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# Mesolithic Scandinavian foraging patterns and hunting grounds targeted through laser ablation derived $^{87}\text{Sr}/^{86}\text{Sr}$ ratios at the Early-Mid Holocene site of Huseby Klev on the west coast of Sweden

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## ABSTRACT

Mobility is one of the most fundamental aspects of a foraging society. Since prehistoric mobility is often difficult to identify in the archaeological record, our understanding is largely based on comparison with ethnographic communities. In recent years the application of  $^{87}\text{Sr}/^{86}\text{Sr}$  isotope analysis has, however, greatly broadened our knowledge of mobility in the past. Despite this, few studies have been undertaken on faunal remains to explore their mobility patterns and infer human exploitation patterns with more precision. In this contribution we sampled 28 mammal teeth from three different occupation phases at the Early to Mid-Holocene coastal site of Huseby Klev, Sweden. We first established the local baseline for seven geographical areas in the region surrounding Huseby Klev. Then, by applying laser ablation-multi collector-inductively coupled plasma-mass spectrometry to the selected teeth, we identified the likely origins of a range of terrestrial and marine fauna, and the possible human mobility patterns required in their exploitation. Overall, our results demonstrate that the prehistoric communities inhabiting Huseby Klev undertook both short- and long-distance forays for the exploitation of particular species. By relating inferences on hunting grounds, derived from strontium isotope data, to zooarchaeological evidence from the site and ethnographic human mobility patterns, we establish and discuss the prerequisites for landscape utilization. Lastly, we demonstrate that glacial meltwater may have temporally affected the local oceanic Sr ratios – suggesting significantly increased soil and bedrock weathering may influence the Sr values in aquatic ecosystems and, consequently, should be considered in such regions and at times of melting glaciers. By applying the method to additional sites and assemblages in the future, our understanding of prehistoric mobility will be greatly enhanced.

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## 1. Introduction

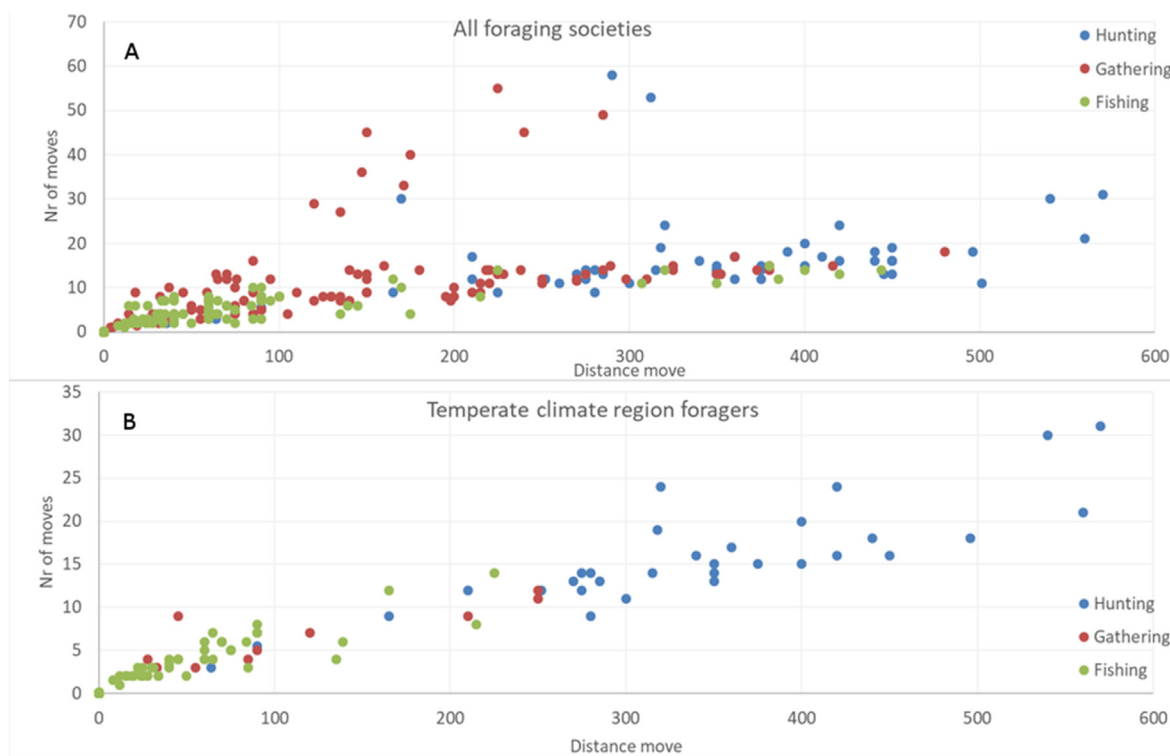
There has long been an interest in hunter-gatherer-fisher mobility and foraging patterns. This research interest goes back to, at least, the 1990s (Kelly, 1992, 1995). Understanding mobility is fundamental for our perception of foraging societies as it relates to all aspects of hunter-gatherer-fisher economies and practices. Mobility patterns are often considered in terms of residential and logistical, where residential mobility refers to settlement/base camp movement, while logistical mobility refers to the mobility of smaller groups while performing a specific task, i.e. hunting,

gathering or raw material procurement excursions etc. (Binford, 1980). At its most fundamental, large residential mobility – more residential moves over greater distances – is often connected to less complex, often egalitarian hunter-gatherer lifeways involving comparably small bands while on a never-ending journey between resource areas. On a global scale, increased residential mobility is connected to foragers primarily subsisting on hunting followed by gathering, while foragers primarily dependent on fishing exhibit the least amount of residential mobility (Fig. 1A). This pattern is strengthened and more pronounced in temperate regions (Fig. 1B).

While an understanding of ethnographic societies can advance our insights into ancient societies, the information is not easily translated into prehistoric foraging groups. Although general trends are visible ethnographically it is still a record created while

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**Fig. 1.** The relationship between yearly mileage mobility and the number of residential moves for foragers primarily subsisting on hunting, gathering or fishing for “all” known foraging societies (A) and foragers in the temperate climate zone,  $\geq 40^\circ$  to  $< 61^\circ$  N/S of Equator, (B). Data from Binford (2001).

in some contact with “modern”/industrialized societies, and the groups themselves are often from remote regions and are not fully representative of a world where foraging societies were the norm instead of rare curiosity. Still, ethnographic comparisons are interesting and useable as a heuristic tool when interpreting archaeological foraging remains. While aquatic dependent foragers, especially if also practising large-scale and long-term storage (Rowley-Conwy and Zvelebil, 1989), tend to live a comparably sedentary life, most of them practise some form of residential mobility (Fig. 1). Even year-round sedentary foragers practice logistical mobility to acquire food, raw materials and keep in contact with neighbouring groups. Terrestrial hunting is, in general, and with the possible exception of life on very remote islands lacking terrestrial mammals, always present. Among some societies and particular regions, e.g. coastal regions at high latitudes, hunting may have contributed little to the daily calorific intake (Marlowe, 2005). Hunting on these occasions indicates the use of secondary products, i.e. the procurement of raw materials from terrestrial mammals (hides, bones, antlers, tendons and organs) to manufacture clothes, tools and dwellings etc. Regardless of whether one practised high or low residential mobility, mobility is always connected to a specific settlement and the need for secondary products would still include movement to acquire these resources. In ethnographic contexts, the extent of the logistical forays is dependent on many factors such as the specific landscape, resource availability and predictability, population levels, societal codes, ability to create storages and level of territoriality (Freeman and Anderies, 2015; Kelly, 2013; Moritz et al., 2020; Rowley-Conwy and Piper, 2016).

In archaeological contexts, little is known and only a limited number of studies have attempted to study specific group foraging ranges and hunting or gathering practises related to a settlement or a specific group of people (Boethius et al., 2022a; David and

Kjällquist, 2018; Haverkort et al., 2008). A deeper understanding of ethnographic forager mobility patterns has contributed to an increased understanding of ethnographic groups and societies (Kelly, 1983). Due to a combination of little research and a lower data resolution, the movement patterns of prehistoric hunter-gatherer-fisher groups has not been comprehensively investigated and needs further exploration.

### 1.1. The use of strontium isotope ratios in archaeological research

Mobility and provenance studies are an integral part of archaeological research and have, since the 1980s, involved the analysis of  $^{87}\text{Sr}/^{86}\text{Sr}$  isotope ratios to study movement and dispersal, networks and population dynamics (Blank et al., 2021; Ericson, 1985; Gron et al., 2016; Kjällquist and Price, 2019; Montgomery, 2010; Montgomery et al., 2003; Price et al., 1994, 2002; Sjögren et al., 2009). The principle of using Sr isotopes in mobility and provenance studies lies within the bedrock of a region where, e.g. an older granitic bedrock has a higher  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio than a young basaltic bedrock (Malainey, 2011). The stable isotope  $^{87}\text{Sr}$  forms through the emission of negative  $\beta$ -particles from Rubidium-87 ( $^{87}\text{Rb}$ ) (Faure and Mensing, 2005). The  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio in the bedrock is dependent on both the original content of rubidium and the age since rock formation. Since the half-life of  $^{87}\text{Rb}$  is very long (ca. 49 billion years) no additional Rb decay needs to be accounted for in archaeological studies. The  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio remains unaltered as it is transferred from the bedrock to the topsoil and further into water and plants in a particular area (Graustein, 1989). Together with the composition of the soil cover, precipitation levels, evapotranspiration patterns, aeolian dust, sea spray etc. this forms the bioavailable Sr ratios, i.e. the range of available  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios at a specific location (Holt et al., 2021). Bioavailable Sr ratios are often established by measuring modern

plants (Holt et al., 2021; Snoeck et al., 2020) archaeological animals with limited mobility, e.g. mice and voles (Kootker et al., 2016), or by measuring the Sr ratios in various water bodies (Blank et al., 2018; Maurer et al., 2012). As animals feed and drink they absorb the bioavailable  $^{87}\text{Sr}/^{86}\text{Sr}$  values into their bodies where it is stored. In soft tissue, hair and bone, the Sr-values are continuously replaced throughout life when the body remodels. Teeth, on the other hand, remain unaltered after the enamel has mineralized.

Traditional Sr analyses involve comparisons of Sr isotope ratios from bulk enamel samples but recent sampling method development allows a finer resolution. By using laser ablation technology (or micro-drilling) it is possible to micro-sample a tooth multiple times to obtain several measurements, each representing a more limited time of averaged Sr ratios. If following the tooth mineralization pattern (Green et al., 2017), and if measuring the enamel at equal depths, it is possible to obtain chronologically ordered data and thus study the subject mobility (Boethius et al., 2022b; Piličiauskas et al., 2022). When correlated with detailed studies of bioavailable Sr this allows us to track animal mobility through a landscape (Lazzerini et al., 2021). For further discussions and references on enamel mineralization, Sr incorporation and the use of laser ablation to study prehistoric mobility see Boethius et al., 2022b.

## 1.2. The site Huseby Klev

Huseby Klev is located in a valley on the outer coast of the modern-day island of Orust in Bohuslän county, Sweden (Fig. 2). To the east of the valley, steep cliffs frame the scenery with the occasional cracks and ravines allowing access to the main part of the island. One of these cracks harboured the site of Huseby Klev (Nordqvist, 2005). At the time of occupation, the site was located close to, or on, the shore of a strait/bay that was directly connected to the Skagerrak, which is a body of water on the fringe of the Atlantic Ocean off the west coast of Sweden, south of Norway.

The site of Huseby Klev was discovered during a survey in 1988, while preliminary excavations were conducted in the autumn of the same year. Additional excavations at the site were carried out between 1992 and 1994 prior to the construction of the road Glimsåsvägen, which today runs where the site was previously located.

Huseby Klev consists of three separate phases of occupation. These include what were originally termed as “the deep pit”, “the tent”, and “the hut” (Nordqvist, 2005). To refine the site chronology, Bayesian chronological modelling was applied to a total of 28 legacy radiocarbon  $^{14}\text{C}$  dates. These dates were obtained from a range of materials, including charcoal (unspecified), hazelnuts (*Corylus avellana*), a dolphin (Delphinidae) bone, human (*Homo sapiens*) remains, a red deer (*Cervus elaphus*) antler punch and tar from birch (*Betula* sp.) bark resin (Table 1).

The model was implemented using OxCal v.4.4.4. The  $^{14}\text{C}$  ages of the charcoal, hazelnuts, red deer antler punch and tar were calibrated using the Northern Hemisphere atmospheric calibration curve, IntCal20 (Reimer et al., 2020). The  $^{14}\text{C}$  ages of the dolphin bone and human remains were calibrated using OxCal's Mix\_Curves function (i.e. IntCal20 offset by  $380 \pm 30$  years, as reported by Günther et al. (2018) and Kashuba et al. (2019), and the global marine calibration curve, Marine 20 (Heaton et al., 2020)). In addition, the function took into consideration the  $\delta^{13}\text{C}$  values (or assumed in the case of the dolphin). These were used to determine the proportion of marine protein in diets by applying a simple linear  $\delta^{13}\text{C}$  model (Arneborg et al., 1999) with estimated endpoints of  $-21.7$  and  $-10.1\%$ , corresponding to 0 and 100% marine diet, respectively (see Fischer et al., 2007).

Our Bayesian chronological model demonstrates that the three occupation phases at Huseby Klev took place from ca. the mid-11th to the mid-8th millennium cal BP (Fig. 3). The so-called “deep pit” dates to the Boreal chronozone (ca. 10,430–9380 cal BP). Despite the spatial separation, “the tent” overlaps somewhat with “the deep pit”, dating from the Boreal to the mid-Atlantic chronozones (ca. 10,110–8260 cal BP). Intriguingly, there is a ‘hiatus’ at the site which appears to coincide with the 8.2 ka event (Fig. 3). Then, Huseby Klev is reoccupied during the Atlantic chronozone (ca. 8150–7560 cal BP) as demonstrated by the dates from “the hut”.

The find material from Huseby Klev was initially only rudimentary published (Hernek and Nordqvist, 1995; Nordqvist, 2005), and the initial preliminary report on the osseous remains only included a table of the various species present from the different phases (Jonsson, 2005). Around twenty years after the excavation, the osseous remains were brought to Lund University and comprehensively analysed (Christensson, 2015; Hellgren, 2015;



Fig. 2. Aerial photography of the area surrounding Huseby Klev. An insert of Sweden is shown in the upper right (map from Lantmäteriet).

**Table 1**

Radiocarbon dates for Huseby Klev, sorted by context and estimated calendar date. The calibrated dates of samples and events were obtained by the OxCal v.4.4.4 model provided in the Supplementary Material, as described in the text.

