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DIETS IN THREE LATE MEDIEVAL TO EARLY MODERN COASTAL POPULATIONS IN FINLAND ACCORDING TO THE δ^{13}C AND δ^{15}N VALUES OF ARCHAEOLOGICAL BONE AND DENTIN COLLAGEN

Abstract

We explored the diets in three populations (Iin Hamina, Oulu, Rauma) dating between the late Middle Ages and mid-19th century. We compared diets of mid-childhood, adolescence, and adulthood based on the carbon and nitrogen stable isotope ratios in dentin (PM2, M3) and bone collagen. The δ^{13}C values were typical of terrestrial C_3 environments and to be expected by the brackish Baltic Sea. The ^{13}C content in the water decreases northwards, which was reflected in the results. The analyses displayed overall elevated δ^{15}N values, which is consistent with fish having been an important part of the nutrition of all the populations. The PM2 and bone collagen δ^{15}N values diverged in the Iin Hamina population, implying different diets of children and adults

Keywords: δ^{13}C, δ^{15}N, collagen, Finland, post-medieval, stable isotope, diet

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INTRODUCTION

This paper explores the carbon and nitrogen stable isotope ratios in collagen of human bones and teeth, collected from three archaeologically excavated former churchyard sites located in the western coastal region of the modern-day nation of Finland.[1] The studied selection of individuals represents the populations of the parishes and towns of Iin Hamina (c. 15th century to early 17th century), Oulu (late 17th to 18th century), and Rauma (late 18th to early 19th century) (Fig. 1).

The aim is to look at the past diets in the coastal region of Finland and to find out whether the diets consumed in these three populations chosen for analysis differ from each other. The skeletal remains of the studied individuals were sampled for bone collagen and permanent second premolar (PM2) and third molar (M3) dentin collagen. While the dentin collagen delta (δ) values represent the mid-childhood and adolescence diets, the bone collagen values represent the diet consumed in adulthood some years prior to death of the individual. This allows not only comparison of the diets in different site-specific populations but even assessment of these diets during different life-phases.

Use of nitrogen and carbon stable isotope ratios in dietary reconstructions

The ratios of stable isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) in tissues of organisms reflect the isotopic composition of their dietary input, facilitating their use in examining the diets of past human populations. The $\delta^{15}N$ value in tissues is related to the subject's trophic position. Fractionation causes enrichment of the heavier isotopes between the consumed diet and body tissues. This results in an increase in the $\delta^{15}N$ value by approximately 3.4 ±1.1‰ with each trophic step (Minagawa & Wada 1984), although variation occurs depending on the analysed tissue (O'Connell et al. 2012). The $\delta^{15}N$ value reveals the level of protein intake and/or the source of protein, as a greater amount of animal protein from species of high tropic position in diet leads to more elevated values (O'Connell & Hedges 1999).

The enrichment for carbon is smaller, often amounting to c. 0–2 ‰ per trophic level (Bocherens & Drucker 2003). The $\delta^{13}C$ values of consumer tissues are typically used to trace the influence of C_3 and C_4 plants in the diet. This is made possible by the very different $\delta^{13}C$ values of these plant types, caused by the different photosynthetic mechanisms they employ (Kohn 2010). C_4 plants, such as maize or millet, do not naturally grow in the Nordic region and by the relevant period, were probably not being imported into the area in notable quantities. Cane sugar from the New World, as an expensive luxury product, had reached the north at least by the period relevant to the Oulu population (Vilkama et al. 2016), while it was probably not consumed to an extent traceable in isotope values (Halila 1953: 201–2). On the other hand, by the period of the Rauma population in the early 19th century, sugar beet, which is a C_3 plant, was already a more common source of processed sugar in the region (Rousi 1997: 197–8).

Another common application of carbon isotope analysis is to evaluate the marine or terrestrial sources of the diet (Tauber 1981; Schoeninger & DeNiro 1984; Schulting 1998). The carbon in marine environments is mostly derived from

Figure 1. Map of the sites of the archaeological populations examined in the study. (Illustration: Tiina Väre.)

dissolved inorganic carbon (HCO_3), in which the ^{13}C concentration is much higher than in the atmospheric CO_2 from which the carbon in terrestrial organisms is derived. This distinction in the carbon source explains why the organisms in oceans typically present with less negative $\delta^{13}C$ values (Smith & Epstein 1971; Ambrose 1993). The water reserves in the target region of this study are brackish or fresh, both of which tend to draw the carbon values towards the lower terrestrial and C_3-end of the range (e.g., Katzenberg 1989; Angerbjörn et al. 2006; Enhus et al. 2011; Danielsson et al. 2015).

Each tissue or integument stores the stable isotope composition representing the conditions during their formation (DeNiro & Epstein 1978; 1981). The differences in their growth mechanisms and formation result in tissues representing varying periods in the individual's life. A bone sample of an adult individual typically represents the average diet of several years during which the bone tissue has been gradually remodelled (e.g., Parfitt 2002; Fahy et al. 2017). There can be quite significant variation between the turnover times depending on the skeletal element or factors such as the age and sex of the subject (Ambrose 1993; Hedges et al. 2007; Lee-Thorp 2008; Fahy et al. 2017).

Unlike bone, dentin grows incrementally according to a rather predictable pattern during childhood, although the schedules can differ slightly between populations and for example due to biological sex or whether the tooth is mandibular or maxillary (Hillson 1996: 123–4). Teeth grow from the top of the crown to the tip of the root, and the isotopic composition of the enamel and primary dentin will not change after their formation during childhood and youth (Hillson 1996: 182; Nanci 2013: 10–2). While some time-averaging may occur as a result of secondary and tertiary dentin formation (Eerkens et al. 2011; Henderson et al. 2014; Beaumont et al. 2015), primary dentin permanently stores isotopic data concerning the diet and health during its growth period, thus adult dentition can be used to trace childhood dietary patterns. The teeth used in this study were PM2 and M3 respectively developed during childhood and youth.

Churchyard sites

Iin Hamina

The remains of the individuals from the Iin Hamina churchyard site were excavated in 2009. The history of the local churches and churchyards surrounding them is poorly known, but during the 15th and 16th centuries, several of the parish's churches were burned in hostilities. The excavated churchyard was in use at least throughout the 15th and 16th centuries, but it is possible that the earliest burials date to the 14th century. In 1620, a new church was built in a different location and burials at the old churchyard were presumably discontinued (Kallio-Seppä 2011).

The biological samples analysed in this study were collected from a few separate contexts containing *in situ* burials but for the major part, from an ossuary forming an almost 2 m in diameter and 1 m deep bone pit in which disarticulated bones from disturbed old graves were collected. These bones were possibly put together as late as in the 1960s during infrastructure work at the site (Tranberg et al. 2020). Being excavated from such a context means that each subject consists of a cranium and in some cases only a mandible, which prevents most osteological interpretations – even the age and sex estimates remain tentative. For this reason, the biological sexes were not compared in this paper. For the same reason, estimating the social standing of the individuals is impossible, although the gravesite is usually a reflection of attributes related to rank and wealth (Talve 1989). However, the Iin Hamina population at the time was likely not strongly hierarchical. Yet, in the 16th century, regardless of its northern location and the repeated hostilities experienced in the area, the parish was one of the richest in Finland (Kallio-Seppä 2011; Tanska 2011).

