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## CONSIDERATION OF FRESHWATER AND MULTIPLE MARINE RESERVOIR EFFECTS: DATING OF INDIVIDUALS WITH MIXED DIETS FROM NORTHERN SWEDEN

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**ABSTRACT.** Human burials from the cemetery at the Rounala church, northern Sweden, were radiocarbon (<sup>14</sup>C) dated to shed light on the use of the cemetery. Carbon, nitrogen and sulfur stable isotope analysis of bone collagen from 19 distinct individuals indicated that these individuals had a mixed diet consisting of freshwater, marine and terrestrial resources. Dietary modeling using FRUITS was employed to calculate the contributions of the different resources for each individual. These data were then used to calculate individual  $\Delta R$  values, taking into account freshwater and multiple marine reservoir effects, the latter caused by Baltic and Atlantic marine dietary inputs, respectively. <sup>14</sup>C dating of tissues from modern freshwater fish species demonstrate a lack of a freshwater reservoir effect in the area. Two OxCal models were used to provide endpoint age estimates. The calibrated data suggest that the site's cemetery was most likely in use already from the 14th century, and perhaps until at least the late 18th century.

**KEYWORDS:** bone collagen, northern sweden, reservoir effects, Sámi, stable isotopes.

### INTRODUCTION

The cemetery of Rounala is associated with the historical Rounala church (Figure 1). Situated alongside one of the main trade routes between the Gulf of Bothnia and the Norwegian Sea (Hoppe 1945:69), it is thought that the church at Rounala was the first church to be built in the Torne *lappmark*, northern Sweden. Based on historical records, Wiklund (1916:10) suggests that the church at Rounala was built in the 1500s, most likely after 1559, when a missionary was sent by King Gustav Vasa to proselytize among the Sámi in that region. The history of Sámi religious practices is complex, with periods of both Swedish and Norwegian Christianization (Aronsson 2013; Kent 2014; Rasmussen 2016). As this building was the first known church in the Torne *lappmark*, it could aid in our understanding of how and when Christianity was spread into this area. According to a written account, the church was abandoned in 1643, at the latest—or possibly already in 1606, as dictated by a royal decree (Wallerström 2017). The church no longer stands today as it fell into disrepair after its abandonment and its material remains were sold and moved to another site during the late 18th century (Wiklund 1916:12). However, during its use as a church, several people were buried at the cemetery.

During the excavation in 1915 by Eskil Olsson, the remains of 23 distinct humans were identified (Wiklund 1916:17–19). According to Manker (1961:96), the burial styles are somewhat diverse, probably reflecting a mix of Sámi and Christian traditions, as recently discussed by historian Siv Rasmussen (2016). The possibility that the graveyard was in use prior to the founding of the church must not be disregarded. Here we aim to date the burial events of the interred individuals so as to understand the relationship between the graveyard and the church; did the burials begin before the church's construction?

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Figure 1 Map of northern Fennoscandia showing the location of Rounala, the lake of Riebnjesjaure, rivers of Målselva and Laisälven, the location of the reindeer samples, and the locations of the marine species used to calculate marine  $\Delta R$  values. The shaded area denotes Torne lappmark (see main text).

A careful calibration of the individuals' radiocarbon ( $^{14}\text{C}$ ) dates will be necessary to establish the time of burial. This calibration must be made with regard to reservoir effects potentially influencing these samples. Marine and freshwater reservoir effects occur due to the accumulation of  $^{14}\text{C}$  depleted carbon (Ascough et al. 2005; Philippsen 2013). Different environmental sources of radiocarbon,  $^{14}\text{C}$  reservoirs or pools depleted in  $^{14}\text{C}$ , yield different average  $^{12}\text{C}/^{14}\text{C}$  ratios. This being the case, modern samples from these reservoirs can be measured as having apparently old  $^{14}\text{C}$  dates. These  $^{14}\text{C}$  reservoir effects can alter a sample's apparent age by hundreds or even thousands of years. Stable isotope analysis, used to reconstruct diets, can be

used to quantify the dietary input from different reservoirs, thereby enabling the estimation of the true age of an individual.

The effect of multiple reservoir effects from different dietary sources on  $^{14}\text{C}$  dating has been previously studied by, e.g. Ascough et al. (2007, 2012) and Sayle et al. (2014, 2016). To address this problem, a series of steps must be taken to accurately date the human remains. Firstly, a multi-isotopic model will be used to help reconstruct the diet of these individuals. Secondly, the presence of any freshwater reservoir effects must be investigated. Thirdly, appropriate  $\Delta\text{R}$  values will be defined for each individual. Finally, an OxCal model, which considers all available reservoir effects and dietary inputs, will be used to calibrate the  $^{14}\text{C}$  dates of these individuals.

Regarding the procurement of these dietary resources, Sámi economies in northern Scandinavia were quite diverse. Sámi cultures have often been subdivided in order to account for these economic differences. The Sea Sámi lived traditionally by combining fishing and small-scale animal husbandry. The term Reindeer Sámi, or Mountain Sámi, describes the nomadic Sámi peoples living as reindeer herders. Forest Sámi traditionally lived by combining fishing in inland rivers and lakes alongside small-scale reindeer-herding (Vorren and Manker 1976:106, 118–119). This investigation into the diets of the Rounala individuals falls into ongoing research and discussion of Sámi subsistence and settlement patterns. A historical map shows that many Forest Sámi settlements were placed close to rivers and lakes (Norstedt and Östlund 2016). This settlement pattern is consistent with ethnographic descriptions of groups with a fish-centered subsistence pattern but perhaps not with a reindeer-centered one (Norstedt and Östlund 2016). It has also been proposed that fish (Norstedt et al. 2014) were more important than has previously been assumed.

## **MATERIALS**

In total, 19 human skeletal samples from Rounala were analysed. Although 23 distinct human individuals were identified during the original excavations, only 21 of the crania were in a condition suitable for recovery. Today only 17 of these 21 crania could be located. A further two human humerus samples from Rounala were sampled for analysis. In addition, 22 faunal samples were analyzed: eight modern fish and 14 reindeer. Three Atlantic salmon were caught from the estuary of Målselva (northern Norway), a 140-km-long river emptying into the Malangen fjord in the Norwegian Sea. Samples of the salmon muscle and bone were taken for stable isotope analysis and  $^{14}\text{C}$  dating. Five specimens of freshwater fish were caught from freshwater bodies in northern Sweden; these included four Arctic char and one brown trout. Archaeological and historical samples from 14 reindeer were sampled from a number of sites in northern Sweden (Figure 1). Data from these samples were considered alongside previously published data, including 54 Atlantic cod and 18 Baltic seals, used to infer Baltic fish values.

## **METHODS**

### **Human and Reindeer Bone Collagen**

To reconstruct the diet of the humans interred at Rounala, stable isotope analysis was performed on bone collagen extracted from human bones, as well as from faunal bones representing animals that were potentially consumed by the human individuals. Samples of human and reindeer bone powder were obtained using a dentist's drill. Surface layers were discarded to avoid contamination. Bone collagen was subsequently extracted by the method of Brown et al. (1988), a modification of the Longin method (1971). This included an ultrafiltration step to remove the <30 kDa fraction which potentially contains contaminants of low molecular weight. All sampling and extraction were performed at Stockholm University Archaeological Research Laboratory while subsequent

EA-IRMS analysis took place at Stockholm University Stable Isotope Laboratory (SIL), Dept. of Geological Sciences, unless otherwise stated. Bone collagen was weighed into tin capsules (ca. 0.5 mg for carbon and nitrogen isotope analysis and ca. 2–5 mg for sulfur isotope analysis) for combustion in a Carlo Erba NC2500 elemental analyzer connected to a continuous flow isotope ratio mass spectrometer—a Finnigan MAT Delta+ for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , and a DeltaV Advantage for  $\delta^{34}\text{S}$  measurements. The precision of the measurements was  $\pm 0.15\%$  or better for both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  ratios, and  $\pm 0.2\%$  or better for  $\delta^{34}\text{S}$  measurements.

### **Fish Muscle and Bone Collagen**

Arctic char and brown trout bone samples were boiled, after which bone was subsequently mechanically defleshed. Bone collagen was extracted following the same protocol as outlined above with the addition of a lipid removal step after demineralization. A 2:1 dichloromethane:methanol solution was added, after which samples were shaken for two hours, then rinsed with deionized water in excess and subsequently dried in a desiccator overnight.