Sample ( <sup>14</sup> C age) or event	Calibrated date (cal BP)		Reference	Context
	68% probability	95% probability		
<i>The deep pit start</i>	10,345–10,029	10,434–9964		
Human ( <i>Homo sapiens</i> ) bone Ua-6411 (9105 ± 100)	10,267–9914	10,364–9811	Nordqvist (2005)	The deep pit
Human ( <i>Homo sapiens</i> ) bone Ua-6410 (9040 ± 80)	10,243–9917	10,292–9893	Nordqvist (2005)	The deep pit
Dolphin ( <i>Delphinidae</i> ) bone Ua-6043 (9010 ± 90)	10,230–9910	10,260–9773	Nordqvist (2005)	The deep pit
Human ( <i>Homo sapiens</i> ) bone Ua-6407 (8965 ± 75)	10,199–9909	10,239–9782	Nordqvist (2005)	The deep pit
Hazelnut ( <i>Corylus avellana</i> ) Ua-6368 (8940 ± 90)	10,188–9897	10,231–9734	Nordqvist (2005)	The deep pit
Hazelnut ( <i>Corylus avellana</i> ) Ua-6364 (8940 ± 85)	10,188–9900	10,231–9750	Nordqvist (2005)	The deep pit
Hazelnut ( <i>Corylus avellana</i> ) Ua-6044 (8820 ± 70)	10,105–9705	10,165–9625	Nordqvist (2005)	The deep pit
Hazelnut ( <i>Corylus avellana</i> ) Ua-6412 (8730 ± 80)	9892–9617	10,116–9546	Nordqvist (2005)	The deep pit
Hazelnut ( <i>Corylus avellana</i> ) Ua-6045 (8730 ± 90)	9893–9618	10,120–9545	Nordqvist (2005)	The deep pit
Tar Ua-56731 (8712 ± 44)	9759–9589	9891–9551	Kashuba et al. (2019)	The deep pit
Hazelnut ( <i>Corylus avellana</i> ) Ua-6414 (8680 ± 80)	9885–9570	10,109–9534	Nordqvist (2005)	The deep pit
Hazelnut ( <i>Corylus avellana</i> ) Ua-6408 (8675 ± 80)	9885–9566	10,109–9534	Nordqvist (2005)	The deep pit
Tar Ua-7156 (8630 ± 105)	9886–9566	10,113–9505	Nordqvist (2005)	The deep pit
Hazelnut ( <i>Corylus avellana</i> ) Ua-6413 (8615 ± 85)	9740–9538	9901–9507	Nordqvist (2005)	The deep pit
<i>The deep pit end</i>	9639–9488	9908–9380		
<i>The tent start</i>	9731–9508	10,108–9463		
Human ( <i>Homo sapiens</i> ) bone Ua-6409 (8560 ± 75)	9555–9470	9674–9427	Nordqvist (2005)	The tent
Hazelnut ( <i>Corylus avellana</i> ) Ua-5652 (8505 ± 80)	9542–9451	9602–9296	Nordqvist (2005)	The tent
Hazelnut ( <i>Corylus avellana</i> ) Ua-6217 (8450 ± 75)	9535–9420	9544–9289	Nordqvist (2005)	The tent
Red deer ( <i>Cervus elaphus</i> ) antler punch Ua-5653 (8375 ± 100)	9522–9277	9538–9038	Nordqvist (2005)	The tent
Charcoal Ua-6362 (8155 ± 80)	9264–9008	9418–8818	Nordqvist (2005)	The tent
Charcoal Ua-6369 (8000 ± 65)	9019–8817	9260–8654	Nordqvist (2005)	The tent
<i>The tent end</i>	8994–8675	9206–8262		
<i>The hut start</i>	7982–7850	8152–7791		
Charcoal Ua-7606 (7090 ± 65)	7936–7835	7982–7776	Nordqvist (2005)	The hut
Hazelnut ( <i>Corylus avellana</i> ) Ua-6365 (7055 ± 65)	7930–7832	7966–7765	Nordqvist (2005)	The hut
Charcoal Ua-6216 (7010 ± 70)	7927–7801	7952–7741	Nordqvist (2005)	The hut
Hazelnut ( <i>Corylus avellana</i> ) Ua-6366 (6960 ± 55)	7925–7793	7935–7729	Nordqvist (2005)	The hut
<i>The hut end</i>	7902–7728	7929–7556		
<i>Outside of the three main cultural layers</i>				
Charcoal Ua-5654 (9400 ± 75)	10,721–10,511	11,068–10,384	Nordqvist (2005)	89:N
Charcoal Ua-6367 (8255 ± 70)	9405–9125	9427–9026	Nordqvist (2005)	Side of the hut
Hazelnut ( <i>Corylus avellana</i> ) Ua-6361 (7900–75)	8974–8597	8992–8550	Nordqvist (2005)	Layer 73 above the hut
Hazelnut ( <i>Corylus avellana</i> ) Ua-6363 (6590 ± 75)	7565–7428	7606–7328	Nordqvist (2005)	Side of the hut

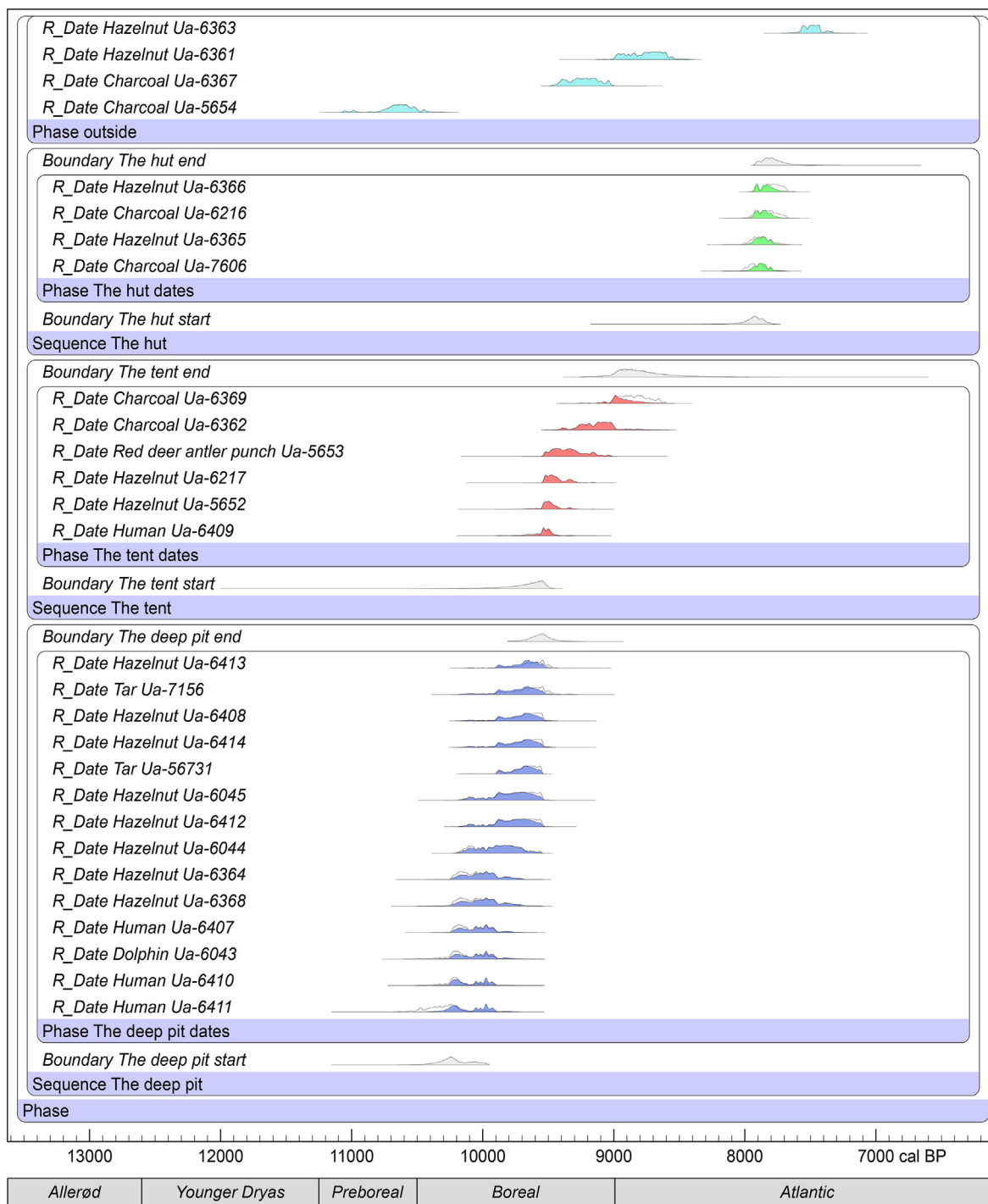
Nemecek, 2015; Widmark, 2015). After minor corrections, quantifications were used to interpret and contextualize the site as a whole (Boethius, 2018a). More recently, the lithic remains from “the deep pit” have also been re-analysed and published along with the ancient DNA results obtained from three birch bark tar mastics (Kashuba et al., 2019).

Previously, biomolecular analyses have been undertaken on osseous remains from the Huseby Klev site. The first study involved carbon and nitrogen stable isotope analysis, undertaken on five human bones and a white-beaked dolphin (*Lagenorhynchus albirostris*), demonstrating that the humans had consumed significant quantities of aquatic-derived protein (Lidén et al., 2004). The second study included a much larger sample set ( $n = 50$ ) and also utilized carbon and nitrogen stable isotope analysis and Bayesian mixing modelling. The results from this study showed that the human diets primarily consisted of an input of at least 75% of protein derived from aquatic resources - mainly high trophic level fish followed by marine mammals, i.e. dolphins and seals (Phocidae) (Boethius and Ahlström, 2018).

### 1.3. Prerequisites for studying mobility at the site of Huseby Klev

Terminal Pleistocene and Early Holocene migration patterns into Scandinavia have been inferred from lithic artefacts on archaeological sites. Different lithic technological traits suggest separate colonization events, from the south and from the northeast (Sørensen et al., 2013). This is also evident on the Scandinavian west coast, where the first colonization route from the south is

associated with Late Pleistocene - direct percussion - lithic traditions (Bang-Andersen, 2003; Kindgren, 1996; Schmitt et al., 2009). The north-eastern colonization route spread from the north along the Norwegian coast (Sørensen et al., 2013). It is associated with indirect percussion and pressure blade technology originating from the Russian/North-East European plains (Rankama and Kankaanpää, 2011; Sørensen et al., 2013). Initially, the groups represented by the different lithic technologies did not appear to homogenize, and contemporaneous sites following the two different technological traditions can be found in northernmost Norway at ca. 11,000 cal BP (Manninen et al., 2021b). In recent years, biomolecular analyses of prehistoric human remains from hunter-gatherer contexts throughout the region have confirmed these migration routes into Scandinavia and suggest a human admixture, over time, between these two groups of people (Günther et al., 2018). At Huseby Klev genetic admixture between these two foraging groups is evident by the analysis of three pieces of birch bark tar mastics retaining human DNA from the individuals that chewed them (Kashuba et al., 2019). These data represent the earliest known genetic admixture between the two Scandinavian colonization groups. No artefacts belonging to the older Early Mesolithic blade production concept from the south were identified in the lithic assemblage from the site (Kashuba et al., 2019; Supplementary Information). This suggests that the older technology had already been abandoned in favour of the more versatile eastern pressure blade technology. The pressure blade technology was also accompanied by an “enhanced” tool kit, including composite tools, e.g. slotted bone points. Recent research has suggested



**Fig. 3.** Bayesian chronological model of <sup>14</sup>C dates from Huseby Klev, as shown in Table 1. The model structure requires the three separate phases of occupation to appear sequentially, beginning with “the deep pit”, which is replaced by “the tent” and then “the hut”. The chronological order of individual samples is sorted by context and estimated calendar date (full OxCal CQL code provided at the end of the Supplementary Material; for details of the algorithms used, see Bronk Ramsey, 2009; Lee and Bronk Ramsey, 2012). Legend: outline distributions are simple calibrations of <sup>14</sup>C ages; colored distributions are posterior density estimates of the dates of samples; occupation phase dates (blue – “the deep pit”; red – “the tent”; green – “the hut”); turquoise – dates from areas outside of the three main cultural layers) are calibrations of individual <sup>14</sup>C ages (R\_Date). Chronozones based on Karlén and Larsson (2007), Mortensen et al. (2014), Jessen et al. (2015) and Jensen et al. (2020). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

that slotted bone points should also be considered a technology, predisposed to situational variation and local modification (Manninen et al., 2021a), to fit the need of meeting occasional, general, specific or cultural demands.

Through both technological innovations (aDNA and stable

isotope analyses), and international collaborative efforts in lithic analyses, much information on Early-Mid Holocene large-scale movement and colonization patterns has been obtained. A renewed research interest in the osseous remains from Huseby Klev has provided further insight into diet and subsistence

strategies, which have provided a glimpse into the prerequisites for an Early-Mid Holocene way of life in the coastal regions of Scandinavian. Since much of how we perceive hunter-gatherer-fisher behaviour and social codes are connected to their movement in and through the landscape, an increased understanding of prehistoric foraging mobility patterns would increase our understanding of these prehistoric societies even further. Here, the strontium ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) isotope ratios obtained from mammal teeth from three different occupation phases at the Early-Mid Holocene Swedish site of Huseby Klev are related to regional bioavailable Sr-signals, and used to study game animal provenience and mobility to evaluate human foraging patterns. The aim was to estimate site-specific foraging ranges, understand the hunting territories connected to the settlement, investigate how circumstances varied between the three occupation phases and evaluate if and/or how the foraging patterns changed between the mid-11th to mid-8th-millennium cal BP in a coastal environment on the island of Orust in the Skagerrak.

## 2. Material

The osseous remains from Huseby Klev were, in 2014, loaned from UV-väst, National Heritage Agency (today Arkeologerna, National Historical Museums of Sweden) and have, following a zooarchaeological analysis, been stored at Lund University while waiting to be permanently deposited at Bohusläns Museum. Permission to sample the remains was obtained from UV-väst before they were brought to Lund University, Sweden.

A total of 28 mammal teeth from the three occupation phases at Huseby Klev were selected for  $^{87}\text{Sr}/^{86}\text{Sr}$  analysis, including teeth from wild boar (*Sus scrofa*,  $n = 6$ ), red deer ( $n = 5$ ), roe deer (*Capreolus capreolus*,  $n = 4$ ), grey seal (*Halichoerus grypus*,  $n = 4$ ), dog (*Canis familiaris*,  $n = 3$ ), beaver (*Castor fiber*,  $n = 2$ ), water vole (*Arvicola amphibius*,  $n = 2$ ), field vole (*Arvicola terrestris*,  $n = 1$ ) and brown bear (*Ursus arctos*,  $n = 1$ ) (Table 2).

The teeth were selected based on their availability and appearance, as only teeth with intact enamel were sampled. The teeth likely represent different individuals as they were derived from different contexts.

## 3. Methods

### 3.1. Laser ablation

The teeth included in the study were washed in distilled water and cleaned with a soft brush. Following cleaning, the teeth were air-dried at room temperature and transported to the Vegacenter at the Swedish Museum of Natural History in Stockholm, to be mounted and fixed in a sample cell on a movable mounting table, and analysed for  $^{87}\text{Sr}/^{86}\text{Sr}$  strontium using LA-MC-ICP-MS.