Iin Hamina is located in the delta of the Iijoki River. Travelling by waterways, it was relatively easily approachable from Swedish towns in the south, the settlements in the northern areas, and by various travelling merchants from the east. This is one reason why, during the Middle Ages, it became a popular marketplace and quite a natural site of exchange, not only of goods but also of ideas and cultural influences. The main item exported from Iin Hamina at the time was fish, but the local people sold furs, seal skins, and blubber as well. In addition to marine and riverine resources, remote lakes yielded fish. Although agriculture had been practised since the 14th century alongside hunting and fishing, cultivation of crops remained rather marginal. In fact, the wealth gained by trading salmon probably hindered the development of time-consuming agriculture in the region by making it unnecessary. Participating in high-yielding fishing activities would often keep the men from labour-demanding agricultural duties, which in turn led to low produce from the fields. Catches of salmon in particular were abundant enough to function as the backbone of the local economy. Some essential products such as barley, wheat, and roots could be obtained from the local marketplace (Halila 1954: 183; Tanska 2011). Generally, animal husbandry was a more important source of livelihood in the region than cultivation (Vahtola 1997).

Oulu

The skeletal remains from Oulu originate from the town's churchyard excavated in 1996 and 2002 by the parish in connection to renovations in the area. The burials in the churchyard date to the 17th–18th centuries. The town churches had been located on the same plot presumably since the 1610s and people were buried there until 1780 when the cemetery was relocated outside the contemporary city borders. The individuals analysed in this study have been estimated to represent the period preceding 1777, when a new church was built on the same site. Although the oldest dates cannot be determined, it is likely that the repeated use of practically the same area for well over a century destroyed the earliest burials. As in Iin Hamina, some of the mandibulae from Oulu originate from ossuaries in which the bones from destroyed graves were deposited while building the new church in the 1770s (Kallio-Seppä & Tranberg 2021). Therefore, the osteological estimations, again, are tentative and the social standing of the subjects unknown.

During the latter part of the 17th and the first half of the 18th century, Oulu was a harbour town with borough rights and sea connections to larger Swedish towns. Its population included a large portion of rich merchants but also people with more modest incomes. Semi-urban life in the town was influenced by both the sea and the location by the mouth of the Oulujoki River (Halila 1953: 162, 333–5; Satokangas 1987). Marine, riverine, and lake fishing played an important role in Oulu at the time. Salmon was particularly important in Oulu as well as the rest of the northern coastal regions of Ostrobothnia – the above-mentioned Iin Hamina included. During the 17th and 18th centuries, the catches from the Oulujoki River and other nearby rivers were large enough for extensive exportation managed by the merchants of Oulu (Halila 1953: 450; Satokangas 1987). On the other hand, the game in the wilderness was well within reach and utilised by the townspeople. Even seals were still hunted on the coastal area during the 17th century, as their blubber was traded off (Halila 1954: 277–8; Vahtola 1987).

Cultivation was practised in Oulu – even inside the town borders, as the distinction between country and urban living was not very clear (Halila 1953: 440; Satokangas 1987; Vahtola 1987). The produce of the fields still remained meagre (Halila 1954: 179–81). Particularly during the 17th century, when the average temperatures dropped (Luoto 2013), harvest failures were common, and supplementary crops needed to be imported. The century ended with one of the worst hunger catastrophes in the whole country connected to the Great Famine ravaging the Baltic and Nordic regions. Animal husbandry provided much better results and butter was one of the most important local export products (Halila 1953: 200, 518; Vahtola 1987). The weather conditions and produce of agriculture slowly progressed during the 18th century, but the early part of it was not much different from the harsh previous century. What is more, the Great Northern War reached Oulu in 1714–21, leaving the town in ruins (Halila 1953: 13; Satokangas 1987; Vahtola 1987).

The population had slowly grown during the 17th century, but its precise size is unknown. In the latter part of the century, the population size has been estimated to have been slightly over 1000 inhabitants, while at the beginning of the 18th century, it may have significantly dropped consequent to the famine and hostilities (Halila 1953: 153). Nevertheless, the following decades were marked by an acceleration of economic and population growth. By the mid-18th century, the population had reached c. 2000 inhabitants, making Oulu the second-largest town in Finland after Turku, which at the time was the capital of Finland (Satokangas 1987; Vahtola 1987).

Rauma

The Holy Trinity churchyard in Rauma was excavated in 2015–6. The churchyard had been used from the late 14th century until 1853, apart from during 1790–1810 (Lähteenoja 1939: 342–6; Uotila & Lehto 2016: 4). The studied individuals were excavated from the northern side of the churchyard, where the most affordable burial plots were located. It has been estimated that these burials likely date to the earlier half of the 19th century and represent the poorer portion of the townsfolk (Uotila & Lehto 2016: 2, 4, 71).

Rauma, located on the south-western coast of Finland, was during the early 19th-century a small harbour town. Most of the town's inhabitants were self-sufficient, with few rich people. In 1832, a population of c. 1600 inhabited the town and by the time burying at the Holy Trinity churchyard was discontinued, the population had grown to nearly 2200 (Lähteenoja 1939: 276–8). Much like generally in Finland, the 19th century was defined by rapid population growth, a rising economy, and eventually, the emerging trend of urbanisation. In 19th-century southern Finland, cultivation of crops, increasingly potatoes, was already the base of the subsistence economy. Products from the surrounding countryside such as cheese, fish, crops, vegetables, and meat were obtained by the townspeople from local markets (Lähteenoja 1939: 242–3). Aquatic resources were still extensively used during the 19th century, although hunting no longer had significance as a source of livelihood in the town (Lähteenoja 1939: 267).

MATERIAL

Thirteen (13) Iin Hamina individuals were chosen for analysis; eight (8) were sampled for all skeletal elements, one for only M3 and bone, and for the remaining four (4) individuals, PM2 and bone were sampled. Ten (10) individuals from the Oulu population and thirteen (13) from Rauma were sampled for three skeletal elements. Required permissions for sampling were granted by the Finnish Heritage Agency and, in the case of the Oulu populations, the local parish authorities governing the burials and archaeological excavations at the site of the church.

The studied cortical bone samples were mainly from mandibulae of which more than 50% was preserved, or the maxillae or associated facial bones of complete or near-complete crania. For every individual from the Oulu population, the mandibula was the only bone available and in Rauma, all bones were collected from individual graves. In Iin Hamina, where the osteological samples were primarily collected from an ossuary, estimated to have contained a minimum number of approximately 160 individuals (Kallio-Seppä et al. 2009) and to prevent overrepresentation that may have followed using different skeletal elements, other bones than maxillae were from separate contexts and evaluated as unlikely to pair up with any of the sampled mandibulae. Some variation between the turnover times of these different bones is evident, but as the sample represents adults in various ages, this will not seriously decrease the representativity of the bone sample.

Dentin samples of c. 50–80 mg were drilled horizontally from the root, just below the cementoenamel junction of the subjects' PM2 and M3 after the surface had been cleaned using a drill bit. Developmentally, the crown of PM2 is complete by approximately 6 to 7 years of age and the first quarter of the root by 8.5 years, and the crown of M3 typically forms between the ages of approximately 9 and 21 years. It is usually completed by c. 13 years of age and the first quarter of the root by 15 to 16 years of age (Haavikko 1970: 127). Thus, the cuts from PM2 dentin represent conditions during the approximate ages between 6 and 8.5 years of age and those from M3 represent the teenage years (likely between 13 and 16 years). However, marked variation occurs in the M3 formation schedule (Hillson 1996: 123), which leads to the potential that the M3 samples used in this study represent quite a wide range of ages, although they can rather safely be narrowed down to have formed some time during adolescence.

