

Reindeer retrieved from melting snow patches reveal information on prehistoric landscape use in Swedish Sápmi

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Abstract: In this study we discuss the remains of reindeer skeletal elements found at two different snow patches at Varánjunnje and Gárránistjåhkká situated in the National Park of Stuor Muorkke in northern Sweden. Unfortunately, glaciers and snow patches are melting; however, this offers a unique opportunity to study the use of mountainous landscape in the past. The purpose of this study was to compare modern, historical and archaeological finds from reindeer in different reindeer herding areas in Swedish Sápmi. By using radiocarbon dating and osteological and stable isotope analysis ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$) we aim to study reindeer mobility and land use in the past. The results from the morphometric data, stable isotope analysis and radiocarbon dating from prehistoric and historic reindeer (n=40) show that there is very little variation over time in the diet of the reindeer retrieved from the snow patches. We also found that these reindeer must have grazed in different geographic areas. There was no correlation between age, gender, pathological changes and diet, and the castrated reindeer did not differ from other reindeer.

Key words: Glacial archaeology, snow patches, domesticated reindeer, wild reindeer, radiocarbon, stable isotope analysis, osteology, reindeer herding districts.

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Introduction

With global warming and climate change glaciers and snow patches in the Swedish mountains are melting and with this, archaeological and environmental objects in the snow are starting to deteriorate (Callanan, 2016; Hollensen *et al.*, 2018). However, the objects exposed due to melting snow provides opportunities for a deepened understanding of the past use of the mountain landscapes (Hollensen *et al.*, 2018:575). Regular surveys of glaciers and perennial snow patches in Norway have

revealed a whole set of unique artefacts which have shed new light upon historic and prehistoric use of passages in the south Norwegian mountainous landscape (Finstad & Vedeler, 2008; Vedeler & Bender Jørgensen, 2013; Callanan, 2016:29; Bjørgo *et al.*, 2015; Rosvold, 2016; Pilø & Solli, 2017; Pilø, 2018; Rosvold *et al.*, 2019; Pilø *et al.*, 2020). Early surveys in the Swedish mountains have also revealed finds of organic materials such as ecofacts and artefacts (Lundholm, 1976; Karlén & Danton,

1976; Öberg & Kullman, 2011; Sandén, 2017; Aronsson, 2020). This suggests that it is important to perform regular surveys of melting glaciers, snow patches and ice sheets also in Sweden (Fjellström, 2018; 2019; 2020; Fjellström *et al.*, 2019; Lidén, 2020).

In the summer of 2016, a total of 21 faunal skeletal elements (Tables 1, 2 & 4) were collected in two areas with permanent snow patches, Varánjunnje and Gárránistjáhkka in the National Park of Stuor Muorkke (*Stora Sjöfallet*, Swe) in the Lule River Valley, Norrbotten County (Fig. 1). The reindeer (*Rangifer tarandus* spp.) skeletal remains were found between two pasture areas within today's reindeer herding district of Unna tjerusj. The national park Stuor Muorkke is part of the Laponia World Heritage in Swedish Lapland and has a varied natural and geological setting with high

alpine areas, glaciers, tundra, birch forests and old pine forests (Forsberg, 1985; Mulk, 1994). Archaeological features in this area, such as pitfalls, cooking pits and dwellings of a Stone Age nature, as well as prehistoric and historic hearths, hearth row-systems, different Sámi dwelling sites and hut constructions (*goatbe*, Sa, singularis) argue for an early human presence in the area (Mulk, 1982; Forsberg, 1985:34–59; Aronsson & Ljungdahl, 2008; Aronsson & Israelsson, 2008; Länsstyrelsen, 2010). Dwelling sites, such as stalló foundations are found at sites such as north of Vákkudavárre (Laponiatjuottjudus, Anna Rimpí, 2020) (Fig. 1) and are generally dated to the Late Iron Age and Early Middle Ages (Liedgren *et al.*, 2007). They also provide information about the long use and human presence in these high alpine areas.

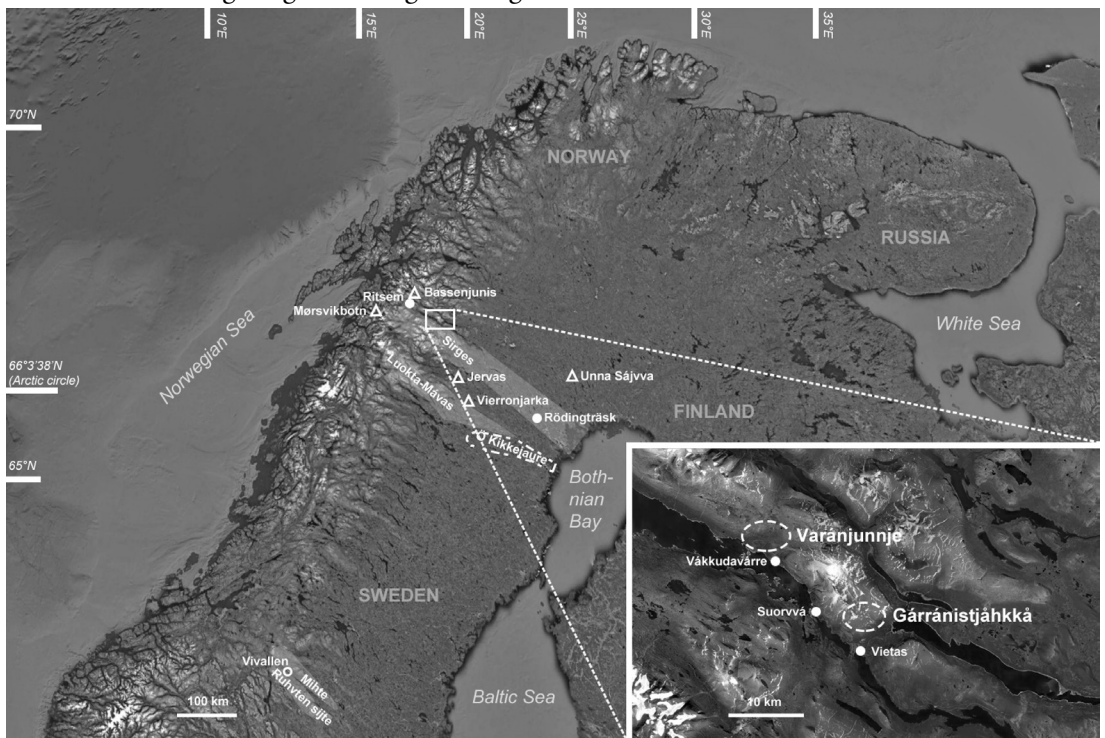


Figure 1. Map of northern Fennoscandia with the archaeological sites mentioned in the study and the modern Sami reindeer herding districts marked. The zoomed-in map shows the location of the two snow patches mentioned in the study. The map has been remodelled by the authors. The background map was a screenshot from © 2022 Google Earth, Map data: Google, DigitalGlobe.

Today there are no wild reindeer left in Swedish Sápmi. According to Ekman (1910:11–15), the wild reindeer in the areas of western Arjeplog and Gällivare parishes, as well as Kvikkjokk, had probably disappeared already by the second half of the 18th century, suggesting that reindeer pre-dating this period in this area could be both wild and domesticated. The find of an iron arrow at Ippátjähkkå, close to Suorvá (Fig. 1), dated to the late Iron Age, suggests that wild reindeer hunting was practiced at this time. Similar finds of arrows have been made near snow patches and glaciers, as well as from at least one Stállu foundation, in other parts of Swedish Sápmi (Lundholm, 1979; Liedgren, 2003:5; Aronsson, 2020:190).

The reindeer skeletal remains in this study were sampled within an area of several taxation lands (*lappskatteländ*, Sw.) which Pirkavärj was part of. A taxation land was an area that was provided and used by an individual or a group of people from the mid-17th to the beginning of the 20th centuries (Hultblad, 1968:81). The Sámi paid an annual tax to the state using a limited land area, which also was inherited (i.e. Hansen and Olsen 2014:280). Pirkavärj was a taxation land within the Kaitum reindeer herding district (Sköld, 1992:2). It was situated in the Lule River Valley, that was and still is an important passage for reindeer and also important for reindeer herders. According to Sköld (1992:69), the Sámi from Pirkavärj also dwelled on the Norwegian side of the border. By the rocky promontory of the mountain Bierká at the Norwegian border (Sköld, 1992:70), are two well-known Sámi offering sites with finds of reindeer. They are situated both north and south of Bierká on the shores of lake Siidasjärvi: Hæsta-gal'lo (Manker, 1957:143, 153) and Bassenjunis (1458–1635 cal CE, Salmi *et al.*, 2018:479). Finds of reindeer skeletal remains at Sámi offering sites, as well as arrow heads connected to wild reindeer hunting supports the idea of human-reindeer related activities

in high mountain areas. According to Salmi *et al.* (2015) the offering of animals at the offering site of Unna Saiva predates the offerings of metal objects, but that the number of offered reindeer at Unna Saiva increased from the late 13th century. Further, this reflects an economic and societal transition within the Sámi society (Salmi *et al.*, 2018).

Based on the taxation of fish and reindeer, Peter Sköld (1992:125) argues that the Sámi in the reindeer herding district of Sirges probably took on reindeer domestication in its extensive form during the 17th century. In connection to that he also argues that wild reindeer hunt must have been more important during the 16th century. According to Hultblad (1968:141), reindeer herding among the Forest Sámi herding districts becomes more important as fishing decreases in importance from around the mid-18th century, and is explained by climatic variation (Hultblad, 1968:141). Mulk (1994:30) argues that the Sirges *sijdda* had its winter settlement (*dálvvdádis*, Sa) by the lake *Stuor Julevo* (SaL.) where there was a good access to resources regarding hunting and fishing. The summer camp was situated in the mountains along the wild reindeer migration routes and with good fishing (Mulk, 1994:30). Taxation and domestication probably had an effect on reindeer mobility, in that they were kept in more local herds.

In order to study the effect of domestication on reindeer mobility and land use in this area, we have analysed skeletal remains of reindeer found at the snow patches Varánjunnje and Gárránistjähkkå north of Vietas in Gällivare parish, Sápmi (Fig. 1), using radiocarbon dating, as well as osteological and stable isotope analysis ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$).

Reindeer diet, hunting, husbandry, and domestication

The reindeer is a herbivore and a intermediate ruminant grazer with a varied diet consisting of

more than 250 different plant species. Its winter diet, from October to April/May, is mostly composed of lichen, and when abundant, lichens can constitute more than 80% of the food (Heggberget *et al.*, 2002:15; Inga, 2008; Ophof *et al.*, 2013; Goudeau, 2019:25). The reindeer also feed on various shrubs, herbs and grasses that are richer in proteins (Klein, 1990; Mårell, 2006:7; Morris *et al.*, 2018). Based on the winter diet, Danell *et al.* (1994) demonstrated from a feeding experiment that reindeer seemed to prefer specific lichens and plants. The tree lichens are important in winter when snow covers other resources that can be hard to reach. In spring, summer and autumn, but also when available in winter, reindeer feed on tussock cotton grass (*Eriophorum vaginatum*), lingonberry shrubs (*Vaccinium vitis-idaea*), wavy hair-grass (*Deschampsia flexuosa*), mushrooms and many more plants (Kuoljok & Blind, 2015:26–29).

The diet of wild reindeer does not differ from that of domesticated reindeer, unless the domesticated reindeer has been fed. The high consumption of lichens, which have a higher carbon and lower nitrogen isotope values (Evans, 2007:85; Britton, 2010; Salmi *et al.*, 2020a; Fjellström *et al.*, 2020), make reindeer stand out in stable isotope values compared to other herbivores. However, deviating isotope values in reindeer can also be due to different physiological or biochemical factors, such as starvation or climate change (Nieminen & Pitilä, 1999; Drucker *et al.*, 2003, 2012; Parker *et al.*, 2005; Barboza & Parker, 2006).

Today, there are no wild reindeer in the studied area. The last wild reindeer from the area studied is said to have disappeared by the end of the 18th century (Ekman, 1910:8, 12; Lundmark, 1982:164). Although the reindeer today are not hunted in the studied area, this was a common practice in prehistoric and historic times (Forsberg, 1985; Hansen & Olsen, 2014). Rock carvings of reindeer and fence

systems in Alta, Norway, dating to the Stone Age (Helskog, 2012), bear witness of an early human-reindeer relationship, the wild reindeer hunt. Archaeological pitfall systems, various trapping sites and wooden scare sticks are further examples of a well organised wild reindeer hunt in the past (Hedman, 2013; Solli, 2016; Seitsonen & Viljanmaa, 2021).

Exactly when reindeer domestication and husbandry took place is highly debated. Besides the fact that there might be regional differences in the reindeer domestication process in northern Fennoscandia, either due to a rearrangement of social structures (Bergman *et al.*, 2013), an increased privatisation of resources (Hedman 2003:223–224) or religious practices (Salmi *et al.*, 2015); some scholars argue for a Late Iron Age/early medieval domestication process (Aronsson, 1991; Hedman, 2003; Bergman *et al.*, 2008; Andersen, 2011). Whereas, others argue for a domestication process that started in the High Middle Ages (Arell, 1977; Vorren, 1980; Lundmark, 1982; Mulk, 1994; Wallerström, 2000; Sommerseth, 2009; Hansen & Olsen, 2006; Karlsson, 2006; Røed *et al.*, 2011; Bjørnstad *et al.*, 2012). It seems that small-scale reindeer herding combined with hunting, fishing, and gathering was practiced from the Late Iron Age onwards, whereas the transition to mobile pastoralism with larger reindeer herds occurred (at least regionally) in the High Middle Ages (Seitsonen & Viljanmaa, 2021; Salmi, 2022).

Ancient DNA studies on reindeer skeletal remains from northern Fennoscandia demonstrate that there was a massive genetic replacement in reindeer during the 16th and 17th centuries, that coincided with the onset of reindeer pastoralism (Røed *et al.*, 2018:285; see also Røed *et al.*, 2021). The modern domesticated reindeer have genetic affiliations with reindeer from two different areas: a north Russian/north American genetic cluster originating from the Beringia refugium and a north European ge-

netic cluster originating from the European refugium (Røed *et al.*, 2011; Weldenogodguad *et al.*, 2019). There is little doubt that the domesticated reindeer were used for different practices: clothing, transport of raw materials (Bromé, 1923:146–164) and the use of skin for the construction of huts (*gáhte*, Sa). However, already during the Late Iron Age, reindeer were kept for transport (*i.e.* castrated males), as decoys to hunt wild reindeer and for possible milking (Eidlitz, 1972; Ingold, 1986; Sommerseth, 2009; Bjørklund, 2013:181; Hansen & Olsen, 2014:195).