$^{87}\text{Sr}/^{86}\text{Sr}$  ratios were measured using an NWR193 excimer laser ablation system (Elemental Scientific Lasers, Bozeman, USA) connected to a Nu Plasma II multi-collector ICP mass spectrometer (Nu Instruments Ltd, Wrexham, UK). Before analysis, each tooth was pre-ablated, using a laser spot size of 150  $\mu\text{m}$  to remove the outer ~10  $\mu\text{m}$  of surface enamel. Between 11 and 20 (median 15) parallel tracks of ca. 400  $\mu\text{m}$  length were then ablated for Sr analysis, except for the vole teeth, which were analysed with only two ablations each to establish the local baseline. The spot size was set to 130  $\mu\text{m}$  and measurements were taken at a consistent depth from the surface. Isobaric interferences, if present, were corrected by subtracting a gas blank ( $^{84}\text{Kr}$ ) and by peak stripping (e.g. doubly charged REE, Ca-dimers/argides,  $^{87}\text{Rb}$ ). The corrections were applied online and resulted in interference-free  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios for each data point. Polyatomic interference on  $m/z$  87 by

$^{40}(\text{Ca,Ar})^{31}\text{P}^{16}\text{O}$  was reduced by low oxide tuning of the gases (Willmes et al., 2016). All measurements were made at equal enamel depths following the tooth development, i.e. starting at the tip of the tooth and moving down towards the cementum–enamel junction.

Instrument operating conditions and data on the two standards, a spine from a velvet belly lantern shark (*Etmopterus spinax*), used for normalization, and a tooth from a mountain hare (*Lepus timidus*), used to verify that all interferences had been successfully removed are presented in Supplementary (S) Tables S1–S4. All available measurement data from the ablated teeth are presented in the Supplementary Material along with photographs of each tooth (Tables S5–S32, Figs. S1–S28).

Four of the teeth had damaged enamel surfaces (HK:153 (red deer), HK:154 and HK:155 (both roe deer), and HK:165 (red deer)); whereby some of the ablations failed to target the enamel at equal depths from the surface and instead struck deeper-lying enamel. The ability to obtain ordinal scale measurements depends on comparable sampling depths in a tooth (Boethius et al., 2022b). Thus, the ablations failing to strike the enamel at comparable depths are not temporally connected to the other ablations from the tooth. Two of these teeth (HK:155–3 ablations, HK:165–1 ablation) had only minor data variance, which indicates low mobility during enamel mineralization. The ablations striking the damaged areas of the teeth, thereby, show only minor deviations from the other measurements. The same is not true for the two remaining teeth with damaged surfaces (Fig. 4). These teeth (HK:153–2 ablations, HK:154–10 ablations) had a greater measurement variance. The measurements still represent the general location during mineralization, but the pattern generated by the measurement sequence (Fig. 4 lower) is not ordinal, due to differences in mineralization timing at different depths in mammal enamel (Green et al., 2017).

Four of the teeth (HK:152 and HK:174 (both red deer), and HK:159 and HK:160 (both grey seal)) had slightly deviant  $^{84}\text{Sr}/^{86}\text{Sr}$  ratios from the accepted value of 0.0565 (Thirlwall, 1991), which could indicate an insufficient correction of interferences or matrix effects from surface contaminations. However, the  $^{84}\text{Sr}/^{86}\text{Sr}$  ratios deteriorate before  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios do when Sr concentrations decrease. Due to the small relative proportions of  $^{84}\text{Sr}$  natural abundance, it has been suggested that the gain of using the  $^{84}\text{Sr}/^{86}\text{Sr}$  ratios to determine offsets in the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio is limited when working with laser ablation technology (Copeland et al., 2010).  $^{84}\text{Sr}/^{86}\text{Sr}$  ranges of  $0.05517 \pm 0.00251$  (at  $2\sigma$ ) have previously been considered acceptable (Copeland et al., 2010), which is well within the offset levels of all teeth from Huseby Klev. The slight  $^{84}\text{Sr}/^{86}\text{Sr}$  offset in four of the Huseby Klev teeth is, consequently, not considered to have affected the measured  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios in such a way that it would influence the interpretations.

## 4. Results

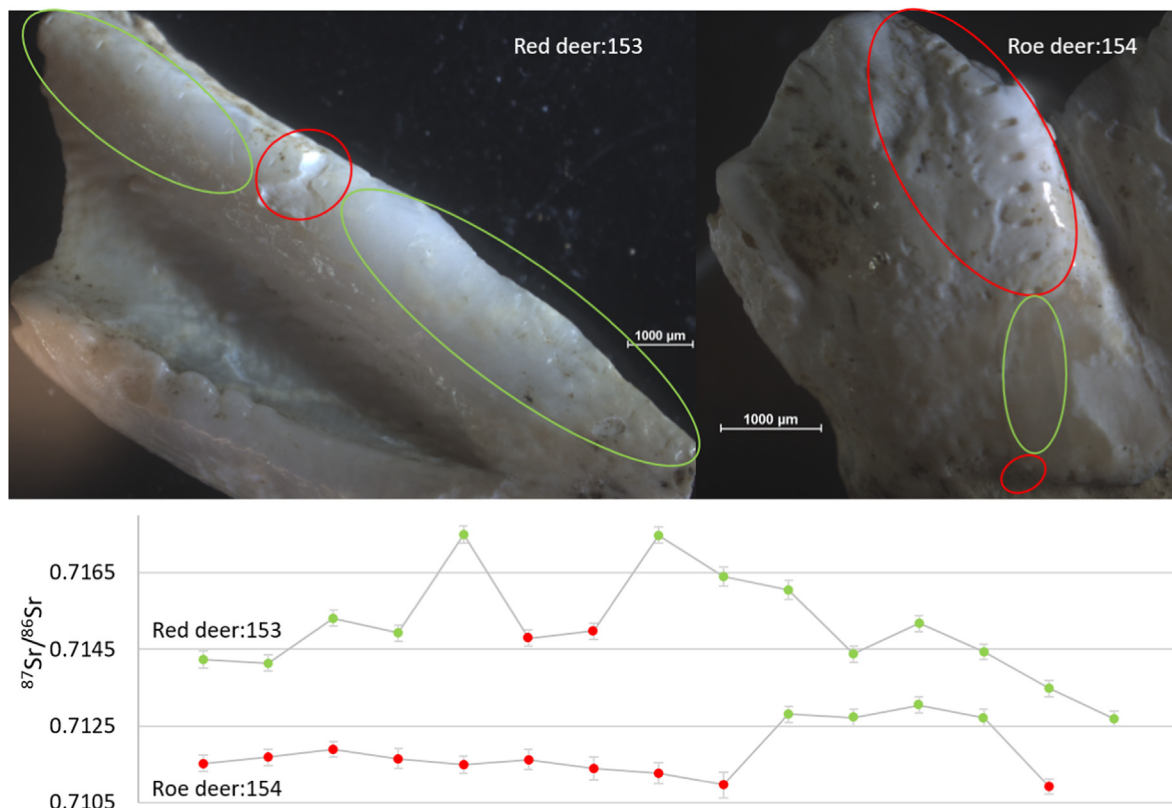
### 4.1. Establishing a bioavailable baseline

Two water vole teeth and one field vole tooth from Huseby Klev were ablated to establish the local Sr range. Due to their limited natural mobility they were considered to have resided on or near to the site during occupation (see Boethius et al., 2021 for detailed information on vole mobility and feeding habits in relation to their Sr uptake). They were recovered from “the deep pit” and “the tent”, and thus representative of a local baseline (Fig. 5).

The vole Sr ratios varied between 0.70932 and 0.71039. The water vole from “the deep pit” displayed slightly higher ratios (median = 0.71023) compared to the water vole from “the tent” (median = 0.70944), and roughly identical Sr ratios compared to

**Table 2**  
Summarized metadata on the analysed teeth from Huseby Klev.

ID number	Occupational phase	Taxon	Tooth	Context	Number of ablations
HK:148	The hut	Wild boar	I1+	L.74 Fnr. 3442	13
HK:149	The hut	Wild boar	M3-	L.73 Fnr. 3115	15
HK:150	The hut	Grey seal	P2+	L.72 F3433	19
HK:151	The hut	Grey seal	P4+	Fnr. 589	13
HK:152	The hut	Red deer	M3-?	L.73 fnr. 3495	17
HK:153	The hut	Red deer	M3+	L.74 fnr. 3113	15
HK:154	The hut	Roe deer	M2-	fnr. 3429	14
HK:155	The hut	Roe deer	M2+	L.74 fnr.3603	14
HK:156	The hut	Dog	P1-	L.74 fnr. 3610	14
HK:157	The hut	Dog	I2-	L.74 fnr. 3579	17
HK:158	The hut	Beaver	I	L.73 fnr. 3369	13
HK:159	The deep pit	Grey seal	C	L.46 fnr.591	16
HK:160	The deep pit	Grey seal	C+	fnr.3727	17
HK:161	The deep pit	Wild boar	P2+	fnr.7	14
HK:162	The deep pit	Wild boar	M2-	L.85 fnr.6273	14
HK:163	The deep pit	Beaver	P4-	L.46 fnr.102	15
HK:164	The tent	Red deer	I-	fnr.602	16
HK:165	The tent	Red deer	M3+	L.20 fnr. 3058	20
HK:166	The tent	Water vole	I	fnr.259	2
HK:167	The tent	Roe deer	M2-	L.22 fnr.122	15
HK:168	The tent	Wild boar	M1-	L.20 fnr.3158	18
HK:169	The tent	Wild boar	M3+	L.20 fnr.3042	19
HK:170	The tent	Field vole	I	L.20 fnr. 3087	2
HK:171	The tent	Roe deer	M2-	L.20 fnr.821	19
HK:172	The deep pit	Brown bear	I3+	fnr.90	15
HK:173	The deep pit	Water vole	I	L.89 fnr.149	2
HK:174	The deep pit	Red deer	M2/3+	L. 46 fnr. 105	11
HK:296	The tent	Dog	P4+	L. 22 Fnr:123	16



**Fig. 4.** The two teeth from Huseby Klev with damaged outer enamel surfaces and the ablations connected to the teeth. Red indicates non-surface enamel targeted and green indicates that the laser targeted the enamel surface. Notice the break in the pattern when the measurements were taken on surface enamel compared to the areas where the surface was missing. Two of the ablations on HK:153 (red deer) hit a damaged area of the tooth where the surface enamel was missing. Only four of the measurements on HK:154 (roe deer) targeted the enamel surface at comparable depths (10 ablations struck deeper-lying enamel) due to more extensive damage on that tooth. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)



the field vole from “the tent” (median = 0.71023). Due to the location of the site, on the outer coastal regions of the island of Orust in the Skagerrak, the local Sr ratios are affected by the sea spray effect (Alonzi et al., 2020). The measurement also corresponds well with previous data from coastal Bohuslän, which suggest that bioavailable Sr up to 10–15 km from the coast can be heavily influenced by oceanic Sr (Price et al., 2021b).

The bioavailable baseline of western Sweden, roughly the area between the coast of Bohuslän and Lake Vättern, have previously been investigated and bioavailable data is available (Blank et al., 2018; Klassen et al., 2020). To obtain a higher resolution on the spot specific Sr baseline, existing data from archaeological large mammals and freshwater fish were excluded from the baseline, as their origin might not correspond with their find location. Thus, the reconstructed baseline in this study is based on modern small mammals (water vole, squirrel (*Sciurus vulgaris*), European hedgehog (*Erinaceus europaeus*), mountain hare (*Lepus timidus*), least weasel (*Mustela nivalis*) and stoat (*Mustela erminea*) (Klassen et al., 2020)), modern water samples and archaeological rodents (Blank et al., 2018), modern snail shells and teeth from archaeological hares, a hedgehog and rodents (Sjögren et al., 2009) (see Table S33 for information on specific baseline data). The data was used to establish seven zones (A–G) of bioavailable strontium ranges (Fig. 6), i.e. isoscapes (Bowen and West, 2008), which were considered when interpreting the origin and mobility patterns of the analysed animals from Huseby Klev.

Zone A is here defined as the Skagerrak and is based on the current global seawater constant of 0.709179 (Mokadem et al., 2015). Zone B is the 10–15 km coastal zone affected by the sea spray effect. Zone C is defined as an interim corridor to the south of Lake Vänern roughly between Zone B and Göta älv. Zone D lies to the east of Göta älv and reaches roughly to the lithotectonic border between the western and eastern Sveconorwegian provinces. Zone E has been divided into two separate regions, based on their higher Sr ranges, the westernmost part of Zone E is concentrated around an area of granite within a region of granitic gneiss (Zone F) and the eastern part of Zone E is the granitic bedrock to the west of Lake Vättern. Zone F mainly derives from the granitic gneiss area between Zone D and the eastern part of Zone E. Zone G constitutes the local areas of the Halle and Hunne mountains, Kinnekulle and Falbygden, which has comparably young sedimentary bedrock.

#### 4.2. Origin and mobility of the animals at Huseby Klev

In total, 390 individual measurements were made on the 25 investigated mammal teeth from Huseby Klev. One, ablation 12 on a beaver tooth (Sample HK:158), struck an area of surface contamination and was excluded (see Fig. S11 and Table S15 for specific

details). All remaining 389 measurements were included in the study (Fig. 7).

As seen in Fig. 7, there is great variability in the observed animal mobility patterns. The two wild boars (HK:161 and HK:162) from “the deep pit” show general homogenous Sr ranges whereas the four wild boars from both “the tent” (HK:168 and HK:169) and “the hut” (HK:148 and HK:149) show higher levels of mobility. Similarly, the one red deer (HK:174) from “the deep pit” had limited mobility, although greater than the wild boar from the same phase, while the four red deer from both “the tent” (HK:164 and HK:165) and “the hut” (HK:152 and HK:153) show diverging patterns where one individual from each phase had homogenous Sr ranges and one showed greater measurement variation. No roe deer teeth were available from “the deep pit” and the two teeth from “the tent” (HK:167 and HK:171) phase show higher measurement variation and higher Sr ratios compared to the two teeth from “the hut” phase. Only one bear tooth was identified in the zooarchaeological material (Boethius, 2018a), from “the deep pit” phase, and it (HK:172) indicated limited, mid-range, Sr ranges during mineralization. The two beaver teeth from “the deep pit” (HK:163) and “the hut” (HK:158) phases had the highest Sr ranges observed among the measured teeth and both showed large measurement variations, indicating mobility between regions with differing Sr baselines. Four grey seal teeth were measured, two from “the deep pit” (HK:159 and HK:160) phase and two from “the hut” (HK:150 and HK:151) phase. All had homogenous measurements but the two teeth from the earlier phase had more diverse and higher Sr ratios compared to the seal teeth from “the hut” phase. Lastly, the three analysed dog teeth, one from “the tent” (HK:296) phase and two from “the hut” (HK:156 and HK:157) phase, show homogenous Sr ranges that overlap with the measurements obtained from seals from “the hut”.