METHODS

The bone samples (mandible) were cleaned by ultrasonication, 10 min in acetone bath and in ultrapure water 3 x 10 min, or until the rinsing water was clear. The collagen extraction from the clean bone sample, ground to powder using cryomilling, was performed according to Bocherens et al. (1997). The elemental content and isotopic composition of carbon and nitrogen were measured in an NC2500 elemental analyser coupled to a Thermo Scientific Delta V Plus isotope ratio mass spectrometer (IRMS) at the Laboratory of Chronology, Finnish Museum of Natural History in 2018. All analyses in Helsinki were performed in duplicate on each sample to ensure quality: the results represented here are averages of these double analyses.

The dentin samples were prepared for analysis at the Archaeological Research Laboratory, Stockholm University in the years 2019–20. Collagen extraction was performed on the ground samples including ultra-filtering according to a modified Longin method introduced by Brown et al. (1988). The stable isotope analyses of nitrogen and carbon were conducted at the Nuclear Research Department, Centre for Physical Sciences and Technology, Vilnius, Lithuania in 2020. Samples were weighed into tin capsules and combusted using a Flash EA 1112 series Elemental analyser connected to a Delta V Advantage Isotope Ratio Mass Spectrometer (IRMS) via a ConFlo III interface (all Thermo, Bremen, Germany). During the analysis, N% and C% were determined using the Elemental analyser and the gases were passed to the IRMS for stable isotope ratio measurement.

Isotope ratios were calculated according to the equation: $\delta X = [(R_{sample}/R_{standard})-1] \times 1000$ and the values presented with the δ notation as parts per thousand (‰).[2] The delta values were calibrated relative to the international standards for carbon (VPDB) or nitrogen (AIR). In Helsinki, we normalised the isotope data with a two-point calibration using international reference materials with known isotopic compositions (USGS-40, USGS-41). The mean measured $\delta^{13}C$ and $\delta^{15}N$ values, respectively, for the calibration references were -26.7‰ and -4.6‰ for USGS-40, and 36.3‰ and 46.6‰ for USGS-41, with $R^2>0.99$ between measured vs. expected values. The external precision, evaluated from lab reference bone material extracted and analysed alongside the unknowns, was ≤ 0.1‰ for both $\delta^{13}C$ and $\delta^{15}N$. In Vilnius, the used standards were Caffeine IAEA-600 ($\delta^{15}N$ = +1‰; $\delta^{13}C$ = –27.77‰), USGS24 ($\delta^{13}C$ = –16.05‰) and IAEA-NO-3 ($\delta^{15}N$ = +4.7‰). The analytical precision was 0.1‰ for both $\delta^{15}N$ and $\delta^{13}C$.

The obtained results were analysed using standard statistical tools provided by the program IBM SPSS Statistics version 27. When divided according to tissue, the data failed the Kolmogorov-Smirnov and Shapiro-Wilk tests of normality and when divided according to the site-specific populations, the data was heteroscedastic, which are both objections against usage of parametric testing. Thus, the site-specific populations (Iin Hamina, Oulu, Rauma) and different skeletal elements (PM2, M3, bone) were compared using rank-based non-parametric Kruskal-Wallis H tests with a confidence level of 95%.

RESULTS

Collagen quality control

Stable carbon and nitrogen isotope analyses were successfully performed on the 36 bone samples and 28 PM2 and 30 M3 tooth samples (Appendix 1, Table 1). The collagen quality of the samples was monitored by calculating the atomic C:N ratios, and those within the range of 2.9–3.6 were considered to represent adequate collagen quality. According to the amino acid composition of collagen, this is the acceptable range (DeNiro 1985), although in a recent study, more refined and species-specific ranges have been suggested (Guiry & Szpak 2021). Furthermore, samples within the carbon and nitrogen weight-% range of 34.3–45.5 for C% and 12.6–16.6 for N% indicating sufficient collagen quality were included in the analyses (Ambrose 1990; van Klinken 1999; Jørkov et al. 2009).

One PM2 sample from Rauma was excluded due to its exceedingly abnormal C% and N% values. Moreover, four PM2 dentin samples from Oulu and two M3 samples from Iin Hamina had atomic C:N ratios outside the acceptable range and were excluded from further discussion. The collagen yield for samples included in the analyses was within the range of 1.2–20.2%, indicating good preservation (Schoeninger et al. 1989; Ambrose & Norr 1993; van Klinken 1999). One PM2 sample from the Rauma population was discarded due to a too-low collagen yield. The obtained $\delta^{15}N$ and $\delta^{13}C$ results, group averages, and minimum and maximum values of dentin and bone collagen are presented in Table 1.

Statistical analyses

As the data failed the requirements for using parametric statistical tools, Kruskal-Wallis H tests (significance level of $p<0.050$) were employed to compare both the skeletal elements and the populations. According to the comparison of the δ values measured in PM2 and M3 dentin and bone collagen, the $\delta^{15}N$ values are different (p=0.001) between the elements but the $\delta^{13}C$ are not (p=0.691). Pairwise comparisons revealed that the $\delta^{15}N$ values in PM2 and bone collagen are particularly different (p=0.001), the latter representing a higher level, while the $\delta^{15}N$ values in M3 are similar to both PM2 and the bone values, with p=0.249 and p=0.200, respectively. In further testing, the difference in the $\delta^{15}N$ values between PM2 and bone collagen was observed only in Iin Hamina (p=0.004) (Table 1; Fig. 2). This suggests that the diets during mid-childhood and adulthood may have been different in Iin Hamina, but not in the Oulu and Rauma populations.

Despite the difference between the isotope values of the skeletal elements, their values were combined for comparison between populations. As the tissues formed at different ages, combining values enabled the diets in the populations to be observed on a holistic level. The site-specific populations differed according to both the $\delta^{13}C$ (p=0.000) and $\delta^{15}N$ (p=0.028) values. In a pairwise comparison of the populations, no differences were observed in the $\delta^{13}C$ values between the Iin Hamina and Oulu populations (p=0.192), but in the Rauma population the values were

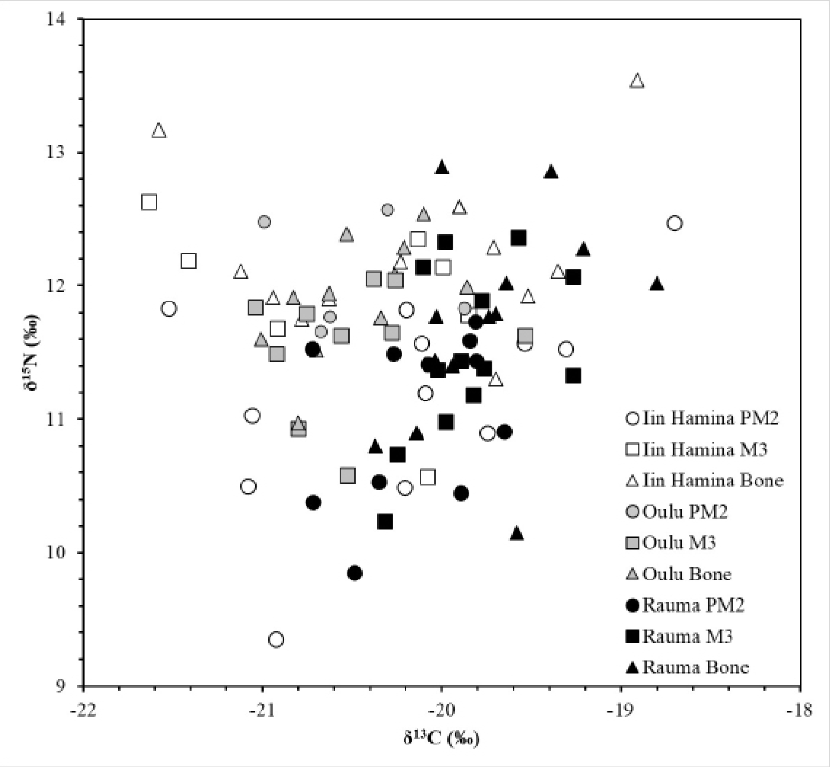

Figure 2. The $\delta^{13}C$ and $\delta^{15}N$ values measured in PM2 (circles), M3 (squares), and bone collagen (triangles) in Iin Hamina (white), Oulu (grey), and Rauma (black).