The bone and flesh of the Atlantic salmon were mechanically separated. Both muscle and bone samples were subject to lipid removal procedures as above. Samples were then placed in a heating block at 70°C until dry. Collagen was extracted from these salmon samples using the following method: Bone samples were placed in 8 mL of 0.6M HCl at 4°C until demineralized. The samples were rinsed with deionized water and left to gelatinise in 4 mL of HCl (pH3) in a heating block at 80°C until the collagen had fully dissolved (Longin 1971; Richards and Hedges 1999; Colonese et al. 2015). Ultrafilters were rinsed with 0.1M NaOH and centrifuged at 850 g for 8 min to remove any contaminants. This process was repeated three times with deionized water. The bone samples were centrifuged down to 0.5 mL and freeze-dried. The lipid-removed muscle samples were freeze-dried and ground down to a powder.

### **Radiocarbon Dating**

AMS  $^{14}\text{C}$  dating was performed on bone collagen from the 19 Rounala human individuals, the modern fish samples, consisting of one Arctic char, one brown trout and three salmon, as well as muscle collagen extracted from the three salmon samples.  $^{14}\text{C}$  dating was performed at the AMS facility at the Dept. of Physics and Astronomy at Uppsala University (a few previous dates of human bone had been made at the Radiocarbon Dating Laboratory at Lund University; see Appendix 1).

## **RESULTS**

All faunal and human samples, except the modern salmon, complied with established collagen quality criteria with regard to yield, carbon and nitrogen concentrations and atomic C:N ratio, as well as sulphur concentration, atomic C:S and N:S ratios (DeNiro 1985; Ambrose 1990; Nehlich and Richards 2009) (due to machine failure, one of the fish, REB 1, did not generate any carbon and nitrogen data). Some of the modern salmon samples have C:N ratios slightly out of range and very high sulphur concentrations, the latter affecting the C:S and N:S ratios. Given that these samples are modern, and that C:S and N:S ratios are consistent both between muscle and bone collagen from the same individual, and also between individuals, these samples have been included in subsequent analysis.

Stable isotopic results are summarized in Figures 2–3 and Table 4 (detailed data in Appendix 2). The only terrestrial animal in this study, reindeer, display  $\delta^{13}\text{C}$  values ranging from  $-21.7\%$  to  $-18.5\%$  and  $\delta^{15}\text{N}$  values between  $2.0\%$  and  $5.9\%$ , consistent with previously analyzed reindeer (Iacumin et al. 2000; Salmi et al. 2015). The  $\delta^{34}\text{S}$  values range from  $7.9\%$  to  $12.8\%$ ,

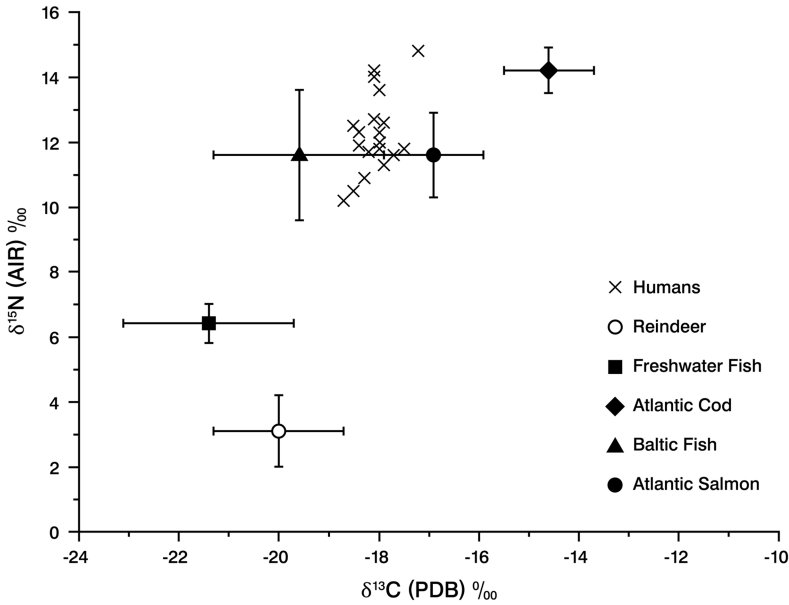


Figure 2 Graph displaying  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values for the Rounala humans and relevant food groups (mean  $\pm 1$  standard deviation). The  $\delta^{13}\text{C}$  values for modern samples have been corrected for the Suess effect by +1.5‰. Reindeer n = 14 (this study), freshwater fish n = 5 (this study), Baltic fish n = 18 (Enhus et al. 2011), Atlantic salmon n = 3 (this study), Atlantic cod n = 51 (Barrett et al. 2011; Nehlich et al. 2013). See Discussion section for Baltic fish values.

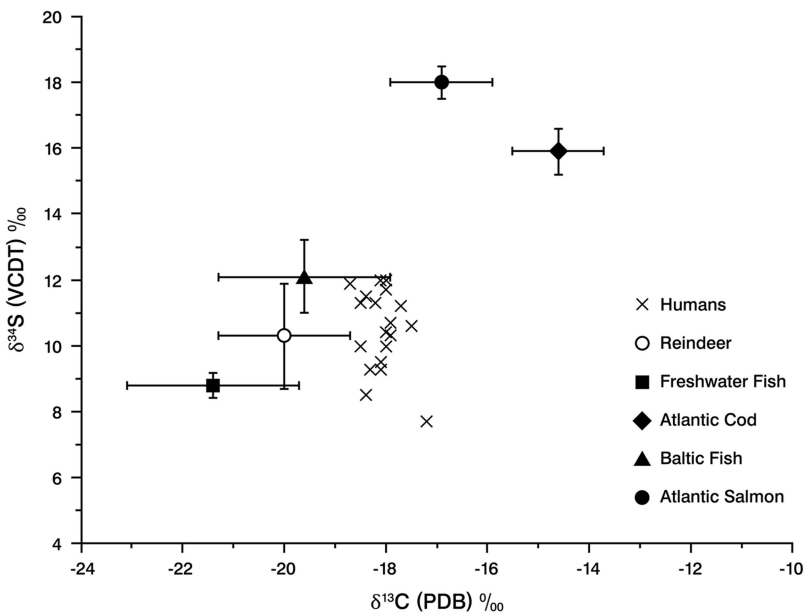


Figure 3 Graph displaying  $\delta^{13}\text{C}$  and  $\delta^{34}\text{S}$  values for the Rounala humans and relevant food groups (mean  $\pm 1$  standard deviation). The  $\delta^{13}\text{C}$  values for modern samples have been corrected for the Suess effect by +1.5‰. Reindeer n = 14 (this study), freshwater fish n = 5 (this study), Baltic fish n = 18 (Linderholm et al. 2008; Enhus et al. 2011), Atlantic salmon n = 3 (this study), Atlantic cod n = 51 (Barrett et al. 2011; Nehlich et al. 2013). See Discussion section for Baltic fish values.

reflecting the large geographical area the reindeer derive from. The freshwater fish display  $\delta^{13}\text{C}$  values ranging from  $-22.6\text{‰}$  to  $-19.0\text{‰}$ ,  $\delta^{15}\text{N}$  values between  $5.8\text{‰}$  and  $7\text{‰}$  and  $\delta^{34}\text{S}$  values range from  $8.2\text{‰}$  to  $9.2\text{‰}$ . The Atlantic salmon bone samples have  $\delta^{13}\text{C}$  values ranging from  $-19.5\text{‰}$  to  $-17.6\text{‰}$ ,  $\delta^{15}\text{N}$  values between  $10.1\text{‰}$  and  $12.4\text{‰}$  and  $\delta^{34}\text{S}$  values between  $17.4\text{‰}$  and  $18.3\text{‰}$ .

Stable isotope values vary along food chains. Typically, there is a large stepwise trophic shift of between  $+3$  and  $5\text{‰}$  in  $\delta^{15}\text{N}$  from prey to consumer (Minagawa and Wada 1984; Bocherens and Drucker 2003). A smaller trophic-level effect of about between  $+1$  and  $2\text{‰}$  is observed for  $\delta^{13}\text{C}$  values between prey and consumer (DeNiro and Epstein 1978). Trophic level shifts in  $\delta^{34}\text{S}$  values between animals and their diet are  $0 \pm 1\text{‰}$  (Barnes and Jennings 2007; Kaufman and Michener 2007).

The isotopic values for the humans range between  $-18.5\text{‰}$  and  $-17.2\text{‰}$  ( $\delta^{13}\text{C}$ ),  $10.2\text{‰}$  and  $14.8\text{‰}$  ( $\delta^{15}\text{N}$ ) and  $7.7\text{‰}$  and  $12\text{‰}$  ( $\delta^{34}\text{S}$ ), showing a wide variation. The  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values are particularly elevated relative to the reindeer, indicating that reindeer did not constitute a major dietary source. Furthermore, the humans have  $\delta^{15}\text{N}$  values similar to the marine fish groups, but considerably lower  $\delta^{13}\text{C}$  values, indicating some marine input, but no linear mixing between solely two major food groups. FRUITS (Food Reconstruction Using Isotopic Transferred Signals), a Bayesian computer model for diet reconstruction, will help estimate the contributions of these marine groups (Fernandes et al. 2014).