Mountain, forest and south Sámi reindeer herding districts

In this study we collected reindeer skeletal elements dating from the 1940s to the 1960s, which is a time period before there was any substantial industrial feeding of the reindeer. These modern reindeer are from six different Sámi reindeer herding districts (Fig. 1). According to Berit Inga (2008), there are two types of reindeer herding today in Sweden: mountain and forest reindeer herding. The forest type is when the reindeer stay in the boreal forests all year round, and the mountain type is when the reindeer are in the mountains in the summer and the boreal forests in winter. Nevertheless, both herding systems depend on the reindeer moving between different areas in search of good pasture (Inga, 2008:8). Sámi in the northern Mountain reindeer herding districts in Sweden move their reindeer over large areas, from the mountains to the boreal forests, sometimes all the way to the coast. The Mountain Sámi further south in Härjedalen however move their reindeer in smaller areas, but still from the mountains to the boreal forests. The Forest Sámi move their reindeer in forest areas with good pastures, more or less in the same ecological zone, between winter and summer (Hedman, 2003; Andersen, 2011).

Mountain Sámi reindeer herding districts in northern Sweden—Sirges and Luokta-Mavás

The largest reindeer herding district in Sweden, Sirges (13,485 km²), has its year-round-area in Jokkmokk municipality in Norrbotten County (Fig. 1). The winter pasture for Sirges stretches from the boreal forest to the coast of the Bothnian Bay.

The other northern Mountain Sámi reindeer herding district is Luokta-Mavás (6,318 km²) (Fig. 1). Its year-round-area is situated in Arjeplog municipality in Norrbotten County, and they have their winter pastures stretching from the inland to the coast encompassing Jokkmokk, Arvidsjaur, Älvsbyn and Piteå municipalities. Luokta-Mavás can be traced back to the 16th century, in the late 17th century Luochta Sámi village is mentioned together with Norrvästerbyn and Sörvästerbyn (Luokta-Mavás Sameby 2007:6).

Forest Sámi reindeer herding districts—Östra Kikkejaure and Udtjá (Rödingträsk, Dábmukjávrrre)

Östra Kikkejaure is a Forest Sámi reindeer herding district with an area of 4,539 km² with its year-round area in Arvidsjaur municipality in Norrbotten County (Fig. 1). The winter pastures are situated close to the Swedish coast.

Rödingträsk (*Dábmukjávrrre*, Sa) in Överluleå parish is part of the Forest Sámi reindeer herding district of Udtjá (Fig. 1). However, Rödingträsk is a free-standing group (Manker 1950:199; Statens offentliga utredningar 1966:26). Reindeer from Rödingträsk are interesting as they are the largest reindeer in this study (Manker, 1950:199), however; little is known about their historic background (Utsi, 2007:95). In contrast to the Mountain Sámi reindeer herding districts, the forest Sámi herding districts of Rödingträsk and Östra Kikkejaure cover smaller areas, mostly in the woodlands and the Bothnian coast.

Mountain Sámi reindeer herding districts in middle Sweden-Ruhvten sijte and Mihte

Ruhvten sijte (SaS) is a Mountain Sámi reindeer herding district in a South Sámi area in Jämtland County (Fig. 1). The Sámi in Ruhvten sijte have their year-round-area (3,920 km²) in Härjedalen municipality and the winter pastures are situated in Härjedalen and Älvdalen municipalities (Ljungdahl, 2013). Today the reindeer pastures are situated in the Swedish part of Sápmi; however, earlier, the reindeer also used to graze in Norway.

In 1912, the Åre-Storsjö *lappby* was divided into several Sámi herding districts, among them were Mittådalen, Skärvagsdalen and Ljungris Sámi reindeer herding districts. The name Mittådalen (*Mihte*, SaS.) refers to the valley of Mittån. The Sámi of the Mihte reindeer herding district have their year-round-area (4,345 km²) in Härjedalen municipality (Fig. 1). During the winter the reindeer graze both in Härjedalen and Berg municipalities. Just as for Luokta-Mavás and Ruhvten sijte, the oldest written records of reindeer husbandry for the area dates back to the 17th century. However, the name might be even older than that (Ljungdahl, 2011). Both these reindeer herding districts are considered to belong to a Mountain Sámi economy, but compared to the Northern Mountain Sámi reindeer herding districts they cover smaller areas.

Material and methods

Twenty-one bone elements of reindeer were selected from a set of reindeer skeletal remains collected from different snow patches from two adjacent areas (Fig. 1), nine skeletal elements from Varánjunnje, north of Vákkudavárre, and 12 from Gárránistjáhkka north of Vietas (Fig. 1, Table 1). Eleven elements were selected for further stable isotope analysis and radiocarbon dating. In order to study the diet and mobility patterns of these reindeer, we compared them to a modern reindeer skeleton collection

from Ájtte, the Swedish Mountain and Sámi Museum in Jokkmokk, dated to between 1947 and 1956. The reindeer skeletal remains were collected by Folke Skuncke in the mid-1900s. The collection holds more than 1,000 domesticated reindeer crania, antlers and mandibles of known origins from Swedish Sápmi. All ages and sex are represented (Göran Sjögren, Ájtte, personal communication; Skuncke, 1973:11). Thirty individuals from six different Sámi reindeer herding districts representing different geographical areas in Swedish Sápmi with different herding practices were also included in this study as comparative material. The reindeer came from two northern Mountain (Sirges and Luokta-Mavás), two Forest (Rödingträsk and Östra Kikkejaure) and two South (Ruhvten sijte and Mihte) Sámi reindeer herding districts. Geographically, the reindeer from Sirges are the one that corresponds most closely to the location of the snow patch reindeer (Table 1).

Osteological analysis

The faunal material from the permanent ice patches were osteologically analysed to determine size, sex, age of death and to look for pathological traits. The modern collection from Ájtte was also osteologically analysed. The age estimation was based on epiphyseal fusion following Takken Beijersbergen & Hufthammer (2012). Skeletal measurements were taken for body size estimation (von den Driesch 1976). The bones were checked for pathological lesions following Mann and Hunt (2005), Bartosiewicz and Gál (2013), Thomas and Worley (2014) and Salmi et al. (2020b).

Stable isotope analysis and bone collagen extraction

In order to not sample the same individual twice we selected our samples according to the minimum number of individuals identified (Table 2).

Stable isotope analyses, $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$,

Table 1. Osteological information on the age, sex, and skeletal elements of the modern reindeer in this study.

Sample	Age at death (year)	Sex	Skeletal elements present	Other
SIR1	2.25	M	Cranium	
SIR2	4	M	Cranium	
SIR3	9	F	Cranium	
SIR4	5	F	Cranium	
SIR5	10.5	F	Cranium	
RÖD1	2.5	M	Cranium	
RÖD2	4.5	F	Cranium	
RÖD3	6	M	Cranium	
RÖD4	3	F	Cranium	
RÖD5	6	M	Cranium	Castrated
ÖKI1	3	M	Cranium	
ÖKI2	4	M	Cranium	
ÖKI3	2	F	Cranium	
ÖKI4	4	F	Cranium	
ÖKI5	4	F	Cranium	
TÄS1	2	M	Cranium	
TÄS2	4	M	Cranium	
TÄS3	2	F	Cranium	
TÄS4	6	F	Cranium	
TÄS5	8	F	Cranium	
LMA1	2	M	Cranium	
LMA2	5	M	Metatarsal and metacarpal	
LMA3	1	F	Cranium	
LMA4	5	F(?)	Metatarsal and phalanges	
LMA5	5	M	Metatarsal, centrotarsal bone, metacarpal	Castrated
MIÄ1	2	M	Mandibles	
MIÄ2	5	M	Cranium	
MIÄ3	2	F	Cranium	
MIÄ4	2	F	Cranium	
MIÄ5	-	M	Cranium	Castrated

are frequently used in archaeology to study both human and animal diet and mobility (Eriksson, 2013). The $\delta^{13}\text{C}$ isotope value is determined by the photosynthetic pathway that different plants use, or by the dissolved carbonate in marine environments (Sealy, 2001:270). The most common photosynthetic pathway in

our region is C3, and since there are no historic signs of feeding reindeer with C4-plants, the latter photosynthetic pathway can be disregarded. For each trophic level, $\delta^{13}\text{C}$ values increase by c. 1‰ (DeNiro & Epstein, 1978). The $\delta^{15}\text{N}$ isotope value varies depending on a number of different factors: the trophic level, physiology,

stress, climate and environment (Ambrose, 1990; DeNiro & Epstein, 1978; O'Connell & Hedges, 1999). For each trophic level the $\delta^{15}\text{N}$ isotope value increases by c. 3–5‰ (Bocherens & Drucker 2003; Minagawa & Wada, 1984). The $\delta^{34}\text{S}$ isotope value vary depending on the local geology of the bedrock, as well as between different terrestrial and marine environments (Richards *et al.*, 2003; Krouse, 1980:436; Faure & Mensing, 2005). In coastal areas, the $\delta^{34}\text{S}$ isotope value of an individual feeding solely from terrestrial plants can be affected by the so-called sea-spray effect that can alter the $\delta^{34}\text{S}$ isotope value towards a more marine value (Nehlich, 2015). Trophic level shifts in $\delta^{34}\text{S}$ are still heavily debated, however, Nehlich (2015) suggested a trophic shift in the fauna around $0.5 \pm 2.4\text{‰}$. Webb *et al.* (2017), on the other hand argues for a depleted value of $-1.5 \pm 0.8\text{‰}$ for each trophic level.

Collagen was extracted from the bones and antlers of both archaeological and modern reindeer using the modified Longin method (Brown *et al.*, 1988). An amount of 0.4–0.6 mg of collagen for carbon and nitrogen isotope analysis, and between 5.6 and 8.5 mg for sulphur isotope analysis were weighed in tin capsules and measured in a massspectrometer. We also used 1.0–2.9 mg for radiocarbon dating. Carbon and nitrogen isotopes were analysed at the Department for Geological Sciences at Stockholm University, combusted in a Carlo-Erba NC2500 elemental analyser connected to a massspectrometer (continuous flow IRMS)—a Finnigan DeltaV Advantage—with a precision of $\pm 0.15\text{‰}$ or better for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. Later, for the modern reindeer samples that had a C:N ratio outside of the accepted ratio (2.7–3.6) and in order to correct for a possible effect of lipid residue, we extracted lipids using a solution of DCM/Methanol (2:1) (Guiry *et al.*, 2016) and then analysed them at the Massspectrometry Laboratory at Vilnius University, using a Flash EA 1112 Series EL-

emental Analyzer that was connected to a Delta V Advantage Isotope Ratio Mass Spectrometer (IRMS) via a ConFlo III Interface with a precision of $\pm 0.1\text{‰}$ for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. Isotope ratio data was normalised to international isotope scale using IAEA standards: IAEA caffeine ($\delta^{13}\text{C} = -27.771$, $\delta^{15}\text{N} = 1$), USGS24 ($\delta^{13}\text{C} = -16.05$), IAEA-N-1 ($\delta^{15}\text{N} = 0.43$). Sulphur isotopes were analysed at Iso-Analytical using a Sercon CNS-EA Elemental Analyser Auto-Sampler linked to a Europa Scientific 20-20 Isotope Ratio Mass Spectrometer with a precision of 0.3‰ . Inhouse standards IA-R068 and IA-R069 were used and calibrated against NBS-127 and IAEA-SO-5. All stable isotope values are expressed in per mille (‰).

Result

Osteology

In total, 21 reindeer fragments were identified to element from the two snow patches (Table 1), *scapula* (n=2), *metatarsal* (n=2), *metacarpal* (n=1), *metapodial* (n=1), *tibia* (n=2), *pars petrosa* (n=1), *femur* (n=1), *radius* (n=1), long bone shaft (n=5) and antlers (n=5). The minimum number of individuals from Varánjunnje was two, based on two metatarsals bones of considerably different sizes. The minimum number of individuals from Gárránistjähkkå was also two, based on the presence of bones of a small, possibly juvenile individual(s) (shaft fragments from a tibia and a femur), and the bones of an adult-sized individual(s) (*scapula* and *radius* fragments). The epiphyses of the latter bone elements were fused, indicating an age at death of at least 2–6 months and at least 4–10 months, respectively (Takken Beijersbergen & Hufthammer, 2012). Due to the fragmentation of the bones from Gárránistjähkkå, measurements were only obtained from one sample, a *scapula* fragment. No pathological lesions were identified on the bones (Table 2). Of the 21 samples 11 were selected for radiocarbon and stable isotope analyses (Table 2).

Additional cranial elements were measured on 30 modern domesticated reindeer from different Mountain and Forest Sámi reindeer herding districts (Table 1). The age at death and sex of the individuals were known and recorded in the museum catalogue. No pathologies were recorded on the bones (Table 3). Although the cranial measurements of the reindeer from Forest Sámi villages were slightly larger on average, the difference was not statistically significant (Table 3).

Radiocarbon analysis

The samples from the snow patches were radiocarbon dated at the Ångström laboratory, Uppsala University. One sample dated to the Roman Iron Age/Migration Period (259–414 cal CE), one sample to the Migration Period (412–541 cal CE), five samples were dated to between 1482 and 1948 cal CE and four were modern (Table 4).

Stable isotope analysis

All samples but one, ICE 11 from Gárránistjåhkkå, gave collagen of good quality (van Klinken, 1999) and fulfilled the quality criteria (DeNiro, 1985; Ambrose, 1990; Nehlich & Richards, 2009).

The $\delta^{13}\text{C}$ values for the archaeological and historical reindeer varied from -20.0‰ to -18.3‰ with a mean value and standard deviation of $-19.1 \pm 0.6\text{‰}$. The $\delta^{15}\text{N}$ values for the same individuals varied between from 1.5‰ to 3.5‰ with a mean value and standard deviation of $2.5 \pm 0.8\text{‰}$ (Fig. 2). The low $\delta^{15}\text{N}$ values reflect the expected dietary intake for reindeer, $<3.0\text{‰}$, see for example Salmi et al. (2020) and Fjellström et al. (2020). According to Finstad and Kielland (2011:543, 548–550), the $\delta^{15}\text{N}$ value of collagen in antlers correlates with that of the value of the diet from spring until the ossification. They also showed that $\delta^{15}\text{N}$ values of lichen are depleted, sometime even negative.