Table 1. Population minimum, maximum, and average $\delta^{15}N$ and $\delta^{13}C$ values of bone and PM2 and M3 dentin samples.

		N	Minimum (‰)		Maximum (‰)		Average (‰)		SD	
			$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Iin Hamina	PM2	12	-21,5	9,4	-18,7	12,5	-20,2	11,2	0,83	0,82
	M3	7	-21,6	10,6	-19,9	12,6	-20,6	11,9	0,74	0,67
	Bone	13	-21,6	11,3	-18,9	13,5	-20,2	12,2	0,78	0,59
	All	32	-21,6	9,4	-18,7	13,5	-20,3	11,8	0,78	0,82
Oulu	PM2	5	-21,0	11,7	-19,9	12,6	-20,5	12,1	0,42	0,43
	M3	10	-21,0	10,6	-19,5	12,1	-20,5	11,6	0,43	0,47
	Bone	10	-21,0	11,0	-19,9	12,5	-20,5	11,9	0,36	0,46
	All	25	-21,0	10,6	-19,5	12,6	-20,5	11,8	0,39	0,48
Rauma	PM2	11	-20,7	9,9	-19,7	11,7	-20,1	11,0	0,38	0,63
	M3	13	-20,3	10,2	-19,3	12,4	-19,9	11,5	0,33	0,64
	Bone	13	-20,4	10,2	-18,8	12,9	-19,7	11,7	0,42	0,78
	All	37	-20,7	9,9	-18,8	12,9	-19,9	11,4	0,41	0,73
Children		28	-21,5	9,4	-18,7	12,6	-20,2	11,3	0,61	0,77
Adolescents		30	-21,6	10,2	-19,3	12,6	-20,2	11,6	0,58	0,60
Adults		36	-21,6	10,2	-18,8	13,5	-20,1	11,9	0,63	0,66
All		94	-21,6	9,4	-18,7	13,5	-20,2	11,6	0,60	0,72

higher than both Iin Hamina (p=0.028) and Oulu (p=0.000). However, for the $\delta^{15}N$ values, a pairwise comparison could not indicate any significant differences between the populations (Iin Hamina vs. Oulu p=1.000, Iin Hamina vs. Rauma p=0.060, Oulu vs. Rauma p=0.086) which is probably an artefact caused by the small sample sizes (Table 1; Fig. 2).

DISCUSSION

Commonalities in dietary practices between the site-specific populations

The obtained $\delta^{13}C$ values (Table 1; Appendix 1), which can be used to trace the marine or terrestrial origin of the diets, are consistent with values typical of human collagen in terrestrial C_3 environments. According to Kohn (2010), the maximum $\delta^{13}C$ value for C_3 plants is -23‰. Considering that the fractionation of carbon between diet and collagen is approximately +5‰ (Krueger & Sullivan 1984; Lee-Thorpe et al. 1989), collagen $\delta^{13}C$ values of c. -18‰ or lower should be expected in present-day C_3 environments. However, due to the c. 1.5–2.0‰ drop in the $\delta^{13}C$ value of atmospheric CO_2 during the industrial era, mainly due to the utilisation of ^{13}C depleted fossil fuels (McCarroll & Loader 2004; Keeling et al. 2017), the corresponding expected collagen $\delta^{13}C$ values for C_3 environments translate to -16.5‰ or lower. In this study, none of the values exceed -18.8‰, and thus do not necessarily suggest any other influences than those from terrestrial C_3 environments or brackish water reservoirs.

In the light of the high $\delta^{15}N$ values throughout the populations, which might indicate marked animal protein consumption and a high tropic position, utilisation of aquatic resources – probably from both the nearby sea and the various freshwater sources local to each population – was likely. Typically, the food chains in water are long and complex, elevating the $\delta^{15}N$ values further than those in terrestrial environments (Ambrose 1993; Enhus et al. 2011; O'Brien 2015). From historical sources, we already know that during the relevant periods, fish – in the north, salmon, in particular – was an important part of the nutrition of all the populations (Lähteenoja 1939: 267; Halila 1953: 450; Satokangas 1987; Tanska 2011). In addition to salmon, species such as herring, pike, bream, ide, and whitefish were commonly caught (Halila 1954: 255–78). Even in 19th-century Rauma, fishing still played an important economic role, and catches of herring, salmon, whitefish, European perch, and pike were particularly significant (Lähteenoja 1939: 267–8).

Different sources of dietary animal protein in the site-specific populations

No significant differences in δ^{15}N values, commonly used in the reconstruction of plant versus animal protein intake, could be pinpointed in pairwise comparisons of the populations, although the initial testing had indicated differences (p=0.028). The δ^{15}N values, however, were higher in Iin Hamina and Oulu (in both, mean 11.8‰) than in Rauma (11.4‰). At least in Iin Hamina, and perhaps also in Oulu, some consumption of seal meat would not have been surprising. Locally in both populations, seals were indeed hunted for blubber and skins, which could be used as versatile raw materials for clothing and various household uses (Halila 1954: 277–8; Tanska 2011; Metsähallitus 2014). Their meat was also consumed in many coastal communities (Luukko 1954: 437–45; Ylimaunu 2000: 332). Even blubber could be used in cooking. The fact that the medieval Catholic Church considered seal as a species of fish is relevant particularly in relation to seal consumption in Iin Hamina. Until the mid-16th century, the parishes of Finland (then Sweden) were Catholic, and while meat consumption during Lent was forbidden, that of fish and thus, seal, was not, which made seal meat an important product (Metsähallitus 2014). Still in the 1770s, on the Swedish side of the Bay, seal was hunted (Halila 1954: 255), and as late as in the beginning of the 20th century, in the archipelago of Qvarken (FI Merenkurkku), seal meat was a seasonal spring delicacy – pups, in particular (Metsähallitus 2014).

However, as can be deduced by the rather high bone collagen δ^{15}N values, for example averaging 15.7±0.7‰ in the Västerbjers population from the island of Gotland in the Baltic Sea with a seal-based diet (Eriksson 2004), the values obtained in our study clearly cannot indicate a diet containing similarly large portions of fish or aquatic mammals. Although similarly anachronistic when used as a reference in this study, the same is obvious from the bone collagen δ^{15}N values of 14.5±0.5‰ of ringed seals (N=12; of which 11 from the Baltic Sea) and 16.6±0.9‰ in grey seals (N=15, 14 from the Baltic Sea) measured in seals dating to 1840 and onwards (Enhus et al. 2011).

The diets of the studied populations must have contained varying amounts of foodstuffs of lower ^{15}N content. The low δ^{15}N isotopic values may represent products from livestock such as cattle and sheep/goat or game lower in the trophic chain, but their proportions may have differed depending on the population. The mean values of certain local species are represented in Figure 3. Unfortunately, the soils in major parts of Finland are highly acidic because of silicon dioxide-based bedrocks which dissolve the remains of skeletal tissues quite effectively (Gordon & Buikstra 1981; Tattari & Rekolainen 2006: 27; Spellman 2009: 50), which is why osteoarcheaological materials are rarely preserved. This poses a challenge for finding suitable reference materials for stable isotope studies, but also highlights the importance of producing isotopic data from the region.