The results of the  $^{14}\text{C}$  dating and stable isotope analysis applied to the human samples are summarized in Table 1. Duplicate  $^{14}\text{C}$  measurements were made for humans 6, 10 and 12, due to their larger uncertainties; their  $^{14}\text{C}$  ages were calculated using *R\_Combine* in OxCal v.4.3, (Bronk Ramsey 2009; see Appendix 1 for sample details).

Table 1 Stable isotopic ratios and  $^{14}\text{C}$  ages of Rounala human samples (see Appendix 1 for details).

Rounala human	$^{14}\text{C}$ age (BP)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{34}\text{S}$ (‰)
1	$580 \pm 85$	$-17.9$	$11.3$	$10.7$
3	$429 \pm 30$	$-18.5$	$12.5$	$10.0$
4	$414 \pm 30$	$-17.1$	$14.0$	$12.0$
5	$492 \pm 30$	$-18.1$	$12.7$	$9.3$
6	$669 \pm 65$	$-18.4$	$12.3$	$11.5$
7	$371 \pm 31$	$-18.0$	$12.3$	$11.7$
8	$527 \pm 30$	$-18.4$	$11.9$	$8.5$
9	$460 \pm 30$	$-18.0$	$13.6$	$10.4$
10	$472 \pm 28$	$-17.9$	$12.6$	$10.3$
11	$451 \pm 30$	$-17.5$	$11.8$	$10.6$
12	$513 \pm 29$	$-17.7$	$11.6$	$11.2$
13	$513 \pm 30$	$-18.0$	$12.0$	$10.0$
14	$407 \pm 30$	$-18.5$	$10.5$	$11.3$
16	$270 \pm 30$	$-18.7$	$10.2$	$11.9$
18	$337 \pm 30$	$-18.2$	$11.7$	$11.3$
20	$552 \pm 30$	$-18.1$	$14.2$	$9.5$
21	$287 \pm 30$	$-18.0$	$11.8$	$12.0$
L17a	$457 \pm 32$	$-17.2$	$14.8$	$7.7$
L17b	$550 \pm 32$	$-18.3$	$10.9$	$9.3$

Table 2 Stable isotope ratios and calibrated  $^{14}\text{C}$  ages for the fish samples.

Sample	Tissue	$^{14}\text{C}$ age			$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{34}\text{S}$ (‰)
		pMC	Cal AD (68.2%)	Cal AD (95.4%)			
Salmon 1	Collagen	104.8 ± 0.3	2007.94–2009.50	1956.54–2009.53	-18.2	12.4	18.3
Salmon 2	Collagen	105.4 ± 0.3	2007.02–2009.52	1956.63–2009.53	-17.6	12.3	17.4
Salmon 3	Collagen	104.2 ± 0.3	1956.54–2009.49	1956.28–2009.53	-19.5	10.1	18.2
Salmon 1	Muscle	105.2 ± 0.3	2007.43–2009.52	1956.61–2009.53	-19.9	13.7	18.4
Salmon 2	Muscle	105.5 ± 0.3	2006.99–2009.52	1956.65–2009.53	-19.8	13.7	18.4
Salmon 3	Muscle	104.7 ± 0.3	2007.94–2009.50	1956.53–2009.53	-20.6	11.4	16.7
Arctic char	Collagen	104.8 ± 0.5	1956.70–2009.52	1956.53–2009.52	-24.1	5.8	9.2
Brown trout	Collagen	105.0 ± 0.5	2007.39–2009.52	1956.55–2009.52	-23.1	7.0	9.2

Table 2 displays stable isotopic and calibrated  $^{14}\text{C}$  data for the fish sampled, demonstrating that all  $^{14}\text{C}$  dates are consistent with modern samples—both the freshwater species and the Atlantic salmon. Calibrated dates were calculated from  $^{14}\text{C}$  pMC values using the  $^{14}\text{C}$  CALIBomb software (Reimer and Reimer 2004). At 95.4% probability, the collagen samples are clearly modern.

Salmon are a migratory fish species, spending some time in marine systems and traveling upriver to spawn. The amount of time these salmon had spent in the river was not known. Due to the difference in turnover rates between bone and muscle tissue, the effect of migration on the  $^{14}\text{C}$  values of these fish could be investigated. There was, however, no reservoir effect noticed in any of the tissues. This was surprising considering the potential migration of these species into marine waters, where there is a known reservoir effect. There appears to be some difference in terms of the  $\delta^{34}\text{S}$  values between salmon tissues, which could be explained by differing turnover rates. Salmon muscle  $\delta^{13}\text{C}$  values were depleted relative to bone collagen whereas  $\delta^{15}\text{N}$  muscle values were enriched.  $\delta^{34}\text{S}$  values were more variable between tissues. Arctic char and brown trout are landlocked freshwater species in this area, and treated as their own group in the FRUITS modeling. The salmon samples also form their own group.

## DISCUSSION

### Defining Marine $\Delta\text{R}$ Values

$\Delta\text{R}$  values for both the North Norwegian Sea and the Bothnian Sea were calculated.  $\Delta\text{R}$  values represent regional offsets from the global average surface water marine reservoir effect, the  $\Delta\text{R}$  of this average being  $\Delta\text{R} = 0$  (Russell et al. 2011). Table 3 presents the marine samples used to calculate the  $\Delta\text{R}$  values for the North Norwegian Sea and the Bothnian Sea. Note the low  $\Delta\text{R}$  value that is calculated for the Bothnian Sea, which is due to the number of freshwater rivers emptying into the north of the Baltic Sea. In fact, the  $\Delta\text{R}$  value for the northernmost part of the Baltic, the Gulf of Bothnia, is likely to be even lower, considering the correlation between salinity and reservoir age (Lougheed et al. 2013), but there is currently no data available on this.

### Dietary Modeling

To investigate the diet of the Rounala individuals, FRUITS 3.0 modeling software (Fernandes et al. 2014) was employed. This required the isotopic characterization of various food groups which were likely to have contributed to the diet of the Rounala individuals. From historical sources, it is known that fish were an important dietary input, also for the people in Rounala (Nickul 1977:3, 10, 15, 32; Ruong 1982:22–26; Fjellström 1985:22–44; Korpjaakko-Labba 1994:81–86, 91–93; Bergman and Ramqvist 2017). In northern Scandinavia there are many



Table 3 Summary of marine samples and  $\Delta R$  values for the Bothnian Sea and North Norwegian Sea. Weighted mean  $\Delta R$  values and uncertainties calculated using the Calib Marine Reservoir Correction tool.

Source	Species	Collection year	Coordinates	$^{14}\text{C}$ age BP	$\Delta R$	Publication
Bothnian Sea	<i>Macoma balthica</i>	1934	63°25'N,20°47'E	265 ± 50	-192 ± 55	Lougheed et al. 2013
	<i>Macoma balthica</i>	1934	63°04'N,20°50'E	275 ± 45	-187 ± 51	Lougheed et al. 2013
					Weighted mean $\Delta R$	-189 ± 4
North Norwegian Sea	<i>Balaenoptera borealis</i>	1894	70°38'N,22°00'E	479 ± 20	-3 ± 20	Mangerud et al. 2006
	<i>Balaenoptera borealis</i>	1879	70°38'N,22°00'E	527 ± 50	51 ± 50	Mangerud et al. 2006
	<i>Mytilus edulis</i>	1922	70°16'N,23°24'E	546 ± 57	96 ± 57	Mangerud 1972
	<i>Chlamys islandica</i>	1857	69°39'N,18°18'E	548 ± 37	65 ± 37	Mangerud and Gulliksen 1975
						Weighted mean $\Delta R$

Table 4 Summary of average  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ , and  $\delta^{34}\text{S}$  values with standard deviations of faunal groups, see Appendix 3 for individual samples (Barrett et al. 2011; Nehlich et al. 2013). Baltic fish values calculated from Enhus et al. (2011) and Linderholm et al. (2008), see main text.

Faunal group	Number of samples	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{34}\text{S}$ (‰)
Reindeer	14	-20.0 ± 1.3	3.1 ± 1.1	10.3 ± 1.6
Freshwater fish	5	-21.4 ± 1.7	6.4 ± 0.6	8.8 ± 0.4
Baltic fish	18	-19.6 ± 1.7	11.6 ± 2.0	12.1 ± 1.1
Atlantic salmon	3	-16.9 ± 1.0	11.6 ± 1.3	18.0 ± 0.5
Atlantic cod	51	-14.6 ± 0.9	14.2 ± 0.7	15.9 ± 0.7

lakes and large rivers from which freshwater fish would have been caught. Because Rounala is positioned between the North Norwegian Sea (100 km) and the north Baltic Sea (330 km), fish from both marine water bodies also need to be considered as a food source. Reindeer too were considered as a potentially important dietary resource. Each dietary group was defined by their  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ , and  $\delta^{34}\text{S}$  values, respectively, and the proportions of three different aquatic resources were calculated by this model (Table 4, Appendix 3). The  $\delta^{13}\text{C}$  measurements for modern collagen samples were adjusted for the Suess effect by adding 1.5‰ (Keeling 1979). FRUITS models were both non-routed and concentration independent.