To contextualize the origin and mobility of the different animals, the laser ablation data can be related to the local isoscapes, i.e. the north-south oriented zones of specific bioavailable baseline ranges (Fig. 6). Isoscapes are not unique and different areas can have the same, similar and overlapping Sr-ratios, which is true both in large-scale geographic comparisons and in local regions as observed here, between the coast of Bohuslän and the western shores of Lake Vättern (Fig. 8).

## 5. Discussion

Huseby Klev is one of the earliest known sites along the Atlantic coast to yield a substantial zooarchaeological assemblage. In addition, the site was likely occupied episodically during the Boreal and Atlantic chronozones, providing a unique opportunity to study the development of Early to Mid-Holocene Scandinavian foraging

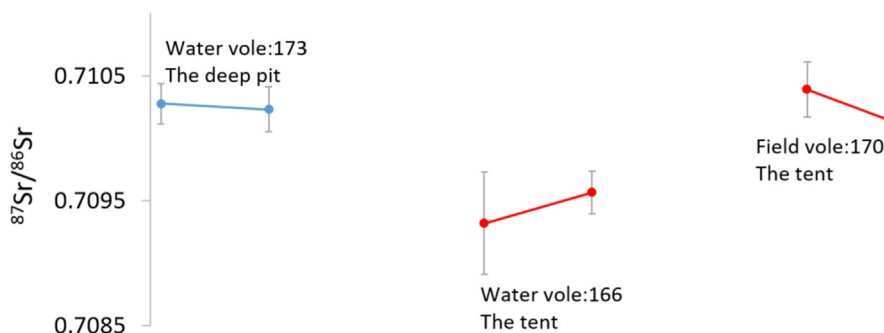
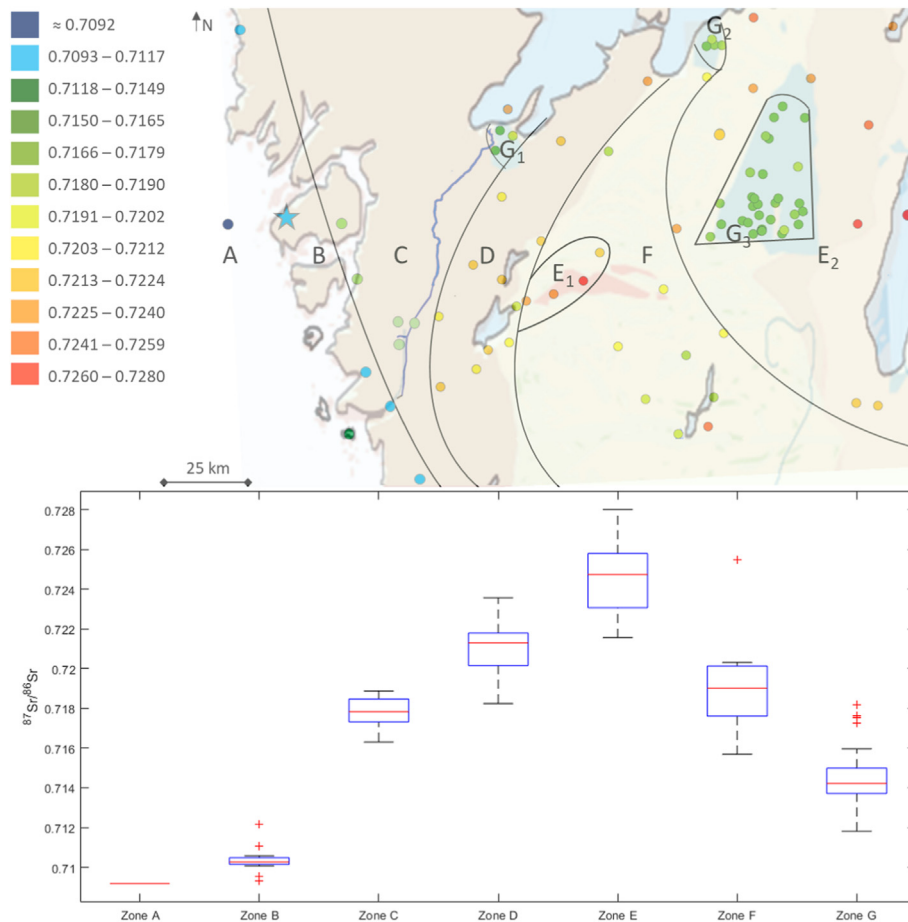


Fig. 5.  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio data obtained from two water voles and one field vole from Huseby Klev.



**Fig. 6.** Bioavailable baseline map (upper) of the area around Huseby Klev (blue star) in western Sweden. Bioavailable baseline information based on data from Blank et al. (2018), Klassen et al. (2020), Sjögren et al. (2009) and this study (water and field voles) (see Table S33 for details). The Sr isotope ranges in zones A–G are based on the bioavailable Sr ranges visualized as boxplots (lower), where the boxes represent the 25–75 percentile of the measurements and the whiskers represent the variation at 1.5 times the interquartile range (or the max/min values when they are within this range). Outliers are highlighted with a '+' mark. Map displayed on the 1:1 M bedrock map from the Geological Survey of Sweden (SGU) where detailed information of bedrocks and lithotectonic units can be found. Key for number of bioavailable sources in each zone: Zone A = 1, Zone B = 13, Zone C = 5, Zone D = 12, Zone E = 17, Zone F = 10 and Zone G = 46. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

activities (Boethius, 2018b) and how aquatic environments were exploited (Boethius et al., 2020). The osseous assemblages from Huseby Klev have provided a number of teeth suitable for Sr analyses, which can be used to improve our understanding of where the exploited animals were hunted and how the human foraging societies were organised.

The origin and networks among Scandinavian Stone Age foragers have previously been studied through Sr ratios (Ahlström and Price, 2021; Kjällquist and Price, 2019; Klassen et al., 2020; Price et al., 2021a, 2021b). Hunter-gatherer-fisher mobility and territory use is, however, limited to the investigation of a few sites (Norje Sunnansund – Maglemose, Skateholm – Ertebølle and Västerbjers – Pitted Ware Culture) showing generally limited mobility ranges with human Sr ratios being reflected in the landscape surrounding the investigated sites (Boethius et al., 2022a). The animals teeth at these sites have, apart from Sr analyses on fish teeth at Norje Sunnansund (Boethius et al., 2021), so far not been analysed. Despite all three sites being interpreted as aquatically oriented and mainly sedentary (Ahlström and Price, 2021; Boethius, 2017; Price et al., 2021a) there were major differences in human mobility patterns. These were interpreted as being caused by differences in landscape territorialisation, with human mobility at Norje Sunnansund interpreted as unbound by territorial restrictions while both Skateholm and Västerbjers were interpreted

as having mobility patterns affected by territorial restrictions from neighbouring groups (Boethius et al., 2022a).

A similar study is not possible at Huseby Klev, as no human teeth were available for Sr analysis. Instead, animal Sr ratios were used to study hunting grounds and associated territories. Huseby Klev was located in a similar environmental setting, close to the sea. The human bone collagen stable isotope data ( $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ) further suggests a diet based on aquatic resources (Boethius and Ahlström, 2018). A similar pattern is equally reflected by the zooarchaeological evidence (Fig. 9) in which aquatic mammals dominate the bone assemblage during “the deep pit” phase and fish dominate the two younger phases of occupation (Boethius, 2018a).

At Huseby Klev, no strontium analyses were made on fish teeth. However, considering the location of the site (Fig. 2) and the exclusivity of marine taxa in the assemblage (Boethius, 2018b), the fish were likely caught in the Skagerrak or in the archipelago surrounding the island of Orust. Similarly, aquatic mammals were likely also exploited from close to the site. During “the deep pit” phase, the inhabitants of Huseby Klev relied heavily on the exploitation of white-beaked dolphins. No dolphin teeth, however, were recovered during the excavations, likely due to their small size and weak attachment to the jaw. Two grey seal teeth from both “the deep pit” and “the hut” phases were analysed (no seal teeth were recovered from “the tent” phase). The seal data from “the hut”

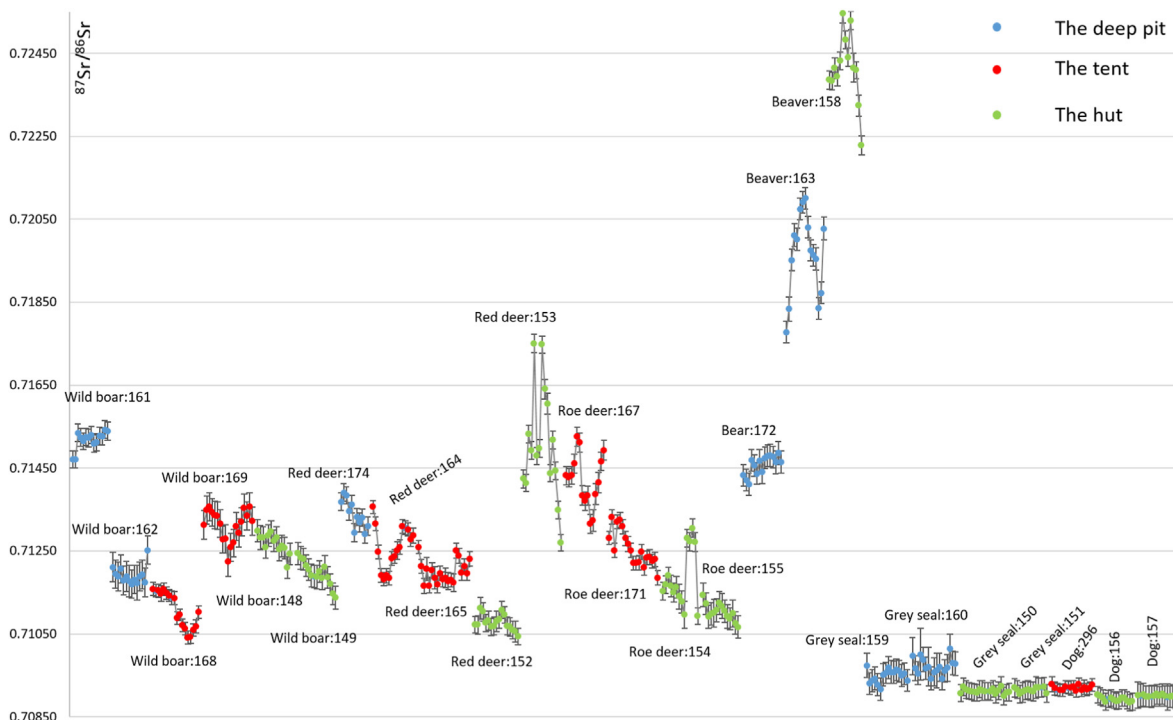


Fig. 7.  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios for the measured animals at Huseby Klev as measured in an ordered sequence from the enamel tip to the enamel-cementum junction through laser ablation.

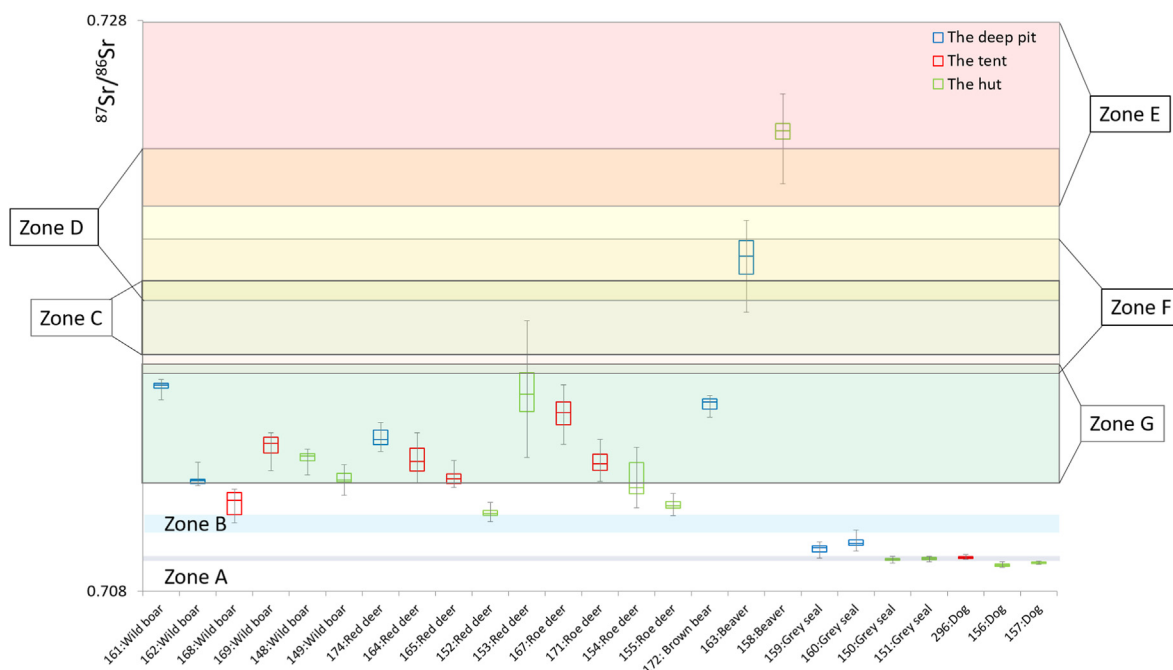


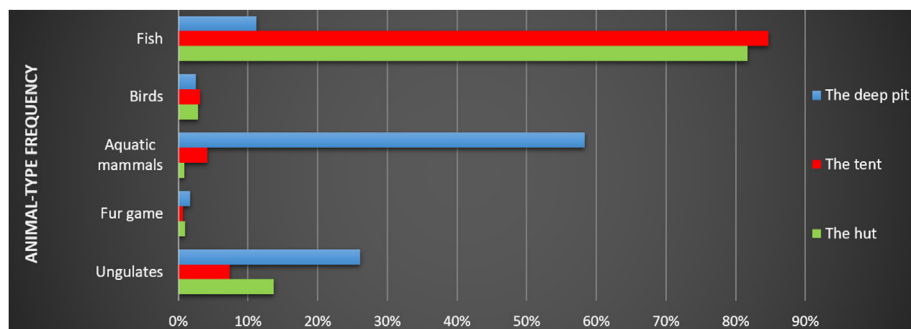
Fig. 8. Boxplots showing the measurement distribution of the ablations from the animals within a group and each tooth related to the Sr ranges from the zones established in Fig. 6.

phase align with the modern global seawater  $^{87}\text{Sr}/^{86}\text{Sr}$  constant, but the two measurement series from “the deep pit” are higher and do not align with current oceanic ratios. This warrants further consideration, as it may also signal an offset to terrestrial Sr ratios.