One sample from Varánjunnje did not yield

enough collagen for further $\delta^{34}\text{S}$ analysis (ICE 5) and one sample from Gárránistjåhkkå (ICE 11) did not fulfil the quality criteria. The nine individuals from Varánjunnje and Gárránistjåhkkå had $\delta^{34}\text{S}$ values between 8.3‰ and 10.8‰ and a mean value and standard deviation of $9.7 \pm 1.1\text{‰}$ (Figs. 3 and 4, Table 4). All modern samples yielded enough collagen for further analysis. For the modern samples that did not fulfill the C:N ratio criteria we took new samples and extracted collagen and removed lipids prior to stable isotope analysis (Table 5). All samples subjected to lipid residue removal, except seven samples (SIR 2–4, ÖKI 1 and 2, MIÅ 5 and TÄS 1), met the expected quality criteria, providing evidence that the lipids caused the erroneous C:N ratio for pure collagen. We could also see that the lipids only effected the samples where the C:N ratio was >3.8 (Table 5). Furthermore, as a fossil fuel effect must be considered for the $\delta^{13}\text{C}$ values of the modern reindeer, all modern samples were corrected for a fossil fuel effect according to the known year of collection and the isotopic value of that years atmospheric CO_2 . The atmospheric CO_2 isotopic value between 1947 and 1956, the year of collection of the different reindeer, do not vary much (from -6.89‰ to -6.92‰) (Francey et al., 1999; Long et al., 2005; Keeling et al., 2017); hence, the correction value we added to the modern samples are 0.22‰ (1948) and c. 0.23‰ (1953/1956), respectively. Also, we applied a correction of c. 1.7‰ to the modern reindeer from Canada and Alaska. In addition, since we do not know the exact date of the modern samples from Varánjunnje at the Gállaktjåhkkå we assume they date to the approximately the same time as when they were collected, i.e. 2016. We thus applied a correction of 1.89‰ to these samples (Graven et al., 2020) (see Salmi et al., 2020a for more details).

Two samples, ICE 1 and 3, that have elevated $\delta^{15}\text{N}$ isotope values ($> 3\text{‰}$), have similar $\delta^{15}\text{N}$ isotope values as the reindeer from the of-

fering sites in Unna Sájjvva and Vierronjarka, as well as the modern reindeer from the Forest reindeer herding areas. The isotope, osteological and the radiocarbon results for ICE 1 and 3 are very similar and suggest that these two elements might originate from the same individual and will be regarded as such from here on (ICE 1/3). Five other samples, ICE 4, 6, 8, 9 and 10, all have similar $\delta^{15}\text{N}$ values to the

reindeer from the modern Mountain reindeer herding districts. However, ICE 4, dated to 1482–1644 cal CE, with similar $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotope values as the reindeer from the offering site of Bassenjunis, has a lower $\delta^{13}\text{C}$ isotope value compared to ICE 6 and 10 (259–541 cal CE) (Fig. 2–4).

ICE 1 and 10 have similar $\delta^{34}\text{S}$ isotope values as the reindeer from the offering sites in

Table 2. Osteological analysis and observations of the reindeer skeletal remains found at the snow patches in this study.

Sample	Area	Bone element	Side	Bone part	Other observations
ICE1	1	Scapula	Left	prox	
	1	Metatarsal		shaft	Small individual
	1	Metacarpal		shaft	Small individual
ICE2	1	Metatarsal	Right	prox	Anterior fragment
ICE3	1	Tibia	Left	shaft	Small individual
ICE5	1	Temporal		pars petrosus	
ICE4	1	Antler	Right	prox	Shed
	1	Long bone		shaft fragment	
	1	Long bone	shaft fragment		
	2	Scapula	Left	complete	Blade broken, epiphysis fused, GLP=42.7, BG=29.4
ICE8	2	Femur	Right	shaft	Small individual
ICE10	2	Radius	Left	prox	Fused epiphysis
	2	Metapodial		shaft	
ICE9	2	Tibia	Right	shaft	Small individual
	2	Antler		prox	
ICE7	2	Antler		prox	Shed
ICE6	2	Antler		prox?	
	2	Antler			
ICE11	2	Long bone			
	2	Long bone			
	2	Long bone			

Table 3. T-test of the osteological measurements regarding the modern reindeer from the mountain and forest reindeer herding districts.

	Mean Mountain Sámi	Mean Forest Sámi	t	p
Total length of cranium	311.2 (n=15)	329.7 (n=9)	-2.027	0.055
Greatest breadth across orbits	147.7 (n=15)	153.0 (n=10)	-1.523	0.142
Molar row length	51.1 (n=11)	53.3 (n=10)	-1.649	0.116

Table 4. Results from the $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ analysis, as well as the radiocarbon dates (^{14}C) of the reindeer samples in this study. The crossed out samples did not fulfil the quality criteria for well-preserved collagen. There is also information on the mean values of the archaeological reindeer and the modern reindeer, their standard deviations (SD), lowest (MIN) and highest values (MAX). * = $\delta^{13}\text{C}$ values of the snow patch reindeer corrected with 1.89‰ for fossil fuel effects. ** = $\delta^{13}\text{C}$ values corrected for the modern reindeer corrected with 0.22‰ (1948) and 0.23‰ (1953/1956) (see description of stable isotope analysis for further details).[†] To be continued

Sample #	Site or Sámi reindeer herding district	Municipality, Landscape	Area	Coordinates (WGS 84)	asl (m)	Coordinates	Inventory #	Gender	Age (year)
ICE 1	Varánjunne	Gällivare, Lappland	Area 1: Snow patch on Varánjunne, Gällaktrjåkka massif	N67390; E18031	1055	N67390; E18031	ind. 1	-	Young
ICE 2*	Varánjunne	Gällivare, Lappland	Area 1: Snow patch on Varánjunne, Gällaktrjåkka massif	N67390; E18031	1055	N67390; E18031	ind. 2	-	Adult
ICE 3	Varánjunne	Gällivare, Lappland	Area 1: Snow patch on Varánjunne, Gällaktrjåkka massif	N67390; E18031	1055	N67390; E18031	ind. 1	-	Young
ICE 4	Varánjunne	Gällivare, Lappland	Area 1: Snow patch on Varánjunne, Gällaktrjåkka massif	N67390; E18031	1055	N67390; E18031	ind. 8	-	-
ICE 5*	Varánjunne	Gällivare, Lappland	Area 1: Snow patch on Varánjunne, Gällaktrjåkka massif	N67390; E18031	1055	N67390; E18031	ind. 9	-	-
ICE 6	Gárránisjáhkká	Gällivare, Lappland	Area 2: Snow patches, eastern side of Gárránisjáhkká, N of Vieras	N67313; E18205	1170	N67313; E18205	ind. 3	-	-
ICE 7*	Gárránisjáhkká	Gällivare, Lappland	Area 2: Snow patches, eastern side of Gárránisjáhkká, N of Vieras	N67313; E18205	1170	N67313; E18205	ind. 4	-	-
ICE 8	Gárránisjáhkká	Gällivare, Lappland	Area 2: Snow patches, eastern side of Gárránisjáhkká, N of Vieras	N67313; E18205	1170	N67313; E18205	ind. 5	-	Young
ICE 9	Gárránisjáhkká	Gällivare, Lappland	Area 2: Snow patches, eastern side of Gárránisjáhkká, N of Vieras	N67313; E18205	1170	N67313; E18205	ind. 7	-	-
ICE 10	Gárránisjáhkká	Gällivare, Lappland	Area 2: Snow patches, eastern side of Gárránisjáhkká, N of Vieras	N67313; E18205	1170	N67313; E18205	ind. 6	-	Adult
ICE 11*	Gárránisjáhkká	Gällivare, Lappland	Area 2: Snow patches, eastern side of Gárránisjáhkká, N of Vieras	N67313; E18205	1170	N67313; E18205	-	-	-
SIR 1**	Sirges	Jokkmokk, Lappland	Mountain Sámi	-	-	-	AJN 4632	male	2.25
SIR 2**	Sirges	Jokkmokk, Lappland	Mountain Sámi	-	-	-	AJN 4665	male	4
SIR 3**	Sirges	Jokkmokk, Lappland	Mountain Sámi	-	-	-	AJN 4634	female	9
SIR 4**	Sirges	Jokkmokk, Lappland	Mountain Sámi	-	-	-	AJN 4636	female	5
SIR 5**	Sirges	Jokkmokk, Lappland	Mountain Sámi	-	-	-	AJN 4651	female	10.5
LMA 1**	Luokta-Mavás	Arjeplog, Lappland	Mountain Sámi	-	-	-	AJN 4753	male	2
LMA 2**	Luokta-Mavás	Arjeplog, Lappland	Mountain Sámi	-	-	-	AJN 4309	male	5
LMA 3**	Luokta-Mavás	Arjeplog, Lappland	Mountain Sámi	-	-	-	AJN 4290	female	1
LMA 4**	Luokta-Mavás	Arjeplog, Lappland	Mountain Sámi	-	-	-	AJN 4757	female (?)	5
LMA 5**	Luokta-Mavás	Arjeplog, Lappland	Mountain Sámi	-	-	-	AJN 4299	castrated	5
RÖD 1**	Udja	Boden, Norrbotten	Forest Sámi	-	-	-	AJN 4701	male	2.5
RÖD 2**	Udja	Boden, Norrbotten	Forest Sámi	-	-	-	AJN 4699	female	4.5
RÖD 3**	Udja	Boden, Norrbotten	Forest Sámi	-	-	-	AJN 4711	male	6
RÖD 4**	Udja	Boden, Norrbotten	Forest Sámi	-	-	-	AJN 4186	female	3
RÖD 5**	Udja	Boden, Norrbotten	Forest Sámi	-	-	-	AJN 4739	castrated	6

Table 4. Results from the $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ analysis, as well as the radiocarbon dates (^{14}C) of the reindeer samples in this study. The crossed out samples did not fulfil the quality criteria for well-preserved collagen. There is also information on the mean values of the archaeological reindeer and the modern reindeer, their standard deviations (SD), lowest (MIN) and highest values (MAX). * = $\delta^{13}\text{C}$ values of the snow patch reindeer corrected with 1.89‰ for fossil fuel effects. ** = $\delta^{13}\text{C}$ values corrected for the modern reindeer with 0.22‰ (1948) and 0.23‰ (1953/1956) (see description of stable isotope analysis for further details). Continued

Sample #	Site or Sámi reindeer herding district	Municipality, Landscape	Area	Coordinates (WGS 84)	asl (m)	Coordinates	Inventory #	Gender	Age (year)
ÖKI 1**	Östra Kikkejaur	Arvidsjaur, Lappland	Forest Sámi	-	-	-	AJN 4346	male	3
ÖKI 2**	Östra Kikkejaur	Arvidsjaur, Lappland	Forest Sámi	-	-	-	AJN 4344	male	4
ÖKI 3**	Östra Kikkejaur	Arvidsjaur, Lappland	Forest Sámi	-	-	-	AJN 4348	female	2
ÖKI 4**	Östra Kikkejaur	Arvidsjaur, Lappland	Forest Sámi	-	-	-	AJN 4357	female	4
ÖKI 5**	Östra Kikkejaur	Arvidsjaur, Lappland	Forest Sámi	-	-	-	AJN 4356	female	4
MIA 1**	Mihre	Tännäs, Härjedalen	South Sámi	-	-	-	AJN 4974	male	2
MIA 2**	Mihre	Tännäs, Härjedalen	South Sámi	-	-	-	AJN 4953	male	5
MIA 3**	Mihre	Tännäs, Härjedalen	South Sámi	-	-	-	AJN 4454	female	2
MIA 4**	Mihre	Tännäs, Härjedalen	South Sámi	-	-	-	AJN 4952	female	2
MIA 5**	Mihre	Tännäs, Härjedalen	South Sámi	-	-	-	AJN 4903	castrated	-
TÅS 1**	Ruhvren sijte	Tännäs, Härjedalen	South Sámi	-	-	-	AJN 4992	male	2
TÅS 2**	Ruhvren sijte	Tännäs, Härjedalen	South Sámi	-	-	-	AJN 5009	male	4
TÅS 3**	Ruhvren sijte	Tännäs, Härjedalen	South Sámi	-	-	-	AJN 5004	female	2
TÅS 4**	Ruhvren sijte	Tännäs, Härjedalen	South Sámi	-	-	-	AJN 5015	female	6
TÅS 5**	Ruhvren sijte	Tännäs, Härjedalen	South Sámi	-	-	-	AJN 4986	female	8

Table 4. Results from the $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ analysis, as well as the radiocarbon dates (^{14}C) of the reindeer samples in this study. The crossed out samples did not fulfil the quality criteria for well-preserved collagen. There is also information on the mean values of the archaeological reindeer and the modern reindeer, their standard deviations (SD), lowest (MIN) and highest values (MAX). * = $\delta^{13}\text{C}$ values of the snow patch reindeer corrected with 1.89‰ for fossil fuel effects. ** = $\delta^{13}\text{C}$ values corrected for the modern reindeer with 0.22‰ (1948) and 0.23‰ (1953/1956) (see description of stable isotope analysis for further details). Continued