In the northern parts of Ostrobothnia, where both Iin Hamina and Oulu are located, the natural meadows gave excellent opportunities for cattle to graze while the conditions, including liability to frost, swampy soils, or short growing periods, did not favour cultivation of crops (Halila 1954: 179–81). Thus, for a long time, cattle, and particularly dairy products, which yield δ^{15}N values at the same level as meat (O'Connell & Hedges 1999), were more important for livelihoods than cultivation (Halila 1954: 210–1; Vahtola 1997; Tanska 2011). Meat production in the north at the time was likely less profitable, as the short growing periods often hindered not only the production of crops but that of winter fodder as well, even despite the extensive meadows (Halila 1954: 210–1; Lahtinen & Salmi 2019).

Still in the 18th century, in northern parts of Ostrobothnia, where both Iin Hamina and Oulu are located, traditional sources of livelihood such as hunting, and perhaps even fowling, were important (Halila 1954: 179–81). The significance of game animals is even evident in the large amount of their bones in northern archaeological sites (Puputti 2010: 37; Salmi 2011). In archaeological investigations of Northern Ostrobothnian settlements dating mainly to early modernity, large quantities of non-domesticated animal bones have been uncovered (Lahtinen & Salmi 2019). Ungulates such as elk consuming were popular game animals hunted for their meat in both Iin Hamina and Oulu, and their δ^{15}N values are rather low (Fig. 3; Lahtinen & Salmi 2019). These species must have contributed to the local diets in Iin Hamina and to some extent in Oulu, particularly among the common townspeople (Halila 1953: 440, 450; Satokangas 1987; Vahtola 1987; Puputti 2010: 37; Tanska 2011). Hunting of predators, such as wolves, was practised to prevent cattle losses, and generally fur-bearing species were hunted for the fur trade and not for their meat (Halila 1953: 441; 1954: 217; Luukko 1954: 383–97). Around the turn of the 19th century, in Rauma, hunting was no longer more than a form of leisure for the townspeople (Lähteenoja 1939: 267–8).

The unusual stable isotope patterns of certain species may be relevant in terms of interpreting the values. For instance, pigs and poultry being omnivorous usually present with more elevated δ^{15}N values than other domestic animals, but as the reference data implies, their values can be varied (Fig. 3). Pigs, however, probably had little economic significance in any of the studied populations during the relevant periods (Lähteenmäki 1939: 274; Halila 1953: 442; 1954: 216; Salmi 2011). Reindeer that are grazing on lichen usually have higher δ^{13}C values than the corresponding values of grass-grazing species from the same ecosystem (e.g., Fizet et al. 1995). Unlike species from aquatic environments, the δ^{15}N values of both the lichen-grazing and grass-grazing species remain at a lower level (Fjellström et al. 2020; Salmi et al. 2020). Still during the 18th century, reindeer were kept in the northern parts of Ostrobothnia, even at the latitude of Oulu, although their popularity was already fading (Halila 1954: 219). Nevertheless, locally the lack of proper winter fodder is known to have prompted cattle's diets to be supplemented with lichen (Halila 1954: 211), which could elevate the δ^{13}C values.

Significance of cultivated nutritional plants in the light of the δ^{15}N values

Cultivation was practised in Iin Hamina and Oulu, but its significance to the diet was marginal, and the produce of fields remained labile throughout the observation periods (Halila 1953: 200, 518; 1954: 179–81; Vahtola 1987; Tanska 2011). Overall, in the north, the short growing season, lack of field labour, skill, technology, and even willingness, hindered development of cultivation, which only began to gain significance as a source of livelihood during the late 18th century (Halila 1954: 183–5). This happened as a result of advances in agricultural technology and the adoption of new, hardier plant varieties (Helistö 2001: 230). Indeed, dental studies of the Iin Hamina individuals revealed a low incidence of caries, which implies low-carbohydrate diets, that are still believed to have contained some sweet berries as well as bread and porridge (Vilkama 2011; Lahtinen et al. 2013). Furthermore, our findings are in line with the findings of a previous stable isotope study of the Iin Hamina population by Lahtinen and Salmi (2019) concerning restricted reliance on domesticated crops as opposed to aquatic resources and terrestrial animal meat and dairy products.

According to a comparison of dental health in the Oulu and Iin Hamina populations, the diets in Iin Hamina seem to have been less cariogenic than those in Oulu (Vilkama et al. 2016). This difference, however, is not reflected in the isotope values obtained in this study, pointing towards the similarity of the two populations. The dating of the Oulu population coincides with a particularly cold period (Luoto 2013). As indicated by repeated harvest failures of the period in the region in general (Halila 1953: 728–9; 1954: 195–6; Satokangas 1987; Vahtola 1987), the produce of cultivation could still not be relied on. Crops were imported into Oulu but could be expensive (Halila 1953: 200–1).

For the Rauma population, which not only inhabited the southernmost site in this study but is also the most modern, cultivation of crops was already much more productive and its significance for the subsistence economy markedly greater (Lähteenoja 1939: 242–3; Vuorela 1999). Its population could rely on the produce of the surrounding countryside including crops of rye and barley in particular, but also the increasingly popular potatoes (Lähteenmäki 1939: 270–3). This could be significant considering the slight but not statistically significant differences observed in the δ^{15}N values between Iin Hamina and Rauma ($p=0.060$) and even Oulu and Rauma ($p=0.086$).

While the Rauma population may have relied on the carbohydrate-rich produce of fields, generally lower in δ^{15}N, to a much greater degree

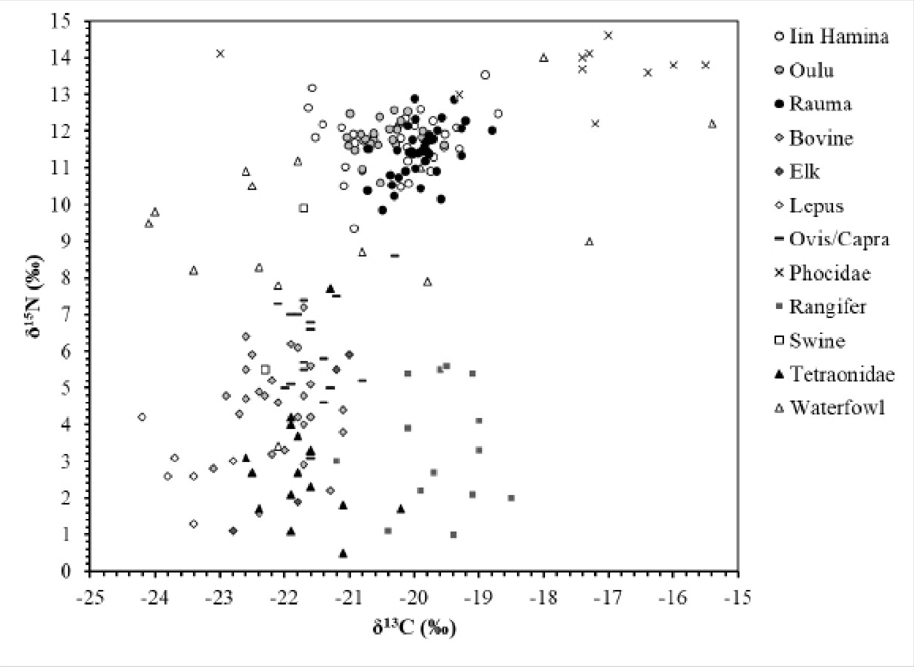

Figure 3. Bone $\delta^{13}C$ and $\delta^{15}N$ values of some animal species (for fish, see Table 2) likely utilised for food by the target populations, plotted with the human isotope data. The utilised faunal isotope data is Finnish and date between the medieval period and 1950 AD, after which a major depletion in atmospheric ^{13}C abundance due to fossil fuel emission has occurred (e.g., McCarroll & Loader 2004). The data were collected from the dIANA database (Bläuer et al. 2016; Lahtinen & Salmi 2018; Etu-Sihvola et al. 2019; Salmi & Heino 2019; Oinonen et al. 2020; Salmi et al. 2020).