5.1. Shifts in local oceanic Sr ratios

Higher oceanic Sr ratios may be caused by higher  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios

from riverine glacial meltwater draining into the Skagerrak. The glacial till and newly exposed bedrock from retreating glaciers are more susceptible to weathering and the releasing of highly radiogenic Sr when subjected to large quantities of glacial meltwater and increasing temperatures (Blum and Erel, 1995). Oceanic  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios are caused by the combined effects of submarine hydrothermal Sr flux to seawater and continental drainage (Peucker-Ehrenbrink and Fiske, 2019). The added weathering caused by the



**Fig. 9.** Frequency comparison of the main animal types represented at the three phases of Huseby Klev occupation. Comparison based on the weight of identified fragments (for mammals to species or family and for bird and fish to class). Data from Boethius (2018a).

deglaciation of the ice sheets in their glacial-interglacial variations have been suggested to, over time, contribute to the slowly increasing oceanic  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios (Palmer and Elderfield, 1985). The finely grained rock material left by the ice sheets is highly radiogenic and prone to extensive weathering (Vance et al., 2009) which, after deglaciation, is dispersed into the oceans through the runoff glacial meltwater. The long term effect is small, with estimations of an increase in  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios at around 5 ppm per 100,000 years (Blum and Erel, 1995). The model does, however, suggest an initial spike in riverine Sr ratios immediately following deglaciation and a subsequent rapid return to 'normal' Sr ratios (Blum and Erel, 1995:Fig. 2).

The ice sheet in southern Norway would have only recently retreated when Huseby Klev was first occupied, cf. e.g. the deglaciation timing of Scandinavia (Cuzzone et al., 2016; Stroeven et al., 2016). The Skagerrak also experienced a large fresh water influx from the "Glomma drainage event". Meltwater from the large Norwegian ice-dammed Lake Nedre Glåmsjø, holding  $>100\text{ km}^3$  of water, drained into the Skagerrak from the Oslo Fjord region ca. 10,400–10,200 cal BP (Longva and Thoresen, 1991). Consequently, large volumes of glacial meltwater, with accumulated radiogenic terrestrial rock debris from the south Norwegian region, drained into the Skagerrak ca. 130 km north of Huseby Klev around the time of occupation of "the deep pit". Moreover, the Swedish part of the ice sheet at the time of "the deep pit" occupation had its southernmost boundary in mid-Sweden, and would continue to release substantial quantities of meltwater. This water likely made its way to Lake Vänern and further on into the sea through Göta älv. The continuously increasing temperatures during the Boreal chronozone (Davis et al., 2003) likely rapidly melted the remaining ice sheet, with final deglaciation occurring at ca. 9100 cal BP (Cuzzone et al., 2016). The large volume of meltwater in the millennium prior to Scandinavia becoming ice-free, thereby, likely contributed to temporarily increased Sr ratios along the drainage rivers. When these rivers drained into the sea it might have contributed to the observed increased Sr ratios there.

To date, no studies have attempted to solve the exact duration of increased riverine, lake or sea Sr ratios after a deglaciation event. The duration of the Sr ratio increases in the sea likely varies greatly depending on specific circumstances, such as size and depth of water body, water flow or currents. However, it might be possible to use deglacial sedimentation of lake systems as a proxy for Sr ratio influence. Most such studies have been conducted on comparably small and shallow lakes, reflecting the lake size prevalence in Scandinavia. This might affect comparability with larger lakes and coastal sea regions. However, larger lakes have also been investigated and evidence from the sediment record from Lake Storsjön in Jämtland County, Sweden's fifth largest lake that covers an area of

ca. 458 km<sup>2</sup>, is available (Labuhn et al., 2018). Lake Storsjön was formed ca. 9800 cal BP, just after the retreating Scandinavian ice sheet had vacated the area, and showed a significant influx from glacier meltwater for around 250 years (Labuhn et al., 2018). While increased Sr ratios might be present for a somewhat extended period in this large lake, i.e. until the lake water had been further diluted by "non-glacial" water, it establishes a lower Sr influx boundary. Although the Sr-ratios influence would have been more limited in a much larger water body, such as the Skagerrak, the 250 years lower boundary might give some indication of the minimum duration of possible influence. This is especially true since the distance from the ice sheet would have been roughly comparable between the ice sheet and Lake Storsjön at 9500 cal BP, and the Skagerrak and the ice sheet at ca. 10,000 cal BP.

Considering the alignment with the grey seal data from "the hut" phase (median ablation  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of 0.70912) and the current global seawater  $^{87}\text{Sr}/^{86}\text{Sr}$  constant (also 0.70912), the ca. 1200 year difference in occupation between "the deep pit" and "the hut" phases appears long enough to remove any remaining Sr-ratio increases caused by the deglaciation. No seal teeth were available from "the tent" phase and no fish teeth were analysed in this study; however, water voles are considered a semi-aquatic species who spend most of their lives within a 2-m range from the edge of the water (Lawton and Woodroffe, 1991), consuming a diet consisting of both aquatic and terrestrial resources. Strontium ratios from water voles have also previously been used as a proxy for water Sr-ratios (Boethius et al., 2021), whereby its use here is warranted. Comparing the Sr-ratio data from grey seals (median = 0.70960) and the water vole (median = 0.71025) from the "the deep pit" phase, the median measurement discrepancy is 0.00065, i.e. the water voles have a slightly higher average Sr-ratio caused by their dietary input from terrestrial resources. By subtracting "the deep pit" phase discrepancy number from the median Sr-ratios for "the tent" phase water voles (median = 0.70944), Sr-ratios of 0.70879 are obtained, i.e. a value below the current global seawater. There may be some differences in the water vole Sr ratios due to seasonal discrepancies in feeding habits or by the availability of plants during the two separate phases of occupation. However, the general impression is that the higher oceanic Sr ratios observed during "the deep pit" phase are not present during "the tent" phase, despite the similar dates (Fig. 3). While more data is needed to confirm these observations, it seems intuitive that aquatic Sr-ratios will, at least, be affected by glacial meltwater as long as there is ongoing sedimentation. The 250 years of deglacial sediment recorded in Lake Storsjön might thus offer a minimum Sr elevation effect. Correspondingly, the temporal differences between "the deep pit" and "the tent" phases at Huseby Klev might offer a maximum duration Sr elevation effect.

## 5.2. Origin and mobility of the terrestrial species

If strictly reliant on the regional baseline data, the Sr ratios from most of the terrestrial animals fall into Zone G (cf. Figs. 6 and 8). Considering what we know of contemporary foraging societies, much of the daily activities occur in what Binford termed the foraging zone. The foraging zone is defined as the mobility range within a single day from the site (Binford, 1982), which is within a 10 km radius (often less, depending on the food return rate) (Kelly, 2013). Similar foraging ranges have also been suggested among prehistoric populations. Among the Californian Mono, logistic mobility ranges have been estimated not to exceed 10 km, based on GIS-analyses of spatial relationships between residential bases and acorn processing sites (Morgan, 2008).

Some of the hunted terrestrial animals may have been caught at a greater distance from the settlement at Huseby Klev. However, it is unlikely that most of the hunted prey came from 150 km away (Zone G<sub>3</sub>) or that they all came from the closer, but more limited, areas (G<sub>1</sub> and G<sub>2</sub>) of sedimentary bedrock in a landscape of otherwise older bedrock with higher Sr-ratios (Fig. 6). It is possible that some of the hunted animals came from one of the Zone G areas. However, other explanations might also be considered, whereby further reflections on the available Sr-baseline are warranted.

Zone B was established based on a perceived sea spray effect up to 10–15 km from the coast (Price et al., 2021b), but the effect from rainwater saturation of the soils might have expanded even further inland. Studies have shown that precipitation may significantly contribute to <sup>87</sup>Sr/<sup>86</sup>Sr ratios in regions of high rainfall (Evans et al., 2010), whereas, in certain regions, the isotopic signatures may approach the radiogenic signatures of local rainfall (Raiber et al., 2009).

Today, the west coast of Sweden has the highest amount of precipitation (together with the northern mountain regions) in the country, with, in the region of study, higher precipitation up to around 35 km from the coast (Persson, 2015). Precipitation levels have varied throughout the Holocene, but inferences from pollen data from the Fennoscandian tree-line area suggests that the period between ca. 11,000–8000 cal BP would have been among the wettest during the Holocene (Seppä and Birks, 2001). While Holocene precipitation along the Swedish west coast has not been specifically studied, considering its exposure to the open sea, it is a fair assumption that the region, similar to today, had a comparably higher rainfall during the Early Holocene. The rainwater effect on the Early Holocene Sr baseline is, however, difficult to measure and some discrepancies from the current baseline may be expected. The current bioavailable baseline is also limited, and while the main Sr zones can be revealed based on the current bioavailable record, finer details are not available. For example, only five baseline measurements are available from Zone C, which are all located to the south of Huseby Klev (where higher modern precipitation levels expand further inland compared to areas at the same or more northern latitudes (cf. Persson, 2015 Fig. 27)). Furthermore, the few available measurements from Zone C are not located near to the 10–15 km distance border covered in Zone B. This means that it is plausible that the higher, but inland gradually diminishing precipitation levels, may have affected Sr-ratios even in Zone C, and that the perceived abrupt change in bioavailable Sr-ratios between Zones B and C would, in reality, have been more gradual as an effect of gradually diminishing influence from rainfall.

### 5.2.1. How can these inferences be used to understand foraging ranges at Huseby Klev?

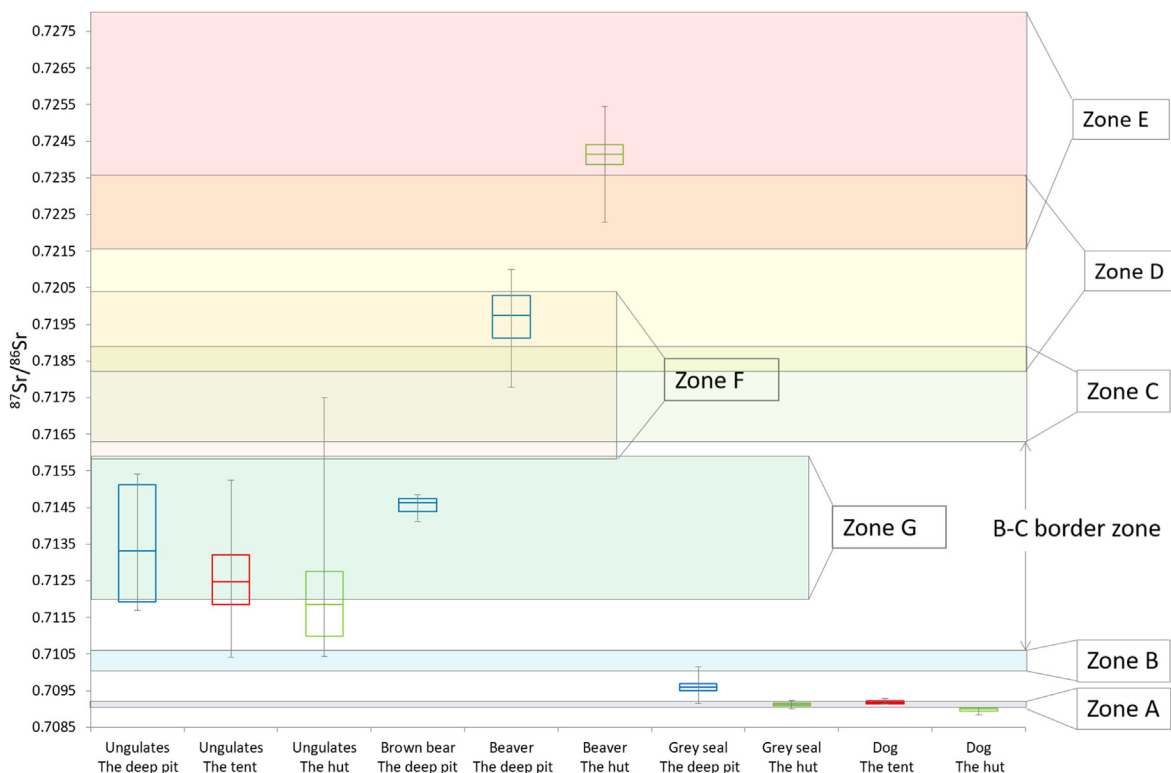
Considering the Sr-ratio overlap between the different zones as argued above, the seemingly large difference between Sr-ratios in Zones B and C is likely artificial and a border zone between them

likely accounts for some of the observed terrestrial game Sr-ratios. By grouping the investigated teeth into categories based on their taxonomic order and occupational phase (Fig. 10), the majority of the terrestrial game originates from either the border between Zones B and C or Zone G. Translated into distances from Huseby Klev, the majority of the terrestrial game came from somewhere between 15 and 20 km (B–C border zone) and 50 km (Zone G<sub>1</sub>) from the site as the crow flies.

There is a clear reduction in Sr-ratios for the ungulates, from being the highest during the earliest phase to having the lowest ratios during the youngest phase. This could be interpreted as more inland-oriented hunting forays during “the deep pit” phase, but considering the possible effects of the deglaciation and a temporally limited increased weathering of the very old bedrock in inland mid-north Scandinavia, it is more likely an effect of a temporally limited increase of bioavailable Sr ratios. The chronological drop in ungulate Sr-ratios acts in favour of the border zone as the main hunting region.

Beavers are separated from the other terrestrial game with higher Sr-ratios and higher mobility signals. Beavers have a different habitat than the other terrestrial game and while they spend the majority of their lives in water, they consume a diet incorporating both aquatic oriented water lilies (*Nymphaeaceae*) or beach-growing herbs, and leaves and bark from trees, such as aspen (*Populus*), birch and willow (*Salix*), which vary depending on the season and availability (Wilsson, 1971) and on the local aquatic habitat, i.e. lacustrine or riverine setting, of the investigated subject (Milligan and Humphries, 2010). Young beavers are known to migrate large distances in search of new habitats (Wilsson, 1971), which could explain part of their variance. Once settled, beavers are territorial and their normal home ranges are most often within 0.5 km from the colony, with a peripheral zone <1 km away (Aleksiuk, 1968). Their diet is mainly based on aquatic plants during the summer and on terrestrial trees during the winter (Wilsson, 1971), which, if the waterways had a different Sr ratio than the surrounding land (e.g. Boethius et al., 2021), might lead to oscillating Sr ratios. Thereby, the Sr-signals perceived as increased mobility may in fact be an artefact of a seasonal diet. As seen in Fig. 7 the oscillation is also greatest for the beaver from “the deep pit” phase. This could be linked to the suggested higher riverine Sr ratios caused by deglaciation. Even though the mobility signals may be caused by a seasonal diet, the ratios are still very high and do not appear in the close vicinity to Huseby Klev. Therefore, the nearest regions for the beavers from “the deep pit” and “the hut” phases are ca. 50 and between ca. 80–90 km, respectively as the crow flies, inevitably longer travelling distances.