Sample #	Skeletal element	Collagen (%)	Initial $\delta^{13}\text{C}$ values (lipids extracted) (‰)	Corrected $\delta^{13}\text{C}$ values (‰)	$\delta^{15}\text{N}$	$\delta^{34}\text{S}$	C (%)	N (%)	S (%)	C:N	C:S	N:S	^{14}C date (BP)	^{14}C Age (cal CE, 2 σ)	^{14}C Lab code
ICE 1	Metatarsal	6.1	-18.5	-18.5	3.5	10.8	38.4	13.5	0.18	3.3	570	200	292±26	1496–1659	Ua-56651
ICE 2*	Metatarsal dx	12.5	-21.2	-19.3	1.4	5.2	39.7	13.9	0.20	3.3	530	186	138.7±0.3 pmC	Modern	Ua-56652
ICE 3	tibia sn	7.4	-18.3	-18.3	3.4	10.7	38.9	13.9	0.19	3.3	546	195	275±25	1520–1794	Ua-56653
ICE 4	Antler	6.2	-20.0	-20.0	1.6	8.3	40.2	14.3	0.18	3.3	596	212	324±27	1482–1644	Ua-56654
ICE 5*	pars petrosa	2.4	-21.7	-19.8	2.7	-	38.4	13.2	-	3.4	-	-	107.8±0.3 pmC	Modern	Ua-56655
ICE 6	antler, prox ?	6.5	-19.1	-19.1	1.5	8.4	40.8	14.4	0.18	3.3	605	214	1586±27	412–541	Ua-56656
ICE 7*	antler, prox	20.2	-23.2	-21.3	1.6	6.0	38.4	13.5	0.19	3.3	539	190	104.5±0.3 pmC	Modern	Ua-56657
ICE 8	Femur dx	8.6	-19.8	-19.8	2.7	9.5	36.5	12.9	0.18	3.3	541	191	88±26	1690–1925	Ua-56658
ICE 9	Tibia dx	9.4	-19.0	-19.0	2.4	9.6	38.2	13.4	0.19	3.3	537	188	147±25	1668–1948	Ua-56659
ICE 10	Radius sn	4.3	-18.7	-18.7	2.1	10.8	35.6	12.5	0.20	3.3	475	167	1689±26	259–414	Ua-56660
ICE 11*	Ossa longa	13.7	-22.1	-21.2	1.9	-	43.8	10.6	-	4.8	-	-	118.2±0.3 pmC	Modern	Ua-56661
SIR 1**	Mandibula dx	7.0	-20.0	-19.8	2.4	7.5	37.8	13.1	0.22	3.4	459	159	Modern	Modern	-
SIR 2**	Mandibula dx	12.5	-20.9	-20.7	2.8	-	36.4	6.5	-	5.3	-	-	Modern	Modern	-
SIR 3**	Mandibula dx	5.9	-21.2	-21.0	1.8	10.8	37.9	12.2	0.18	3.6	562	180	Modern	Modern	-
SIR 4**	Mandibula dx	7.1	-20.7	-20.5	1.9	-	40.1	12.6	-	3.7	-	-	Modern	Modern	-
SIR 5**	Mandibula dx	7.5	-20.9	-20.7	2.0	7.3	39.4	13.2	0.23	3.5	458	153	Modern	Modern	-
LMA 1**	Oxipitale	12.4	-19.8	-19.6	2.6	7.0	33.5	11.2	0.26	3.5	344	115	Modern	Modern	-
LMA 2**	Mandibula sin	17.8	-20.6	-20.3	2.1	6.2	43.7	15.0	0.21	3.4	555	191	Modern	Modern	-
LMA 3**	Mandibula dx	8.6	-20.5	-20.2	2.3	6.1	41.6	13.7	0.19	3.5	585	192	Modern	Modern	-
LMA 4**	Metatarsal dx	16.3	-20.5	-20.3	1.2	7.3	43.2	14.4	0.21	3.5	549	183	Modern	Modern	-
LMA 5**	Metatarsal	10.2	-19.2	-19.0	2.8	6.3	43.3	14.9	0.22	3.4	525	180	Modern	Modern	-
RÖD 1**	Mandibula dx	13.2	-20.5	-20.3	4.5	8.0	42.5	14.9	0.26	3.3	436	153	Modern	Modern	-
RÖD 2**	Mandibula dx	13.1	-20.8	-20.6	3.2	8.8	42.1	14.9	0.27	3.3	148	148	Modern	Modern	-
RÖD 3**	Mandibula dx	13.9	-19.8	-19.6	3.1	8.3	40.7	14.4	0.23	3.3	167	167	Modern	Modern	-
RÖD 4**	Mandibula dx	15.0	-20.9	-20.7	4.5	8.4	42.8	15.2	0.31	3.3	131	131	Modern	Modern	-
RÖD 5**	Mandibula dx	18.3	-19.9	-19.7	2.0	7.3	43.8	15.7	0.26	3.3	161	161	Modern	Modern	-

Table 4. Results from the $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ analysis, as well as the radiocarbon dates (^{14}C) of the reindeer samples in this study. The crossed out samples did not fulfil the quality criteria for well-preserved collagen. There is also information on the mean values of the archaeological reindeer and the modern reindeer; their standard deviations (SD), lowest (MIN) and highest values (MAX). * = $\delta^{13}\text{C}$ values of the snow patch reindeer corrected with 1.89‰ for fossil fuel effects. ** = $\delta^{13}\text{C}$ values corrected for the modern reindeer corrected with 0.22‰ (1948) and 0.23‰ (1953/1956) (see description of stable isotope analysis for further details). Continued

Sample #	Skeletal element	Collagen (%)	Initial $\delta^{13}\text{C}$ values (lipids extracted) (‰)	Corrected $\delta^{13}\text{C}$ values (‰)	$\delta^{15}\text{N}$	$\delta^{34}\text{S}$	C (%)	N (%)	S (%)	C:N	C:S	N:S	^{14}C date (BP)	^{14}C Age (cal CE, 2 σ)	^{14}C lab code
ÖKI 1**	Mandibula sin	12.5	-20±2	-20±0	3.6	-	43±1	13±4	-	3.8	-	-	Modern	Modern	-
ÖKI 2**	Mandibula sin	11.9	-20.1	-19.9	4.6	7.6	41.4	14.1	0.24	3.4	460	157	Modern	Modern	-
ÖKI 3**	Mandibula dx	11.0	-21.2	-21.0	3.4	7.1	39.4	13.7	0.23	3.4	457	159	Modern	Modern	-
ÖKI 4**	Mandibula dx	8.1	-20±7	-20±5	3.8	6±1	40±7	13±0	0.25	3.6	434	139	Modern	Modern	-
ÖKI 5**	Mandibula dx	7.5	-21.3	-21.0	3.2	6.4	42.2	13.7	0.26	3.59	433	141	Modern	Modern	-
MIÄ 1**	Mandibula sin	8.8	-19.6	-19.4	1.4	6.9	41.5	13.5	0.20	3.59	554	180	Modern	Modern	-
MIÄ 2**	Mandibula dx	7.6	-19.5	-19.2	2.5	6.1	40.0	13.6	0.20	3.4	534	182	Modern	Modern	-
MIÄ 3**	Oxipitale	12.7	-19.2	-18.9	3.3	5.8	39.7	13.8	0.22	3.4	482	168	Modern	Modern	-
MIÄ 4**	Mandibula dx	8.4	-19.7	-19.5	2.1	7.4	37.9	13.2	0.21	3.4	482	167	Modern	Modern	-
MIÄ 5**	Mandibula dx	11.1	-20±2	-20±0	2.8	6±8	42±6	13±6	0.18	3.7	63±1	20±1	Modern	Modern	-
TÄS 1**	Mandibula dx	9.9	-19±6	-19±4	4.9	-	39±7	12±4	-	3.7	-	-	Modern	Modern	-
TÄS 2**	Mandibula dx	8.9	-19.9	-19.7	1.7	6.3	40.3	13.3	0.28	3.5	385	127	Modern	Modern	-
TÄS 3**	Mandibula dx	10.9	-19.3	-19.1	2.8	6.8	41.2	14.3	0.25	3.4	439	153	Modern	Modern	-
TÄS 4**	Mandibula dx	13.0	-20.5	-20.2	1.9	7.2	39.5	12.8	0.23	3.60	458	149	Modern	Modern	-
TÄS 5**	Mandibula dx	11.8	-20.7	-20.4	2.1	7.3	39.0	13.2	0.24	3.5	433	146	Modern	Modern	-
Mean value - archaeological reindeer					2.5	9.7									
SD					0.6	1.1									
MIN					-20.0	8.3									
MAX					-18.3	10.8									
Mean value - modern reindeer					2.6	7.0									
SD					0.7	0.9									
MIN					-21.3	5.2									
MAX					-18.9	8.8									

Unna Sávjva and Vierronjarka, but not as the modern reindeer from the modern Forest reindeer herding districts. The $\delta^{34}\text{S}$ isotope values of the two oldest reindeer (ICE 6 and 10) differ, indicating that they have different origins (Figs. 5–7). Furthermore, ICE 4 and 6 have similar $\delta^{34}\text{S}$ isotope values as the reindeer from the offering sites of Bassenjunjis and Jervas, as well as to the modern reindeer from Rödningträsk. Samples ICE 8 and 9 have similar $\delta^{34}\text{S}$ isotope values, but not similar to any of the other archaeological sites, nor to the modern reindeer from any of the mountain or forest reindeer herding districts.

The reindeer samples from Ájtte and the four modern reindeer samples from Varánjunnje and Gárránistjähkkå have corrected $\delta^{13}\text{C}$ isotope values that vary from -21.3‰ to -18.9‰ with a mean and standard deviation of $-20.0\pm 0.7\text{‰}$. The $\delta^{15}\text{N}$ isotope values vary from 1.2‰ to 4.6‰ with a mean and standard deviation of $2.6\pm 0.9\text{‰}$. Five samples were not analysed for sulphur isotopes, due to not fulfilling the quality criteria. The $\delta^{34}\text{S}$ values, for the analysed individuals, varied between 5.2‰ and 8.8‰ with a mean and standard deviation of $7.0\pm 0.9\text{‰}$ (Table 4).

There is a small difference between the sites for both the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ mean values. The modern reindeer from Rödningträsk have a higher standard deviation (SD) in $\delta^{15}\text{N}$ values (SD=1.1‰) compared to the other modern sites (Fig. 8). Reindeer from both modern Forest Sámi reindeer herding districts have higher $\delta^{15}\text{N}$ values than the reindeer from the modern mountain reindeer herding districts (Fig. 6). There is no difference in $\delta^{34}\text{S}$ mean values between the modern reindeer from Sirges and Rödningträsk, indicating that the reindeer might have been grazing on the same lands during winter (Fig. 5). Luokta-Mavás, Östra Kikkejaure, Mihte and Ruhvten sijte are all from different geographic areas, however, they all have similar $\delta^{34}\text{S}$ mean values with small standard

deviations (Table 4). Here, the $\delta^{34}\text{S}$ isotope values suggest that these reindeer were grazing in areas with similar $\delta^{34}\text{S}$ values.

Discussion

Diet

Stable isotope values from the modern reindeer are in accordance with the stable isotope of their natural habitat. According to Fjellström *et al.* (2020) low $\delta^{13}\text{C}$ and low $\delta^{15}\text{N}$ isotope values are expected for reindeer that has not been fed, as for example in Mountain Sámi herding districts. This is also in accordance with stable isotope data from modern and historical caribou populations in North America (Britton, 2009; McManus-Fry *et al.*, 2018) and non-fed free-ranging domesticated reindeer in Finland (Fig. 10) (Salmi *et al.*, 2020). In this study the reindeer from the Mountain Sámi reindeer herding districts had, as expected, the lowest $\delta^{13}\text{C}$ ($< -18.9\text{‰}$) and the lowest $\delta^{15}\text{N}$ values ($< 3.0\text{‰}$), except one reindeer from Mihte (MIÅ 3, $\delta^{15}\text{N} = 3.3\text{‰}$) that had a high $\delta^{15}\text{N}$ value (Fig. 2, Table 4).

In contrast, reindeer from the Forest Sámi reindeer herding districts, with a more stationary reindeer husbandry tradition (Hultblad, 1936; Manker, 1968:229), had elevated $\delta^{15}\text{N}$ values compared to reindeer from the Mountain Sámi reindeer herding districts (Fig. 6). The exception was one castrated reindeer from Rödningträsk with a $\delta^{15}\text{N}$ isotope value of 2.0‰ (Fig. 2). However, this reindeer also had a lower $\delta^{34}\text{S}$ value compared to the other reindeer from Rödningträsk, indicating it might originate from another geographic area. The other castrated male, included in this study, show similar $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotope values as reindeer from its respective area (Table 4).

According to Fjellström *et al.*, (2020), low $\delta^{13}\text{C}$ and high $\delta^{15}\text{N}$ isotope values could indicate feeding, thus the higher $\delta^{15}\text{N}$ isotope values of reindeer from Forest Sámi reindeer herding districts suggests that they had been

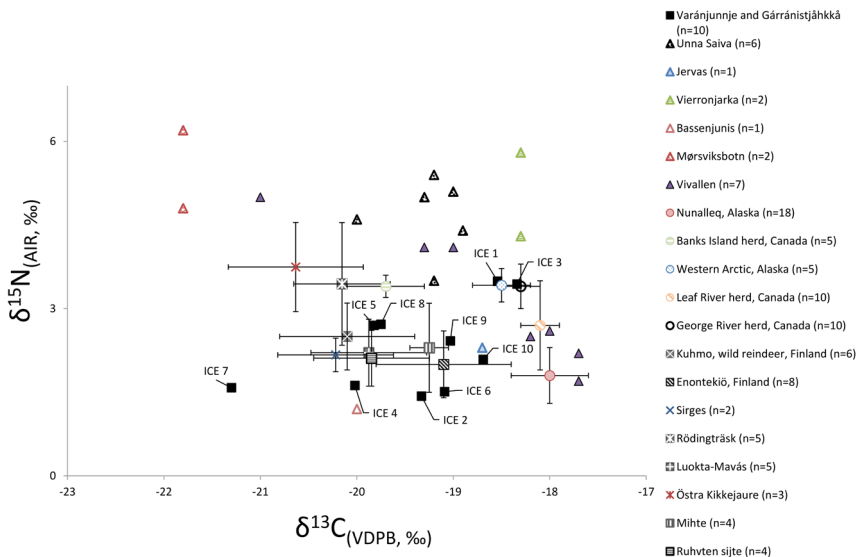


Figure 2. Carbon and nitrogen isotope values for reindeer from the snow patches of Varánjunnje and Gárránistjähkká, the modern reindeer (this study) and previously published data (Salmi *et al.*, 2015, 2020; Fjellströmet *et al.*, 2020). The $\delta^{13}\text{C}$ values for all modern samples have been corrected for a fossil fuel effect (Table 4) (Francey *et al.*, 1999; Long *et al.*, 2005; Keeling *et al.*, 2017).

