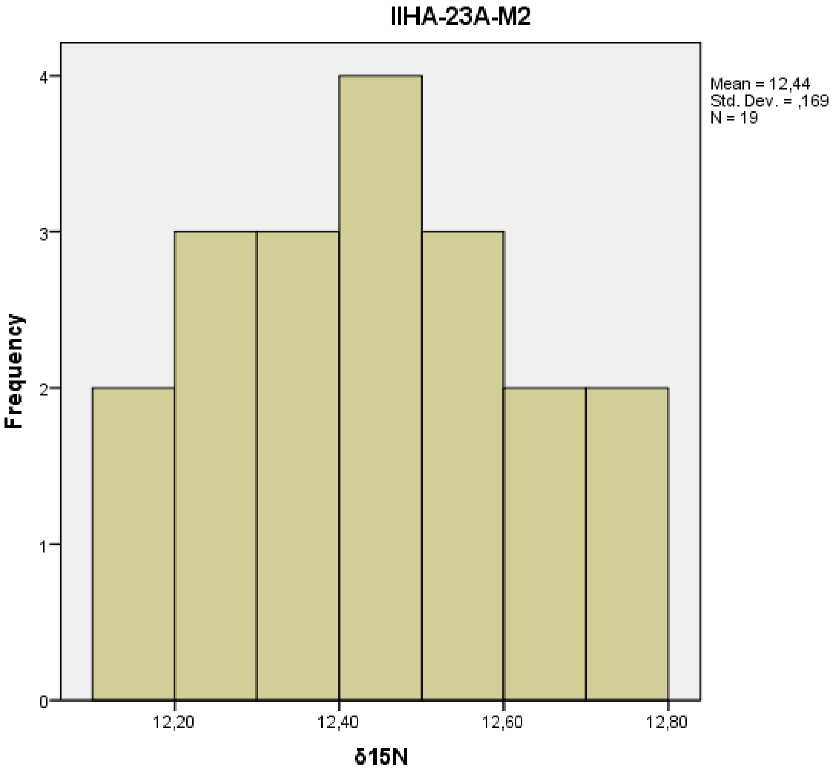
δ^{13}C

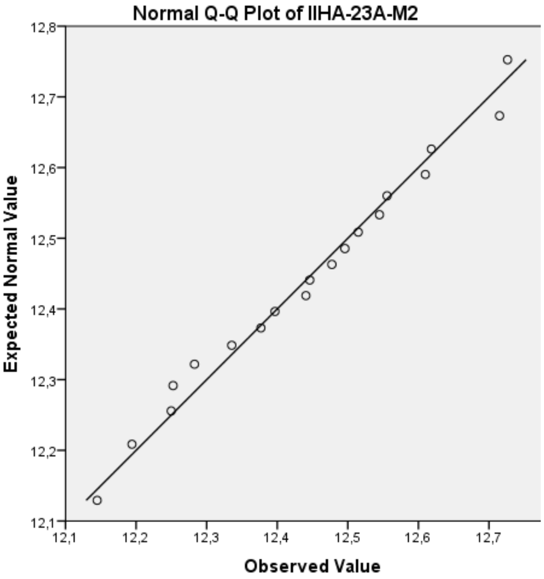


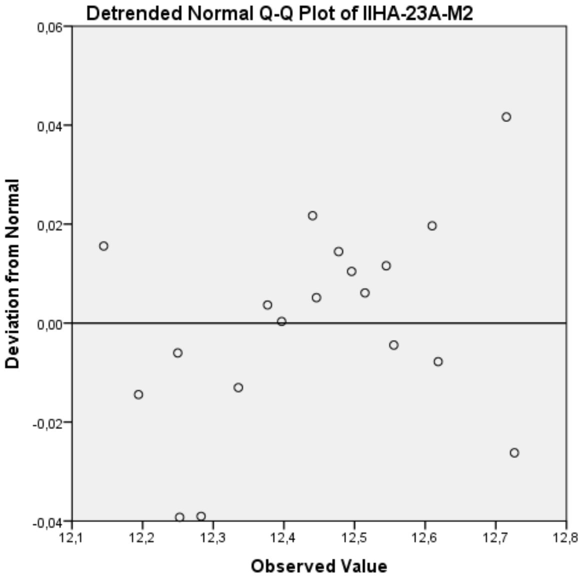




δ^{15}N


IIHA-23A-M2
Mean = 12,44
Std. Dev. = ,169
N = 19
Frequency
0
1
2
3
4
12,20
12,40
12,60
12,80
δ15N


Normal Q-Q Plot of IIHA-23A-M2
Expected Normal Value
12,1
12,2
12,3
12,4
12,5
12,6
12,7
12,8
12,1
12,2
12,3
12,4
12,5
12,6
12,7
Observed Value


Detrended Normal Q-Q Plot of IIHA-23A-M2
Deviation from Normal
-0,04
-0,02
0,00
0,02
0,04
0,06
12,1
12,2
12,3
12,4
12,5
12,6
12,7
12,8
Observed Value