The suggested 15–20 km distance to the catchment area for the bulk of the terrestrial game is somewhat extended compared to ethnographic analogies on foraging radii (Binford, 1982; Kelly, 2013). However, these studies only account for terrestrial mobility and do not include the use of watercraft. Canoes would have been an essential component at Huseby Klev, inferred from both the location of the site and the osseous remains, which are dominated by aquatic animals (Fig. 9). More direct evidence for the use of canoes is also available. The numerous birch bark tar pieces bearing wooden imprints are interpreted as having been used to seal canoes (Nordqvist, 2005). Contemporaneous finds of a canoe from the Netherlands (Beuker and Niekus, 1997; van Zeist, 1957), paddles (e.g. Friesack IV (Gramsch, 1992; Gramsch and Kloss, 1989), Duvensee (Bokelmann, 2012), Star Carr (Taylor et al., 2018) and Holmegaard (Broholm et al., 1924)) also demonstrates that the use of canoes was contemporaneously widely available. Finally, newly discovered rock art from northern Norway depicting a canoe, and bearing a strong resemblance to skin umiaks, has been shoreline dated to the Early Mesolithic period (ca. 11,000–10,000 cal BP)



**Fig. 10.** Boxplots showing the measurement distribution of the ablations when the studied animals have been grouped according to taxonomic order and chronological phase. A possible B–C border zone has been added to the figure as a way to indicate a less sharp boundary between the measured Zones B and C (cf. Fig. 6).

(Gjerde, 2021). Consequently, canoes were likely the norm during the Early and Mid-Holocene of the Scandinavian peninsula (Bjerck, 2017) and not an exotic novelty.

The use of canoes would substantially increase the daily foraging ranges – estimations regarding aquatic oriented foragers suggest comfortable daily round trips of distances up to 30 km from the residential site (Ames, 2002), which is well within the estimated distance to the terrestrial game, as suggested by the Sr-ratios. The use of canoes would also allow the transport of large-sized animals, without butchering them *in situ* on the kill site. This also accords with the zooarchaeological evidence from the site. Despite large discrepancies in ungulate species distribution during the different occupations, all regions of the body were, apart from wild boar body core elements (ribs, vertebrae and pelvic bones) lacking in “the hut” phase, represented in the material from all three phases (Fig. 11).

Ungulate species hunting grounds were, considering their Sr-ratios, likely located both on the island of Orust itself, at the closest regions of mainland Sweden, and on the sedimentary bedrock areas in the region (Fig. 12).

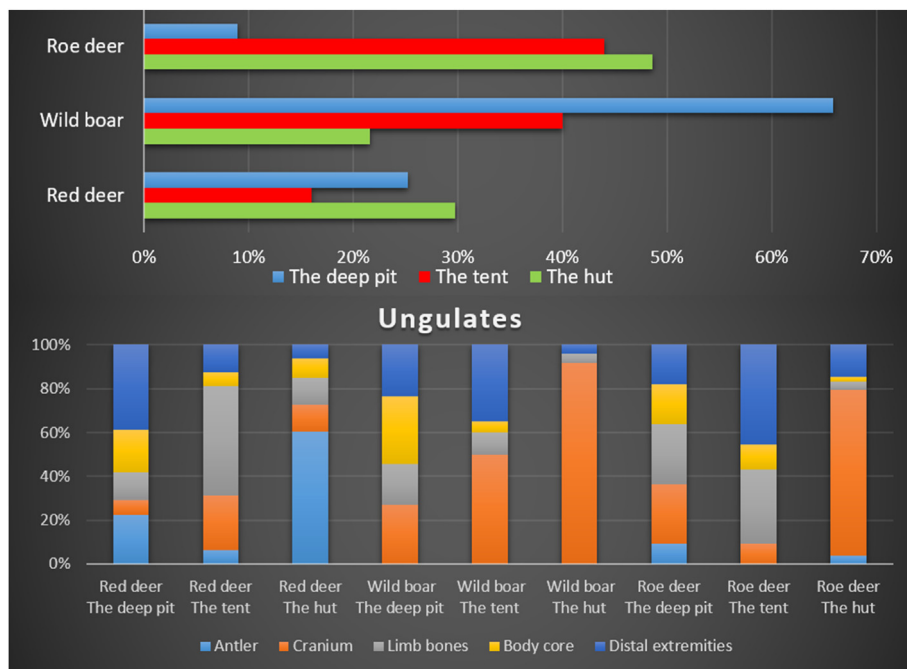
A similar elemental distribution is not present among the beaver remains. Only loose lower incisors and a nearly complete mandible were present in the osseous material. Considering its deviant and higher Sr-ratios coupled with the suggestion that beaver mandibles were part of the Mesolithic foraging toolkit (Hatting, 1969), it is possible that the beaver teeth do not represent the foraging radius but instead what Binford (1982) defines as a logistical radius, i.e. where the task groups spent at least one night away from their residential camp. If we consider a daily maximum range using a canoe to be ca. 60 km, by following the waterways east into mainland Sweden the logistical border was at least two days travel away from the settlement during “the deep pit” phase and a minimum of three days away during “the hut” phase (Fig. 12). However,

it is also possible that the beaver teeth were acquired via exchange and/or trade and instead represent forays into other groups’ territory, i.e. what Binford (1982) defines as the visiting zone, used for trade and interaction with neighbouring groups. Considering that no Sr-ratios are currently available for human teeth or unique objects (e.g. tooth pendants) from Huseby Klev, this remains unsubstantiated.

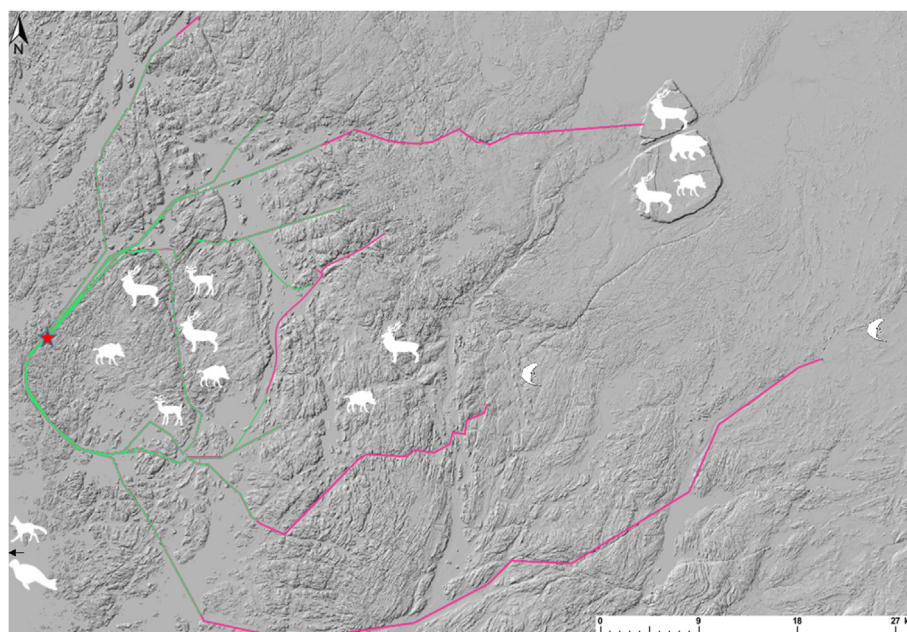
Similar to the beaver, bear bones are rare in the Huseby Klev assemblage and all fragments are derived from either the skull or are represented by phalanges (Boethius, 2018a). The scarce number of bones from specific body regions could indicate that bears were opportunistically hunted, butchered *in situ* with only selected parts (e.g. pelts – with the phalanges still attached, skull trophies, tendons and the meat) being brought back to the main settlement. If viewed in the context of the Sr isotope ratios, a kill site in Zone G (in Fig. 12 shown as the closest sedimentary bedrock area at the Halle and Hunne mountains) may be suggested.

What then does understanding the foraging ranges at Huseby Klev do for understanding the nature of the settlement? Was it a seasonal or a temporary campsite along the route of mobile foragers or does it represent a more permanent settlement, i.e. frequently revisited or long lastingly occupied, as a more or less permanent residence?

Among ethnographic hunter-gatherer-fishers, dependence on reliable aquatic resources is often associated with low residential mobility (Binford, 2001; Kelly, 2013; Marlowe, 2005). However, even though previous studies have shown that aquatic animals dominate the faunal assemblages it does not tell anything about the level of sedentism practised among the occupants of the site. The same can be said about the Sr-data from the hunted animals, i.e. they do not help us understand the level of sedentism or the number of residential moves per year, as teeth from the hunted animals could represent what was foraged in the local area and



**Fig. 11.** Species distribution of the three most frequently occurring ungulates at the different phases of occupation (upper), and their elemental distribution (lower). N = 344. Data from (Boethius, 2018a).



**Fig. 12.** Topographic map showing the catchment area for the different animals from Huseby Klev based on inferences from their <sup>87</sup>Sr/<sup>86</sup>Sr isotope ratios. The shoreline has been estimated around 25 m above sea level at the time of “the deep pit” occupation (Kashuba et al., 2019). The colored lines follow the Early Holocene waterways based on the topographic data. Green lines represent distances that would be possible to undertake within a day (back and forth) using canoes. Pink lines represent distances where a minimum of an overnight stay is required. Note that the lines in the map only represent travel time and not the actual time spent hunting and/or gathering in the particular region (map from Lantmästarieriet). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

brought back to the site, before moving on to next settlement. The Sr data from the dogs (“the tent” and “the hut” phases) are a different matter as they are, similar to the seals, aligned with the global seawater constant with mean Sr-ratios of  $0.70909 \pm 0.00012$  (Figs. 8 and 10). Sr-ratios in an animal body are dependent on the origin of the diet, which suggests that the dogs consumed marine fish or mammals, during the mineralization of their tooth enamel.

In turn, this suggests that the inhabitants of the Huseby Klev settlements did not practise extended residential mobility between the coast and inland, and if they brought young dogs on their hunting trips inland, the trips were short enough not to leave any traces in the dog teeth. A pattern of limited mobility between the coast and hinterland is not only valid for Huseby Klev, but for most known Early Holocene Scandinavian human foragers. There is only

one clear isotopic overlap out of 89 investigated Early Holocene humans found in coastal and inland contexts during the Early and Middle Mesolithic period (Boethius and Ahlström, 2018; Boethius et al., 2020). It is possible that residential mobility did take place along the coastline, however, given the strong dietary input from aquatic resources and the reliable and recurrent nature of fish, it seems likely that along the coast residential mobility was also limited. Furthermore, while only the lithic remains from “the deep pit” phase at Huseby Klev have been thoroughly analysed, all stages in tool production are present, suggesting an extended residency. The final stages of tool production are, however, less common, compared to the earlier stages, which might suggest that the prepared cores were transported from the site to be finished elsewhere. The cultural layer from “the deep pit” phase is largely considered as waste disposal in water, which may have resulted in a sorting effect where the micro-debitage from the last stages of tool production was left on land, i.e. mostly outside of the area of excavation (Kashuba et al., 2019: Supplementary Information). Thereby, it is somewhat difficult to determine if the final stages of blade production were conducted at the (likely) adjacent settlement area or at greater distances from the site. Since the settlement area corresponding to “the deep pit” phase is not known, it is also not possible to safely estimate the actual size of the settlement.

Based on the finds-material from Huseby Klev, it is, consequently, difficult to safely estimate the level of sedentism for the human population during the different occupation phases. High mobility rates and a strong reliance on aquatic mammals has been suggested among the pioneer colonizing groups of western Scandinavia (Bjerck, 2017). Following the initial expansion, it has also been suggested that foraging groups were settling the coastal regions more permanently (Bergsvik et al., 2016) at the same time as fish became more visible and abundant in the archaeological record (Boethius et al., 2020; Ritchie et al., 2016). The osteological material and the stable isotope data from Huseby Klev indicate the extensive consumption of both fish and marine mammals during the initial occupation phase, suggesting that the more marine mammal oriented lifestyle associated with the pioneer settlers of the region were not practised. Marine mammals are also all but absent in the osseous remains during the two later occupation phases and human diets appear to have been dominated by fish. This fits well with the temporal frame for western Scandinavia and suggests that the Huseby Klev assemblages did not originate from highly mobile foragers. However, if the degree of seal and dolphin bones in the osseous remains may be considered an indicator of mobility, it might suggest that the foragers from “the deep pit” phase were slightly more mobile than the foragers from the two later phases. All considered, this suggests that the hunting regions and the origins of the various hunted game should be viewed from the perspective of sedentary communities in which the animal origins reflect the hunting grounds associated with the “territory” of the Huseby Klev settlements.

## 6. Conclusions

$^{87}\text{Sr}/^{86}\text{Sr}$  isotope ratios on mammal teeth from three phases of Early-Mid Holocene occupation at Huseby Klev were analysed by LA-MC-ICP-MS. By relating the data to bioavailable Sr values from the surrounding landscape it has been possible to obtain information on where different species were hunted and their mobility patterns during the time of enamel formation. The results show that most of the ungulate species (wild boar, red deer and roe deer) were likely hunted on the opposite side of the island of Orust, on the nearby mainland of Sweden or possibly in the smaller areas of sedimentary bedrock in the study region. Beavers were hunted further inland, up to three days travel by canoe, or were exchanged

with neighbouring groups. Brown bears were, considering their low frequencies of only selected elements, likely hunted at the sedimentary bedrock areas in the study region, although, if only considering their Sr ratios, it is possible they were hunted on the far side of the island of Orust or on nearby mainland Sweden as well.

All seals have isotope ratios corresponding with the global seawater constant. The ratios were somewhat higher during “the deep pit” phase, which is likely due to an influx of higher Sr ratios from glacial meltwater incorporated into the Skagerrak at the time of occupation. This temporally limited increase had likely disappeared during the later occupations at the site.

Moreover, this temporally limited Sr-isotope ratio increase likely affected the mainland riverine systems as well, which contributed to slightly increased ratios for terrestrial mammals during “the deep pit” phase. Thereby, it is unlikely that the human foraging ranges altered much between the different phases, despite the ca. 2870-years between the earliest and latest radiocarbon dates for the site.

The Sr-ratios from the Huseby Klev dogs align with the data obtained from the seals, suggesting a diet consisting (almost) exclusively of fish and/or marine mammals. This, in turn, suggests a limited coast to inland mobility with inland trips lasting for only limited time periods that were too short to be able to affect the Sr-ratios of the dogs, if they were part of the hunting trips.

The evidence obtained from the Sr ratios from mammal teeth found at Huseby Klev provides information on their provenance, i.e. the region where the hunted mammals originated. By connecting the information obtained from various animals from a site it is possible to estimate the hunting grounds related to a settlement. Using this information in tandem with other evidence enabled us to discuss prehistoric foraging ranges and settlement territories, greatly expanding our understanding of prehistoric foraging societies. Considering the lack of previous studies, the results from Huseby Klev can greatly contribute to our understanding of Early and Mid-Holocene hunter-gatherer-fisher groups. Furthermore, if the methodological approach used here is applied to other sites and assemblages, we may gain greater insights of these societies and how the foraging ranges relating to specific sites varied across time and space. This, in turn, may facilitate a knowledge-leap similar to that obtained when data on ethnographic hunter-gatherer-fishers was collated and compared to generate generalizations, whereby a more profound understanding of prehistoric foraging societies may be achieved.