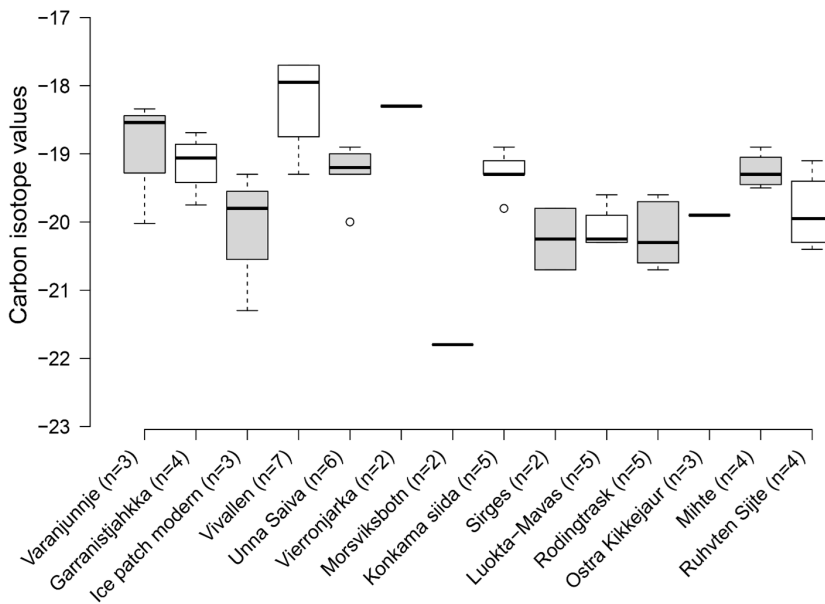


Figure 3. Boxplot of the stable carbon isotope data for the analysed reindeer. Center lines show the medians; box limits indicate the 25th and 75th percentiles; whiskers extend 1.5 times the interquartile range from the 25th and 75th percent (Spitzer *et al.* 2014). The $\delta^{13}\text{C}$ values for all modern samples have been corrected for a fossil fuel effect (Table 4) (Francey *et al.*, 1999; Long *et al.*, 2005; Keeling *et al.*, 2017).

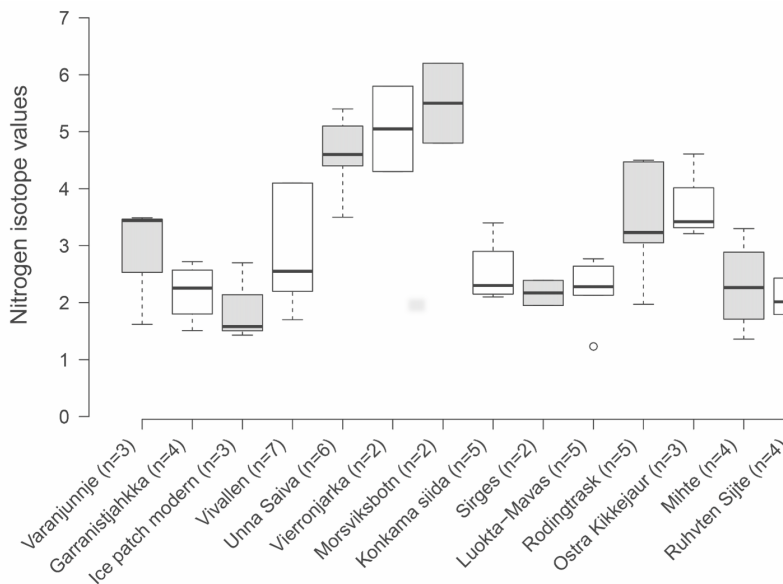


Figure 4. Boxplot of the stable nitrogen isotope data for the analysed reindeer. Center lines show the medians; box limits indicate the 25th and 75th percentiles; whiskers extend 1.5 times the interquartile range from the 25th and 75th percent (Spitzer *et al.* 2014).

fed (Fig. 6). However, there might be other factors that influence the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. Drucker *et al.* have for example suggested that a decrease in lichen consumption could result in lower $\delta^{13}\text{C}$ values, and higher altitudes could cause a decrease in $\delta^{15}\text{N}$ values and an increase in $\delta^{13}\text{C}$ values (2003:169; 2012:325–327). Following this argument, ICE 2, 6, 10 and 9 that were found on the snow patches at high altitudes and that had higher $\delta^{13}\text{C}$ values and lower $\delta^{15}\text{N}$ values could have resided at higher altitudes for longer periods. The one reindeer offered at Jervas with higher $\delta^{13}\text{C}$ and low $\delta^{15}\text{N}$ values could also have spent long periods at high altitudes. This could also be the case regarding four reindeer from the archaeological dwelling site at Vivallen (Fig. 2) (Zachrisson 1997). The low $\delta^{13}\text{C}$ values of ICE 4 and 7, and the one reindeer from the offering site of Bassenjunis, could represent a diet comprised of less lichen.

Although situated close to each other, the stable isotope results from the archaeological and modern reindeer from Varánjunnje and

Gárránistjáhkká vary quite substantially. There is, however, very little variation over time in the reindeer diet at these sites (Figs. 9 and 10). In this study, the variation in $\delta^{13}\text{C}$ values from the skeletal remains from the snow patches, could reflect greater land use in several Sámi reindeer herding districts.

Mobility

The reindeer from all modern Sámi reindeer herding districts had lower inter-individual variation in $\delta^{34}\text{S}$ isotope values, indicating low mobility (Figs. 3, 4, 5, 6 and 7), *i.e.* that the reindeer grazed in an area with low variation in $\delta^{34}\text{S}$ values. Further, all modern reindeer have lower $\delta^{34}\text{S}$ values than the archaeological and historical reindeer. This could be due to anthropogenic acid rain in modern times, providing lower sulphur values (Nriagu, 1979; Zhu *et al.*, 2015; Yan *et al.*, 2020), but also due to a change in climate (Reade *et al.*, 2020; Britton *et al.*, 2023). However, reindeer from two of the modern reindeer herding districts have slightly higher $\delta^{34}\text{S}$ values than the other modern rein-

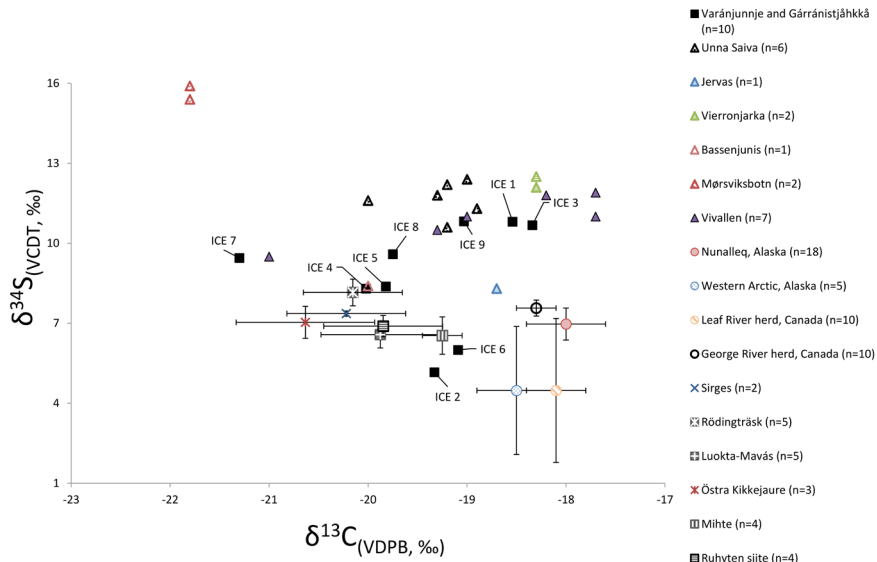


Figure 5. Carbon and sulphur isotope values for reindeer from the snow patches of Varánjunnje and Gárránistjáhká, the modern reindeer (this study) and previously published data (Salmi *et al.*, 2015, 2020; Fjellström *et al.*, 2020). The $\delta^{13}\text{C}$ values for all modern samples have been corrected for a fossil fuel effect (Table 4) (Francey *et al.*, 1999; Long *et al.*, 2005; Keeling *et al.*, 2017).

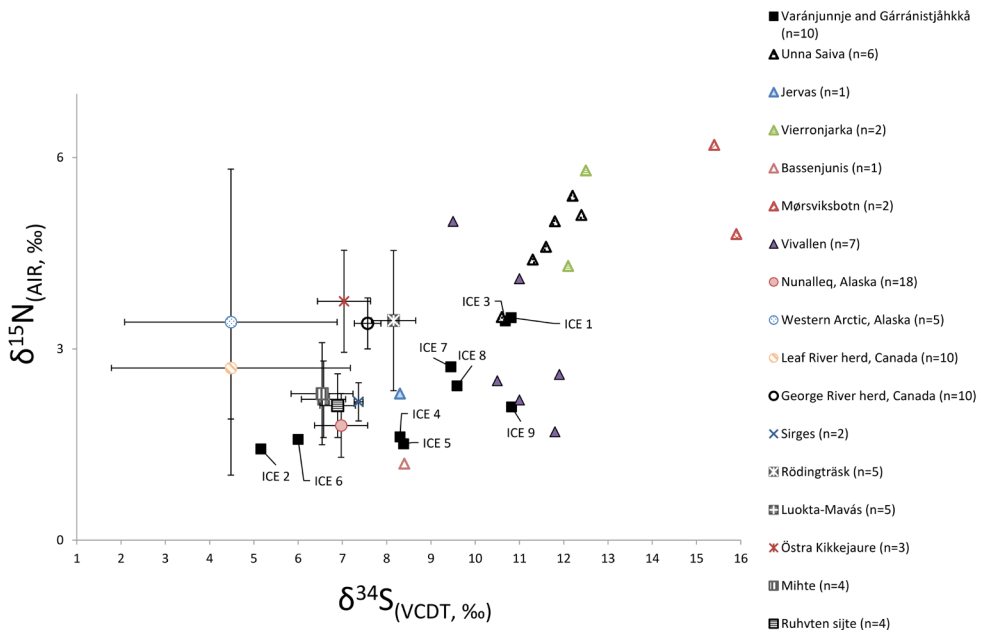


Figure 6. Nitrogen and sulphur isotope values for reindeer from the snow patches of Varánjunnje and Gárránistjáhká, the modern reindeer (this study) and previously published data (Salmi *et al.*, 2015, 2020; Fjellström *et al.*, 2020).

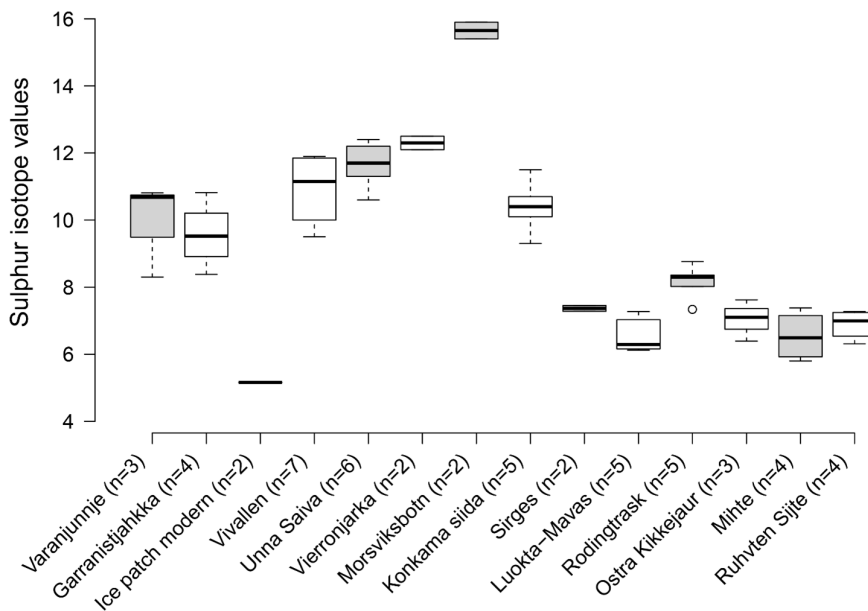


Figure 7. Boxplot of the stable sulphur isotope data for the analysed reindeer. Center lines show the medians; box limits indicate the 25th and 75th percentiles; whiskers extend 1.5 times the interquartile range from the 25th and 75th percent (Spitzer et al. 2014).

deer indicating their two different geological catchment areas with different isotopic values (Figs. 3 and 7).

Terrestrial plants in coastal areas can be subjected to a sea-spray effect that can lead the animal eating from that plant to have $\delta^{34}\text{S}$ isotope values like marine environments (Wadleigh *et al.*, 1994). Hence, more elevated $\delta^{34}\text{S}$ isotope values would have been expected if the reindeer was feeding from coastal plants or if there was a sea-spray effect (Nehlich, 2015). Two reindeer from the archaeological offering site Morsviksbotn (Andersen, 2018) by the Norwegian coast differ substantially from the other reindeer (Figs 3 and 7); hence, even though it is a small sample size from Norway, we are quite confident that the studied reindeer stayed in coastal Norway. However, none of our studied reindeer were grazing at the Norwegian coast.

The sulphur isotope values of the reindeer from Varánjunnje and Gárránistjáhkka had

quite a substantial variation. The two modern reindeer (ICE 2 and 7) from the snow patches with sulphur values have the lowest $\delta^{34}\text{S}$ values of all reindeer (5.2‰ and 6.0‰) and are similar to most of the other modern Swedish reindeer: at Östra Kikkejaure, Luokta-Mávas, Mihte and Ruhvten sijte. One of the prehistoric and three of the historic reindeer from the snow patches (ICE 4, 6, 8 and 9), together with two historic reindeer from the offering sites of Jervas and Bassenjunis (Salmi *et al.*, 2015; Salmi *et al.*, 2020), and one prehistoric reindeer from the dwelling site at Vivallen (Fjellström *et al.*, 2020), have similar $\delta^{34}\text{S}$ values to most of the modern reindeer from the reindeer herding district of Rödingträsk.