Few studies using stable isotope data from the North Baltic are published. In order to isotopically define the Baltic fish food group, published seal data was considered. Enhus et al. (2011) measured the  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of bone collagen from one harbour seal, eight grey seal and eight ringed seal. In total, these 17 individual seals from the North Baltic yielded  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of



$-18.1 \pm 1.6$  and  $15.6 \pm 1.7$  respectively. These values were adjusted to represent the Baltic fish consumed by the seals, by subtracting  $1.5\text{‰}$  from the  $\delta^{13}\text{C}$  value and  $4\text{‰}$  from the  $\delta^{15}\text{N}$  value to correct for the trophic-level shift (the application of different fractionation offsets between  $3\text{‰}$  and  $6\text{‰}$  for  $\delta^{15}\text{N}$  made no substantial difference). For each Baltic fish isotopic value, the root sum squared of the associated fractionation offsets and the standard deviation of each isotopic value was taken to be the uncertainty. A  $\delta^{34}\text{S}$  value of  $12.6\text{‰}$  was measured from a seal sample that was recovered from Björned, Torsåker parish, Ångermanland (Linderholm et al. 2008), from which we subtracted  $0.5\text{‰}$ , and assumed a standard deviation to equal  $1\text{‰}$ . These uncertainties can be seen in Table 4.

Isotopic values for relevant dietary groups (Table 4) were placed into FRUITS models (Fernandes et al. 2014). The models assumed fractionation offsets of  $+1.5 \pm 0.5\text{‰}$  for  $\delta^{13}\text{C}$  values,  $+4 \pm 1\text{‰}$  for  $\delta^{15}\text{N}$  values and  $+0.5 \pm 0.5\text{‰}$  for  $\delta^{34}\text{S}$  values between the collagen of the food source and consumer. For each human sample, uncertainties of  $0.15\text{‰}$  were applied to carbon and nitrogen measurements and  $0.2\text{‰}$  for sulfur measurements, in line with instrumentation error. No dietary priors were applied to the models. The purpose of these models were to estimate the dietary input of aquatic sources which carry with them a  $^{14}\text{C}$  reservoir effect.

### OxCal Modeling

Two OxCal 4.3 models (Bronk Ramsey 2009) were prepared as part of the recalibration of the Rounala individuals, one “mixed marine-reservoirs” model and one “Baltic reservoir” model. Based on the  $^{14}\text{C}$  dates of modern freshwater fish and salmon, no reservoir effect from freshwater fish or from Atlantic salmon (or from reindeer) is considered. Both OxCal models required separate dietary analysis to assess marine protein contributions.

The first OxCal model, “mixed marine-reservoirs,” assumed dietary inputs from reindeer, freshwater, Atlantic cod and Baltic fish food groups. Because each human was found to consume different amounts of Baltic and Atlantic resources, respectively, and because samples from these two environments carry different  $\Delta R$  values, each human sample was assigned a unique  $\Delta R$  value. These unique  $\Delta R$  values were averages of the Baltic and Atlantic  $\Delta R$  values, weighted according to the mean Atlantic and Baltic dietary inputs of each individual, as calculated by the FRUITS model. The errors associated with the Baltic and Atlantic  $\Delta R$  values were propagated to 36.2, and this value was set as the uncertainty for each consumer’s unique  $\Delta R$  values. The data was calibrated against the IntCal13 and Marine13 curves (Reimer et al. 2013). The total marine dietary input for each individual was calculated by combining their Baltic and Atlantic mean marine input estimates. The total marine dietary input uncertainty was taken to be the root sum squared of the Baltic and Atlantic mean estimates. The data used to construct this model have been summarized in Table 5.

The second OxCal model, “Baltic reservoir,” considered some historical information concerning the dietary practices of these individuals. On historical grounds, it is known that salmon were particularly important to the Sámi living in the north of Scandinavia; salmon fishing was practiced widely along several rivers (Kent 2014:240–246). For the people in Rounala, the river of Storfjordselva, characterized as a good salmon carrying river, was particularly important (Korpijaakko-Labba 1994:91f; Guttormsen 2005:431, 417). As such, reindeer, freshwater fish, Baltic fish, and Atlantic salmon were considered as part of a FRUITS model, whereas Atlantic cod was excluded. Because no reservoir effect could be measured in the salmon sampled in this study, this OxCal model considered only Baltic  $\Delta R$  values and Baltic marine dietary estimates

Table 5 Summary for information entered into the “mixed marine-reservoirs” OxCal model.

Rounala consumer	<sup>14</sup> C age (BP)	Marine dietary inputs (%)						Weighted $\Delta R$
		Baltic fish	$\pm$	Atlantic cod	$\pm$	Total marine	$\pm$	
1	580 $\pm$ 85	19.8	13.0	12.9	7.7	32.7	15.1	-107.8
3	429 $\pm$ 30	23.4	15.7	9.1	6.5	32.5	17.0	-131.2
4	414 $\pm$ 30	31.4	19.6	25.1	11.7	56.5	22.8	-97.5
5	492 $\pm$ 30	22.3	14.2	7.3	5.5	29.5	15.2	-138.2
6	670 $\pm$ 65	26.9	17.2	14.9	9.2	41.8	19.5	-115.5
7	371 $\pm$ 31	26.2	17.2	16.3	8.9	42.6	19.3	-109.9
8	527 $\pm$ 30	14.5	11.7	4.9	4.5	19.4	12.6	-136.8
9	460 $\pm$ 30	31.0	18.4	11.8	7.9	42.8	20.0	-132.2
10	515 $\pm$ 85	26.1	17.9	12.0	8.1	38.1	19.7	-124.3
11	451 $\pm$ 30	23.0	16.2	13.6	8.3	36.5	18.2	-112.5
12	395 $\pm$ 100	22.7	16.7	15.6	8.6	38.4	18.8	-105.1
13	513 $\pm$ 30	19.7	14.3	10.3	6.9	30.0	15.8	-118.4
14	407 $\pm$ 30	19.8	14.9	11.6	7.1	31.4	16.5	-112.9
16	270 $\pm$ 30	20.9	14.2	11.6	7.3	32.5	16.0	-115.7
18	337 $\pm$ 30	20.3	14.1	15.2	7.9	35.4	16.1	-100.8
20	552 $\pm$ 30	33.9	18.5	7.8	6.1	41.7	19.5	-150.4
21	287 $\pm$ 30	23.1	15.8	18.2	9.3	41.3	18.4	-98.1
L17a	457 $\pm$ 32	48.3	21.2	4.8	5.2	53.1	21.8	-170.2
L17b	550 $\pm$ 32	15.2	12.9	6.7	5.4	22.0	14.0	-126.0

and calibrated samples against IntCal13 and Marine13 curves (Reimer et al. 2013) (Table 6). This assumes that the only reservoir effect acting on the Rounala consumers would come from the Baltic.

Some prior information concerning the church and the graveyard’s use was included in both OxCal models. It is known on historical grounds that the church was used less frequently by 1643 (Lidén et al. in press). The church building itself was sold in 1796 and dismantled (Wiklund 1916:12). Based on this, a maximum calendar date for the buried individuals of 1800 AD was used, which gives some room for error. The model would not accept age estimates for samples which fell after this date. No earliest date was set.

The probability distributions of the Rounala consumers as calculated by both OxCal models are displayed in Figure 4. The distribution plots represent a range of possible ages. The range takes into account any uncertainties included in the OxCal model. Here, uncertainties associated with  $\Delta R$  values, marine dietary contribution and calibration curves have led to some broad probability distributions, even at 68.2% probability. The differences between the two OxCal models are minor. In general, the model which assumed only salmon constituted the Atlantic dietary contribution (the “Baltic reservoir” model), yielded slightly older mean estimates. The two models, however, share a similar pattern. The amount of Atlantic salmon consumed by the Rounala individuals, relative to Atlantic cod consumed, cannot be estimated with any reasonable certainty. Given the overlap of the two calibration models, this should not affect the calibration of their <sup>14</sup>C dates. Dashed lines at 1559 AD and 1800 AD represent the earliest possible founding of the church and the latest possible abandonment of the church, respectively, based on historical records. The distribution plots, relative to the estimates of the

Table 6 Summary for information entered into the “Baltic reservoir” OxCal model, assuming a  $\Delta R$  value of  $-189 \pm 4$ .