## Authors' contributions

**Adam Boethius:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Writing – original draft, review & editing. **Melanie Kielman-Schmitt:** Data curation (LA-MC-ICP-MS operation), Review. **Harry K Robson:** Bayesian chronological model, Review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data available in Supplementary material



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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.quascirev.2022.107697>.

## References

- Ahlström, T., Price, T.D., 2021. Mobile or stationary? An analysis of strontium and carbon isotopes from Västerbjers, Gotland, Sweden. *J. Archaeol. Sci.: Report* 36, 102902.
- Aleksziuk, M., 1968. Scent-mound communication, territoriality, and population regulation in beaver (*Castor canadensis* Kuhl.). *J. Mammal.* 49, 759–762.
- Alonzi, E., Pacheco-Forés, S.I., Gordon, G.W., Kuijt, I., Knudson, K.J., 2020. New understandings of the sea spray effect and its impact on bioavailable radiogenic strontium isotope ratios in coastal environments. *J. Archaeol. Sci.: Report* 33, 102462.
- Ames, K.M., 2002. Going by boat: the forager-collector continuum at sea. In: Fitzhugh, B., Habu, J. (Eds.), *Beyond Foraging and Collecting: Evolutionary Change in Hunter-Gatherer Settlement Systems*. Kluwer/Plenum, New York, pp. 19–52.
- Arneborg, J., Heinemeier, J., Lynnerup, N., Nielsen, H.L., Rud, N., Sveinbjörnsdóttir, Á.E., 1999. Change of diet of the Greenland Vikings determined from stable carbon isotope analysis and <sup>14</sup>C dating of their bones. *Radiocarbon* 41 (2), 157–168.
- Bang-Andersen, S., 2003. Southwest Norway at the Pleistocene/Holocene transition: landscape development, colonization, site types, settlement patterns. *Norweg. Archaeol. Rev.* 36, 5–25.
- Bergsvik, K., Hufthammer, A., Ritchie, K., 2016. The emergence of sedentism in mesolithic western Norway. A case-study from the rockshelters of søvarhelleren and olsteinhelleren by the hardanger Fjord. In: Bjerck, H.B., Breivik, H.M., Frøtheim, S.E., Piana, E.L., Skar, B., Tivoli, A.M., Zangrando, A.F. (Eds.), *Marine Ventures-Archaeological Perspectives on Human-Sea Relations*. Equinox Publishing, Sheffield, pp. 15–33.
- Beuker, J., Niekus, M., 1997. De kano van Pesse: de bijl erin. *Nieuwe Drentse Almanak* 114, 122–126.
- Binford, L.R., 1980. Willow smoke and dogs' tails: hunter-gatherer settlement systems and archaeological site formation. *Am. Antiq.* 45, 4–20.
- Binford, L.R., 1982. The archaeology of place. *J. Anthropol. Archaeol.* 1, 5–31.
- Binford, L.R., 2001. *Constructing Frames of Reference: an Analytical Method for Archaeological Theory Building Using Ethnographic and Environmental Data Sets*. University of California Press, Berkeley.
- Bjerck, H.B., 2017. Settlements and seafaring: reflections on the integration of boats and settlements among marine foragers in Early Mesolithic Norway and the Yámana of Tierra del Fuego. *J. I. Coast Archaeol.* 12, 276–299.
- Blank, M., Sjögren, K.-G., Knipper, C., Frei, K.M., Malmström, H., Fraser, M., Svensson, E.M., Günther, T., Yngve, H., Jakobsson, M., Götherström, A., Storå, J., 2021. Mobility patterns in inland southwestern Sweden during the neolithic and early bronze age. *Archaeological and Anthropological Sciences* 13, 64.
- Blank, M., Sjögren, K.-G., Knipper, C., Frei, K.M., Storå, J., 2018. Isotope values of the bioavailable strontium in inland southwestern Sweden—a baseline for mobility studies. *PLoS One* 13, e0204649.
- Blum, J.D., Erel, Y., 1995. A silicate weathering mechanism linking increases in marine <sup>87</sup>Sr/<sup>86</sup>Sr with global glaciation. *Nature* 373, 415–418.
- Boethius, A., 2017. Signals of sedentism: faunal exploitation as evidence of a delayed-return economy at Norje Sunnansund, an Early Mesolithic site in south-eastern Sweden. *Quat. Sci. Rev.* 162, 145–168.
- Boethius, A., 2018a. Huseby klev and the quest for pioneer subsistence strategies: diversification of a maritime lifestyle. In: Persson, P., Skar, B., Breivik, H.M., Riede, F., Jonsson, L. (Eds.), *The Ecology of Early Settlement in Northern Europe - Conditions for Subsistence and Survival*. Equinox, Sheffield, pp. 99–128.
- Boethius, A., 2018b. Fishing for ways to thrive: integrating zooarchaeology to understand subsistence strategies and their implications among Early and Middle Mesolithic southern Scandinavian foragers. In: *Acta Archaeologica Lundensia Series in 8°*, vol. 70. Lund University, Studies in Osteology 4, Lund.
- Boethius, A., Ahlström, T., 2018. Fish and resilience among Early Holocene foragers of southern Scandinavia: a fusion of stable isotopes and zooarchaeology through Bayesian mixing modelling. *J. Archaeol. Sci.* 93, 196–210.
- Boethius, A., Ahlström, T., Kielman-Schmitt, M., Kjällquist, M., Larsson, L., 2022b. Assessing laser ablation multi-collector inductively coupled plasma mass spectrometry as a tool to study archaeological and modern human mobility through strontium isotope analyses of tooth enamel. *Archaeological and Anthropological Sciences* 14, 97.
- Boethius, A., Bergsvik, K.A., Nilsson, B., 2020. Knowledge from the ancient sea – a long-term perspective of human impact on aquatic life in Mesolithic Scandinavia. *Holocene* 30, 632–645.
- Boethius, A., Kjällquist, M., Kielman-Schmitt, M., Ahlström, T., Larsson, L., 2021. Early Holocene Scandinavian foragers on a journey to affluence: Mesolithic fish exploitation, seasonal abundance and storage investigated through strontium isotope ratios by laser ablation (LA-MC-ICP-MS). *PLoS One* 16, e0245222.
- Boethius, A., Kjällquist, M., Kielman-Schmitt, M., Ahlström, T., Larsson, L., 2022a. Diachronic forager mobility: untangling the Stone Age movement patterns at the sites Norje Sunnansund, Skateholm and Västerbjers through strontium isotope ratio analysis by laser ablation. *Archaeological and Anthropological Sciences* 14, 176.
- Bokelmann, K., 2012. Spade padding on a mesolithic lake—remarks on preboreal and boreal sites from duvensee (northern Germany). In: Niekus, M.J.L.T., Barton, R.N.E., Street, M., Terberger, T. (Eds.), *A Mind Set on Flint: Studies in Honour of Dick Stapert* 369–380. Barkhuis, Groningen.
- Bowen, G.J., West, J.B., 2008. Isotope landscapes for terrestrial migration research. *Terrestrial Ecology* 79–105 (Elsevier).
- Broholm, H., Jessen, K., Winge, H., 1924. Nye fund fra den ældste stenalder. Homegaard- og Sværdborgfundene. Aarbøger for Nordisk oldkyndighed og historie, pp. 1–144, 1924.
- Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51, 337–360.
- Christensson, V., 2015. Vilt I Området Kring Kustboplatsen Huseby Klev En Analys Av Vilt Som Påträffats I Det Osteologiska Materialet Inom Huseby Klev Från Tidigmesolitikum. Department of Archaeology and Ancient History: Lund University. Unpublished seminar paper in Historical Osteology.
- Copeland, S.R., Sponheimer, M., Lee-Thorp, J.A., le Roux, P.J., de Ruiter, D.J., Richards, M.P., 2010. Strontium isotope ratios in fossil teeth from South Africa: assessing laser ablation MC-ICP-MS analysis and the extent of diagenesis. *J. Archaeol. Sci.* 37, 1437–1446.
- Cuzzone, J.K., Clark, P.U., Carlson, A.E., Ullman, D.J., Rinterknecht, V.R., Milne, G.A., Lunkka, J.-P., Wohlfarth, B., Marcott, S.A., Caffee, M., 2016. Final deglaciation of the Scandinavian Ice Sheet and implications for the Holocene global sea-level budget. *Earth Planet Sci. Lett.* 448, 34–41.
- David, E., Kjällquist, M., 2018. Transmission of knowledge, crafting and cultural traditions, interregional contact and interaction, 7300 cal BC. In: Glørstad, H., Knutsson, K., Knutsson, H., Apel, J. (Eds.), *The Technology of Early Settlement in Northern Europe - Transmission of Knowledge and Culture*. Equinox Publishing, Sheffield, pp. 231–276.
- Davis, B., Brewer, S., Stevenson, A., Guiot, J., 2003. The temperature of Europe during the Holocene reconstructed from pollen data. *Quat. Sci. Rev.* 22, 1701–1716.
- Ericson, J.E., 1985. Strontium isotope characterization in the study of prehistoric human ecology. *J. Hum. Evol.* 14, 503–514.
- Evans, J.A., Montgomery, J., Wildman, G., Boulton, N., 2010. Spatial variations in biosphere <sup>87</sup>Sr/<sup>86</sup>Sr in Britain. *J. Geol. Soc.* 167, 1–4.
- Faure, G., Mensing, T.M., 2005. *Isotopes: Principles and Application*. John Wiley & Sons, Hoboken, p. 3.
- Fischer, A., Olsen, J., Richards, M., Heinemeier, J., Sveinbjörnsdóttir, Á.E., Bennike, P., 2007. Coast—inland mobility and diet in the Danish Mesolithic and Neolithic: evidence from stable isotope values of humans and dogs. *J. Archaeol. Sci.* 34, 2125–2150.
- Freeman, J., Anderies, J.M., 2015. The socioecology of hunter–gatherer territory size. *J. Anthropol. Archaeol.* 39, 110–123.
- Gjerde, J.M., 2021. The earliest boat depiction in Northern Europe: newly discovered Early Mesolithic rock art at Valle, northern Norway. *Oxf. J. Archaeol.* 40, 136–152.
- Gramsch, B., 1992. Friesack mesolithic wetlands. In: Coles, B. (Ed.), *The Wetland Revolution In Prehistory*. 65–72. The Prehistoric Society and WARP, Exeter.
- Gramsch, B., Kloss, K., 1989. Excavations near friesack: an early mesolithic marshland site in the northern plain of central europe. In: Bonsall, C. (Ed.), *The Mesolithic in Europe: Papers Presented at the Third International Symposium*. John Donald Publishers, Edinburgh, pp. 313–324.
- Graustein, W.C., 1989. <sup>87</sup>Sr/<sup>86</sup>Sr ratios measure the sources and flow of strontium in terrestrial ecosystems. In: Rundel, P., Ehleringer, J., Nagy, K. (Eds.), *Stable Isotopes in Ecological Research*. Springer, New York, pp. 491–512.
- Green, D.R., Green, G.M., Colman, A.S., Bidlack, F.B., Tafforeau, P., Smith, T.M., 2017. Synchronrotron imaging and Markov chain Monte Carlo reveal tooth mineralization patterns. *PLoS One* 12, e0186391.
- Gron, K.J., Montgomery, J., Nielsen, P.O., Nowell, G.M., Peterkin, J.L., Sørensen, L., Rowley-Conwy, P., 2016. Strontium isotope evidence of early Funnel Beaker Culture movement of cattle. *J. Archaeol. Sci.: Report* 6, 248–251.
- Günther, T., Malmström, H., Svensson, E.M., Omrak, A., Sánchez-Quinto, F., Kilinc, G.M., Krzewińska, M., Eriksson, G., Fraser, M., Edlund, H., Munsters, A.R., Coutinho, A., Simões, L.G., Vicente, M., Sjölander, A., Jansen Sellevold, B.,