One of the reindeer from Gárránistjáhkka (ICE 10), dated to the Roman Iron Age/Migration Period, and one reindeer from Varánjunnje (ICE 1/3), dated from 1482 to 1794, have similar $\delta^{34}\text{S}$ values as previously published data

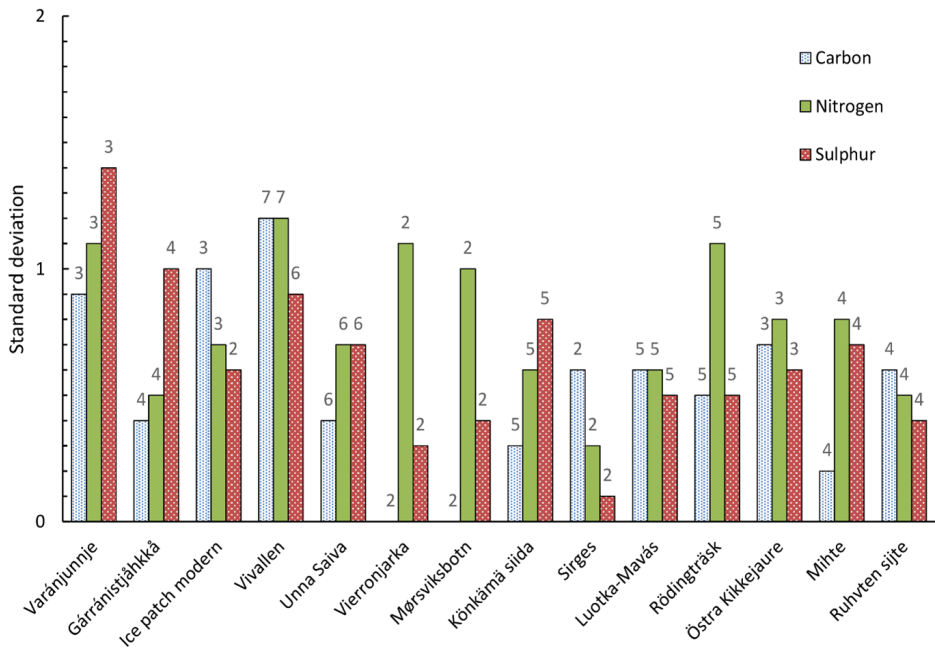


Figure 8. Variation of the standard deviation of the stable carbon, nitrogen and sulphur isotope data for the reindeer in this study, and previously published data (Salmi *et al.*, 2015, 2020; Fjellström *et al.*, 2020). The number above each column corresponds to the number of samples per site.

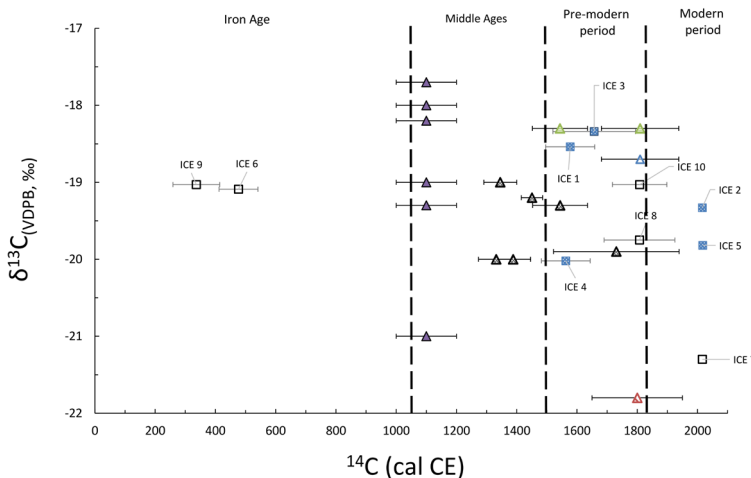


Figure 9. Stable carbon isotope data and radiocarbon date for reindeer in this study and Salmi *et al.*, 2015, 2018; Fjellström *et al.*, 1999; Long *et al.*, 2005; Keeling *et al.*, 2017). The $\delta^{13}\text{C}$ values for all modern samples have been corrected for a fossil fuel effect (Table 4). There are two different colours for the snow patches sites: blue = Varánjunnje and red = Gárránistjähkká. The symbols for the same site depend on their radiocarbon dates. The filled purple triangle represent Vivallen, the black dotted triangles Unna Sáivva, the lined green triangles Vierronjarka, the dashed red triangles Mørsviksbotn and the empty blue triangle Jervas.

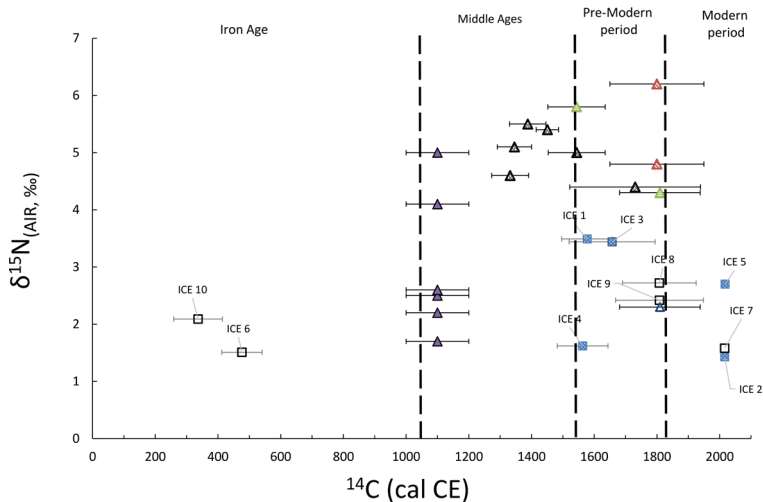


Figure 10. Stable nitrogen isotope data and radiocarbon date for reindeer in this study and Salmi *et al.*, 2015, 2018; Fjellström *et al.*, 2020. There are two different colours for the snow patches sites: blue = Varánjunnje and red = Gárránistjáhkka. The symbols for the same site depend on their radiocarbon dates. The filled purple triangle represent Vivallen, the black dotted triangles Unna Sárvva, the lined green triangles Vierronjarka, the dashed red triangles Mørsviksbotn and the empty blue triangle Jervas.

from the offering sites of Unna Sárvva and Vieronjarka (Salmi *et al.*, 2015, 2018). Although ICE 1/3 has a higher $\delta^{15}\text{N}$ value than ICE 10, we assume that these two individuals grazed in the same areas. The difference in $\delta^{15}\text{N}$ values could be explained by feeding. Reindeer ICE 1/3 has a similar sulphur isotope value and is dated to the same time period as the reindeer from the offering site of Unna Sárvva and could thus be a reindeer from the same population. A further aDNA analysis might solve this issue. The diet of the two prehistoric reindeer from the snow patches (ICE 6 and 10) are similar,

Based on these results, it is impossible to define a specific grazing area for the reindeer. Further analysis of strontium and oxygen isotope analysis could provide a more detailed picture of where that could be. Nevertheless, based on the $\delta^{34}\text{S}$ values, reindeer found at the snow patches at Varánjunnje and Gárránistjáhkka must have grazed in different areas with different geological backgrounds.

Conclusion

From the use of morphometric data, stable isotope analysis ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$) and radiocarbon dating from prehistoric and historic reindeer we have been able to show that there was very little variation over time in diet for the reindeer retrieved from the snow patches. We also found that these reindeer must have grazed in different geographic areas, maybe coming from different Sámi herding districts. We could also see that reindeer from Forest Sámi herding districts were probably fed, in contrast to the reindeer from Mountain Sámi herding districts where the stable isotope values reflect their natural habitat. This further indicates that reindeer in various herding districts were managed differently.

We found no correlation between age, gender, pathological changes and diet, and the castrated reindeer did not differ from other reindeer.

The analysis of the modern reindeer from the different reindeer herding districts has given a

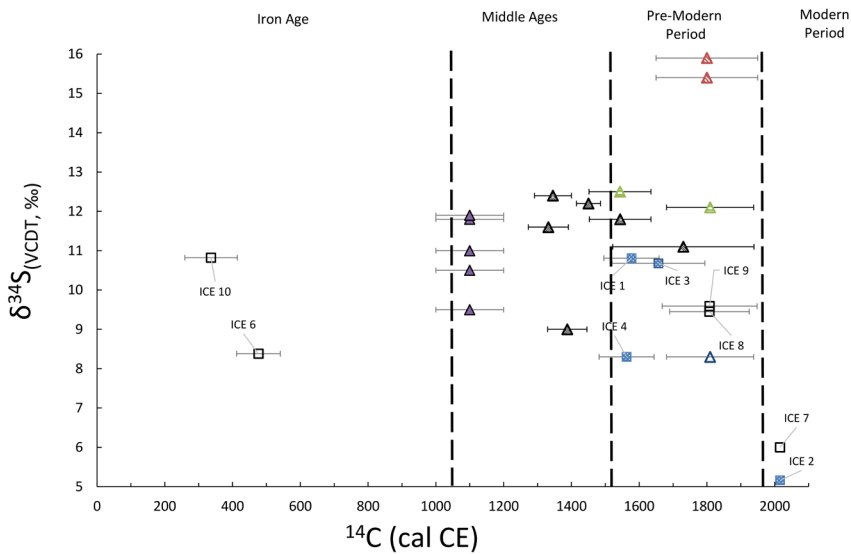


Figure 11. Stable sulphur isotope data and radiocarbon date for reindeer in this study and Salmi *et al.*, 2015, 2018; Fjellström *et al.*, 2020. There are two different colours for the snow patches sites: blue = Varánjunnje and red = Gárránistjáhkka. The symbols for the same site depend on their radiocarbon dates. The filled purple triangle represent Vivallen, the black dotted triangles Unna Sájjvva, the lined green triangles Vierronjarka, the dashed red triangles Mørsviksbotn and the empty blue triangle Jervas.

good foundation for interpreting archaeological reindeer remains. Osteological and stable isotope analysis are effective methods to understand natural and cultural approaches to reindeer skeletal remains found at snow patches. Further studies with a broader analytic approach are needed to understand human-reindeer relationships in the past.

This new dataset adds to the understanding of reindeer mobility and historic reindeer herding strategies through time and the “natural” use of the landscape by reindeer, but also by humans.

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References

- Ambrose, S.H.** 1990. Preparation and characterization of bone and tooth for isotopic analysis. – *Journal of Archaeological Science* 17: 431–451. [https://doi.org/10.1016/0305-4403\(90\)90007-R](https://doi.org/10.1016/0305-4403(90)90007-R)
- Andersen, O.** 2011. Reindeer-herding cultures in northern Nordland, Norway: Methods for documenting traces of reindeer herders in the landscape and for dating reindeer-herding activities. – *Quaternary International* 238: 63–75. <https://doi.org/10.1016/j.quaint.2010.09.007>
- Andersen, O.** 2018. *Feltrapport: Dokumentasjon av offerplassen i Mørsvikbotn, Sørfold kommune. Arran lulesamisk senter.*
- Arell, N.** 1977. *Rennomdismen i Torne lappmark – markanvändning under kolonisationsepoken i fr.a. Enontekis socken.* Dissertation, Umeå. Kungliga Skytteanska samfundets handlingar 17.
- Aronsson, K.-Å.** 1991. *Forest reindeer herding*

A.D. 1-1800: an archaeological and palaeoecological study in northern Sweden. Dissertation, Umeå University.

- Aronsson, K.-Å. & Ljungdahl, E.** 2008. Stuor Muorkke, Stora Sjöfallet. Dokumentation av fornlämningar och kulturlämningar inom område för planerat naturum vid Stora Sjöfallet. – *Arkeologisk rapport 2008:1*. Åttte svenskt fjäll- och samemuseum, Jokkmokk.
- Aronsson, K.-Å. & Israelsson, I.** 2008. Kunskapsuppbyggnad om fjällens natur och kulturvärden särskilt det biologiska kulturarvet. – *Arkeologisk rapport 2008:2*. Åttte svenskt fjäll- och samemuseum, Jokkmokk.
- Aronsson, K.-Å.** 2020. Fynd ur snölegan. – *In: Gustafsson Reinius, L. (Ed.). Arktiska spår*. Nordiska museets förlag.
- Barboza, P. S. & Parker, K. L.** 2006. Body Protein Stores and Isotopic Indicators of N Balance in Female Reindeer (*Rangifer tarandus*) during Winter. – *Physiological and Biochemical Zoology* 79(3):628–644. <https://doi.org/10.1086/502811>
- Bartosiewicz, L. & Gál, E.** 2013. Shuffling Nags, Lame Ducks: The Archaeology of Animal Disease. Oxford, Oxbow Books. <https://doi.org/10.2307/j.ctvh1djdq>
- Bergman, I., Liedgren, L., Östlund, L. & Zackrisson, O.** 2008. Kinship and Settlements: Sami Residence Patterns in the Fenoscandian and Alpine Areas around A.D. 1000. – *Arctic Anthropology* 45(1): 97–110. <https://doi.org/10.1353/arc.0.0005>
- Bergman, I., Zackrisson, O. & Liedgren, L.** 2013. From Hunting to Herding: Land Use, Ecosystem Processes, and Social Transformation among Sami AD 800-1500. – *Arctic Anthropology* 50(2): 25–39. <https://doi.org/10.3368/aa.50.2.25>
- Björge, T., Linge, T., Skår, Ø., Lohne Ronngved, S. & Slinning, T.** 2015. Fragments of a Late Iron Age Sledge Melted Out of the Vossaskavlen Snowdrift Glacier in Western Norway. – *Journal of Glacial Archaeology* 2: 73–81. <https://doi.org/10.1558/jga.v2i1.27719>
- Bjørklund, I.** 2013. Domestication, Reindeer Husbandry and the Development of Sámi Pastoralism. – *Acta Borealia* 30(2): 174–189. <https://doi.org/10.1080/08003831.2013.847676>
- Bjørnstad, G., Flagstad, Ø., Hufthammer, A. K. & Røed, K. H.** 2012. Ancient DNA reveals a major genetic change during the transition from hunting economy to reindeer husbandry in northern Scandinavia. – *Journal of Archaeological Science* 39: 102–108. <https://doi.org/10.1016/j.jas.2011.09.006>
- Bromé, J.** 1923. *Nasafjäll. Ett norrländskt silververks historia*. Violas förlag, Stockholm.
- Britton, K. H.** 2010. *Multi-isotope analysis and the reconstruction of prey species palaeomigration and palaeoecology*. Durham theses, Durham University.
- Britton, K., Jimenez, E.-L., Le Corre, M., Pederzani, S., Daujeard, C., Jaouen, K., Vettese, D., Tütken, T., Hublin, J.-J. & Moncel, M.-H.** 2023. Multi-isotope zooarchaeological investigations at Abri du Maras: The paleoecological and paleoenvironmental context of Neanderthal subsistence strategies in the Rhône Valley during MIS 3. – *Journal of Human Evolution* 174. <https://doi.org/10.1016/j.jhevol.2022.103292>
- Brown T.A., Nelson, D.E., Vogel, J.S. & Southon, J.R.** 1988. Improved collagen extraction 545 by modified Longin method. – *Radiocarbon* 30(2): 171–177. <https://doi.org/10.1017/S0033822200044118>
- Callanan, M.** 2016. Managing frozen heritage: Some challenges and responses. – *Quaternary International* 402:1–8. <https://doi.org/10.1016/j.quaint.2015.10.067>
- Danell, K., Utsi, M., Palo, T. & Eriksson, O.** 1994. Food plant selection by reindeer during winter in relation to plant quality. – *Ecography* 26: 153–158. <https://doi.org/10.1016/j.ecography.1994.03.005>