Consumer	$^{14}\text{C}$ age (BP)	Dietary contribution (%)	
		Baltic	$\pm$
1	580 $\pm$ 85	22.2	14.3
3	429 $\pm$ 30	26.6	15.4
4	414 $\pm$ 30	45.1	19.4
5	492 $\pm$ 30	27.2	16.9
6	670 $\pm$ 65	28.7	16.1
7	371 $\pm$ 31	27.0	16.5
8	527 $\pm$ 30	16.1	14.7
9	460 $\pm$ 30	43.3	17.1
10	515 $\pm$ 85	26.8	14.2
11	451 $\pm$ 30	20.3	12.9
12	395 $\pm$ 100	24.5	15.0
13	513 $\pm$ 30	25.1	15.7
14	407 $\pm$ 30	18.7	13.4
16	270 $\pm$ 30	17.9	13.6
18	337 $\pm$ 30	29.7	17.7
20	552 $\pm$ 30	41.4	15.8
21	287 $\pm$ 30	28.0	17.7
L17a	457 $\pm$ 32	57.5	19.5
L17b	550 $\pm$ 32	14.5	11.3

church’s founding, indicate that it is likely that many individuals (to varying degrees of certainty) were interred in the cemetery before 1559 AD. It must be noted, however, that the events being dated are the formations of the bone tissues sampled rather than the date of death. In some individuals, part of the tissue may have formed up to 20 years prior to their burial, depending on their age at death. Given this, the date of some of the individual’s burial events may have been slightly overestimated (their true burial dates being more recent than estimated). This is likely to be the case for all adult individuals (excluding the subadult individuals 16, 18, 20, and 21). From the available evidence presented here and considering all uncertainties, however, the site of the cemetery was most likely in use for a time prior to the church’s founding, as well as after its alleged abandonment. Calibrated without prior date constraints, samples 16 and 21 yield later dates, closer to present, especially for the mixed marine model. Knowing their archaeological contexts, this demonstrates the importance of the inclusion of the date constraint.

## CONCLUSION

Despite historical records on the building and abandonment of the church at Rounala, the relationship between the cemetery and the church had yet to be investigated fully. The timing of the burial of these individuals is important for wider discussions concerning the religious practices of these individuals as well as the Christianization of the Sámi in this region. It was demonstrated, by measuring the  $^{14}\text{C}$  values of modern freshwater fish from the region, that there does not appear to be a freshwater reservoir effect in the bodies of water investigated; this was an important point to illustrate. From the available evidence presented here and considering all uncertainties, the site of the cemetery was most likely in use for a time prior to the church’s earliest possible founding, possibly as early as the 14th century, but also after its

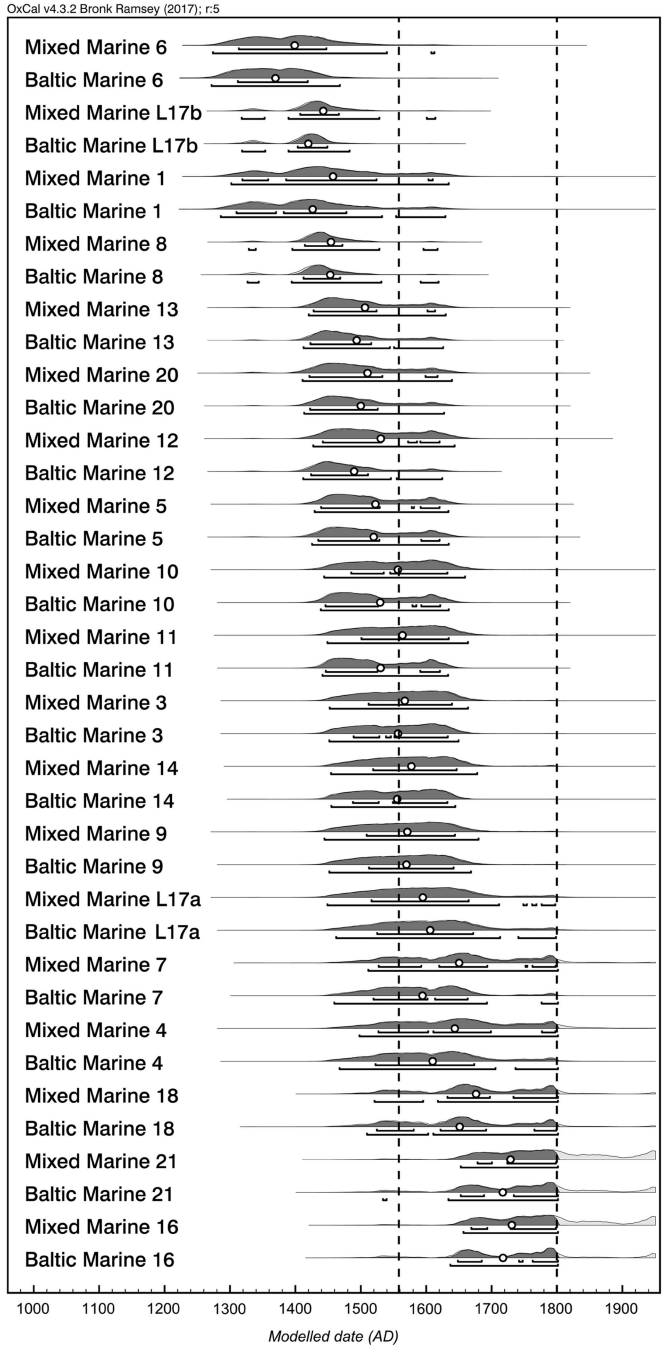


Figure 4 OxCal plot displaying the 68.2% and 95.4% probability distributions and mean age estimates (marked with a circle) of both models for Rounala samples. Dashed lines at 1559 AD and 1800 AD represent the earliest possible founding and the latest possible abandonment of the church, respectively, based on historical records. The model would not accept age estimates for samples which fell after 1800 (see main text).

alleged abandonment. The majority of the sampled individuals, however, appear to have been buried throughout the graveyard's use as a church site.

## ACKNOWLEDGMENTS

This project has received funding from the European Union's EU Framework Programme for Research and Innovation Horizon 2020 under Marie Curie Actions Grant Agreement No. 676154. This research has benefited from several useful discussions with Prof. Peter Jordan (The Arctic Centre, University of Groningen). Thanks go to Geoffrey Metz at the Museum Gustavianum in Uppsala, Leena Drenzel at the Swedish History Museum in Stockholm, Kjell-Åke Aronsson at Äjtte – the Swedish Mountain and Sami Museum in Jokkmokk, to the Nordic Museum in Stockholm, for access to the skeletal material, Anna Kjellström for making the osteological analysis of the human material, to Charlotte Damm for the Atlantic salmon, and to Heike Siegmund at SIL for running the EA-IRMS. Some of the stable isotope data formed part of MF's master's thesis (Fjellström 2011).

## SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit <https://doi.org/10.1017/RDC.2018.78>

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**APPENDIX 1. LAB CODES AND <sup>14</sup>C AGES REPORTED FOR ROUNALA HUMAN SAMPLES.**

Rounala human	Lab code	<sup>14</sup> C age BP	±
1	LuA-5023	580	85
3	Ua-39943	429	30
4	Ua-40582	414	30
5	Ua-40581	492	30
6	LuA-5041	595	90
6	LuA-5144	750	95
7	Ua-39944	371	31
8	Ua-39941	527	30
9	Ua-39945	460	30
10	LuA-5040	515	85
10	Ua-42006	467	30
11	Ua-40584	451	30
12	LuA-5039	395	100
12	Ua-42005	523	30
13	Ua-40585	513	30
14	Ua-40583	407	30
16	Ua-39947	270	30
L17a	Ua-48690	457	32
L17b	Ua-48691	550	32
18	Ua-39942	337	30
20	Ua-39946	552	30
21	Ua-39948	287	30

**APPENDIX 2. THE  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$  AND  $\delta^{34}\text{S}$  VALUES AND COLLAGEN QUALITY INDICATORS FOR THE ROUNALA HUMANS AND ANALYZED REINDEER AND FISH. SAMPLES AND  $\delta^{13}\text{C}$  VALUES MARKED WITH AN (\*) HAVE BEEN ADJUSTED FOR THE SUESS EFFECT ( $\delta^{13}\text{C} + 1.5\text{‰}$ ).**