- Jørgensen, R., Claes, P., Shriver, M.D., Valdiosera, C., Netea, M.G., Apel, J., Lidén, K., Skar, B., Storå, J., Götherström, A., Jakobsson, M., 2018. Population genomics of Mesolithic Scandinavia: investigating early Postglacial migration routes and high-latitude adaptation. *PLoS Biol.* 16, e2003703.
- Hatting, T., 1969. Er bæverens tænder benyttet som redskaber i stenalderen i Danmark. *Aarbøger Nordisk Oldkyndighed og Hist.* 116–126.
- Haverkort, C.M., Weber, A., Katzenberg, M.A., Goriunova, O.I., Simonetti, A., Creaser, R.A., 2008. Hunter-gatherer mobility strategies and resource use based on strontium isotope ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) analysis: a case study from Middle Holocene Lake Baikal, Siberia. *J. Archaeol. Sci.* 35, 1265–1280.
- Heaton, T.J., Köhler, P., Butzin, M., Bard, E., Reimer, R.W., Austin, W.E.N., Bronk Ramsey, C., Grootes, P.M., Hughen, K.A., Kromer, B., Reimer, P.J., Adkins, J., Burke, A., Cook, M.S., Olsen, J., Skinner, L.C., 2020. Marine 20—the marine radiocarbon age calibration curve (0–55,000 cal BP). *Radiocarbon* 62, 779–820.
- Hellgren, F., 2015. En Osteologisk Analys Av Benmaterialer Från Den Mesolitiska Kustboplatsen Huseby Klev. Department of Archaeology and Ancient History, Lund University, Lund. Unpublished seminar paper in Historical Osteology.
- Hernek, R., Nordqvist, B., 1995. Världens Äldsta Tuggummi? Ett Urval Spännande Arkeologiska Fynd Och Upptäckter Som Gjordes Vid Huseby Klev, Och Andra Platser Inför Väg 178 Över Orust. Riksantikvarieämbetet UV väst, Kungsbacka.
- Holt, E., Evans, J.A., Madgwick, R., 2021. Strontium ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) mapping: a critical review of methods and approaches. *Earth Sci. Rev.* 216, 103593.
- Jensen, T.Z.T., Sjöström, A., Fischer, A., Rosengren, E., Lanigan, L.T., Bennike, O., Richter, K.K., Gron, K.J., Mackie, M., Mortensen, M.F., Sørensen, L., Chivall, D., Iversen, K.H., Taurozzi, A.J., Olsen, J., Schroeder, H., Milner, N., Sørensen, M., Collins, M.J., 2020. An integrated analysis of Maglemose bone points reframes the Early Mesolithic of Southern Scandinavia. *Sci. Rep.* 10 (1), 1–12.
- Jessen, C.A., Pedersen, K.B., Christensen, C., Olsen, J., Mortensen, M.F., Hansen, K.M., 2015. Early maglemosean culture in the preboreal landscape: archaeology and vegetation from the earliest mesolithic site in Denmark at lundby mose, sjælland. *Quat. Int.* 378, 73–87.
- Jonsson, L., 2005. Rapport over inledende osteologisk underökning. In: Nordqvist, B. (Ed.), *Huseby Klev, en kustboplats med bevarat organiskt material från äldsta mesolitikum till järnålder*, Bohuslän, Morlanda socken, Huseby 2:4 och 3:13. RAA 89. Mölndal: Riksantikvarieämbetet, UV Väst, p. 485.
- Karlén, W., Larsson, L., 2007. Mid-Holocene climatic and cultural dynamics in Northern Europe. In: Anderson, D.G., Maasch, K.A., Sandweiss, D.H. (Eds.), *Climate Change and Cultural Dynamics: A Global Perspective on Mid-holocene Transitions*. Academic Press/Elsevier, Amsterdam, pp. 407–434.
- Kashuba, N., Kirdök, E., Damlien, H., Manninen, M.A., Nordqvist, B., Persson, P., Götherström, A., 2019. Ancient DNA from mastics solidifies connection between material culture and genetics of Mesolithic hunter-gatherers in Scandinavia. *Communications Biology* 2, 185.
- Kelly, R., 1995. *The Foraging Spectrum: Diversity in Hunter-Gatherer Lifeways*. Smithsonian, Washington, DC.
- Kelly, R., 2013. *The Lifeways of Hunter-Gatherers: the Foraging Spectrum*. Cambridge University Press, Cambridge.
- Kelly, R.L., 1983. Hunter-gatherer mobility strategies. *J. Anthropol. Res.* 39, 277–306.
- Kelly, R.L., 1992. Mobility/sedentism: concepts, archaeological measures, and effects. *Annu. Rev. Anthropol.* 21, 43–66.
- Kindgren, H., 1996. Reindeer or seals? Some late palaeolithic sites in central Bohuslän. In: Larsson, L. (Ed.), *The Earliest Settlement Of Scandinavia And its Relationship With Neighbouring Areas*. 191–205. Almqvist & Wiksell International, Stockholm.
- Kjällquist, M., Price, T.D., 2019. Mesolithic mobility and social contact networks in south Scandinavia around 7000 BCE: lithic raw materials and isotopic proveniencing of human remains from Norje Sunnansund, Sweden. *J. Anthropol. Archaeol.* 53, 186–201.
- Klassen, L., Price, T.D., Sjögren, K., Wincenz, L., Philippsen, B., 2020. Strontium and lead isotope studies of faunal and human remains from Kainsbakke and Kirial Bro. In: Klassen, L. (Ed.), *The Pitted Ware Culture on Djursland supra-regional Significance and Contacts in the Middle Neolithic of Southern Scandinavia*. Aarhus Aarhus University Press and East Jutland Museum, pp. 407–446.
- Kootker, L.M., van Lanen, R.J., Kars, H., Davies, G.R., 2016. Strontium isoscapes in The Netherlands. Spatial variations in  $^{87}\text{Sr}/^{86}\text{Sr}$  as a proxy for palaeomobility. *J. Archaeol. Sci.: Report* 6, 1–13.
- Labuhn, I., Hammarlund, D., Chapron, E., Czymzik, M., Dumoulin, J.-P., Nilsson, A., Régnier, E., Robygd, J., Von Grafenstein, U., 2018. Holocene hydroclimate variability in central Scandinavia inferred from flood layers in contourite drift deposits in Lake Storsjön. *Quaternary* 1, 2.
- Lawton, J.H., Woodroffe, G.L., 1991. Habitat and the distribution of water voles: why are there gaps in a species' range? *J. Anim. Ecol.* 79–91.
- Lazzerini, N., Balter, V., Coulon, A., Tacail, T., Marchina, C., Lemoine, M., Bayarkhuu, N., Turbat, T., Lepetz, S., Zazzo, A., 2021. Monthly mobility inferred from isoscapes and laser ablation strontium isotope ratios in caprine tooth enamel. *Sci. Rep.* 11, 2277.
- Lee, S., Bronk Ramsey, C., 2012. Development and application of the trapezoidal model for archaeological chronologies. *Radiocarbon* 54 (1), 107–122.
- Lidén, K., Eriksson, G., Nordqvist, B., Götherström, A., Bendixen, E., 2004. The wet and the wild followed by the dry and the tame—or did they occur at the same time? Diet in Mesolithic–Neolithic southern Sweden. *Antiquity* 78, 23–33.
- Longva, O., Thoresen, M.K., 1991. Iceberg scours, iceberg gravity craters and current erosion marks from a gigantic Preboreal flood in southeastern Norway. *Boreas* 20, 47–62.
- Malainey, M.E., 2011. *A Consumer's Guide To Archaeological Science: Analytical Techniques, Manuals in Archaeological Method, Theory and Technique*. Springer, New York.
- Manninen, M.A., Asheichyk, V., Jonuks, T., Kriiska, A., Osipowicz, G., Sorokin, A.N., Vashanau, A., Riede, F., Persson, P., 2021a. Using radiocarbon dates and tool design principles to assess the role of composite slotted bone tool technology at the intersection of adaptation and culture-history. *J. Archaeol. Method Theor* 28, 845–870.
- Manninen, M.A., Damlien, H., Kleppe, J.L., Knutsson, K., Murashkin, A., Niemi, A.R., Rosenvinge, C.S., Persson, P., 2021b. First encounters in the north: cultural diversity and gene flow in Early Mesolithic Scandinavia. *Antiquity* 95, 310–328.
- Marlowe, F.W., 2005. Hunter-gatherers and human evolution. *Evol. Anthropol.* 14, 54–67.
- Maurer, A.-F., Galer, S.J.G., Knipper, C., Beierlein, L., Nunn, E.V., Peters, D., Tütken, T., Alt, K.W., Schöne, B.R., 2012. Bioavailable  $^{87}\text{Sr}/^{86}\text{Sr}$  in different environmental samples — effects of anthropogenic contamination and implications for isoscapes in past migration studies. *Sci. Total Environ.* 433, 216–229.
- Milligan, H.E., Humphries, M.M., 2010. The importance of aquatic vegetation in beaver diets and the seasonal and habitat specificity of aquatic-terrestrial ecosystem linkages in a subarctic environment. *Oikos* 119, 1877–1886.
- Mokadem, F., Parkinson, I.J., Hathorne, E.C., Anand, P., Allen, J.T., Burton, K.W., 2015. High-precision radiogenic strontium isotope measurements of the modern and glacial ocean: limits on glacial–interglacial variations in continental weathering. *Earth Planet Sci. Lett.* 415, 111–120.
- Montgomery, J., 2010. Passports from the past: investigating human dispersals using strontium isotope analysis of tooth enamel. *Ann. Hum. Biol.* 37, 325–346.
- Montgomery, J., Evans, J.A., Neighbour, T., 2003. Sr isotope evidence for population movement within the Hebridean Norse community of NW Scotland. *J. Geol. Soc.* 160, 649–653.
- Morgan, C., 2008. Reconstructing prehistoric hunter-gatherer foraging radii: a case study from California's southern Sierra Nevada. *J. Archaeol. Sci.* 35, 247–258.
- Moritz, M., Scaggis, S., Shapiro, C., Hinkelman, S., 2020. Comparative study of territoriality across forager societies. *Hum. Ecol.* 48, 225–234.
- Mortensen, M.F., Henriksen, P.S., Christensen, C., Petersen, P.V., Olsen, J., 2014. Vegetation development in south-east Denmark during the Weichselian Late Glacial: palaeoenvironmental studies close to the Palaeolithic site of Hasselø. *Danish Journal of Archaeology* 3 (1), 33–51.
- Nemecek, M., 2015. Ett Skiftade Mesolitikum En Analys Av Artsammansättningen Av Klövilt På Nordiska Boplatser under Mesolitikum. Department of Archaeology and Ancient History, Lund University, Lund. Unpublished seminar paper in Historical Osteology.
- Nordqvist, B., 2005. Huseby klev: en kustboplats med bevarat organiskt material från äldsta mesolitikum till järnålder: Bohuslän, Morlanda socken, Huseby 2: 4 och 3: 13, RAA 89 och 485: arkeologisk förundersökning och undersökning. Mölndal: Riksantikvarieämbetet, UV Väst.
- Palmer, M.R., Elderfield, H., 1985. Sr isotope composition of sea water over the past 75 Myr. *Nature* 314, 526–528.
- Persson, G., 2015. Sveriges klimat 1860–2014: underlag till dricksvattenutredningen. *Klimatologi* 13, 1–66.
- Peucker-Ehrenbrink, B., Fiske, G.J., 2019. A continental perspective of the seawater  $^{87}\text{Sr}/^{86}\text{Sr}$  record: a review. *Chem. Geol.* 510, 140–165.
- Piličiauskas, G., Simčenka, E., Lidén, K., Kozakaitė, J., Miliauskienė, Ž., Piličiauskienė, G., Kooijman, E., Sinkūnas, P., Robson, H.K., 2022. Strontium isotope analysis reveals prehistoric mobility patterns in the southeastern Baltic area. *Archaeological and Anthropological Sciences* 14, 74.
- Price, D.T., Larsson, L., Magnell, O., Borić, D., 2021a. Sedentary hunters, mobile farmers: the spread of agriculture into prehistoric Europe. In: Borić, D., Antonović, D., Mihailović, B. (Eds.), *Foraging Assemblages*. 579–583. The Italian Academy for Advanced Studies in America. Columbia University, New York.
- Price, T.D., Burton, J.H., Bentley, R.A., 2002. The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. *Archaeometry* 44, 117–135.
- Price, T.D., Johnson, C.M., Ezzo, J.A., Burton, J.H., Ericson, J.A., 1994. Residential mobility in the prehistoric southwest United States: a preliminary study using strontium isotope analysis. *J. Archaeol. Sci.* 21, 315, 315.
- Price, T.D., Klassen, L., Sjögren, K.-G., 2021b. Pitted ware culture: isotopic evidence for contact between Sweden and Denmark across the Kattegat in the Middle Neolithic, ca. 3000 BC. *J. Anthropol. Archaeol.* 61, 101254.
- Raiber, M., Webb, J.A., Bennetts, D.A., 2009. Strontium isotopes as tracers to delineate aquifer interactions and the influence of rainfall in the basalt plains of southeastern Australia. *J. Hydrol.* 367, 188–199.
- Rankama, T., Kankaanpää, J., 2011. First evidence of eastern Preboreal pioneers in arctic Finland and Norway. *Quartar* 58, 183–209.
- Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer, J.G., Pearson, C., van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S.M., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., Talamo, S., 2020. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon* 62, 725–757.
- Ritchie, K., Hufthammer, A.K., Bergsvik, K.A., 2016. Fjord fishing in Mesolithic western Norway. *Environ. Archaeol.* 21, 309–316.
- Rowley-Conwy, P., Piper, S., 2016. Hunter-gatherer variability: developing the models for the northern coasts. *Arctic* 69, 1–14.

- Rowley-Conwy, P., Zvelebil, M., 1989. Saving it for later: storage by prehistoric hunter-gatherers in Europe. In: Halstead, P., O'Shea, J. (Eds.), *Bad Year Economics: Cultural Responses to Risk and Uncertainty*. 40–56. Cambridge University Press, Cambridge.
- Schmitt, L., Larsson, S., Burdukiewicz, J., Ziker, J., Svedhage, K., Zamon, J., Steffen, H., 2009. Chronological insights, cultural change, and resource exploitation on the west coast of Sweden during the Late Palaeolithic/Early Mesolithic transition. *Oxf. J. Archaeol.* 28, 1–27.
- Seppä, H., Birks, H.J.B., 2001. July. Mean temperature and annual precipitation trends during the Holocene in the Fennoscandian tree-line area: pollen-based climate reconstructions. *Holocene* 11, 527–539.
- Sjögren, K.-G., Price, T.D., Ahlström, T., 2009. Megaliths and mobility in south-western Sweden. Investigating relationships between a local society and its neighbours using strontium isotopes. *J. Anthropol. Archaeol.* 28, 85–101.
- Snoeck, C., Ryan, S., Pouncett, J., Pellegrini, M., Claeys, P., Wainwright, A.N., Mattioli, N., Lee-Thorp, J.A., Schulting, R.J., 2020. Towards a biologically available strontium isotope baseline for Ireland. *Sci. Total Environ.* 712, 136248.
- Stroeven, A.P., Hättstrand, C., Kleman, J., Heyman, J., Fabel, D., Fredin, O., Goodfellow, B.W., Harbor, J.M., Jansen, J.D., Olsen, L., Caffee, M.W., Fink, D., Lundqvist, J., Rosqvist, G.C., Strömberg, B., Jansson, K.N., 2016. Deglaciation of fennoscandia. *Quat. Sci. Rev.* 147, 91–121.
- Sørensen, M., Rankama, T., Kankaanpää, J., Knutsson, K., Knutsson, H., Melvold, S., Eriksen, B.V., Glørstad, H., 2013. The first eastern migrations of people and knowledge into Scandinavia: evidence from studies of Mesolithic technology, 9th–8th millennium BC. *Norweg. Archaeol. Rev.* 46, 19–56.
- Taylor, M., Bamforth, M., Robson, H.K., Watson, C., Little, A., Pomstra, D., Milner, N., Carty, J.C., Colonese, A.C., Lucquin, A., Allen, S., 2018. The wooden artefacts. In: Milner, N., Conneller, C., Taylor, B. (Eds.), *Star Carr Volume 2: Studies in Technology, Subsistence and Environment*. White Rose University Press, York, pp. 367–418.
- Thirlwall, M., 1991. Long-term reproducibility of multicollector Sr and Nd isotope ratio analysis. *Chem. Geol. Isot. Geosci.* 94, 85–104.
- van Zeist, W., 1957. De mesolithische boot van Pesse 75, 4–11s.
- Vance, D., Teagle, D.A.H., Foster, G.L., 2009. Variable Quaternary chemical weathering fluxes and imbalances in marine geochemical budgets. *Nature* 458, 493–496.
- Widmark, G., 2015. Huseby klev en jämförelse mellan kust och inland, en studie om jaktstrategier och resursutnyttjande under mesolitikum. Department of Archaeology and Ancient History, Lund University, Lund. Unpublished seminar paper in Historical Osteology.
- Willmes, M., Kinsley, L., Moncel, M.-H., Armstrong, R., Aubert, M., Eggins, S., Grün, R., 2016. Improvement of laser ablation in situ micro-analysis to identify diagenetic alteration and measure strontium isotope ratios in fossil human teeth. *J. Archaeol. Sci.* 70, 102–116.
- Wilsson, L., 1971. Observations and experiments on the ethology of the European beaver (*Castor fiber* L.): a study in the development of phylogenetically adapted behaviour in a highly specialized mammal. *Viltrevy (Stockh.)* 8, 115–266.