than the other populations during their respective observed periods, the measured $\delta^{15}N$ values were high. The development of cultivation technologies and practices may have influenced the values in Rauma. Manuring with animal dung elevates the $\delta^{15}N$ values of crops, thus obscuring the patterns of plant- versus animal-based protein intake (Bogaard et al. 2007; Treasure et al. 2013). In the regions of Oulu and Iin Hamina, despite the importance of animal husbandry, the number of cows would for a long time not have been significant enough to have produced the dung needed to adequately manure the fields (Halila 1954: 183, 189). In addition, the traditional burn-beating technique requiring vast areas of old forests was used occasionally up until the 18th century in the coastal region in the north, although its significance diminished over time as the permanent settlements grew (Halila 1954: 182). This cultivation technique would not require the use of animal dung for fertilisation (Skrubbeltrang 1964). Moreover, based on the low $\delta^{15}N$ values measured in local contemporary cow remains, manuring is suspected not to have been practised in the natural meadows grazed by Ostrobothnian cattle (Lahtinen & Salmi 2019). In contrast, in Rauma, even the cultivation of fodder involved manuring (Lähteenoja 1939: 271), which would have led to higher $\delta^{15}N$ values in the animal products utilised as nutrition.

Effect of brackish reservoirs and marked consumption of aquatic species

In the coastal area of the Baltic Sea, $\delta^{13}C$ values pointing towards a terrestrial C_3 environment are to be expected. Despite its name, the Baltic Sea is not isotopically equivalent to a marine environment, as it is a brackish water reservoir. The $\delta^{13}C$ values of organisms living in connection to brackish bodies of water resemble those encountered in terrestrial C_3 plant environments (Katzenberg 1989). The ocean water from the North Sea is distributed into the Baltic Sea in

Brackish water pool	**Bothnian Bay**					**Bothnian Sea**					**Northern Baltic Proper**				
Kiljunen et al, 2020	δ13C‰	SD	δ15N‰	SD	N	δ13C‰	SD	δ15N‰	SD	N	δ13C‰	SD	δ15N‰	SD	N
Herring (*C, harengus*)	-23,4	0,85	9,7	0,63	85	-20,3	0,60	10,9	0,63	136	-20,4	0,92	11,8		45
Salmon (*S, salar*)	-19,7	0,83	12,7	0,64	73	-19,5	0,60	12,9	0,52	14	-18,6	0,24	12,4	0,47	10
Venduce (*C, Albula*)	-24,3	1,14	10,8	0,73	30										
Smelt (*O, eperlanus*)	-22,4	0,94	10,8	0,73	25										
Sprat (*S, sprattus*)						-20,2	0,43	9,6	0,51	40	-19,3	0,74	11,8	1,16	21
Gray seal (*H, grypus*)	-20,4	0,96	13,7	0,73		-19,3		14,6	0,77	18	-19,7		14,0		9

Table 2. Modern $\delta^{13}C$ and $\delta^{15}N$ values of species of fish and seal living in different parts of the brackish Baltic Sea measured in muscle (according to Kiljunen et al. 2020). When compared to the archaeological values, both the SUESS effect decreasing the modern carbon isotope values and the possible difference between the values yielded by the analyses of different tissues should be considered (e.g., McCarroll & Loader 2004; Leuenberger 2007; Bownes et al. 2017). Nevertheless, as these values are presented only as a demonstration of the gradient in $\delta^{13}C$ values, such modifications were not necessary.

limited pulses via the narrow Danish straits and its fraction decreases northwards. A dilution of the ocean water is caused by the large rivers descending into the Bothnian Bay, carrying organic material containing terrestrial carbon with low $\delta^{13}C$ values. Due to this, the isotopic composition of water near the northernmost corners of the Baltic Sea, known as the Bothnian Bay (Fig. 1), closely corresponds to that of fresh water. The slightly higher fraction of ocean water with a higher $\delta^{13}C$ value in front of Rauma may explain the relatively elevated values measured in the population of Rauma in comparison to the populations of both Oulu ($p=0.000$) and Iin Hamina ($p=0.028$).

A similar gradient has been observed in an isoscape study of the stable isotopes values of dissolved inorganic carbon ($\delta^{13}C_{DIC}$) in the water of the Baltic Sea (Torniainen et al. 2017). This gradient is evident in the $\delta^{13}C$ values measured in muscle tissues of fish and seals caught from different major basins of the Baltic Sea (Kiljunen et al. 2020). As seen in Table 2, the stable carbon isotopes values rather systematically elevate from the northernmost basin, the Bothnian Bay, towards the Baltic proper in the south. Only the values of grey seal (*H. grypus*) diverged slightly from the trend (Kiljunen et al. 2020), but perhaps their low number may have affected the representativity of the results. Furthermore, grey seals are known to move extensive distances, particularly in their youth (Ronald & Gots 2003; Reeves 2014), and thus, contain isotopic influences from many different areas (cf. Ben-David et al. 1997a; 1997b).

The $\delta^{13}C$ values in the Baltic Sea are clearly lower than those encountered in marine environments, but, particularly in the southern parts of the sea, in most cases they are still higher than those measured in freshwater organisms. For instance, Auttila et al. (2015) measured average $\delta^{13}C$ values between nearly -28‰ and -25‰ (and average $\delta^{15}N$ values between c. 8 and 14) in Lake Saimaa, Eastern Finland depending on the region, and the type of fish (benthic, pelagic, littoral). In Jyväsjärvi, Central Finland, the periphyton utilised as the nutrition of many fish species had $\delta^{13}C$ values ranging between -32.0‰ and -22.3‰ (and $\delta^{15}N$ values between 3.6‰ to 8.0‰) (Syväranta et al. 2006). Nevertheless, notable variation in the $\delta^{13}C$ values of the species as well as the composition and size of the Baltic Sea has been observed to occur over time (Ukkonen et al. 2014; Etu-Sihvola et al. 2019; Lahtinen & Salmi 2019), which makes comparisons over large temporal gaps difficult.

Children, adolescents, and adults

The statistical testing indicated different $\delta^{15}N$ values in PM2 dentin collagen and bone collagen in the Iin Hamina population, with higher values obtained from the bone collagen samples ($p=0.004$). This implies that the adults and children in 15th to early 17th-century Iin Hamina may have had different diets. Aquatic environments are typically elevated in $\delta^{15}N$ (e.g., Minagawa & Wada 1984; Schoeninger & DeNiro 1984; Ambrose 1993; Schulting 1998; Enhus et al. 2011; O'Brien 2015). As already discussed, aquatic predatory species, such as salmon, probably played an important role in the diets of the study subjects. The detected difference may reflect an increasing abundance of animal protein or a greater proportion of protein with high trophic levels, perhaps fish, in diets towards adulthood. Children in Iin Hamina may have eaten more food items such as bread, roots, berries, or porridge.

On the other hand, the effect of growth on the $\delta^{15}N$ values is worth considering. It has been suggested that the metabolic differences in growing versus adult individuals consuming similar diets lead to different $\delta^{15}N$ values (Millard 2000). This has been demonstrated in pregnant women growing new tissues and presenting with lower $\delta^{15}N$ values (e.g., Fuller et al. 2004). Many authors, nevertheless, lean towards a presumption that if such an effect can be measured in growing individuals, the decline caused by it remains minor (e.g., Ponsard & Averbuch 1999; Waters-Rist & Katzenberg 2010; Nitsch et al. 2011).