Lab code	Species/individual	Site	Skeletal element	Collagen yield (%)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{34}\text{S}$ (‰)	%C	%N	%S	C: N	C: S	N: S
ROU3A	<i>Homo sapiens</i> 1	Rounala	Cranium	7.0	-17.9	11.3	10.7	43.5	15.7	0.19	3.2	611	189
ROU12A	<i>Homo sapiens</i> 3	Rounala	Cranium	6.3	-18.5	12.5	10.0	43.2	15.4	0.21	3.3	548	167
ROU5A	<i>Homo sapiens</i> 4	Rounala	Cranium	7.0	-17.1	14.0	12.0	42.0	15.4	0.22	3.2	513	160
ROU8A	<i>Homo sapiens</i> 5	Rounala	Cranium	5.1	-18.1	12.7	9.3	43.6	15.8	0.21	3.2	553	172
ROU4A	<i>Homo sapiens</i> 6	Rounala	Cranium	3.6	-18.4	12.3	11.5	40.3	14.0	0.22	3.4	488	146
ROU13A	<i>Homo sapiens</i> 7	Rounala	Cranium	3.4	-18.0	12.3	11.7	42.3	15.3	0.23	3.2	491	152
ROU10A	<i>Homo sapiens</i> 8	Rounala	Cranium	5.7	-18.4	11.9	8.5	42.6	15.6	0.21	3.2	540	170
ROU14A	<i>Homo sapiens</i> 9	Rounala	Cranium	3.2	-18.0	13.6	10.4	43.2	15.8	0.25	3.2	461	144
ROU7A	<i>Homo sapiens</i> 10	Rounala	Cranium	4.3	-17.9	12.6	10.3	43.3	15.8	0.22	3.2	524	164
ROU2A	<i>Homo sapiens</i> 11	Rounala	Cranium	5.5	-17.5	11.8	10.6	43.4	15.7	0.22	3.2	526	163
ROU6A	<i>Homo sapiens</i> 12	Rounala	Cranium	2.4	-17.7	11.6	11.2	42.2	15.5	0.24	3.2	469	148
ROU1A	<i>Homo sapiens</i> 13	Rounala	Cranium	5.1	-18.0	12.0	10.0	44.0	15.8	0.22	3.2	533	164
ROU9A	<i>Homo sapiens</i> 14	Rounala	Cranium	5.8	-18.5	10.5	11.3	43.5	15.9	0.2	3.2	579	181
ROU16A	<i>Homo sapiens</i> 16	Rounala	Cranium	3.2	-18.7	10.2	11.9	42.6	15.5	0.22	3.2	516	161
ROU11A	<i>Homo sapiens</i> 18	Rounala	Cranium	3.2	-18.2	11.7	11.3	43.7	15.8	0.23	3.2	506	157
ROU15A	<i>Homo sapiens</i> 20	Rounala	Cranium	3.0	-18.1	14.2	9.5	43.3	16.0	0.23	3.2	503	159
ROU17A	<i>Homo sapiens</i> 21	Rounala	Cranium	4.6	-18.0	11.8	12.0	43.2	15.8	0.21	3.2	549	172
ROU18	<i>Homo sapiens</i> L17a	Rounala	Humerus	4.5	-17.2	14.8	7.7	35.2	12.8	0.13	3.2	723	225
ROU19	<i>Homo sapiens</i> L17b	Rounala	Humerus	6.0	-18.3	10.9	9.3	41.1	15.2	0.14	3.2	782	248
KÖN 1*	<i>Rangifer tarandus</i>	Könkämä siida	Mandibula	8.6	-18.5*	2.2	10.7	44.9	16.5	0.27	3.2	444	140
KÖN 2*	<i>Rangifer tarandus</i>	Könkämä siida	Mandibula	9.1	-18.9*	2.1	9.3	43.4	15.0	0.30	3.4	446	132
KÖN 3*	<i>Rangifer tarandus</i>	Könkämä siida	Mandibula	10.5	-19.5*	3.4	10.4	47.0	15.6	0.27	3.5	464	132
KÖN 4*	<i>Rangifer tarandus</i>	Könkämä siida	Mandibula	12.2	-19.0*	3.0	11.5	45.6	16.0	0.25	3.3	487	146
KÖN 5*	<i>Rangifer tarandus</i>	Könkämä siida	Mandibula	9.8	-18.8*	2.4	10.1	44.9	15.7	0.28	3.3	428	128
LEP 1	<i>Rangifer tarandus</i>	Leppäkoski hytta	Ulna	9.1	-19.8	3.1	8.6	42.5	15.3	0.20	3.2	567	175
LEP 2	<i>Rangifer tarandus</i>	Leppäkoski hytta	Vertebra	3.2	-20.2	2.3	12.8	41.3	15.0	0.19	3.2	580	181
LEP 3	<i>Rangifer tarandus</i>		Scapula	10.1	-19.5	2.8	7.9	42.0	15.3	0.20	3.2	561	175

APPENDIX 2. *Continued*

Lab code	Species/individual	Site	Skeletal element	Collagen yield (%)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{34}\text{S}$ (‰)	%C	%N	%S	C: N	C: S	N: S
		Leppäkoski hytta											
NMS 6	<i>Rangifer tarandus</i>	Vallevare	Mandibula	3.6	-19.1	2.3	—	41.0	14.4	—	3.3	—	—
NMS 10	<i>Rangifer tarandus</i>	Unna Paddus	Mandibula	4.1	-21.9	5.9	—	41.4	14.5	—	3.3	—	—
NMS 11	<i>Rangifer tarandus</i>	Unna Paddus	Mandibula	1.3	-21.9	4.7	—	34.8	11.7	—	3.5	—	—
NMS 12	<i>Rangifer tarandus</i>	Unna Paddus	Mandibula	3.5	-21.6	3.2	—	42.0	14.9	—	3.3	—	—
NMS 13	<i>Rangifer tarandus</i>	Unna Paddus	Mandibula	4.3	-21.7	4.3	—	41.1	14.7	—	3.3	—	—
RAU 7	<i>Rangifer tarandus</i>	Rautasjaure	Tibia	3.5	-18.9	2.0	11.6	35.1	13.3	0.23	3.1	408	132
FB1*	<i>Salmo salar</i>	Målselva	vertebra	3.7	-16.7*	12.4	18.3	41.8	13.8	1.07	3.5	104	29
FB2*	<i>Salmo salar</i>	Målselva	vertebra	5.9	-16.1*	12.3	17.4	49.0	16.8	1.00	3.4	131	38
FB3*	<i>Salmo salar</i>	Målselva	vertebra	3.0	-18.0*	10.1	18.2	42.0	13.3	1.25	3.7	89	24
FM1*	<i>Salmo salar</i>	Målselva	Muscle	—	-18.4*	13.7	18.4	48.7	15.5	1.14	3.7	114	31
FM2*	<i>Salmo salar</i>	Målselva	Muscle	—	-18.3*	13.7	18.4	48.6	15.4	1.21	3.7	107	29
FM3*	<i>Salmo salar</i>	Målselva	Muscle	—	-19.1*	11.4	16.7	48.8	15.6	1.24	3.7	105	29
REB 5*	<i>Salmo trutta</i>	Riebnesjaure	vertebra	6.3	-21.6	7.0	9.2	44.9	17.2	0.50	3.1	240	79
REB 1*	<i>Salvelinus alpinus</i>	Riebnesjaure	vertebra	2.3	—	—	8.7	—	—	0.53	—	—	—
REB 2*	<i>Salvelinus alpinus</i>	Riebnesjaure	vertebra	3.9	-22.5	6.0	8.9	43.9	16.8	0.51	3.1	230	75
REB 3*	<i>Salvelinus alpinus</i>	Riebnesjaure	vertebra	8.5	-22.6	5.8	9.2	44.9	16.7	0.51	3.1	235	75
LAI 2*	<i>Salvelinus alpinus</i>	Laisälven	vertebra	8.4	-19.0	6.9	8.2	44.8	17.0	0.51	3.1	235	76

**APPENDIX 3. THE  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$  AND  $\delta^{34}\text{S}$  VALUES OF FAUNAL SAMPLES USED FOR FRUITS MODELING. SAMPLES MARKED WITH AN (\*) HAVE  $\delta^{13}\text{C}$  VALUES ADJUSTED FOR THE SUESS EFFECT.**

Species	Common name	Site	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{34}\text{S}$ (‰)	Publication
Atlantic cod						
<i>Gadus morhua</i>	Atlantic cod	Helgøygården	-16.0	13.9	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Helgøygården	-15.5	12.8	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Helgøygården	-12.4	14.4	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Helgøygården	-13.7	14.3	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Helgøygården	-14.6	14.6	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Helgøygården	-13.5	14.4	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Kongshavn	-15.4	13.8	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Kongshavn	-15.3	14.8	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Kongshavn	-14.4	13.8	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Kongshavn	-17.1	13.2	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Kongshavn	-15.9	13.7	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Måsøy	-14.8	13.9	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Måsøy	-14.2	14.1	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Måsøy	-14.7	14.4	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Måsøy	-14.7	14.8	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Måsøy	-13.6	13.8	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Måsøy	-15.3	13.6	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Måsøy	-14.8	13.8	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Måsøy	-15.2	12.6	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Måsøy	-14.7	14.6	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Måsøy	-13.1	14.7	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Skonsvika	-13.7	14.3	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Skonsvika	-14.8	14.2	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Skonsvika	-14.0	15.7	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Skonsvika	-14.4	13.6	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Storvågan	-14.8	13.7	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Storvågan	-15.6	14.2	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Storvågan	-13.9	14.3	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Storvågan	-13.6	15.8	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Vannareid	-14.9	13.9	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Vannareid	-15.4	14.2	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Vannareid	-13.9	15.0	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Vannareid	-13.8	15.3	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Vannareid	-15.1	14.0	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Vannareid	-14.4	13.1	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Vannareid	-14.6	14.4	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Vannareid	-15.4	15.6	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Vannareid	-14.7	14.9	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Vannareid	-14.6	14.6	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Vannareid	-13.7	13.4	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Vannareid	-15.0	14.1	—	Barrett et al. 2011
<i>Gadus morhua</i>	Atlantic cod	Alstahaug	—	—	16.5	Nehlich et al. 2013