[org/10.1111/j.1600-0587.1994.tb00088.x](https://doi.org/10.1111/j.1600-0587.1994.tb00088.x)

- DeNiro, M.J. & Epstein, S.** 1978. Influence of diet on the distribution of carbon isotopes in animals. – *Geochimica et Cosmochimica Acta* 42: 495–506. [https://doi.org/10.1016/0016-7037\(78\)90199-0](https://doi.org/10.1016/0016-7037(78)90199-0)
- DeNiro, M.J.** 1985. Post mortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. – *Nature* 317: 806–809. <https://doi.org/10.1038/317806a0>
- Drucker, D., Bocherens, H. & Billiou, D.** 2003. Evidence for shifting environmental conditions in Southwestern France from 33 000 to 15 000 years ago derived from carbon-13 and nitrogen-15 natural abundances in collagen of large herbivores. – *Earth and Planetary Science Letters* 216: 163–173. [https://doi.org/10.1016/S0012-821X\(03\)00514-4](https://doi.org/10.1016/S0012-821X(03)00514-4)
- Drucker, D., Hobson, K. A., Münzel, S.C. & Pike-Tay, A.** 2010. Intra-individual variation in stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotopes in mandibles of modern caribou of Qamanirjuaq (*Rangifer tarandus groenlandicus*) and Banks Island (*Rangifer tarandus pearyi*): Implications for tracing seasonal and temporal changes in diet. – *International Journal of Osteoarchaeology* 22, pp. 494–504. <https://doi.org/10.1002/oa.1220>
- Drucker, D., Bridault, A. & Cupillard, C.** 2012. Environmental context of the Magdalenian settlement in the Jura Mountains using stable isotope tracking (^{13}C , ^{15}N , ^{34}S) of bone collagen from reindeer (*Rangifer tarandus*). – *Quaternary International* 272–273: 322–332. <https://doi.org/10.1016/j.quaint.2012.05.040>
- Eidlitz, K.** 1972. Renmjölkningen hos samerna. – *Rig* 55(1): 74–76.
- Ekman, S.** 1910. Norrlands jakt och fiske. Två Förläggare Bokförlag, Umeå.
- Eriksson, Gunilla.** 2013. Stable isotope analysis of humans. – In: Nilsson Stutz, L. & Tarlow, S. (eds.). *The Oxford Handbook of the Archaeology of Death and Burials*, 123–146. Oxford, Oxford University Press.
- Evans, R.D.** 2007. Soil Nitrogen Isotope Composition. – In: Michener, Robert H. & Lajtha, Kate (ed.). *Stable isotopes in ecology and environmental science*. 2. ed. Malden, Mass., Blackwell Pub. <https://doi.org/10.1002/9780470691854.ch4>
- Faure, G. & Mensing, T. M.** 2005. Isotopes: principles and applications. 3. ed. Hoboken: John Wiley & Sons.
- Finstad, E. & Vedeler, M.** 2008. En bronsealderko fra Jotunheimen. – *Viking* 2008:61–70.
- Finstad, G. L. & Kielland, K.** 2011. Landscape Variation in the Diet and Productivity of Reindeer in Alaska Based on Stable Isotope Analyses. – *Arctic, Antarctic, and Alpine Research* 43 (4), pp. 543–554. <https://doi.org/10.1657/1938-4246-43.4.543>
- Fjellström, M.** 2018. Glaciärarkeologisk inventering vid Ålmallojekna, Jokkmokk socken, Lappland (20–24 augusti 2017). – *Rapporter från Arkeologiska forskningslaboratoriet* 29, ISSN 1653–2910.
- Fjellström, M.** 2019. Glaciärarkeologisk inventering vid Ekman-, Låktatjåkko-, Kårsa-, Kåtotjåkko-, Gällanvärri- och Sälajiegnaglaciärerna i Norrbottens län, Lappland (8–15 augusti 2018). – *Rapporter från Arkeologiska forskningslaboratoriet* 30, ISSN 1653–2910.
- Fjellström, M.** 2020. Glaciärarkeologisk inventering vid Sälajiegn- och Stuorjieg-naglaciärerna i Norrbottens län, Lappland (23–26 augusti 2019). – *Rapporter från Arkeologiska forskningslaboratoriet* 33, ISSN 1653–2910.
- Fjellström, M., Ahlgren, H., Holmlund, P., Schytt Holmlund, E. & Lidén, K.** 2019. Nya ^{14}C -dateringar av glaciärfynd vid Ålmallojekna i Jokkmokks kommun, Lapp-

- land. – *Fornvännen*, 114(4): 253–257.
- Fjellström, M., Eriksson, G., Angerbjörn, A. & Lidén, K.** 2020. Approaching historic reindeer herding in Northern Sweden by stable isotope analysis. – *Journal of Nordic Archaeological Science*.
- Fjellström, M., Lindgren, Å., López-Costas, O., Eriksson, G. & Lidén, K.** 2021. Food, mobility and health in an Arctic 17th–18th century mining population. – *Arctic* 74(2): 206–226. <https://doi.org/10.14430/arctic72709>
- Forsberg, L.** 1985. *Site variability and settlement patterns. An analysis of the hunter-gatherer settlement system in the Lule River Valley 1500 B.C. – B.C./A.D.* Thesis. Department of Archaeology, Umeå University.
- Francey, R.J., Allison, C.E., Etheridge, D.M., Trudinger, C.M., Enting, I.G., Leuenberger, M., Langenfelds, R.I., Michel, E. & Steele, L.P.** 1999. A 1000-year high precision record of $\delta^{13}\text{C}$ in atmospheric CO_2 . – *Tellus* 51B, 170–193. <https://b.tellusjournals.se/articles/10.3402/tellusb.v51i2.16269>
- Goudeau, C.** 2019. *Land reclamation by reindeer lichen. On the complexity of substrate and reindeer grazing on artificial Cladonia spp. dispersal.* Master's Degree Thesis in Biology, Umeå University.
- Graven, H., Keeling, R. F., & Rogelj, J.** 2020. Changes to carbon isotopes in atmospheric CO_2 over the industrial era and into the future. – *Global Biogeochemical Cycles* 34. <https://doi.org/10.1029/2019GB006170>
- Guiry, E. J., Szpakk, P. & Richards, M. P.** 2016. Effects of lipid extraction and ultrafiltration on stable carbon and nitrogen isotopic compositions of fish bone collagen. – *Rapid Communications in Mass Spectrometry* 30(13): 1591–1600. <https://doi.org/10.1002/rcm.7590>
- Hansen, L. I. & Olsen, B.** 2006. *Samenes historie fram til 1750.* Cappelen Akademisk Forlag, Oslo.
- Hansen, L. I. & Olsen, B.** 2014. *Hunters in Transition. An Outline of Early Sámi History.* Brill, Leiden. <https://doi.org/10.1163/9789004252554>
- Hedman, S.-D.** 2003. *Boplatser och offerplatser. Ekonomisk strategi och boplatzmönster bland skogssamer 700–1600 AD.* Dissertation, Umeå University.
- Hedman, S.-D.** 2013. *I ställetufternas land. Rapport över dokumentation av samiska kulturminnen i Saltfjellet/Lönsdalen, Saltdalen kommun, Nordland.* Tromsø, Universitetet i Tromsø, Sámi dutkamiid guovddáš
- Heggberget, T.M., Gaare, E. & Ball, J.P.** 2002. Reindeer (*Rangifer tarandus*) and climate change: importance of winter forage. – *Rangifer* 22: 13–31. <https://doi.org/10.7557/2.22.1.388>
- Helskog, K.** 2012. Ancient depictions of reindeer enclosures and their environment. – *Fennoscandia archaeologica* XXIX: 29–54.
- Hollensen, J., Callanan, M., Dawson, T., Fenger-Nielsen, R., Max Friesen, T., Jensen, A.M., Markham, A., Martens, V.V., Pitulko, V.V. & Rockman, M.** 2018. Climate change and the deteriorating archaeological and environmental archives of the Arctic. – *Antiquity* 92 (363):573–586. <https://doi.org/10.15184/aqy.2018.8>
- Hultblad, F.** 1936. *Flyttlapparna i Gällivare socken.* Geographica, Appelbergs boktryckeriaktiebolag, Uppsala.
- Hultblad, F.** 1968. *Övergång från nomadism till agrar bosättning i Jokkmokks socken.* PhD thesis. Uppsala University, Berlingska boktryckeriet, Lund.
- Inga, B.** 2008. *Traditional Ecological Knowledge among Reindeer Herders in Northern Sweden.* Licentiate thesis, Swedish University of Agricultural Sciences, Umeå.
- Ingold, T.** 1986. Reindeer economies and the origin of pastoralism. – *Anthropology Today* 2(4): 5–10. <https://doi.org/10.2307/3032710>

- Karlsson, N.** 2006. *Bosättning och resursutnyttjande: miljöarkeologiska studier av boplatser med härdar från perioden 600-1900 e. Kr inom skogssamiskt område*. PhD dissertation, Arkeologi och samiska studier, Umeå University.
- Keeling, R. F., Grave, H. D., Welp, L. R., Resplandy, L., Bi, J., Piper, S. C., Sun, Y., Bollenbacher, A. Meijer & H. A.** 2017. Atmospheric evidence for a global secular increase in carbon isotopic discrimination of land photosynthesis. – *Earth, Atmospheric, and Planetary sciences* 114(39):10361-10366. <https://doi.org/10.1073/pnas.1619240114>
- Karlén, W. & Danton, G. H.** 1976. Holocene glacial variations in Sarek National Park, northern Sweden. – *Boreas* 5(1): 25–56. <https://doi.org/10.1111/j.1502-3885.1976.tb00329.x>
- Klein, D.R.** 1990. Variation in quality of caribou and reindeer forage plants associated with season, plant part, and phenology. – *Rangifer* 3: 123–130. <https://doi.org/10.7557/2.10.3.841>
- Krouse, H.R.** 1980. Sulphur isotopes in our environment. – In: Fritz, P. & Fontes, J. Ch. (eds.). *Handbook of environmental geochemistry Vol. 1 The terrestrial environment A*: Elsevier, Amsterdam, pp. 435–471. <https://doi.org/10.1016/B978-0-444-41780-0.50017-1>
- Kuoljok, K. & Blind, A.-C.** 2014. Renskötare berättar om myrens betydelse för renen och renskötelsen – en kunskapssammanställning. – In: Blind, A.-C., Kuoljok, K., Axelsson Linkowski, W. & Tunón, H. (Eds.). *Myrens betydelse för renen och renskötelsen Biologisk mångfald på myrar i renskötelland*. NAPTEK, Centrum för biologisk mångfald & Sametinget, Uppsala & Kiruna.
- Laponiatjuottjudus.** World Heritage in Swedish Lapland. Available at: <https://laponia.nu/en>
- Länsstyrelsen Norrbotten,** 2010. *Norrbottens kulturmiljöprogram 2010–2020*. Länsstyrelsen Norrbotten. Available at: https://ext-dokument.lansstyrelsen.se/Norrbotten/Planeringsunderlag/Kulturmiljo/Kulturmiljoprogram_Kalix.pdf
- Lidén, K.** 2020. Vid Ekmanglaciärer. – In: Gustafsson-Reinius, L. (ed.). *Arktiska spår. Natur och kultur i rörelse*. Nordiska museets förlag, Stockholm, pp. 192–193.
- Liedgren, L.** 2003. Utgrävningar av stalotomter i Adamvaltaområdet, Arjeplog, Lappland, 2002. Silvermuseet, Rapport 35. ISSN 1101-2900.
- Liedgren, L., Bergman, I., Hörnberg, G., Zackrisson, O., Hellberg, E., Östlund, L. & DeLuca, T. H.** 2007. Radiocarbon dating of prehistoric hearths in alpine northern Sweden: problems and possibilities. – *Journal of Archaeological Science* 34: 1276–1288. <https://doi.org/10.1016/j.jas.2006.10.018>
- Ljungdahl, E.** 2011. *Mittådalens sameby. Historia, kulturmiljöer och turister*. Östersund, Gaaltije.
- Ljungdahl, E.** 2013. *Ruhvten sijte. Historia, kulturmiljöer och turism*. Östersund, Gaaltije.
- Long, E.S., Sweitze, R.A., Diefanbach, D.R. & Ben-David, M.** 2005. Controlling for Anthropologically Induced Atmospheric Variation in Stable Carbon Isotope Studies. – *Oecologia* 146(1): 148–156. <https://doi.org/10.1007/s00442-005-0181-6>
- Lundholm, K.** 1976. Två kompletta pilar från Lappland. *Fornvännen* 71: 110–116.
- Lundmark, L.** 1982. *Uppbörd, utarmning, utveckling: det samiska fångstsamhällets övergång till rennomadism i Lule lappmark*. Dissertation. Umeå University. Umeå.
- Manker, E.** 1950. Silbonah. Några fältanteckningar från Rödingträsk 1949. – In: Lindblom, A., Berg, G. & Andrén, E. (Eds.). *Fataburen. Nordiska museets och Skansens Årsbok 1950*. Tryckeri Aktiebolag Thule, Stockholm, pp. 199–212.
- Manker, E.** 1957. *Lapparnas heliga ställen*.