Another explanation for the difference may even simply reflect the fact that the analyses of bone (adult) and dentin (childhood/adolescent) samples were performed in different laboratories (Helsinki and Vilnius). Differences in sample preparation and analytical conventions (e.g., instrumentation, working standards, and normalisation protocols) can result in offsets in stable isotope data levels between laboratories. Considering the findings of typical inter-laboratory differences of 0.4‰ for collagen $\delta^{15}N$ data (Pestle et al. 2014), it is entirely possible that some of the difference in $\delta^{15}N$ mean values between the adolescents and adults detected as significant by the statistical analysis is an artefact stemming from analytical causes.

Other factors to consider

Serious epidemics, famines, and wars have affected all the studied populations. In Iin Hamina, this period was disrupted several times by attacks from Novgorod (Kallio-Seppä 2011; Tanska 2011). Living in Oulu was complicated by the difficult climate conditions brought about by the particularly harsh climatic spell and even the Great Northern War and other hostilities during the 18th century (Satokangas 1987; Vahtola 1987; Luoto 2013). The Finnish War in 1808–9 likely coincided with the lifetime of some of the individuals in the Rauma sample. This may be worth consideration, as the influence of such stressors as nutrition and health concerns on stable isotope values have a better chance of being stored in rapidly and incrementally growing tissues (dentin, hair, nail). Under stress, a negative nitrogen balance necessitates the release of protein, already enriched with heavier nitrogen isotopes in relation to the diet, from muscles to enable new protein synthesis, which leads to an elevation in $\delta^{15}N$ values. Starvation may lead to the body utilising stored adipose tissues low in heavier carbon isotopes as an energy source, which is observable as a depletion of $\delta^{13}C$ values (DeNiro & Epstein 1977; Lee-Thorpe et al. 1989; Ambrose 1993; Katzenberg & Lovell 1999; Fuller et al. 2005; Beretta et al. 2010; Reitsema 2013; D'Ortenzio et al. 2015; Webb et al. 2015; Doi et al. 2017). However, it is unclear how these episodes of stress affect the stable isotope composition of bone tissues that present average conditions over an extended period of several years. Especially in the absence of anything resembling anamnesis, it is impossible to conclusively tell whether such conditions could have influenced the signals measured in the sample.

All individuals included in this analysis had an erupted M3 according to which they could be interpreted as adults. While the group of adolescents is age-wise quite constant because of the relatively systematic time window of PM2 and even M3 formation, the range of ages at death, however, is much wider, as the sample includes individuals from young to mature adults. Due to this, the biological ages their bone collagen samples represent vary greatly. In fact, the bone samples of the youngest may still contain some isotope signals formed during adolescence, which may bring the average values of the age-specific groups closer to each other. What is more, there may have been differences between the diets of younger and older adults which were obscured due to the makeup of the sample.

CONCLUSION

The $\delta^{13}C$ values yielded by the analyses are consistent with the values typical of terrestrial C_3 environments and to be expected in the coastal area of the brackish Baltic Sea. A larger fraction of ocean water (Atlantic/North Sea) with a higher $\delta^{13}C$ value outside the coast of Rauma compared to the two more northerly sites likely explains why the $\delta^{13}C$ values measured in the Rauma population are significantly elevated in comparison to the populations of both Oulu and Iin Hamina.

Elevated levels of $\delta^{15}N$ values are observed throughout the populations, implying continuous utilisation of aquatic resources as a common part of diets. The historical information concerning the populations suggests that both the nearby sea and the various freshwater sources local to each population were used. Particularly salmon, high in the food chain, presenting with elevated $\delta^{15}N$ values, has been plentifully consumed especially in Iin Hamina and Oulu, but to some extent in Rauma as well. In Iin Hamina and even in Oulu, some consumption of seal meat may well have been possible, and although the difference was not significant, it may explain the slightly higher $\delta^{15}N$ values in these populations in comparison to the Rauma population.

The diets of the studied populations still contained varying amounts of foodstuffs of lower ^{15}N content. Depending on the population, they may be products of livestock or game. During the relevant period, in the northern parts of Ostrobothnia, where both Iin Hamina and Oulu are located, animal husbandry was an important part of livelihoods and hunting contributed to local diets. The significance of the cultivation of crops, however, was not as great in late medieval to early modern Iin Hamina or even in early modern Oulu as it was in the south-western 19th-century Rauma. Nevertheless, despite the greater reliance on crops and potatoes lower in protein than aquatic resources, the $\delta^{15}N$ values in Rauma are high. They may have been influenced by the adoption of more advanced agricultural technologies, including extensive manuring with animal dung of both meadows growing winter fodder and fields growing crops.

The samples divided into groups according to tissue types representing childhood, adolescence and adulthood differ from each other – in Iin Hamina, the $\delta^{15}N$ values measured in dentin collagen of PM2 representing childhood diets and in bone collagen representing adulthood diets were significantly different. This may be due to the larger amount of aquatic foodstuffs in the diets of adults in Iin Hamina. Children may also have eaten more foods such as bread, porridge, berries, and roots.

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NOTES

[1] During the period relevant to this study, the area of modern-day nation of Finland was first part of the Kingdom of Sweden known as Österland and from 1809 onward, autonomous Grand Duchy of Finland in the Russian Empire. Later in this paper, we will refer this entity as Finland, although its geographical area has not remained unchanged during all historical periods.

[2] X= Isotope ratio of interest ($^{13}C/^{12}C$ or $^{15}N/^{14}N$), R= Isotope ratio of the sample or a standard.

APPENDIX

*Appendix 1. Results of the $\delta^{13}C$ and $\delta^{15}N$ analyses of the PM2 and M3 dentin and bone collagen from archaeological populations of Iin Hamina, Oulu, and Rauma. * Poor collagen quality **Skeletal element: 1=mandible 2=maxilla*