## APPENDIX 3. Continued

Species	Common name	Site	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{34}\text{S}$ (‰)	Publication
<i>Gadus morhua</i>	Atlantic cod	Alstahaug	—	—	14.6	Nehlich et al. 2013
<i>Gadus morhua</i>	Atlantic cod	Alstahaug	—	—	15.5	Nehlich et al. 2013
<i>Gadus morhua</i>	Atlantic cod	Alstahaug	—	—	16.2	Nehlich et al. 2013
<i>Gadus morhua</i>	Atlantic cod	Alstahaug	—	—	15.3	Nehlich et al. 2013
<i>Gadus morhua</i>	Atlantic cod	Helgøygården	—	—	15.7	Nehlich et al. 2013
<i>Gadus morhua</i>	Atlantic cod	Helgøygården	—	—	15.5	Nehlich et al. 2013
<i>Gadus morhua</i>	Atlantic cod	Helgøygården	—	—	16.4	Nehlich et al. 2013
<i>Gadus morhua</i>	Atlantic cod	Storvågan	—	—	16.0	Nehlich et al. 2013
<i>Gadus morhua</i>	Atlantic cod	Storvågan	—	—	16.9	Nehlich et al. 2013
<b>Reindeer</b>						
<i>Rangifer tarandus</i> *	Reindeer	Könkämä siida	-18.5	2.2	10.7	This study
<i>Rangifer tarandus</i> *	Reindeer	Könkämä siida	-18.9	2.1	9.3	This study
<i>Rangifer tarandus</i> *	Reindeer	Könkämä siida	-19.5	3.4	10.4	This study
<i>Rangifer tarandus</i> *	Reindeer	Könkämä siida	-19.0	3.0	11.5	This study
<i>Rangifer tarandus</i> *	Reindeer	Könkämä siida	-18.8	2.4	10.1	This study
<i>Rangifer tarandus</i>	Reindeer	Leppäkoski hytta	-19.8	3.1	8.6	This study
<i>Rangifer tarandus</i>	Reindeer	Leppäkoski hytta	-20.2	2.3	12.8	This study
<i>Rangifer tarandus</i>	Reindeer	Leppäkoski hytta	-19.5	2.8	7.9	This study
<i>Rangifer tarandus</i>	Reindeer	Rautasjaure	-18.9	2.0	11.6	This study
<i>Rangifer tarandus</i>	Reindeer	Vallevare	-19.1	2.3	—	This study
<i>Rangifer tarandus</i>	Reindeer	Unna Paddus	-21.9	5.9	—	This study
<i>Rangifer tarandus</i>	Reindeer	Unna Paddus	-21.9	4.7	—	This study
<i>Rangifer tarandus</i>	Reindeer	Unna Paddus	-21.6	3.2	—	This study
<i>Rangifer tarandus</i>	Reindeer	Unna Paddus	-21.7	4.3	—	This study
<b>Freshwater fish</b>						
<i>Salvelinus alpinus</i> *	Arctic char	Riebnesjaure	-22.5	6.0	8.9	This study
<i>Salvelinus alpinus</i> *	Arctic char	Riebnesjaure	—	—	8.7	This study
<i>Salvelinus alpinus</i> *	Arctic char	Riebnesjaure	-22.6	5.8	9.2	This study

APPENDIX 3. *Continued*

Species	Common name	Site	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{34}\text{S}$ (‰)	Publication
<i>Salvelinus alpinus</i> *	Arctic char	Laisälven	-19.0	6.9	8.2	This study
<i>Salmo trutta</i> *	Brown trout	Riebnesjaure	-21.6	7.0	9.2	This study
Atlantic salmon						
<i>Salmo salar</i> *	Atlantic salmon	Måselva	-16.7	12.4	18.3	This study
<i>Salmo salar</i> *	Atlantic salmon	Måselva	-16.1	12.3	17.4	This study
<i>Salmo salar</i> *	Atlantic salmon	Måselva	-18.0	10.1	18.2	This study

**APPENDIX 4. OXCAL MODEL CODE**

Plot() { Curve("IntCal13","IntCal13.14c"); Curve("Marine13","Marine13.14c"); Delta_R("LocalMarine",-115.5,36.2);	R_Date("Baltic Marine 1", 580,85)& Date (U(0,1800)); Curve("IntCal13","IntCal13.14c"); Curve("Marine13","Marine13.14c"); Delta_R("LocalMarine",-136.8,36.2);
Mix_Curve("Mixed","IntCal13", "LocalMarine",41.8,19.5); R_Date("Mixed Marine 6", 669, 65) & Date (U(0,1800)); Curve("IntCal13","IntCal13.14c"); Curve("Marine13","Marine13.14c"); Delta_R("LocalMarine",-189,4);	Mix_Curve("Mixed","IntCal13", "LocalMarine",19.4,12.6); R_Date("Mixed Marine 8", 527, 30) & Date (U(0,1800)); Curve("IntCal13","IntCal13.14c"); Curve("Marine13","Marine13.14c"); Delta_R("LocalMarine",-189,4);
Mix_Curve("Mixed","IntCal13", "LocalMarine",28.7,16.1); R_Date("Baltic Marine 6", 670, 65)& Date (U(0,1800)); Curve("IntCal13","IntCal13.14c"); Curve("Marine13","Marine13.14c"); Delta_R("LocalMarine",-126.0,36.2);	Mix_Curve("Mixed","IntCal13", "LocalMarine",16.1,14.7); R_Date("Baltic Marine 8", 527, 30)& Date (U(0,1800)); Curve("IntCal13","IntCal13.14c"); Curve("Marine13","Marine13.14c"); Delta_R("LocalMarine",-118.4,36.2);
Mix_Curve("Mixed","IntCal13", "LocalMarine",22.0,14.0); R_Date("Mixed Marine L17b", 550, 32) & Date(U(0,1800)); Curve("IntCal13","IntCal13.14c"); Curve("Marine13","Marine13.14c"); Delta_R("LocalMarine",-189,4);	Mix_Curve("Mixed","IntCal13", "LocalMarine",30.0,15.8); R_Date("Mixed Marine 13", 513, 30) & Date(U(0,1800)); Curve("IntCal13","IntCal13.14c"); Curve("Marine13","Marine13.14c"); Delta_R("LocalMarine",-189,4);
Mix_Curve("Mixed","IntCal13", "LocalMarine",14.5,11.3); R_Date("Baltic Marine L17b", 550, 32) & Date(U(0,1800)); Curve("IntCal13","IntCal13.14c"); Curve("Marine13","Marine13.14c"); Delta_R("LocalMarine",-107.8,36.2);	Mix_Curve("Mixed","IntCal13", "LocalMarine",25.1,15.7); R_Date("Baltic Marine 13", 513, 30)& Date (U(0,1800)); Curve("IntCal13","IntCal13.14c"); Curve("Marine13","Marine13.14c"); Delta_R("LocalMarine",-150.4,36.2);
Mix_Curve("Mixed","IntCal13", "LocalMarine",32.7,15.1); R_Date("Mixed Marine 1", 580,85) & Date (U(0,1800)); Curve("IntCal13","IntCal13.14c"); Curve("Marine13","Marine13.14c"); Delta_R("LocalMarine",-189,4);	Mix_Curve("Mixed","IntCal13", "LocalMarine",41.7,19.5); R_Date("Mixed Marine 20", 552, 30) & Date(U(0,1800)); Curve("IntCal13","IntCal13.14c"); Curve("Marine13","Marine13.14c"); Delta_R("LocalMarine",-189,4);
Mix_Curve("Mixed","IntCal13", "LocalMarine",22.2,14.3);	Mix_Curve("Mixed","IntCal13", "LocalMarine",41.1,15.8);