- Kultplatser och offerkult i belysning av Nordiska museets och landsantikvariernas fältundersökningar.* Nordiska museet, Acta lapponica XIII, Almqvist & Wiksell.
- Manker, E.** 1968. *Skogslapparna i Sverige: fältanteckningar.* Stockholm, Almqvist & Wiksell.
- Mann, R.W. & Hunt, D.R.** 2005. *Photographic Regional Atlas of Bone Disease. A Guide to Pathologic and Normal Variation in the Human Skeleton.* 2nd edition. Cornell University Press, Ithaca, NY.
- Mårell, A.,** 2006. *Summer Feeding Behaviour of Reindeer: A Hierarchical Approach.* Swedish University of Agricultural Science, Umeå.
- McManus-Fry, E., Knecht, R., Dobney, K., Richards, M. P. & Britton, K.** 2018. Dog-human dietary relationships in Yup'ik western Alaska: The stable isotope and zooarchaeological evidence from pre-contact Nunalleq. – *Journal of Archaeological Science: Reports* 17, pp. 964–972. <https://doi.org/10.1016/j.jasrep.2016.04.007>
- Minagawa, M. & Wada, E.** 1984. Stepwise enrichment of ^{15}N along food chains: Further evidence and the relation between $\delta^{15}\text{N}$ and animal age. – *Geochimica et Cosmochimica Acta* 48: 1135–1140. [https://doi.org/10.1016/0016-7037\(84\)90204-7](https://doi.org/10.1016/0016-7037(84)90204-7)
- Morris, A. D., Muir, D. C. G. Solomon, R. K., Teixeira, C. F., Duric, M. D. & Wang, X.** 2018. Bioaccumulation of polybrominated diphenyl ethers and alternative halogenated flame retardants in a vegetation–caribou–wolf food chain of the Canadian Arctic. – *Environmental Science & Technology* 52 (5): 3136–3145. <https://doi.org/10.1021/acs.est.7b04890>
- Mulk, I.-M.** 1982. *Kulturbistorisk undersökning inom fjällområden efter Stora Lule älvssystem, Gällivare och Jokkmokks sn, Lappland 1981.* Rapport 4, Department of Archaeology, Umeå University.
- Mulk, I.-M.** 1994. *Sirkas – ett samiskt fångst-samhälle i förändring Kr. f. – 1600 e.Kr.* Dissertation. Department of Archaeology, Umeå University.
- Nehlich, O.** 2015. The application of sulphur isotope analysis in archaeological research: a review. – *Earth-Science Reviews* 142: 1–17. <https://doi.org/10.1016/j.earsci-rev.2014.12.002>
- Nehlich, O. & Richards, M.P.** 2009. Establishing collagen quality criteria for sulphur isotope analysis of archaeological bone collagen. – *Archaeological and Anthropological Sciences* 1: 59–75. <https://doi.org/10.1007/s12520-009-0003-6>
- Nieminen, M. & Pietilä, U.** 1999. Peurasta poroksi (From wild to semi-domesticated reindeer). Gummerus kir-japaino Oy, Helsinki, Finland.
- Nriagu, J.** 1978. Global inventory of natural and anthropogenic emissions of trace metals to the atmosphere. – *Nature* 279: 409–411. <https://doi.org/10.1038/279409a0>
- O'Connell, T. C. & Hedges, R. E. M.** 1999. Isotopic comparison of hair and bone: Archaeological analyses. – *Journal of Archaeological Science* 26: 661–665. <https://doi.org/10.1006/jasc.1998.0383>
- Öberg, L. & Kullman, L.** 2011. Recent Glacier Recession – a New Source of Postglacial Treeline and Climate History in the Swedish Scandes. – *Landscape Online* 26, 1–28. <https://doi.org/10.3097/LO.201126>
- Ophof, A.A., Oldeboer, K.W. & Kumpula, J.** 2013. Intake and chemical composition of winter and spring forage plants consumed by semi-domesticated reindeer (*Rangifer tarandus tarandus*) in northern Finland. – *Animal Feed Science and Technology* 185: 190–195. <https://doi.org/10.1016/j.anifeed-sci.2013.08.005>
- Reade, H., Tripp, J.A., Charlton, S., Grimm, S.B., Leesch, D., Müller, W., Sayle, K.L.,**

- Fensome, A., Higham, T.F.G., Barnes, I. & Stevens, R.E. 2020. Deglacial landscapes and the Late Upper Palaeolithic of Switzerland. – *Quaternary Science Review* 239: 106372. <https://doi.org/10.1016/j.quascirev.2020.106372>
- Richards, M.P., Fuller, B. T., Sponheimer, M., Robinson, T. & Ayliffe, L. 2003. Sulphur Isotopes in Palaeodietary Studies: a Review and Results from a Controlled Feeding Experiment. – *International Journal of Osteoarchaeology* 13: 37–45. <https://doi.org/10.1002/oa.654>
- Parker, K.L., Barboza, P.S. & Stephenson, T.R. 2005. Protein conservation in female caribou (*Rangifer tarandus*): effects of decreasing diet quality during winter. – *Journal of Mammals*. 86(3): 610–622. [https://doi.org/10.1644/1545-1542\(2005\)86\[610:PCIFCR\]2.0.CO;2](https://doi.org/10.1644/1545-1542(2005)86[610:PCIFCR]2.0.CO;2)
- Pilø, L. & Solli, B. 2017. SPOR etter gammel ferdsel smelter ut av isen. – *SPOR* 2: 41–46.
- Pilø, L. Finstad, E., Bronk Ramsey, C., Robert Post Martinsen, J., Nesje, A., Solli, B., Wangen, V., Callanan, M. & Barrett, J. H. 2018. The chronology of reindeer hunting on Norway's highest ice patches. – *Royal Society Open Science* 5(1): 171738. <https://doi.org/10.1098/rsos.171738>
- Pilø, L. Finstad, E. & Barrett, J. H. 2020. Crossing the ice: an Iron Age to medieval mountain pass at Lendbreen, Norway. – *Antiquity* 94 (374):437–454. <https://doi.org/10.15184/aqy.2020.2>
- Rosvold, J. 2016. Faunal Finds from Alpine Ice: Natural or Archaeological Depositions? – *Journal of Glacial Archaeology* 3: 79–108. <https://doi.org/10.1558/jga.32414>
- Rosvold, J., Hansen, G. & Røed, K. H. 2019. From mountain to towns: DNA from ancient reindeer antlers as proxy for domestic procurement networks in medieval Norway. – *Journal of Archaeological Science: Reports* 26: 1–9. <https://doi.org/10.1016/j.jasrep.2019.05.025>
- Ryg, M. & Jacobsen, E. 1982. Effects of castration on growth and food intake cycles in young male reindeer (*Rangifer tarandus tarandus*). – *Canadian Journal of Zoology* 60:942–945. <https://doi.org/10.1139/z82-128>
- Røed, K.H., Flagstad, Ø., Bjørnstad, G. & Hufthammer, A. K. 2011. Elucidating the ancestry of domestic reindeer from ancient DNA approaches. – *Quaternary International* 238:83–88. <https://doi.org/10.1016/j.quaint.2010.07.031>
- Røed, K. H., Bjørklund, I. & Olsen, B. J. 2018. From wild to domestic reindeer – Genetic evidence of a non-native origin of reindeer pastoralism in northern Fennoscandia. – *Journal of Archaeological Science: Reports* 19: 279–286. <https://doi.org/10.1016/j.jasrep.2018.02.048>
- Røed, K.H., Kvie, K.S., Bårdsen, B.-J., Laaksonen, S., Lohi, H., Kumpula, J., Aronsson, K.Å., Åhman, B., Våge, J. & Ø. Holand. 2021. Historical and social-cultural processes as drivers for genetic structure in Nordic domestic reindeer. – *Ecology and Evolution* 11: 8910–8922. <https://doi.org/10.1002/ece3.7728>
- Salmi, A.- K., Äikäs, T., Fjellström, M. & Spangen, M. 2015. Animal offerings at the Sámi offering site of Unna Saiva – Changing religious practices and human–animal relationships. – *Journal of Anthropological Archaeology* 40: 10–22. <https://doi.org/10.1016/j.jaa.2015.05.003>
- Salmi, A.- K., Äikäs, T., Spangen, M., Fjellström, M. & Mulk, I.- M. 2018. Tradition and transformation in Sámi animal-offering practices. – *Antiquity* 92 (362): 472–489. <https://doi.org/10.15184/aqy.2018.20>
- Salmi, A.-K., Fjellström, M., Äikäs, T., Spangen, M. Núñez, M. & Lidén, K. 2020a. Zooarchaeological and stable isotope evidence of Sámi reindeer offerings.

- *Journal of Archaeological Science: Reports* 29: 102129. <https://doi.org/10.1016/j.jas-rep.2019.102129>
- Salmi, A.-K., Niinimäki, S. & Pudas, T.** 2020b. Identification of working reindeer using palaeopathology and enthesal changes. – *International Journal of Paleopathology* 30: 57–67. <https://doi.org/10.1016/j.ijpp.2020.02.001>
- Salmi, A.** 2022. The archaeology of reindeer domestication and herding practices in Northern Fennoscandia. – *Journal of Archaeological Research*. <https://doi.org/10.1007/s10814-022-09182-8>
- Sandén, E.** 2017. Håll ögonen öppna i fjällen. – *Populär arkeologi* 5, s 38.
- Sealy, J.** 2001. Body tissue chemistry and paleodiet. – In: Brothwell, D.R. & Pollard, A.M. (eds.), *Handbook of Archaeological Sciences*. John Wiley & sons, New York: pp. 269–279.
- Seitsonen, O. & Viljanmaa, S.** 2021. Transnational landscapes of Sámi reindeer: Domestication and herding in Northernmost Europe 700–1800 AD. – *Journal of Field Archaeology* 46: 172–191. <https://doi.org/10.1080/00934690.2021.1881723>
- Sköld, P.** 1992. *Samisk bosättning i Gällivare 1550–1750*. Center för arktisk kulturforskning. Umeå universitet. Rapport nr 22.
- Solli, B.** 2016. Reindeer Hunting, Materiality, Entanglement and Society in Norway. – *Journal of Glacial Archaeology* 3:1–26. <https://doi.org/10.1558/jga.32444>
- Sommerseth, I.** 2009. *Villreinfangst of tamreindrif i indre Troms. Belyst ved samiske boplasser mellom 650 og 1923*. Dissertation. Insitutt for arkeologi og sosialantropologi, Tromsø Univeristy.
- Spitzer, M., Wildenhain, J., Rappsilber, J. & Tyers, M.** 2014 BoxPlotR: a web tool for generation of box plots. – *Nature Methods* 11, 121–122. <https://doi.org/10.1038/nmeth.2811>
- Statens offentliga utredningar.** 1966. *Renbetesmarkerna. Betänkande avgivet av renbetesmarksutredningen*. Jordbruksdepartementet, Sverige. 1966:12.
- Takken Beijersbergen, L.M. & Hufthammer, A.K.** 2012. Age determination of reindeer (*Rangifer tarandus*) based on postcranial elements. – In: Raemaekers, D.C.M., Esser, E., Lauwerier, R.C.G..M., Zeiler, J.T. (Eds.). *A Bouquet of Archaeozoological Studies*. Essays in Honour of Wietske Prummel. Barkhuis, Groningen, pp. 11–20. <https://doi.org/10.2307/j.ctt227285m.4>
- Thomas, R. & Worley, F.** 2014. *Recording pathology*. In *Animal Bones and Archaeology. Guidelines for Best Practice*. Historic England.
- Utsi, P. M.** 2007. *Traditionell kunskap och sedvänjor inom den samiska kulturen – relaterat till bevarande och hållbarhet nyttjande av biologisk mångfald*. Sametinget, Kiruna & Centrum för biologisk mångfald, Uppsala.
- Van Klinken, G.J.** 1999. Bone collagen quality indicator for paleodietary and radiocarbon measurements. – *Journal of Archaeological Science* 26 (6), 687–695. <https://doi.org/10.1006/jasc.1998.0385>
- Vedeler, M. & Bender Jøregensen, L.** 2013. Out of the Norwegian glaciers: Lendbreen – a tunic from the early first millennium AD. – *Antiquity* 87:788–801. <https://doi.org/10.1017/S0003598X00049462>
- von den Driesch, A.**, 1976. *Das Vermessen von Tierknochen aus Vor- und Frühgeschichtlichen Siedlungen*. Universität München, München.
- Vorren, Ø.** 1980. Samisk bosetning på Nordkalotten, arealdisponering og resursutnytting i historisk-økologisk belysning. – In: E. Baudou (ed.). *Nord-Skandinaviens historie i tvärvetenskapelig belysning*. *Acta universitatis Umensis* 24: 235–261, Umeå.
- Wadleigh, M.A., Schwarcz, H.P. & Kramer, J.R.** 1994. Sulphur isotope tests of sea salt

- correction factors in precipitation: Nova Scotia, Canada. – *Water, Air and Soil Pollution* 77 (1): 1–16. <https://doi.org/10.1007/BF00483047>
- Wallerström, T.** 2000. The Saami between East and West in the Middle Ages: an archaeological contribution to the history of reindeer breeding. – *Acta Borealia* 17(1): 3–39. <https://doi.org/10.1080/08003830008580501>
- Webb, C., Newton, J., Lewis, J., Stewart, A., Miller, B., Tarlton, J.F. & Evershed, R.P.** 2017. Sulphur-isotope composition of pig tissues from a controlled feeding study. – *STAR: Science & Technology of Archaeological Research* 3 (1): 71–79. <https://doi.org/10.1080/20548923.2017.1368821>
- Zachrisson, I.** 1997. *Möten i gränsland. Samer och germaner i Mellanskandinavien*. Monographs 4, Statens Historiska Museum, Stockholm.
- Zhu, Y., Sun, J., Zhu, Y., Wang, L. & Qi, B.** 2015. Endogenic oxidative stress response contributes to glutathione over-accumulation in mutant *Saccharomyces cerevisiae* Y518. – *Applied Microbiology and Biotechnology* 99(17):7069–78. <https://doi.org/10.1007/s00253-015-6629-7>
- Yan, J., Zhang, M., Jung, J., Lin, Q., Zhao, S., Xu, S. & Chen, L.** 2020. Influence on the conversion of DMS to MSA and SO₄²⁻ in the Southern Ocean, Antarctica, – *Atmospheric Environment* 233: 117611. <https://doi.org/10.1016/j.atmosenv.2020.117611>

Ben och horn av renar från smältande snöfläckar avslöjar information om förhistorisk landskapsanvändning i svenska Sápmi

Abstract in Swedish/Sammanfattning: I den här studien undersöker vi fynd av ben och horn av renar från två smältande snölegor vid Varánjunnje och Gárránistjáhkka inom *Stuor Muorkke* (Stora sjöfallets) nationalpark. I studien ingår också renben från domesticerade renar insamlade från samebyar i Sverige, daterade till mitten på 1900-talet. Syftet med studien är att jämföra moderna, historiska och arkeologiska fynd från renar inom olika renskötselområden i svenska Sápmi. Genom osteologiska analyser av kvarlevorna, ¹⁴C analyser och stabila isotopanalyser ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$ och $\delta^{34}\text{S}$) försöker vi förstå renarnas rörelsemönster och användning av landskapet. Resultatet från de morfometriska, radiometriska och stabila isotopanalyserna visar på liten variation i diet över tid för renarna från snölegorna. Vi har även kunnat visa att renarna betat inom olika geologiska områden samt att det inte fanns någon korrelation mellan ålder, kön, patologiska förändringar och diet. Kasttrade renar skiljde sig inte heller från övriga renar.

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