Sample	Individual	Skeletal element**	δ^{13}C (‰)	δ^{15}N (‰)	N%	C%	C/N atom	Yield %
PM2 dentin collagen								
Iin Hamina (IHA)	CH15_100/56 _I	1	-20,1	11,2	14,94	39,57	3,1	1,5
	CH15 XX	2	-20,9	9,4	14,80	38,47	3,0	2,7
	SH1_5	1	-19,7	10,9	14,85	38,27	3,0	6,1
	CR1_24A	1	-21,1	10,5	14,14	36,48	3,0	5,5
	CR1_36A	1	-21,1	11,0	14,30	37,16	3,0	3,1
	CR1_59	2	-20,1	11,6	13,69	36,64	3,1	2,1
	CR1_102/54_165	2	-19,5	11,6	13,87	36,28	3,1	4,1
	CR1_102/54_251	2	-21,5	11,8	14,77	38,80	3,1	6,9
	CR1_288	2						
	CR1_57	2	-18,7	12,5	14,12	37,20	3,1	5,8
	CR1_71	2	-19,3	11,5	12,56	34,27	3,2	1,2
	CR1_102/54_166	2	-20,2	10,5	14,92	38,43	3,0	2,6
	CR1_102/54_177	2	-20,2	11,8	13,88	37,27	3,1	4,4
Oulu (OTK)	42P18*	1	-22,5	11,4	9,79	36,49	4,4	11,1
	H29	1	-19,9	11,8	14,24	39,33	3,2	5,6
	4860	1	-21,0	12,5	13,81	37,99	3,2	3,7
	O49750*	1	-23,3	11,8	9,61	38,45	4,7	10,1
	208178*	1	-22,0	12,1	10,72	37,43	4,1	7,4
	4710	1	-20,3	12,6	14,25	39,07	3,2	7,4
	2201625	1	-20,6	11,8	13,41	37,06	3,2	2,0
	20042	1	-20,7	11,7	13,36	36,73	3,2	5,6
	20439*	1	-22,7	10,5	11,02	38,52	4,1	7,0
	203G20*	1	-22,9	12,3	10,17	38,93	4,5	9,5
Rauma (RAU)	12	1	-20,1	11,4	14,34	38,26	3,1	3,5
	122	1	-20,3	11,5	14,27	38,76	3,2	5,5
	123	1	-19,7	10,9	14,53	38,36	3,1	5,9
	124	1	-19,8	11,4	13,95	38,06	3,2	3,3
	150	1	-19,8	11,7	13,84	37,87	3,2	4,7
	151	1	-20,4	10,5	14,32	38,99	3,2	4,2
	166	1	-19,8	11,6	14,62	39,95	3,2	7,5
	193*	1	-20,2	7,1	14,30	35,83	2,9	0,9
	196	1	-20,5	9,9	14,46	37,59	3,0	5,7
	197	1	-20,7	11,5	14,59	39,94	3,2	6,7
	200	1	-20,7	10,4	13,94	38,49	3,2	7,0
	202*	1	-20,7	11,0	9,82	29,90	3,6	5,7
	208	1	-19,9	10,5	14,93	36,83	2,9	4,9

Sample	Individual	Skeletal element**	δ^{13}C (‰)	δ^{15}N (‰)	N%	C%	C/N atom	Yield %
M3 dentin collagen								
Iin Hamina (IHA)	CH15_100/56 _I	1	-20,0	12,1	13,98	40,13	3,3	6,4
	CH15 XX	2	-20,1	10,6	13,91	38,77	3,3	3,4
	SH1_5	1	-19,9	11,8	14,19	39,24	3,2	5,3
	CR1_24A*	1	-21,7	11,6	11,61	36,68	3,7	3,2
	CR1_36A	1	-21,4	12,2	13,73	38,20	3,2	4,2
	CR1_59*	2	-21,6	11,5	11,40	37,29	3,8	3,3
	CR1_102/54_165	2	-20,1	12,4	12,65	37,65	3,5	4,2
	CR1_102/54_251	2	-21,6	12,6	14,01	39,88	3,3	6,2
	CR1_288	2	-20,9	11,7	13,13	36,79	3,3	1,5
	CR1_57	2						
	CR1_71	2						
	CR1_102/54_166	2						
	CR1_102/54_177	2						
Oulu (OTK)	P18	1	-20,3	11,7	14,49	39,84	3,2	6,8
	H29	1	-20,8	10,9	14,59	40,26	3,2	5,6
	4860	1	-21,0	11,8	14,27	39,35	3,2	6,7
	049750	1	-20,9	11,5	14,93	41,01	3,2	6,8
	208178	1	-19,5	11,6	14,54	39,97	3,2	3,9
	4710	1	-20,3	12,0	14,42	39,51	3,2	5,1
	2201625	1	-20,8	11,8	14,42	39,57	3,2	5,1
	20042	1	-20,6	11,6	14,43	38,80	3,1	7,5
	20439	1	-20,5	10,6	14,73	39,42	3,1	8,1
	203G20	1	-20,4	12,1	14,50	38,88	3,1	6,6
Rauma (RAU)	12	1	-20,0	12,3	14,03	39,21	3,3	2,0
	122	1	-19,6	12,4	14,14	38,30	3,2	4,7
	123	1	-19,9	11,4	13,68	37,36	3,2	6,2
	124	1	-19,3	12,1	14,75	40,49	3,2	6,7
	150	1	-20,0	11,4	14,35	39,05	3,2	7,9
	151	1	-19,8	11,4	14,46	39,61	3,2	7,5
	166	1	-19,8	11,9	14,16	38,36	3,2	7,2
	193	1	-19,3	11,3	14,34	38,55	3,1	5,8
	196	1	-20,0	11,0	14,50	38,70	3,1	7,0
	197	1	-20,1	12,1	14,25	38,38	3,1	6,0
	200	1	-20,3	10,2	14,93	39,37	3,1	4,5
	202	1	-20,2	10,7	14,50	39,76	3,2	7,2
	208	1	-19,8	11,2	14,14	38,06	3,1	6,3

Sample	Individual	Skeletal element**	δ^{13}C (‰)	δ^{15}N (‰)	N%	C%	C/N atom	Yield %
Bone collagen								
Iin Hamina (IHA)	CH15_100/56 _I	1	-19,4	12,1	16,15	44,35	3,2	12,7
	CH15 XX	2	-19,7	11,3	14,76	40,65	3,2	15,1
	SH1_5	1	-19,7	12,3	15,45	42,90	3,2	17,0
	CR1_24A	1	-20,6	11,9	16,60	45,45	3,2	16,5
	CR1_36A	1	-21,1	12,1	16,10	44,40	3,2	15,4
	CR1_59	2	-20,2	12,2	16,25	44,45	3,3	17,8
	CR1_102/54_165	2	-19,9	12,6	16,25	44,50	3,2	18,5
	CR1_102/54_251	2	-21,6	13,2	16,30	44,85	3,2	18,7
	CR1_288	2	-20,9	11,9	15,18	41,90	3,2	16,2
	CR1_57	2	-18,9	13,5	15,20	42,45	3,3	18,2
	CR1_71	2	-19,5	11,9	15,30	42,05	3,2	18,5
	CR1_102/54_166	2	-20,8	11,8	15,70	42,80	3,2	18,8
	CR1_102/54_177	2	-20,3	12,1	15,03	40,50	3,1	3.8
Oulu (OTK)	P18	1	-20,2	12,3	16,20	44,05	3,2	18,7
	H29	1	-20,7	11,5	15,02	41,60	3,2	18,7
	4860	1	-21,0	11,6	15,75	43,05	3,2	18,0
	049750	1	-20,8	11,0	14,94	41,05	3,2	17,8
	208178	1	-19,9	12,0	14,20	38,90	3,2	17,6
	4710	1	-20,1	12,5	16,05	44,15	3,2	17,2
	2201625	1	-20,8	11,9	15,55	43,10	3,2	15,9
	20042	1	-20,6	11,9	14,88	40,70	3,2	17,3
	20439	1	-20,3	11,8	15,45	42,45	3,2	20,2
	203G20	1	-20,5	12,4	15,35	41,75	3,2	17,4
Rauma (RAU)	12	1	-19,6	12,0	15,65	42,75	3,2	16,1
	122	1	-19,4	12,9	15,10	40,85	3,2	7,9
	123	1	-20,0	11,8	15,07	41,20	3,2	3,5
	124	1	-19,2	12,3	14,64	40,35	3,2	5,2
	150	1	-18,8	12,0	15,85	43,30	3,2	11,7
	151	1	-19,7	11,8	15,50	42,30	3,2	12,1
	166	1	-19,7	11,8	16,00	43,40	3,2	12,4
	193	1	-19,6	10,2	15,80	43,40	3,2	19,4
	196	1	-20,0	11,4	16,15	43,80	3,2	17,8
	197	1	-20,0	12,9	15,85	43,30	3,2	18,5
	200	1	-20,4	10,8	14,84	41,40	3,3	5,6
	202	1	-20,1	10,9	15,95	43,85	3,2	14,4
	208	1	-19,9	11,4	15,50	42,40	3,2	13,3