R_Date("Baltic Marine 20", 552, 30) & Date (U(0,1800)); Curve("IntCal13", "IntCal13.14c"); Curve("Marine13", "Marine13.14c"); Delta_R("LocalMarine", -105.1, 36.2);	R_Date("Baltic Marine 10", 472, 28) & Date (U(0,1800)); Curve("IntCal13", "IntCal13.14c"); Curve("Marine13", "Marine13.14c"); Delta_R("LocalMarine", -112.5, 36.2);
Mix_Curve("Mixed", "IntCal13", "LocalMarine", 38.4, 18.8); R_Date("Mixed Marine 12", 513, 29) & Date (U(0,1800)); Curve("IntCal13", "IntCal13.14c"); Curve("Marine13", "Marine13.14c"); Delta_R("LocalMarine", -189, 4);	Mix_Curve("Mixed", "IntCal13", "LocalMarine", 36.5, 18.2); R_Date("Mixed Marine 11", 451, 30) & Date (U(0,1800)); Curve("IntCal13", "IntCal13.14c"); Curve("Marine13", "Marine13.14c"); Delta_R("LocalMarine", -189, 4);
Mix_Curve("Mixed", "IntCal13", "LocalMarine", 24.5, 15.0); R_Date("Baltic Marine 12", 513, 29) & Date (U(0,1800)); Curve("IntCal13", "IntCal13.14c"); Curve("Marine13", "Marine13.14c"); Delta_R("LocalMarine", -138.2, 36.2);	Mix_Curve("Mixed", "IntCal13", "LocalMarine", 20.3, 12.9); R_Date("Baltic Marine 11", 451, 30) & Date (U(0,1800)); Curve("IntCal13", "IntCal13.14c"); Curve("Marine13", "Marine13.14c"); Delta_R("LocalMarine", -131.2, 36.2);
Mix_Curve("Mixed", "IntCal13", "LocalMarine", 29.5, 15.2); R_Date("Mixed Marine 5", 492, 30) & Date (U(0,1800)); Curve("IntCal13", "IntCal13.14c"); Curve("Marine13", "Marine13.14c"); Delta_R("LocalMarine", -189, 4);	Mix_Curve("Mixed", "IntCal13", "LocalMarine", 32.5, 17.0); R_Date("Mixed Marine 3", 429, 30) & Date (U(0,1800)); Curve("IntCal13", "IntCal13.14c"); Curve("Marine13", "Marine13.14c"); Delta_R("LocalMarine", -189, 4);
Mix_Curve("Mixed", "IntCal13", "LocalMarine", 27.2, 16.9); R_Date("Baltic Marine 5", 492, 30) & Date (U(0,1800)); Curve("IntCal13", "IntCal13.14c"); Curve("Marine13", "Marine13.14c"); Delta_R("LocalMarine", -124.3, 36.2);	Mix_Curve("Mixed", "IntCal13", "LocalMarine", 26.6, 15.4); R_Date("Baltic Marine 3", 429, 30) & Date (U(0,1800)); Curve("IntCal13", "IntCal13.14c"); Curve("Marine13", "Marine13.14c"); Delta_R("LocalMarine", -112.9, 36.2);
Mix_Curve("Mixed", "IntCal13", "LocalMarine", 38.1, 19.7); R_Date("Mixed Marine 10", 472, 28) & Date (U(0,1800)); Curve("IntCal13", "IntCal13.14c"); Curve("Marine13", "Marine13.14c"); Delta_R("LocalMarine", -189, 4);	Mix_Curve("Mixed", "IntCal13", "LocalMarine", 31.4, 16.5); R_Date("Mixed Marine 14", 407, 30) & Date (U(0,1800)); Curve("IntCal13", "IntCal13.14c"); Curve("Marine13", "Marine13.14c"); Delta_R("LocalMarine", -189, 4);
Mix_Curve("Mixed", "IntCal13", "LocalMarine", 26.8, 14.2);	Mix_Curve("Mixed", "IntCal13", "LocalMarine", 18.7, 13.4);

- R\_Date("Baltic Marine 14", 407, 30) & Date  
(U(0,1800));  
Curve("IntCal13", "IntCal13.14c");  
Curve("Marine13", "Marine13.14c");  
Delta\_R("LocalMarine", -132.2, 36.2);
- Mix\_Curve("Mixed", "IntCal13",  
"LocalMarine", 42.8, 20.0);  
R\_Date("Mixed Marine 9", 460, 30) & Date  
(U(0,1800));  
Curve("IntCal13", "IntCal13.14c");  
Curve("Marine13", "Marine13.14c");  
Delta\_R("LocalMarine", -189, 4);
- Mix\_Curve("Mixed", "IntCal13",  
"LocalMarine", 43.3, 17.1);  
R\_Date("Baltic Marine 9", 460, 30) & Date  
(U(0,1800));  
Curve("IntCal13", "IntCal13.14c");  
Curve("Marine13", "Marine13.14c");  
Delta\_R("LocalMarine", -170.2, 36.2);
- Mix\_Curve("Mixed", "IntCal13",  
"LocalMarine", 53.1, 21.8);  
R\_Date("Mixed Marine L17a", 457, 32) &  
Date(U(0,1800));  
Curve("IntCal13", "IntCal13.14c");  
Curve("Marine13", "Marine13.14c");  
Delta\_R("LocalMarine", -189, 4);
- Mix\_Curve("Mixed", "IntCal13",  
"LocalMarine", 57.5, 19.5);  
R\_Date("Baltic Marine L17a", 457, 32) &  
Date(U(0,1800));  
Curve("IntCal13", "IntCal13.14c");  
Curve("Marine13", "Marine13.14c");  
Delta\_R("LocalMarine", -109.9, 36.2);
- Mix\_Curve("Mixed", "IntCal13",  
"LocalMarine", 42.6, 19.3);  
R\_Date("Mixed Marine 7", 371, 31) & Date  
(U(0,1800));  
Curve("IntCal13", "IntCal13.14c");  
Curve("Marine13", "Marine13.14c");  
Delta\_R("LocalMarine", -189, 4);
- Mix\_Curve("Mixed", "IntCal13",  
"LocalMarine", 27.0, 16.5);  
R\_Date("Baltic Marine 7", 371, 31) & Date  
(U(0,1800));  
Curve("IntCal13", "IntCal13.14c");  
Curve("Marine13", "Marine13.14c");  
Delta\_R("LocalMarine", -97.5, 36.2);
- Mix\_Curve("Mixed",  
"IntCal13",  
"LocalMarine", 56.5, 22.8);  
R\_Date("Mixed Marine 4", 414, 30) & Date  
(U(0,1800));  
Curve("IntCal13", "IntCal13.14c");  
Curve("Marine13", "Marine13.14c");  
Delta\_R("LocalMarine", -189, 4);
- Mix\_Curve("Mixed", "IntCal13",  
"LocalMarine", 45.1, 19.4);  
R\_Date("Baltic Marine 4", 414, 30) & Date  
(U(0,1800));  
Curve("IntCal13", "IntCal13.14c");  
Curve("Marine13", "Marine13.14c");  
Delta\_R("LocalMarine", -100.8, 36.2);
- Mix\_Curve("Mixed", "IntCal13",  
"LocalMarine", 35.4, 16.1);  
R\_Date("Mixed Marine 18", 337, 30) &  
Date(U(0,1800));  
Curve("IntCal13", "IntCal13.14c");  
Curve("Marine13", "Marine13.14c");  
Delta\_R("LocalMarine", -189, 4);
- Mix\_Curve("Mixed", "IntCal13",  
"LocalMarine", 29.7, 17.7);  
R\_Date("Baltic Marine 18", 337, 30) & Date  
(U(0,1800));  
Curve("IntCal13", "IntCal13.14c");  
Curve("Marine13", "Marine13.14c");  
Delta\_R("LocalMarine", -98.1, 36.2);
- Mix\_Curve("Mixed", "IntCal13",  
"LocalMarine", 41.3, 18.4);  
R\_Date("Mixed Marine 21", 287, 30) &  
Date(U(0,1800));  
Curve("IntCal13", "IntCal13.14c");  
Curve("Marine13", "Marine13.14c");  
Delta\_R("LocalMarine", -189, 4);
- Mix\_Curve("Mixed", "IntCal13",  
"LocalMarine", 28.0, 17.7);  
R\_Date("Baltic Marine 21", 287, 30) & Date  
(U(0,1800));  
Curve("IntCal13", "IntCal13.14c");

```
Curve("Marine13","Marine13.14c");  
Delta_R("LocalMarine",-115.7,36.2);
```

```
Mix_Curve("Mixed","IntCal13",  
"LocalMarine",32.5,16.0);  
R_Date("Mixed Marine 16", 270, 30) &  
Date(U(0,1800));  
Curve("IntCal13","IntCal13.14c");
```

```
Curve("Marine13","Marine13.14c");  
Delta_R("LocalMarine",-189,4);
```

```
Mix_Curve("Mixed","IntCal13",  
"LocalMarine",17.9,13.6);  
R_Date("Baltic Marine 16", 270, 30)& Date  
(U(0,1800));  
};
```